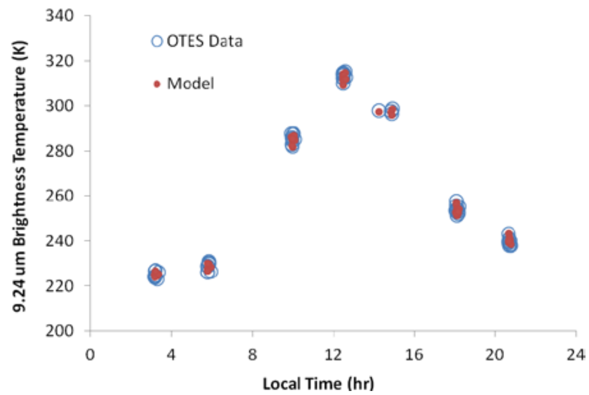
THERMAL INERTIA AND SURFACE ROUGHNESS MAPS OF (101955) BENNU FROM OSIRIS-REX INFRARED OBSERVATIONS. B. Rozitis[1], J. P. Emery[2,3], A. Ryan[4], P. R. Christensen[5], V. E. Hamilton[6], A. A. Simon[7], D. C. Reuter[7], B. E. Clark[8], M. Delbo[9], E. S. Howell[4], L. F. Lim[7], M. C. Nolan[4], H. C. M. Susorney[10], K. J. Walsh[6], and D. S. Lauretta[4]. [1]Open University, Milton Keynes, UK (benjamin.rozitis@open.ac.uk); [2]Northern Arizona University, Flagstaff, AZ, USA; [3]University of Tennessee, Knoxville, TN, USA; [4]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ, USA; [5]Arizona State University, Tempe, AZ, USA; [6]Southwest Research Institute, Boulder, CO, USA; [7]NASA Goddard Spaceflight Center, Greenbelt, MD, USA; [8]Ithaca College, Ithaca, NY, USA; [9]Observtoire de la Côte d'Azur, Nice, France; [10]University of British Columbia, Vancouver, Canada.

Introduction: Asteroid (101955) Bennu is the target of NASA's OSIRIS-REx mission, which will return a sample of ≥60 grams of regolith from its surface [1]. Before picking up the sample from the surface, OSIRIS-REx will have spent more than a year characterising the surface with cameras, spectrometers, and the laser altimeter that are onboard the spacecraft. The primary data set used for thermophysical analyses are thermal spectra from the OSIRIS-REx Thermal Emission Spectrometer (OTES) [2]. Additionally, the long-wavelength end of spectra obtained by the OSIRIS-REx Visible and InfraRed Spectrometer (OVIRS) is also dominated by thermal emission [3].

From the Approach phase of the mission, disk-integrated data returned by OTES and OVIRS confirmed the previous Spitzer-based thermal inertia measurement of Bennu [4]. In particular, a thermal inertia of 350 ± 20 J m^{-2} K^{-1} $s^{-1/2}$ and a surface roughness RMS slope of 43 ± 1° were derived from OSIRIS-REx thermal emission lightcurves and the updated shape model of Bennu [5]. These observations also found no significant variations in thermal inertia, or surface roughness, with rotational phase.

While the Approach-phase observations rule out large hemispheric differences in thermal inertia, they do not rule out smaller-scale variations. During the Detailed Survey phase of the mission, OTES and OVIRS measured the infrared radiation from the surface at ~20- to ~40-m spatial scales, enabling us to produce detailed maps of thermal inertia and roughness for the entire surface of Bennu. Such maps will aid in the interpretation of local variations seen in the geology and/or composition on the surface of Bennu, and also in generating detailed Yarkovsky and YORP effect predictions for Bennu.

Observations and Methods: During the Detailed Survey phase, OTES and OVIRS observed the surface of Bennu at seven different local times of day (see [6] for more details). We carried out thermophysical analysis of this data by using a custom thermal model that is based on the Advanced Thermophysical Model of Rozitis and Green [7,8,9]. See Figure 1 for an example comparison between observed and fitted brightness temperatures for the Nightingale candidate sample site.



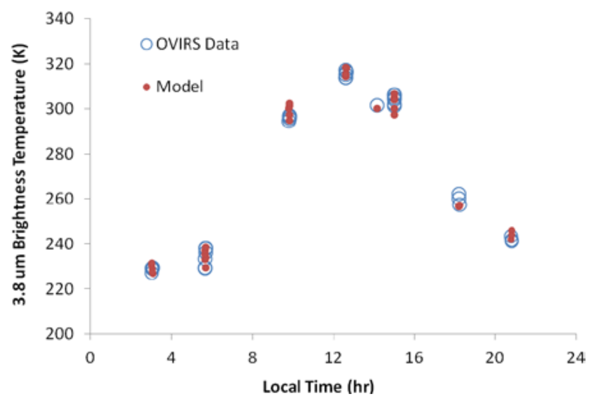


Figure 1: Observed and fitted brightness temperatures for the Nightingale candidate sample site. (a) OTES observations at 9.24-µm fitted with a thermal inertia of 280 J m^{-2} K^{-1} $s^{-1/2}$ and a surface roughness of 39° RMS slope. (b) OVIRS observations at 3.8-µm fitted with a thermal inertia of 270 J m^{-2} K^{-1} $s^{-1/2}$ and a surface roughness of 35° RMS slope.

Results: An analysis of OTES data collected from all seven local times of day finds definitive spatial variations in thermal inertia and surface roughness (see Figure 2). In particular, local thermal inertia values range from ~200 to ~400 J m^{-2} K^{-1} $s^{-1/2}$ with a global average thermal inertia value of ~300 J m^{-2} K^{-1} $s^{-1/2}$. Similarly, local surface roughness values range from ~30° to ~50° RMS slope with a global average surface roughness value of ~40° RMS slope. These results and spatial variations were checked for consistency by performing an independent analysis using the OVIRS data, and we found an excellent agreement between the OTES- and OVIRS-derived results.

Discussion: Unexpectedly, the lowest thermal inertia values are associated with the largest boulders on Bennu, and the highest thermal inertia values are found in association with regions lacking large boulders (see Figure 2a). This unexpected result prompts a re-evaluation of the interpretation of thermal inertia for small rubble-pile asteroids, and provides insight into the nature of the unusual boulders found on the surface of Bennu [10]. Interestingly, we find a strong trend of increasing thermal inertia with increasing Bond albedo [11], which suggests that the brighter boulders have different physical and/or compositional properties to the darker boulders found on Bennu.

Spatial variations in surface roughness appear to correlate with the spatial density of large boulders resting on the surface of Bennu (see Figure 2b). Similar to thermal inertia, we also find a strong trend of decreasing surface roughness with increasing Bond albedo, which might be explained by the different textures expressed on the surfaces of the bright and dark boulders.

The excellent agreement between the model (i.e. which assumed a constant thermal inertia value with depth) and the brightness temperature data (see Figure 1) suggests the lack of a substantial global dust layer, which is consistent with independent analysis of spectral data of Bennu [12]. In particular, dust layers as thin as 10-100 μm would significantly affect the shape of diurnal temperature curves [13] but we do not see any signatures of this in the temperature data of Bennu. However, very thin layers and/or mono-layers of dust cannot yet be ruled out until more sophisticated 3D heat conduction models are applied to the temperature data of Bennu [14].

Finally, we used the thermal inertia and surface roughness maps to produce a detailed estimate of the Yarkovsky accelerations acting on Bennu throughout its orbit. By comparing to the observed Yarkovsky semi-major axis drift rate [15], we were able to estimate the bulk density of Bennu to be within ~1% of that determined by radio science [16]. This Yarkovsky result demonstrates the high accuracy to which we have measured, and subsequently modeled, the thermal emission from Bennu.

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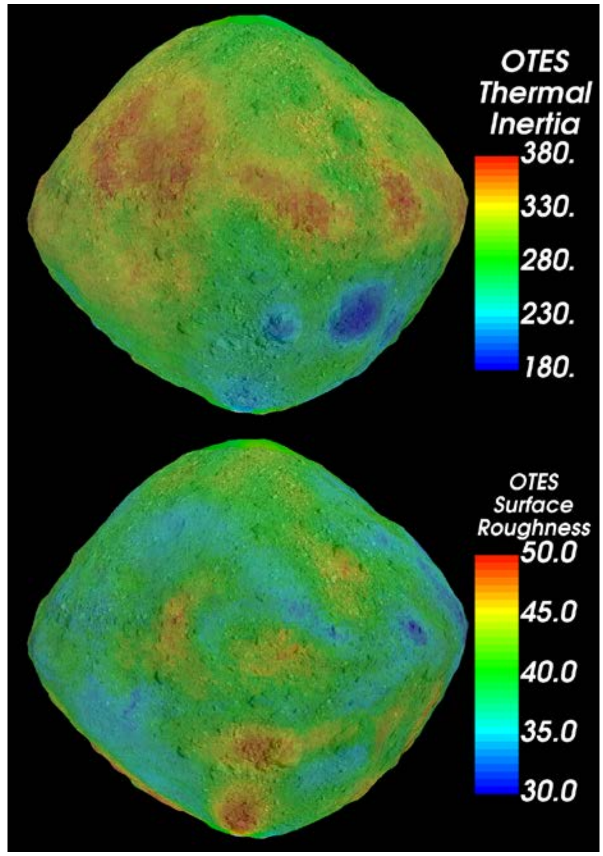

Figure 2: (a) Thermal inertia and (b) surface roughness maps of Bennu derived by thermophysical modeling of OTES observations. Equivalent maps derived from OVIRS observations are in excellent agreement with the OTES maps shown here. For reference, thermal inertia is given in J m^{-2} K^{-1} $s^{-1/2}$, and surface roughness is given in degrees RMS slope.

References: [1] Lauretta D. S. et al. (2017) *Space Sci Rev.*, 212, 925-984. [2] Christensen P. R. et al. (2018) *Space Sci Rev.*, 214, id87. [3] Reuter D. C. et al. (2017) *Space Sci Rev.*, 214, id54. [4] Emery J. P. et al. (2014) *Icarus*, 234, 17-35. [5] DellaGiustina D. N. and Emery J. P. et al. (2019) *Nature Astronomy*, 3, 341-351. [6] Emery J. P. et al. (2019) *this meeting*. [7] Rozitis B. and Green S. F. (2011) *MNRAS*, 415, 2042-2062. [8] Rozitis B. and Green S. F. (2012) *MNRAS*, 423, 367-388. [9] Rozitis B. and Green S. F. (2013) *MNRAS*, 433, 603-621. [10] Ryan A. et al. (2019) *EPSC-DPS Joint Meeting*, Abstract #EPSC-DPS2019-324. [11] Zou X.-D. et al. (2019) *EPSC-DPS Joint Meeting*, Abstract #EPSC-DPS2019-377. [12] Hamilton V. E. et al. (2019) *Nature Astronomy*, 3, 332-340. [13] Biele J. et al. (2019) *Prog. in Earth and Plan. Sci.*, 6, id48. [14] Ryan A. et al. (2019) *this meeting*. [15] Chesley et al. (2014) *Icarus*, 235, 5-22. [16] Scheeres et al. (2019) *Nature Astronomy*, 3, 352-361.