OVERVIEW OF OSIRIS-REX THERMAL OBSERVATIONS. J. P. Emery[1], B. Rozitis[2], P. R. Christensen[3], V. E. Hamilton[4], C. Haberle[3], A. A. Simon[5], D. C. Reuter[5], M. Delbó[6], L. F. Lim[5], B. E. Clark[7], A. Ryan[6,8], S.R. Chesley[9], W. V. Boynton[8], A. Polit[8], M. Westerman[8], T. Becker[8], R. Garcia[8], D. Lambert[8], J. Kidd[8], E. S. Howell[8], M. C. Nolan[8], H. L. Enos[8], D. S. Lauretta[8]. [1]Northern Arizona University (joshua.emery@nau.edu), [2] Open University, Milton Keynes, UK; [3]Arizona State University, Tempe, AZ; [4]Southwest Research Institute, Boulder, CO; [5]NASA Goddard Space Flight Center, Greenbelt, MD; [6]Observatoire de la Côte d'Azure, Nice, France; [7]Ithaca College, Ithaca, NY; [8]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ; [9]NASA Jet Propulsion Lab, Pasadena, CA.

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 fundamental questions, such as: How did the Solar System form? How did life evolve in the Solar System? Are asteroids harbingers of life or death – or both? [1]

Before picking up the sample from the surface, OSIRIS-REx will have spent more than a year characterizing the surface with cameras, spectrometers, and the laser altimeter that are onboard the spacecraft [1]. Surface temperatures at multiple local times of day, orbital positions, and viewing geometries are among the important quantities to be determined and mapped. Global and local surface temperatures are the basis for determining thermophysical properties of the surface, and they inform maps of sampleability, spacecraft safety, and science value of the surface. The thermophysical properties are crucial for studies of the Yarkovsky and YORP effects.

We will present an overview of thermal observations of Bennu by OSIRIS-REx and the associated mission and long-term science goals.

Methods: The primary data set for determining surface temperatures consists of infrared (6–100 μm) spectra from the OSIRIS-REx Thermal Emission Spectrometer (OTES) [2]. OTES is a point spectrometer with a FOV of 8 mrad, leading to a spatial resolution of ~40 m during the main global mapping phase, when the spacecraft is 5 km above the surface. The long-wavelength end of spectra obtained by the OSIRIS-REx Visible and InfraRed Spectrometer (OVIRS; 0.4 to 4.0 μm) [3] is also dominated by thermal emission. As a result, the OVIRS spectra can also be used to determine temperatures. OVIRS is a point spectrometer with a FOV of 4 mrad and a resulting spatial resolution half that of OTES.

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.

Disk-integrated thermal radiance measurements 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. Results from these Approach phase thermal observations are published in [4].

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 during the Preliminary Survey phase in early-to-mid December 2018. OTES and OVIRS obtained spectra during passes over both poles and the equator. 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.

Detailed Survey: During the Baseball Diamond sub-phase of Detailed Survey (March to April 2019), the spacecraft observed Bennu from various stations having different sub-spacecraft latitudes and local times of day. OTES collected data during all of these stations and OVIRS during the first three. These observations were optimized for imaging, but the ride-along thermal observations enabled production of the first temperature and thermal inertia maps of Bennu.

The Equatorial Stations sub-phase of Detailed Survey (April to June 2019) was designed for global mapping of Bennu at seven different local times of day (3:20 am, 6:00 am, 10:00 am, 12:30 pm, 3:00 pm, 6:00 pm, and 8:40 pm). The spacecraft was positioned above the equator at each local solar time and scanned N-S while Bennu completed a full rotation. We used the diurnal thermal radiance measurements to determine and map the thermal inertia of Bennu at a spatial scale of ~40 m with OTES data and ~20 m with OVIRS data. These maps reveal exciting correlations

between thermophysical properties and geology of the surface of Bennu [5, 6].

Orbital A and Orbital B: Two orbital phases of the mission focused on obtaining data required for developing detailed shape and topography models of Bennu. The orbits for both phases were approximately over the terminator. OTES was turned on for ride-along observations during portions of both phases, but no OVIRS data were collected during these orbits due to limitations in downlink data volume. During Orbital A, the spacecraft was pointed toward the sunlit side of the asteroid, resulting in observations over a range of local times of day. OTES collected data for about five days (Feb 22 – 27, 2019) of Orbital A, during which the spatial resolution of OTES was ~10 m. Coverage is therefore sparse.

During Orbital B, OTES collected data over the course of more than a month (July 1 – Aug 5, 2019). The spacecraft was nadir-pointed during these observations and optimized for laser altimetry measurements, leading most observations to occur at local times of ~6:00 am or 6:00 pm. Orbital B had a lower altitude than Orbital A, leading to a spatial resolution of ~6 m for OTES. Coverage was better than in Orbital A, because of the longer duration of observations, but was still not complete. Nevertheless, these data from the orbital phases are valuable for their better spatial resolution than the Detailed Survey phase.

Reconnaissance: As part of the systematic analysis of the surface that will result in selection of the best site on Bennu to sample, the spacecraft will perform Recon flyovers of four potential sample sites. The thermal analysis goals for these Recon data are to produce measured temperature maps and thermal inertia maps of the sites. From this information, we will also predict the temperature of the surface at the time of sample acquisition. These high spatial resolution local maps will be scientifically valuable for assessment of the variability of thermal properties at small spatial scales on Bennu.

Emission Phase Function: The directional dependence of thermal emission is not very well studied for asteroids. This dependence can affect the inversion of radiance data into thermal inertia and influences the Yarkovsky and YORP effects. The suite of thermal observations described above provided some different viewing geometries, but would not have allowed a detailed analysis of the emission phase function. Several additional observations were conducted to more completely sample the global emission phase function. These included E-W scans from above the equator after several of the Equatorial Station observations and E-W zig-zag scans at mid-latitudes during two of the transit legs between equatorial stations. Figure 1 shows an example of the emission angle and azimuth angle coverage at a certain time of day (~3:00 pm) at the equator. Similar plots at other times of day and latitudes reveal good overall coverage for studying Bennu's emission phase function.

Summary: The OSIRIS-REx mission is providing a wealth of thermal data of Bennu. Both spectrometers have returned excellent thermal radiances that reveal boulders with a much lower thermal inertia than anticipated prior to arrival. The Hayabusa2 mission is finding Ryugu to be a similarly fascinating asteroid in terms of its thermophysical properties [e.g., 7,8]. Analyses are just beginning to mine the deep potential of these thermal data.

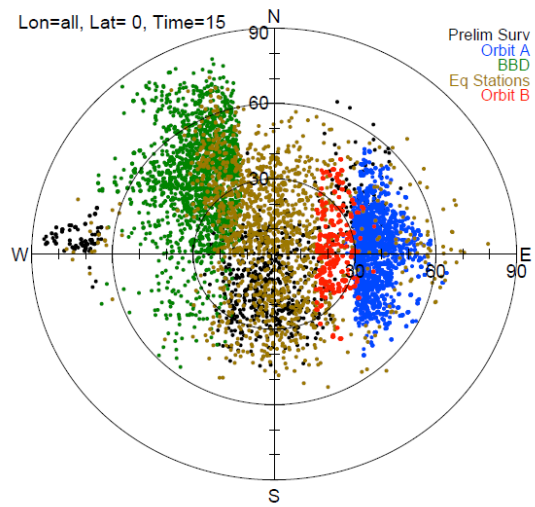

Figure 1. Emission angles and azimuths of OTES observations at ~3:00 pm (1:30-4:30 pm) near the equator (-15 to +15° latitude). This particular time of day and latitude received nearly complete coverage at all azimuths to an emission angle of 60° and includes some observations at even higher emission angles. The colors represent different mission phases, as indicated on the legend to the upper right.

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