MODELING SURFACE TEMPERATURES ON THE URANIAN SATELLITES. E. C. Cooper[1], C. M. Elder[2], and M. E. Kenyon[2], [1]Pitzer College, Claremont, CA, [2]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA

Introduction: Infrared observations of planetary surfaces can reveal material properties such as coherent block content and regolith packing density, which contribute to our understanding of surface evolution and comparative planetology. Infrared observations of icy satellites have been used extensively in the Jovian and Saturnian systems with many discoveries including lower thermal inertias at the Saturnian satellites than the Galilean satellites [1], evidence of moon magnetosphere interactions [2], and a thick layer of unconsolidated material on Rhea's poles [3]. By contrast, we know relatively little about the Uranian moons. Voyager IRIS observations obtained only the maximum brightness temperature near the subsolar point on Miranda and Ariel [4]. Herschel Space Observatory measurements of the Uranus system suggest thermal inertia values in a similar range to the Saturnian satellites, with hints of a possible leading/trailing side asymmetry on some of the moons [5]. Future infrared observations of these satellites could reveal differences between moon systems and spatial variation across individual moons.

Here we attempt to constrain the range of possible temperatures expected on the surfaces of the Uranian satellites to inform the design of future instruments and mission concept of operations. Specifically, the Jet Propulsion Laboratory's Microdevices Laboratory is developing a Cold OBject RAdiometer (COBRA) to detect radiation from objects with temperatures < 60 K. COBRA is a thermal imaging radiometer that incorporates cutting-edge technology that makes it suitable to study extremely cold bodies. Among COBRA's proposed science goals is quantifying the thermal inertias of the Uranian satellites, which will require COBRA to measure the diurnal variation in the satellites' surface temperatures as a function of time. In this study, we used a one dimensional (1-d) thermal model to determine a range of likely surface temperatures on the five largest Uranian satellites and used Wien's law to determine the range of wavelengths at which the Uranian satellites radiate as functions of latitude and time.

Background: The surface temperature on an airless body is controlled by the thermal inertia (Γ) of its surface and shallow subsurface. Thermal inertia is a function of density, thermal conductivity, and heat capacity. Different values of these properties result in different surface temperature curves as a function of time over both diurnal and seasonal scales. By collecting surface temperature measurements as a function time, observations can be compared to temperature curves derived through thermal modeling, allowing one to determine the best-fit thermophysical properties of the surface [e.g. 6].

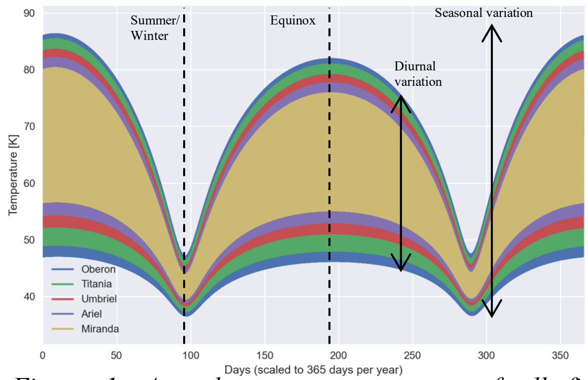

Figure 1. Annual temperature curves of all five satellites. Oberon's diurnal and seasonal variation is greater than that of its fellow satellites due to its longer day.

Due to Uranus's high obliquity (~ 98°), the planet's poles experience extreme seasonal temperature variations such that, unlike most planetary systems, the amplitude of seasonal temperature variations exceeds that of diurnal variations. The satellites orbit in Uranus's equatorial plane and therefore also experience this extreme seasonal variability. The goal of this work is to determine the upper and lower bounds on the range of wavelengths needed to observe thermal radiation from the five major Uranian moons. Assuming synchronous rotation, Oberon would have the longest day and therefore the widest range of possible surface temperatures (Figure 1).

Methods: We used a 1-d thermal model, developed for Ceres and the Moon, which employs a finite difference method to calculate temperature as a function of depth and time [6, 7]. In addition to adjusting the orbital parameters, we adjusted the default model parameters [6] to m=1000, n=10, and a model domain 20 skin depths deep to resolve both diurnal and seasonal temperature changes. We assumed an emissivity of 0.95 and a Bond albedo of 0.1 after [8]. We considered Oberon's equator and poles and varied thermophysical parameters based on the range of values observed on other icy bodies [1] to determine the maximum and minimum surface temperatures Oberon experiences. Using Wien's Law, we found the wavelengths of the peaks of the blackbody curves corresponding to these minimum and maximum temperatures.

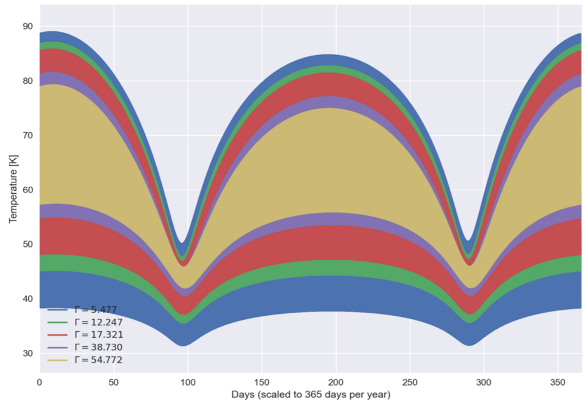

Figure 2. Surface temperature curves at Oberon's equator for five values of thermal inertia. The lowest value, $\Gamma = 5.477\ \mathrm{J\,m^{-2}\,K^{-1}\,s^{-1/2}}$*, yields the highest and lowest temperature extremes, as expected.*

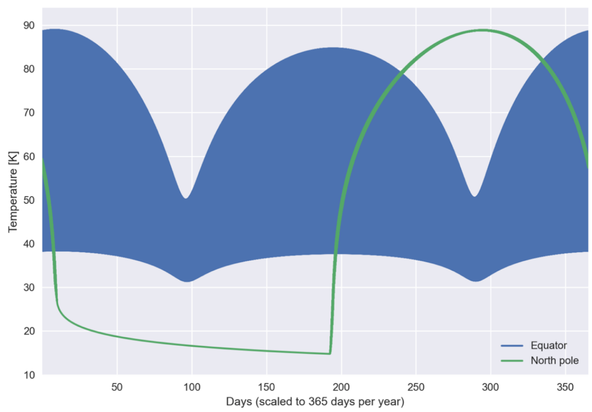

Figure 3. Annual temperature curves for Oberon's equator (blue) and its poles (green) for $\Gamma = 5.477\ J\,m^{-2}\,K^{-1}\,s^{-1/2}$*. The maxima of the two curves are very similar, but the polar minimum is ~15 K lower than the equatorial minimum.*

Results and Discussion: We find that temperatures on the Uranian satellites could range from approximately 15 to 90 K during the Uranian year if the surface thermal inertia is as low as suggested by [5] (Figures 2 and 3). The peak blackbody radiation associated with these temperatures occurs at approximately 195 µm and 30 µm respectively (Figure 4). However, the minimum temperature at the equator is closer to 30 K (Figure 2), which corresponds to 100 µm. The peak wavelengths associated with the temperature maxima for the equator and poles would be covered by by six of COBRA's nominal spectral channels, but the minima for the poles and equator are covered by one and two spectral channels, respectively (Figure 4). In theory, it is possible to fit a blackbody curve to an observation at a single wavelength, but in practice multiple bands spanning the blackbody curves facilitate thermophysical studies. Therefore, contrary to typical observation plans for thermophysics, at the Uranian satellites, nighttime

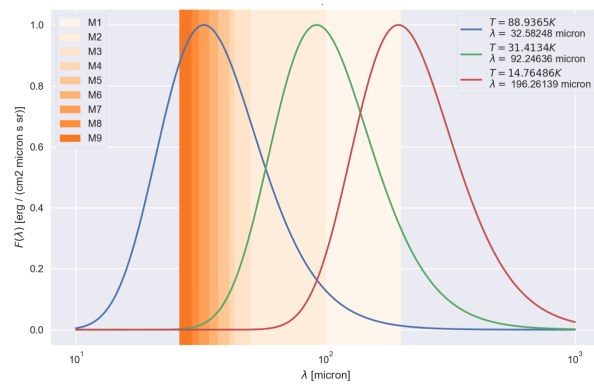

Figure 4. Blackbody curves for Oberon's equator's and poles' shared surface temperature maximum (blue, $T_{max} = 88.9365K$*), the poles' surface temperature minimum (red,* $T_{min} = 88.9365K$*), and the equator's temperature minimum (green,* $T_{min} = 31.4134K$*) for* $\Gamma = 5.477\ J\,m^{-2}\,K^{-1}\,s^{-1/2}$*. In the background are the ranges of wavelengths covered by each of COBRA's spectral channels.*

observations might be less favorable for observations with instruments that lack a cryocooler due to the very low temperatures.

Arriving at Uranus close to equinox would benefit observations for thermophysics and simplify the concept of operations. On the equators of the Uranian satellites', the diurnal temperature variation is significantly larger at equinox than during summer or winter. This means that, during winter or summer, it would be harder to resolve the temperature difference at different times, which is required to derive thermal inertia. Arriving at equinox would relax requirements on the separation in time of multiple observations.

Conclusion: Multispectral infrared observation of the Uranian satellites could reveal variability in thermophysical processes across and between the different satellites, informing our understanding of the endo- and exogenic processes that modify their surfaces. Comparisons to the Jovian and Saturnian satellites could reveal differences in the processes modifying those systems. Diurnal temperature variability would be easiest to measure with an arrival close to equinox.

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