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Near surface temperature modelling of 2014 MU$_{69}$

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Abstract

New Horizons REX radiometer observed of the small Kuiper Belt Object 2014 MU$_{69}$ at relatively high phase angle and measured a disk averaged brightness temperature of about 23 K. In this study, we perform a thermophysical analysis of the body to better understand this radio observation. We find for assumed thermophysical parameters, the REX radiometer may have been observing about 0.5 meters beneath MU$_{69}$'s surface.

1. Introduction

On January 1st 2019 The New Horizons spacecraft had its close encounter with the 15.9 hour rotating bilobate Kuiper Belt Object (KBO) 2014 MU$_{69}$, nicknamed Ultima Thule (UT) [1]. The onboard radiometer, REX, observed UT on its backlit side. The REX beam, containing the entirety of UT's sky projected, measured an approximate brightness temperature of about T_B = 23 K, but the depth to which the radar penetrated is not clear and could lie anywhere from 5-50 cm [1]. Analysis of all approach images indicates that the larger lobed "Ultima" is relatively flattened while the smaller lobe "Thule" is more spherical. This analysis has also led to a series of preliminary shape models determining UT to have an obliquity of approximately 99°, i.e., it is a highly inclined retrograde rotator [2]. ***Aims***: Explaining the observed brightness temperature requires analyzing the thermal-conductive-radiative-insolation balance on UT. UT's odd shape means that a substantial part of its surface reradiates back upon itself. As such, a correct thermophysical analysis must be global. In this study we present a thermal analysis of UT given the derived shape model presented at this meeting [2].

2. Modelling procedure

We work with the so-called "lowpoly" shape model, which consists of 1920 triangulated facets [2]. For a given facet i, with surface area σ_i and outward pointing normal vector $\mathbf{n}_i$, we determine which other faces j are viewable from it using simple ray-tracing, and from this we develop a logical face network N_{ij} (see Fig. 1a). For each i-j pair, we assess their relative distance r_{ij} with corresponding unit vector $\mathbf{r}_{ij}$. We adopt a body-surface + 1D-subsurface model to describe the near surface energy balance in which losses to radiation and subsurface conduction are balanced by the net received energy, Φ_i, which is the sum of solar insolation and surface reradiation, i.e.,

$$\sigma_B T_i^4 + k\partial_z T_i\Big|_{z=0} = \Phi_i = (1-A_i)F_i(\mathrm{sol}) + \sum\nolimits_j \sigma_B K_{ij} T_j^4, \quad (1)$$

where the summation is over all non-zero N_{ij}. The scaled radiated power emanating from facet j and received by facet i is quantified by the following expression: $K_{ij} \equiv \sigma_j \mathrm{N}_{ij} (\mathbf{n}_i \cdot \mathbf{r}_{ij})(-\mathbf{n}_j \cdot \mathbf{r}_{ij})/2\pi r_{ij}^2$. T_i is the surface temperature of element i, $(1-A_i)F_i(\mathrm{sol})$ is its absorbed solar radiation flux (taking into account self-shadowing, see also [3]), and A_i its albedo We adopt the 1D heat equation for the subsurface,

$$\rho C_p \partial_t \Theta_i = k\partial_z^2 \Theta_i, \quad (2)$$

ρ is the material density, C_p is its heat capacity, Θ_i is the depth dependent (z) temperature of facet i where surface temperature is denoted by $T_i = \Theta_i(z=0)$, and finally k is the material conductivity. Solutions to eq. (2) are developed in the oscillatory time-asymptotic limit where we impose the condition that the conductive flux goes to zero suffiently deep underneath the surface [4]. We construct solutions based on daily averaged solar insolation and we proceed by building a received insolation profile for 256 evenly selected times over the course of 1 orbit. We then build solutions to eqns. (1) and (2) via an iterative procedure: We start by solving eq. (1) for T_i

with k set to zero and calculate a first iteration of Φ_i. Then we correct T_i by solving equation (2) using this first guess for Φ_i, and determine the corresponding surface conduction term $k\partial_z\Theta_i$. Then we input this back into eq. (1) and repeat the procedure with an updated value of Φ_i and using this (in turn) to determine an updated solution to eq. (2), and so on until a converged solution is found (usually after 2-4 iterates).

3. Preliminary Results

Based on comparisons to other KBO's we assume the thermal inertias of the top layer of materials are very low $k = 3.5\times10^{-5}$ W/m/K [1]. Together with the assumption $\rho = 500$ kg/m^3 and $C_p = 350$ J/kg/K, the thermal skin depth over the course of 1 orbit (~298 years) is about 1.7 m [1]. The flux of solar radiation at UT's orbit is approximately 0.7 W/m^2. In Figs. 1b-d we show a selection of solutions: Fig. 1b shows the average surface temperature over the course of one orbit. We note that the flattened sides of Ultima are much cooler than the edges and this is a result of the assumption of an efficient insulator. Fig. 1(c-d) shows a mockup view of the shape model as seen by New Horizons during the REX observation. Fig 1(c) shows the predicted surface temperature of the observed backlit side to be in the vicinity of 10-14K. However, Fig 1(d) shows the temperature for the same view at a depth of about 50 cm below the surface with an average of about 23K. Further model analysis and observational constraints will be presented at the meeting.

References

[1] Stern, S. A., et al. (2019) Science, Vol. 364, eaaw9771.

[2] Porter, S. A., et al. (2019) DPS Abstract (this meeting)

[3] Earle, A., et al. (2019) DPS Abstract (this meeting)

[4] White, O. L., et al. (2016) JGR Planets, Vol. 121, doi:10.1002/2015JE004846

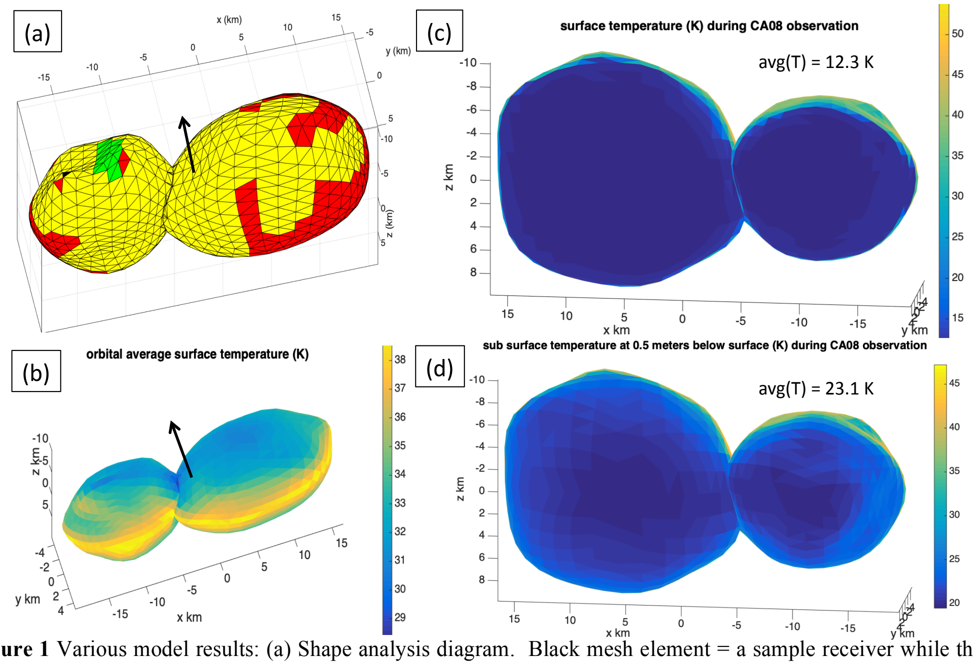

Figure 1 Various model results: (a) Shape analysis diagram. Black mesh element = a sample receiver while the green facets are observable by the receiver. Yellow meshes are not observable by receiver. The red meshes correspond to surfaces that are never self-shadowed. Pole indicated by arrow. (b) Orbital averaged surface temperatures. (c) Mock-up view of UT during REX observation (sun position behind object), predicted disk averaged surface temperature ~12.3 K while (d) is like (c) except temperature at 50 cm below surface with predicted disk averaged surface temperature ~ 23.1 K.