DEVELOPMENT OF A THERMOPHYSICAL MODEL FOR BINARY ASTEROID SYSTEMS AND APPLICATION TO JANUS MISSION TARGET 1996 FG3.

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Introduction: Binary asteroids comprise approximately 16% of the Near-Earth Asteroid population [1] and demonstrate a unique set of dynamical and evolutionary pathways. NASA's upcoming Janus mission [2], with a planned launch in August of 2022, will send dual spacecraft to perform flybys of two different binary asteroid systems. The first, (175706) 1996 FG3, is in an ordered, stable end state with a synchronously rotating secondary [3]. The second system, (35107) 1991 VH, is believed to be dynamically evolving [4]. By combining flyby observations of the binary systems with ground-based observations, Janus will collect high-resolution (about 10 m/pixel at closest approach) thermal data in addition to visible images, which can be leveraged into accurate topographical and morphological models for each body.

A primary mission goal of Janus will be to observe these systems in the thermal infrared (IR). For small bodies, differential thermal emission induces perturbations that can affect their orbital evolution. In binary systems, the most notable of these thermal effects is the Binary YORP (BYORP) effect [5]. When two small bodies orbit each other, asymmetric emission results in a net torque that can alter the orbit of the secondary. Though small in magnitude, over time BYORP can dramatically alter binary orbits. For a tidally locked secondary (as suspected for 1996 FG3), BYORP torques are removed through dissipation in the interior of the primary. Therefore, measurements of BYORP may potentially provide a constraint on asteroid interior structure. Since BYORP depends on the complex shapes of asteroids, constraining its magnitude requires a detailed understanding of surface temperatures on these bodies.

In this study, we develop an advanced 3D thermophysical model capable of reproducing the complex radiation environments and interactions of binary asteroids. We begin by creating an initial single-body model, which we use to provide 3D temperature maps of individual bodies in the 1996 FG3 system. However, effects such as radiation exchange between a binary pair can significantly alter surface temperatures. We describe the development of a 3D ray-tracing thermophysical model that will include consideration of critical effects, such as shadowing, reflections and eclipses. We will utilize this thermophysical model to calculate highly accurate temperatures of the surfaces of the 1996 FG3 system.

Methods: Our 3D thermophysical model calculates temperatures and thermal IR fluxes, first for single

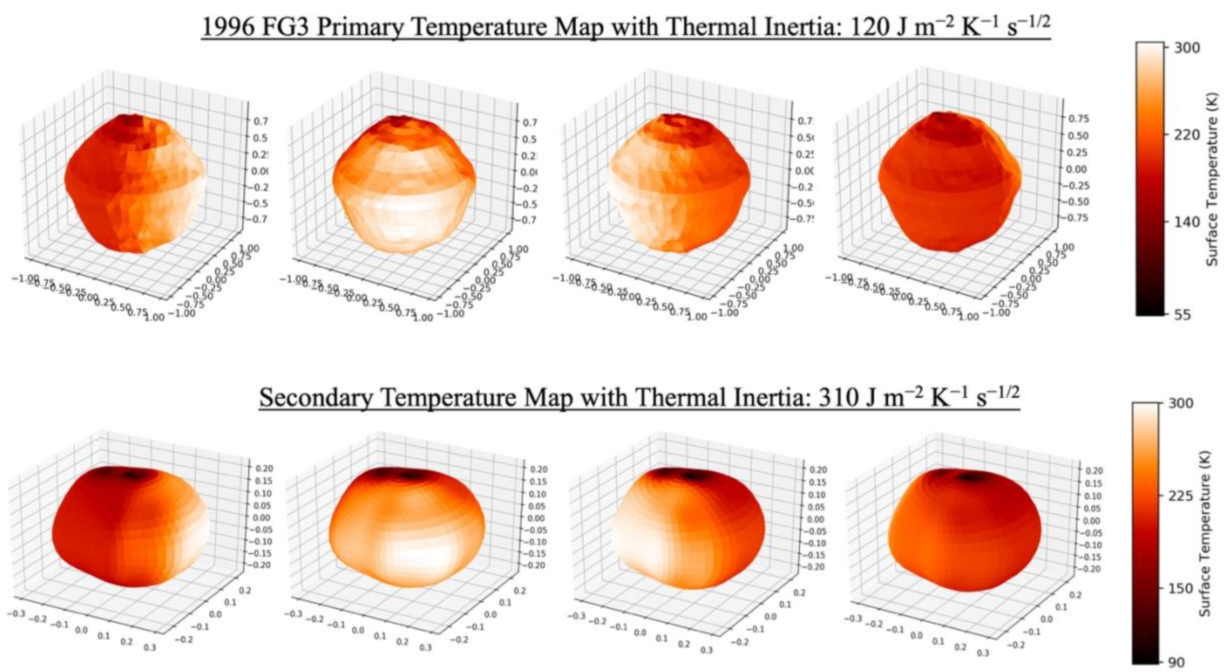

Figure 1: Global temperature maps for the 1996 FG3 system using the single-body model. This map shows predicted diurnal temperatures during the Janus flyby. It uses a most likely thermal inertia for the primary of 120 ±50 J m^{-2} K^{-1} $s^{-1/2}$ and 310 ± 70 J m^{-2} K^{-1} $s^{-1/2}$ for the secondary

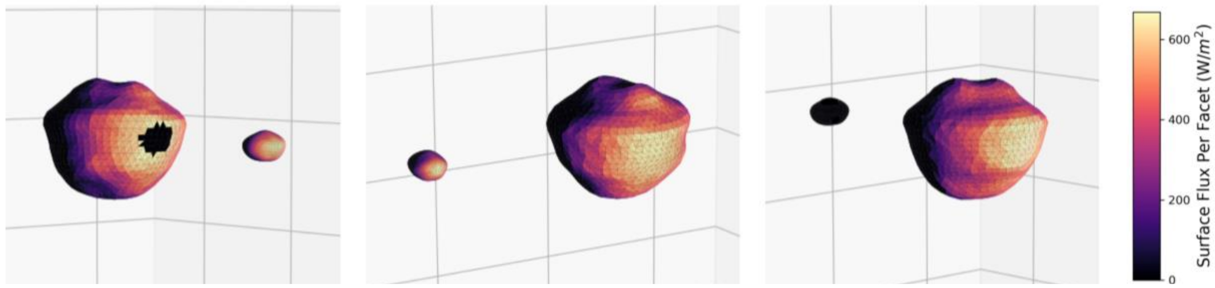

Figure 2: Progression of the 1996 FG3 secondary about the primary showing an eclipse of the secondary on the primary body (left), an orientation with no inter-body shadowing (center) and complete shadowing of the secondary by the primary. Color gradient represents direct solar insolation on each facet.

bodies and then binary systems. This model couples a 1D thermophysical model [7] to a 3D shape model composed of triangular facets. Using time-dependent solar fluxes, the model equilibrates for several model years and then outputs diurnal temperatures for the asteroid's surface and near subsurface. The result is a global map of diurnal temperatures and thermal fluxes. This initial 3D model is capable of producing global temperature estimates for a single body.

To model binaries, we implement an efficient ray-tracing method. The model calculates view factors between facets on both bodies. It iteratively updates which facets are in shadow and calculates reflected and re-emitted flux. This accounts for re-radiation and eclipses between the binary pair. The completed model will calculate temperatures by balancing IR emission, visible light reflection, scattered IR radiation, direct insolation and 1D heat conduction.

Using the initial single-body model, we calculate temperatures for Janus targets 1996 FG3 and 1991 VH. For the purposes of this study, we only consider the stable system 1996 FG3, although unsettled rotation will eventually be enabled in the model for consideration of the chaotic 1991 VH system. For the 1996 FG3 primary, we use a shape model generated by the Janus team. A scaled 1999 KW4 secondary shape model is assumed for the secondary's shape. We use a primary spin period of 3.6 hours [3] and a secondary orbital period of 16.15 hours [8]. Thermal inertia has been reported between 120 ± 50 J m^{-2} K^{-1} $s^{-1/2}$ (SI units) for the primary [9]. We assume a Bennu-like value of 310 ± 70 SI units for the secondary [10].

Results & Discussion: Figure 1 shows the resulting single-body temperature maps for the 1996 FG3 primary and secondary at thermal inertia values of 120 and 310 SI units, respectively. As expected, higher thermal inertia dampens temperature extremes and leads to decreased diurnal amplitudes. For a primary thermal inertia of 120 SI units, we calculate the global temperature range to be ~50 K to 300 K, with a median diurnal amplitude of ~100 K at the equator. For the lower bound thermal inertia of 70 SI units, this amplitude increases to ~130 K, and for the upper bound of 170 SI units, this amplitude reduces to ~85 K.

For the secondary, we calculate a temperature range over the whole body to be ~90 to ~300 K. A thermal inertia of 240 SI units yields a diurnal temperature amplitude of ~90 K, a thermal inertia of 310 SI units yields an amplitude of ~80 K, and a thermal inertia of 380 SI units produces an amplitude of ~70 K.

For the two-body model, preliminary results show the model is capable of reproducing binary properties. Its ability to model eclipses, a critical binary effect, is shown in Figure 2.

Future Work: Following validation, we will use the binary model to estimate surface and subsurface temperatures of 1996 FG3 during the Janus flybys. Our predictions for surface temperatures and dynamical effects will be directly testable during the Janus mission, with anticipated flybys of both asteroid systems in 2026.

We will investigate the sensitivity of temperatures to changes in thermal inertia. Thermal inertia introduces a lag in the local time of peak temperatures on a body, which could potentially affect the magnitude of BYORP. Existing BYORP models neglect thermal inertia and flux from the primary. As seen by results in this work, thermal inertia can markedly impact the range of temperatures on a surface, as well as how those temperatures change with time. We will use our model to perform numerical estimations of the BYORP effect and quantify the effect of thermal inertia on its magnitude.

Acknowledgments: This work was supported in part by the NASA Janus project.

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