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MASTER PROJECT REPORT
Simulation of thermal camera images from a spacecraft around asteroid for the HERA mission

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January 2020

Abstract

Didymoon is an asteroid of the binary system Didymos. It is orbiting around a bigger asteroid called Didymain for convenience. In order to prepare the defense of the Earth in the case of a direct impact of an asteroid, the Hera mission will initiate in the years to follow an impact onto Didymoon. The NASA is in charge of the collision with the asteroid. The ESA will study the outcomes of the impact. The spacecraft Hera will be equiped of sensors such as cameras. Studying the evolution of the temperature on Dydimoon will help us to understand what happened to after the collision. This work fits into the scheme of the simulations of thermal camera images from the spacecraft around the asteroid. This paper shows a method using asteroid thermophysical model, 3D numerical solver, NASA/NAIF SPICE and shape models.

1 The Hera mission

Cruising some 250 million kilometers around the Sun is an object first identified in 1996, by a Spacewatch survey at the University of Arizona. It was later named Didymos (Greek word for twin), after a smaller companion, Didymoon, was discovered orbiting it. Didymain and Didymoon are now both classified as potentially hazardous, near-Earth system.

Hera, named after the greek goddess of marriage, will be humanity's first probe to rendezvous with a binary asteroid system.

Hera is part of an international collaboration, alongside Nasa's DART which is due to deliver a kinetic impact Didymoon's surface, leading to to a deflection of its orbit around the bigger brother.

The mission's main objectives are to deepen our understanding of a planetary defense technique while also demonstrating numerous technologies, the likes of autonomous navigation around asteroids and gathering scientific data, further developping our understanding of asteroid compositions and structures.

Hera is set to launch in 2024, before traveling to Didymos where it will first focus on Didymoon for its study: High resolution mapping relying on Optical, radio and laser techniques.

In addition to planetary defense objectives, Hera will also carry two CubeSats on board, to be launched around the asteroid system for crucial scientific studies before touching down on their surface.

2 Current work

This paper is following the work of a previous document *Didymoon's surface thermal modeling*. The former presents a method to simulate the temperature at the surface of an asteroid. It describes in details the following thermophysical model and the numerical method:

$$\begin{cases} u(x,0) = f(x), & \forall x \in [0, l_s] \\ \dfrac{\partial u}{\partial x}(0,t) = \dfrac{Q_{out} - Q_{Sun}}{k} & \forall t \geq 0 \\ \dfrac{\partial u}{\partial x}(l_s,t) = 0, & \forall t \geq 0 \end{cases} \tag{1}$$

with u the 1 dimensional temperature in space and time, f a initial temperature repartition, Q_{out} the flux emitted from the asteroid, Q_{Sun} the flux received from the Sun, k the conductivity and l_s the annual thermal skin depth. The expression of Q_{out} is:

$$Q_{out} = \epsilon \sigma u^4 \tag{2}$$

with ϵ the emissivity of the asteroid and σ the Stephan-Boltzman constant. Q_{Sun} is stated as:

$$Q_{Sun} = \frac{S_{\odot}\,(1-A)\cos\varsigma}{r^2} \tag{3}$$

with $S_{\odot}$ the solar constant heat flux, A the bond albedo of the asteroid, ς the incidence angle and r the heliocentric distance in AU. The annual thermal skin depth is written as:

$$l_s = \sqrt{\alpha \pi p} \tag{4}$$

where α is the diffusivity and p is the orbital period. The diffusivity is expressed as:

$$\alpha = \frac{k}{\rho c} \tag{5}$$

where ρ is the density and c the heat capacity. The second equation of this thermophysical model is the heat flux at the surface of the asteroid and the third is an adiabatic condition set at several annual thermal skin depth. This model is based on the heat transfer equation:

$$\frac{\partial u}{\partial t} = \alpha \frac{\partial^2 u}{\partial x^2} \tag{6}$$

This ensures the conduction of the temperature inside the asteroid. To express the temperature from this equation, we used a second order finite-difference method and iterative techniques such as the Newton method. During the process, we defined the numerical stability parameter:

$$S = \alpha \frac{\Delta t}{\Delta x^2} \tag{7}$$

This parameter must remain lower than 0.25 for stability purposes. For the simulations, it is important to define the thermal inertia:

$$\Gamma = \sqrt{k \rho c} \tag{8}$$

3 Objectives

Following the former document, the main objectif of this paper is to have a more complex thermophysical model to get closer to the reality. The heat flux from the Sun is the main source of heating for asteroids but there are more phenomenons happening to implement and especially for a binary system of asteroid. The most important from the secondary effects is the mutual heating between the two bodies of the binary system. Another effect to implement for crateres or rough-shape asteroids is the self heating. This paper also aims to present a method to include the asteroid obliquity in our model. The document is mainly focused on the study of Didymos's secondary object Didymoon but it also presents another planetary defense mission with very different orbital and asteroid parameters which is interesting for comprehension purposes.

4 A thermophysical model for a binary system of asteroids

In this section, we present the implementation of the mutual heating. As Didymos is a binary system of asteroid, the current thermophysical model is not enough to fully describe the temperature at the surface of the asteroid. The Hera mission focuses on the secondary object in this binary system. Its surface temperature depends also on the primary object for two main reasons: 2) the reflection of the Sun on the surface of the primary to the secondary, this phenomenon depends on the primary albedo and on its position with respect to the Sun and the secondary, and it is named the mutual direct heating, 2) the heat received from the primary itself, just as the Sun, considering it as a black body, it only depend on the distance and is called the mutual diffuse heating.

5 Advanced thermophysical model for rough surface including cratere

In this section we present the implement of the self heating. A normal at the surface of an asteroid may appear to be hidden from the direct solar flux even if it situated in the day side, for instance inside a cratere. In this scenario, it is important to take in consideration what is called the self heating of the asteroid. Due to its albedo, the surface of the asteroid relfects sunlight rays and thus, if the asteroid is not pure smooth, some reflected rays might impact another location on the asteroid.

6 Another important celestial parameter: the obliquity

This section describes the implementation of the obliquity and the explanation of the impact on the surface temperature. The obliquity is defined as the angle of tilt of the body's axis of rotation. Thus, it has an immediat impact on the repartition of temperature on the body as this figure describes:

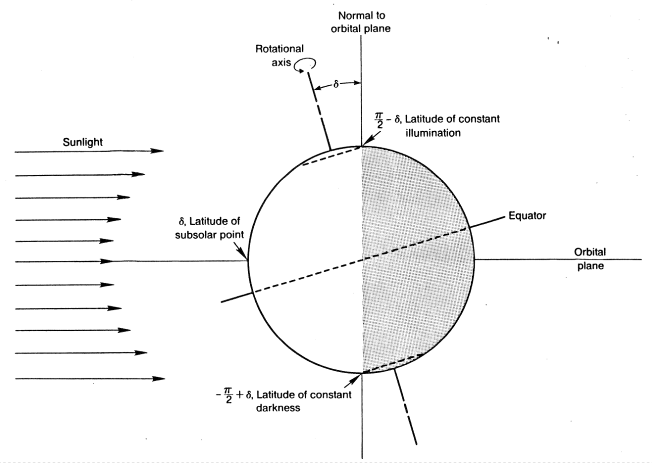

Figure 1: *Representation of the obliquity with the orbital plane and the rotational axis*

The subsolar point is not anymore located on the equator. Depending on the position of the asteroid on its orbit, only one pole is not receiving direct heating from the Sun.

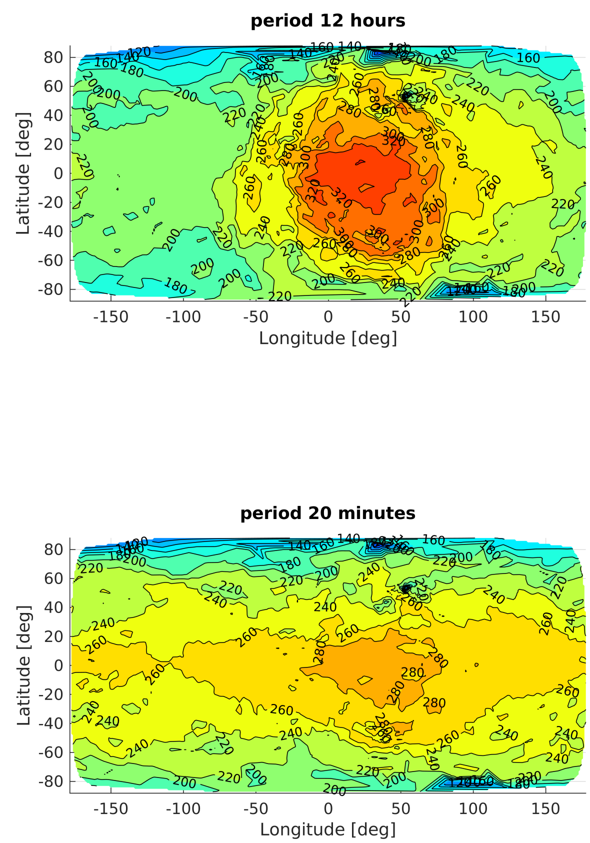

Figure 2: *HO3*

7 Another planetary defense mission: 2016 HO3

Description of the mission. To explain we have been requested to work for them.

8 Further works

Hera we talk about the further works.

References

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