Dynamical Environment and Surface Characteristics of Asteroid (16) Psyche

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Abstract

The asteroid (16) Psyche, localized in the main belt and having a diameter of approximately 250 km, is thought to be the most massive among the M type asteroids. Observations made from Earth indicated an Iron-Nickel composition. It is believed that this body may be what was left from a metallic core of a protoplanet that would have had a catastrophic collision. Early this year, a space mission with the same name, Psyche, was selected by NASA within the Discovery Program. The mission goal is to study the origin of planetary cores based on the exploration of asteroid (16) Psyche. The launch of the mission is planned for 2022 and, after a 4 years journey, it will explore the target for about 20 months. Therefore, a previous good knowledge of the target might be very useful for its planning. In the present work is studied a variety of dynamical aspects related to the surface, as well as, the environment around this asteroid. In our studies was adopted the shape of the asteroid determined by radar observations. The shape is given by a polyhedron of 2292 triangular faces and 1148 vertices. Assuming constant values for its density and rotational period. We used computational tools to explore the gravitational field generated by this asteroid. It was determined a set of physical and dynamical characteristics over the whole surface of the asteroid. Among them were computed the altitude, acceleration, tilt and slope. Then, an analysis of such results was made. In order to explore the neighborhood close to asteroid (16) Psyche, the location and linear stability of the equilibrium points were found. The system has four external equilibrium points and an internal one. Two of the external points are unstable and the other two stable. A set of numerical simulations of massless particles around the asteroid confirmed the stability of these points, and also showed an asymmetry in the size of the stable regions. That information is also relevant in order to estimate regions on the surface of (16) Psyche that might have a higher amount of accumulated particles.

Physical characteristics

Data from (16) Psyche (Shepard et al., 2017) used in computational simulations:

Dimensions: $279 \times 232 \times 189$ km	Rotation period: 4.195948 hours
Density: 4.5 g/cm^3	Mass: 2.72×10^{19} kg

For purposes of calculations we consider that the shape is centered at the center of mass and aligned with the principal axes, and then the geopotential takes on the simpler form

$$V(\vec{r}) = -\frac{1}{2}\omega^2(x^2+y^2) - U(\vec{r}) \qquad (1)$$

where $\vec{r} = x\hat{x} + y\hat{y} + z\hat{z}$ is the position of a particle in the body-fixed frame measured from the center of mass, with the unit vectors $\hat{x}$, $\hat{y}$ and $\hat{z}$ defined along the minimum, intermediate and maximum moments of inertia, respectively, ω is the angular velocity and $U(\vec{r})$ is the gravitational potential evaluated at given location $\vec{r}$.

Geometric altitude and geopotential

In Fig. 1 we can see a certain relation between the geometric changes in the surface and the changes in the geopotential. On the surface of small bodies with high rotation speed, this correlation does not occur in general, due to large rotational component in the geopotential. Note that the geopotential maximum lies at the ends of the equatorial region, since this location comprises the highest point in the geopotential. While the geopotential minimum is preferably located in the polar regions, since this location comprises the lowest point in the geopotential.

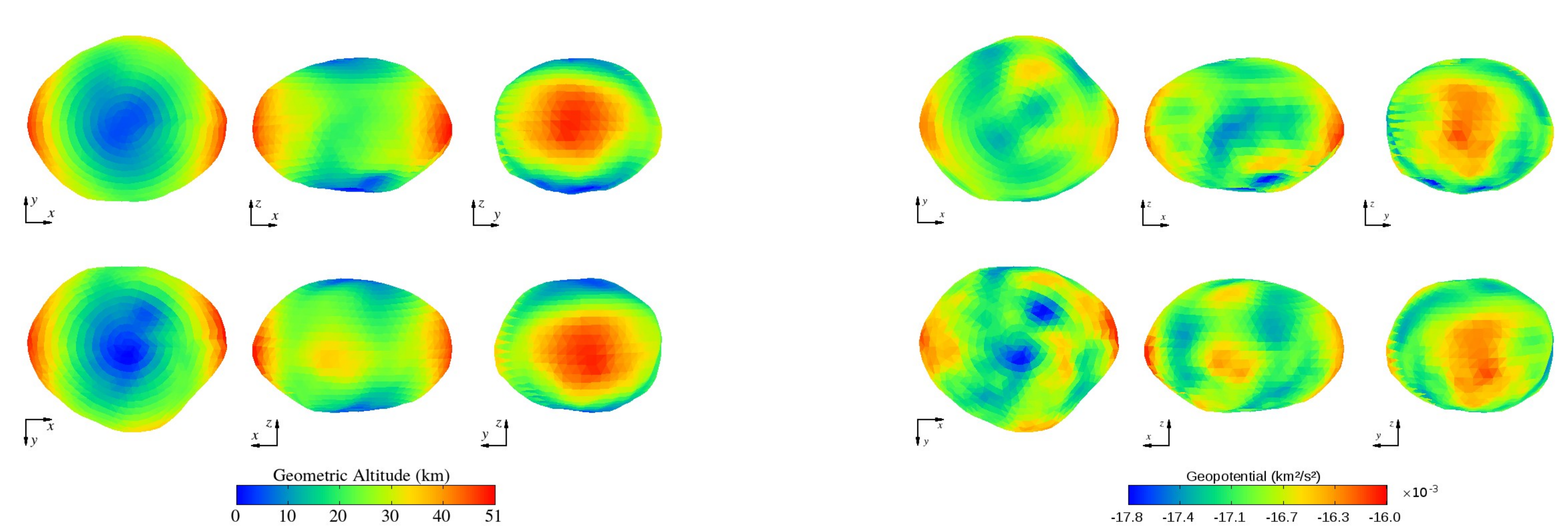

Figure 1: Geometric altitude and geopotential across the surface (16) Psyche. Geometric altitude is measured from the minimum radius value of the shape.

Slopes

The slope angle is defined as the supplement of the angle between the surface normal and the total acceleration vector at a given location. Since the surface acceleration is divided into a normal and tangential component, the acceleration vectors tangent to the surface generally point towards regions with slopes close to zero. In this way, there will be places on the surface of the body that are predisposed to accumulate material. As an example we identified Regions A and B in the southern hemisphere of the body (reddish region in Fig. 2), which are places that concentrate the highest slope values, and whose direction of the tangential acceleration vectors clearly point to low slope regions located near Regions A and B.

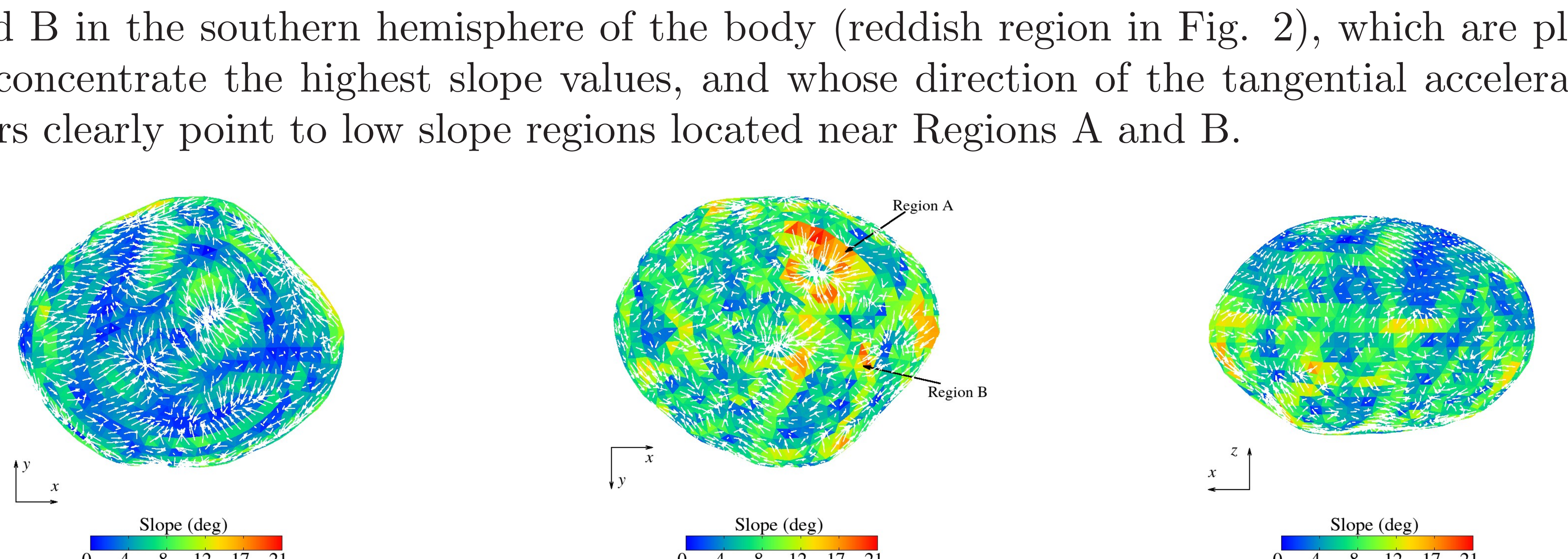

Figure 2: Directions of the tangential acceleration vectors mapped across the surface (16) Psyche, under the views of the northern and southern hemispheres and equatorial region, respectively..

Acceleration and Potential Speed

Fig. 3 (right) show the acceleration being minimized at the equator and maximized at the poles, this is due to the competition between the gravitational and centripetal accelerations.

The geopotential can be defined in terms of the kinetic energy or velocity that a particle would gain or lose in travel between two regions: $\Delta v_j(\boldsymbol{r}) = \sqrt{v_j(\boldsymbol{r})^2 - (v_j^m)^2}$ (Scheeres et al., 2016), where $v_j(\boldsymbol{r}) = \sqrt{-2V(\boldsymbol{r})}$ and v_j^m is the minimum value among those calculated on the surface of the object (sets the highest point in the geopotential).

Fig. 3 (left) shows the value Δv_j that a particle would require at a point $\boldsymbol{r}$ to reach the highest point of the geopotential.

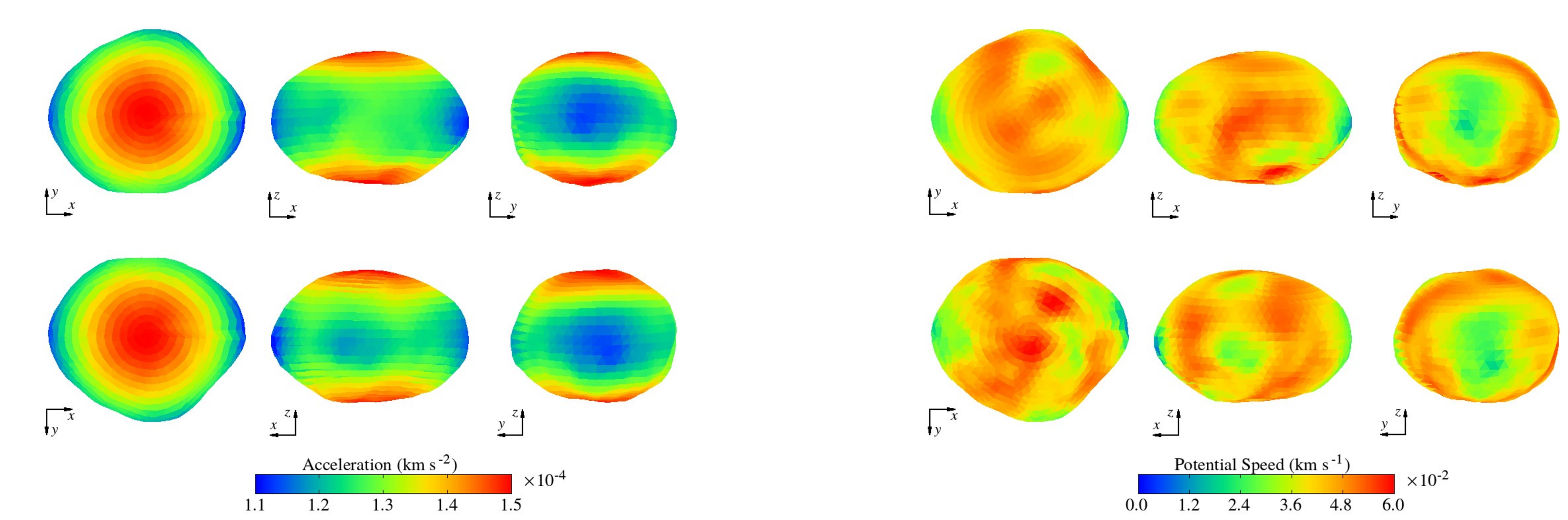

Figure 3: Total acceleration and potential speed across the surface (16) Psyche.

Equilibrium points

The next step was to explore the neighborhood close to asteroid Psyche. Then, we compute the equilibrium points and investigate the location and linear stability of these points. The equilibrium points satisfy the following condition: $\partial V/\partial\vec{r} = \vec{0}$. We find four external equilibrium points, E_1 - E_4, and an internal point, E_5 (see Fig. 4). We verify, through the eigenvalues, that the points E_3, E_4 and E_5 are linearly stable, while the others are unstable.

Next we integrate 15000 particles around Psyche, in a band that encompasses the external equilibrium points, during two years. At the end we obtained particles orbiting only the region in the vicinity of the linearly stable points (see Fig. 4, the remaining particles are represented by yellow dots). This result is in agreement with the analysis of the stability of the equilibrium points.

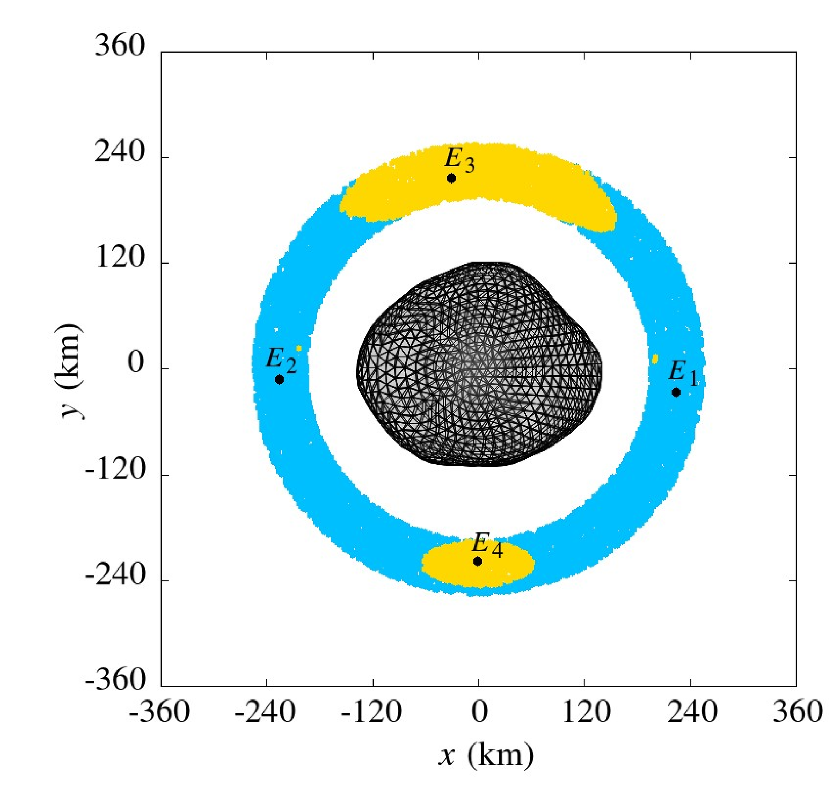

Figure 4: Blue represents the positions in the xoy plane of 15000 particles randomly distributed around (16) Psyche at the initial time. Yellow represents the positions of the particles that remained after two years of integration. Black represents the position of the equilibrium points.

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