EPSC Abstracts
Vol. 17, EPSC2024-1009, 2024, updated on 20 Sep 2024
https://doi.org/10.5194/epsc2024-1009
Europlanet Science Congress 2024

Binary craters on Ceres and Vesta and implications for binary asteroids

Carianna Herrera[1,2,3], Benoit Carry[2], Anthony Lagain[4,5,6], and Dmitrii Vavilov[7]
[1]German Aerospace Center (DLR), Institute of Planetary Research, Berlin, Germany (carianna.herrera@dlr.de)
[2]Université Côte d'Azur, Observatoire de la Côte d'Azur, CNRS, Laboratoire Lagrange, Nice, France
[3]Master track in Astrophysics, Université Côte d'Azur \& Observatoire de la Côte d'Azur, Parc Valrose, 06100 Nice, France
[4]Space Science and Technology Centre, School of Earth and Planetary Sciences, Curtin University, Perth, WA, Australia
[5]Aix Marseille Univ., CNRS, IRD, INRA, CEREGE, Aix en Provence, France
[6]Aix-Marseille Univ., Institut ORIGINES, Marseille, France
[7]Institut de Mécanique Céleste et de Calcul des Éphémérides (IMCCE), Observatoire de Paris

ABSTRACT

Planetary surfaces present binary craters that can be associated with the synchronous impact of binary asteroids. In this work, we identify binary craters on asteroids (1) Ceres and (4) Vesta, and aim to characterize the properties (size ratio and orbital plane) of the binary asteroids that might have formed them. We used global crater databases developed in previous studies and mosaics of images from the NASA DAWN mission. We established selection criteria to identify craters that were most likely a product of the impact of a binary asteroid. We find geomorphological evidence of synchronous impacts on the surfaces of Ceres and Vesta. The associated binary asteroids are widely separated and similar in diameter in contrast to the current census of binary asteroids. The distributions of the orientation of these binary craters on both bodies are statistically different from numerical impact simulations that assume binary asteroids with coplanar mutual and heliocentric orbits. These findings agree with a population of well-separated and similarly sized binary asteroids with non-zero obliquity that remains to be observed.

INTRODUCTION

Planetary surfaces present binary craters that are associated with the synchronous impact of binary asteroids. The detection and characterization of satellites of small asteroids rely on observations by radar echoes for near-Earth asteroids (NEAs) [1] and optical light curves for both NEAs and main belt asteroids (MBAs) [2]. Although these observations are efficient and precise, they are biased by a limited range from the Earth for radar observation and a strong preference for compact and low-obliquity systems for light curves.

To have a better understanding of the distribution of the binary asteroid population in the Solar System, we created a catalog of binary craters for Ceres and Vesta that are associated to binary asteroids that might have formed them, focusing on the size ratio and orbital plane of the binary system. Out catalog was based on the global crater databases of Ceres [3] and Vesta [4], combined with high altitude mapping orbit (HAMO) and low altitude mapping orbit (LAMO) images for each body from the NASA's DAWN mission [5].

METHODS

Airless planetary objects have their surfaces covered by craters but proximity between two of them is not enough to determine if they are product of the impact of binary asteroids. We created a criterion of classification for binary craters on Ceres and Vesta which main aspects are that:

- The pairs of craters must be in contact and show a septum. We cannot label objects separated as synchronous because there is no ejecta blanket surrounding them since their surfaces are not hydrated enough.
- These craters should not exhibit poligonality, which has been observed on Ceres [6], since this feature can be confused with a pair having a septum and be misidentified as synchronous.
- An inspection on the surroundings is critical to avoid identifying possible secondary craters from previous impacts as a binary asteroid.
- Each pair of craters must have a similar degradation state, and similar depth when they have a similar size.

We established a level of confidence in our catalog and distinct between likely and very likely pairs of craters. We compared our results according to their main-to-secondary diameter ratio, the separation between the craters, the morphological classification of the binary system [7] and the orientation of the line that connects the center of both craters. We also found ranges for the sizes of the impactors which formed the binary craters.

RESULTS

We identified 39 and 18 synchronous impacts on the surfaces of Ceres and Vesta, respectively. Some examples are shown in Fig. 1, in which the contact between all rim pairs is characterized by a continuous septum without any visible stratigraphic relationship, as well as a similar preservation state, thus indicating a very likely synchronous formation. We note that in the case of the pairs on Vesta presented here, an excess of ejecta material is visible in the direction of the septum, which is expected in the case of a binary asteroid impact [7].

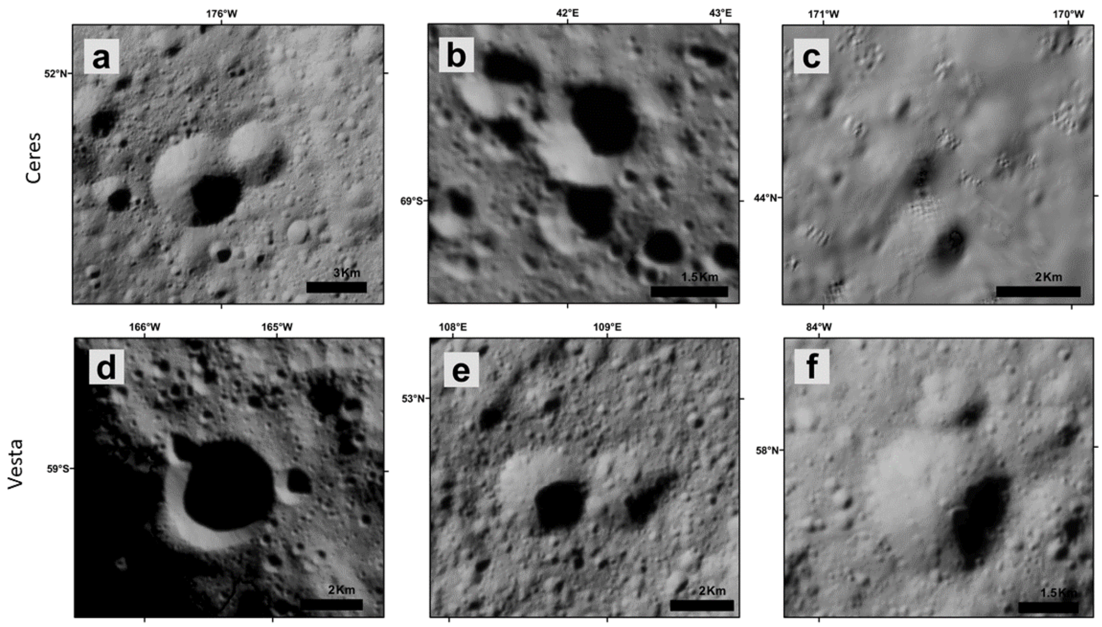

Fig. 1. Examples of binary craters identified on the surface of Ceres (top) and Vesta (bottom). Background imagery: LAMO mosaic

We compared the orientation of the binary crater with the numerical simulations considering a population of binary asteroids with zero obliquity impacting a surface. We performed a two-sample Kolmogorov-Smirnov test [8] to determine if the distribution of the observed and simulated orientation is similar (null hypothesis). We found that for values of significance level between 0.01 and 0.2, the D-statistic resulting from the tests on both Ceres and Vesta is always higher than the significance level. Hence, there is a significant difference between the distributions of the simulations and the observations. These results support what was found by a previous study on Mars [8]: binary craters on planetary surfaces cannot be explained by a population of binary asteroids with zero obliquity.

SUMMARY AND OUTLOOK

Our findings are consistent with well-separated and similarly-sized binary asteroids. Additionally, comparing our catalogs with numerical simulations indicates a non-zero obliquity. A population with these characteristics remains to be observed, as suggested by a previous study of binary craters identified on Mars.

Considering the recent discoveries of unexpected satellites (e.g., around Dinkinesh and Arecibo, during Lucy flyby and using Gaia astrometry [9]), the current census of binary asteroid systems is likely biased. Future observations using for instance astrometry or stellar occultations may reveal satellites that have so far remained beyond the reach of direct imaging, light curves, and radar echoes [10,11].

REFERENCES

[1] Benner et al., 2015; [2] Pravec et al., 2006; [3] Zeilnhofer & Barlow, 2021a; [4] Liu et al., 2018; [5] Russell et al., 2015; [6] Zeilnhofer & Barlow, 2021b; [7] Miljkovic et al., 2013; [8] Vavilov et al., 2022; [9] Tanga et al., 2023; [10] Pravec & Scheirich, 2012; [11] Segev et al., 2023.