ASYMMETRIC CRATERS ON CERES. K. Krohn[1], R. Jaumann[2], K Wickhusen[1], Katharina A. Otto[1], Elke Kersten[1], K. Stephan[1], R. J. Wagner[1], C. A. Raymond[3] and C. T. Russell[4],
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Introduction: Most craters on planetary surfaces have a circular shape, but on smaller airless bodies, such as the Moon [1], Vesta [2], and Lutetia [3], craters with a specific asymmetric shape are observed. The craters show a sharp uphill crater rim and a smooth downhill crater rim. The origin of asymmetric craters is manifold, and in most cases, is not fully solved yet. Generally, impact crater formation is discussed for impacts into more or less planar surfaces, but there are theories that asymmetries in the crater forms are a result of projectile trajectory. An asymmetric ejecta distribution could be due to shallow impact angles. The shallower the impact angle, the more elongated is the crater. Furthermore, the topography or the heterogeneity of stratigraphy can play a role in the formation process of the asymmetry of craters. Additionally, the initial circular impact crater structure could be overprinted by post-impact modification, such as volcanism, tectonics, or erosion, and could change the circular structure into an asymmetric shape. Three-dimensional hydrocode simulations of those craters on Vesta revealed that the shape is caused by the formation of craters on slopes [2]. That study [2] showed that the slope prevents the deposition of ejected material in uphill direction and results in a larger accumulation of ejecta within the crater and on the downhill crater rim. We analyzed and discussed the formation processes for the asymmetries of craters on Ceres in comparison to our findings for Vesta [4].

Data and Methods: We used the data of the last orbit of Dawn around Ceres, with a spatial resolution of 3 to 5 m/pixel. The data cover Ceres' surface in the range of 60◦ N to 60◦ S latitude and 197◦ E to 265◦ E longitude, focusing on the observation of the prominent impact crater Occator and parts of the Urvara region.

In order to analyze the morphology of these craters, we made use of a digital terrain model (DTM) derived from stereo-photogrammetrically processed FC High Altitude Mapping Orbit (HAMO) data with a spatial resolution of ~135 m/pixel. Where available, we also used the DTMs resulting from the Low Altitude Mapping Orbit (LAMO) data with a spatial resolution of 32 m/pixel.

We identified and mapped the outline of each asymmetric crater and defined the diameters from rim crest to rim crest. The morphology of asymmetric craters is described by asymmetrical crater shapes on sloping surfaces with sharp and smooth crater rims, asymmetric interior morphology, and ejecta distribution [2]. Therefore, to obtain the most accurate impression of the surface, we generated a slope map from the HAMO DTM using the ArcGIS slope map tool. The slope is calculated by the maximum rate of change in value from each cell to its neighbors. Due to the resolution of 3 to 5 m/pixel for the FC XM2 data, we can identify asymmetrical craters with diameters down to 300 m with sufficient accuracy.

Results: The analysis of XM2 data reveals 269 craters with a crater similar to asymmetric craters observed on Vesta, the Moon, and Lutetia. The crater diameters of asymmetric craters on Ceres vary from 0.30 to 4.2 km, with a mean diameter of 0.98 km [4].

They show an asymmetric crater interior with an oblique and a shallower side, as well as an asymmetric ejecta distribution. The craters show a semi-circular sharp and well-formed rim on the uphill side, and a smooth rim on the downhill side. Due to local accumulation of material covering the downhill crater rim, the rim crest is not clearly detectable [4]. Ejecta deposits are only sporadically detected in thin layers on the uphill rim. The majority of the upslope inner crater walls show mass wasting features. Most asymmetric craters on Ceres show a relative straight border in the lower third through the crater, separating the oblique from the shallower crater floor. The uphill crater wall shows a smooth texture with a downslope movement of material accumulated at the border. Some craters show a slightly more elongated shape in uphill direction than the other craters. The uphill rim seems to merge with the slope. The downhill rim shows a less elevated rim than the other craters, but with the same ejecta and mass wasting material distribution. Nevertheless, the craters also show the border between the steeper and the shallower crater parts. However, the crater floor appears wider than the others. The projectile forming this crater seems to have impacted on the slope crest [4].

Asymmetric craters occur on slope angles between 5 to 10 degrees as well as over 20 degrees. Asymmetric craters on slope angles from 10 to 20 degrees are significantly above the average [4].

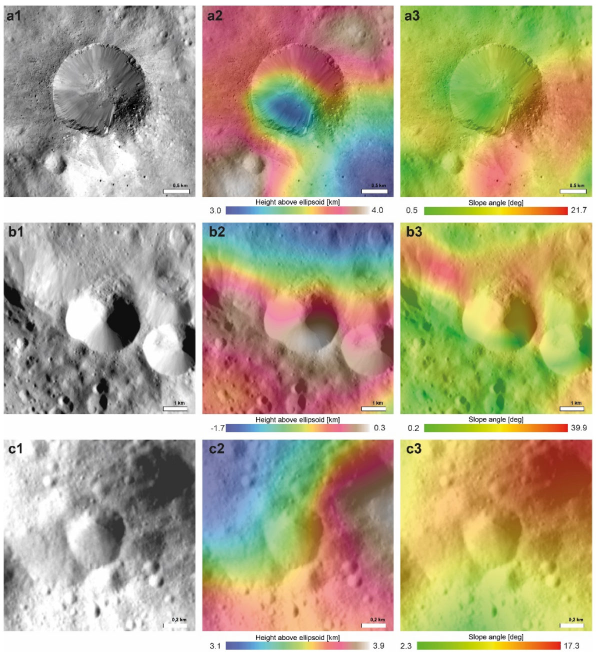

Fig. 1: Examples of asymmetric craters on Ceres. (a1) unnamed crater at 245.96◦ E and 12.57◦ N; and (b1) unnamed crater at 218.18◦ E and 9.55◦ S show the typical asymmetric crater form, with a sharp uphill rim and a smooth downhill rim, covered with mass wasting material from the crater flanks. There are little ejecta visible above the uphill rim. The DTM (a2) and slope map (a3) of the crater shows that the crater was formed on a slope crest. (b2) DTM and (b3) slope map shows the formation on a slope. (c1) Clear filter image of an unnamed crater at 245.16◦ E and 12.63◦ N shows a more elongated shape in the uphill direction than the other craters. The uphill rim seems to merge with the slope. (c2) DTM of 245.16◦ E and 12.63◦ N. (c3) Slope map of 245.16◦ E and 12.63◦ N.

Discussion and Conclusion: Asymmetric craters on Vesta are characterized by a sharp edge on the uphill side, a smooth rim and material accumulation downhill, with little or no ejecta deposits on the uphill side [2]. The craters on Ceres look quite similar. They also show a sharp crater rim with little or no ejecta on the uphill side and a smooth-material-covered crater rim on the downhill side. On Vesta, the diameters of asymmetric craters range from 0.3 to 42.6 km on slope angles from > 5 to over 20 degrees, with a maximum appearance on slope angles > 10 degrees [2]. On Ceres, however, we observed asymmetric crater diameters varying from 0.30 to 4.2 km on slope angles between 5 and 20 degrees, with a maximum appearance on slope angles between 5 to 10 degrees. Only a few craters are found on slope angles over 20 degrees. The crater frequency ratio is similar on both bodies, indicating a similar formation process for the asymmetries due to slope angles [4].

Another possible explanation for the asymmetries of the craters could be erosion or tectonic processes. Erosional processes on Ceres are mainly caused by seismic shaking due to impact events, or flow features such as cryovolcanic flows [e.g., 5] and ground-ice flows [e.g., 6]. However, those flows would be characterized by a more compact morphology with relatively smooth surfaces and no loose material, as on the downhill rim of the studied craters. Moreover, the material of uphill ejecta, if present and downhill material seem to be deposited simultaneously. This means that they were not influenced by post-emplacement modifications. We also see no signs of recent tectonic activity near the asymmetric craters, such as an active uplift of Hanami Planum, which might cause the uplift of crater parts and mass wasting material, flowing down the crater walls and remaining on the downhill crater rim. However, Hanami Planum appears relatively old. The surface is densely cratered and the flanks showing no young landslide as in the flanks of Ahuna Mons [7]. On the contrary, the asymmetric craters appear relatively young.

In conclusion, this work shows that the three prominent features of the asymmetric craters on Ceres are a sharp uphill crater rim, a smooth downhill rim with mass wasting material, and little or no ejecta deposits on the uphill side of craters formed on a slope. Although there are only small craters showing such asymmetries, we conclude that topography is the main cause for the asymmetries observed in these craters on Ceres. Larger craters with asymmetries are unlikely due to the low topographic variations on Ceres.

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