THE DISTRIBUTION OF IMPACT EJECTA ON CERES.

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Introduction: Since March 6 2015 the Dawn spacecraft [1] has been in orbit around the dwarf planet Ceres. High resolution global mapping with its Framing Camera (FC) [2] revealed a much more densely cratered surface than expected [3]. Relative to the number of mid-sized craters (10-70 km) large impact basins that are comparable to Veneneia or Rheasilvia on asteroid Vesta are missing on Ceres [4, 5]. This behavior might be related to a gradual increase with depth of the water ice content in the subsurface [6]. At small crater diameters Ceres appears to be peppered with secondary craters that often align in chains or form clusters. Some of such possible crater chains follow curved geometries and are not in a radial orientation with respect to possible source craters [7]. Ceres is a fast rotating body (~9 h per revolution) with comparatively low surface gravity (~0.27 m/s^2). A substantial fraction of impact ejecta may be launched with velocities similar to Ceres' escape velocity (510 m/s), which implies that many ejected particles follow high and long trajectories. Thus, due to Ceres' fast rotation the distribution pattern of the reimpacting ejected material is heavily affected by Coriolis forces that results in a highly asymmetrical and curved pattern of secondary crater chains.

The Model: In order to simulate flight trajectories and distribution of impact ejected material for individual craters on Ceres we used the scaling laws by [8] adjusted to the Cerean impact conditions, the impact ejecta model by [9] and for more sophisticated simulations regarding the ejection angles the modified Maxwell Z-model by [10]. These models provide the starting conditions for tracer particles in the simulation. The trajectories of the particles are computed as n-body simulation. The simulation calculates the positions and impact velocities of each impacting tracer particle with respect to the rotating surface of Ceres, which is approximated by a two-axis ellipsoid. The trajectory of each tracer particle is stored in 8.64 second (10^{-4} of an Earth day) intervals permitting post processing plotting and analysis of particle trajectories. That allows for comparison of observed ejecta rays and modelled particle trajectories. Since high and far flying particles reach significant fractions of the escape velocity, disturbing gravitational forces by the Sun and the major planets are also taken into account. For our simulation we used a Matlab environment with parallel computing, mapping, optimization, statistics toolboxes as well as the JPL NAIF (Navigation and Ancillary Information Facility) "mice" toolkit. Planetary constants and positions of each body at the arbitrary time of impact (Jan 1 2015) are taken from NAIF SPICE kernels.

In the model we assume an impact with an angle of 45 degrees and a symmetric geometry for the ejected particles. The scaling parameters for the projectile-crater size conversion are given in [4] (LDM model). The more simplistic model further assumes that all particles are ejected at a 45 degree angle with the local surface. The more sophisticated model is using the modified Maxwell Z-model [10] in order to adjust ejection angles depending on the ejection point/velocity within the source crater. All particles that are ejected at lower velocities than 150 m/s are neglected, because they are deposited fairly symmetrical around the source crater (continuous ejecta) but due to the high number of particles take most of the computing time. The value of 150 m/s is chosen because this might be the lower limit for forming secondary craters [11].

Results: Initial results of the more simplistic model show a number of interesting features in the deposition geometries of specific craters that are roughly in agreement with features that can be observed in FC imaging data of the Cerean surface.

Fast jets ejected at shallow angles: Fast jets that leave the source crater at low ejection angles appear to form systems of rays around fresh impact craters. In the case of Occator one of such rays can be mapped half way around the circumference of Ceres in color ratio data. Our ejecta model is able to reproduce this feature if a narrow beam of particles is assumed to leave Occator crater at a shallow angle of 10 degrees w.r.t. the local surface at an azimuth of 256 degree (Fig. 1 & 2).

Crater chains: Areas of high tracer particle density of the Yalode/Urvara impacts coincide with observed possible crater chains (Junina Catenae) that are not in a radial orientation to any nearby crater (Fig. 3).

Curved border of eastward ejected particles: Particles that are ejected faster than a certain velocity into the rotation direction of Ceres are overtaken by the rotation of Ceres during their flight. This effect is causing a slowing down of the eastward propagation speed of the back falling ejecta curtain and eventually the direction is reversed, such that eastward ejected particles are falling back into and west of the source crater. For the case of the Urvara impact the curved geometry of the border line where the ejecta curtain changed its propagation direction can be identified in color ratio data (Fig. 1 & 3).

The higher color ratio closer to Urvara further indicates a relatively young age for the ejecta deposition time [12].

Conclusion: Our ejecta simulation is able to give reasonably good indication of how specific features in color ratio data and certain crater chains might have formed. The simulations are primarily visualizing the probability for secondary cratering by the spatial density distribution of tracer particles. It is important to note that there could be any number of tracer particles be fed into the simulation in order to increase resolution or computing speed resulting in more or less particles. The ejected volume of specific craters is limited. Thus, individual tracer particles are not representative for individual secondary projectiles/craters. Furthermore, we do not account for highly oblique impacts that would result in asymmetric ejection geometries. This effect could contribute to deviations between observed and modelled feature geometries. The more sophisticated modified Maxwell Z-model can be used in future work for simulating oblique impacts.

References:

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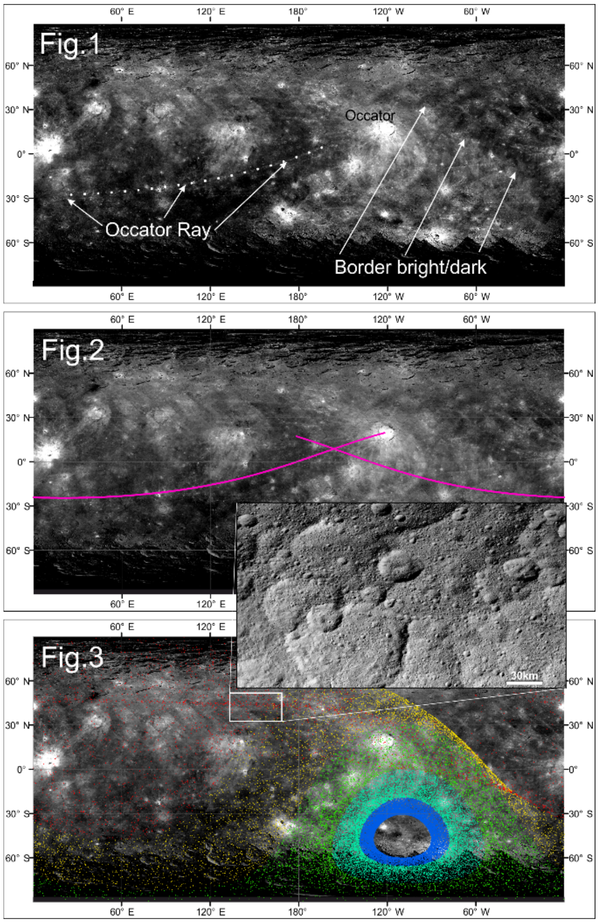

Fig. 1: *F8(438 nm)/F5(965 nm) FC color ratio with marked ray of Occator crater and a border between high/low color ratio.* ***Fig. 2:*** *Trajectory of tracer particles that are ejected from Occator at 10 degree angle with the local surface and 256 degree azimuth with velocities of ~500 m/s. The modelled particle trajectory is precisely following the observed Occator ray from Fig. 1.* ***Fig. 3:*** *Colored points represent the positions where tracer particles reimpacted on the surface after they were ejected during the Urvara impact. Colors indicate the impact velocities from low 140 – 200 m/s (deep blue) to high 390 – 520 m/s (red). The inlay shows a magnified clear filter version of the boxed area. The inlay confirms several E-W oriented crater chains where the global map also indicates an E-W oriented narrow band of increased tracer particle density reimpacting at high velocities (~500 m/s). The dark/bright boundary from Fig.1 is nearly coinciding with yellow dots (320 – 390 m/s) marking the eastern boundary for eastward ejected particles.*