Investigation of Doublet Craters on Ceres as Evidence of Main Belt Asteroid Systems

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**BACKGROUND**

**Doublet Crater:** a pair of nearby impact craters that are created by the same primary impact event [1]. Doublets are observed on Earth, on Luna, on Mercury, on Venus, on Mars [2,3,4,5,6,7,8], and now on Ceres.

**Formation:** doublet crater formation had been attributed to a single impactor broken up by either atmospheric disruption [9] or tidal forces [1,10], but further studies showed these processes could not result in sufficient separation to create observed doublets [11],[12]. It is now believed that well-separated binary asteroids are the source of doublet craters [12]. This makes doublets a source of evidence for the prevalence and nature of binary asteroid systems. The percentage of doublets in the inner solar would require ~15% of planet-crossing asteroids to be binaries [12]. 290 binary asteroids have been identified in the Earth-crossing, Main Belt, Trojan, and TNO populations [13,14,15].

**OBJECTIVE**

Use doublet craters on Ceres to constrain Main Belt binary asteroids

Images acquired recently from NASA's Dawn mission to Ceres [16,17] provide a new opportunity for using doublet craters to estimate the size of the binary asteroid population within the main belt, particularly for smaller asteroids that likely remain undetected at such a distance from Earth.

**METHODS**

We took an approach similar to Melosh et al. [8]:

- **Initial Study Area:**
  - Chose terrain near large craters Urvalo and Yalode [18] for its lower crater density, to minimize randomly-adjacent craters
  - Small sample area bounded by 250°E to 270°E and 10°S to 30°S (~28,000 km²)

- **Visual Survey:**
  - Counted impact craters ≥ 3 km in Dawn Framing Camera images [17], using JMARS [19]
  - Evaluated all unique crater pairs with separations < 20 km using scoring system
  - Points added for similar and lighter erosion, possible septum and/or ejecta lobes
  - Points subtracted for superimposition, differing erosion (implies different ages) and heavy erosion

- **Monte Carlo Simulation:**
  - Creates an expected distribution of crater pair separations if all impact events are single asteroids, and compares with observed pairs.
  - Will generate random impacts within the study area (the same number counted), and measure separations between all unique pairs
  - Simulation will run 100 times, average results
  - Actual doubles should cause excesses in comparison to the expected distribution.

**RESULTS**

- **Visual Survey and Evaluation:**
  - Counted 80 craters ≥ 3 km (Figure 1a)
  - 172 unique pairs separated by less than 20 km
  - 4 pairs received positive scores (Table 1)
  - 63 pairs were inconclusive
  - 105 pairs were eliminated for differing erosion, extreme erosion, or being superimposed.

- **Monte Carlo Simulation:**
  - 80 random lat/lon pairs within the sample region
  - Separations < 20 km tallied into logarithmic bins
  - Figure 2 shows expected distribution (“Random”) along with observed crater pairs tallied into the same bins (“Observed”)

There is a pronounced excess in the bin centered at 2.88 km separation, which is where Pairs 1-3 of the candidate double impacts in Table 1 are tallied. This supports the interpretation that the four candidate crater pairs are not due to random chance, but instead are the result of a double impact.

**CONCLUSIONS**

If Pairs 1 and 2 are true doublet craters:

- Our data place a lower bound of 2.6% on impact events in study area that are doublets
- This is consistent with 2-3% for Earth & Mars [2]

If we apply previous experimental data showing 15% of binary impacts produce doublets [2]:

- Our initial study suggests ~17% of main belt asteroids are binary
- Previous radar and photometric studies show ~15% of NEAs & MBAs < 10km are binary [2,20]

Our preliminary sample is small. We plan to expand the survey to other parts of Ceres, and work toward a model for estimating binaries in the Main Belt.

**REFERENCES**