INVESTIGATION OF DOUBLET CRATERS ON CERES AS EVIDENCE OF MAIN BELT BINARY ASTEROID SYSTEMS P. F. Wren[1] and R. A. Fevig[1], [1]Department of Space Studies, University of North Dakota, Clifford Hall Room 512, 4149 University Ave Stop 9008, Grand Forks, ND, 58202 paul.wren@und.edu

Introduction: A doublet crater is a pair of impact craters in proximity to one another that are created by the same primary impact event [1]. Doublet craters have been observed on Earth [2], on the Moon [3][4][5], on Mercury [4][6], on Venus [7], and on Mars [8].

Doublet crater formation. Early research attributed doublet crater formation to a single impactor broken up by either atmospheric disruption [9] or tidal forces [1][10], but further analysis revealed that these processes could not result in sufficient separation of the components to create observed doublets [11][12]. It is now believed that well-separated binary asteroids are the true source of doublet craters [12]. The percentage of impact craters in the inner solar system that are doublets would require ~15% of planet-crossing asteroids to be binaries [12]. This makes doublets an excellent source of evidence for the prevalence of binary asteroidal systems, and can constrain the possible nature and formation processes for such binaries.

Binary asteroids. The existence of satellites orbiting asteroids was considered as early as 1971 based on light curve observations of 624 Hektor [13]. The Galileo spacecraft made the first direct observation of a binary system when it spied a satellite of 243 Ida [14]. Using both ground- and space-based instruments, a total of 290 binary asteroids have been identified in the Earth-crossing, Main Belt, Trojan, and TNO populations [15].

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

Data and Methods: More lightly-cratered regions are preferred when searching for doublets, since randomly-adjacent single craters are less likely. The region in Ceres' southern hemisphere around the large impact craters *Urvala* and *Yalode* features low crater density terrain [18], and we chose it for our initial survey.

Inspired by [8], we adopted a similar data collection and analysis approach. We began with a sample region bounded by 250°E to 270°E and 10°S to 30°S, roughly 28,000 km^2. Using JMARS [19], we counted impact craters ≥ 3 km appearing in Dawn Framing Camera images from this region captured during the Low Altitude Mapping Orbit (LAMO) [17].

We designed a Monte Carlo simulation to create randomly-distributed impact points within the initial study region. The separations between all unique pairs of random impacts are computed as great-circle distances. These are tallied to produce a distribution we would expect if impactors are single bodies, and their impact locations are due solely to chance.

If any craters appear to suggest a binary impactor, we will categorize them using the doublet crater morphology classification system developed by [2]. The categories used are: Elliptical, Teardrop, Peanut, Overlapping, and Doublet (see Figure 1).

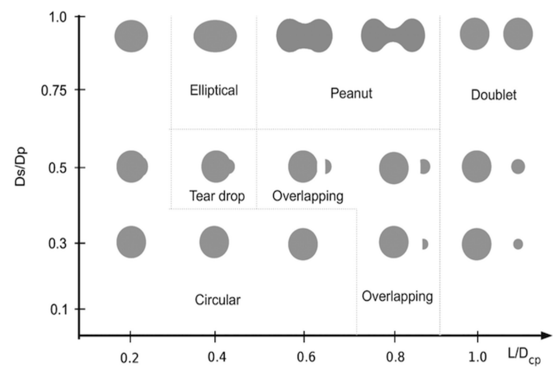

Figure 1: Crater morphology formed in close binary impact depending on Ds/Dp and L/Dp (figure 8 from [2])

Results: We counted 80 craters ≥ 3 km in the initial study region, as depicted in Figure 2. Of 3160 total possible pairings, we considered any two craters separated by < 20 km to be potential doublets (172 pairs met this criterion).

Visual evaluation. Our initial approach was to inspect the potential doublets with small separations. We eliminated pairs from consideration if their relative erosion implied different ages, or if one crater was clearly superimposed on the other. The two pairs listed in Table 1 are of similar age and showed evidence of a septum separating the craters. Both would be classified as "Peanut" in shape per Figure 1. Pair 2 is shown in Figure 3.

Monte Carlo simulation. We randomly generated 80 latitude/longitude pairs within the sample region to represent impact locations, and tallied impact pairs with separations < 20 km into logarithmic bins based on their separation distance. The simulation was run

100 times and the results averaged. These values are graphed as the curve labeled "Random" in Figure 4, along with the separations of observed crater pairs on Ceres tallied into the same bins ("Observed"). There is a pronounced excess in the bin centered at 2.88 km separation, which includes the two suspected double impacts in Table 1.

Table 1. Candidates for Doublet Craters on Ceres

Crater Pair	*Longitude*	*Latitude*	*Diameter (km)*	*Separation (km)*
Pair 1	252.679	-13.583	3.0	2.92
	252.938	-13.831	3.2	
Pair 2	259.332	-25.994	3.8	3.38
	259.771	-26.107	3.5	

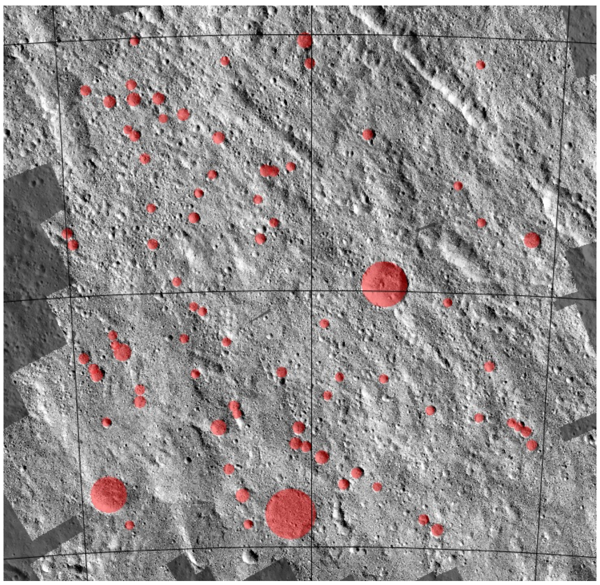

Figure 2: Crater counting on Ceres in JMARS [19]

Figure 3: Doublet crater "Pair 2" (img FC21B0047316 [17])

Conclusion: If Pairs 1 and 2 are true doublets, then our preliminary study places a lower bound on the percentage of doublet craters in this region of Ceres at 4.6% (2 out of 78 impact events), a value higher than the current estimate of 2-3% for both Earth and Mars [2]. We are encouraged that our first look revealed excesses in the statistical data when compared to random values. It is also encouraging that two potential doublets were identified visually. Prior to the 48th LPSC conference, we plan to systematically examine all 172 candidate pairs and classify them as to their suitability to be considered doublet craters.

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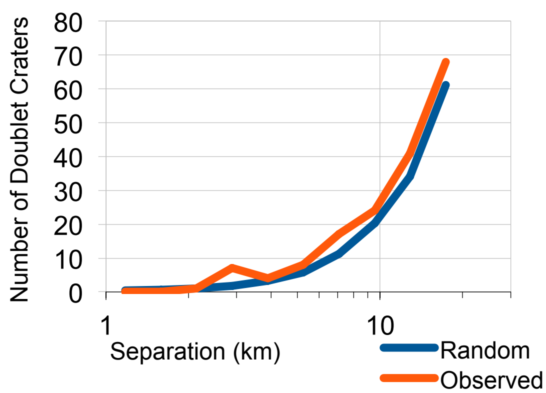

Figure 4: Observed counts of doublet craters by separation, plotted against expected distribution from random impacts.