USING DOUBLET CRATERS ON CERES TO CONSTRAIN 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: What is a doublet crater? It is a pair of nearby impact craters that are created by the same primary impact event [1]. Doublets have been observed on Earth, the Moon, Mercury, Venus, and Mars [2,3,4,5,6,7,8], and now on Ceres (see Figure 1).

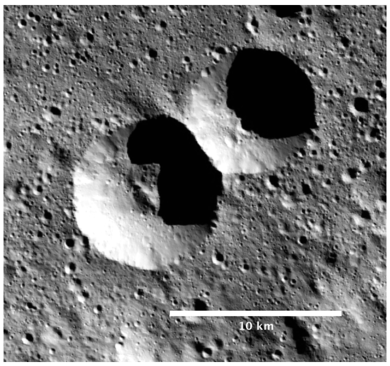

Figure 1: Doublet crater on Ceres taken by Dawn FC [15].

Doublet crater formation. Originally, doublet crater formation was 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 of the impactors to create the 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.

Constraining binary asteroid populations. The percentage of asteroids in the near-earth population that are binary is fairly well established at 15%, and doublet craters on Mars, Earth, Venus, and the Moon have been used to confirm this value [2,18]. 144 binary asteroids have been identified in the main belt using ground-based and spaceraft observations [13], but smaller binary systems have likely gone undetected. The recent arrival of the Dawn spacecraft at Ceres [14,15] has provided a large collection of detailed images of the dwarf planet's surface. Doublet craters on Ceres would provide evidence for the abundance of binary asteroid systems in the main belt, down to smaller diameters than were possible before.

Previous Efforts: We studied a sample area on Ceres bounded by 250°E to 270°E and 10°S to 30°S, approximately 28,000 km^2 [19]. Terrain was chosen near the large craters *Urvala* and *Yalode* for its low crater density, to minimize the number of randomly-adjacent impact craters [16]. Taking an approach similar to [8], we identified all impact craters 3km or greater in diameter (80 were counted), and noted all pairs of craters in this group that were < 20km separated. These pairs were evaluated to identify those that were most likely to represent doublets using criteria such as similar erosion (as a proxy for age), visible signs of simultaneous impact. Pairs that displayed superimposition or differing erosion were rejected. The four best candidates are shown in Figure 2.

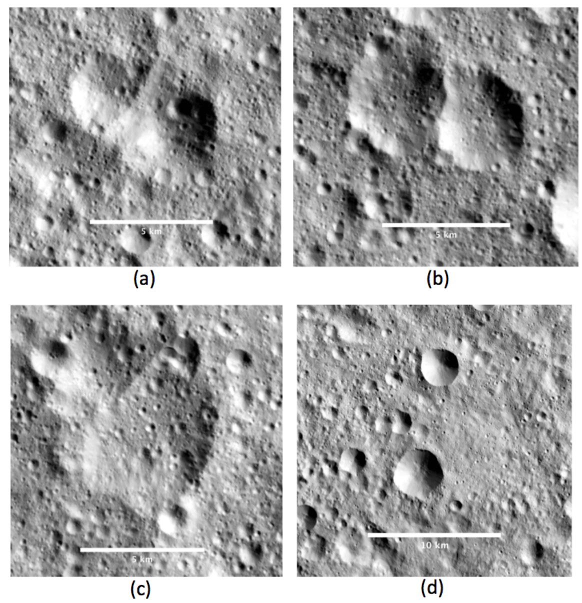

Figure 2: Potential doublet craters: a) "Pair 1" from Dawn FC image 0052195 [15]; b) "Pair 2" from Dawn FC image 0047316 [15]; c) "Pair 3" from Dawn FC image 0051873 [15]; d) "Pair 4" from Dawn FC image 0051871 [15].

We also created a Monte Carlo simulation, which generated 80 random impact locations within the study area (the same number as observed in our survey). Our software then measured separations between all location pairs that were within 20km of each other. The simulated crater pairs were tallied into logarithmic bins based on their separation, and the same bins were used to group the pairs of observed craters (See Figure 3).

Secondary Craters: During the 48th Lunar and Planetary Science Conference, Jay Melosh [20] observed that most of the likely doublets we had identified (see Figure 2a, 2b, 2c) may be secondary craters formed by ejecta re-impacting the surface, not primary impacts from binary asteroids. This raised the question: How might secondaries be distinguished from primaries?

Secondary impact craters occur singly, but also in clusters and lines. The lower velocities of secondary impactors and interference with other ejecta produces craters that are generally irregular in form [21].

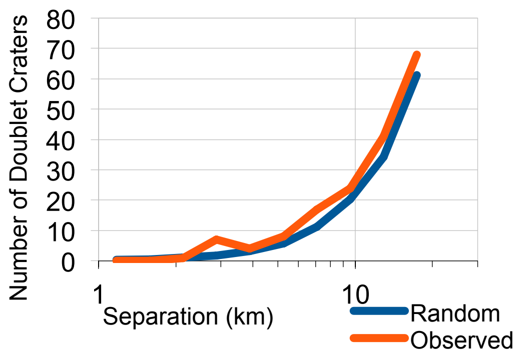

Figure 3: Observed counts of crater pairs by separation, plotted against expected distribution from random impacts.

Continuing Efforts: Fred Calef III et al. described quantitative measures useful in identifying secondary craters on Mars [22]. Prominent among these measures are the circularity ratio and the form ratio. These ratios quantify the compactness of a form [23], and in [22] secondary craters produced distinctly lower ratios.

Using the JMARS [17] Custom Shape Layer, we created outlines of the craters from our four candidate doublets, and computed the form and circularity ratios for each. Table 1 gives the ratios for Pairs 1 through 4, along with those for a very likely doublet feature discovered elsewhere on Ceres (depicted in Figure 1).

Returning to our analysis of observed crater pairs, we applied the Chi Square test to our observed vs. random crater pair separations. A P-value of 0.0086 indicates a high probability that the statistical excesses in Figure 3 are not the result of random placement.

Results: Based on the ratio analysis, we conclude that potential doublet crater pairs 1, 2, and 3 are likely to be secondaries. Pair 4 is still a candidate doublet.

How do we reconcile this conclusion with the non-random excess in the observed crater pairs with separations around 3km? The excess is likely represented by secondary craters. The doublets we observed are simultaneous secondary impacts. Even though they are not the result of a binary asteroids striking the surface, they are still non-random placement of impact craters.

Conclusion: Our approach, similar to that used by [8], was validated for identifying the presence of non-random crater patterns, even though most of what we discovered were likely secondary impacts.

There is one potential doublet (Pair 4). As it lacks direct evidence for being a doublet (e.g. ejecta lobes, septum), it is not a strong candidate. If treated as a true doublet, it would indicate a lower bound of 1.3% on impact events in the study area that were doublets, which is lower than the 2-3% seen for Earth and Mars [2]. We plan to further this work by surveying a different region of the same size as our first study area.

Table 1: Circularity and Form Ratios for Crater Pairs

Crater Pair	*Longitude*	*Latitude*	*Circularity Ratio*	*Form Ratio*
Pair 1	252.68	-13.58	0.90	0.67
	252.94	-13.83	0.91	0.77
Pair 2	259.33	-25.99	0.85	0.75
	259.77	-26.11	0.88	0.74
Pair 3	251.77	-21.94	0.84	0.68
	252.02	-22.24	0.90	0.77
Pair 4	255.20	-17.10	0.93	0.87
	255.43	-16.15	0.94	0.85
Pair in Figure 1	330.06	-50.41	1.00	0.96
	331.22	-49.72	1.00	0.99

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