LUNAR DOUBLET CRATERS: CONSTRAINING BINARY ASTEROIDS IN THE NEAR-EARTH POPULATION P. F. Wren[1] and R. A. Fevig[2], [1]Mars Space Flight Facility, School of Earth and Space Exploration, Arizona State University, 201 Orange Mall, Tempe, AZ 85287 [2]Department of Space Studies, University of North Dakota, Clifford Hall Room 512, 4149 University Ave Stop 9008, Grand Forks, ND, 58202. paul.wren@asu.edu

Introduction: A doublet is a pair of impact craters created by the same primary impact event [1]. Doublet craters have been observed on Earth, the Moon, Mercury, Venus, Mars, Ceres, and Vesta [2-8, 16, 17].

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 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 of binary asteroid systems.

Constraining binary asteroids. The percentage of asteroids in the current near-earth population that are binary is fairly well established at 15% [2,18]. A systematic study of doublet craters on the Moon could provide insight into the (1) size of the components of NEA binaries, (2) frequency of impact, and (3) percentage of NEA binaries since the formation of the regions of interest.

Methods and Data: It is ultimately our goal to identify lunar doublet craters on a global scale, but initially we have selected study areas from both lightly-cratered *maria* and the heavily cratered lunar highlands. We considered several *maria*, but eliminated some to minimize the effects of secondary craters from proximal post-mare impacts. Using Wilhelms' geologic map of the Moon [18], we eliminated *Mare Imbrium* and *Oceanus Procellarum* for their proximity to the large craters Copernicus, Kepler, and Aristarchus. To this point, we have surveyed *Mare Serenitatis*, *Mare Tranquillitatis*, *Mare Fecunditatis*, *Mare Humorum*, and *Mare Crisium*. We have also chosen an equatorial region in the highlands, which we will refer to as "*Daedalus*", since it contains this prominent crater.

Visual evaluation of crater pairs. For convenience, we are defining search areas whose boundaries align with lines of longitude and latitude (e.g. Figure 1). In JMARS [13], we use Robbins' global database of lunar craters [19] to locate all impact craters larger than 1 km, and smaller than 500 km in diameter. Pairs of proximal craters are considered potential doublets. Following the same process as in our previous work [14,16,17], these crater pairs are examined in LROC NAC images [20] and evaluated using our scoring system.

Monte Carlo simulation. A Monte Carlo simulation is applied to create randomly-distributed impact points within each study region. Separation distance between

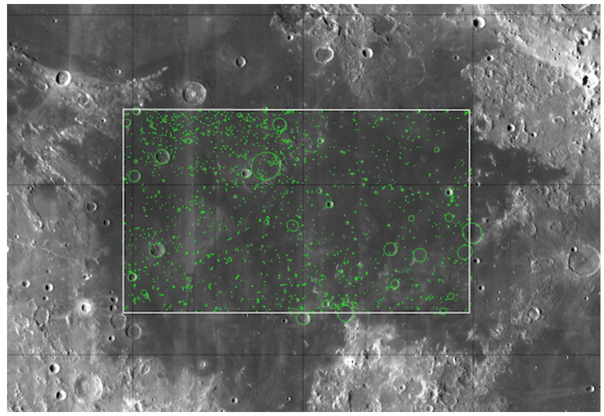

Figure 1: Study area with identified craters in Mare Tranquillitatis.

All unique pairs of random impacts are computed as great-circle distances. These are tallied to produce a distribution we would expect if impactors were single bodies, and their impact locations are due solely to chance.

Results: We have completed the data collection and crater pair analysis for all five maria, as well as for the Daedalus study area in the highlands. This includes the identification and location of all craters in the search areas, the determination of all crater pairs that have the potential to be doublets (see Table 1), and the grading of these candidate pairs.

A total of 1,923 pairs of craters were identified across all six areas using a Python [21] program described in [16]. The algorithm selected pairs of craters whose centers are separated by a distance that is equal to or below their combined radii (i.e., their rims either touch or overlap). These pairs are the most likely to exhibit conclusive evidence for a binary impact.

Table 1: Study areas

Region	*Area (km^2)*	*Number of Craters*	*Candidate Crater Pairs*
Crisium	95,019	470	32
Fecunditatis	149,313	2,434	795
Humorum	80,647	395	21
Serenitatis	212,850	801	41
Tranquilitatis	223,000	1,895	214
Daedalus	91,218	3,622	820
totals:	852,047	9,617	1,923

We completed our examination of the 308 candidate pairs within *Crisium*, *Humorum*, *Serenitatis*, and *Tranquilitatis*, a combined area of 611,516 km^2. 26 of these pairs received a positive score, with 8 being identified as likely or definite doublets (see Figures 2 and 3 for examples). We have partially completed our analysis of the remaining areas, and Daedalus regions, evaluating 100 of the 795 pairs in *Fecunditatis*, and 250 of the 820 pairs in the *Daedalus* region.

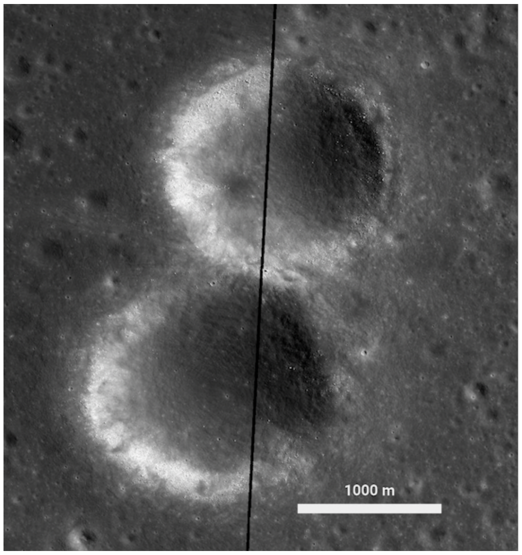

Figure 2: Likely doublet crater with faint ejecta lobes in *Mare Humorum.* (Image credit: NASA/GSFC/LROC)

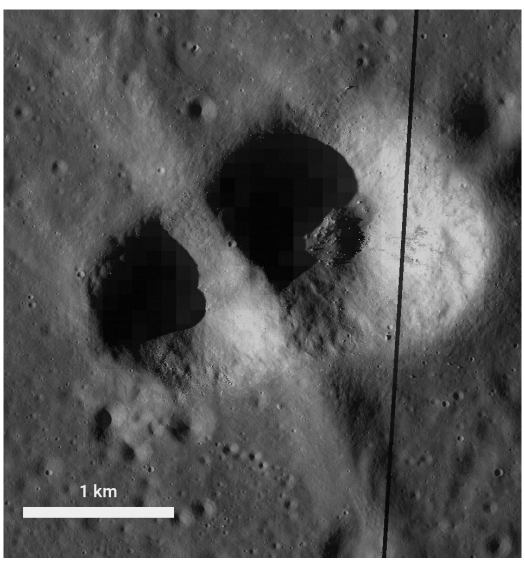

Figure 3: Definite doublet crater with septum and ejecta lobes in *Mare Tranquilitatis.* (Image credit: NASA/GSFC/LROC)

Conclusion: Considering the 8 likely or definite doublet craters against the 3,561 total craters in the completed study areas, we find the percentage of lunar impacts caused by binary asteroids to be only 0.23%, a percentage much lower than the 15% expected for NEAs [2,18], After applying the Monte Carlo simulation to the completed study areas, we saw an excess of observed crater pairs across all separation ranges. This suggests that non-random processes are involved in producing the observed craters. We suspect that secondary craters are the major source of these excesses. We also believe that a significant number of secondary craters are present in our total crater count, which would result in a reduced value for the percentage of impacts attributed to binary asteroids.

Continuing Work: First, we will complete the crater pair evaluation for the *Fecunditatis* and *Daedalus* regions. We are concerned with the effects secondary impact craters have on our results, as secondaries falsely inflate our count of total primary impacts. Before we can work toward an estimate of binary systems in the near-Earth asteroid population, we must identify as many of the secondary craters among those in our study as possible. Once this is done, we can re-run the Monte Carlo simulations to compare randomized primary impacts to actuals. We hope to complete much of this work prior to the 52nd LPSC.

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