NEW CRATERS ON MARS AND THE MOON.

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Introduction: Discoveries of recent, dateable impacts establish the present-day impact cratering rate on the Moon and Mars, eventually leading to a better understanding of the bombardment rate throughout the inner Solar System. We aim to use these discoveries to evaluate crater-dating models and clarify the effectiveness of using small craters to date small areas and/or geologically recent terrains. With the addition of these new discoveries on the Moon, we also have the potential for a direct measurement of the Moon/Mars cratering rate ratio, previously only estimated [*e.g.*, 1]. Although it may not be representative of geologic time or all impactor sizes, it is a definitive measurement that can be compared to models.

Previous results: Malin *et al.* [2] reported finding 20 new (formed within months to years) impact sites using the Mars Orbital Camera, 19 of which the High-Resolution Imaging Science Experiment (HiRISE) has confirmed as new [3-5]. Since then, the Mars Reconnaissance Orbiter has provided repeated coverage at medium resolution with the Context (CTX) camera, plus high-resolution follow-up imaging with HiRISE. This method has thus far revealed an additional 170 new impact sites with incredible variety and detail. Our progress has previously been reported in [3-7].

Methods: New martian impact sites are recognized in CTX data as "dark spots" caused by the disturbance of surrounding high-albedo dust primarily by the impact airburst – spots which are not present in previous data (CTX or various other, older Mars data sets). The HiRISE camera then follows up to confirm an impact origin. This method requires a surface covering of dust, so discoveries are almost all limited to the dustiest regions of Mars [Fig. 1].

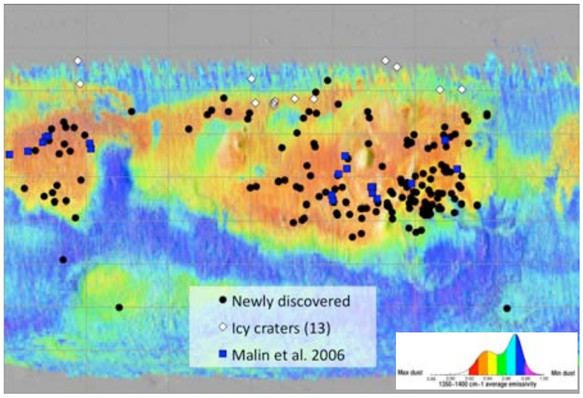

Fig. 1: Global TES dust cover index map [16] showing locations of 189 newly discovered recent impact sites on Mars. The majority of sites are in areas of high dust cover.

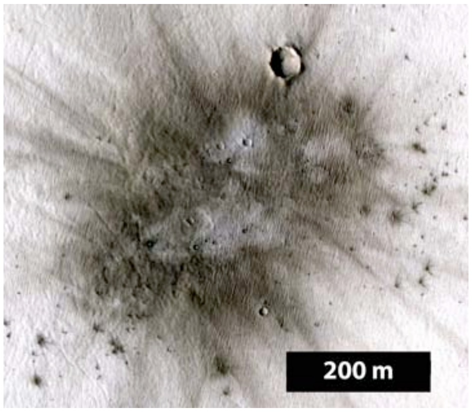

Fig. 2: An example of a new clustered impact site on Mars, formed between April 1978 and May 2010. HiRISE observation ID ESP_019926_2070. North is up.

In the case of lunar impacts, we are not so fortunate as to have an atmosphere to disturb an extended area around the impact site. However, the albedo difference between bright ejecta and dark regolith [Fig. 3] aids in identifying new craters. Unfortunately the relative extent of the albedo difference is much smaller, and the bright lunar ejecta and rays are not as uncommon as the characteristic Martian dark spots (reflecting a much longer time to equilibrate to the surrounding albedo, for different reasons: space weathering on the Moon versus dust deposition or redistribution on Mars).

Although the lunar images span a much longer time (38-41 years) than the martian data sets can provide, we are limited by the minimal amount of previous high-resolution data, which must be able to detect the crater if present. While the Lunar Reconnaissance Orbiter Camera (LROC) [8] provides excellent 50-cm to 100-cm pixel scale "after" images, the best available "before" images are Apollo orbital panoramic camera scans [9], covering only a small area on the near side. The varying geometry and photographic artifacts make using these Apollo data difficult as well. Despite these challenges, we have been able to successfully identify new lunar craters using this method.

New Martian Craters: Since our last report [7], the number of confirmed new impact sites has nearly doubled, to 189 as of this writing [Fig. 1] (not including several with no identifiable craters, interpreted to be recent airbursts or sites of localized aeolian darkening). A slight majority (57%) of these are "cluster" sites [*e.g.* Fig. 2], with multiple craters formed by the breakup of the impactor in the martian atmosphere.

Measured new crater diameters range from 1.6 m to 52.4 m, where effective diameters are calculated for clusters of multiple craters as $D_{eff} = (\Sigma D^3)^{1/3}$ [10]. Individual craters within clusters range from smaller than HiRISE can resolve to tens of meters.

Impacts exposing clean, shallow, subsurface water ice have previously been reported [11]. The number of such discoveries has since increased to 13. New sites remain consistent with the original conclusions.

New Lunar Craters: In our search of 44 pairs of lunar images, an area estimated to be ~5700 km^2, we have thus far found five new craters on the Moon [Table 1]. In addition, we have four unconfirmed identifications, where the quality of the Apollo data was not high enough to confirm the crater's absence, or the lighting conditions differed too greatly between the two images. We hope to be able to verify or refute those as more of the Apollo image scans become available. Two of the five confirmed sites have measurable crater diameters ~10 meters. The other three craters are not resolved in the LROC images, so we can only place upper limits on the crater diameters.

	LROC image ID (discovery)	Apollo image ID	Latitude	Longitude (E)	Crater diameter (m)
1	M106855508RE	as15_p_9430	26.92	3.94	*1.3**
2	M106855508RE	as15_p_9430	26.48	3.89	*1.3**
3	M108971316LE	as15_p_9527	16.92	40.50	9.7
4	M124253664LE	as15_p_9494	13.73	48.44	*0.5**
5	M126636371LE	as15_p_9508	15.68	44.90	8.0

Table 1: New lunar craters, their locations and approximate sizes. Asterisks (*) mark those diameters that are upper limits. Crater #3 is shown in Figures 3 and 4.

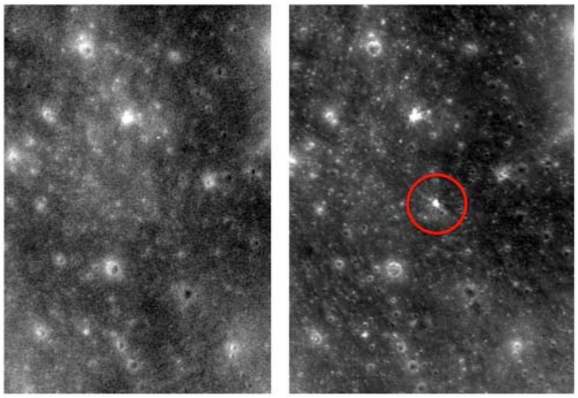

Fig. 3: (L) Apollo 15 Panoramic Camera (AS15-9527) from August 1971; (R) LROC Narrow-Angle Camera (M108971316L) from September 2009 showing new crater. Apollo image has been reprojected and warped to match the geometry of the LROC image. New impact site is circled in

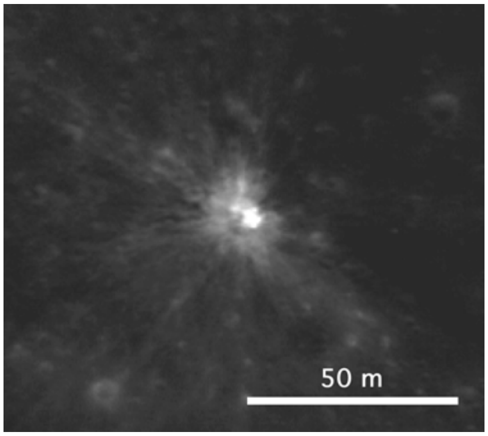

Fig. 4: Close-up of crater in Fig. 3, reprojected with North up. LROC image ID M108971316LE.

Future Work: We hope to find many more new lunar impacts with more person-power and time, and as LROC coverage and availability of digital high-resolution Apollo data increases. With better statistics, we will be able to make comparisons with established production functions [e.g. 12-15]. Already, models that predict very large numbers of small impacts seem to be excluded, although the uncertainties in the statistics are large, and our study is not yet complete.

Our statistics for new martian craters are much more robust. The 25-cm pixel scale HiRISE data allows us to accurately measure the diameters of most new craters, so improved comparisons to established model size-frequency distributions and model ages will also be possible (as in [7]). However, comparisons to model predictions are less accessible due to the combination of multiple data sets and time increments. We have developed an approach for calculating the area-time covered by the image overlaps; using that will allow us to report on the calibrated impact rate.

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