DARK IMPACT HALOS ON MARS. G. D. Bart[1] , I. J. Daubar[2], B. A. Ivanov[3], C. M. Dundas[4], A. S. McEwen[5] [1]University of Idaho, Department of Physics, 875 Perimeter Dr. MS 0903, Moscow, ID 83843, USA. gbarnes@uidaho.edu [2]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA. [3]Institute for Dynamics of Geospheres, Moscow, Russia. [4]U.S. Geological Survey, Flagstaff, AZ. [5]University of Arizona, Tucson, AZ.

Introduction: Recent studies show that small impactors continue to hit Mars up to and including in the present day [1, 2]. In fact, scientists have discovered more than 700 sites at which new impact craters formed within the last two decades, that is, since Mars Global Surveyor. Many of these new impacts ejected boulders and produced rays, which are standard features of fresh impact craters observed even on airless bodies such as the Moon and Mercury. However, some of the new martian impact craters also have a roughly circular, low-albedo “halo” feature. This halo is distinct from the usual visible ejecta deposits or ray patterns because the halos’ albedo increases slowly and smoothly from the center to the edge of the halo (**Figure 1**). The martian halos have been mentioned in past work as part of the “dark spot” or “blast zone” surrounding the new craters [2-4]. A preliminary analysis of these features was performed by [5], but the halos have not been subsequently evaluated as a distinct feature. Because the halos’ albedo varies slowly and smoothly throughout the halo, and because the halos are not observed on other bodies such as the Moon, it has been proposed [1, 6] that these features form as a result of interaction between the atmosphere and some aspect of the impact process. Therefore, the halos present a unique opportunity to study recent impact/atmosphere interactions, which will enable a better understanding of the underlying physical processes involved.

Description: We define a “halo” as quasi-circular, smoothly-varying albedo feature that surrounds an impact crater (or cluster of craters) and is much larger than the crater and its ejecta. A halo’s albedo is lower than that of the surrounding terrain and the albedo increases slowly and smoothly from the center to the indistinct edge of the halo, where it gradually blends in with the background albedo. In this work we present an observational study of the smaller martian halo features and we discuss the results of this study with respect to the nature of the halos: what they are and how they may have formed. To begin to address these questions, we first turn to the question of whether there is a relationship between the crater diameter and the halo diameter. Previous studies reported no correlation [1] or a rough linear correlation [5] between halo diameter and crater diameter. However, those studies used a more limited data set. For several possible mechanisms (such atmospheric shock wave propagation), we expect that halo sizes should be correlated with crater diameter because the overall energy of the impact also scales with crater diameter [7]. To test this idea, we therefore made quantitative halo and crater measurements.

Methods: The goal of this study was to determine what relationship, if any, exists between halo diameter and crater diameter. We studied 48 impact sites which hosted a total of 75 halos and measured the diameters of both the halos and the craters. We selected a variety of halos to examine: large and small halos, single and multiple clustered impacts, and halos with and without more typical observed ejecta patterns. We selected only unambiguous examples of halos to best ensure the results accurately reflect a single halo formation process. For these measurements, we excluded the cases where a cluster of impacts was located within a single

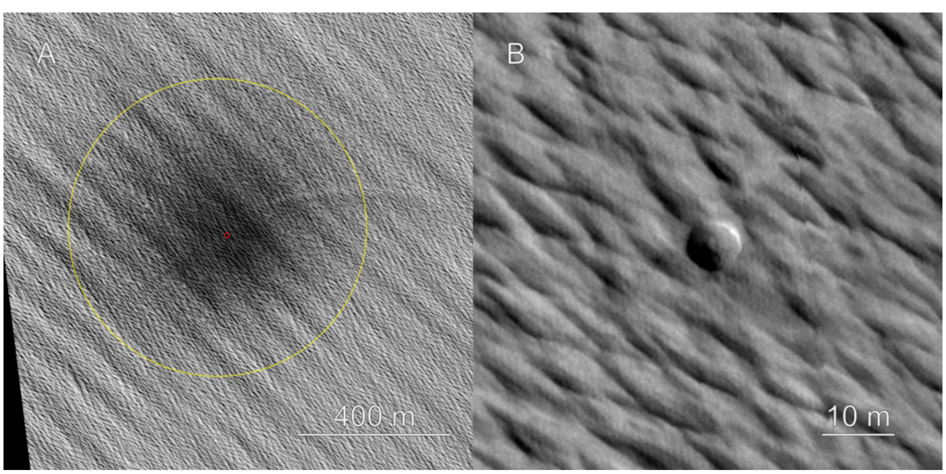

Figure 1: (A) An 8 m diameter crater (outlined in red) formed a 790 m diameter halo (outlined in yellow), observed in HiRISE image ESP_013893_1755. (B) The crater from frame A.

halo; we only measured halos that have single central craters to ensure our measured relationship between crater diameter and halo diameter would not be confused by overlapping halos or different impact energies deposited by a single impactor vs. a highly fragmented impactor. This procedure establishes a clear relationship between halo diameter and crater diameter, and then also with the impact energy that may be available for halo formation.

Results: To examine the data for a relationship between halo diameter and crater diameter, we plot a comparison of the two in **Figure 2**. We find that halo diameter generally increases with increasing crater diameter. Although there is considerable scatter, the trend with size can be quantified with a power law, $D_H = 8.20\ D_C^{1.75}$ (R^2=0.82). The increase in halo diameter with crater diameter is reasonable because larger impacts have more kinetic energy available to disrupt larger areas of the martian surface and/or affect larger volumes of atmosphere. Our result improves the previous preliminary work that suggested only loose proportionality between halo diameter and crater diameter [5]. We propose that our larger dataset enables this trend of halo diameter with crater diameter to be better observed, and that it is the large amount of scatter about the best fit line that previously obscured this trend.

Conclusion: Halo size is controlled by impact energy according to the non-linear relationship close to $D_H \sim E^{2/3}$ in contrast to anticipated "energy scaling" for crater size $D_c \sim E^{1/3}$. The halo-crater size correlation was separately established also by looking at clustered impact sites, where each crater within the cluster had its own halo. At these cluster sites, all impactor and target characteristics are the same and only the individual impactor size (and therefore energy) changes. Therefore, we find that halo size is fundamentally governed by the impact energy. This specific energy relationship provides a key constraint for future work creating detailed descriptions of air shock waves propagating above an impact site. Our work implies that $D_H \sim E^{2/3}$ corresponds to a critical value of pressure impulse (both positive and negative) at the outer halo boundary.

We also found that a thicker dust layer and lower elevations are both correlated with larger halos. From these correlations we conclude that the local surface characteristics as well as local atmospheric pressure influence the formation of the halos. The results we derive in this work provide a framework upon which more specific halo formation mechanisms can be developed and tested in the future.

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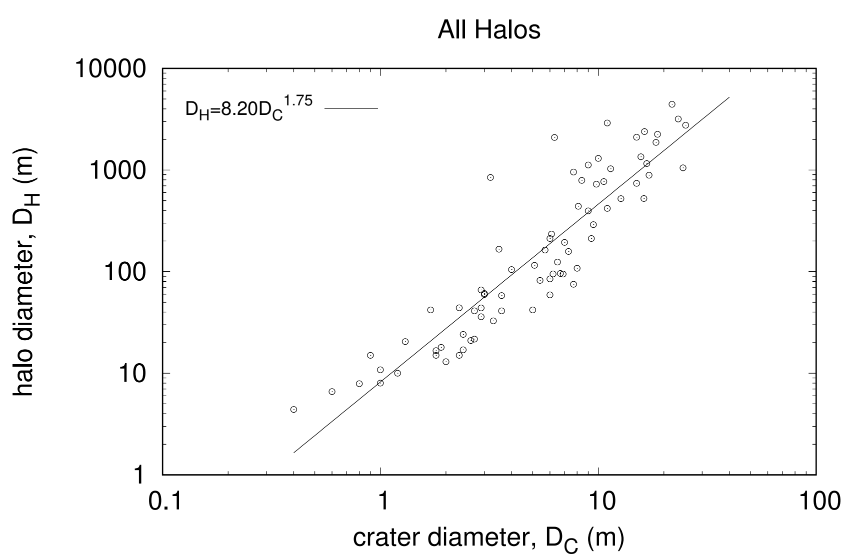

Figure 2: Plot of halo diameter (m) vs. crater diameter (m) for each of the halos measured in this study. The best fit line is also plotted. This plot shows that halo diameter does increase with increasing crater diameter, although there is a lot of scatter.