THE MODERN IMPACT CRATERING FLUX AT THE SURFACE OF MARS. Oded Aharonson, Division of Geological and Planetary Sciences, California Institute of Technology, MC 150-21, Pasadena, CA 91125, USA (oa@caltech.edu).

Introduction: The recent discovery of 20 new impact craters on Mars allows, for the first time, a direct determination of the modern impact flux on the surface of a solar system body [1] and therefore the dating of younger surfaces than previously possible. In their groundbreaking work, Malin *et al.* document the occurrence of craters in the size range between 2 and 150 m in diameter, and conclude that the observed population is consistent with predictions of models [2] extrapolating the lunar cratering rate to Mars. Here we show that the observed distribution is in fact inconsistent with the models at a high statistical certainty, with a significant deficit in small craters.

Analysis & Results: The Mars Orbiter Camera [3] (MOC) on board Mars Global Surveyor [4] (MGS) imaged the surface of Mars at scales from meters to hundreds of kilometers for nearly a decade. Using a carefully designed observational strategy, Malin *et al.* [1] detected the formation of 20 new impact craters in an area of 21.5×10^6 km^2. The detailed description of the observations and detection strategy was described previously; here the focus is on the interpretation of the statistical distribution of crater sizes. Figure 2 shows an incremental histogram of the crater diameters organized in logarithmically sized bins. Points are plotted at the bin-center diameters, and $\sqrt{n}$ error bars are drawn, where n is the number of events in the bin. Also shown are the predicted fluxes from models [2] as a function of surface age. These theoretical isochrons are based on crater counts on the Moon extrapolated to Mars, and may be uncertain by a multiplicative factor [2], *i.e.* a shift in log-log coordinates. The power-law exponent (the isochron slope) of approximately 3 in this size range, is a characteristic of the impacting population, with an assumed correction for atmospheric filtering [5].

The solid line in Figure 2 shows statistically robust values for the parameters b and n_0 derived from a maximum-likelihood estimation, as described below. The most likely values are $\hat{b} = 1.55$ and $\hat{n}_0 = 3.42 \times 10^{-5}$ km^{-2}. A 1-σ uncertainly range for the allowed values of b may be obtained from the probability function. We find $\hat{b} = 1.55^{+0.36}_{-0.31}$. Even if the largest event at $D = $148 m is omitted from the analysis, the most likely value is $\hat{b} = 1.86^{+0.45}_{-0.39}$ (omitting the two largest diameters results in $\hat{b} = 2.01^{+0.50}_{-0.42}$).

These low values for $\hat{b}$ depart significantly from equal mass in equal logarithmic bins implied by the canonical -3 slope. The disagreement cannot be attributed to chance or statistics of small numbers. While a impact crater of 150 m diameter is expected to form once a century or so [1], the probability that an isochron with an exponent of -3 or steeper (and any n_0) is compatible with the entire data set is $< 0.1\%$.

In the absence of the largest crater a significant deficit in small diameters is still present. However, the observation of the largest event must not be dismissed. It is tempting but incorrect to interpret the $\sqrt{n}$ error bars in comparison to model isochrons. These error bars indicate the 1-σ range of likely $observations$ not $models$ given the actual number seen.

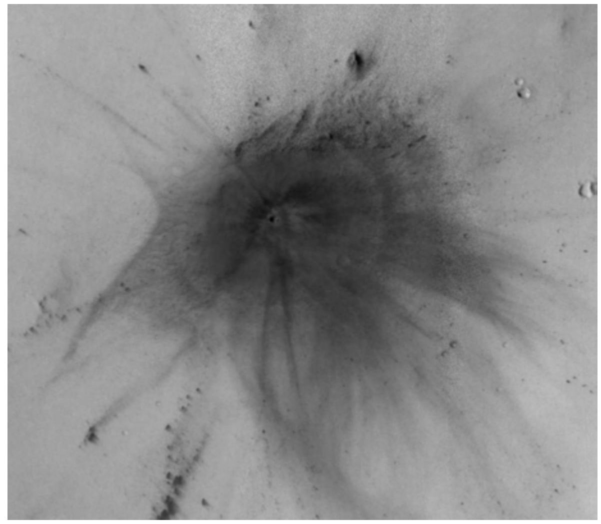

Figure 1: A new crater with diameter ∼23 m detected to have formed on the surface of Mars between 8 December 2003 and 26 November 2005 seen in MOC image #S16-01674. This discovery was reported by Malin et al. [1].

For example, if we observe one event in one year, and we wait an additional year, we may observe no additional events. However in this example the real flux clearly cannot be 0, given that a single event has been observed and so models with exceedingly low formation rates must be formally rejected.

Methods: The size scaling of impact crater formation at the surface is written as a power law in the diameter D,

$$\frac{dn}{dD} = \frac{n_0 b}{D_{\min}} \left(\frac{D}{D_{\min}}\right)^{-1-b}. \quad (1)$$

An estimate for the parameters n_0, and b, as well as for the minimum observable crater diameter $D_{\min}$, may be obtained by maximizing the log-likelihood function L of the set of observations $\{D_i\}$ where i=1..N. Solving $(\partial L/\partial b)_{\hat{b}} = 0$ and $(\partial L/\partial n_0)_{\hat{n}_0} = 0$, gives the maximum-likelihood estimates,

$$\hat{b} = \frac{N}{\sum_i \log \frac{D_i}{D_{\min}}} \quad \text{and} \quad \hat{n}_0 = \frac{N}{A}. \quad (2)$$

The expressions above are robust estimates of the parameters and should be useful for future studies of crater distributions. For ease of comparison with previous work, we choose to plot the histogram in logarithmic bins, hence the model flux is

$$\frac{dn}{d\log D} = n_0 b \left(\frac{D}{D_{\min}}\right)^{-b}. \quad (3)$$

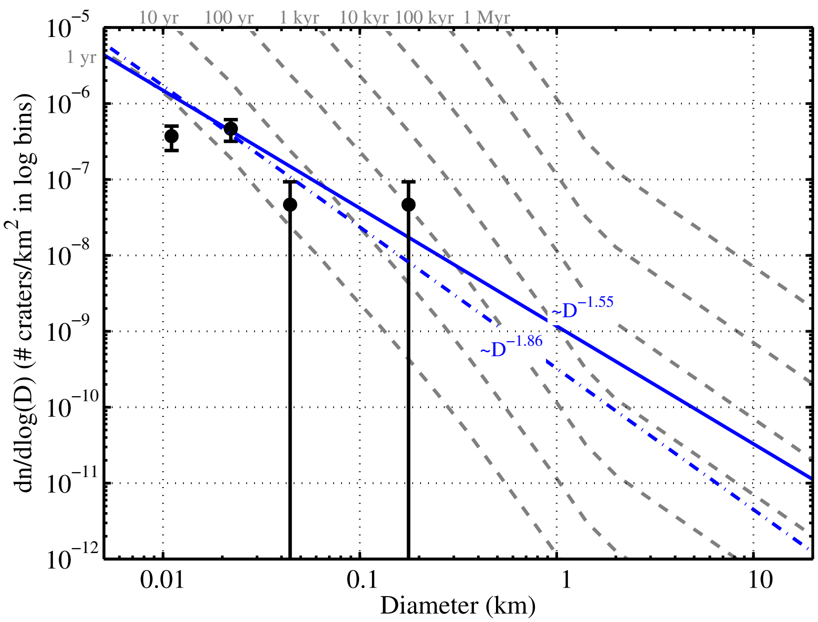

Figure 2: Incremental distribution of observed new impact craters in logarithmic diameter bins, from Malin et al [1]. Model isochrons [2] are plotted as dashed gray curves. The solid line shows the expected distribution using the maximum-likelihood parameters for this data. The dash-dot line is the fit with the largest diameter crater omitted. The data are plotted at bin centers to allow comparison with model isochrons. Note that the models are not fits to this histogram, but rather are robustly derived from the individual measurements.

Conclusions: There are at least three possible explanations for the observed deficit in small craters in comparison with past models, each with important implications. First, the correction of atmospheric filtering of small projectiles due to ablation, deceleration and fragmentation that has been applied [2, 5] may be insufficient, and models with a significantly enhanced effect are required.

Second, the population of objects that is responsible for the new craters may not be representative of the overall population and is skewed towards larger sizes. This possibility is considered unlikely because the impact events were not coincident but rather were shown to be distributed in time [1]. Furthermore, the timescale for fragmentation in the asteroid belt is much smaller than the dynamical lifetime (due to Poynting-Robinson decay of the orbit) and hence the impacting population is expected to reflect the collisional environment in the asteroid belt.

Finally, it is possible that the observations are systematically biased towards large craters, missing a considerable fraction of the small, meters to tens of meters, diameter craters. The origin of the steep branch of the isochrons is under debate [6], with some indications that it may be due to secondary impacts [2, 7]. If indeed the small crater distribution is dominated by secondary impacts then it is possible that the observational strategy of searching for large areas of dust disturbance on the surface discriminates between primaries and secondaries since the latter do not cause the strong atmospheric waves that clear out dust regionally. The shallower power-law observed would then reflect the primary population only. It is noteworthy that in the "primary branch" of the isochrons, where $D > 2$ km, the traditionally reported distribution [2] indeed has a shallower slope of approximately -2, a value that is significantly closer to the $-\hat{b}$ we find here.

The implications of this last possibility are twofold. If correct, it resolves the controversy over the steepness of the distribution at small diameter as they are due to secondary ejecta. Furthermore, it provides a recipe for dating fresh surfaces in the solar system, but demonstrates that a distinction must be made between a primary and secondary population in order to obtain the correct age.

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