NEW DATED IMPACTS ON MARS AND AN UPDATED CURRENT CRATERING RATE.

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Finding new craters on Mars: Over the last eight years, more than 400 new impact sites have been found on Mars. They are initially recognized by the presence of characteristic dark spots seen in Context Camera (CTX) images (Fig. 1) [1]. If the dark spots are not present in previous medium-resolution images, the High Resolution Imaging Science Experiment (HiRISE) follows up to confirm a recent impact origin and to measure the craters.

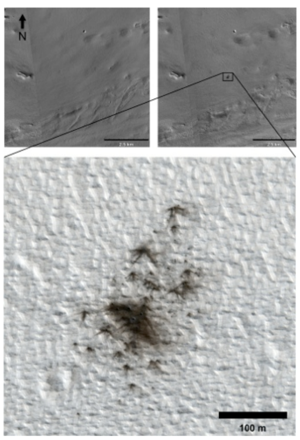

Fig. 1. *New impact site at 4.472°N, 246.893°E. CTX images G02_018995_1846_XI_04N113W (August 2010, left) and G11_022608_1848_XI_04N113W (May 2011, right) constrain formation. HiRISE image ESP_022964_1845 is at bottom. Image credits: NASA/ JPL / UA / MSSS. Figure from [1].*

Measured crater production function (PF): The dark blast zones used for the initial detection are 1-2 orders of magnitude larger than the craters themselves [2, 3]. We interpret these as being formed by disturbance of high-albedo surface dust in the impact blast. Because this is key to the identification of new impact sites, the data set has an obvious spatial bias toward the dustiest areas of Mars (Fig. 2). This bias is minimized by scaling the number of new impacts to only those areas with repeat coverage and a minimum amount of dust cover, and by a spatial randomness correction.

Area-Time Factor (ATF): The ATF is a sum of area covered repeatedly by CTX, multiplied by the time difference between images at each spot. Fig. 3 shows the current PF using effective diameters (combined for clusters as in [4]) for 110 impacts with CTX before and after images, scaled to an ATF of 4.68×10^7 km^2 yr (see [1] for methods). Our measured PF falls below model PFs by Ivanov/Neukum [7] and Hartmann [8] by a factor of ~4. If long-term orbital eccentricity variation were taken into account [7], this discrepancy might increase by another factor of two to ~8.

PF models based on lunar crater counts may include both primary and secondary craters while our results quantify only the primary flux. The least squares best fit slope of our new impact differential PF for D≥3.9 m is -2.55±0.19, shallower than the slope of the models over the same size range. This supports the hypothesis that the primary PF for small craters is significantly less steep than that of combined primary + secondary craters in this size range (e.g. [5, 6]).

The close match of our updated PF to previous results [1], despite including more than twice as many new impact sites and more than doubling the ATF, suggests that this is a stable result.

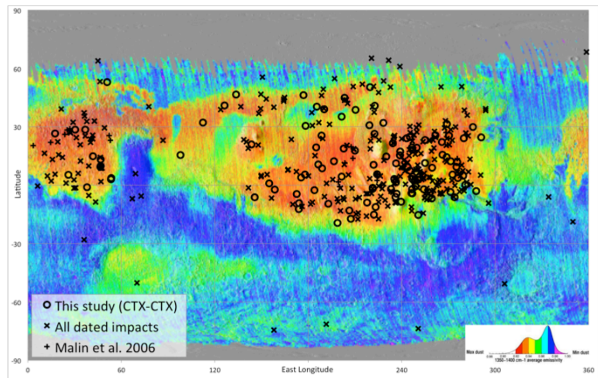

Fig. 2. *403 new dated impact sites on a map of the TES DCI [10]. 19 confirmed sites from [4] are shown, as are the subset of 110 sites constrained by CTX. Our PF includes only areas with DCI<0.96, lat. 60°N-60°S.*

Spatial Randomness: Only dusty areas are used in calculating our PF, but it is possible that not all dusty areas form CTX-detectable dark spots with equal efficiency. If the entire area within our ATF records all impacts then we expect these sites to be randomly distributed. We test this null hypothesis with a Monte-Carlo approach. We quantify the homogeneity of the spatial distribution of 84 of the new craters with D≥3.9m, using several methods [12, 13] including the mean nearest neighbor distance, the standard deviation of the nearest neighbor distance, the standard deviation of the adjacent area, and the standard deviation of the local density. We compare these statistics with the same statistics for 2000 pseudo-random crater distributions. When generating populations we assume that the probability of a model crater forming at a given point and being detected is proportional to the time difference between earliest and latest CTX images at that point. This does not take into account any seasonal dependence in the impact rate, which may be present [15]. As when calculating the ATF, we consider only locations 60°S-60°N and where the Thermal Emission Spectrometer Dust Cover Index (TES DCI) [10]<0.96.

If at least one statistic of the real population differs from the same statistic for the great majority of random models, then we conclude that the randomness of the real population is rejected by our statistical test. We use a conservative definition of 98% confidence level for rejection of randomness.

Randomness of the detected population (even within dusty areas) is rejected with great confidence. Obviously, dark spots are not uniformly created or detected everywhere in dusty regions.

To determine where dark spots are efficiently forming, we exclude manually chosen areas with no new craters from dusty territory (by setting the cratering probability to zero in our Monte-Carlo simulations), recalculate the ATF, and repeat the simulations. We find that the observed population becomes consistent with spatial randomness when the ATF is reduced by a factor ≥1.7. Thus, to compensate for the effect of non-uniform crater detection efficiency we need to increase the derived cratering rate by a factor of 1.7, bringing our current PF to only ~4× lower than model PFs. The geographic distribution (Fig. 2) of the new craters suggests that impacts form CTX-detectable dark spots efficiently in Tharsis and Elysium, but not in western Arabia, despite its dustiness.

Discussion: Considering the many assumptions in the model PFs, the agreement between these new impact data and previous model predictions is quite good, although our improved statistics and extended range of diameters reveal a divergence between the models and the current measured impact rate that increases at smaller diameter. From our results, one might conclude that model ages based on craters in the ~10-50 meter size range should be increased by a factor of ~4 or more. However, the situation is probably not that simple. For example, diameter-dependent atmospheric ablation and deceleration is occurring at small sizes [14]. In addition, unrecognized secondaries contribute to models based on older surfaces. Our measured PF is based on a population of known primaries, so excludes any secondary contamination. Additionally, clusters on older surfaces could be mistaken for individual primaries, which would significantly steepen the slope of the SFD and erroneously increase the resulting model age if based on the smallest craters [1]. Short-term variation of the impacting population due to collisions in the asteroid belt could also explain discrepancies, as could other uncertainties in the derived model PFs. Target properties also have an effect on the size of small craters [e.g. 9], and dusty surfaces may be systematically different from average Mars. All of these issues imply that craters <~50 m diameter should not be used for dating unless the error bars are adjusted accordingly.

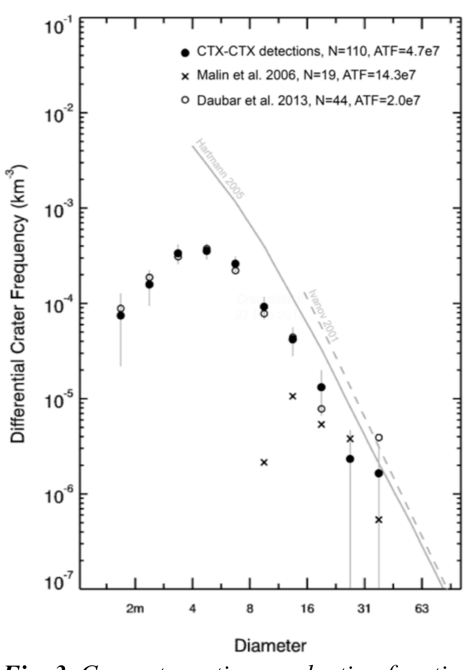

Fig. 3. *Current martian production function (PF): Differential size-frequency diagram of 110 dated impacts constrained by CTX, scaled to ATF. Models of 1-year PFs from [7, 8] and results from [1, 4] shown for comparison. Plot created with Craterstats2 [11].*

Conclusions: New meter- to decameter-sized craters on Mars are currently forming at a measurable rate: 1.8×10^{-6} craters/km^2/yr with $D_{eff}\geq3.9$ m (before a correction for randomness is applied, which would increase this by 1.7×). This modern PF is lower than models commonly used to estimate crater retention ages on Mars, and it results in model ages that are lower by a factor of ~four than those models. The surprising near-agreement might yet be an accident if the current impact rate is not typical of geologic time, i.e., we can't rule out short-term fluctuations of up to an order of magnitude. The published martian isochrones should be used with great caution for small craters. Our current impact rate statistics provide the best empirical isochrones for the youngest surfaces on Mars, but they still include uncertainties of a factor of ~4.

References: [1] Daubar *et al.* (2013) *Icarus* 225, 506-516 [2] Ivanov *et al.* (2010) LPSC abs. 2020 [3] Bart *et al.* (2014) *LPSC* abs. 2852 [4] Malin *et al.* (2006) *Science*, 314, 1573-1577 [5] Wilhelms *et al.* (1987) [6] Xiao & Strom (2012) *Icarus* 220, 254–267 [7] Ivanov (2001) *SSR* 96, 87-104 [8] Hartmann (2005) *Icarus* 174, 294-320 [9] Dundas *et al.* (2010) *GRL* 37, 12203 [10] Ruff and Christensen (2002) *JGR*, 107, 5127 [11] Michael and Neukum (2010) *EPSL* 294, 223-229 [12] Kreslavsky (2007) 7th *Mars* abs. 3325 [13] Michael *et al.* (2012) *Icarus* 218, 169-177 [14] Ivanov *et al.* (2014) *LPSC* abs. 1812 [15] Daubar *et al.* (2012) *LPSC* abs. 2740