FATE OF METEOROID IMPACTS ON MARS DETECTABLE BY THE INSIGHT MISSION.

K. Miljković[1], E. K. Sansom[1], I. J. Daubar[2], F. Karakostas[3], P. Lognonné[3]. [1]Dept. of Applied Geology, Curtin University, Australia (Katarina.Miljkovic@curtin.edu.au), [2]Jet Propulsion Laboratory, California Institute of Technology, Pasadena CA 91109, [3]Institut de Physique du Globe de Paris, France.

Introduction: This work investigates the impact conditions required for Martian meteoroids to be capable of making seismic signatures recordable by the SEIS (Seismic Experiment for Interior Structure) instrument during the lifetime of the InSight mission on Mars. Considering that lifetime of a space mission is short on a geologic timescale, only small, more frequent meteoroids are expected to impact Mars during this period [1,2].

Depending on the fate meteoroids experience while passing through the Martian atmosphere, they can be grouped into three classes: a) Meteoroids that survive the entire trajectory through the atmosphere and make a single impact in the ground (no breakup); b) Meteoroids that burst and fragment in the atmosphere, but those fragments predominantly burn up in the atmosphere (airburst); c) Meteoroids that burst and fragment in the atmosphere, but the fragments do not completely burn up in the atmosphere; rather they make an impact in the ground in the form of a cluster of multiple craters.

Break-up altitudes: Basic description of atmospheric entry [3] includes an atmospheric drag (we use C_d=1.3), where the dynamic break-up at altitude z is approximated by comparing the meteoroid crushing strength and stagnation pressure: $Y=\rho(z)V^2(z)$, where Y is the impactor crushing strength, ρ and V are the atmospheric density and impactor velocity at z. To calculate the break-up altitudes, we used a modified model from [3] applied to the current Martian atmosphere. Martian atmosphere was assumed to have an exponentially changing density ($\rho(z)=\rho_0 e^{-z/H}$, where H=11.1 km is the scale height and ρ_0=0.02 kg/m^3 surface atmospheric density).

In this simplified model, the threshold for atmospheric break-up depends largely on impactor properties (density, crushing strength and speed). The break-up threshold for stronger impactors is at higher speeds and, in this model, cometary impactors (Y=0.1 MPa, ρ=1000 kg/m^3) break at speeds larger than 2.5 km/s and carbonaceous impactors (Y=1 MPa, ρ=2200 kg/m^3) at speeds larger than 7.5 km/s. For impactors smaller than 20 m, moving at speeds lower than 20 km/s, the break-up is not strongly dependent on the impactor size (Figures 1 and 2). We also investigated stony (Y=10 MPa, ρ=3500 kg/m^3) and iron meteoroids (Y =100 MPa, ρ=7900 kg/m^3 [4]), and in this model, such impactors could only form single impacts on Mars without breaking up in the atmosphere.

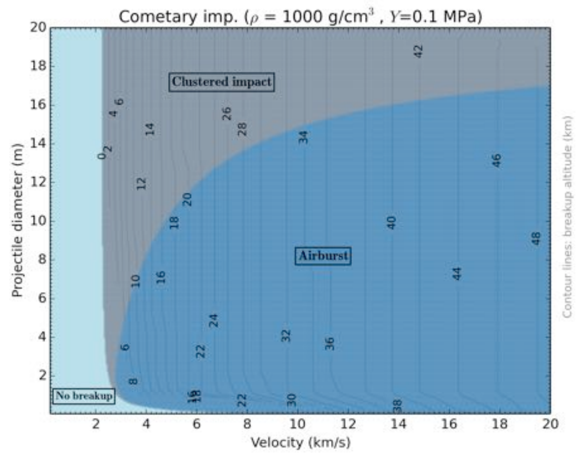

Figure 1. Contour lines show the break-up altitudes for cometary impactors. Dark blue regions denote parameter space in which impactors burn up in the atmosphere (labeled "Airburst"); Grey regions denote the parameter space in which impactors fragment in the atmosphere but survive to form a cluster of craters on the surface of Mars.

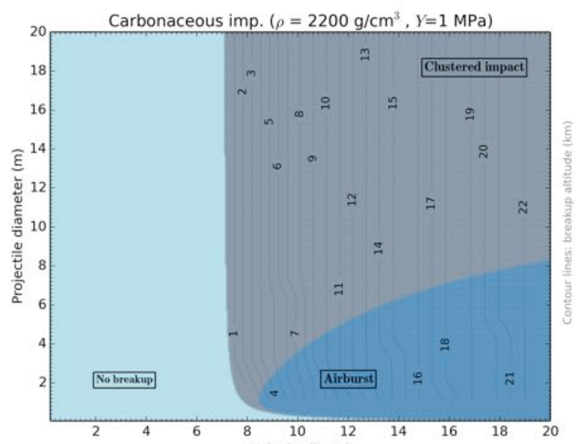

Figure 2. Similarly to Figure 1, but showing fate for carbonaceous impactors.

Velocity and projectile size marked on axes in Figures 1 and 2 are given at atmospheric entry. For impactors that are ~1-20 m in diameter, moving at speeds lower than 20 km/s, the impactor size and speed do not change markedly by the time meteoroids reach their break-up altitudes. In this parameter space and Martian atmosphere, this model estimates less than 10% diameter loss due to ablation for impactors larger than 5 m in diameter. However, for smaller impactors, with a decrease in impactor size and increase in entry speeds above 6 km/s, the ablation becomes increasingly important. There is no change in velocity due to drag for carbonaceous impactors with entry diameter larger than 1 m or larger than 0.5 m for cometary impactors, which is in agreement with [5], where detailed effects of ablation and drag are investigated for smaller and faster impactors.

Clustered craters: After break-up, the dispersion of fragments could be simplified by a so-called pancake model, in which fragments disperse under the differential pressure between front and back surfaces [4,6]. We adopted the analytical approximation from [3].

In this model, the threshold for a clustered crater depends largely on the impactor size, density and strength, and to some extent on impactor speed range. Figure 3 shows a ground spread of fragmented impactors of up to 120 m for cometary impactors, assuming a vertical impact. The dispersion area for oblique impact angles (α) should scale as $L(\alpha) = L(90^o)/\sin(\alpha)$ in a simplified approximation.

The HiRISE observations of clustered craters on Mars show that the dispersion in clustered craters varies greatly, from a few tens to a few hundreds of meters [1], which loosely corresponds to our results shown in Figure 3.

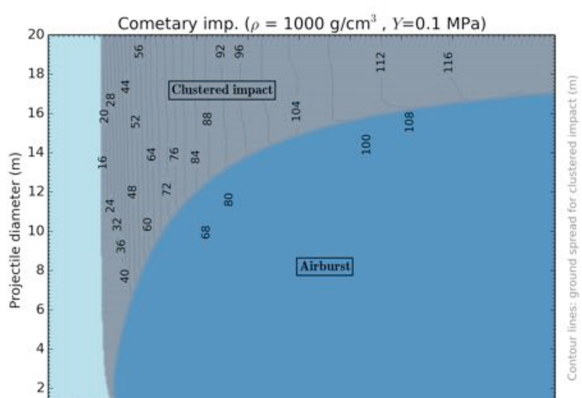

Figure 3. Contour lines show dispersion of fragmented impactors assuming a pancake model for cometary (low strength, low density) impactors.

Strength-dominated impact-scaling: During the two years of the InSight primary mission, the largest impacts on Mars expected during that time will likely be smaller than approximately 50 m in effective diameter [2]. Also, HiRISE data analyses of single and clustered crater diameters indicated that those craters have small effective diameters (for clusters, this is the reconstructed diameter, summed as if the projectile had not broken up in the atmosphere), ranging from less than a meter to approximately up to 40 m, from over a ~decade of observations [1]. The final crater size for such small simple craters largely depend on the target properties (namely, target strength).

We applied the crater-scaling laws for the strength-dominated regime [7] for four different target strengths and densities (simulants for lunar soil, dry sand, soft and hard rock [5]), and considering four types of impactors (cometary, carbonaceous, stony and iron [4]) that also differ in strength and density. We determined that an impactor should be of the order of a meter up to a maximum of a few meters to form craters smaller than 50 m.

Impact-scaling laws estimate the size of an impactor as it reaches the ground, not its size at atmospheric entry. Considering that HiRISE observations include many clustered craters with a small effective diameter, it is possible that impactors have extremely low strengths. However, another possibility is that the modeled crushing strength may not be the most relevant parameter that determines the break-up process, and that the fragmentation process is complex. In the case of the Chelyabinsk impactor, the tensile strength of the incoming impactor was estimated to ~1 MPa, with stronger stony components estimated to ~15 MPa that survived initial atmospheric entry, but later clustered over the ground suggesting that the entry impactor was composed of different components and likely pre-existing fractures [8].

Conclusion: This work separates meteoroid bombardment on Mars into three classes that would greatly differ in terms of their seismic signature in the Martian atmosphere and ground. Further investigations will feed into modeling of different seismic signatures associated with these impact classes [9,10].

References: [1] Daubar, I.J. et al. (2013) *Icarus* 225, 506-516. [2] Daubar, I.J. et al. (2015) 46th *LPSC*, Abstract #2468. [3] Collins, G.S. et al. (2005) *MAPS* 40, 817-840. [4] Chyba C. F. et al. (1993) *Nature* 361, 40–44. [5] Williams, J.-P. et al. (2014) *Icarus* 235, 23-36. [6] Melosh H.J. (1981) In *Multi-ring basins*, New York: Pergamon Press. pp. 29–35. [7] Holsapple, K.A. and Housen, K.R. (2007) *Icarus* 191, 586-597. [8] Borovička, J. et al. (2013) *Nature*, 503, 235–237. [9] Lognonné P., and Johnson C.L. (2015) *Planetary Treatise on Geophysics*, 2nd ed. 10, 65–120. [10] Lognonné et al. (2015) J. Acoust. Soc. Am, submitted.