Meteoroid fragmentation in planetary atmospheres and the formation of crater clusters on Earth and Mars

Professor Gareth Collins (g.collins@imperial.ac.uk)

Rationale: Establishing the present rate of impacts and on Mars is important for dating small, young surfaces on Mars and other planetary surfaces as well as assessing the impact hazard to spacecraft on Mars. On airless bodies, impact rates are determined from crater counts. However, a complication on Mars is that about half of small meteoroids will disrupt in the atmosphere to produce a cluster of small craters (Fig. 1) as opposed to a single large crater (1–3). Meteoroid break-up also has implications for the seismic signals generated by impacts. Such impacts may transfer much of the asteroid's initial kinetic energy to the atmosphere, resulting in a detectable atmospheric blastwave (4). Even when a single impact crater is formed, the impacting object is likely to be in a fragmented and distended state. As a result, a range of possible impact-source seismic signals are expected (5) depending on: the strength of the atmospheric blastwave that strikes the ground; the number, size, density, speed and separation of fragments that form crater clusters; and the integrity, bulk density and speed of impactors that form a single crater.

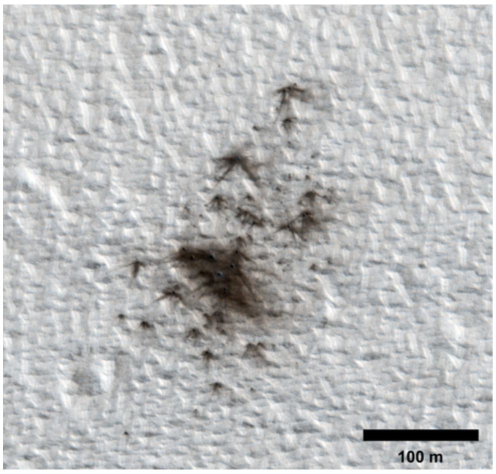

Figure 1 *More than half of the impacts likely to be detected by InSight result in crater clusters. The proposed work will simulate the diversity of impact outcomes from such small impacts and the seismic signals they generate. Image Credit: NASA/JPL-Caltech/MSSS/Univ. of Arizona*

To address these science goals, requires a good understanding of the potential disruption of m-scale asteroids in the martian atmosphere and the diversity of seismic signatures of the resultant impacts on Mars. **The aim of the proposed project is to develop and apply software to simulate atmospheric entry of asteroids on Mars to further understanding of crater cluster formation.** The project will also apply the same model to crater strewn fields on Earth.

Atmospheric Disruption Modelling: In Feb. 2013, a ~20-m asteroid disrupted at ~30-km altitude above a densely-populated region in Russia, causing blastwave damage on the ground (6,7). This well-documented airburst has provided important constraints for the improvement of semi-analytical models of asteroid disruption in an atmosphere (6–10). In particular, a recently-developed model, known as the Fragment Cloud Model (FCM, (11); Fig. 2) combines the principal features of two different classes of approach—separated fragments models (12,13) and catastrophic disruption models (14,15). The hybrid FCM is therefore able to self-consistently describe both atmospheric energy deposition (blastwave generation) and crater cluster formation. Here, the FCM will be used to simulate the fate of m-scale impactors on Mars, as it allows the proportion of the initial impact energy transferred to the atmosphere and the ground to be determined, as well as the effective burst altitude (blastwave centre) and properties of the impacting fragments (and resulting craters).

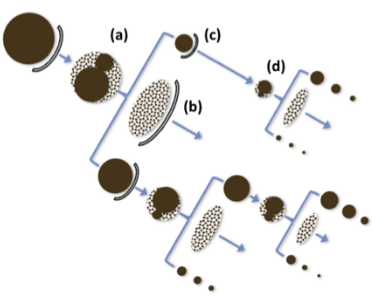

Figure 2 *Schematic representation of the Fragment Cloud Model [14]. Deceleration of the initial asteroid is modelled until first failure (a), at which point fragmentation is assumed to produce two large fragments of different mass and a prescribed separation speed, and a cloud of smaller particles. The evolution of the cloud (b) is simulated using a conventional pancake-type model [16,17]. Each separate fragment (c) is tracked recursively and may undergo further fragmentation according to the same assumptions (d) before striking the ground. Modified from [13].*

The successful candidate will join, and be supported by, a vibrant and dynamic research group with world-class expertise modelling impact processes. They will be trained in state-of-the-art numerical methods for simulating hypervelocity impact, impact physics and high-performance computing. The candidate will have the opportunity to develop their career and profile by presenting at international conferences and publishing in high impact journals. Candidates for PhD positions should have a good mathematical background and a good degree in an appropriate field, such as earth science, physics, mathematics or computer science.

Research Environment & Training

The Department of Earth Science and Engineering (ESE) is an STFC-accredited PhD training program. The Department is well-equipped with modern laboratories, offices and high-performance computing facilities. It also benefits from a formal collaboration (facilities and staff access; joint symposia) with colleagues in the Department of Mineralogy at the Natural History Museum (NHM). Project-specific research training will be provided by the supervisors through weekly one-to-one meetings, group meetings and a mixture of supervised and online tutorials. In addition, students have access to high-quality transferable skills training provided by the Graduate School of Engineering and Physical Sciences (GSEPS). All students in ESE are automatically members of GSEPS. The Postgraduate programme involves regular report writing and presentation events in addition to research section and research group presentations. Students are strongly encouraged and enabled to attend international conferences and publish their work in respected journals.

References

1. Daubar IJ, McEwen AS, Byrne S, Kennedy MR, Ivanov B. The current martian cratering rate. Icarus. 2013 Jul 1;225(1):506–16.
2. Popova OP, Hartmann WK, Nemtchinov IV, Richardson DC, Berman DC. Crater clusters on Mars: Shedding light on martian ejecta launch conditions. Icarus. 2007 Sep 1;190(1):50–73.
3. Williams J-P, Pathare AV, Aharonson O. The production of small primary craters on Mars and the Moon. Icarus. 2014 Jun 1;235:23–36.
4. Stevanović J, Teanby NA, Wookey J, Selby N, Daubar IJ, Vaubaillon J, et al. Bolide Airbursts as a Seismic Source for the 2018 Mars InSight Mission. Space Sci Rev. 2017 Jan 9;1–21.
5. Schmerr NC, Banks ME, Daubar IJ. The Seismic Signatures of Impact Events on Mars: Implications for the InSight Lander. In 2016 [cited 2017 Jul 19]. p. 1320. Available from: http://adsabs.harvard.edu/abs/2016LPI....47.1320S
6. Brown PG, Assink JD, Astiz L, Blaauw R, Boslough MB, Borovička J, et al. A 500-kiloton airburst over Chelyabinsk and an enhanced hazard from small impactors. Nature. 2013 Nov 14;503(7475):238–41.
7. Popova OP, Jenniskens P, Emel'yanenko V, Kartashova A, Biryukov E, Khaibrakhmanov S, et al. Chelyabinsk Airburst, Damage Assessment, Meteorite Recovery, and Characterization. Science. 2013 Nov 29;342(6162):1069–73.
8. Avramenko MI, Glazyrin IV, Ionov GV, Karpeev AV. Simulation of the airwave caused by the Chelyabinsk superbolide. J Geophys Res Atmos. 2014 Jun 27;119(12):2013JD021028.
9. Collins GS, Lynch E, McAdam R, Davison TM. A numerical assessment of simple airblast models of impact airbursts. Meteorit Planet Sci. 2017;1542–60.
10. Register PJ, Mathias DL, Wheeler LF. Asteroid fragmentation approaches for modeling atmospheric energy deposition. Icarus. 2017 Mar 1;284:157–66.
11. Wheeler LF, Register PJ, Mathias DL. A fragment-cloud model for asteroid breakup and atmospheric energy deposition. Icarus. 2017 Oct 1;295:149–69.
12. Passey QR, Melosh HJ. Effects of atmospheric breakup on crater field formation. Icarus. 1980 May;42(2):211–33.
13. Artemieva NA, Shuvalov VV. Motion of a fragmented meteoroid through the planetary atmosphere. J Geophys Res. 2001 Feb 25;106(E2):3297–309.
14. Chyba CF, Thomas PJ, Zahnle KJ. The 1908 Tunguska explosion: atmospheric disruption of a stony asteroid. Nature. 1993 Jan 7;361(6407):40–4.
15. Hills JG, Goda MP. The fragmentation of small asteroids in the atmosphere. The Astronomical Journal. 1993 Mar 1;105:1114–44.