New class of Mars quakes reveals daily meteorite strikes

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First meteoroid impact detected by NASA's InSight mission; the image was taken by NASA's Mars Reconnaissance Orbiter using its High-Resolution Imaging Science Experiment (HiRISE) camera. Credit: NASA/JPL-Caltech/University of Arizona: https://science.nasa.gov/resource/insight-detects-an-impact-for-the-first-time/

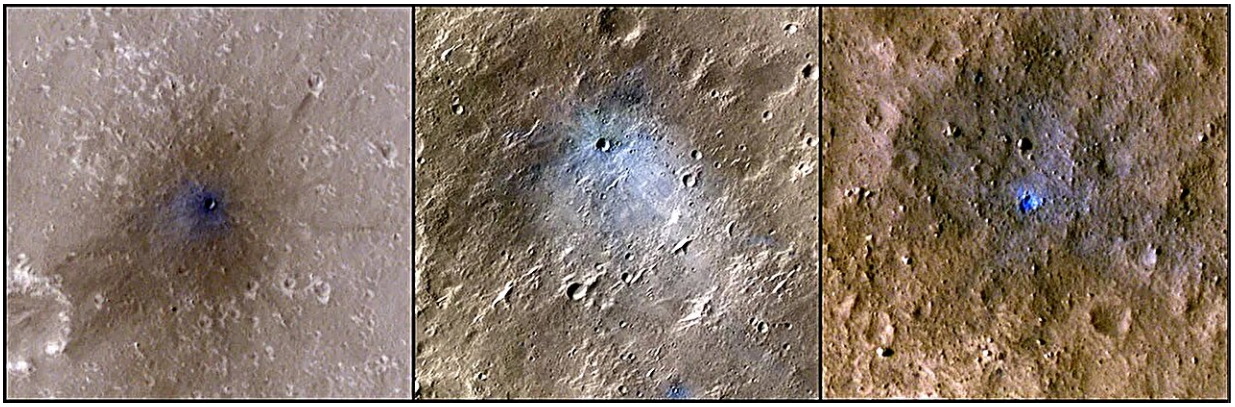
An international team of researchers, co-led by ETH Zurich and Imperial College London, has derived the first estimate of global meteorite impacts on Mars using seismic data. Their findings indicate that between 280 to 360 meteorites strike the planet each year, forming impact craters greater than 8 meters (about 26 feet) across.

Geraldine Zenhaeusern, who co-led the study, commented, "This rate was about five times higher than the number estimated from orbital imagery alone. Aligned with orbital imagery, our findings demonstrate that seismology is an excellent tool for measuring impact rates."

Seismic 'chirp' signals new class of quakes

Using data from the seismometer deployed during the NASA InSight Mission to Mars, researchers found that 6 seismic events recorded in the near proximity of the station had been previously identified as meteoric impacts—a process enabled by the recording of a specific acoustic atmospheric signal generated when meteorites enter the Martian atmosphere.

Now, Zenhäusern from ETH Zurich, co-lead Natalia Wójcicka from Imperial College London, and the research team have found that these 6 seismic events belong to a much larger group of marsquakes, so-called very high frequency (VF) events. The source process of these quakes occurs much faster than for a tectonic marsquake of similar size. Where a normal magnitude 3-quake on Mars takes several seconds, an impact-generated event of the same size takes only 0.2 seconds or less, due to the hypervelocity of the collision. By analyzing marsquake spectra, the team identified 80 more marsquakes that are now thought to be caused by meteoroid strikes.



Collage showing three meteoroid impacts that were first detected by the seismometer on NASA's InSight lander and later captured by the agency's Mars Reconnaissance Orbiter using its HiRISE camera. Credit: NASA/JPL-Caltech/University of Arizona

Their research quest began in December 2021, a year before accumulated dust on the solar panels put an end to the InSight mission, when a large distant quake recorded by the seismometer reverberated a broadband seismic signal throughout the planet. Remote sensing associated the quake with a 150-meter-wide crater. To confirm, the InSight team partnered with Mars Reconnaissance Orbiter (MRO) Context Camera (CTX) to search for other fresh craters that would match the timing and location of the seismic events detected by InSight.

The teams' detective work paid off and they were lucky to find a second fresh crater over 100 meters (320 feet) in diameter. Smaller craters, however, formed when basketball-sized meteoroids strike the planet and which should be far more common, remained elusive. Now, the number of meteorite strikes is newly estimated by the occurrence of these special high-frequency quakes.

First meteorite impact rate from seismic data

Approximately 17,000 meteorites fall to Earth each year, but unless they streak across the night sky, they are rarely noticed. Most meteors disintegrate as they enter Earth's atmosphere, but on Mars the atmosphere is 100 times thinner, leaving its surface exposed to larger and more frequent meteorite strikes.

Until now, planetary scientists have relied on orbital images and models inferred from well-preserved meteorite impacts on the moon, but extrapolating these estimates to Mars proved challenging. Scientists had to account for the stronger gravitational pull of Mars and its proximity to the asteroid belt, which both mean that more meteorites hit the red planet. On the other hand, regular sandstorms result in craters that are much less well-preserved than those on the moon, and therefore, not as easily detected with orbital imagery. When a meteorite strikes the planet, the seismic waves of the impact travel through the crust and mantle and can be picked up by seismometers.

Wójcicka explains, "We estimated crater diameters from the magnitude of all the VF-marsquakes and their distances, then used it to calculate how many craters formed around the InSight lander over the course of a year. We then extrapolated this data to estimate the number of impacts that happen annually on the whole surface of Mars."

Zenhäusern adds, "While new craters can best be seen on flat and dusty terrain where they really stand out, this type of terrain covers less than half of the surface of Mars. The sensitive InSight seismometer, however, could hear every single impact within the lander's range."

Insight into the age of Mars, and future missions

Much like the lines and wrinkles on our face, the size and density of craters from meteorite strikes reveal clues about the age of different regions of a planetary body. The fewer craters, the younger the region of the planet. Venus, for example, has almost no visible craters because its surface is continually reworked by volcanism, while Mercury and the moon with their ancient surfaces are heavily cratered. Mars falls in between these examples, with some old and some young regions that can be distinguished by the number of craters.

New data shows that an 8-meter (26-foot) crater happens somewhere on the surface of Mars nearly every day and a 30-meter (98-foot) crater occurs about once a month. Since hypervelocity impacts cause blast zones that are easily 100 times larger in diameter than the crater, knowing the exact number of impacts is important for the safety of robotics, but also future human missions to the Red Planet.

"This is the first paper of its kind to determine how often meteorites impact the surface of Mars from seismological data—which was a level one mission goal of the Mars InSight Mission," says Domenico Giardini, Professor of Seismology and Geodynamics at ETH Zurich and co-Principal Investigator for the NASA Mars InSight Mission. "Such data factors into the planning for future missions to Mars."

According to Zenhäusern and Wójcicka, the next steps in advancing this research involve the use of machine learning technologies to aid researchers in identifying further craters in satellite images and identifying seismic events in the data.

More information: An estimate of the impact rate on Mars from statistics of very-high-frequency marsquakes., *Nature Astronomy* (2024). DOI: 10.1038/s41550-024-02301-z

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