PUBLISHED: 2 FEBRUARY 2017 | VOLUME: 1 | ARTICLE NUMBER: 0041

METEORITES

A shift in shooting stars

Measurements now show that the distribution of meteorite compositions arriving to Earth was significantly different in the past and that the flux changes on short timescales.

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Meteorites that fall on Earth originate primarily from the main asteroid belt. These small bodies drift slowly over time and end up on a trajectory towards near-Earth space. Once on this path, these bodies eventually either fall into the Sun, are ejected from the Solar System, or in rare cases, fall onto the surface of a planet. While there is a solid understanding of the current influx of meteorites, including the variety of meteorite compositions falling today, it is much more challenging to decode what the meteorite flux looked like in the past. Do the types of meteorites delivered to Earth change over time, and if so, on what timescales? In this issue of *Nature Astronomy*, Heck *et al.*[1] demonstrate that not only does the composition of the meteorite flux change over time, but that specific events in the asteroid belt cause a dramatic change on short timescales.

The history of the main asteroid belt is marked by big catastrophic events. Major collisions between large asteroids can smash their bodies entirely, like fireworks exploding into thousands of small fragments forming what is then called an asteroid family. An asteroid family is a group of small asteroids, generally with similar composition, originating from the same parent body, and traveling on similar orbits around the Sun[2,3]. More than half of all the small asteroids (with diameters ≲10 km) are members of families that originated from large asteroids[4].

The smallest of these bodies (with metre-size diameters), formed either during these smashing events or through subsequent breakups, are too faint to be detected by telescope while they reside in the distant main belt. Thus, we are unable to track them and understand the pace of their journey from the main belt. We also don't know how numerous those small family members are relative to other small bodies.

We know the current mix of meteorite types that fall on Earth by counting the number of aptly named 'falls' that are discovered as they make it to the ground. Today, the vast majority of meteorite falls are ordinary chondrites, a stony meteorite class that is made up of three subclasses, H, L, and LL, which are distinguished by the iron contents in their olivine and pyroxene minerals and their metal abundances[5]. Uncovering the meteorite flux from the past is more challenging. In Sweden, China, and Russia there are large regions of limestone that are nearly 500 million years old. Embedded in these rocks are remnants of meteorites that fell around the time the rock formed. By studying these embedded fossil meteorite samples at different depths, and thus different ages, we have begun to stitch together measurements from multiple time periods.

One striking example was the detection, in that rock record, of a family-forming event known as the L-chondrite parent body breakup (LCPB), named after the

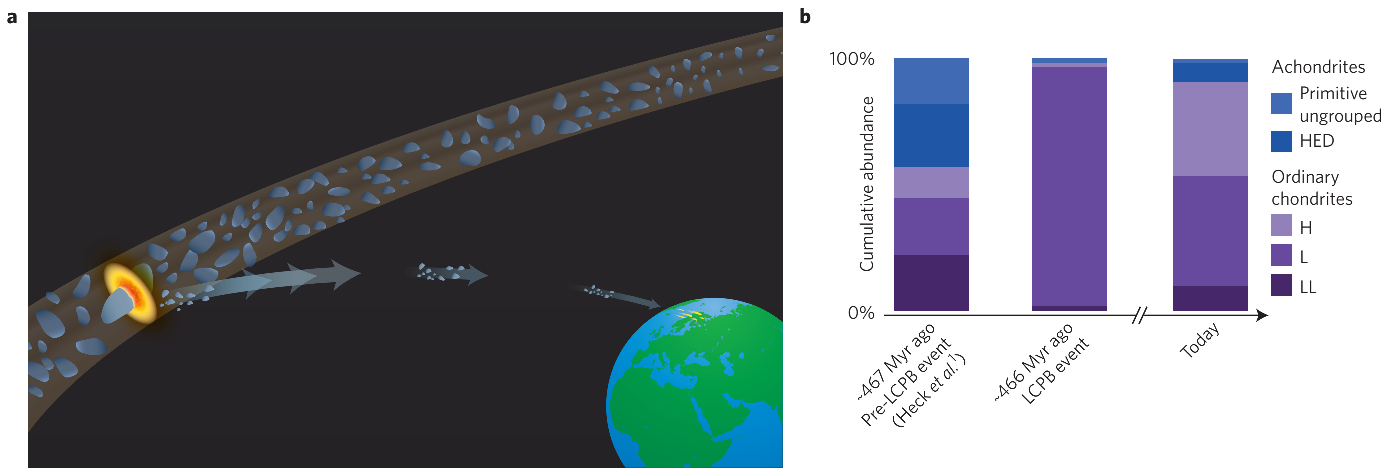

Figure 1 | The meteorite flux on Earth. **a**, An illustration of a meteorite's journey, starting from a major collision in the main asteroid belt that forms thousands of fragments. Those fragments follow similar orbits around the Sun and drift over time until they reach an 'escape hatch' that may put them on an Earth-crossing orbit and eventually fall to Earth. As they heat up while entering Earth's atmosphere they are colloquially named shooting stars. Any surviving pieces on the ground are called meteorites. Only a small fraction of fragments from the main belt ever makes it to the surface of a planet. **b**, The relative composition of micrometeorite flux on Earth over time. The types of meteorites falling to Earth change dramatically over time and are linked to events in the main asteroid belt. The data exclude major meteorite groups poor in chrome spinel, since these groups cannot be detected in the fossil meteorite record. The legend shows the meteorite types that were measured. HED stands for howardite, eucrite, and diogenite meteorites, which are linked to asteroid Vesta.

particular meteorite type that made up the bulk of the material arriving on Earth at that time. Through measurements of fossil meteorites and extraterrestrial chromite grains embedded in limestone, it was found that the flux of meteorites 466 Myr ago, at the time of the breakup, was two orders of magnitude greater than the current flux today and was made up nearly entirely of these L-chondrite bodies[6,7]. This result demonstrated that the flux of meteorites on Earth could be greatly changed by specific events in the asteroid belt.

In 2004, Heck and colleagues[8] studied meteorites from that same time period, measuring gas produced by cosmic rays within chromite grains from fossil meteorites to determine how much time passed between the LCPB family-forming event and the transport of some of the resulting fragments to Earth. They found that the meteorites from that event were delivered on extremely short timescales: the first pieces arrived within one to two hundred thousand years of the event[8]. They had proved that major events in the main belt could cause sudden, dramatic changes in both the quantity and composition of the meteorite flux. The question that remained unanswered from this work was if there was a steady baseline flux that would continue before and after these events. By securing samples just one million years older than this specific event, Heck *et al.*[1] are now able for the first time to create a baseline before and after the event.

The results of Heck *et al.*[1] show that the flux just one million years prior to this event was dramatically different from both the event and the current flux. This suggests that rather than a steady baseline of meteorites, the flux is instead constantly changing depending on events in the main belt (Fig. 1). The flux of meteorites on Earth provides observational physical evidence of events in the main belt. Like when a supernova bursts, showing a sudden strong increase in brightness then dimming over time, a spike in the meteorite flux will occur soon after a major catastrophic event in the main belt. That spike will then fade over time until the next event, causing an ebb and flow of different meteorites arriving on Earth over time, in sync with the events in the main belt.

Now, with data from three points in time — today, 466 Myr ago and in the work by Heck *et al.*[1] for ~467 Myr ago — and the basic understanding that the meteorite flux is dominated by specific, large, recent events, we are ready to connect the dots to see the full picture. By making similar measurements of meteorites embedded in limestone that formed throughout other time periods we can recreate the change in flux and attempt to match that flux to particular families and events in the main belt. In essence, we are catching in the limestone on Earth the leftover glitter from a cosmic dance of asteroids waltzing in the main asteroid belt. ❐

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