Fireball observations in relation to the asteroid-meteorite connection

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This is an invited review of ongoing efforts to document the arrival orbits of meteorites that have been recovered on the ground from fireball observations [1]. The goal of this effort is to identify the source of our meteorites in the asteroid belt. The semi-major axis of the approach orbit often points to the delivery resonance, while the inclination of the orbit often still alligns with the inclination of the source region. The goal and some of the methods are shared by ongoing taxonomic studies of Near-Earth Asteroids (NEA), meteorite reflectance and space weathering studies, and taxonomic and dynamical studies of asteroid families in the main belt. That includes efforts to identify the origin of the Ryugu and Bennu Near-Earth Asteroids. The objects targeted in fireball observations are mostly meteoroids (0.1 – 1 m in size) and small asteroids (1 – 20m in size), while NEA observations target mostly larger asteroids (10 – 200 m), including asteroids that are mostly rubble piles (0.2 – 37 km in size). Those can have different source regions.

The tools used to track the approach orbit of meteoroids include photographic and video cameras deployed in dedicated camera networks around the globe, as well as video security cameras, dashcams, and doorbell and iphone cameras that record the meteors serendipitously in video shared via social media. On average, there are about 13 reported meteorite falls per year around the globe. In recent years, the fraction of falls that are documented has steadily increased. Since my last review in 2018, the number of documented meteorite falls has doubled to around 70.

While back in 2018 there were just hints that different meteorite types arrived on different orbits, now distinct patterns have emerged. Most notable is a cluster of H-chondrites with orbits at low inclination between the 3:1 and 5:2 mean-motion resonances. They point to a source region just beyond the 5:2 resonance. Three of these meteorites have the ~6.5 Ma cosmic ray exposure age that is similar to the 5.8 Ma dynamical age of the Karin cluser in the Koronis family. Also remarkable is that all CM2 chondrites to date have been detected on orbits with low $i < 3^o$ inclination, arriving to us from the 3:1 mean-motion resonance. The most likely source for CM chondrites is therefore not the Polana or Veritas families, located at significantly higher inclination, but rather the Themis family in the outer main belt, perhaps related to the <10 Ma old Beagle cluster.

Compared to the recently published compilations of NEA observations [2, 3], meteoroids of a given meteorite type arrive on similar orbits as NEA of corresponding taxonomic type, but there are also differences. As with NEA, LL-type ordinary chondrites arrive from the inner main belt via the nu-6 secular resonance. The cluster of H-chondrites from the outer main belt, however, is not seen in NEA observations. The approach pattern for CM2 chondrites is unlike the expected C- and P- class taxonomic type NEA, but rather similar to D-type NEA, likely due to space weathering of the NEA surfaces.

Future fireball observations by amateur and professional astronomers can bring these patterns into better focus and also provide information on other meteorite types that are hard to recognize among the different asteroid taxonomic classes.

References

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