METEOR SHOWERS FROM BROKEN COMETS. P. Jenniskens, SETI Institute (515 N. Whisman Rd., Mountain View, CA 94043; pjenniskens@mail.arc.nasa.gov).

Introduction: When Whipple [1] discovered a mechanism to accelerate meteoroids by the drag of water vapor in1951, the old idea of meteor showers originating from comet breakup went into remission. Even though comets were frequently observed to break, there was no strong evidence that the meteoroids generated in these discrete and relatively rare events accounted for our meteor showers on Earth. Now, recent minor planet discoveries have recovered remnants of those breakups in some of our strongest showers.

The giant comet hypothesis: Active Jupiter Family Comets are known to frequently break and shed a series of 10-m to 1000-m sized fragments [2]. Examples are the 1832 breakup of 3D/Biela and the 1995 breakup of 73P/Schwassmann-Wachmann 3. Both comets used to, or will in the future, pass by Earth orbit. During those fragmentations, meteoroids are created that can lead to temporary meteor showers on Earth when the resulting dust trails are steered in Earth path. If the amount of dust is substantial, fragmentations can even lead to annual showers when the streams evolve into elongated structures that cross Earth's path.

The idea that the fragmentation of comets is a source of meteoroids causing meteor showers on Earth was first proposed following the 1872 and 1885 Andromedid storms, which followed the breakup of lost comet 3D/Biela in 1832, and the continued fragmentation of the comet observed in the returns of 1846 and 1852 [3]. At the time, comets were seen by many as a flying sand bank, dust grains orbiting each other and held together by their mutual gravity [4] and there was no clear distinction between a comet ensemble and individual meteoroids.

In recent years, the products of fragmentations are known to be comets in their own right, possibly creating new meteoroid streams by water vapor drag. Nuclear fragments in orbits with other orbital period than the parent comet were implicated in the periodic returns of the Lyrids [5], which we now know are due to periodic perturbations by Jupiter, which steer a continuous trail of dust in Earth's path instead. Another example of comet fragmentation implicated as the source of a meteor shower is the Giant Comet Hypothesis for the origin of the Taurid complex [6]. While in my opinion the Taurid shower is indeed likely the product of comet fragmentation, most of the implicated minor bodies have been proven to be unrelated asteroids, instead.

Fragments of broken comets in meteoroid streams: In 1983, Fred Whipple discovered a minor planet 3200 Phaethon among the meteoroid stream responsible for the Geminid shower [7]. The reflectance properties of the minor planet (taxonomic type B) make the nature of this object as an extinct comet nucleus uncertain, but only because of the small perihelion distance. The surface of the minor planet and the properties of the meteoroids are altered from repetitive heating by the Sun. It has since been shown that the Geminids appear to have been created close to perihelion, more typical of comet ejection than asteroidal collisions [8].

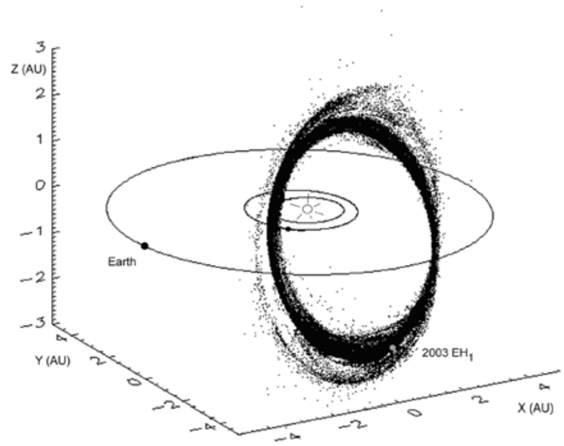

Fig. 1: 2003 EH_1 and the Quadrantid meteoroid stream, in a model by Jerémié Vaubaillon.

In 2003, I identified a minor planet 2003 EH_1 in the high-inclination orbit of the Quadrantids [9]. This is a massive stream, containing a thousand times more mass than typically ejected by an active Jupiter Family Comet. The minor planet passes outside of Earth orbit, but the stream evolves rapidly due to perturbations of Jupiter at aphelion (and at the ascending node). Accurate measurements of meteoroid orbits imply that the stream is not older than 500 years and must have formed in a short period of time. The comet C/1490 Y_1, seen in early 1491, may have been the manifestation of that breakup [10].

Now, a second such minor planet has been recognized, 2003 WY_{25}, which traces back to comet D/1819 W1 (Blanpain) [11]. The comet orbit is not known well and the comet was lost after the 1819 sighting,. However, 2003 WY_{25} has angular elements within 0.2° from those of Blanpain at that time, and is therefore most likely a fragment of a breakup that must have occurred in the 18th or early 19th century, most likely just before the return of 1819.

We demonstrated that the dust generated in a breakup in 1819 would have wandered in Earth's path in 1951 and 1956, and could have been responsible for the strong 1956 Phoenicid outburst. The trail has not been in Earth's path since (at least not when Earth was at the node). Hence, the 1956 Phoenicids were likely the debris from the breakup of comet Blanpain in or shortly before 1819 [11].

More recently, the Marsden group of sunskirting comets was found to have a short orbital period [12], which implies that whatever was responsible for this large family of comet fragments is also responsible for the Daytime Arietids. The associated delta-Aquariids are then also formed after the breakup of a comet of that same group, albeit further evolved along a Kozai cycle.

In summary, the meteor showers that are likely from the fragmentation of comets rather than from Whipple-type ejection by water vapor drag are the Quadrantids, Daytime Arietids, delta-Aquariids, Andromedids, Phoenicids, and Geminids, and probably also the Capricornids, kappa-Cygnids, and Taurids, representing most of our annual showers.

Comet fragmentation: One of the more interesting results from comparing mass estimates of the comet fragments and the meteoroid streams of these Jupiter-Family-Comet parents is that the streams represent a mass no more than that of a single fragment [11]. In contrast, the disruption of long-period comet C/1999 S4 (Linear) was thought to have created as much as 200 times more mass than the sum of fragments combined [13]. Hence, the fragmentations in question are not necessary wholescale, but could pertain to the release of just a small number of cometesimals from their parent comet, in the process brightening the comet by a few magnitudes from the release of fine dust and gas.

The cause of those fragmentations remains unknown, but the impact of large meteoroids has been implicated as a mechanism to trigger such events [14]. While containing a relatively small amount of kinetic energy, such impacts may heat trapped subterranean gasses that can lead to sufficient pressure buildup to gently break off cometesimals.

The Deep Impact probe hit 9P/Tempel 1 in terrain dotted by impact craters that had clearly weathered similar events in the past. The approach images did not immediately show the breaking off of a fragment.

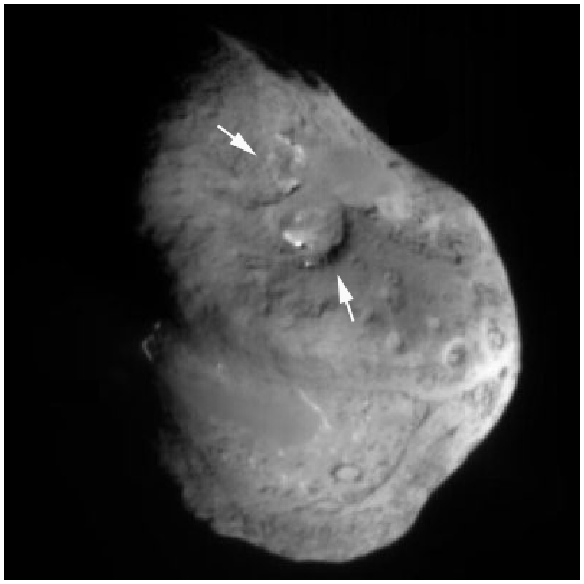

Fig. 2: Deep Impact target 9P/tempel-1. Arrows mark areas that might be the scars from recent fragmentation. Photo: NASA/JPL/Deep Impact.

However, the surface of comet 9P/Tempel 1 (Fig. 2) shows some areas with steep ridges that containing spots of high albedo terrain. Instead of impact craters, these structures could be the site of such fragmentation. In the case of 9P/Tempel 1, at least two 0.5-km sized fragments may have been lost from the comet. Other terrain is smooth, without much albedo variation, at the bottom of larger bowl-shaped depressions. That flat terrain likely resulted from dust fallen back to the comet that accumulated at the bottom of the bowls. It is not clear, at present, if that debris could have been created during the disruption, or was the result of normal Whipple-type ejection of meteoroids by the drag of water vapor instead.

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