Atmospheric behavior of the Chelyabinsk impactor

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The impact of a 19-m diameter asteroid near Chelyabinsk, Russia on February 15, 2013 has already been studied extensively [e.g., 1–3]. The main sources of information were casually recorded videos, which provided the images of the superbolide as well as acoustic records of the sonic booms. From these data, the bolide trajectory, velocity, deceleration, and lightcurve have been derived after careful calibration and analysis. Such detailed data are not available for any other impactor larger than about 5 meters. The Chelyabinsk event represents therefore a unique opportunity to study the interaction of asteroids in the decameter size range through the terrestrial atmosphere.

In comparison with our previous study [1], we used more calibrated videos in this work. We will present the refined trajectory, velocity, and orbit but will mainly concentrate on the atmospheric fragmentation analysis. The extent of the dust trail up to the heights of 70 km demonstrates that significant mass loss occurred from the early parts of the luminous trajectory. Nevertheless, no flare was seen on the early portion of the lightcurve, suggesting that no sudden disruption occurred here and the mass was probably being lost from the asteroid surface. The first break-up occurred at the height of about 47 km. The large scale disruption, documented both by the lightcurve and sonic booms, occurred between the heights of 39–30 km. The fragmentation then ceased temporarily, but a number of surviving meter-sized boulders fragmented extensively again below 26 km. We will present a fragmentation model fitting both the observed lightcurve and deceleration. At lower heights, the deceleration of several individual fragments could be measured. The transverse speed of the major fragment was 400 m/s, much larger than expected, but of the same order of magnitude as observed in other cases including a sample of tiny meteoroids [4]. The unique aspect of Chelyabinsk was the formation of an extended dust trail containing thermal hot spots, which retained their forward momentum and continued the flight in the original asteroid direction after formation. The usual assumption that the positions of dust concentrations are identical with the fragmentation points proved invalid in the case of Chelyabinsk. The nature of the hot spots will be discussed.

The fragmentation analysis confirms that the Chelyabinsk asteroid was not a rubble pile, which would be expected to disintegrate under the atmospheric ram pressures experienced in the beginning of entry. On the other hand, Chelyabinsk was not a particularly strong body. About 95 % of mass was lost at heights above 30 km under the action of dynamic pressure less than 5 MPa. In many respects, the Chelyabinsk fragmentation resembles the fragmentation behavior exhibited by the Košice meteoroid (H5 chondrite, 1 meter size) [5]. Both events were characterized by catastrophic disruption above the height of 30 km and the survival of only a few large pieces in addition to numerous small meteorites. Since the bulk strength and fragmentation behavior of meter-sized objects varies from case to case [6], we do not expect that all Chelyabinsk-sized impactors will behave similarly.

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