The Big Fizzle

Paul Weissman

How will the fragments of comet Shoemaker-Levy 9 meet their end, with a bang or a whimper? That is the question on everyone's mind as the icy fragments rush toward their cosmic rendezvous with Jupiter, beginning July 16. Will Jupiter's atmosphere be tom with massive explosions, each greater than the sum of all the nuclear weapons on Earth, or will it be a giant fizzle? We are about to find out.

Whatever the outcome, the breakup of comet Shoemaker-Levy 9 has provided fresh clues as to the structure of cometary nuclei and their bulk density. One fascinating example is the paper by Eric Asphaug and Winy Benz on page XXX of this issue. Asphaug and Benz used a high-speed computer workstation to model the breakup of Shoemaker-Levy 9 when it passed within Jupiter's Roche limit two years ago. They assumed that the comet was a "primordial rubble pile, " a collection of hundreds to thousands of dirty snowballs, held together only by their own self-gravity.

This model for comets was independently proposed a decade ago by myself,[1] and by Bertram Donn and David Hughes,[2] who referred to their idea as the " fractal model. " An improved description of how such 50-meter diameter dirty snowballs (or more aptly, frozen mudballs) might form in the primordial solar nebula and then come together to form kilometer-sized nuclei was recently provided by Stuart Weidenschilling.[3]

Asphaug and Benz's dynamical simulations show the nucleus of tightly packed snowballs being torn apart by Jupiter's gravity during the close approach, the hundreds or thousands of snowballs stretching into a long column in space. But as the column lengthens and moves away from Jupiter, the individual snowballs begin to clump together clue to their own self-gravity. The truly amazing result is that the number of clumps formed appears to be a function of the density of the individual snowballs. At a density less than 0.4 g cm^{-3}, no clumping occurs; at a density of 2.4 g cm^{-3} all the snowballs come back together to form a single body. But at intermediate values, in particular between 0.4 and 0.9 g cm^{-3}, the snowballs form 15 to 20 clumps. Comet Shoemaker-1 .evy 9 consisted of21 individual nuclei when it was discovered last year. (Note, the densities quoted here refer to the density of the individual snowballs; Asphaug and Benz usc the bulk densit y of comet Shoemaker-l .evy 9 before it broke up, which is about 27% less because of the voids between the packed snowballs).

Results arc modified if the original comet nucleus was rotating. Asphaug and Benz's simulations rule out a retrograde rotation, because the snowballs then form a large central clump and smaller outlying clumps; this was not observed for Shoemaker-1 .evy 9. But if the comet had a prograde rotation, one obtains 15-20 clumps if the density of the snowballs is higher, perhaps 1.3 g cm^{-3}. Asphaug and Benz's results also suggest that the original comet nucleus was fairly mall, at most 1.5 km in diameter, in agreement with work by Scotti and Melosh.[4]

Past estimates of the bulk density of cometary nuclei have ranged from 0.1 to 1.3 g cm^{-3}, based on comparisons of the predicted effects of gases jetting from the sunlit surface of comet Halley, with detailed observations of Halley's orbital motion.[5,6,7] But the many free parameters in such comparisons make the est imates highly uncertain, More recently, meteorit icists have measured the density of microscopic cometary dust grains recovered by U-2 aircraft high in the Earth's atmosphere;[8] those values arc typically between 1 and 2 g cm^{-3}. Asphaug and Benz's results clearly rule out the lower range of values from the estimates of jetting forces, but may be in conflict with some of the higher values from the cometary dust grains.

A question not answered by Asphaug and Benz is whether the individual dirty snowballs in each clump of Shoemaker-Levy 9 have reaccreted into a single body, or whether they are only gravitationally bound dynamical swarms, like bees buzzing around a hive. Several of the clumps in Shoemaker-Levy 9 have been observed to split, well away from Jupiter's tidal pull, suggesting that within each clump, several sub-nuclei may reaccrete, but that a single solid body did not form. Other clumps have dissipated completely with time, suggesting that the snowballs don't reaccrete and/or do sublimate away.

What dots this say about the coming impacts on Jupiter? As the clumps approach Jupiter for their final plunge into the atmosphere at 60 km sec^{-1}, Jupiter's gravity will again pull them apart. Rather than hitting as a single solid body, they will likely come in as an elongated shotgun blast of smaller pellets. Because of Jupiter's rapid rotation, the impact sites will be spread in longitude, like machine gun bullets lacing into a moving target. Each snowball will individually ablate and bum up like a meteor in Jupiter's upper atmosphere. Lacking the momentum and the structural integrity of a single solid body, they will likely not penetrate deeper into the atmosphere where they might explode with multi-thousands of megatons of energy .

Thus the giant impacts will produce a spectacular meteor shower of bright bolides, but not the massive fireball explosions that have been predicted by some researchers. The impacts will be a cosmic fizzle. The cometary meteors may resemble the bolide which exploded harmlessly at 25-34 km altitude over the south Pacific on February 1 of this year, with an estimated yield of 15-20 kilotons. The Shoemaker-Levy 9 snowball explosions may be closer to about 30 megatons each, but still far less than the 100,000 megaton explosions that some have predicted.

Nevertheless, Shoemaker-Levy 9's legacy will likely be an improved understanding of the nature of cometary nuclei. It will provide a dramatic confirmation of the primordial rubble pile and fractal models, and will provide the first definitive bounds on the bulk density of cometary nuclei. Or maybe, it won't.

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References:

1. Weissman, P. R. *Nature 320, 242-244 (1986).*
2. Donn, B. & Hughes, D. *Proc. 20th ESLAB Symposium on the Exploration of Halley's Comet* (eds. Battrick, B., Rolfe, E. J. & Reinhard, R.) pp. 523-524 (1986).
3. Weidenschilling, S. J. *Nature* 368, 721-723 (1994).
4. Scotti, J. V. & Melosh, H. J. *Nature 365, 733-735 (1993).*
5. Rickman, H. in *The Comet Nucleus Sample Return Mission* (ed. Melita, O.) ESA SP-249, pp. 195-205 (1986).
6. Sagdeev, R. Z., Elyasberg, P. E. & Moroz, V. I. *Nature 308, 240-242 (1988).*
7. Peale, S. J. *Icarus* 82, 36-49 (1989).
8. Love, S. & Brownlee, D. *Icarus*, in press (1994).