COMET SHOEMAKER-LEVY 9 FRAGMENT SIZE AND MASS ESTIMATES FROM LIGHT FLUX OBSERVATIONS D. A. Crawford, Sandia National Laboratories, P. O. Box 5800, MS 0820, Albuquerque, NM, 87185-0820 (dacrawf@sandia.gov).

The impact of Comet Shoemaker-Levy 9 on Jupiter in July, 1994 was the largest, most energetic impact event on a planet ever witnessed. Many observations were made from Earth-based telescopes, the Hubble Space Telescope (HST) and the Galileo spacecraft en route to Jupiter[1-6]. In this work, time-resolved light-flux observations are used in conjunction with computational simulations performed with the CTH shock-physics hydrocode to determine the size and mass of the 15 fragments that made impact features on the planet discernible to HST. To do this, CTH was equipped with a radiative ablation model and a post-processing radiative ray-trace capability that enabled light-flux predictions for the viewing geometry of Galileo at the time of the impacts.

The seven events recorded by Galileo were calibrated against CTH simulations to give fragment size estimates. Data from four of the largest events, compared against the simulations, are shown in Figure 1. Interestingly, fragment density plays a role in the late-time character of the light curves. According to this model, the most likely fragment density at time of impact was approximately 0.25 g/cm^3, about half the parent body density estimated by Asphaug and Benz[7]. Hence, the fragments were probably rubble piles with at least 50% porosity.

To determine the sizes of the remaining eight fragments (see Table I), the Galileo/CTH estimates were incorporated into a least-squares analysis assuming linear energy scaling of the main infrared peak[2]. The three largest fragments (L, K and G) were each greater that 1 km in diameter and represent approximately 74% of the mass of Shoemaker-Levy 9. If combined, all 15 fragments would make a sphere 1.8 km in diameter. Assuming a pre-breakup density of 0.5 g/cm^3, the parent body of Shoemaker-Levy 9 had a probable diameter of 1.4 km. The total kinetic energy of all the impacts was equivalent to the explosive yield of 300 Gigatons of TNT.

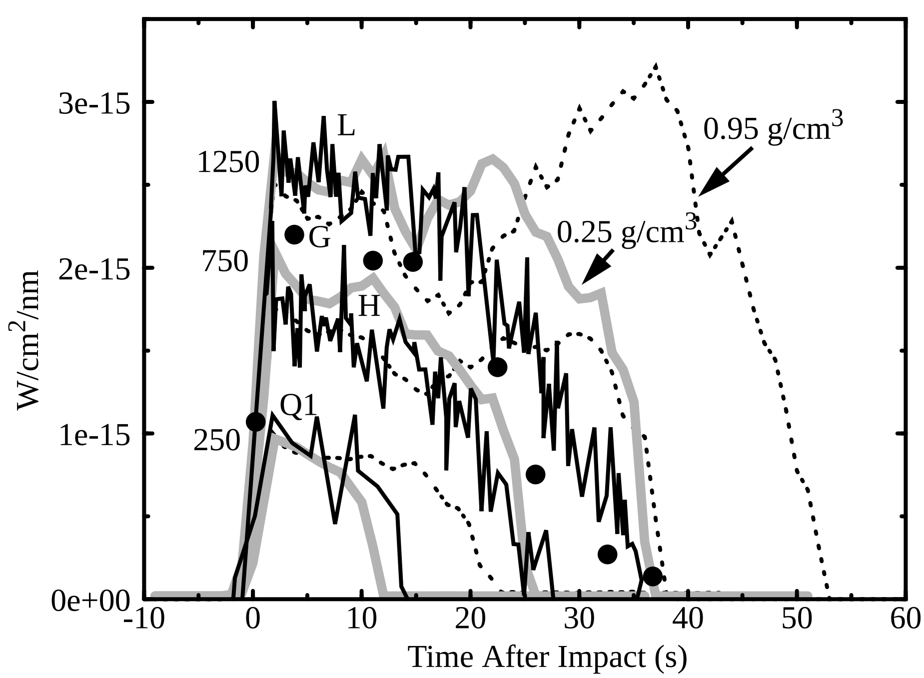

Figure 1. Comparison of CTH-simulated light curves (for 250, 750 and 1250 m fragments) against Galileo spacecraft observations[6] (at 945 nm) of the impacts of fragments L, H and Q1 (solid curves) and G (dots). Gray lines and dashed lines are simulations performed assuming fragment densities of 0.25 and 0.95 g/cm^3, respectively.

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Table 1: Comet Shoemaker-Levy 9 Fragment and Parent Body Size Estimates

Fragment*	HST Class†	2.3 μm Peak (Jy)‡	12 μm Peak (Jy)‡	Diameter (m)♦
A	2a	20	1,200	450
B	3			(50)
C	2a	25		380
D	3	4		200
E	2a	100	1,550	610
G	1	460		1,000•
H	2a	100	2,400	660•
K	1	460		1,000•
L	1	1,000	12,700	1,270•
N	3	0.04		45•
Q2	3			(50)
Q1	2b	90	1,700	600•
R	2b	70	990	530
S	2c	120		640
W	2c	60		490•
Parent	-	-	-	1,400¶

*Fragments F, P2, T, U and V produced no discernible impact features. Fragments J, M and P1 faded from view before impact[1]. The letters I and O were not used.

†from [1]. Based on first view of the impact site with the Hubble Space Telescope. Class 1 = large dark feature (>10,000 km radius), Class 2 = medium dark feature (4000-8000 km radius), Class 3 = small dark feature (<3000 km radius).

‡Observed light flux of the main infrared event seen from Earth at 2.3 and 12 μm [2-5].

♦Diameter is estimated from a least squares analysis incorporating Galileo light-flux observations[6] (marked with • symbol and calibrated against CTH light-output calculations) and assuming r^3 dependence of the peak flux (for given wavelength) observed by Earth-based telescopes[2]. Values in parentheses are estimates assuming diameter equivalence within HST class 3. Uncertainty (1 σ) of individual fragment diameter is 15% for fragments A, E, H, L, Q1 and R and 30% for fragments B, C, D, G, K, N, Q2, S and W. Best fitting fragment density is about 0.25 g/cm^3.

¶Assuming a density of 0.5 g/cm^3 before breakup in 1992. The total volume of the fragments would make a sphere 1760 m in diameter (at 0.25 g/cm^3). Uncertainty of these estimates is dominated by uncertainties of the largest fragments (L, K and G), about 25%.

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References: [1] H. B. Hammel, in *The Collision of Comet Shoemaker-Levy 9 and Jupiter*, K. Noll *et al.*, eds., Cambridge Univ. Press, 111-120 (1996). [2] P. D. Nicholson, *ibid.*, 81-109. [3] P. O. Lagage *et al.*, *GRL*, *22*, 1773 (1995). [4] S. Takeuchi, *et al.*, *ibid.*, 1581. [5] P. McGregor *et al.*, *Icarus* (submitted). [6] C. R. Chapman, in *The Collision of Comet Shoemaker-Levy 9 and Jupiter*, *op. cit.*, 121-132. [7] E. Asphaug and W. Benz, *Nature, 370*, 120-124 (1994).