COMET SHOEMAKER-LEVY 9, IMPACT ON JUPITER - THE FIRST TEN MINUTES : Toshiko Takata, John D. O'Keefe, Thomas J. Ahrens, and Glenn S. Orton*, Division of Geological and Planetary Sciences, Caltech, Pasadena, CA 91125, * : Jet Propulsion Laboratory, Caltech, Pasadena, CA 91109

We have employed three-dimensional numerical simulations of the impact of Comet Shoemaker - Levy 9 (SL9) on Jupiter and the resulting vapor plume expansion using Smoothed Particle Hydrodynamics (SPH) method. An icy body with a diameter of 2 km can penetrate to an altitude of -350 km (0 km = 1 bar) and most of the incident kinetic energy is transffered to the atmosphere between -100 km to -250 km. This energy is converted to potential energy of the resulting gas plume. The unconfined plume expands vertically and rises a few tens of atmospheric scale heights in $\sim 10^2$ seconds. The rising plume reaches the altitude of $\sim$ 3000 km, however no atmospheric gas is accelerated to the escape velocity ($\sim$ 60 km/s) in our calculations.

Fragments of Comet, SL9 are predicted to impact Jupiter in July 1994 [1,2]. Observations of the Hubble Space Telescope indicates the maximum fragment size is $\sim$ 4 km, and approximately 10 fragments are $\sim$ 3 km [3]. The total energy released to the Jovian atmosphere upon impact of all of the comet fragments (CF's) will be 10^{29-31} erg.

We modeled the impact of CF's onto Jupiter and the resulting plume expansion using the Lagrangian method called Smoothed Particle Hydrodynamics (SPH) [4]. A tillotson equation of state for ice was used for the cometary materials [5] and an ideal gas with $\gamma = 1.4$ is employed for the atmosphere. We used the atmospheric structure observed by Voyager. This model atmosphere is extended adiabaticlly into the interior of Jupiter. We performed calculations for two sizes of CF's, 2 and 10 km in diameter with an impact velocity of 60 km/s and impact angle of 40° from the zenith. These sizes characterize the range of maximum sizes and energy of the Comet SL9 fragments as perceived since discovery [3,6,7,8].

As the CF penetrates the atmosphere, the gas in its wake expands as a cylindrical blast wave and the CF is flattened by drag forces [fig. 1]. The lateral spreading of the CF is constrained by the strong bow shock surrounding the comet and its cross sectional area approaches 2.3 times its initial value. The CF can penetrate to an altitude of -350 km ($\sim$ 200 bar), in the case of an initial diameter, D = 2 km and to the altitude of -550 km ($\sim$ 800 bar), in the case of D = 10 km. The energy transfer from the CF to the atmosphere occurs mostly in the altitude range from -100 km ($\sim$ 10 bar) to -250 km ($\sim$ 100 bar) in the case of D = 2 km and -350 km ($\sim$ 200 bar) to -480 km ($\sim$ 500 bar) in the case of D =10 km [fig. 2].

Next, we carried out the calculation of a plume expansion [fig. 3]. We distributed $\sim 10^5$ atmospheric particles in model atmospheric box of 550 km width extending from 350 to -400 km altitude in the case of the CF of D = 2 km. The energy density of deposition shown in figure 2 is placed on atmospheric particles along the trajectory. The fireball, whose temperature is reduced to $\sim 10^3$ K in $\sim 10^2$ seconds after the impact, can easily rise a few tens of atmospheric scale heights and the unconfined plume expands vertically rather than horizontally in an inhomogeneous atmosphere. Buoyancy forces result in the upward motion of the plume. Some 25% of the energy deposited in the deep atmosphere can be transported above 100 km in 10^2 seconds and most of the energy is brought up above 100 km in $\sim$ 200 seconds. The impact energy is ultimately released to space by thermal radiation. A mass of atmospheric gas equal to 10 times of the CF mass is transported from below the cloud deck to above 100 km in 10^2 seconds and a total of $\sim$ 20 times the initial CF mass is elevated above 100 km. The rising plume achieves an altitude of $\sim$

3000 km, however no atmospheric gas is accelerated to escape velocity in our calculations. The plume transport results in the vertical mixing of deep atmospheric constituents, such as, NH_3, H_2O, and CH_4, in addition to the vaporized cometary materials. Subsequent condensation of both deep atmospheric and cometary materials may be a source of dust condensates in the upper atmosphere.

The energy released by the impact and subsequent expanding plume can be observed by optical and infrared instruments on the Galileo space craft and the plume, upon rising to $\sim 10^3$ to $\sim 10^4$ km may be promptly observed with optical and infrared earth - based instruments before the impact point is in direct view of the earth.

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References : [1] Shoemaker C.S. et al.(1993) IAU Circ.,5725. [2] Yeomans D.K. & Chodas P. (1993) *Minor Planet Circ.*, 22197. [3] Weaver H.A. et al.(1993) *Bull. Am. Astron. Soc.*, 25, 1042. [4] Gingold R.A. & Monaghan J.J.(1977) *Month. Not. Astr. Soc.*, 181, 375. [5] O'Keefe J.D. & Ahrens T.J. (1982) *JGR*, 87, 6668. [6] Scotti J.V. & Melosh H.J, (1993) *Nature*, 365, 7333. [7] Chapman C.R. (1993) *Nature*, 363, 492. [8] Sekanina Z. et al. (1993) *submitted to Astron. J.*. [9] Bronshten V. A. (1983) *Physics of meteoric phenomena* 356 pp.

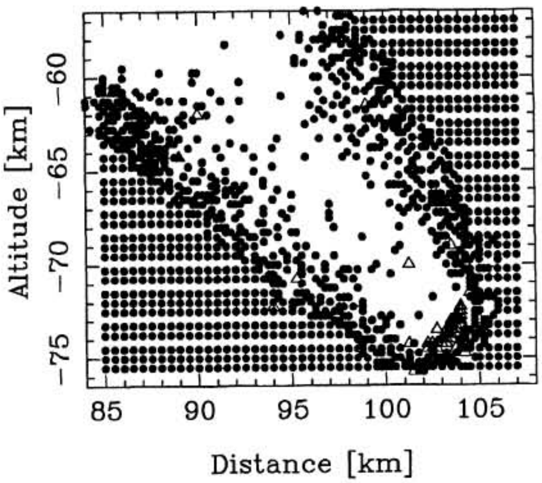

Figure 1. The position of particles at t = 2.6 s for the entry of the 2 km size - cometary fragment into the Jovian atmosphere. Triangles and circles represent cometary particles and atmospheric particles, respectively.

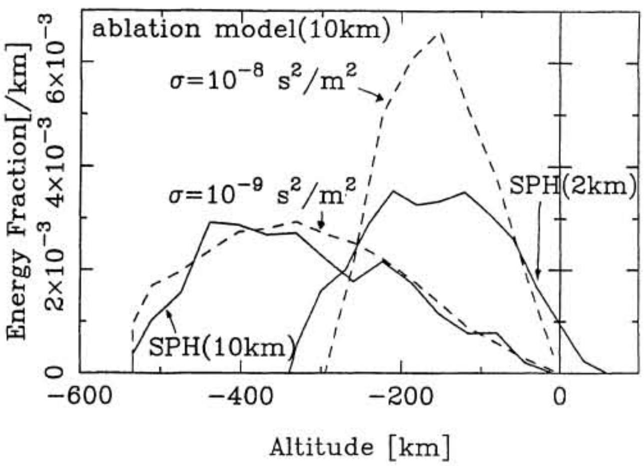

Figure 2. The fractional energy deposition of the initial kinetic energy of the comet as a function of altitude in the case of 2 and 10 km diameter - cometary fragments. The results of SPH calculation are shown by the solid lines, and the results of meteoric ablation model [9], with the ablation coefficients, σ, of 10^{-9} and $10^{-8} s^2/m^2$ for D = 10 km, are shown by dashed lines.

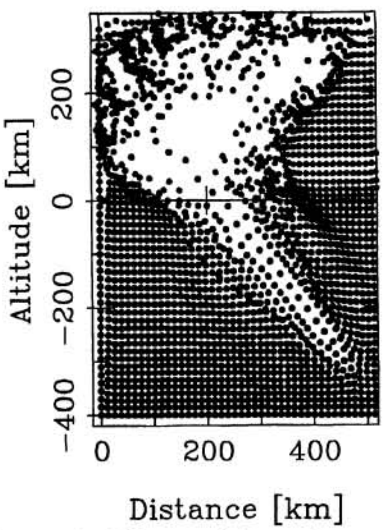

Figure 3. The position of atmospheric particles for the plume expansion of D = 2 km cometary fragment after 82.6 s.