**PRE-IMPACT ORBITAL EVOLUTION OF P/SHOEMAKER-LEVY 9;** Lance A.M. Benner and William B. McKinnon, Department of Earth and Planetary Sciences and McDonnell Center for the Space Sciences, Washington University, Saint Louis, MO 63130-4899, lance@wunder.wustl.edu.

We investigate the orbital evolution of P/Shoemaker-Levy 9 as a temporarily captured satellite and focus on its heliocentric motion prior to capture by Jupiter, and on its jovicentric motion after capture but prior to impact. We numerically integrate the comet's motion backward and forward in time using the orbital elements determined by D.K. Yoemans and P.W. Chodas (solution 28) [1]. We include the gravitational effects of Jupiter, Saturn, and the Sun, and Jupiter's oblateness $J_2$ and $J_4$. Assuming that no orbital energy changes occurred during the 1992 disruption, we find that the comet's jovicentric orbit prior to the July, 1992 perijove was not hyperbolic. Integration of the nominal solution 28 elements indicates that Shoemaker-Levy was captured by Jupiter in 1970 and has since completed nine irregular, eccentric, and steeply inclined orbits about the planet. The comet's nominal pre-capture heliocentric orbit orginated interior to that of Jupiter and crossed the asteroid belt; however, varying the initial elements within the formal uncertainties indicates that a pre-capture orbit between Jupiter and Saturn is also possible. The range of pre-capture heliocentric eccentricities ($e \sim 0.1$ - $0.3$) and inclinations ($i \sim 1°$ - $4°$) are consistent with a short-period comet or asteroid, but not with a highly inclined and eccentric long-period comet.

Figure 1 shows Shoemaker-Levy's heliocentric trajectory extending 21 Jovian years prior to the 1994 collision; for comparison, the radial distance in astronomical units from Jupiter and the Sun during this interval appears in Figure 2. Shoemaker-Levy orbits Jupiter backward in time for ~ 2 Jovian years, and "escapes" into an orbit interior to that of the planet. Prior to capture, the comet frequently approached within ~ 1.5 AU of Jupiter when it experienced the distinct changes in its heliocentric orbit that are visible in Fig. 1. Discrete changes in Shoemaker-Levy's heliocentric eccentricity and inclination also occurred during the closest approaches to Jupiter. The discrete changes in Shoemaker-Levy's heliocentric elements, as well as the sensitivity of the orbit to inital conditions noted above, are hallmarks of chaotic dynamics. Indeed, temporary gravitational capture orbits are, in general, chaotic [2]. Using the method of divergent trajectories in phase space [3], we find P/Shoemaker-Levy 9 to be fundamentally chaotic with a Lyapunov time of ~ 1.3 Jovian years.

Figure 3 shows Shoemaker-Levy's jovicentric distance after capture, including that which would result if the 1994 collision with Jupiter is ignored. If the impact is ignored, the comet passes within ~ 0.5 $R_J$ of the planet's center and completes one additional, distant orbit prior to escaping to an orbit between that of Jupiter and Saturn. Consequently, any orbital energy dissipation that P/Shoemaker-Levy 9 experienced when it fragmented in 1992 was insufficient to bind it into permanent orbit about Jupiter. For comparison, the distance that would result ignoring Jupiter's oblateness is also included. The motion backward in time changes only slightly, but because of the comet's extremely close approach to Jupiter in 1994, the trajectories including and ignoring oblateness rapidly diverge forward in time.

Capture by Jupiter occurs when the comet's jovicentric eccentricity decreased below unity, indicating (temporarily) bound motion (Fig. 4). Shoemaker-Levy's subsequent jovicentric orbit is strongly perturbed by the Sun because of the comet's generally large distance from the planet. The orbit alternates between prograde and retrograde motion and is highly inclined, common characteristics of weakly bound and unbound satellites, and ones that we have observed in our simulations of Triton's capture by Neptune [3]. At the time of impact, the orbital inclination is ~ 78° and the eccentricity near unity.

REFERENCES: [1] Yoemans, D.K., and P.W. Chodas, posted on the Comet Shoemaker-Levy 9 bulletin board 11/4/93; [2] Murison, M.A.(1989), *Astron. J.* **98**, 2346-2359; [3] Wisdom, J. (1983), *Icarus* **56**, 51-74; [4] Benner, L.A.M., and W.B. McKinnon, submitted to *Icarus*.

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