THE COMETARY AND ASTEROIDAL IMPACTOR FLUX AT THE EARTH; Paul R. Weissman, Jet Propulsion Laboratory, Pasadena, CA 91109

The cratering records on the Earth and the lunar maria provide upper limits on the total impactor flux at the Earth's orbit over the past 600 Myr and the past 3.3 Gyr, respectively. These limits can be compared with estimates of the expected cratering rate from observed comets and asteroids in Earth-crossing orbits, corrected for observational selection effects and incompleteness, and including expected temporal variations in the impactor flux. Both estimates can also be used to calculate the probability of large impacts which may result in biological extinction events on the Earth.

The estimated cratering rate on the Earth for craters > 10 km diameter, based on counted craters on dated surfaces is 2.2 +/- 1.1 x 10^{-14} $km^{-2}yr^{-1}$ (Shoemaker et al., 1979). Using a revised mass distribution for cometary nuclei based on the results of the spacecraft flybys of Comet Halley in 1986, and other refinements in the estimate of the cometary flux in the terrestrial planets zone, it is now estimated that long-period comets account for 11% of the cratering on the Earth (scaled to the estimate above), and short-period comets account for 4% (Weissman, 1987). However, the greatest contribution is from large but infrequent, random cometary showers, accounting for 22% of the terrestrial cratering. This results because major perturbations on the Oort cloud sample both the classical outer comet cloud and the larger inner reservoir, and because the comets from the inner Oort cloud reservoir are more tightly bound to the Sun and thus make more returns, typically 8 to 9 versus 5, than the steady state flux of long-period comets from the outer cloud. The result assumes a conservative population estimate for the inner Oort cloud of 10 times the outer cloud (Shoemaker and Wolfe, 1986).

Given the revised cometary cratering rate estimates above, and Shoemaker's (1982) estimate of the expected cratering rate from asteroids of 1.9 x 10^{-14} $km^{-2}yr^{-1}$, the total cratering rate of 2.7 x 10^{-14} $km^{-2}yr^{-1}$ is about 23% above the measured terrestrial rate. However, the error bars on these estimates are 50% or more, so it is difficult to conclude very much from this result, other than that the current rates are in rough agreement.

The measured lunar cratering rate over the past 3.3 Gyr is only about half the terrestrial rate over the past 600 Myr (Shoemaker et al., 1979) though the error bars of the two estimates do overlap. The reason for this apparent recent enhancement in the cratering flux is not known.

Temporal variations in the flux of Earth-crossing asteroids are not expected to be very large or to persist for much longer than the typical lifetime of objects in Earth-crossing orbits: 30 - 100 Myr (Wetherill, 1975). The cause of such variations would be stochastic fluctuations in the number of objects supplied into Earth-crossing orbits from the main belt, through secular perturbations and chaotic motion at orbital commensurabilities.

On the other hand, large variations in the flux of long-period comets are expected. Heisler et al. (1987) showed that random star passages close to the Oort cloud can cause variations in the flux of a factor of 2 to 3 typically, and a factor of 10 occasionally. Even larger variations in the flux are expected if one includes the predicted inner Oort cloud, which can only be sampled by very close, penetrating stellar passages, or by close passages of very massive objects. In such a case, the increase in the flux can be on the order of a factor of several hundred or more (Hut and Weissman, 1985). As noted above, it is now estimated that the flux from such showers dominate the total cometary cratering at the Earth. In addition, it is possible that long-period comets from the showers evolve to become short-period comets and eventually extinct cometary nuclei, thus further contributing to the impactor flux over an extended period of time.

The expected frequency of random cometary showers must be comparable to the expected frequency of close stellar passages. It is estimated that a star will penetrate to within 3×10^3 AU of the Sun every 500 Myr, resulting in a major shower of 7×10^8 comets, whereas minor showers due to a stellar passage within 10^4 AU will occur every 50 Myr on the average and involve some 8×10^7 comets. Each shower comet will make an average of 8 to 9 returns.

All estimates of cometary cratering assume that the currently observed flux of long and short-period comets in the terrestrial planets zone is the average flux. Departures from that assumption would cause the estimated cratering rates to scale accordingly.

Various arguments have been advanced to explain the alleged 26 Myr periodicity in the extinction record on the Earth, including the existence of an unseen solar companion star in a distant eccentric orbit (Whitmire and Jackson, 1984; Davis et al., 1984), the existence of a 10th planet at 100 to 150 AU from the Sun in an inclined, precessing orbit (Whitmire and Matese, 1985), and the Sun's epicyclic motion above and below the galactic plane (Schwartz and James, 1984; Rampino and Stothers, 1984). Both the companion star and 10th planet hypotheses involve constructs for which there is no evidence other than the alleged periodicity. In addition, numerous dynamical problems exist with each hypothesis, rendering them essentially untenable. Lastly, the expected cratering from the repeated cometary showers involved in these hypotheses would result in 7.2 times the measured record of lunar cratering over the past 3.3 Gyr. In the case of the Sun's epicyclic motion, which has a period of 32 Myr, encounters with giant molecular clouds close to the galactic plane are not expected to produce a recognizable signature over the past 250 Myr (Thaddeus and Chanan, 1985) due to the dispersion of GMC's both above and below the galactic plane. The same criticism with regard to the expected excess cratering from periodic cometary showers cited above, if that is the extinction mechanism, also applies. It is concluded that there is, at present, no workable mechanism for causing periodic impact driven extinctions every 26 to 32 Myr.

References: Davis, M., et al. 1984, Nature 308, 715-717; Heisler, J., et al. 1987, Icarus 70, 269-288; Hut, P., & Weissman, P. R. 1985, BAAS 17, 690; Rampino, M. R., & Stothers, R. B. 1984, Nature 308, 709-712; Schwartz, R. D., & James, P. B. 1984, Nature 308, 712-713; Shoemaker, E. M., et al. 1979, in Asteroids, ed. T. Gehrels, pp. 253-282; Shoemaker, E. M., 1982, in The New Solar System, eds. J. K. Beatty, B. O'Leary, & A. Chaikin, pp. 33-44; Shoemaker, E. M., & Wolfe, R. F., 1986, in The Galaxy and the Solar System, eds. R. Smoluchowski, J. N. Bahcall, and M. S. Matthews, pp. 338-386; Thaddeus, P., & Chanan, G. A. 1985, Nature 314, 73-75; Weissman, P. R. 1987, BAAS 19, 861; Wetherill, G. W. 1975, in Proc. 6th Lunar Sci. Conf., pp. 1539-1561; Whitmire, D. P., & Jackson, A. A. 1984, Nature 308, 713-715; Whitmire, D. P., & Matese, J. J. 1985, Nature 313, 36-38.