Comparing the Earth Impact Flux from Comets and Near-Earth Asteroids

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INTRODUCTION

Long-period comets (LPC), defined here as those active comets with orbital periods greater than 200 years, are the most difficult objects to mitigate should one be found on an Earth threatening trajectory. The arrival of these objects from the distant Oort cloud cannot be predicted and the impact warning time would be measured in a few months – not years. At the distance of Jupiter, an inactive cometary nucleus with a diameter of one kilometer and a geometric albedo equal to 0.04 would have an apparent magnitude fainter than 25 near opposition and, hence would be well outside the detection capability of current NEO search telescopes. In general LPCs do not become active, and hence discoverable, until inside the orbit of Jupiter and it takes but nine months for a LPC to travel the distance from Jupiter’s orbit to that of the Earth.

Estimating the impact energy for long-period comets is particularly difficult because the sizes and masses of these objects are not well known. Their solid nuclei are hidden from ground-based telescopes by their gas and dust atmospheres and even when nearby spacecraft observations can determine a size and shape for a cometary nucleus, there are no direct determinations of any cometary mass or bulk density to date. However, a variety of indirect bulk density determinations consistently provide values below one gram per cubic centimeter, the value for water [1]. From measurements made by the Deep Impact spacecraft during its encounter with comet Tempel 1 in July 2005, the bulk density was estimated to be 0.6 grams per cubic centimeter [2]. The mean impact velocity of a LPC is about 51 km/s, three times the 17 km/s value for a typical near-Earth asteroid (NEA) so the impact energy for an LPC would be 9 times that of a NEA of similar mass. However, the bulk density of a comet (~ 0.6 g/cm³) is several times less than the density of a stony NEA (~2.6 g cm³) so for a LPC and a stony NEA of the same size, the LPC’s impact energy would be about twice that of the NEA.

To properly allocate the limited resources available for NEO surveys and physical characterization, it is important to understand the relative threat from long-period comets versus the threat posed by near-Earth asteroids.

EARLIER ESTIMATES OF THE RELATIVE FLUX OF IMPACTING COMETS VERSUS ASTEROIDS

Shoemaker and Wolfe noted a relatively high threat of long-period comets but the values provided in their work were meant to be crude upper limits [3]. For example, they took as an upper bound on the cratering rate of active comets the value of the one standard deviation uncertainty for the asteroid cratering rate. They also concluded that the majority of Earth-crossing asteroids are extinct comets and these were themselves derived
from long-period comets. Both of these ideas have since been abandoned in light of more recent results [4,5].

Weissman computed an annual Earth impact rate of $10^{-6}$ for long period comets capable of causing a crater diameter of 10 kilometers [6]. These comets were assumed to have an absolute magnitude of 16.8 or less. He used Öpik’s [7,8] relationship for the number of long-period comets as a function of their absolute magnitude and his own conversion between the absolute magnitude and the mass of the nucleus. He compared his annual impact rate for LPCs ($10^{-6}$) capable of creating 10 km diameter impact craters on Earth with the NEA impact rate for 10 km craters given by Shoemaker et al. [9], which was $9.1 \times 10^{-6}$. Hence he concluded that the threat of long-period comets is ~10% the threat from NEAs. However, for this to be correct some 415 LPCs with absolute magnitudes 16.8 or brighter must cross the Earth’s orbit each year. Since less than three Earth-crossing comets of any absolute magnitude are actually observed each year, some 99% of these objects must go unobserved, which seems unlikely.

Sekanina and Yeomans plotted the number of Earth encounters in history by all comets within a particular separation distance versus the minimum separation distance itself [10]. For a sample time of 700 years (1300 – 2000), and taking into account the northern hemisphere observing bias, they found an average impact interval of 43 million years. Despite the improvements in telescopes and orbit determination techniques, the Earth approach rate for LPCs remained relatively constant from 1700 to 2000. Hence, they concluded there is a paucity of small active LPCs. According to an estimate by Shoemaker et al. [11], the average Earth impact interval for NEAs with absolute magnitudes brighter than 18 is about 300,000 years so Earth impacts by LPCs are < 1% the rate for NEAs.

OUR CURRENT ESTIMATES OF THE RELATIVE COMET AND ASTEROID IMPACT FLUX

Using a technique employed by Marsden [12], we found that throughout history until the end of January 2011, there have been 5320 known NEAs of all sizes that came to perihelion to within 1.05 AU. Their average orbital period is ~2.2 years so about 2400 NEAs arrived at perihelion (and crossed the Earth’s orbit) each year. During the same interval, if we exclude temporary cometary fragments, 28 Jupiter family comets (JFCs) were discovered (average orbital period ~6 years) that had a perihelion distance less than 1.05 AU. Hence ~5 of these JFCs reached perihelion near Earth’s orbit each year. The JFC impact flux compared to the NEA impact flux would be roughly 5/2400 or 0.2% with the flux of LPC and Halley-type impactors being far less.

By taking advantage of the interactive Earth close approach tables on the JPL NEO website (neo.jpl.nasa.gov), we note that during the interval from 1900 through 2011 January, 2460 known NEAs of all sizes made 3901 Earth close approaches to within 0.05 AU. During the same interval, only three Jupiter family comets (7P/Pons-Winnecke in June 1927, 1991 R1 SOHO in April 1947 and 1999 J6 SOHO in June 1999) and one LPC (1983 H1 IRAS-Araki-Alcock in May 1983) have come as close. Hence, when compared to the discovered set of NEAs, the impact flux of all known active comets, including JFCs, Halley-type and LPCs, is well below 1%.
While active long-period comets that pass closely by, or impact, the Earth are relatively rare when compared with the total near-Earth asteroid population, it may well be that at the larger sizes, the differences in the impact flux rates are not so dramatic. While there are no reliable size frequency distributions for LPCs, it seems plausible that this distribution is similar to that for Jupiter family comets.

The size frequency distribution for near-Earth asteroids is steeper than the corresponding distribution for Jupiter family cometary nuclei [13,14] and the number of NEAs larger than 2 kilometers drops off very steeply. Hence it is possible, perhaps even likely, that long-period comets provide most of the large impact craters on the moon (diameter > 60 km) and most of the extinction level large impacts on Earth [9].

It has been argued that we are currently in a period of a relatively low cometary flux into the inner solar system and that some future comet shower, perhaps due to the perturbation of the Oort cloud by a passing star or the galactic plane, could greatly increase this flux. However, the time scale for such an increase is far longer than one hundred years so the current near-Earth object survey programs can afford to concentrate their efforts on the NEAs rather than the long-period comets.

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REFERENCES


