Letters

DOD's University Research Initiative

In Mark Crawford's article "R&D budgets: Congress leaves a parting gift" (News & Comment, 31 Oct., p. 536), the Department of Defense University Research Initiative (URI) was reported to be funded at $8.75 million in fiscal year 1987 (FY 87). Actually, Congress appropriated $35 million in FY 87 for URI, or $8.75 million *each* for the three military Services and the Defense Advanced Research Projects Agency. DOD had requested $50 million for URI in FY 87.

In fiscal year 1986 (FY 86), Congress appropriated $100 million to begin the URI program, although Gramm-Rudman-Hollings and other reductions resulted in a FY 86 budget of approximately $90 million. The FY 86 cuts, coupled with the FY 87 reduction, have resulted in a FY 86–87 total of $125 million for URI, or $25 million less than planned for the 2-year period. The recent congressional action will require us to adjust our expenditure rates for URI in FY 87.

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Comet Showers, Periodic Extinctions, and Iridium

In their investigation of iridium depositions over the period of 33 to 67 million years ago, Frank Kyte and John T. Wasson (Articles, 6 June, p. 1225) detected no anomalous iridium levels other than the known strong peak near the Cretaceous-Tertiary boundary. They conclude that there were no comet storms of the kind predicted by several theories (*1–4*). But their measurements were not sensitive enough to see comet storms of the kind expected, and their data do not provide evidence against the comet storm theories.

Kyte and Wasson did their analysis on the basis of a calculation of comet impact rates (*3*) in which we suggested that periodic comet storms could be triggered by a companion star to the sun, which we called "Nemesis." In our calculation, we took the number of comets in the region affected by Nemesis to be 10^{13}, on the basis of a model of Hills (*5*), and from this we deduced that typically 25 comets would hit the earth during a comet storm. But we also stated clearly that this number was uncertain by "one or two orders of magnitude," so the estimate of 25 should not be taken as a hard prediction. The Nemesis theory *allows* 25 or more impacts per storm, but it does not *require* that many.

An improved estimate for the number of comets in the hypothesized storms can be obtained by studying accurately dated impact craters. In our analysis of 11 impact craters on the earth (*6*), Alvarez and I found approximately one impact per comet storm, although because we could not include craters that have been inaccurately dated and because impacts in the oceans left no identifiable craters, this figure must be lower than the true average impact rate. In a later analysis that used 17 craters, Trefil and Raup (*7*) concluded that as few as a third of the impacts on their list may have contributed to the comet storm signal. From the fact that the periodic extinction data of Raup and Sepkoski (*8*) show few (if any) mass extinction cycles missing, we can conclude that the average cratering rate was one or more per cycle. From these considerations, and the discovery of two to three levels of microtektites near the Eocene-Oligocene boundary (*9*), I estimate the average number of impacts during recent comet storms to be in the range of one to four per storm. (We are including only impacts large enough to produce craters 10 kilometers in diameter or larger.) For further calculation here, I shall assume that the average number of impacts per storm is 2.5, midway in the allowed range. This is a factor of 10 less than the value of 25 per storm assumed by Kyte and Wasson. The duration of the comet storm has been estimated (*3, 10*) to be between 1 and 3 million years; I shall use the value of 2 million years. Then the average impact rate during the storm is about 1.5 per million years, but the true value could easily be a factor of 2 larger or smaller.

Of course, any one storm may have one or even zero impacts. If the average rate is 2.5 impacts per storm, then the probability of only one impact is $(2.5)\exp(-2.5) = 21\%$, and the probability of zero impacts is $\exp(-2.5) = 8\%$. Thus we can make no firm prediction that any particular storm will involve multiple impacts, although most storms will.

Kyte and Wasson state that the modern flux of long-period comets that could potentially hit the earth (those with perihelia of 1 astronomical unit or less) is 16 per year, out of which three are dynamically new, that is, entering the inner solar system for the first time. The remaining 13 are comets that have become trapped into relatively short-period orbits. We shall assume that the fraction of dynamically new comets during a comet storm is the same as now, 3/16. This is a plausible assumption, as the dynamics of trapping do not change during a storm.

Since the cratering data indicate that the number of impacts per storm is 2.5 rather than 25, the total number of comets intersecting the disk of the earth's orbit during a comet storm is not 2×10^9, as assumed by Kyte and Wasson, but closer to 2×10^8. Only 3/16 of these comets, that is, 4×10^7, are dynamically new. If the storm lasts for 2 million years, then the average flux of these new comets is 20 per year crossing the disk of the earth's orbit, a factor of 7 greater than the current flux of three per year. Likewise the number of comets trapped into stable orbits is a factor of 7 greater during the comet storm than it is now. The rate of impacts during a comet storm will be seven times larger than during the periods between storms; this is enough to give the significantly higher extinction rate of fossil families reported by Raup and Sepkoski (*8*).

Kyte and Wasson estimate that 20% of the iridium in their sample comes from cometary dust. An increase in this component by a factor of 7 would roughly double the total iridium concentration. In contrast, Kyte and Wasson estimate that the iridium concentration would increase by a factor of about 200. The difference in the two answers comes from several factors. The biggest effect comes from their assumption that there are 2×10^9 new comets in a storm, a value that we originally proposed as the midpoint in a range of values extending over four orders of magnitude, but which can now be ruled out by Earth impact crater data. We replace this value by the more realistic 4×10^7.

We can now compare our factor of 2 expected change in the iridium level to the variations observed by Kyte and Wasson. Their observed iridium concentration varies between 1.0 and 2.0 nanograms per gram in the period near the Eocene-Oligocene boundary, about 37 million years ago. It is not clear what causes the data to vary over this range; there seem to be systematic changes as well as statistical fluctuations. The variations could be due to changes in sedimentation rate, but they could also be due to variations in the influx rate of extraterrestrial material. The factor of 2 variation that they observe is consistent with the behavior expected from a comet storm according to our calculation, but the obvious systematic fluctuations in the background make a more definite conclusion impossible.

The continuum iridium level is five times lower near the Cretaceous-Tertiary iridium peak 66 million years ago, the other region where a comet storm is thought to have occurred. It is conceivable that the large iridium peak occurred near the end of a 2-million-year comet storm, and that evidence of such a storm will be found in the period immediately before 67 million years ago, for which Kyte and Wasson have no data. If the mass extinction during this period was truly extended in time, then more than one impact must have occurred near the Cretaceous-Tertiary boundary.

To determine whether comet storms have actually taken place will require study of rock that had a higher sedimentation rate than the sample used by Kyte and Wasson. With such rock the background level of iridium will be lower and iridium spikes from individual impacts can be resolved. Kyte and Wasson were unable to detect clearly even the well-known iridium peak near the Eocene-Oligocene boundary (*11*). They saw two broad bumps in the region and stated that either of them "could represent this event." They do not mention the obvious possibility that they could be seeing two impacts, evidence of a comet storm.

It is incorrect to conclude that the data of Kyte and Wasson give "strong evidence" against the occurrence of comet storms. In fact, their data are consistent with the factor of 2 change in the level of iridium that comet storms are expected to give.

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Kyte and Wasson point out that the size and stratigraphic span of the iridium maximum at the Cretaceous-Cenozoic boundary in the central North Pacific seem too small to fit the cometary swarm model of Davis *et al.* (*1*). Their conclusions, however, that this "is strong evidence against the occurrence of comet showers" and that it casts doubt on the existence of periodic catastrophic extinctions are not justified by their observations.

Although details of the model of Davis *et al.* (*1*) for periodic cometary impacts are not supported by the observations of Kyte and Wasson, this does not negate periodic comet showers, if such a shower can involve appreciably fewer terrestrial impacts than the approximately 25 suggested by Davis *et al.* (*1*). Kyte and Wasson indicate that the dynamics of alternative models must be similar to those of Davis *et al.* (*1*) "in order to ensure that there are enough large impacts to yield periodic extinctions." This conclusion is questionable. Perhaps 25 impacts are 24 more than necessary to account for a major extinction event.

Evidence against the existence of periodic comet showers of the intensity and duration proposed by Davis *et al.* (*1*) is not evidence against periodicity in catastrophic mass extinctions, whether caused by extraterrestrial body impact or not. Several studies have indicated that the more catastrophic biological extinctions are periodic (*2*), although periodicity has not been firmly established. If major extinctions are periodic, the periodicity may or may not be causally related to episodic impact by comets or asteroids. If the cause is cometary impact, the duration and number of impacts per extinction event may or may not be as great as suggested by Davis *et al.* (*1*). Of the above considerations, it is only this last point that is critically examined by the observations of Kyte and Wasson.

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Response: In his comment on our work, Muller states that our data on iridium in sediments are insensitive to comet storms of the sort predicted by him and others. He then proceeds to reduce his hypothesized comet storm to a comet drizzle that we indeed could not have detected. However, the intensity of this drizzle was much too low to have produced periodic extinctions. It sounds like the first line of a joke: "How many impacts does it take to make an extinction?" Hatfield's explicit (and Muller's implicit) answer that it only takes one is correct, but misses the key point, namely, that it seems to require a very large impact. The mass of the body that impacted at the end of the Cretaceous appears to have been $\gtrsim 10^{18}$ grams (*1*); thus it seems that the complete answer to the question is that only one comet or asteroid with a mass of 10^{18} grams was needed to produce the degeneration at the K-T. But a swarm of Oort-cloud comets with masses up to 10^{18} grams will have a size distribution that can probably be approximated by $n = kr^{-2}$, where k is a constant and n is the number of objects having radii $\geq r$ (*2*). According to this size relationship, an expectation value of 1 $\geq 10^{18}$-gram object implies 3.6 objects having masses between 10^{17} and 10^{18} grams, 21 objects having masses between 10^{16} and 10^{17} grams, and 74 objects having masses between 10^{15} and 10^{16} grams. Thus the intrusion of a comet swarm into the inner solar system will necessarily produce a large number of smaller impacts as well as the enhanced accretion of cometary dust that we showed (*3*) to be absent.

A serious deficiency of the paper by Davis *et al.* (*4*) proposing that periodic extinctions resulted from periodic comet swarms was that they did not define a lower radius limit on the comet population, which leaves order-of-magnitude uncertainties in the terrestrial mass influx during such a hypothetical comet swarm. Their estimate of 25 terrestrial impacts during the passage of a comet swarm through the inner solar system offered no information about the number of 10^{18}-gram bodies expected to strike the earth during the 1 to 3 million years of the duration of this episode.

In our article, we assumed that the 25 impacts of Davis *et al.* (*4*) corresponded to a population with radii of ≥ 0.5 kilometer and masses of $\geq 10^{15}$ grams (*5*). Under these circumstances the expectation value of a comet with $\geq 10^{18}$-gram mass (≥ 5 km radius) is ~ 0.3, considerably lower than the expectation value of ~ 2 required in order to have a 90% probability of at least one such event per swarm passage. Thus the cometary dust influx with which we tested the comet shower hypothesis in our article was already conservatively low. Reduction of the size of the comet swarm by a factor of ≥ 10 reduces the probability of a Cretaceous-Tertiary (K-T)–sized event to ≤ 0.03 per swarm passage.

The reduced comet swarm of the size now proposed by Muller cannot be distinguished from random noise. Davis *et al.* (*4*) assumed that each shower comet, on average, makes four trips through the inner solar system and has two chances to hit the earth during each perihelion passage; they set the probability that an individual comet will impact the