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Evidence for a variation – but no periodicity – in the terrestrial impact cratering rate

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Abstract

Giant impacts by comets and asteroids have probably had an important influence on terrestrial biological evolution. There are about 180 confirmed high velocity impact craters on the Earth with ages up to 2400Myr and diameters up to 300km. Some studies have identified a periodicity in their age distribution, with periods ranging from 13 to 50Myr, e.g. [1] [4] [6] [7] [8] [10]. It has further been claimed that such periods may be causally linked to a periodic motion of the solar system through the Galactic plane. However, many of these studies suffer from methodological problems, for example misinterpretation of p-values, overestimation of significance in the periodogram or a failure to consider plausible alternative models. (These problems I discuss in [2], as part of a review of extraterrestrial influence on terrestrial climate and biodiversity.)

Here I examine the cratering record (Figure 1) from a new perspective, using a Bayesian approach to treat impacts as a stochastic phenomenon [3]. I define models for the time variation of the impact probability and then compare the evidence for them in the geological record using Bayes factors. This probabilistic approach obviates the need for ad hoc statistics and also makes explicit use of the age uncertainties. I find strong evidence for a monotonic decrease in the recorded impact rate up to the present over the past 250Myr for craters larger than 5km (see Figures 2 and 3). The same is found for the past 150Myr when craters with upper age limits are included. This is consistent with a crater preservation/discovery bias modulating an otherwise constant impact rate, but would also be broadly consistent with the observed decrease in lunar cratering rate during the past 500Myr [5]. On the other hand, the set of craters larger than 35km (so less affected by erosion and infilling) and younger than 400Myr are best explained by a constant impact probability model. Periodic models are strongly disfavoured in all data sets. There is also no evidence for a periodicity superimposed on a constant rate or trend, although this more complex signal would be harder to distinguish.

This lack of periodicity is consistent with the prior implausibility of periodic mechanisms for comet or asteroid impacts, e.g. [2]. Although there is limited evidence that biodiversity variations show a periodic component, e.g. [9], one conclusion of my study is that bolide impacts cannot be responsible for this. More generally, the method developed in this study is a robust method which will be useful for modelling palaeontological variations of climate and biodiversity.

References

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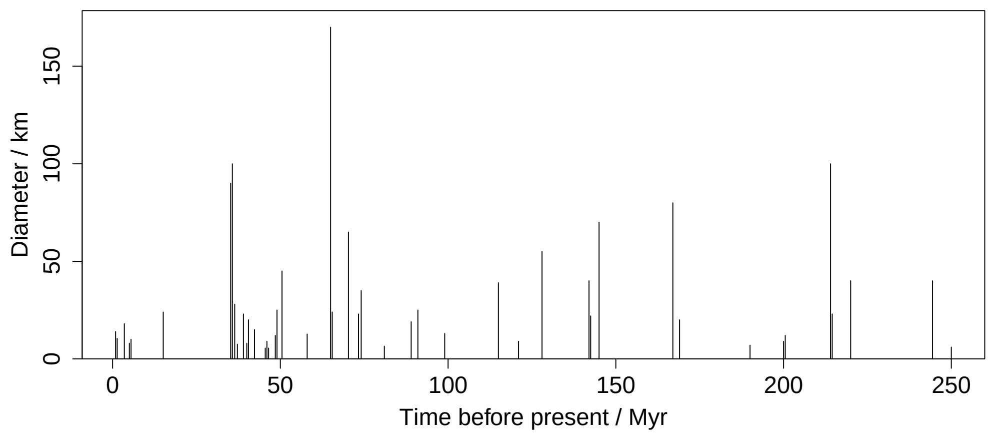

Figure 1: Ages and diameters of the 46 confirmed terrestrial impact craters with ages below 250 Myr and diameters greater than 5km. 13 craters with upper/lower limits on their ages are not shown, although they are included in the analysis in a consistent manner.

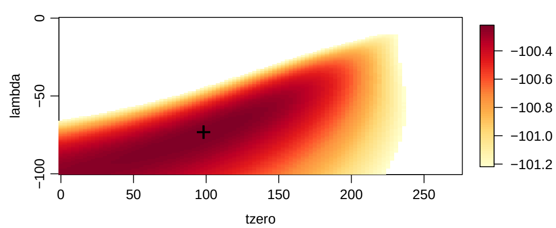

Figure 2: Distribution of the log likelihood of the trend model as a function of the two model parameters, λ and t_0, calculated using the data show in Figure 1. This trend model gives the variation in the impact probability, $P(t)$, as a function of time, t, using the sigmoidal function, $P(t) = \left(1 + e^{-(t-t_0)/\lambda}\right)^{-1}$. The black cross marks the maximum likelihood solution, which is shown in Figure 3. The evidence, which is used in the Bayesian model comparison, is the average of the likelihood over the whole parameter space and does not simply rely on the single maximum likelihood solution.

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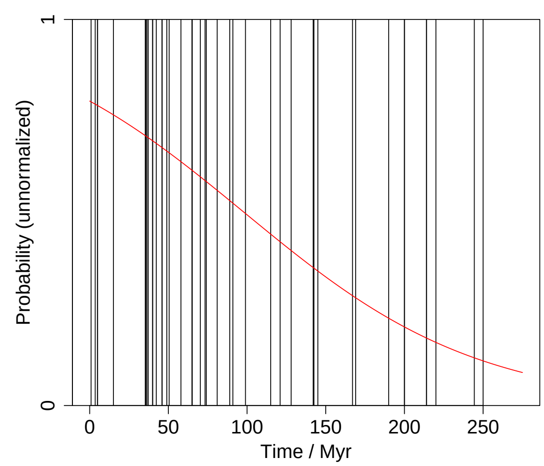

Figure 3: The maximum likelihood solution model (red curve) for the variation of the impact cratering rate plotted over the times of the craters (black). The model parameters are $\lambda, t_0 = (-75, 98)$.