

2 Bombardment episodes

diameter (km)	in	out
>20	15	7
10–20	4	6
3–10	6	3

Membership of bombardment episodes for the 41 accurately dated terrestrial impact craters. There is no evidence of a systematic trend with diameter.

of the terrestrial environment induced by such comet dusting would be required, as proposed by Hoyle (1981), but no one mechanism on its own explains the YD cooling (Renssen *et al.* 1981).

Apart from their effects on atmospheric opacity, a swarm of Tunguska-level fireballs could yield wildfires over an area of order 1% of the Earth's surface (Napier 2010). Large comets in Encke-like orbits may sporadically generate a substantial population of small, albeit short-lived, impactors. To test this idea, the 41 craters culled from the Earth Impact Database were divided by membership of bombardment episodes and crater diameter. The

results are shown in table 2. The statistics reveal no significant difference between the temporal behaviour of large and small craters over the size range tested, 3 km upwards, corresponding to bolides of ≥ 200 m dimensions. On this evidence, large comets arrive accompanied by a flotilla of fragments, and we do not receive a steady rain of small bolides through time. Further evidence of current nonequilibrium among the sub-km meteoroids comes from the fireball study of Brown *et al.* (2013), who find that the number of impactors with diameters of tens of metres may be an order of magnitude higher than estimates based on telescopic surveys and lunar counts. They suggest that there is a departure from equilibrium in the NEO population for objects between 10 and 50 m in diameter. The current Tunguska-level rate inferred from their study is in line with an assessment based on lunar impact counts (Asher *et al.* 2005). All three major 20th-century impacts (Tunguska, British Guiana, Curuçà River) coincided with our passage through major meteoroid streams (respectively the β Taurids, Geminids and Perseids); the odds against this arising by chance are about 1000:1 (Napier & Asher 2009).

Other existential hazards

The main existential hazards to be faced over the next few centuries are likely to be anthropogenic (Bostrom 2013), but these can in principle be countered. No natural existential risks are known to be imminent, although solar superflares and cometary encounters are currently unpredictable. A centaur arrival carries the risk of injecting, into the atmosphere, from above, a mass of dust and smoke comparable to that assumed in nuclear winter studies. Thus, in terms of magnitude, its ranking among natural existential risks appears to be high. Further, according to the analysis presented here, such events happen at least a hundred times more frequently than globally incinerating asteroid impacts. Whether the calamities at 2350 BC and 12800 BP were in fact due to passages through cometary debris is a matter for further enquiry; irrespective of this, there is a need for a more thorough exploration of the centaur population from both theoretical and observational points of view, and for a better understanding of the environmental consequences of encountering a dense complex of cosmic dust and meteoroids. ●

AUTHORS

All four authors of this review have had some association with the Armagh Observatory (AO). **Mark Bailey** has served as director there for the past 20 years; **David Asher** is currently an astronomer at AO; **Bill Napier** was formerly an astronomer there; and **Duncan Steel** is a visiting astronomer at AO. Napier and Steel also hold positions as visiting professors of astrophysics at the University of Buckingham.

DEDICATION

This article is dedicated to the memory of Ernst Öpik (1893–1985), a long-term staff member at the Armagh Observatory, on the 30th anniversary of his death.

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