about the hips[6–8] and by back extension; weight support is biased towards the forelimbs[8]. This mechanism is characteristic of cursorial quadrupeds. It is associated with muscular hip retractors and with forelimbs that are dominated by bone, tendon and highly pennate muscles, which act almost like passive springs[9,10] and are capable of opposing considerable weight-induced forces. This means that the muscles that power greyhounds are virtually independent of weight support and so are not affected by an increase in effective weight.

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## ASTROPHYSICS

# Is a doomsday catastrophe likely?

The risk of a doomsday scenario in which high-energy physics experiments trigger the destruction of the Earth has been estimated to be minuscule[1]. But this may give a false sense of security: the fact that the Earth has survived for so long does not necessarily mean that such disasters are unlikely, because observers are, by definition, in places that have avoided destruction. Here we derive a new upper bound of one per billion years (99.9% confidence level) for the exogenous terminal-catastrophe rate that is free of such selection bias, using calculations based on the relatively late formation time of Earth.

Fears that heavy-ion collisions at the Brookhaven Relativistic Heavy Ion Collider might initiate a catastrophic destruction of Earth have focused on three possible scenarios: a transition to a lower vacuum state that propagates outwards from its source at the speed of light[2]; formation of a black hole or gravitational singularity that accretes ordinary matter[2]; or creation of a stable 'strangelet' that accretes ordinary matter and converts it to strange matter[3]. A careful study[1] concluded that these hypothetical scenarios are overwhelmingly more likely to be triggered by natural high-energy astrophysical events, such as cosmic-ray collisions, than by the Brookhaven collider.

Given that life on Earth has survived for nearly 4 billion years (4 Gyr), it might be assumed that natural catastrophic events are extremely rare. Unfortunately, this argument is flawed because it fails to take into account an observation-selection effect[4,5], whereby observers are precluded from noting anything other than that their own species has survived up to the point when the observation is made. If it takes at least 4.6 Gyr for intelligent observers to arise, then the mere observation that Earth has survived for this duration cannot even give us grounds for rejecting with 99% confidence the hypothesis that the average cosmic neighbourhood is typically sterilized, say, every 1,000 years. The observation-selection effect guarantees that we would find ourselves in a lucky situation, no matter how frequent the sterilization events.

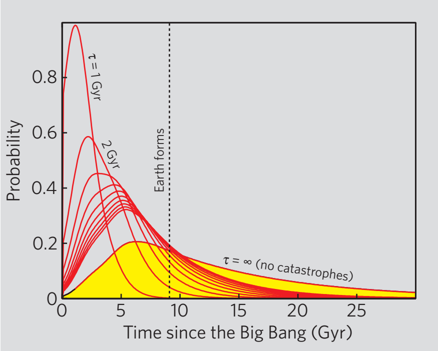

**Figure 1 | The catastrophe timescale cannot be very short.** The probability distribution is shown for observed planet-formation times, assuming catastrophe timescales, $\tau$, of 1, 2 ,3, 4, 5, 6, 7, 8, 9, 10 Gyr and infinity (shaded yellow), respectively (from left to right). The probability of observing a formation time $\geqslant 9.1$ Gyr for Earth (area to the right of the dotted line) drops below 0.001 for $\tau < 1.1$ Gyr.

Figure 1 indicates how we derive an upper bound on the cosmic catastrophe frequency $\tau^{-1}$ that is free from such observer-selection bias. The idea is that if catastrophes were very frequent, then almost all intelligent civilizations would have arisen much earlier than ours. Using data on planet-formation rates[6], the distribution of birth dates for intelligent species can be calculated under different assumptions about the rate of cosmic sterilization. Combining this with information about our own temporal location enables us to conclude that the cosmic sterilization rate for a habitable planet is, at most, of the order of 1 per 1.1 Gyr at 99.9% confidence. Taking into account the fact that no other planets in our Solar System have yet been converted to black holes or strange matter[1–3] further tightens our constraints on black hole and strangelet disasters. (For details, see supplementary information.)

This bound does not apply in general to disasters that become possible only after certain technologies have been developed — for example, nuclear annihilation or extinction through engineered microorganisms — so we still have plenty to worry about. However, our bound does apply to exogenous catastrophes (for example, those that are spontaneous or triggered by cosmic rays) whose frequency is uncorrelated with human activities, as long as they cause permanent sterilization. Using the results of the Brookhaven analysis[1], the bound also implies that the risk from present-day particle accelerators is reassuringly small: say, less than $10^{-12}$ per year.

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## CORRIGENDUM

### Avian flu: Isolation of drug-resistant H5N1 virus

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Yuko T. Sakai, T. Hien Nguyen, Khan H. L. Nguyen,
N. Dinh Pham, Ha H. Ngyen, Shinya Yamada,
Yukiko Muramoto, Taisuke Horimoto, Ayato Takada,
Hideo Goto, Takashi Suzuki, Yasuo Suzuki,
Yoshihiro Kawaoka
*Nature* **437,** 1108 (2005)

We omitted the accession numbers for the sequences of the A/Hanoi/30408/2005 clones, which are registered in the DNA Data Bank of Japan. These are:
AB239125 20051020120345.25409 for the haemagglutinin gene in clone 9; and
AB239126 20051020122743.63420 for the neuraminidase gene in clone 7.

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# Supplementary Material to "How Unlikely is a Doomsday Catastrophe?"

Max Tegmark (MIT) & Nick Bostrom (Oxford)

(Dated: October 16, 2005.)

## METHOD FOR PLACING AN UPPER BOUND ON THE CATASTROPHE RATE

The formation rate $f_p(t_p)$ of habitable planets as a function of time since the Big Bang is shown in Figure 1 (left panel, shaded distribution). This estimate is from [6], based on simulations including the effects of heavy element buildup, supernova explosions and gamma-ray bursts.

Suppose planets get randomly sterilized or destroyed at some rate $\tau^{-1}$ which we will now constrain. This means that the probability of a planet surviving a time $t$ decays exponentially, as $e^{-t/\tau}$. It implies that the conditional probability distribution $f_p^*(t_p)$ for the planet formation time $t_p$ seen by an observer is simply the shaded distribution $f_p(t_p)$ multiplied by $e^{-t_p/\tau}$ and rescaled to integrate to unity, giving the additional curves in Figure 1 (left panel).[1] As we lower the catastrophe timescale $\tau$, the resulting distributions (left panel) are seen to peak further to the left and the probability that Earth formed as late as observed (9.1 Gyr after the Big Bang) or later drops (right panel). The dotted lines show that we can rule out the hypothesis that $\tau < 2.5$ Gyr at 95% confidence, and that the corresponding 99% and 99.9% confidence limits are $\tau > 1.6$ Gyr and $\tau > 1.1$ Gyr, respectively.

Risks related to impacts, supernovae and gamma-ray bursts are unique in that we have good direct measurements of their frequency that are free from observer selection effects. In contrast, if another spatial region is destroyed by vacuum decay, any information about this event would reach us only at the instant when we too were destroyed. Our analysis therefore used the habitable planet statistics from [6] that folded in such risks.

Our bound does not apply in general to disasters of anthropogenic origin, such as ones that become possible only after certain technologies have been developed, *e.g.*, nuclear annihilation or extinction via engineered microorganisms or nanotechnology. Nor does it apply to natural catastrophes that would not permanently destroy or sterilize a planet. In other words, we still have plenty to worry about [7–10]. However, our bound does apply to exogenous catastrophes (e.g., spontaneous or cosmic ray triggered ones) whose frequency is uncorrelated with human activities, as long as they cause permanent sterilization. As regards risk category 1, our bound therefore applies not only to vacuum decay triggered by a high-energy event, but also to spontaneous vacuum decay. If planets destroyed as in risk category 2 or 3 release particles destroying nearby objects and triggering a chain reaction and permanent sterilization, then our bound applies — otherwise we obtain comparable limits on $\tau$ from the observation that no other planets in our solar system have yet been converted to black holes or strange matter.

Our calculations made a number of assumptions. For instance, we treated the exogenous catastrophe rate $\tau^{-1}$ as constant, even though one could easily imagine it varying by of order 10% over the relevant timescale, since our bound on $\tau$ is about 10% of the age of the Universe. Second, the habitable planet formation rate involved several assumptions detailed in [6] which could readily modulate the results by 20%. Third, the risk from events triggered by cosmic rays will vary slightly with location if the cosmic ray rate does. Fourth, due to cosmological mass density fluctuations, the mass to scatter off of varies by about 10% from one region of size $c\tau \sim 10^9$ lightyear region to another, so the risk of cosmic-ray triggered vacuum decay will vary on the same order. In summary, although a more detailed calculation could change the quantitative bounds by a factor of order unity, our basic result that the exogenous extinction rate is tiny on human and even geological timescales appears rather robust.

The Brookhaven Report [1] suggests that possible disasters would be triggered at a rate that is at the very least $10^3$ times higher for naturally occurring events than for high-energy particle accelerators. Assuming that this is correct, our 1 Gyr limit therefore translates into a conservative upper bound of $1/10^3 \times 10^9 = 10^{-12}$ on the annual risk from accelerators.

We would like to thank the authors of [6] for use of their data.

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[1] Proof: Let $f_o(t_o)$ denote the probability distribution for the time $t_o$ after planet formation when an observer measures $t_p$. In our case, $t_o = 4.6$ Gyr. We obviously know very little about this function $f_o$, but it fortunately drops out of our calculation. The conditional probability distribution for $t_p$, marginalized over $t_o$, is

$$f_p^*(t_p) \propto \int_0^\infty f_o(t_o) f_p(t_p) e^{-\frac{t_o+t_p}{\tau}} dt_o \propto f_p(t_p) e^{-\frac{t_p}{\tau}}, \qquad (1)$$

independently of the unknown distribution $f_o(t_o)$, since $e^{-(t_o+t_p)/\tau} = e^{-t_o/\tau} e^{-t_p/\tau}$ and hence the entire integrand is separable into a factor depending on $t_p$ and a factor depending on $t_o$.

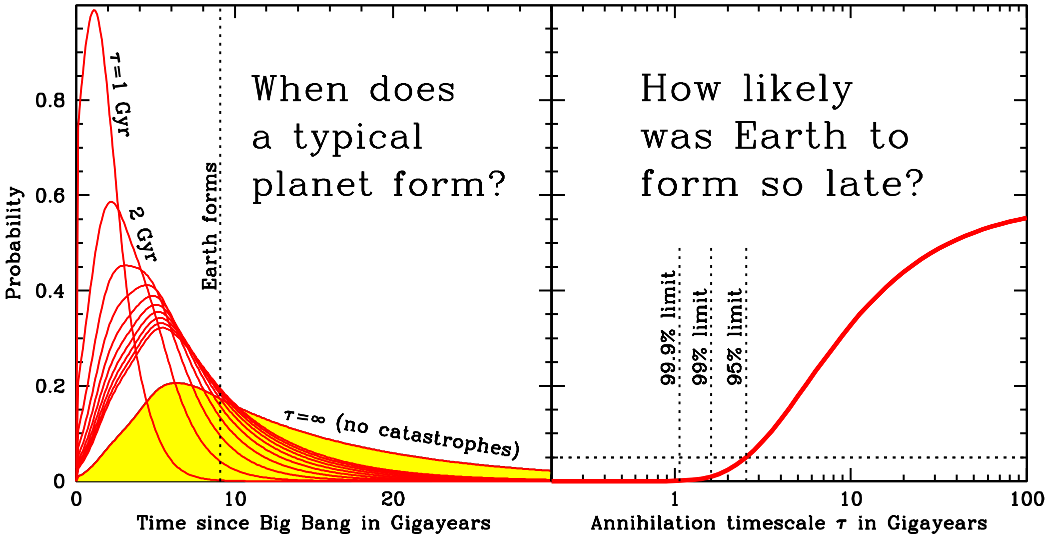

FIG. 1: The left panel shows the probability distribution for observed planet formation time assuming catastrophe timescales $\tau$ of $\infty$ (shaded), 10, 9, 8, 7, 6, 5, 4, 3, 2 and 1 Gyr, respectively (from right to left). The right panel shows the probability of observing a formation time $\geq$9.1 Gyr (that for Earth), *i.e.*, the area to the right of the dotted line in the left panel.

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