

# Life and the Sun's lifetime

SIR—Carter<sup>1</sup> has noted the remarkable coincidence between the timescale of biological evolution on Earth and the lifetime of the Sun. He has used this fact, in conjunction with the anthropic principle, to argue that extraterrestrial civilizations are exceedingly rare, even if conditions favourable to the development of life are common. Barrow and Tipler<sup>2</sup> have discussed this point further.

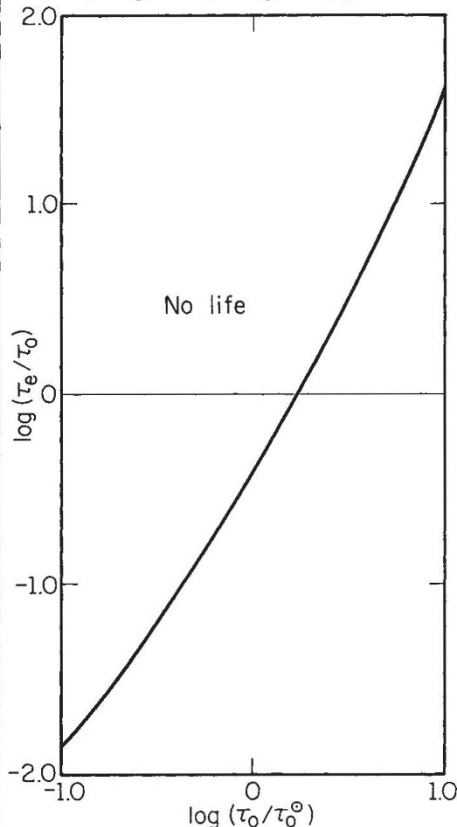
Carter's conclusions rely on the supposition that the two timescales are independent, but we argue that there does exist a definite relationship between the stellar mass (and therefore its lifetime) and the timescale for the development of life on a suitable planet. If such a relationship exists, a coincidence of the type  $\tau_e \approx \tau_0$  can no longer be dismissed on the basis of *a priori* probabilities. Here  $\tau_e$  is the timescale of biological evolution, taken for simplicity to correspond to the appearance of land life, and  $\tau_0$  is the lifetime of the star. We assume that the criterion for life to develop is that oxygen must reach some critical level in the atmosphere of a planet<sup>3,4</sup>.

This simple conjecture is based on the idea that filtering out of ultraviolet radiation is necessary to make the planet inhabitable; it is certainly a reasonable assumption for carbon-based life. To obtain a quantitative relationship, we consider planets similar to the Earth in terms of location, radius and initial composition, that belong to planetary systems around different stars. This is sufficient for our purpose, because the statement of Carter and Barrow and Tipler that there is no physical connection between the timescales of stellar and biological evolutions means essentially that if we were to keep the Earth in place and change the central star (within reasonable limits), this would not affect biological evolution. This approach means that we consider only a limited fraction of parameter space, but we are interested only in general trends.

Two main phases in the development of oxygen in a planet's atmosphere can be identified. In the first, oxygen released from photolysis of water vapour removes all reduced gases (such as  $\text{CH}_4$  and  $\text{NH}_3$ ) from the atmosphere. In the second, the amounts of  $\text{O}_2$  and  $\text{O}_3$  in the atmosphere become large enough to reduce the intensity of ultraviolet radiation to tolerable levels. In simulations of the evolution of the Earth's atmosphere<sup>4</sup>, the first stage lasted about  $2.4 \times 10^9$  yr and the second lasted about  $1.6 \times 10^9$  yr. This simulation was tailored to fit the conditions on Earth, requiring that a stable atmosphere would develop over  $\sim 4.5$  Gyr; we emphasize, however, that our conclusions do not depend at all on the details of these simulations. The timescale for the first phase is

inversely proportional to the intensity of radiation in the range 1,000–2,000 Å (refs 3–5). For the second phase, we assume that the ultraviolet radiation must be reduced by extinction in the atmosphere roughly to the present-day level on Earth:  $I_{\text{uv}}^{\text{planet}} \approx I_{\text{uv}}^{\text{Earth}} \approx 10^{-4} I_0^\odot$ , where  $I_0^\odot$  is the incident intensity on the upper atmosphere. We consider stars with lifetimes in the range  $0.1 \leq \tau_0/\tau_0^\odot \leq 10$ .

In the calculations, we use (1) a mass-luminosity relation for main-sequence stars<sup>6</sup> ( $L/L_\odot \approx (M/M_\odot)^{3.45}$ ); (2) a mass-



The ratio of the timescale for life to develop,  $\tau_e$ , to the stellar main-sequence lifetime,  $\tau_0$ , as a function of  $\tau_0$ . Life cannot develop for  $\tau_e > \tau_0$ .

radius relation<sup>6</sup> ( $R/R_\odot = (M/M_\odot)^\alpha$ , with  $\alpha$  in the range 0.6–1.0 for this mass range; and (3) the fraction of the total energy emitted in the range 1,000–2,000 Å (ref. 6). Expressing the ultraviolet extinction as  $I_{\text{uv}}^{\text{planet}} = I_0 e^{-kx}$ , where  $I_0$  is the intensity impinging on the planet's atmosphere,  $k$  is the absorption coefficient and  $x$  is the depth of the atmosphere, we use relations (1)–(3), combined with the assumption about the necessary level of extinction, to calculate, for each stellar lifetime  $\tau_0$ , the timescales of the two phases in the evolution of oxygen in the planet's atmosphere and therefore the timescale for the development of life.

The results are presented in the figure. Clearly there exists a relationship between  $\tau_0$  and  $\tau_e$ ,  $\tau_e$  being a monotonic

function of  $\tau_0$ . Although the quantitative details are uncertain, as many complicating factors have not been considered, we thus consider the case for a qualitative relationship to be established. Therefore, the possibility that  $\tau_e \approx \tau_0$  cannot be excluded on the basis of *a priori* probabilities.

Carter's argument was based on the absence of any such relation, in which case all intervals (of equal length) along a vertical line passing through  $\log(\tau_e/\tau_0) = 0$  in the figure are equally probable. Once a  $\tau_e$ – $\tau_0$  relation is established, however, this is no longer the case. Why  $\tau_e(\tau_0)$  passes through the particular point  $(0.4 \tau_0, \tau_0)$ , corresponding to the case of the Earth, is a question that depends on the detailed physics and biology of the development of life. But if we accept the fact that  $\log(\tau_e/\tau_0)$  is a monotonically increasing function of  $\tau_0$  (even if different from the one in the figure), then because the number of stars increases with increasing  $\tau_0$  (for a Salpeter initial mass function<sup>7</sup>), the probability of finding  $\tau_e/\tau_0 \approx 1$  is the highest.

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## Mummy RNA lasts longer

SIR—Svante Pääbo suggests<sup>1–3</sup> that nucleic-acid fractions isolated from mummified archaeological remains are composed of depolymerized and chemically modified DNA, with a minor proportion (less than about 1 per cent) of unmodified double stranded DNA.

The presence of modified DNA is inferred from two main kinds of evidence. First, HPLC elution profiles of the hydrolysis products of ancient nucleic acids show extremely reduced thymine peaks compared with modern standards and second ancient polynucleotides are highly alkali-sensitive.

We have recently analysed the composition of the nucleic-acid fractions isolated both from 1,000- and 3,300-year-old seeds of maize and cress from Peru and the Thebes necropolis<sup>4,5</sup> and from a tissue fragment isolated from an unidentified Egyptian mummy (courtesy of Lanfredo Castelletti, Museo Civico 'Paolo Giovio',