Written in the stars

The little I know about phytoplankton fits easily into one paragraph. These tiny little creatures, individually invisible to the human eye, float around in the oceans and lakes. They harvest sunlight and, indirectly, represent a major food source for larger organisms, including many fish, seals and whales. Indeed, it takes only two steps along the food chain to move from phytoplankton, eaten by shrimp-like krill, up to the largest creatures in the sea, baleen whales, which feed on krill predominantly.

One of the many things I didn't know about phytoplankton, until recently, is how utterly essential are these species — about 5,000 of them — to the existence of all higher life forms on Earth. Not only in the oceans but in freshwater ecosystems as well, phytoplankton are responsible for most of what biologists call 'primary production' — the biological fixation of solar energy in carbon compounds. They stand at the very base of the food web. Knock out the phytoplankton and most of the biosphere would collapse.

Which is how, surprisingly enough, phytoplankton may provide a mechanism by which exotic astrophysical events — supernovae, gamma-ray bursts (GRBs) and the like — stand a good chance, on geological timescales, of extinguishing much of the life on this planet. Forget doomsday scenarios of asteroids or comets annihilating the Earth through cataclysmic impacts. As physicists Adrian Melott and Brian Thomas have detailed in a recent survey, intense bursts of radiation coming from astrophysical sources could easily do severe damage within the next billion years or so, with phytoplankton providing the key causal link (A. L. Melott & B. C. Thomas, arXiv:1102.2830).

As they point out, the radiation from an intense GRB (or other source) could set off an indirect chain of events with ultimately lethal consequences. An intense burst of radiation would, first, strongly ionize the Earth's atmosphere, thereby altering its chemistry. In particular, ionizing radiation creates oxides of nitrogen — NO and NO_2 — which support a catalytic cycle converting ozone (O_3) into ordinary oxygen (O_2). A sufficiently intense or long-lived burst could significantly deplete the concentration of ozone in the stratosphere.

Stratospheric ozone is, of course, the Earth's protective blanket against ultraviolet light from the Sun, which is quite harmful to living organisms as ultraviolet photons

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carry enough energy to break bonds in DNA. Loss of the ozone layer would be especially hazardous to phytoplankton, which require sunlight. Hence, a sufficient blast from a GRB, by exposing phytoplankton to a deadly bath of ultraviolet light, could effectively knock out the base of the global food chain.

The ensuing biosphere collapse might take a couple years to play out in full, even if the triggering burst of radiation lasted only a few seconds. Melott and Thomas have now estimated how often various astrophysical causes are likely to make this happen. The numbers aren't reassuring.

First up, supernovae. These terrific explosions happen somewhere in our Galaxy about three times per century. Given the amount of energy they release, any supernovae happening within about 8–10 parsecs (pc) of Earth — about one three-hundredth of the Galaxy's diameter — would deliver lethal energy into the Earth's atmosphere. This translates, Melott and Thomas calculate, into a rate of deadly events of about two per billion years.

Next up, GRBs — the brightest electromagnetic events known in the Universe. Their total energy is comparable to that released in supernovae, yet is focused into narrow beams, so that Earth might receive enough radiation to trigger extinction-level ozone depletion even from bursts initiated at a distance of several thousand parsecs. Two types of GRBs seem to be most worrisome.

So-called short–hard GRBs typically last two seconds or less and their photons carry high energy, around 800 keV. Their total energy is around 10^{43} J, and they occur at a rate of about 40 per cubic Gpc per year, giving a rate of lethal events, Melott and Thomas estimate, at something like one per 300 million years. In comparison, lower-energy GRBs (photon energy around 200 keV) last longer and release more total energy, of the order 10^{45} J. The lethal distance in this case would be roughly one tenth of the diameter of the Galaxy (2 kpc). As current observations suggest that such events happen within our Galaxy every few million years, lethal events from low-energy GRBs should take place about once every billion years.

Both kinds of events together give a total rate of extinction-level events from GRBs to be approximately four per billion years. Melott and Thomas also discuss various other potential threats, including radiation and cosmic rays emanating from pulsars, magnetars, active galactic nuclei, solar flares and so on, none of which are comparable to supernovae or GRBs. But they do identify one other significant hazard of a rather different kind.

The Earth is under continuous bombardment by cosmic rays, the full flux of which would be deadly to life on Earth were it not for the Earth's magnetic field and the magnetic field of the solar plasma wind, which together deflect charged particles. But this protection may occasionally be withdrawn. Melott and Thomas note that several groups have argued that the Sun, in moving through the Galaxy, probably encounters dense molecular clouds, irregularly, but on average every 30 million years or so. Such encounters would tend to deflect the solar wind into the inner Solar System, exposing the Earth to the full force of interstellar cosmic rays for about a million years.

As the Earth's magnetic field reverses itself every 200 thousand years or so, there would be brief intervals during which the Earth's own field also has a negligible screening effect. Crude estimates suggest that 'de-screening' events of this kind could produce 40% global average ozone depletion — plenty to spell disaster for the biosphere. However, Melott and Thomas note that uncertainty over these events makes estimates of likely timescales impossible.

All together, these estimates suggest that astrophysical events should cause an almost total biosphere collapse several times every billion years. Most higher life forms (above bacteria) have only been in existence for some 500 million years, so perhaps we've just been lucky so far. To put it mildly, life on Earth has no guaranteed future.

But what I find most fascinating isn't so much the prospects for bio-annihilation, as the surprising possibilities for astrophysical events that seem so far away to reach over enormous distances and touch Earth in a serious way. The Universe is awfully big, but perhaps, at the same time, its distant parts aren't as remote as they seem. ❐

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