Our Final Century: Will Civilisation survive the 21st Century?

Blackett Memorial Lecture

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Professor Martin Rees

It's a privilege to speak in a lecture series associated with Patrick Blackett – a great man and a great scientist. He played an important role in this nation's history – specially through his friendship with Nehru. The organisation of science in India today bears the imprint of Blackett's advice. But even he would have found it hard to conceive the transformation in the world in the decades since he was with us.

Blackett lived in an era of European and North American hegemony. But all will be changing in the 21st century. As Professor Mashelkar has insistently and rightly emphasised, India is poised to become a scientific superpower. Our future will depend on what happens here and in China – that's where the world's intellectual capital will be concentrated, and where the world's fate – economic, political and environmental will be decided.

SCIENTIFIC PRELUDE

The impact of science on society, and how scientists should engage with the world, will be my main theme today But science for its own sake – motivated by intense curiosity and wonder – is the driving passion of the best scientists. So I'll start with some vignettes of science itself.

Indeed, I'll start with a text: "Whilst this planet has been cycling on according to the fixed law of gravity, from so simple a beginning forms most wonderful have been, and are being, evolved." These are the closing words of Darwin's "Origin of Species". This is a fitting text for biologists, who glory in the teeming variety of living things – under a microscope, in farms and parks, or in the forest or ocean.

Cosmologists (like myself) are environmental scientists too. We explore our cosmic habitat, with spaceprobes and telescopes. Cosmologists try to probe back before Darwin's simple beginning – to understand the origin of the Earth, of the Sun and Stars, and the atoms from which they and we are made. We can do this by, in effect, looking back in time.

Darwin has been part of general culture ever since the 1860s; today he's an even more iconic figure than ever. He's matched only by Einstein – the pre-eminent figure of 20th century science. It's Einstein, of course, whose work relates more directly to the cosmos.

These two great creative figures have both impacted on general culture far beyond science. Both have suffered tendentious distortions. Darwin's work, in particular, in applications to human psychology and in imputed inconsistencies with religious belief. Einstein's cultural impact has, like Darwin's, been ambivalent. It's a pity, in retrospect, that he called his theory 'relativity'. Its essence is that the local laws are just the same in all inertial frames. 'Theory of invariance' might have been an apter choice, and would have staunched the misleading analogies with relativism in other contexts.

[There is a crucial difference between these olympian scientific figures, and great artists. Nature's secrets are 'out there' waiting to be discovered. If scientist A hadn't made a discovery, scientist B would have done so – and generally quite soon. But in the arts it's different. As Peter Medawar noted, when Wagner took ten years off in the middle of the Ring Cycle to compose Meistersinger and Tristan, he wasn't worried that someone else would scoop him on Gotterdammerung. The works of even run-of-the mill composers and painters display their individuality, even if they are soon forgotten.

Had Einstein never existed, all his theories would have been discovered by now, though more gradually and by several people, rather than from the insight of a single great mind. And Darwin's concept of natural selection would surely have emerged, but not in ‘one long argument' in one great book.]

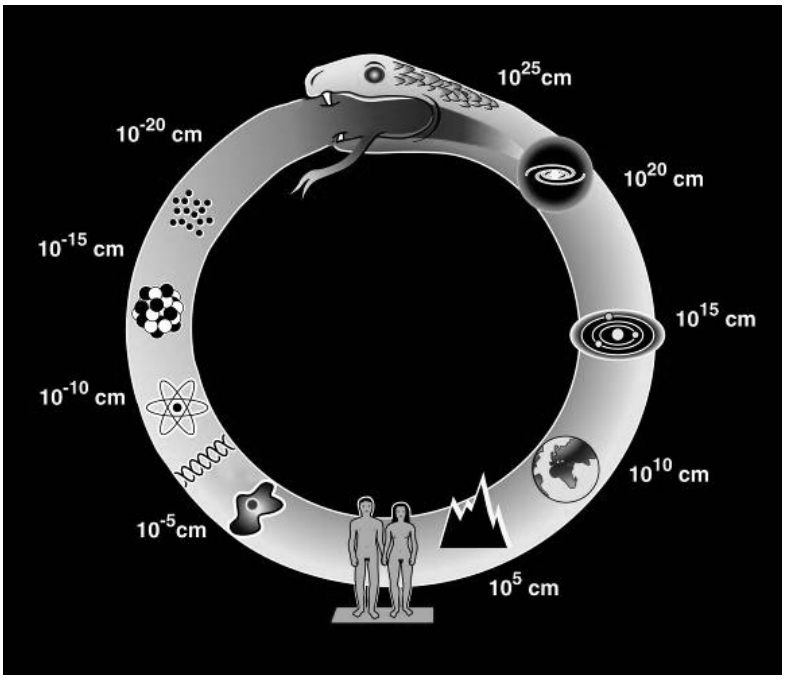

Figure 1

If I wanted a logo for my research group, I'd choose an oraborus (Figure 1). It depicts the interconnectedness of microworld (on left) and cosmos (on right) – the inner space of atoms and the outer space of the universe. There are links between small and large – left and right. Our everyday world is determined by atoms and chemistry. Stars are powered by fusion of the nuclei within those atoms. And we’re linked to the stars. All the atoms we're made of were forged from pristine hydrogen inside stars. We are literally the ashes of long-dead stars – the ‘nuclear waste' from the fuel that makes stars shine. On the left is the domain of the quantum – the very small. The right hand side – the very large – is the domain of gravity.

Einstein’s theory of gravity and quantum theory are the twin pillars of 20th century physics. But at the deepest level they contradict each other – they haven’t yet been meshed together into a single unified theory. In most contexts, this doesn't impede us because their domains of relevance don't overlap. Astronomers can ignore the quantum fuzziness in the orbits of planets. Conversely, chemists can safely ignore gravitational forces between single atoms. But at the very beginning, when everything was squeezed smaller than a single atom, quantum fluctuations could shake the entire universe. To confront the overwhelming mystery of what banged and why it banged we need a unified theory of cosmos and microworld (depicted 'gastronomically' at top). This is a challenge for 21st century science. It would unify two great scientific frontiers, the very big and the very small.

But there's a third scientific frontier (at the bottom of the figure) – the very complex. The most complex entities we know of – we ourselves – are midway between atoms and stars. It would take about as many human bodies to make up a star as there are atoms in each of us. All living creatures are big enough – compared to atoms – to have layer upon layer of intricate structure inside them. But not so huge – like stars and planets themselves – that gravity crushes them.

The living world presents intellectual challenges just as daunting as those of the cosmos or the quantum. Insects, with their layer upon layer of internal structure, are far more complex than stars – which are little more than vast balls of amorphous incandescent gas.

20th CENTURY THREATS

So much for science as such. The group of Londoners who founded the Royal Society in 1660 was inspired by Francis Bacon. For him, science was a search for enlightenment, but it was driven also by a second imperative: 'the relief of man's estate'.

We're in a world transformed by scientific advances that Wren, Pepys, Boyle and Newton could never have conceived. And surely, on balance, transformed vastly for the better. For most people in most nations, there's never been a better time to be alive. But, despite the huge credit balance, there have been catastrophic debits – nuclear weapons being the prime instance. During the Cold War we were at greater hazard then ever before: a nuclear war between the superpowers could have killed a billion people, and devastated the fabric of civilisation. The superpowers could have stumbled towards armageddon through muddle and miscalculation. This is something that Blackett appreciated.

The Cuban Missile stand-off in 1962 was the most dangerous moment in history. Robert MacNamara was then the US Secretary of Defense. He later wrote that "we came within a hair's breadth of nuclear war without realising it. It's no credit to us that we escaped – Khrushchev and Kennedy were lucky as well as wise. And had their bluff failed, catastrophe would have engulfed not just the protagonists, but nations like India too

We're, some of the time, absurdly risk-averse. We fret about statistically tiny risks; carcinogens in food, a one-in-a-million chance of being killed in train crashes, and so forth. It's hard to contemplate just how great the risks of nuclear catastrophe once were.

Einstein did his great work when young. The old Einstein over-reached himself in a premature search for a unified theory. But we owe a great human debt to the 'old Einstein'. When the nuclear threat first loomed over us, Einstein was a moral compass. Under his inspiration, some academic physicists who'd worked on the bomb started a journal called the Bulletin of Atomic Scientists, aimed at promoting arms control. The 'logo' on the Bulletin's cover is a clock, the closeness of whose hands to midnight indicates the Editor's judgement on how precarious the world situation is. Every few year the minute hand is shifted, either forwards or backwards. The torch was taken up by Joseph Rotblat – founder and moving spirit of the Pugwash movement.

When the cold war ended, the Bulletin's clock was put back to 17 minutes to midnight. There was thereafter far less chance of tens of thousands of bombs devastating our civilisation. But this catastrophic threat could be merely in temporary abeyance. During the last century the Soviet Union rose and fell, there were two world wars. In the next hundred years, geopolitical realignments could be just as drastic, leading to a nuclear standoff between new superpowers, which might be handled less well than the Cuba crisis was.

And there's now more chance then ever of a few nuclear weapon going off in a localised conflict. We are confronted by proliferation of nuclear weapons (in North Korea and Iran for instance). Al Qaeda-style terrorists might some day acquire a nuclear weapon. If they did, they would willingly detonate it in a city centre, killing tens of thousands along with themselves; and millions around the world would acclaim them as heroes.

The nuclear threat will always be with us – it's based on fundamental (and public) scientific ideas that date from the 1930s – Blackett played his part. What are the distinctive new threats from 21st century science? I wrote a short book on this subject a few years ago. I entitled it 'Our Final Century?' My UK publishers deleted the question-mark. The American publishers wanted a scarier title: 'Our Final Hour'. In the US, you must have instant (dis)gratification.

My theme was that the Promethean power of science offers myriad opportunities – but also confronts us with ever more threats and ethical conundrums than nuclear weapons did. They may not threaten a sudden world-wide catastrophe – the doomsday clock is not such a good metaphor – but are, in aggregate, worrying and challenging. I guessed that, taking all risks into account, there was only a 50 percent chance that we would get through to 2100 without a disastrous setback. This seemed a depressing conclusion. However, I was surprised by how many of my colleagues thought a catastrophe was even more likely than I did, and so considered me an optimist. But I stand by this optimism.

There are indeed powerful grounds for being a techno-optimist. The innovations that will drive economic advance – information technology, biotech and nanotech – can boost the developing as well as the developed world. We're becoming embedded in a cyberspace that can link anyone, anywhere, to all the world's information and culture – and to every other person on the planet. Creativity in science and the arts is open to hugely more than in the past – and scientists here in India are 'networked' with the rest of the world in a fashion that would have been inconceivable in Blackett's time. 21st century technologies will offer lifestyles that are environmentally benign – involving lower demands on energy or resources than what we'd consider a good life today. And we could readily raise the funds – were there the political will – to lift the world's two billion most deprived people from their extreme poverty

But there are risks. Some stem from humanity's collective impact – in this category of risks, top of the agenda is global warming. Remedial action may come too late to prevent 'runaway' climatic or environmental devastation.

CLIMATE CHANGE, ETC

Because of all the fossil fuels we've burnt, there is already more carbon dioxide in the atmosphere than there's ever been for at least half a million years: moreover, its concentration is rising at about 0.5 percent per year. This fact alone, combined with simple ideas on greenhouse warming dating back 100 years, would be enough to motivate deep concern about impending climate change.

On current projections, coal, oil and gas will supply most of the world's every-growing energy needs for decades to come – a new coal fired power station opens every few days. If that trend continues, the concentration of CO_2 will rise to twice the pre-industrial level by 2050, and three times that level later in the century.

What will be the consequences? The details of the warming are uncertain. But the higher CO_2 rises, the greater will be the chance of something grave and irreversible: rising sea levels due to the melting of Greenland's icecap and so forth. The environmental cost curve is convex – twice as much temperature rise is more than twice as bad.

Some adverse effects of warming can be offset by adaptation, but the most vulnerable people – in, for instance, Africa or in Bangladesh – are the least able to adapt. The cost of coping with increased heat and drought, more storms, rising sea levels, and reduced biodiversity would negate the benefits of foreign aid.

The recent report by Sir Nick Stern for the UK Treasury has galvanised and transformed the debate. It report will resonate internationally because of his standing as former Chief Economist at the World Bank. He has charted an economic course that could see us through this century without risking the worst consequences of climate change. The science is intricate. But it's simple compared to the economics and politics. The market failure that leads to global warming poses a unique challenge for two reasons: First, the main downsides are not immediate, but lie a century or more in the future: intergenerational justice comes into play; how do we rate the rights and interests of future generations compared to our own?

In all discussions of the economics, what's crucial is the appropriate discount rate. Stern argues that equity to future generations – plus the possibility that 'business as usual' could itself choke off economic growth – justifies expenditure now (and, in effect a discount rate well below the commercial rate) There are of course precedents for thinking long-term. Indeed, in discussing nuclear waste disposal people talk with a straight face about what might happen more than 10,000 years from now, thereby implicitly applying a zero discount rate. To concern ourselves with the 'post-human' era might be controversial. But, be that as it may, all of us can surely think at least a century ahead. We're mindful of our heritage, and the debt we owe to centuries past. History will judge us harshly if we discount too heavily what might happen when our grandchildren grow old. And other decisions, to be made very soon, will have an impact extending through much of the 21st century. Power stations commissioned today will still be operating in 50 years time.

Unlike the consequences of more familiar kinds of pollution, the effect is diffuse: the CO_2 emissions from this country have no more effect here than they do in England or Australia, and vice versa. That means that any credible framework for mitigation has to be broadly international. Also there are issues of equity between countries. At present, it is the US and Europe who produce far more per capita – and who have the prime obligation to cut back. But of course it is the great Asian countries that would be the dominant emitters if they reached the present level in Europe and the US. But of course, the hope is that all of us can develop 'clean energy' options that weren't open to the western countries when they ramped up their emissions. That is the real challenge.

It's deeply worrying that there's no satisfactory fix yet on the horizon that will allow the world to break away from the projected accelerating rise in CO_2 emissions. But there is an opportunity. To quote Al Gore; "We must not leap from denial to despair. We can do something and we must." The President of India in a recent speech set out an optimistic scenario for a transition to a low-carbon economy. One hopes also that India can exert leverage over the G8 + 5.

This challenge should stimulate R and D into a whole raft of techniques for storing energy and generating it by 'clean' or low-carbon methods. Even if we discount climate change completely, this is worthwhile on grounds of energy security, diversity and efficiency. The stakes are high – the world spends nearly 3 trillion dollars per year on energy and its infrastructure. Such efforts deserve a priority and commitment from governments akin to that were once accorded by the Americans the Manhattan project or the Apollo moon landing. They should appeal to the idealistic young – indeed I can't think of anything that could do more to attract the brightest and best of them into science than a strongly proclaimed multinational commitment to take a lead in providing clean and sustainable energy for the entire world.

Climate scientists need to forge ahead on several fronts. The first aim, of course, is to firm up the predictions and narrow the uncertainties in the models. That's important because the main concern is the smallish probability of some horrendous runaway, rather than the 50 percent chance of something only moderately disruptive. We need to know whether there's a 'safe' threshold below which the risk of positive feedbacks drops sharply. Another related goal for climate modellers is to produce predictions with higher spatial resolution: What will the effect on rainfall in this country? Where will drought strike hardest in Africa?

ENVIRONMENTAL ETHICS

Human activities are ravaging the entire biosphere – perhaps irreversibly. There are other global `threats without enemies', apart from (though linked with) climate change. Among these is a threat to biodiversity. There have been 5 great extinctions in the geological past. Humans are now causing a 6th. The extinction rate is 1000 times higher than normal and is increasing. We are destroying the book of life before we have read it. There are 10 million species, most not even recorded – mainly insects, plants and bacteria. Scientists do not fully understand the consequences of our many-faceted assault on the interwoven fabric of atmosphere, water, land and life in all its biological diversity.

And I'd like to quote EO Wilson. He is one of the world's most distinguished ecologists – certainly its most eloquent. He's also the world expert on ants (very complex!), but mindful of the big picture and the imperative of conservation. According to Wilson "At the heart of the environmentalist world view is the conviction that human physical and spiritual health depends on the planet Earth – where humanity and its ancestors existed for all the millions of years of their evolution. Natural ecosystems – forests, coral reefs, marine blue waters – maintain the world as we would wish it to be maintained. Our body and our mind evolved to live in this particular planetary environment and no other. The world is too complicated to be turned into a garden. There is no biological homeostat that can be worked by humanity; to believe otherwise is to risk reducing a large part of Earth to a wasteland."

Biodiversity is a crucial component of human wellbeing and economic growth: we're clearly harmed if fish stocks dwindle to extinction; there are plants in the rain forest whose gene pool might be useful to us. But for Wilson, and indeed for many of us, these 'instrumental' – and anthropocentric – arguments aren't the only compelling ones. Preserving the richness of our biosphere has value in its own right, over and above what it means to us humans.

But we also face new vulnerabilities of a quite different kind, stemming from the greater empowerment of individuals or small groups by 21st century technology.

The new genetics will transform healthcare – and agriculture. We'll be embedded in a cyberspace that will soon link anyone, anywhere, to all the world's information. That's good news. But some of these advances could have a dark side. For instance, here's a quote from the American National Academy of Sciences: "Just a few individuals with specialised skills […] could inexpensively and easily produce a panoply of lethal biological weapons that might seriously threaten the US population. […] The deciphering of the human genome sequence and the complete elucidation of numerous pathogen genomes […] allow science to be misused to create new agents of mass destruction." Not even an organised network would be required: just a fanatic, or a weirdo with the mindset of those who now design computer viruses – the mindset of an arsonist. The techniques and expertise for bio or cyber attacks will be accessible to millions.

We're kidding ourselves if we think that technical education leads to balanced rationality: it can be combined with fanaticism – not just the traditional fundamentalism that we're so mindful of today, but new age irrationalities too. Individuals will soon have far greater 'leverage' than present-day terrorists possess. Can our open society be safeguarded against error or terror without having to sacrifice its diversity and individualism? This is a stark question, but I think it's a serious one.

These concerns aren't remotely futuristic – we'll surely confront them within next 10-20 years. But what of the later decades of this century? It's harder to predict the world 100 years from now than it was for HG Wells to predict the present world. Science is not only changing things faster, but in qualitatively new ways. One thing that's been unchanged for millennia is human nature and human character. But in this century, targeted mind-enhancing drugs, genetics, and 'cyborg' techniques may change human beings themselves. That's something qualitatively new in recorded history.

Darwin said that 'no species would preserve its identity into a distant futurity'. But the human species could be transformed, not on the millions of years of Darwinian selection, but within a few centuries. We should keep our minds open, or at least ajar, to concepts that seem on the fringe of science fiction.

One thing we can be sure of, however: there will be a widening gulf between what science allows us to do, and what it's prudent or ethical actually to do – more doors that science could open but which are best kept closed.

The benefits of earlier technology weren't achieved without taking risks. In the early days of steam, people died when poorly designed boilers exploded. Most surgical procedures, even if now routine, were risky and often fatal when they were being pioneered. We can't reap the benefits of science without accepting some risks – though we must plainly minimise them.

A blanket prohibition on all potentially risky innovations (even if it could be enforced) would paralyse science and deny us all its benefits. The uses of academic research generally can't be foreseen: Rutherford famously said, in the mid-thirties, that nuclear energy was 'moonshine'; the inventors of lasers didn't foresee that an early application of their work would be to eye surgery; the discoverer of x-rays was not searching for ways to see through flesh.

But something has changed. Most of the 'old' risks were localised. If a boiler explodes, it's horrible but there's an 'upper bound' to just how horrible. In our ever more interconnected world, there are new risks whose consequences could be widespread – perhaps global. Even a tiny probability of an 'existential risk' is unacceptable.
Scientists obviously guard against themselves creating such risks. For instance, at a conference in Asilomar, California in 1975, prominent molecular biologists proposed a moratorium on some types of experiments rendered possible by the then-new technique of recombinant DNA. This moratorium soon came to seem unduly cautious, but that doesn't mean that it was unwise at the time, since the level of risk was then genuinely uncertain. It showed that an international group of leading scientists could agree a self-denying ordinance, and influence the research community powerfully enough to ensure that it was implemented. Recently there were moves to control the still more powerful techniques of 'synthetic biology'. A voluntary consensus would however be harder to achieve today: the academic community is far larger, and competition (enhanced by commercial pressures) is more intense.

There will be ever more areas – human reproductive cloning, genetically-modified organisms and the rest – where regulation will be called for, on ethical as well as prudential grounds Regulations must take cognisance too of our emotional recoil from innovations that violate or degrade what we perceive as the natural order. Guidelines and licensing requirements will need to be international. If one country alone imposed regulations, the most dynamic researchers and enterprising companies would migrate to another that was more sympathetic or permissive. This is happening already in stem cell research.

It is professional scientists and their academies who are best placed to assess purely scientific issues. But these assessments should be offered to a wide public. Decisions about GM technology, stem cell research, and energy policy are not solely 'scientific': Strategic, economic, social, and ethical ramifications enter as well, and here scientists have no special credentials. That's why everyone needs a 'feel' for science and a realistic attitude to risk – otherwise public debate won't get beyond sloganising. Choices on how science is applied shouldn't be made just by scientists.

Scientists surely, however, have a special responsibility. Men like Jo Rotblat who helped make the first atomic bombs set an admirable example for researchers in any branch of science that has grave societal impact. They returned to academia; they know that their influence was limited and could be over-ridden; but they sustained a lifelong concern with arms control. We feel there is something lacking in parents who don't care what happens to their children in adulthood, even though it's generally beyond their control. Likewise, scientists shouldn't be indifferent to the fruits of their ideas – their intellectual creations. They should try to foster benign spin-offs, but campaign to resist, so far as they can, ethically dubious or threatening applications.

Because of extraneous influences, scientific effort isn't deployed optimally – neither in purely intellectual terms, nor in respect of likely benefit to human welfare. Some subjects have had the 'inside track' and gained disproportionate resources. Huge resources are still devoted to new weaponry. On the other hand, environmental researches, renewable energy, and so forth, deserve more effort. In medicine, the focus is disproportionately on cancer and cardiovascular studies, the ailments that loom largest in prosperous countries, rather than on the infections endemic in the tropics.

Individual scientists – with views spanning the entire political and philosophical spectrum – should engage more willingly with the media and political fora in addressing priorities. University scientists and independent entrepreneurs have a special obligation because they've more freedom than civil servants, or company employees subject to commercial pressure. Such individuals can sensitise our consciences. They can catalyse dialogue with the wider public. And they can aim a spotlight on long-term issues that otherwise sink too low on the political agenda.

COSMIC PERSPECTIVE

My special subject is cosmology – the study of our environment in the widest conceivable sense. I can assure you, from having observed my colleagues, that a preoccupation with near-infinite spaces doesn't make any of them specially 'philosophical' in coping with everyday life. But a 'cosmic perspective' actually strengthens my own concerns about the here and now: I'll conclude by explaining why.

The stupendous timespans of the evolutionary past are now part of common culture – except in the American deep south and a few other benighted locations. It is surely a cultural deprivation to be unaware of the marvellous vision of nature offered by Darwinism and by modern cosmology – the chain of emergent complexity leading from a still-mysterious beginning to atoms, stars, planets, biospheres and human brains.

We and the biosphere are the outcome of more than four billion years of evolution, but most people still somehow think we humans are necessarily the culmination of the evolutionary tree. That's not so. Our Sun is less than half way through its life – so we're maybe barely at the half way stage. Any creatures witnessing the Sun's demise 6 billion years hence won't be human – they'll be as different from us as we are from bacteria. But, even in this 'concertinaed' timeline – extending billions of years into the future, as well as into the past – this century may be a defining moment. It's the first in our planet's history where one species has Earth's future in its hands, and could jeopardise life's immense potential.

We're all familiar with pictures of the Earth seen from space – its fragile biosphere contrasting with the sterile moonscape where the astronauts left their footprints. Suppose some aliens had been watching our planet for its entire history, what would they have seen?

Over nearly all that immense time, 4.5 billion years, Earth's appearance would have altered very gradually. The continents drifted; the ice cover waxed and waned; successive species emerged, evolved and became extinct. But in just a tiny sliver of the Earth's history – the last one millionth part, a few thousand years – the patterns of vegetation altered much faster than before. This signalled the start of agriculture. The pace of change accelerated as human populations rose.

Then there were other changes, even more abrupt. Within fifty years – little more than one hundredth of a millionth of the Earth's age – the carbon dioxide in the atmosphere began to rise anomalously fast. The planet became an intense emitter of radio waves (the total output from all TV, cellphone, and radar transmissions.) And something else unprecedented happened: small projectiles lifted from the planet's surface and escaped the biosphere completely. Some were propelled into orbits around the Earth; some journeyed to the Moon and planets.

If they understood astrophysics, the aliens could confidently predict that the biosphere would face doom in a few billion years when the Sun flares up and dies. But could they have predicted this unprecedented 'pulse' less than half way through the Earth's life – these human-induced alterations occupying, overall, less than a millionth of the elapsed lifetime and seemingly occurring with runaway speed? If they continued to keep watch, what might these hypothetical aliens witness in the next hundred years? Will a final spasm be followed by silence? Or will the planet itself stabilise? And will some of the objects launched from the Earth spawn new oases of life elsewhere?

The answer depends on us. The challenges of the 21st century are more complex and intractable than those of the nuclear age. Wise choices will require idealistic and effective campaigners – not just physicists, but biologists and environmentalists as well – inspired by a vision of our fragile planet and its future.
