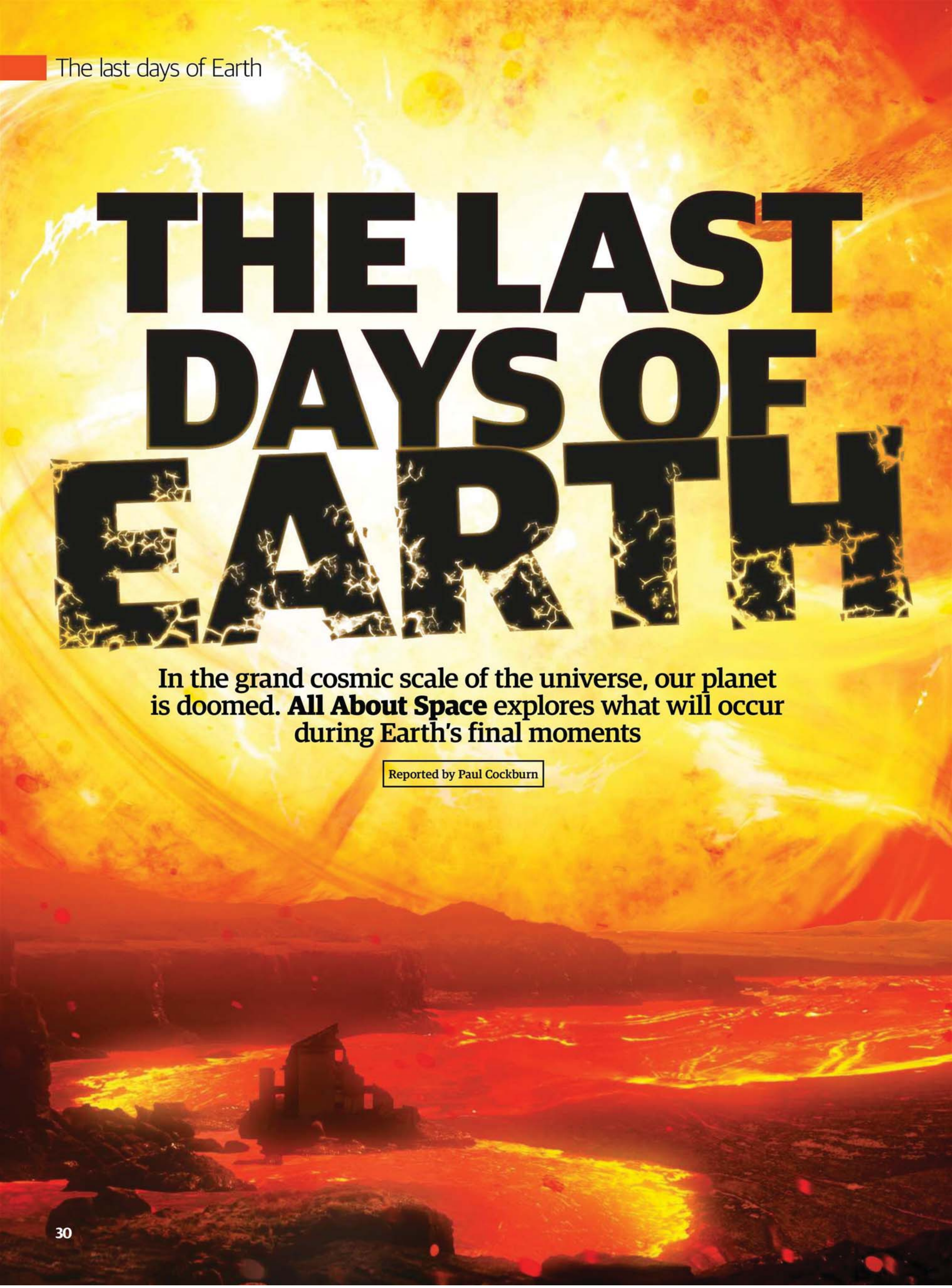

THE LAST DAYS OF EARTH

In the grand cosmic scale of the universe, our planet is doomed. **All About Space** explores what will occur during Earth's final moments

Reported by Paul Cockburn

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Apollo 17 may have been the 20th century's final crewed mission beyond Earth orbit, but its crew left us with one very public legacy – the iconic 'Blue Marble' image of planet Earth, which during the last 48 years has become one of the most reproduced images in human history. Admittedly that's barely a pinprick when compared to the history of life on Earth as a whole: when you consider that the first 'living' molecules appeared some 3.8 billion years ago – and that by current estimates the last are likely to disappear from existence around 3 billion years from now – we're still pretty much the new kids on the block.

Perhaps that explains our insecurity as a species and why we have spent so much of our recorded history predicting the end of the world as we know it – or at least the end of humanity's time on Earth. Even now in 2020, cosmological events including predictable solar eclipses are taken by some people as evidence of an approaching Armageddon, and any new scientific advancements the rapture.

Yet very few scientists would suggest that our home will always be the beautiful 'Blue Marble' photographed by the Apollo 17 crew in 1972. Even assuming that we humans manage to hold out for significantly longer than most mammalian species on the planet have done so – say a few hundred million years – the small rock that we call home will inevitably become quite a different place during the next few billion years.

Left: If a large asteroid strikes a populated area of Earth, it would cause devastation across a wide area

In the much-quoted ending to his poem *The Hollow Men*, T. S. Eliot suggested that the world will end "not with a bang but a whimper". In truth it could be either, if by 'bang' you mean an unexpected, catastrophic event that comes 'out of the blue', contrasted with the 'whimper' of the passage of time and ongoing natural evolution. Either could cause existence-threatening devastation at a global level, but clearly these would take place over different time scales.

Certainly there's evidence suggesting that numerous 'bangs' have already happened, even during the planet's relatively recent geological history. Most famously there's the Chicxulub impactor, the comet or asteroid now generally believed to have triggered the mass extinction of three-quarters of Earth's plant and animal species – including non-avian dinosaurs – at the end of the Cretaceous Period.

The Chicxulub impactor is estimated to have been about ten kilometres (6.2 miles) in diameter. There are plenty of comparable objects in the Solar System, but while none are seen as an immediate threat to our planet, there's still the chance that even 'safe' near-Earth objects will have their orbits dangerously deflected in the future. This isn't just in the short term either; some 1.4 million years in the future, the star Gliese 710 will pass within 1.1 light years of the Sun. It's been predicted that this will lead to a five per cent increase in the number of objects originating from the gravitationally disturbed Oort Cloud that are likely to hit Earth.

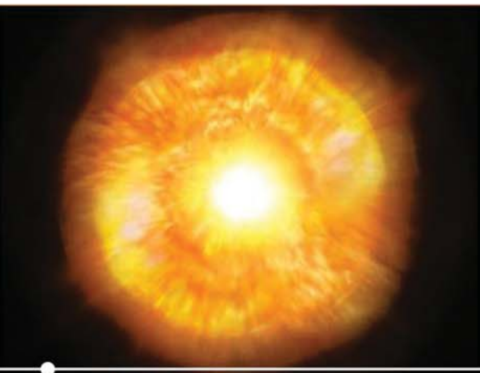
Timeline of our planet's fate

Predictions are never easy, but what is the likely route to Earth's demise?

Present day

An oasis for life

Earth is the most fertile spot in the known universe, with a protective atmosphere and liquid water in abundance.



Around 300,000 years

Wolf-Rayet star WR 104 would have exploded, killing life on Earth

Part of a binary star system 7,800 light years from Earth, WR 104 and its companion are expected to turn supernova within the next few hundred thousand years. Depending on WR 104's axis of rotation, any resulting gamma ray burst could be aimed at Earth.

500,000 years

Earth will be hit by an asteroid one kilometre (0.62 miles) wide

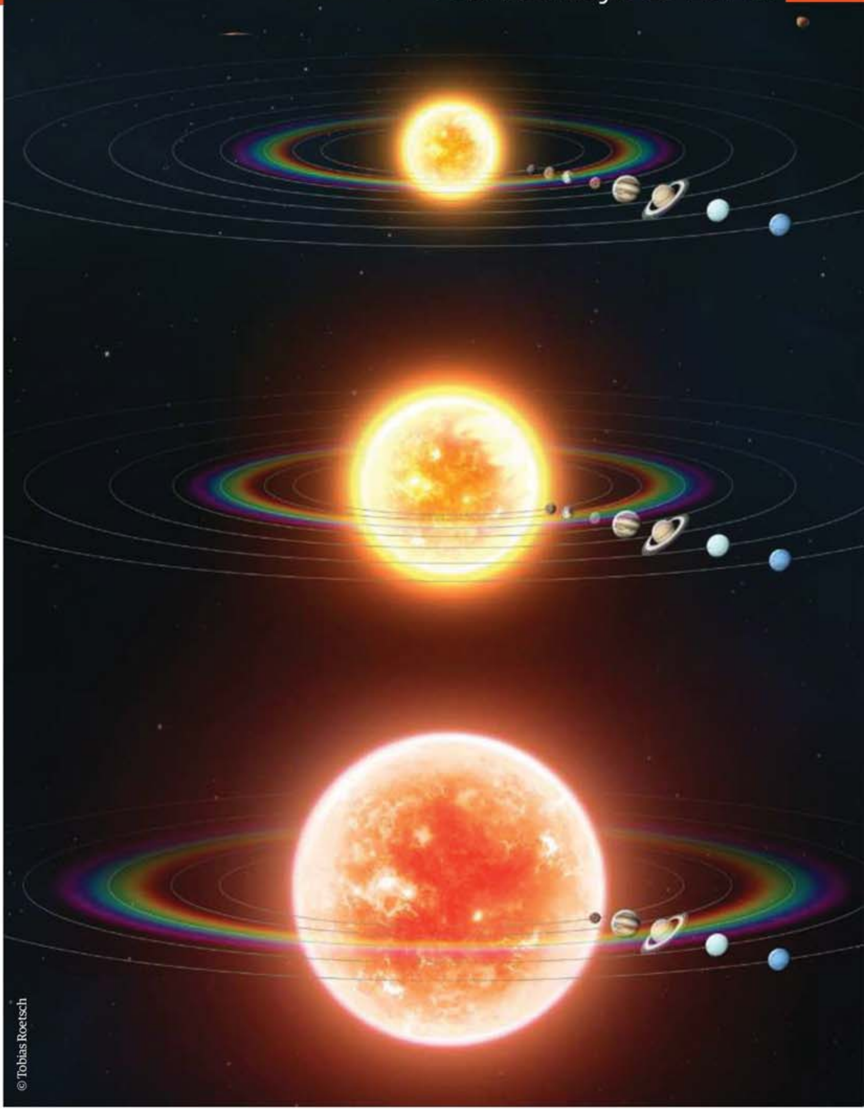
Earth is hit by a large asteroid roughly once every 500,000 years, leading to damage on a potentially global scale. Given sufficient advanced warning, however, it's surely likely that the space technology needed to divert such asteroids could be developed, regardless of cost.

Indeed, the gravity of any massive object – a star, large planet or black hole – could prove catastrophic if it came sufficiently close to the Solar System.

Nor is it just asteroids; back in 2008, two computer simulations of long-term planetary motion in our own Solar System – one by Jacques Laskar of the Observatoire de Paris, the other by Konstantin Batygin and Gregory Laughlin of the University of California – suggested that Jupiter was still enough of a gravitational bully to potentially pull innermost planet Mercury out of its current elliptical orbit and throw it into a collision course with Earth. Other possible fates for the small planet were colliding with Venus, crashing into the Sun or being ejected from the Solar System altogether.

Before you get too worried, however, these models also suggested that there was only a one to two per cent chance of Mercury going for a wander before the Sun bloated in size sufficiently to swallow it up in a few billion years. However, given the global consequences of the Chicxulub impactor, it's clear that nothing would survive the impact of a body some 4,879 kilometres (3,032 miles) in diameter. The last time anything on that scale happened – the hypothesised Mars-sized body astronomers call Theia smashing into the early

Right: The Sun swells into a red giant, swallowing Mercury, Venus and Earth too



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"THERE'S STILL THE CHANCE THAT EVEN 'SAFE' NEAR-EARTH OBJECTS WILL HAVE THEIR ORBITS DANGEROUSLY DEFLECTED IN THE FUTURE"

10 million years

Extinction of plants and animals, mainly due to human activity

Extinctions are an arguably inevitable aspect of life, with a predictable underlying rate against which major extinction events – including human-influence – are contrasted. By this point most species will have become extinct, resulting in a perilous future for any new evolving species.

100 million years

An asteroid hits Earth, similar in size to the asteroid that wiped out the dinosaurs

On top of the impact itself, shock waves and debris thrown into the upper atmosphere would cause massive climatic change around the entire globe – assuming, of course, that it wasn't detected in sufficient time to either destroy it or deflect its path.

230 million years

Orbit of Earth becomes unpredictable

Lyapunov time is the period after which it's no longer possible to accurately predict the movement of elements in a chaotic system. Named after the Russian mathematician Aleksandr Lyapunov, this is when the cumulative effects of small chaotic factors in the Solar System currently make accurately predicting Earth's orbit impossible.

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Below: A charred Earth, 7 billion years from now, circling a red giant Sun

© Science Photo Library

Earth some 4.5 billion years ago - the resulting debris was sufficient enough to form the Moon.

Scientists have also suggested a range of more distant cosmological events which could prove equally disastrous: from increases in cosmic dust impacting on comets and asteroids and leading to increased matter falling down on Earth to a statistically rare but decidedly possible gamma-ray burst from a nearby - at least in astronomical terms - supernova. Or, if that's not big enough a threat, a super-luminous supernova - also known as a hypernova - which is ten or more times more powerful than the standard variety.

Some scientists have suggested that just such a hypernova within our own Milky Way Galaxy caused the second-largest extinction seen in Earth's history, the Ordovician-Silurian extinction events which led to the loss of about 85 per cent of all species between 443.8 million and 440.8 million years ago. The theory is that a sufficiently powerful and long burst of gamma rays hit Earth, stripping away at least half of the ozone from Earth's atmosphere and exposing surface-dwelling life - including everything responsible for planetary photosynthesis - to dangerously high levels of ultraviolet radiation.

But what about the whimper? We know that Earth has undergone significant climate change during its existence, including numerous glacial ice ages and potentially at least one period around 650 million years ago when all the oceans were covered by ice - the so-called 'snowball Earth'. A severe change in our existing environment - either hotter or colder - could yet undermine human civilisation. Yet even abrupt changes in the global climate regime are likely to pale in comparison to the natural evolution of our nearest star. The Sun which gives us life is as equally likely to end it.

James Lovelock is best known for the 'Gaia hypothesis', which he developed with support from microbiologist Lynn Margulis in the 1970s. This proposed that the evolution of our environment and all life on Earth is part of a large, generally self-regulating physiological system. This even included some form of climate control, which Lovelock suggested had ensured the maintenance of an "equable climate" since life had begun.

Yet as far back as 1982, in a scientific paper written alongside Michael Whitfield of the Marine Biological Association, Lovelock had considered ways in which levels of the greenhouse gas carbon dioxide had helped planet Earth to so far resist the warming tendency of the Sun. It was a system that Lovelock suggested might one day be in danger of breaking down.

Compared with when it first started to shine, the Sun we see in the sky today is thought to be about 30 per cent brighter thanks to 4.5 billion years worth of hydrogen in its core being converted into

"EARTH HAS UNDERGONE SIGNIFICANT CLIMATE CHANGE DURING ITS EXISTENCE, INCLUDING NUMEROUS GLACIAL ICE AGES"

500 to 600 million years

Nearby gamma-ray burst or hypernova strips Earth's ozone layer

This is the estimated time by which a gamma-ray burst from a supernova or hypernova located within 6,500 light years of Earth will strip away much of Earth's ozone layer, potentially triggering a mass extinction. This assumes, however, that the supernova burst will be precisely aligned with Earth.

600 million years

Sun's increased luminosity affects Earth

Energy levels from the Sun begin to unbalance the carbonate-silicate cycle, which sees the increased trapping of carbon dioxide in carbonate rocks. Rocks harden, causing plate tectonics to slow and eventually stop, while falling carbon dioxide levels lead to the extinction of much plant life.

1 billion years

Earth's surface temperature gets hotter

Reaching 47 degrees Celsius (116.6 degrees Fahrenheit), the evaporation of oceans will create a 'moist greenhouse' atmosphere. A proportion of the water vapour will reach the stratosphere and beyond where sunlight will split it into its constituent atoms, the hydrogen lost to space.

helium via nuclear fusion. The heavier element has increased the pressure at the Sun's core and heated up the rate of the nuclear reactions, so it shines much more brightly.

Currently accepted theories about the evolution of main sequence stars - and our Sun is a very standard example - suggest that this energy output will continue to increase over time. Not even the Sun beginning to run out of hydrogen fuel in a few billion years' time is likely to stop more energy hitting Earth, with very real consequences for life on the planet as average temperatures rise, affecting the environment and wildlife.

The fading energy derived from the fusion of hydrogen into helium will no longer be enough to hold back gravity, meaning the core of the Sun will begin to shrink. However, it's believed that the shrinking will maintain the core's internal pressure enough to ensure the remaining hydrogen outside the core burns even faster. That in turn will increase both the pressure in the core and the rate at which hydrogen is fused into heavier elements.

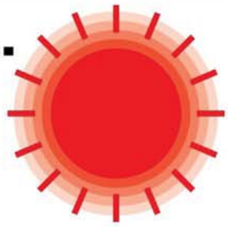
Currently our Sun is about halfway through the shift from burning hydrogen at its heart to burning the hydrogen in a spherical shell wrapped around an intensely hot, very dense helium core. Once the Sun makes that transition, however, it'll be entering its twilight years - not that it'll get darker.

Thanks to gravitational pressure, the nuclear furnace at the heart of the Sun will slowly begin to overheat, reaching extreme temperatures where the helium can undergo nuclear fusion to form heavier elements. Energy released in the process will see the Sun expand into a red giant that will undoubtedly swallow up Mercury and Venus - and could even swallow Earth and Mars. Even if our

How can we...

...avoid an asteroid impact

The Minor Planet Center in Cambridge, Massachusetts, has been cataloguing asteroid and comet orbits for over 70 years. Proposed strategies involve breaking up asteroids so they burn up harmlessly in the atmosphere or delaying arrival times so they miss Earth.

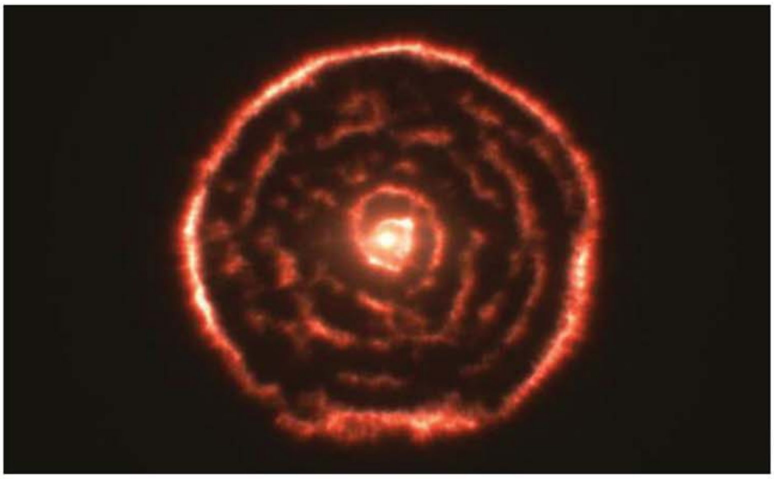


...escape an expanding red giant Sun

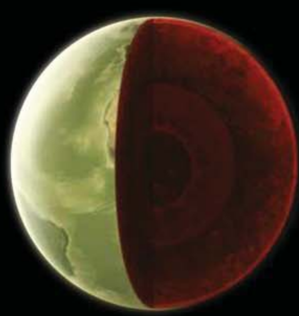
If we could push Earth just a little bit further out from the Sun - say, an additional 15 per cent - it's been suggested that it would definitely survive the furthest reach of the Sun's expansion into a red giant, although it still wouldn't be a viable place on which to grow crops.

...avoid a runaway greenhouse effect

In the long term, this looks unavoidable. Once the Sun's luminosity overtakes Earth's ability to dissipate absorbed radiation into space - from 1 to 3 billion years from now - temperatures will steadily rise until most of Earth's oceans evaporate into water vapour.



Right: Spiral structure around R Sculptoris, a red giant star 1,500 light years from Earth



2.3 billion years
Earth's magnetic field shuts down

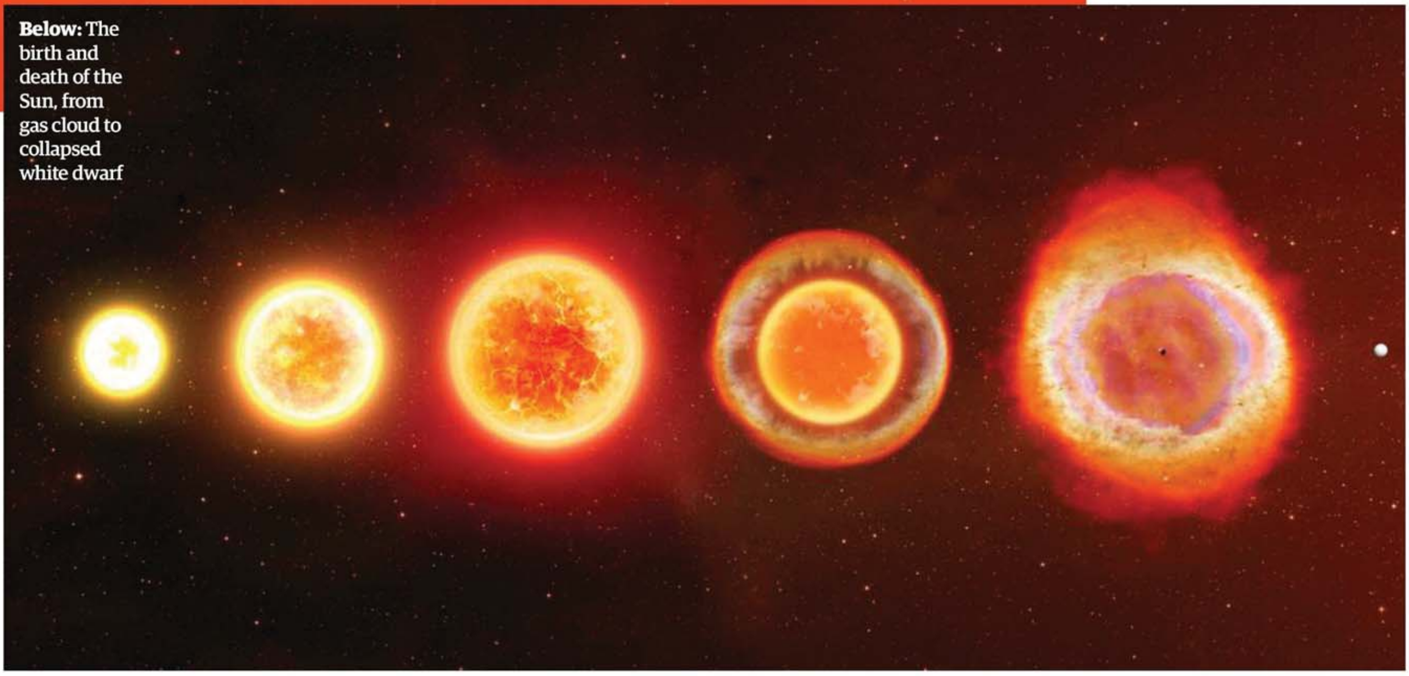
The freezing of Earth's outer core shuts down Earth's magnetic field, with drastic consequences for any remaining life on the planet as there is nothing to deflect the DNA-damaging, potentially deadly cosmic rays and solar wind. The latter would also strip away any remaining atmosphere, leaving the surface totally defenceless.

2.8 billion years
Entirety of Earth is scorching hot

By this point Earth's environment is hostile to any multicellular life, but when global temperatures - even at the poles - reach an average of 147 degrees Celsius (297 degrees Fahrenheit), even the last remaining unicellular life on the planet - in isolated refuges such as high-altitude lakes or cold-trap caves - can no longer survive.

3 billion years
Moon becomes unstable and Earth's poles become chaotic and extreme

The Moon has long been moving away from Earth - at roughly four centimetres (1.6 inches) a year - but this is the point at which it is sufficiently distant to no longer effectively influence Earth's axial tilt, resulting in the planet's true poles increasingly 'wandering' as its spin becomes less stable.



Below: The birth and death of the Sun, from gas cloud to collapsed white dwarf

planet physically survives this expansion, however, it will no longer be that precious and recognisable Blue Marble – it will be a charred rock no longer capable of supporting even single-celled life. Its oceans and atmosphere will boil away into space, although not before contributing to rising global surface temperatures capable of melting stone.

Assuming that humans are still around in some form, it's extremely unlikely we'll still be living on Earth by that point. We'll likely have moved further out, perhaps to the moons of the gas giants that will by then be well within the bloated Sun's habitable zone. We might explore even further in search of exoplanets beyond the Solar System that we can make into our very own Earth 2.0.

"THE FADING ENERGY WILL NO LONGER BE ENOUGH TO HOLD BACK GRAVITY, MEANING THE CORE OF THE SUN WILL BEGIN TO SHRINK"

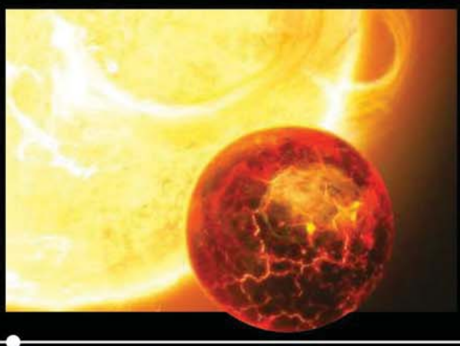
Unexpected catastrophes notwithstanding, the end of life on Earth certainly won't be a simple decline into nothing. As the continental plates continue to move, as mountains rise and are eroded away, as continents move and change, new species may well evolve to fill some much-changed ecological niches.

None of this will happen the day after tomorrow, so don't get too worried about it all. Besides, we're arguably the one species on the planet that – through science and technology – might just be capable of giving ourselves a stay of extinction.

3.3 billion years

Mercury or Venus could collide with Earth

There is a one to two per cent chance that Jupiter's long-term gravitational influence on the inner Solar System makes Mercury's orbit so eccentric that the small inner world might collide with the gassy Venus or even come as far as Earth, crash into the Sun or be ejected from the Solar System entirely.



3.5 to 4.5 billion years

Surface heats to 1,130 degrees Celsius (2,066 degrees Fahrenheit)

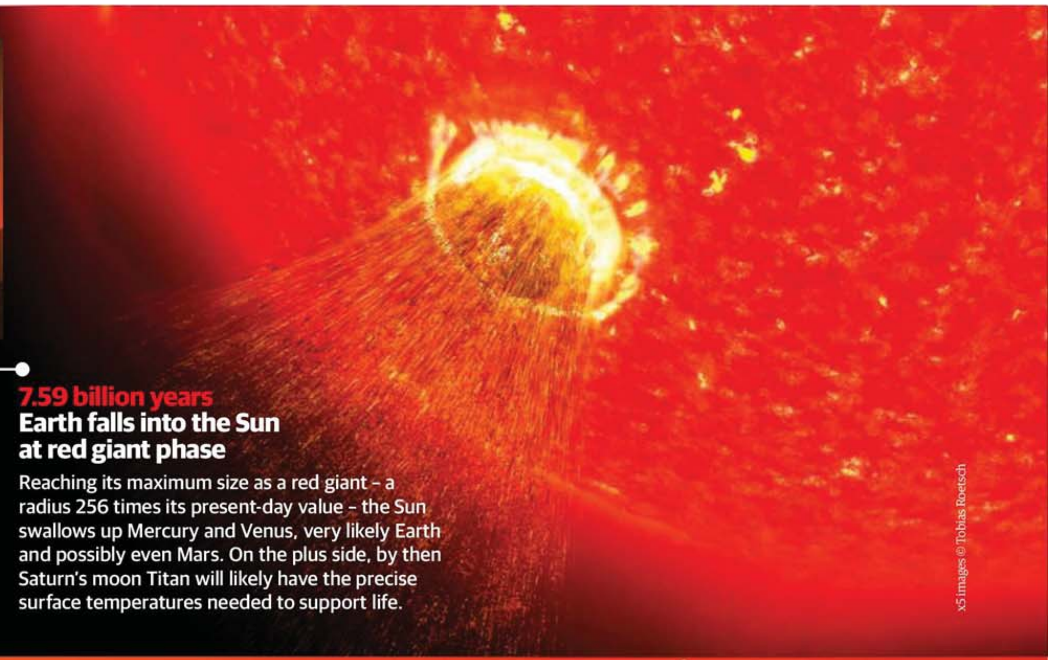
Water vapour in Earth's lower atmosphere increases to 40 per cent. This, combined with the Sun now being 40 per cent brighter than in the 21st century, leads to a rampant runaway hothouse environment with surface temperatures hot enough to melt rock. Essentially it's a hotter version of today's Venus.

7.5 billion years

Earth and Mars become tidally locked with an expanding subgiant Sun

Having one side of a planet constantly facing the Sun leads to more than just temperature differences between the two sides; any remaining atmosphere will necessarily move between the light and dark faces, creating storms and causing serious landscape erosion – not good for continued life in any form.

Earth as it might look following extreme climate change or another catastrophe



7.59 billion years

Moon falls towards Earth, breaking into debris that rains on it

Orbital drag in the vicinity of the Sun's apparent surface – the photosphere – reduces the Moon's orbit until it reaches the point where the gravity holding it together is weaker than the tidal forces pulling it apart. Earth will again briefly have a ring of debris before it falls down on the planet.

7.59 billion years

Earth falls into the Sun at red giant phase

Reaching its maximum size as a red giant – a radius 256 times its present-day value – the Sun swallows up Mercury and Venus, very likely Earth and possibly even Mars. On the plus side, by then Saturn's moon Titan will likely have the precise surface temperatures needed to support life.