Under a cold sun

How did life on Earth get started, when our young planet should have been frozen and inhospitable? **Stuart Clark** investigates

WHY are we here? As questions go, it's a big 'un, beloved of philosophers and theologists in a navel-gazing, hand-wringing sort of way. Scientists often find themselves raising an objection before the others even start: we probably shouldn't be here to ask the question in the first place.

The existence of life on Earth seems to have been the product of many lucky turns of events. Take the sun's early history. According to everything we know about how stars like it develop, it should have been born feebly dim, only gradually warming to its present level. Earth, born with the sun 4.5 billion years ago, should have spent its first two billion years or so as a frozen ball of ice, devoid of life.

Yet in rocks laid down during this time we find sediments clearly deposited in aquatic environments, and ample fossil evidence of bacteria that indicate our planet was already a clement, inhabited world, perhaps within a billion years or so from the off. This mismatch, known as the faint young sun paradox, has many potential solutions. None quite has the ring of truth. But as suggestions accumulate and are discarded, one conclusion seems ever harder to ignore: we are even luckier to be here than we thought.

The faint young sun paradox has its origins in the 1960s, when astrophysicists ran the first crude computer simulations of how changes in chemical composition affect the luminosity and heat output of stars such as our sun. The results were clear: the greater abundance of hydrogen in the early sun's core would have given it a higher internal pressure, expanding the star's nuclear heart and lowering its temperature. As a result, the sun's output in its early years was 25 to 30 per cent lower than it is today. That translates into an average surface temperature of the early Earth some 20 degrees cooler –

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about 10 degrees below water's freezing point.

Yet records of liquid water on Earth go back almost as far as the planet itself. Deposits of the mineral zircon in rocks from Jack Hills in Western Australia have been dated to 4.4 billion years ago, and contain oxygen isotopes that point to their having formed in a watery environment. In the same region there are fossil stromatolites, layered structures formed in shallow water by microbial communities, thought to date to 3.5 billion years ago.

"This clearly tells us that simple models for planetary habitability are wrong," says David Minton, a planetary scientist at Purdue University in West Lafayette, Indiana. "There was life on Earth when it should have been a frozen wasteland." Minton was one of a few dozen astrophysicists and geophysicists who met in Baltimore, Maryland, last year to discuss ways out of this bind. "It turned out that there were almost as many potential solutions as there were participants," he says.

An early proposal is still the most popular: that some greenhouse gas allowed the early Earth's atmosphere to trap more of the weak sun's rays. The suggestion was first made in 1972 in *Science* by astronomers Carl Sagan and George Mullen. But as they discovered, finding the right gas is tricky.

Correct cocktails

Carbon dioxide seems unlikely to be the sole culprit. CO_2 enters soil either in raindrops or through direct diffusion, and drives chemical weathering that is reflected in the mineral composition of rocks known as palaeosols. Studies of ancient palaeosols do suggest atmospheric CO_2 levels were higher back in the Archean era, which ran from 3.8 billion years ago to 2.5 billion years ago. But to keep the oceans at a surely liquid temperature of 5 degrees above freezing, they would need to be some 300 times the current amount – 10 times more than even the most generous palaeosol estimates.

James Kasting, a palaeoclimatologist at Penn State University in Philadelphia, still thinks a CO_2-based greenhouse effect is the solution, pointing to other evidence of its role in mediating Earth's temperature (see "Carbon control", page 47). "I pay attention to those estimates even if I don't completely agree with some them," he says. All that is needed is to find the correct cocktail of other gases that was mixed in with the CO_2.

Back in 1972, Sagan and Mullen suggested ammonia and methane. But ammonia is highly susceptible to ultraviolet light and, with no protective ozone layer around the early Earth, would have been destroyed easily even by the faint young sun's rays. Methane is a powerful greenhouse gas but above a certain ›