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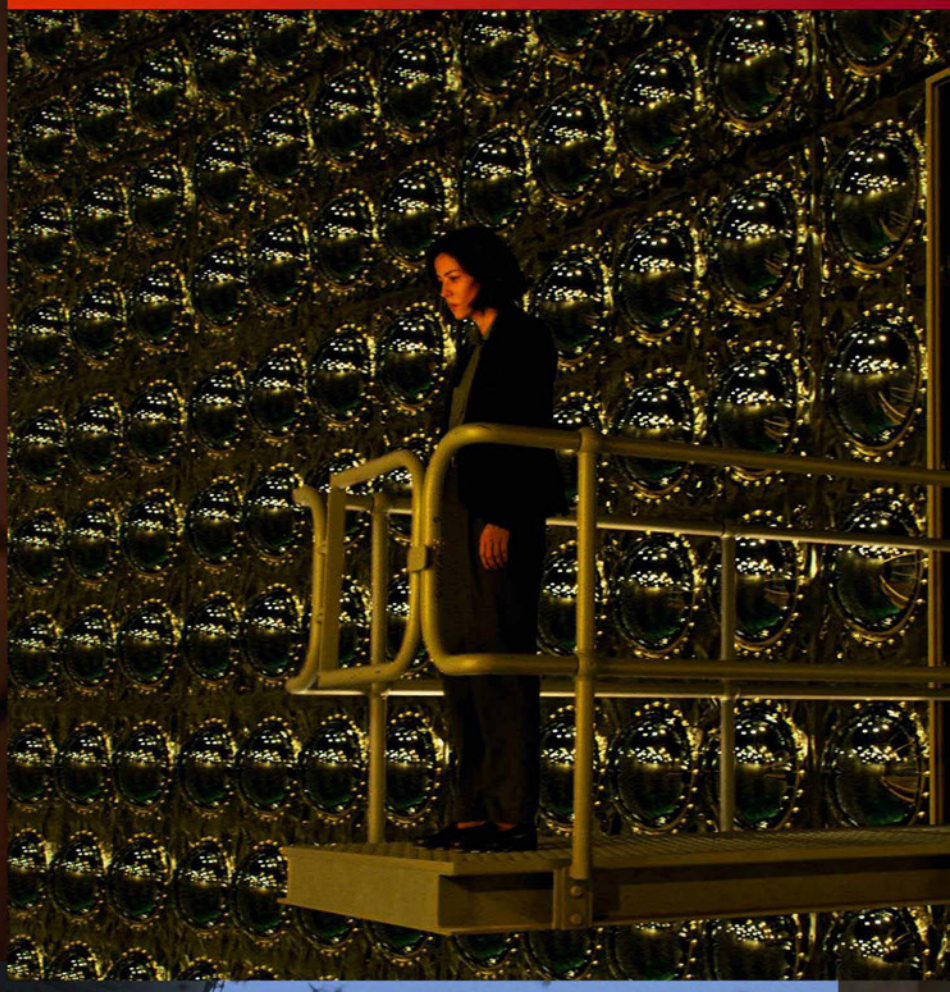

THE THREE BODY PROBLEM

A SCIENTIFIC PRIMER

WORDS: DR STUART CLARK

THIS MONTH, A NEW TV ADAPTATION OF ONE OF THE BIGGEST (AND ONE OF OUR FAVOURITE) SCI-FI BOOKS FROM THIS CENTURY LANDS ON NETFLIX. IT'S A THRILLING STORY ANCHORED BY IDEAS AND BREAKTHROUGHS FROM THE CUTTING-EDGE OF SCIENCE AND TECH. FOR THOSE OF YOU WHO HAVEN'T READ *THE THREE-BODY PROBLEM* YET, HERE'S A GUIDE TO THE SCIENCE ON SHOW

THE SOURCE MATERIAL

The sheer scale of Cixin Liu's *The Three-Body Problem* and its two sequels, *The Dark Forest* and *Death's End*, is extraordinary. Known collectively as the *Remembrance of Earth's Past* trilogy, it's a masterpiece of science-fiction storytelling in which the Universe itself is as much a main character as the humans, aliens and artificial intelligences that the readers encounter.

From the detection of an extraterrestrial signal to the eventual fate of the Universe, Liu's story is both an exuberant investigation into the cracks that have appeared in modern science and an exploration into the unexpected grandeur of the Universe that our most current theories seem to have revealed. He then mixes in a solar →

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→ system's worth of 'what ifs' to bring it all to fictional life. Originally published in 2006 as a serial in the Chinese magazine, *Science Fiction World*, it became an instant classic. Although it appeared in book form in China in 2008, an English translation would have to wait until 2014, but its impact was immediate as it won the Hugo Award – the Oscars of the science-fiction literary world – for best novel.

Now, it has been turned into a Netflix television series by David Benioff and DB Weiss, the creative pair behind the wildly popular *Games of Thrones* adaptation.

One of Liu's greatest talents has been exploring ideas that were emerging in the popular-science zeitgeist. For example, a reason why the tiny micro-animals known as tardigrades, or water bears, are so fascinating is their ability to dehydrate in times of hardship. Liu expanded on this ability and made it the defining characteristic of an intelligent race central to his story.

He also honours great works of science popularisation. The classic 1962 book *Silent Spring* by Rachel Carson, is something of a catalyst for the events of *The Three-Body Problem*. Carson's book was an exposé of the environmental harm caused by artificial pesticides in the aftermath of the Second World War. It was instrumental in fostering the environmental movement in the United States and bringing about the ban on the infamous pesticide DDT in the 1970s.

While this is an acknowledgement that not all scientific 'advances' are positive – that in the desire to do good, scientists can end up making things worse – there is another facet of science that Liu plays with. Modern physics is at

"LIU WONDERS WHETHER SCIENCE IS 'BROKEN' IN A FUNDAMENTAL WAY"

something of an impasse. It's well known that quantum physics, describing the nuclear forces of nature, is incompatible with General Relativity, which describes gravity. Most scientists think that we simply need to find the unification that must surely exist. Without it, we'll never understand black holes. The problem is that experiments which try and reach beyond current limits have yet to yield any new clues.

A prime example is the lack of 'supersymmetric' particles being discovered by the Large Hadron Collider at CERN in Geneva, Switzerland. Many particle physicists had been quietly confident that these hypothetical particles would show up, and so extend our understanding of particle physics and provide a candidate for the dark matter that astronomers believe pervades the Universe. To date, nothing has been found. Liu takes this frustration and wonders whether science is 'broken' in a fundamental way.

This all adds up to a fascinating exploration of the limits and language of modern science. Here (and with care to avoid any spoilers) are just some of the most provocative ideas that Liu explores and develops in his groundbreaking novel.

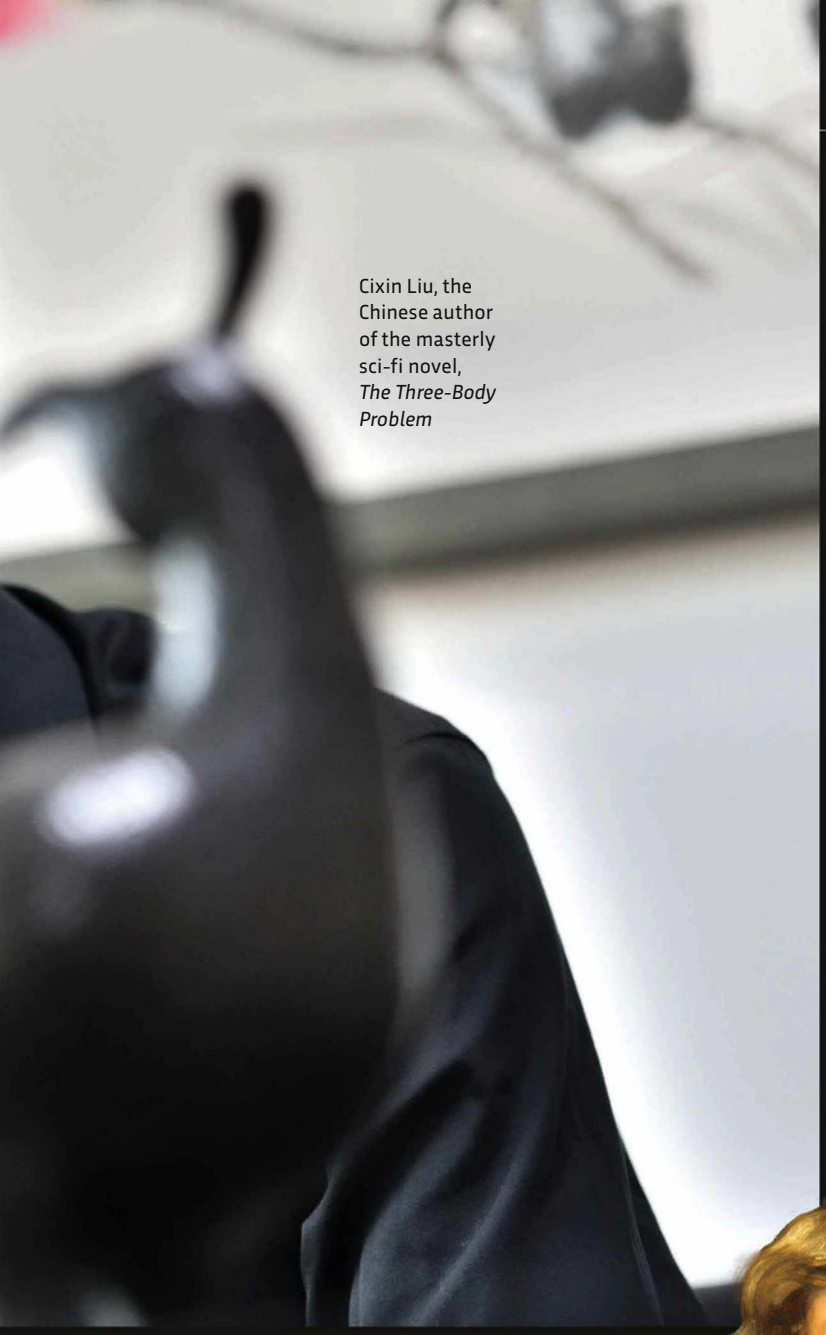
THE THREE-BODY PROBLEM

The title of Liu's first book in the trilogy is taken from an enduring problem in mathematical astronomy, one revealed in what many consider to be the greatest work of science ever published: Isaac Newton's *Philosophiæ Naturalis Principia Mathematica* (*The Mathematical Principles of Natural Philosophy*).

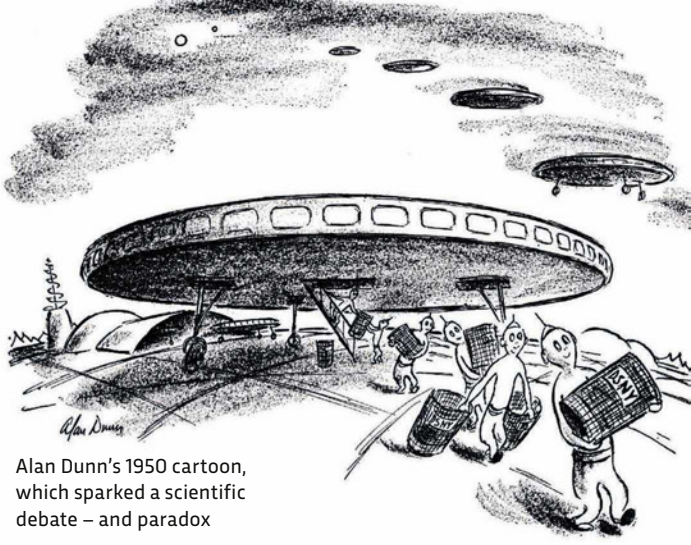
Published in 1687, this cornerstone of the scientific revolution described Newton's laws of motion and his law of universal gravitation. It showed how the two could be equated together to solve the way that two celestial bodies orbited one another.

And yet Newton was plagued by the fact that he could not derive a solution for the Moon's orbit around Earth. The reason for this was because the Moon and Earth can't be considered in isolation, since the Sun's gravity is a significant perturbing factor.

Hence, a three-body problem. The term was coined in the 1740s, at a time when astronomers hoped to use the



Cixin Liu, the Chinese author of the masterly sci-fi novel, *The Three-Body Problem*



Alan Dunn's 1950 cartoon, which sparked a scientific debate – and paradox

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Moon's movement across the sky as a way of finding longitude at sea. While the perturbations to the Moon's path were not huge, those studying the problem soon realised that three similarly sized celestial objects would never settle into regular orbits. Instead, they would follow chaotic orbits that grew and shrank seemingly at will.

Even today, we have no means of finding exact solutions, except for a small set of special cases. Three equally sized bodies could 'chase' each other around a figure-of-eight path, for instance, but having something that specific develop by chance in the real Universe seems highly unlikely.

In his novel, Liu uses the three-body problem – and the idea that it leads to chaos, both literally and metaphorically – as the driving quest of his extraterrestrial culture, the Trisolarans.

THE FERMI PARADOX

It's one of the most profound questions that humans ask: are we alone in the Universe? Looking up at a night sky full of stars, it's easy to dwell on the thought that we can't be the only intelligent life out there. But if that's true, where are they? Why haven't we seen evidence of extraterrestrials? This is the Fermi Paradox.

The name dates to 1950, amid a spate of thefts of trash cans, of all things, in New York City. A cartoonist for *The New Yorker*, Alan Dunn, put forward his idea for the identity of the culprits: alien visitors, which he drew landing their fleet of flying saucers on a distant planet and unloading a cargo of pilfered trash cans.

The cartoon came up in conversation between physicists at the Los Alamos National Laboratories in New Mexico. The Italian-American physicist Enrico Fermi suggested that the illustration was actually a reasonable hypothesis to account for two puzzling phenomena: the disappearance of New York's trash cans and the rise of UFO sightings gripping the popular press at the time.

The others laughed his comment off and conversation moved on, but before long, Fermi cut across his colleagues and quite seriously put to them: "But where is everybody?"

Fermi explained that even though it would take centuries to cross the vast distances between the stars, that was still less than the blink of an eye in relation to the age of the Milky Way, currently pegged at more than 13 billion years old.

He reasoned that if a single race of extraterrestrials began exploring, and if they sent out multiple ships and manufactured more at each star system they visited, then they would spread exponentially – like a virus – through the galaxy. This would give the aliens ample time to visit, or even colonise, the whole galaxy many times over.

So, to reiterate Fermi's question, where are they? Liu provides his own dark answer in the story. →

Douglas Vakoch, who founded METI International in 2015

A reproduction of the Arecibo message, with a DNA double helix above a human figure

SIGNALS SENT INTO SPACE

The simplest way to resolve the Fermi Paradox is to find evidence of intelligent life in the Universe. That's the goal of the Search for Extraterrestrial Intelligence (SETI). But what good is it for the galaxy to be filled with life if no one makes a sound? That's where Messaging to Extraterrestrial Intelligence (METI) comes in.

Since 1962, around 20 messages have been transmitted into space. "About a dozen of these are serious attempts to contact extraterrestrials, and they vary in how soon the response might come," says Douglas Vakoch, founder and president of METI International. The first message was in Morse code and beamed towards Venus from the Yevpatoria Planetary Radar complex in Crimea. Although no one seriously thought that extraterrestrials lived on Venus, it was a useful test to pick a location that allowed the message to have a transit time of just a few minutes.

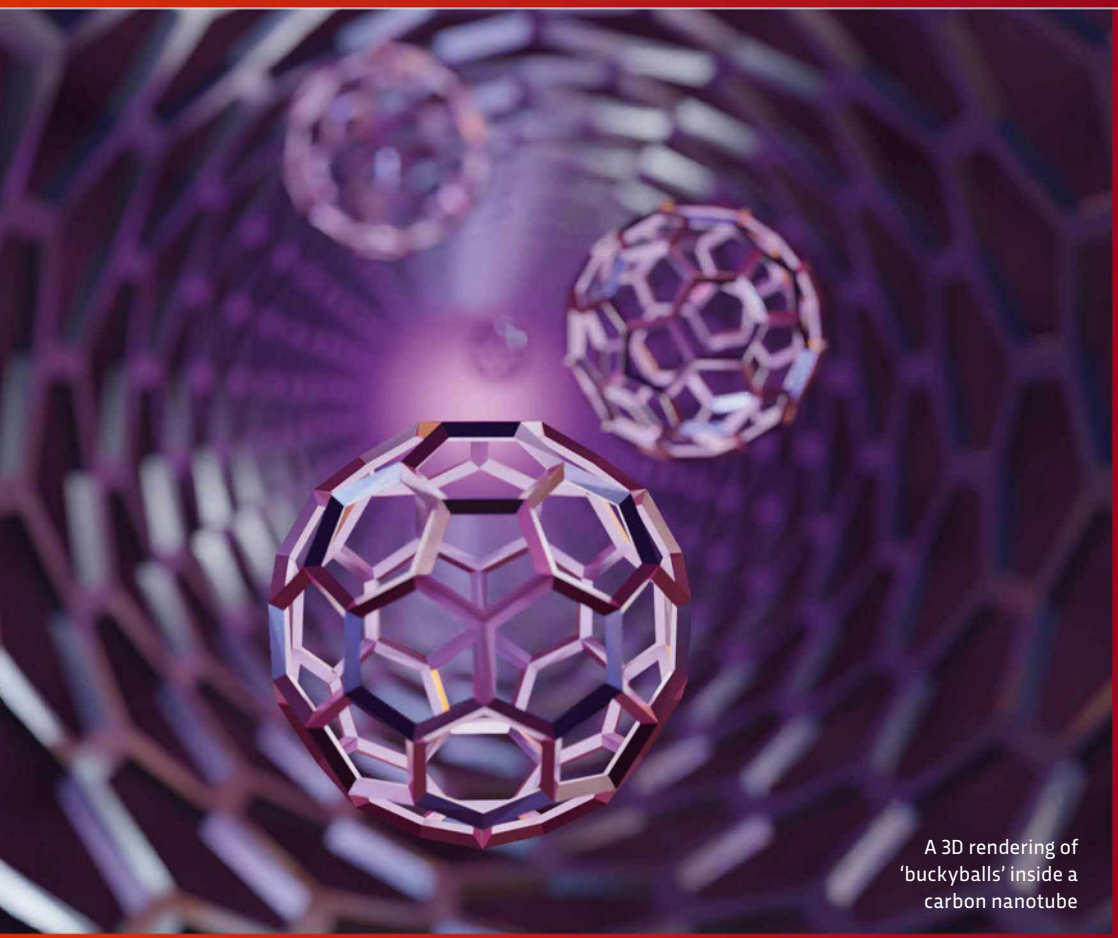
In 1974, an especially powerful transmission was made from the Arecibo Radio Telescope in Puerto Rico to send a pictorial message towards the globular star cluster M13. Yet since that's located more than 20,000 light-years away, it's going to take a long time for any answer to arrive.

All this searching and messaging does raise a question: is it wise to broadcast our existence? While keeping clear of spoilers, Liu thinks not. Stephen Hawking would have agreed, given that the late physicist likened a meeting between us and extraterrestrials to the Native Americans encountering Christoper Columbus.

For Vakoch, it's already too late. "For two billion years, Earth's microbial life has been making itself known to the Universe through changes to our planet's atmosphere," he says. "Similarly, for the past century, Earth has been leaking accidental radio and television signals into space, letting eavesdropping aliens know we have rudimentary technology. Broadcasts of *Are You Being Served?* have been our interstellar emissaries for decades."

Then there's the issue of what happens if we do receive a signal, but can't decipher its intent. It could be a friendly 'anybody out there?' or the celestial equivalent of a phishing email. While the SETI community has protocols advising that no replies be sent without international consultation, these have no legal force. Who's to stop anyone with a transmitter sending anything they want?

One thing is for certain, stresses Vakoch. "If we receive a signal, you can be sure humans will reply. If the signal is targeted at us, we have an obligation to reply out of a sense of interstellar fairness. Humans have been listening for radio signals from the stars for over 60 years, hoping to learn about life on other worlds. We have a responsibility to send the same information-rich signals to other worlds that we seek from them."



A 3D rendering of 'buckyballs' inside a carbon nanotube

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"WHAT IF A FULLY FUNCTIONING SPACECRAFT COULD BE MADE OF NANOTECHNOLOGY, WHERE EVERYTHING FITTED INTO A DEVICE THE SIZE OF A SHOEBOX?"

NANOTECHNOLOGY

It seems there's a large gulf between machinery and chemistry or biology, but when it comes to nanotechnology that distinction is blurred almost to the point of non-existence. Nanotechnology is officially defined as something that can manipulate matter on a scale of between 1 to 100 nanometres, which is the scale at which quantum mechanical effects become important. Crudely, we can think of it as the manipulation of matter on the molecular, or even atomic, scale.

Although the concept was initially discussed in the late 1950s, it wouldn't be until the 1980s that the first example of nanotechnology appeared. It came from the invention of the scanning tunnelling microscope (STM), adapted not only to visualise individual atoms, but also to manipulate them. Then the discovery of carbon 'buckyballs' (roughly spherical molecules of 60 pure carbon atoms) opened the door for engineers to create elongated carbon nanotubes, which, in turn, helped nanotechnology to be taken seriously.

At present, artificially produced molecules (nanomaterials) are used in many products around the world: molecules of titanium dioxide can be found in sunscreens, for example. They also raised alarm. Since nanomaterials are so small, and designed to interface directly with molecules and atoms, they could be extremely toxic. It's easy to draw comparisons to the pesticides that Rachel Carson wrote about in *Silent Spring*. Research is continuing into how to ensure the safe development and use of nanomaterials and nanomachines.

Looking into the future, researchers envisage nanorobots capable of computation and highly specified functions, such as the delivery of drugs to precisely controlled areas of the human body. Ecological cleanup could be another application. At present, iron nanoparticles are used to reduce the levels of arsenic in water, providing safe drinking water to parts of the world, but more advanced nanotechnology could significantly help ecological operations to reclaim damaged environments and aide sustainability.

Nanotechnology could even open up space exploration as never before. One of the most substantial costs comes with the launches: each kilogram launched into space costs upwards of $11,000 (approx £8,600), and spacecraft routinely weigh many tonnes. Take the European Space Agency's (ESA) Mars Trace Gas Orbiter, for example, which weighed 4,332kg (about 9,550lbs).

But what if a fully functioning spacecraft could be made of nanotechnology, where everything fitted into a device the size of a shoebox? Both NASA and ESA are investigating this. Indeed, the latter unveiled a thruster last year called ATHENA (Adaptable THruster based on Electrospray powered by NAnotechnology), which could be used to move small satellites in space. In his novels, Liu extrapolates this thinking to an extraordinary degree, forcing the readers to consider the ethics of developing such 'tools'.

All in all, Liu's *Remembrance of Earth's Past* trilogy is built on a vast array of influences and inspirations taken from modern science and science popularisation. His novels weave together a factual story of our investigation of the Universe, with an exploration of why we pursue such knowledge and the attempts we've made to understand our place in the cosmos. Now that's something worth writing a book about. SF

by DR STUART CLARK

Stuart is an astronomer and author. His latest book is Beneath the Night: How the Stars Have Shaped the History of Humankind *(Guardian Faber, 2020), which was adapted for radio and is available on BBC Sounds.*