New Scientist

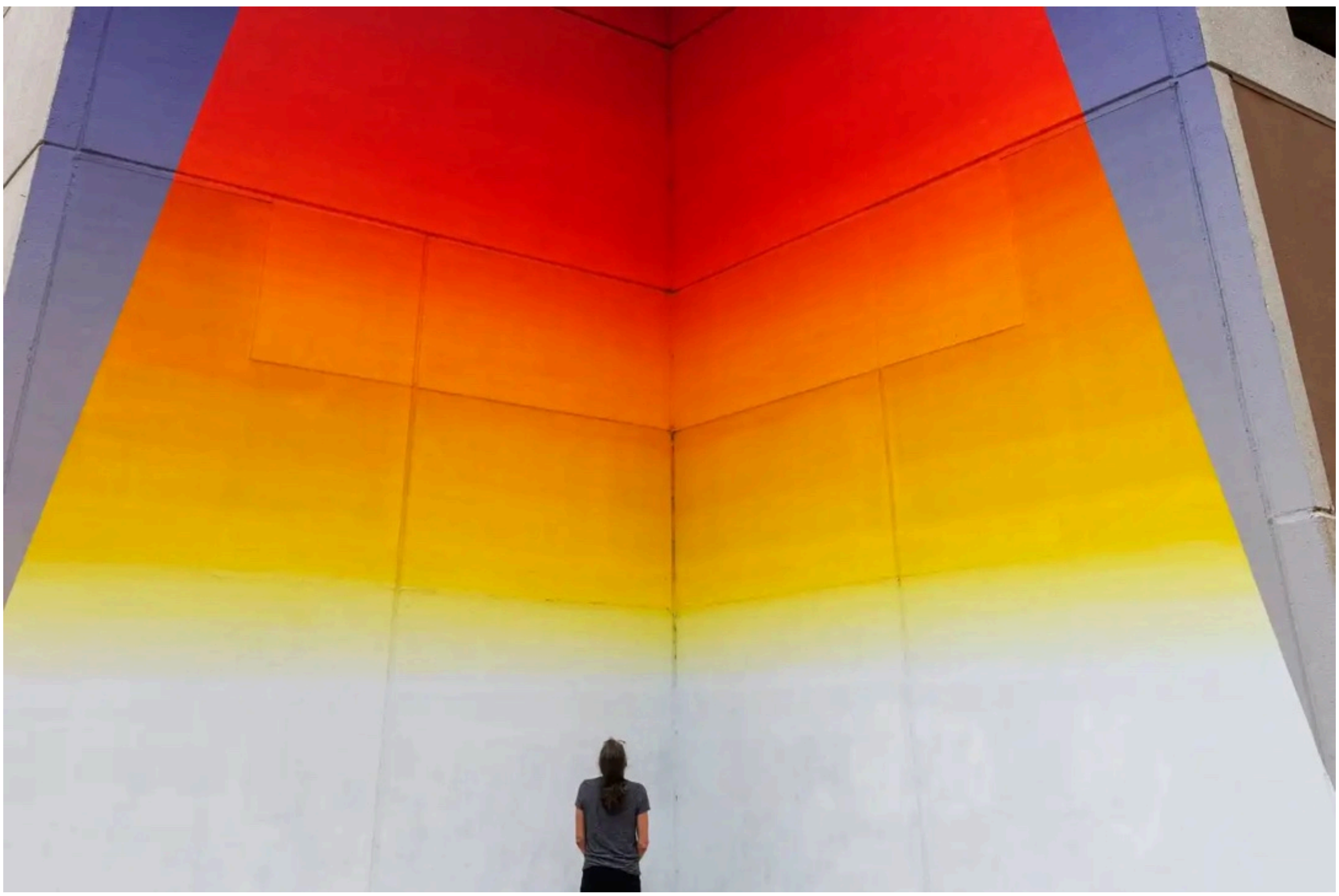
Physics

Quantum to cosmos: Why scale is vital to our understanding of reality

From the vastness of the universe to the infinitesimal particles that comprise it, extremes of scale defy comprehension – and present a problem for physicists seeking a unified theory of everything

By Chen Ly

22 May 2024



It can be hard to wrap our minds round the very large and the very small. Ron Koeberer/Millennium Images, UK

Imagine setting off on a spacecraft that can travel at the speed of light /article/0-why-is-there-a-cosmic-speed-limit-it-could-even-be-why-were-here/. You won't get far. Even making it to the other side of the Milky Way 🔗 /definition/milky-way/ would take 100,000 years. It is another 2.5 million years to Andromeda 🔗 /article/mg24432602-000-how-to-find-andromeda-a-spiral-galaxy-you-can-see-with-the-naked-eye/, our nearest galactic neighbour. And there are some 2 trillion galaxies beyond that.

The vastness of the cosmos defies comprehension. And yet, at the fundamental level, it is made of tiny particles 🔗 /article/mg23831840-500-how-to-think-about-particles/particles/."It is a bit of a foreign country – both the small and the very big," says particle physicist Alan Barr 🔗 https://www.ox.ac.uk/news-and-events/find-an-expert/professor-alan-barr at the University of Oxford. "I don't think you ever really understand it, you just get used to it."

Still, you need to have some grasp of scale to have any chance of appreciating how reality works 🔗 /round-up/reality/.

Let's start big, with the cosmic microwave background 🔗 /definition/cosmic-microwave-background/ (CMB), the radiation released 380,000 years after the big bang 🔗 /article/mg24432601-200-big-bang-retold-the-weird-twists-in-the-story-of-the-universes-birth/. "The biggest scales we've measured are features in the CMB," says astrophysicist Pedro Ferreira 🔗 https://www.physics.ox.ac.uk/our-people/ferreira, also at the University of Oxford. These helped us put the diameter of the observable universe at 93 billion light years.

At the other end of the scale, the smallest entities are fundamental particles like quarks. Yet quantum physics 🔗 /definition/quantum-physics/ paints these as dimensionless blips in a quantum field, with no size at all. So what is the shortest possible distance? The best we can do is the so-called Planck length, which is about 100 billion billion times smaller than a proton 🔗 /article/mg25934480-100-five-of-the-biggest-unanswered-questions-about-the-proton/.

What is the Planck length?

This arises out of an idea in quantum mechanics known as Heisenberg's uncertainty principle 🔗 /definition/uncertainty-principle/, which says that certain pairs of properties, including position and momentum, can't both be known precisely at the same time. The upshot is that we can never measure anything beneath the Planck length, no matter how advanced our technology. Similar constraints apply to measuring other things, such as energy, too.

For physicists, though, the challenge goes way beyond just measurement. The nub of the problem is that reality appears to operate differently at various scales, making it maddeningly hard to pin down a unified description of everything.

Take the four fundamental forces of nature. The strong force binds quarks together to make subatomic particles such as protons and neutrons, the weak force corrals neutrons and protons in atomic nuclei, while the electromagnetic force keeps the whole atom together, electrons included. These three forces are way more muscular than the fourth – gravity. Even the weak force is 10_{24} times stronger than gravity /definition/gravity/. Naturally, physicists want to understand why there is such a huge discrepancy.

We live in a cosmic void so empty that it breaks the laws of cosmology

Mounting evidence suggests our galaxy sits at the centre of an expanse of nothingness 2 billion light years wide. If so, we may have to rethink our understanding of the universe

/article/mg26234870-100-we-live-in-a-cosmic-void-so-empty-that-it-breaks-the-laws-of-cosmology/

To make matters worse, we are also forced to use separate theories to describe these forces. Albert Einstein's theory of general relativity /definition/general-relativity/ describes gravity on the scale of stars and galaxies. Meanwhile, the other three forces are governed by quantum mechanics, which applies to the subatomic realm. We have yet to find a way to meld the two into a theory of quantum gravity /article/mg25834382-100-how-we-could-discover-quantum-gravity-without-rebuilding-space-time/. "One of the biggest problems in physics is the disparity in scales between the size of atoms and the size of the universe," says Barr.

Perhaps our struggles with scale are telling us something deeper about the universe. Maybe, at the fundamental level, there is no scale at all.

That is the idea being pursued by Manfred Lindner at the Max Planck Institute for Nuclear Physics in Germany via a hypothesis called "scale symmetry". The basic idea is that scale is "emergent", in the sense that it arises from the collective effect of more fundamental entities for which scale is meaningless. "At the end of the day, all scales in nature are a quantum effect," says Lindner.

This article is part of a series in which we explore 12 of the trickiest concepts in science and technology.

What is thought and how does thinking manifest in the brain? /article/mg26234920-900-what-is-thought-and-how-does-thinking-manifest-in-the-brain/

Why are there so many rogue planets and what do they look like? /article/mg26234921-000-why-are-there-so-many-rogue-planets-and-what-do-they-look-like/

How indefinite causality could lead us to a theory of quantum gravity /article/mg26234921-100-how-indefinite-causality-could-lead-us-to-a-theory-of-quantum-gravity/

Why viewing cancer as an ecosystem could lead to better treatments /article/mg26234921-900-why-viewing-cancer-as-an-ecosystem-could-lead-to-better-treatments/

Quantum biology: New clues on how life might make use of weird physics /article/mg26234921-300-quantum-biology-new-clues-on-how-life-might-make-use-of-weird-physics/

To rescue biodiversity, we need a better way to measure it /article/mg26234921-200-to-rescue-biodiversity-we-need-a-better-way-to-measure-it/

What neurodiversity means for psychiatrists and the people they help /article/mg26234921-500-what-neurodiversity-means-for-psychiatrists-and-the-people-they-help/

What is artificial general intelligence, and is it a useful concept? 🔗 /article/mg26234921-600-what-is-artificial-general-intelligence-and-is-it-a-useful-concept/

What are fractals and how can they help us understand the world? 🔗 /article/mg26234921-400-what-are-fractals-and-how-can-they-help-us-understand-the-world/

Will we get to net zero fast enough, and how will the climate respond? 🔗 /article/mg26234921-700-will-we-get-to-net-zero-fast-enough-and-how-will-the-climate-respond/

How quantum entanglement really works and why we accept its weirdness 🔗 /article/mg26234921-800-how-quantum-entanglement-really-works-and-why-we-accept-its-weirdness/