Original spin

Was the universe born whirling? That dizzying idea might explain why matter exists in the first place, says
Anil Ananthaswamy

ALBERT EINSTEIN was right about many things. The universe was not one of them. To him, as to many before him, the cosmos was a static, unchanging entity. In 1915, on deriving his equations of general relativity and discovering that the universe they described did not work like this, he added in an extra term to make sure that it did.

Whoops. A decade later, observations of nearby galaxies revealed that the universe is far from static, but has expanded furiously since its birth in an infinitely hot, dense fireball billions of years ago: the big bang.

That’s not all. In the 1990s, light from distant supernovae convinced us that the universe’s expansion is accelerating. That was posthumous luck for Einstein: the fudged term in his equations was revived to describe a “dark energy” fuelling that acceleration.

So the universe is both expanding and accelerating. Fine. Now, though, hold on to your hats – it might be spinning, too.

That is what physicist Michael Longo at the University of Michigan in Ann Arbor thinks he has found. If so, a wholesale review of our assumptions about the cosmos would be on the cards – and perhaps a solution to one of its biggest mysteries, the puzzling fact of matter’s existence. As an anonymous peer-reviewer of Longo’s most recent paper wrote: “Such a claim, if proven true, would have a profound impact on cosmology and would very likely result in a Nobel prize.” What gives?

At the heart of the story is a basic rule called the law of conservation of parity. Nature, it says, does not discriminate between physical processes and objects and their mirror images. Take a spinning top: it does not spin clockwise and anticlockwise in any fundamentally different way. In mathematical shorthand, we say a quantity called parity remains the same whenever you flip a spatial coordinate and make things point or move in the opposite direction.

Heretical question

Except, of course, when it doesn’t. For a start, biology thumbs its nose at parity. Chiral molecules come in distinct right and left-handed forms that react in different ways. Amino acids, the building blocks of proteins, favour left-handedness over right. Why this might be is a mystery.

Then there are particles. Between Christmas Day and New Year’s Eve 1956, when most people around them were enjoying a well-earned break, a group of physicists led by Chien-Shiung Wu was studying the radioactive beta decay of spinning cobalt-60 nuclei at the National Bureau of Standards in Washington DC. Assuming parity conservation, the nuclei should have emitted a beta particle, or electron, just as often along the direction of their spin as in the opposite direction.

But they didn’t. About 70 per cent more electrons were emitted against the nuclear spin. The weak nuclear force, which governs beta decay, favours objects and processes that move in certain directions. That insight was crucial in later establishing the standard model of particle physics, and the two theorists who had proposed the effect, Tsung-Dao Lee and Chen Ning Yang, were awarded a Nobel prize in short order the following year.

So if it happens on small scales, might parity conservation also be disregarded on large scales, perhaps on the very largest? That’s the question Longo began pondering a few years ago. “The fact that the universe might violate parity was pretty fascinating,” he says. Fascinating – and heretical. The assumption of cosmic parity conservation is tied up with what is known as the cosmological principle: that wherever you are in the universe, and in whatever direction you look, things on average look the same. The universe does not tell left from right; in fact, it knows no special places or directions at all. As far as the philosophical bases of modern cosmology go, things don’t come more fundamental than that.
That makes Longo’s findings all the odder. In 2007, he was mining the databases of the Sloan Digital Sky Survey (SDSS), a project that since 2000 has been using a 2.5-metre telescope at Apache Point Observatory in Sunspot, New Mexico, to collect images of about a million galaxies across the northern sky. He was looking for spiral galaxies whose swirling arms were clearly visible, showing what direction the galaxies are spinning in.

That was not easy. Many spirals face us at the wrong angle for their arms to be clear, while bursts of star formation in others suggest recent collisions and mergers that might have disrupted their original spin.

Longo soon whittled an initial 40,000 candidates down to just 2817 clear examples.

**Synchronised spinning**

All other things being equal, you would have expected these galaxies generally to be spinning in random directions, according to local conditions when they formed. And that indeed was the case. In most sectors of the northern sky, equal numbers of galaxies were spinning in the right direction, or clockwise, and to the left, anticlockwise. But along one direction, at about 10 degrees to our own galaxy’s spin axis, there were more left-handed spirals than right-handed ones. That was intriguing, but nothing more. “It gave a positive result, but with that number of galaxies the statistical significance was marginal,” says Longo.

By 2010, there were some 230,000 suitable galaxies in the SDSS database, and Longo decided to take another look. This time, he needed a team of graduate students to repeat his analysis. They ended up with a sample of 15,158 clearly rotating spiral galaxies, the farthest 1.2 billion light years away.

The effect was not just still there, it was stronger. This time, there was just a 0.006 per cent chance of it being a statistical fluke (Physics Letters B, vol 699, p 224).

That’s when Longo looked at the southern sky, which is not covered by the SDSS. Back in 1991, astronomers Hajime Sugai of the University of Tokyo and Masanori Iye of the National Astronomical Observatory of Japan had compiled a catalogue of the spin direction of about 8000 southern galaxies using data from the European Southern Observatory’s telescope in La Silla, Chile. They had been looking for a similar “dipole” effect of more galaxies spinning one way than the other, but had given up the chase. “We did see some evidence for the presence of a dipole,” says Masanori. “But it was not very significant.”

Longo saw something they hadn’t. Stretching off as far as the telescope could see, along the same axis in the southern sky, there was a clear excess this time of right-handed spirals. It was the same effect, only in reverse.

For Longo, that pointed to a mind-boggling conclusion. “If this asymmetry is real, it means the universe has a net angular momentum,” he says. Angular momentum, like energy, cannot be created or destroyed, so that means it must also have been born in a spin. Only that would explain why galaxies along one line, the universe’s own original spin axis, received an extra kick to make most of them rotate in the same direction.

And the universe might well be spinning still. Not that we would notice. “We can’t see the spinning, because we are inside, and we can’t see outside, so we can’t directly show it’s spinning,” says Longo. Nevertheless, if the idea stands up, it is a bombshell. The universe is not the same wherever you look; it has special directions in which certain things occur and others do not. Parity is violated; the cosmological principle seems weakened.

Let’s start with what that does not mean: Earth is not in a special place. Although it might look as if we are ideally positioned to look along the universe’s unique spin axis, all of space expanded from just one infinitesimally small point at the big bang. The original spin axis has expanded with it, so wherever you are in the cosmos, it will be there too, pointing in the same direction (see diagram, below right).

As to what might have set the universe spinning, or what the observations might say about the possibility of other universes beyond, Longo would rather not speculate. As far as the interior workings of our cosmos are concerned, though, his findings have set at least one cosmologist in a spin. “I was blown away,” says theorist Stephon Alexander of Haverford College in Pennsylvania. “It sits well with an idea he has been pushing for the best part of a decade—one that he thinks could also explain another asymmetry: why matter dominates antimatter in our cosmos.”

This is one of the thorniest problems in physics. The standard model says that there is absolute symmetry between matter and antimatter; both should have been created in equal amounts after the big bang, and would have annihilated each other completely within a fraction of a second. The existence of galaxies, stars, planets, dust and life made of matter is, to put it mildly, an embarrassment to this otherwise wildly successful theory.

There is a way nature could have engineered matter’s dominance: through a phenomenon known as CP violation. This idea emerged from asking whether, if the weak nuclear force does not respect parity (P) alone, there are symmetries it does respect. One answer was that it might respect parity and charge (C) conservation together. In effect, this means if you take a process such as a particle reaction, flip it in a mirror and simultaneously swap all the particles for identical particles of the opposite charge – their antiparticles – the reaction should proceed as before.

“It would be a bombshell: the universe is not the same wherever you look; it has special directions in which certain things happen and others do not”
That is not the case. Experiments from the 1960s onwards revealed that CP symmetry is also broken by the weak force; a reaction and its mirror-inverted, charge-reversed equivalent proceed at slightly different rates. The Soviet physicist Andrei Sakharov showed in 1967 that a hugely CP-violating process at work in the early universe, when matter and antimatter were being produced, could explain why the one won out over the other.

But what process? In 2004, Alexander, then at the Stanford Linear Accelerator Center in Menlo Park, California, and colleagues identified a possible culprit: gravity, the only one of the four fundamental forces of nature not covered by the standard model.

They showed that a two-step process might pull off the desired trick. If gravity violated the law of parity conservation in the first instants after the big bang, that would have produced ripples in space-time, gravitational waves, asymmetrically. This was a time when the universe entered a period known as inflation, asymmetrically. This was a time when the universe expanded and cooled enough to let photons through, some 370,000 years into its existence. The radiation has a uniform temperature of some 2.725 kelvin, but look closely and you see warmer and colder spots. This dappling is even across the sky, except when you look on the very largest scales. Then some of the spots seem to start lining up, all pointing in pretty much the same direction. In 2005, Kate Land and Joao Magueijo of Imperial College London dubbed this alignment the “axis of evil”.

NASA’s WMAP team, which has created stunningly detailed maps of the cosmic background radiation, says that while “the fact of the alignment is not in doubt”, it is best explained as a statistical fluke (arxiv.org/abs/1001.4758). Others are less sure, and the issue of strange patterns in the background radiation will not go away. And as far as Alexander is concerned, it is just the kind of effect his asymmetric gravitational waves would produce.

Now along comes Longo. Intriguingly, the axis along which galaxies seem to be rotating with the same handedness is in roughly the same direction as the axis of evil. “It suggests they are related,” he says. Alexander thinks he knows how.

It is too early for him to have incorporated the details of the galaxy asymmetry into his work explicitly, but he sees a suggestive thread: an initially spinning universe brought on a parity-violating asymmetry in gravity that allowed matter to triumph over its antimatter rival. And that process left two marks behind: the axis of evil in the cosmic background radiation, and the inconspicuous alignment of galaxies that Longo has spotted.

That’s certainly a well-spun yarn. Luckily, we should soon have the data to decide whether it is fiction or reality. The European Space Agency’s Planck satellite is set to provide the most detailed map of the cosmic background radiation ever made. If Planck, like WMAP, finds an axis of evil, it would be the best sign yet that the effect is genuine.

Masanori’s team also plans to use the National Astronomical Observatory of Japan’s 8.2-metre Subaru Telescope on Mauna Kea, Hawaii, to study northern galaxies in greater detail. “We will be able to [see] a huge number of galaxies with much finer resolution to judge the spin orientation more easily,” he says. The Large Synoptic Survey Telescope, with an 8.4-metre mirror and 3200-megapixel camera, will study the southern skies from Cerro Panchón in Chile from 2020.

That should settle the question of the spinning universe one way or the other. Will we have been wrong yet again about how the universe works? If so, the door really would be open for that Nobel prize.

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