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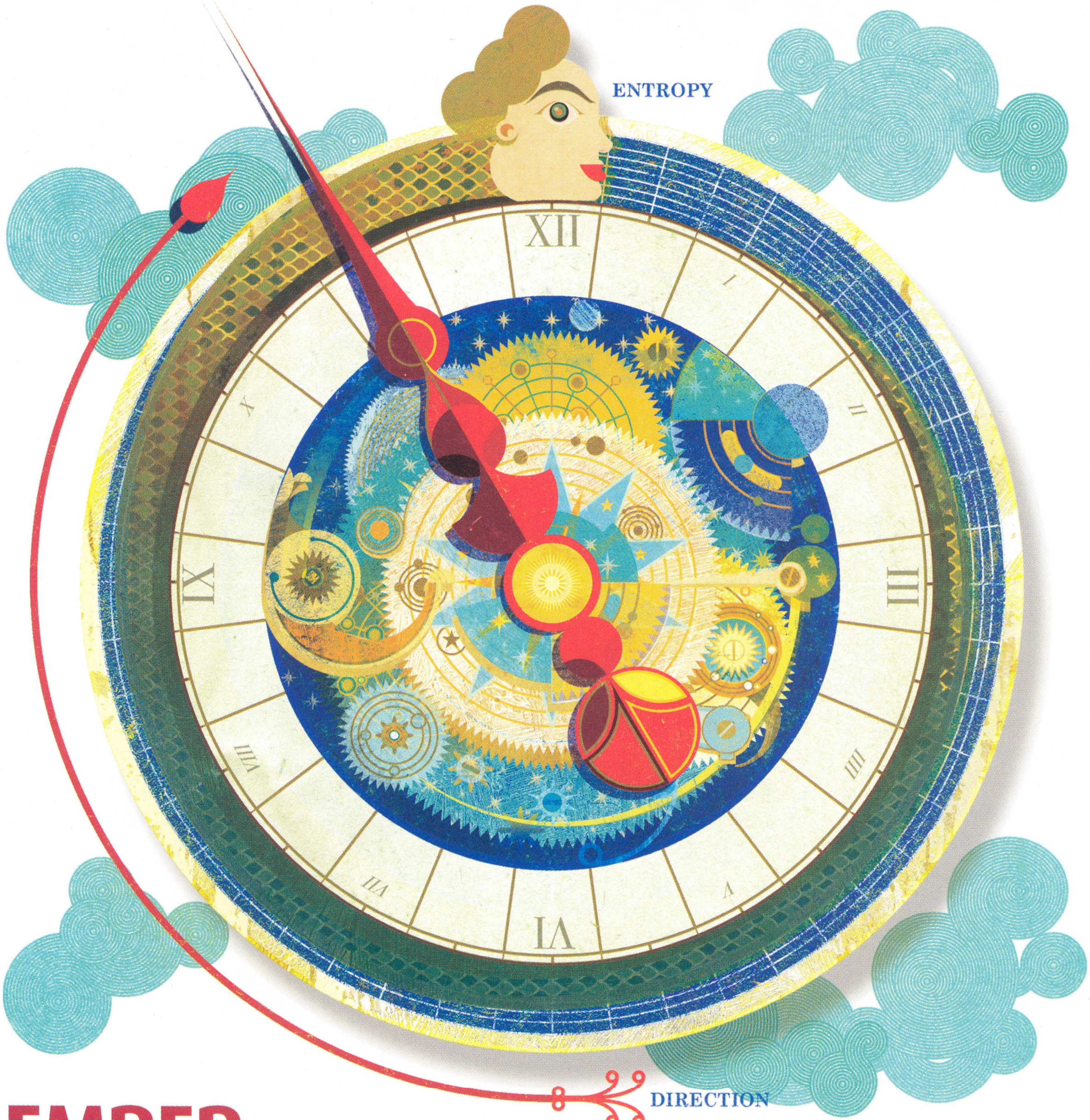
THE ORIGIN OF TIME



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What keeps the cosmic clock surging onwards? The answer is written in curious elliptical patterns in the sky, says **Amanda Gefter**

The riddle of time

YOU wake up one morning and head into your kitchen, where you get the distinct feeling that something strange is going on. A swirl of milk separates itself from your coffee, which seems to be growing hotter by the minute. Scrambled eggs are unscrambling and leaping out of the pan back into their cracked shells, which proceed to reassemble. And the warm sunlight that had flooded the room seems to be headed straight for the window. Apparently, you conclude, time is flowing in reverse.

You can deduce this because it is obvious that time has an arrow, which, this morning aside, always points in the same direction. We take the unchanging arrow of time for granted. Yet there is nothing in the laws of physics as we know them that says it can't point the other way. So the riddle is: where does time's arrow come from?

Our perception of the direction of time is linked to the fact that the world's entropy, or disorder, tends to increase. When you pour milk into your coffee, the concoction, at first, is highly ordered, with all the milk molecules entering the coffee in a neat stream. But as time passes, the milk loses its organisation and mixes randomly with the coffee. Keep watching and you will see it become thoroughly mixed, but you won't see the milk suddenly regroup. Strange as it may seem, it's not that such a scenario is impossible. It's just incredibly unlikely.

That's because there are vastly more ways for the molecules to arrange themselves in a random, spread out, high-entropy fashion than in the tight formation in which they began. It's a matter of probability: as the molecules perpetually rearrange, they almost always find themselves in high-entropy arrangements. Of course, if they start off in a high-entropy arrangement, we won't notice any change. But if entropy is low at the start, it's bound to increase.

Therein lies the origin of the arrow of time as we perceive it. It has two essential ingredients. The first is a low-entropy beginning, like the milk starting out in an ordered arrangement. The second is mixing: the constant rearrangement of the milk and coffee molecules. Mixing is necessary for the system to evolve and rearrange from a low-entropy to a higher-entropy state.

And exactly the same must be true on much grander scales. The cosmological arrow of time – the process that started with the big bang – requires the universe to have started off with low entropy, and the contents of the cosmos to have mixed ever since.

First evidence

So can we find these ingredients for time's arrow in our universe? Cosmologists already have evidence for the first one. They see that the universe had a low-entropy beginning by looking at the arrangement of the photons in the cosmic microwave background radiation that provides a snapshot of the universe near the beginning of time.

The CMB photons are uniformly spread out, with variations in density and temperature detectable at a mere 1 part in 100,000. If the spread of the CMB photons is uniform, we can assume that the other contents of the nascent universe – such as the atoms – were also spread uniformly at that time.

At first glance, that seems like the very definition of a disordered, high-entropy state, but it's not. The universe is governed by gravity, which always clumps things together, so a spread-out state is incredibly unlikely. Although no one knows exactly why, it seems the universe was born in a low-entropy state.

So what provides the second ingredient? What mixes and rearranges the contents of the universe? According to Vahe Gurzadyan, a physicist at the Yerevan Physics Institute in Armenia and La Sapienza University in Rome, the answer is the shape of space itself.

In 1992, Gurzadyan and his student Armen Kocharyan were looking at what a universe with "negative curvature" would do to the CMB. Negative curvature – the exact opposite of the curvature of a sphere – means that every point in space would be curved both up and down, like the mid-point of a saddle or a Pringle chip. Physicists have long considered this to be a possible geometry for the universe.

The temperature of the CMB varies slightly from point to point in the sky, and maps of this variation reveal a multitude of hot and cold spots. These maps have enabled cosmologists to infer many things about the universe: its age and composition, for example. In their ▶

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theoretical work, Gurzadyan and Kocharyan found that negative curvature would stretch the CMB spots into ellipses. That's because the CMB photons we observe today have been travelling through the universe for nearly 14 billion years. If that journey took them through negatively curved space, each little patch of light would appear as if it has been through a distorting lens. Five years later, Gurzadyan was looking at data from NASA's COBE satellite, one of the first to map the CMB, and saw exactly what he and Kocharyan had predicted: all the spots appeared elongated (*Astronomy and Astrophysics*, vol 321, p 19).

The observation was exciting but inconclusive because COBE did not provide sufficiently fine resolution to measure the shape of the spots precisely. Perhaps, Gurzadyan and Kocharyan reasoned, this apparent elongation was just an illusion created by the low-quality images. But when vastly more detailed CMB maps arrived from NASA's Wilkinson Microwave Anisotropy Probe (WMAP) in 2003, Gurzadyan and colleagues ran the data through their programs, removing all irrelevant distortion effects – and there it was (*Modern Physics Letters A*, vol 20, p 813). "All the spots have the same constant elongation, independent of temperature and the size of the spots," Gurzadyan says.

Because spots of all sizes are distorted in exactly the same manner, this effect can't be due to something that happened at the time the radiation was created. Some of the spots are so big that their extremities were already out of causal contact at the time of their creation: light from one side could never reach the other. Just as there is no way for us to communicate with a region that has slipped beyond our causal horizon (*New Scientist*, 20 October 2001, p 36), there is no way a distortion effect at that point in time could have produced the symmetry of the ellipse. So it must have happened some time later, during the photons' journey through the universe.

> "Some think the arrow of time might arise from the strange metaphysics of the quantum world"

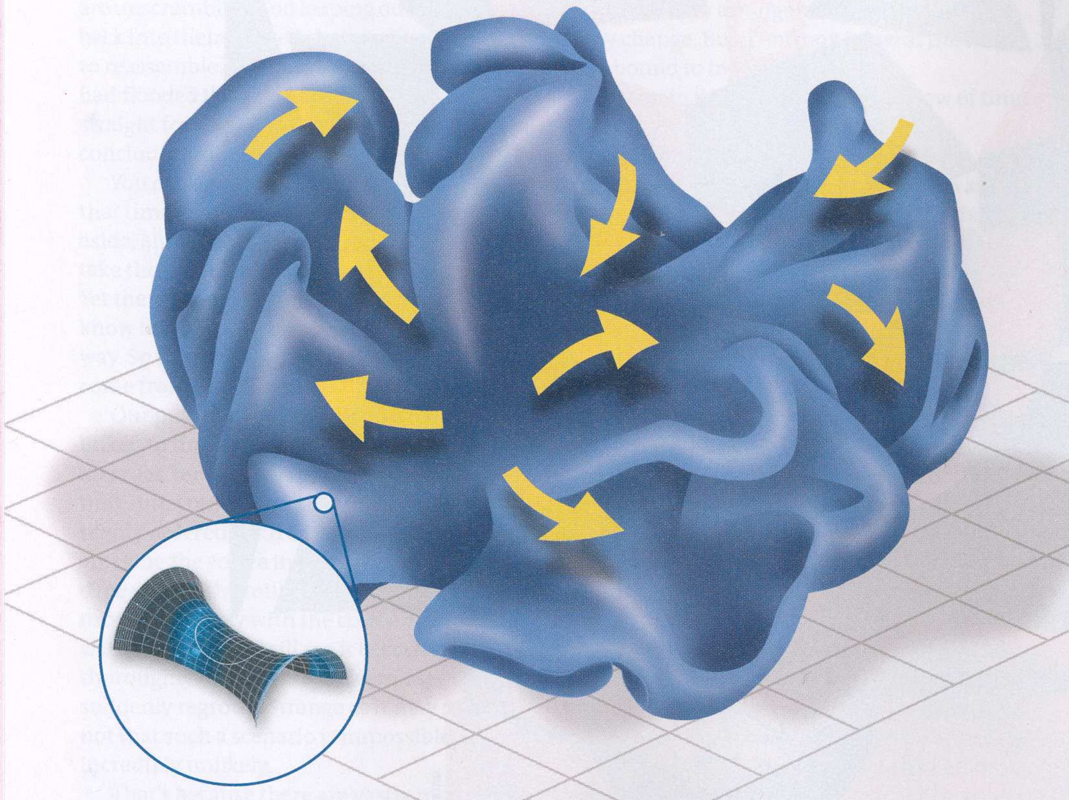
And if that's the case, Gurzadyan says, we have all the ingredients we need for the arrow of time. The universe starts out in an unlikely, low-entropy arrangement, with all of its contents almost perfectly spread out. But as particles travel through the universe, their paths follow the curves of space. In a negatively curved space, any two particles that start off next to one another quickly diverge, which means all the particles dramatically rearrange: the geometry of space mixes the cosmos.

Since most particle arrangements correspond to high entropy, the negative curvature inevitably guides matter into higher-entropy states. In the case of the universe, that means states with gravitational clumping: as entropy increases, things like stars and galaxies form and with them heavy elements and, eventually, us.

Evidence of this process is encoded in the CMB. The elliptical shape of the CMB spots reveals that the photons' paths diverged in precisely the way Gurzadyan expected for a negatively curved universe. If spatial geometry mixed the photons, then it also mixed everything else. And low-entropy beginnings plus mixing equals the arrow of time.

THE CHAOS OF TIME

Our perception of the arrow of time is marked by the universe moving into ever more disordered states. In a universe with negative curvature, every point in space is bent up in one dimension and down in another, like the mid-point of a saddle. This will send photons whizzing through the universe on chaotic paths, constantly increasing the disorder, which we perceive as the passing of time



Although Gurzadyan has published his ideas and his data in various places, the work remains controversial: the traditional view is that the universe is flat, not negatively curved. The usual interpretation of the WMAP results, which comes not from looking at the shape of the temperature spots but instead from what's called the power spectrum, is that the universe is flat. And most cosmologists believe this flatness supports the cherished theory of inflation, the idea that the universe underwent a fleeting moment of faster-than-light expansion shortly after its birth.

The trouble with that objection is that a different aspect of WMAP's findings goes against inflation's predictions. When astronomers plot the power spectrum of the data, they see a big problem – hints of which had also been seen with COBE. The power spectrum compares the amount of temperature variation at different scales in the sky. When close regions of the sky are being compared, the temperature variations of the CMB fit with the predictions of inflation. But on very large angular scales the variation conflicts with inflation's prediction. The anomaly, for which there is no accepted explanation, suggests that there is something strange going on in the large-scale geometry of the cosmos, perhaps because it is not flat. "This anomaly is very curious," says Roger Penrose, a mathematical physicist at the University of Oxford. "It seems to be out of kilter with the inflation model, and it could be due to negative curvature."

Gurzadyan regards the elongation of the hot and cold spots as powerful evidence that the universe is negatively curved, and Penrose agrees. Negative curvature would distort the CMB far more than a flat universe could, Penrose explains, squashing the light in one direction and stretching it in another. "If the geometry of space is negative, then you expect the ellipses to stretch much more than they would in positively curved or flat space," he says. "And this is exactly what Gurzadyan sees."

Nonetheless, most cosmologists are still not ready to abandon the flat universe or inflation. Although no one has actually shown or even suggested that there is anything wrong with Gurzadyan's elliptical spots, they are hesitant to accept its implications. "At the moment, I don't feel that we have any compelling evidence against space being flat," says Max Tegmark, a cosmologist at the Massachusetts Institute of Technology. Princeton University's Lyman Page, a member of the WMAP team, is similarly reluctant. "Though I'm a strong believer in alternative analyses of data, it is too early to put much stock into the interpretation of Gurzadyan's result," Page says.

Penrose, however, is excited by the result, and says there is much more to be gained from the CMB than physicists so far seem to realise. "There's vastly more information in the data than people look at normally. So far we've seen an infinitesimal amount, and people tend to look at the same things that everyone else is looking at. Gurzadyan is only using a tiny bit, but it's a different tiny bit. I think the analysis has to be taken very seriously."

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Life and time

Vahe Gurzadyan's idea has a startling implication: if the geometry of space were different, there would be no "arrow" of time. Could life exist in a universe without an arrow? If not, would that help explain why the geometry of our universe is as we observe? Gurzadyan has dubbed this idea the "curvature anthropic principle".

The standard anthropic principle says that certain aspects of the universe – like the values of physical constants – are the way they are because otherwise we wouldn't be here to wonder about them. For instance, if the mass of the electron were different, the universe would be unable to support human life, so we shouldn't be surprised by its value, given our very existence. Some scientists consider this common sense, while others see it as a sorry stand-in for a real explanation. The curvature anthropic principle applies this logic to the shape of space: without this negative curvature, we wouldn't have evolved as we did, Gurzadyan suggests.

Elliptical time

Of course, directly linking the ellipses to the flow of time is even more controversial, but we don't have any other satisfactory explanation. The flow of time we observe is certainly not compulsory: it is perfectly possible for the time-symmetry of relativity, quantum theory and our other descriptions of the universe to produce a universe where time doesn't flow – or even one where time flows in the opposite direction to the one we experience. In 1999 Lawrence Schulman of Clarkson University in Potsdam, New York, showed that in principle regions of the universe where time flows in the normal direction can coexist with regions where it flows backwards (*New Scientist*, 6 February 2000, p 26).

But in our universe a negative curvature would stop this by imposing a global condition for the increase of disorder. This may even be what allows life to exist in the universe, Gurzadyan suggests: a new kind of anthropic principle (see "Life and time", above).

Of course, if the saddle-shaped universe provides us with a mechanism for the increasing cosmic disorder, it still doesn't explain the arrow's ultimate origin: it doesn't explain the first ingredient, why the universe began with low-entropy conditions. "Of course you need mixing," explains University of Chicago physicist Sean Carroll, "but that's the easy part. The hard part is getting the initial entropy to be low."

That remains a mystery, perhaps only to be resolved by the "theory of everything" that physicists are avidly searching for. And we do have hints that this final theory might address the problem. For example, Rafael Sorkin of Syracuse University in New York state has proposed "causal set theory", which attempts to unite quantum theory and relativity. It supposes that the fabric of the universe grows as effects follow causal events – giving a sense of time's flow (*New Scientist*, 4 October 2003, p 36). Although Sorkin and his colleagues admit it is not yet a complete theory of quantum gravity, it does at least install a one-way arrow of time and a low-entropy beginning.

Of course, all these attempts to understand the irrepressible passage of time assume that time's arrow is a "real" phenomenon to do with the physical universe – and that is not entirely certain. Some think it might arise from the strange metaphysics of the quantum world; others see it as a purely psychological phenomenon, an artefact of our consciousness.

But Gurzadyan is now convinced that the passage of time is a cosmological process. The hands on the cosmic clock are driven round by the chaotic movements of photons through the negatively curved universe, he says. Though that may be a little beyond what most cosmologists are willing to accept for now, the idea must be worth exploring: the search for answers to the flow of time goes to the heart of physics, Penrose believes. "The problem of the arrow of time is absolutely fundamental," he says. "It's telling us something very deep about the universe." ●