Dark flow: Proof of another universe?

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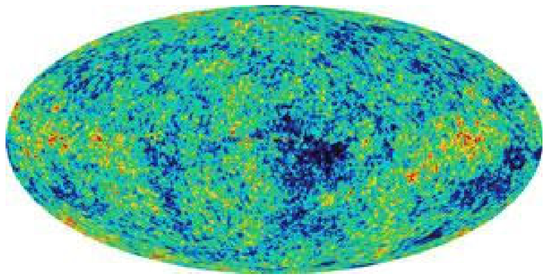
FOR most of us the universe is unimaginably vast. But not for cosmologists. They feel decidedly hemmed in. No matter how big they build their telescopes, they can only see so far before hitting a wall. Approximately 45 billion light years away lies the cosmic horizon, the ultimate barrier because light beyond it has not had time to reach us.



This high-resolution map of microwave light emitted only 380,000 years after the Big Bang defines our universe more precisely than ever before. The eagerly-awaited results from the orbiting Wilkinson Microwave Anisotropy Probe resolve several long-standing disagreements in cosmology (Image: WMAP Science Team / NASA)

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So here we are, stuck inside our patch of universe, wondering what lies beyond and resigned to that fact we may never know. The best we can hope for, through some combination of luck and vigilance, is to spot a crack in the structure of things, a possible window to that hidden place beyond the edge of the universe. Now Sasha Kashlinsky believes he has stumbled upon such a window.

Kashlinsky, a senior staff scientist at NASA's Goddard Space Flight Center in Greenbelt, Maryland, has been studying how rebellious clusters of galaxies move against the backdrop of expanding space. He and colleagues have clocked galaxy clusters racing at up to 1000 kilometres per second - far faster than our best understanding of cosmology allows. Stranger still, every cluster seems to be rushing toward a small patch of sky between the constellations of Centaurus and Vela.

Kashlinsky and his team claim that their observation represents the first clues to what lies beyond the cosmic horizon. Finding out could tell us how the universe looked immediately after the big bang or if our universe is one of many. Others aren't so sure. One rival interpretation is that it is nothing to do with alien universes but the result of a flaw in one of the cornerstones of cosmology, the idea that the universe should look the same in all directions. That is, if the observations withstand close scrutiny.

All the same colleagues are sitting up and taking notice. "This discovery adds to our pile of puzzles about cosmology," says Laura Mersini-Houghton of the University of North Carolina, Chapel Hill. Heaped in that pile is 95 per cent of the universe's contents, including the invisible dark matter that appears to hold the galaxies together, and the mysterious dark energy that is accelerating the universe's expansion. Accordingly, Kashlinsky named this new puzzle the "dark flow".

Kashlinsky measures how fast galaxy clusters up to 5 billion light years away are travelling by looking for signs of their motion in the cosmic microwave background, the heat left over from the big bang. Photons in the CMB generally stream uninterrupted through billions of light years of interstellar space, but when they pass through a galaxy cluster they encounter hot ionised gas in the spaces between the galaxies. Photons scattered by this gas show up as a tiny distortion in the temperature of the CMB, and if the cluster happens to be moving, the distortion will also register a Doppler shift.

In any individual cluster, this shift is far too small to detect, which is why no one had ever bothered looking for it. However, Kashlinsky realised if he combined measurements from a large enough number of clusters, the signal would be amplified to a measurable level.

Kashlinsky and his team collected a catalogue of close to 800 clusters, using telescopes that captured the X-rays emitted by the ionised gas within them. They then looked at the CMB at those locations, using images snapped by NASA's WMAP satellite. What they found shocked them. Galaxy clusters are expected to wander randomly through their particular region of space, because matter is distributed in uneven clumps, creating local gravitational fields that tug on them. Over large scales, however, matter is assumed to be spread evenly, so on these scales the clusters should coast along with space as it expands. What's more, everything in the standard model of cosmology suggests that the universe should look pretty much the same in all directions.

Out of bounds

So what is behind the dark flow? It can't be caused by dark matter, Kashlinsky says, because all the dark matter in the universe wouldn't produce enough gravity. It can't be dark energy, either, because dark energy is spread evenly throughout space. That, leaves only one possible explanation, he concludes: something lurking beyond the cosmic horizon is to blame.

Before the findings were published in October in *The Astrophysical Journal Letters* (vol 686, p L49), Kashlinsky knew how heretical his idea would seem. "We sat on this for over a year checking everything," he says. "It's not what we expected or even wanted to find, so we were sceptical for a long time. But ultimately it's what's in the data."

No one knows exactly what might lurk over the horizon or indeed how large the cosmos is (see "Just how big is the universe?") But Kashlinsky suspects it is a remnant of the chaotic state that existed just a fraction of a second after the beginning of time, before a phenomenon known as inflation took hold.

It is generally thought that our universe began as a tiny patch in some pre-existing space-time forming a bubble which then underwent a burst of exponential expansion. This period of inflation stretched and smoothed our universe, leaving an even distribution of matter and energy. Outside this bubble, far beyond our cosmic horizon, things might look very different. Without inflation's ironing skills, space-time could be highly irregular: smooth in one neighbourhood and with massive structures or giant black holes in another. "It could be as bizarre as one can imagine, or something rather dull," says Kashlinsky. Either way, he suggests that something outside our bubble is tugging on our galaxy clusters, causing the dark flow.

Other, more radical, explanations for dark flow have also been floated. It is possible - even likely, some say - that ours wasn't the only bubble to inflate out of primordial space-time. In this "eternal inflation" scenario, bubbles pop up all all over the place, each defining its own universe within a larger multiverse.

Many cosmologists are happy to relegate those other universes to that dusty corner of theory where unobservable by-products are stored. Mersini-Houghton is not one of them. She argues that the dark flow is caused by other universes exerting a gravitational pull on galaxy clusters in our universe. She and her colleagues calculated how other universes, scattered at random around our bubble, would alter the gravity within it (www.arxiv.org/abs/0810.5388). "When we estimated how much force is exerted on the clusters in our universe, I was surprised that the number matched amazingly well with what Kashlinsky has observed," she says. "I firmly believe that this is the effect of something outside of our universe."

Others believe dark flow could be a sign that our bubble universe crashed into another bubble just after the big bang. In eternal inflation each bubble universe can pop into existence with its own unique set of particles and forces of nature, so collisions between bubbles can have dramatic consequences. If two universes with the same physics collide, they will generate a burst of energy, then merge. However, if two very different universes collide, a cosmic battle ensues. At the site of the crash, a wall of energy called a domain wall will form, holding the two incompatible worlds apart. The bubble with lower energy then expands, sending the domain wall sweeping through its rival, obliterating everything in its path.

> The dark flow could be a sign that our bubble universe crashed into another soon after the big bang

If our universe underwent such a collision, any lingering evidence of the cosmic wreckage should appear in the part of the sky facing the impact site. The collision's impact should distort space, and that would in turn affect how light rays, including the CMB, travel through it and how large-scale structures, including galaxies and clusters, evolve. Looking out across the sky today, we would expect to see the universe exhibiting strange properties in the direction of the collision.

The collision might have imprinted a special direction onto the CMB, says physicist Anthony Aguirre of the University of California, Santa Cruz. "As you move away from the special direction, the temperature [of the CMB] would change." Physicists are now combing the data looking for the hallmarks of such a shift. Whenever there are weird things happening on a large scale within the galaxy, the remnants of a collision are a candidate for explaining it, Aguirre says.

A completely different take on dark flow comes from Luciano Pietronero of La Sapienza University in Rome, Italy and Francesco Sylos Labini of the Enrico Fermi Center in Rome, Italy. They say the standard cosmological model is wrong, and that a different model might explain the motion of galaxy clusters that Kashlinsky found. "This is just another element pointing toward the fact that the standard picture of galaxy formation is not correctly describing what is going on in the real universe," Pietronero says.

Predictions of the motion of galaxy clusters based on the conventional model assume matter is evenly distributed throughout space on very large scales. Pietronero and Sylos Labini claim analysis of the distributions of galaxies and galaxy clusters throughout the sky shows that this is not true, and that at large scales matter is like a fractal. If that is the case, the gravitational field throughout the universe would also be irregular and could lead to the effects Kashlinsky observed. New results from the Sloan Digital Sky Survey, which has already mapped about a million galaxies, will help give Pietronero and Sylos Labini a more precise picture of the spread of matter, which they hope will confirm their ideas. "I think we will have interesting news very soon," says Sylos Labini.

A fractal universe would, however, raise big problems of its own. For one thing, a fractal distribution of matter is incompatible with cosmic inflation, so theorists would be left to figure out how it arose in the first place (*New Scientist*, 10 March 2007, p 30).

Probing the multiverse

Physicist Douglas Scott of the University of British Columbia in Vancouver, Canada, is also sceptical that dark flow is evidence of anything outside our observable universe. "There is no reason at all to expect it to come from structures beyond the horizon," he says. Scott notes that so far dark flow has only been observed out to distances that are only a few per cent of the total distance to the horizon. "If the effect is real," he says, "then the likely explanation would be some very large-scale structure, but still within the horizon." Such a structure, though, would still present a major challenge to cosmology's standard model.

The most important thing now is to confirm that dark flow is real and that it continues all the way out to the cosmic horizon. Two other teams have made measurements consistent with Kashlinsky's results, but only on scales less than 200 million light years - just a short step compared to the distance out to the horizon.

To confirm their finding, Kashlinsky's team will be analysing more recent WMAP data and working with researchers at the University of Hawaii on data from an all-sky X-ray catalogue. The tiny Doppler effect that Kashlinsky uses to measure the clusters' velocities is only observable in bulk, which means the more galaxy clusters he can look at the better. "If confirmed, this will be an exciting way of probing the ultimate structure of the universe and perhaps even the multiverse," Kashlinsky says. "But you have to check and recheck."

"If this thing is confirmed and it is real, it will be incredibly important," says Aguirre, "on the same order of discovery as the realisation that those little smudges on the sky are other galaxies. The most important thing it would tell us is that the standard picture is broken in some way. And the most exciting thing it could tell us is that there are other universes." If it does, space and time will open up to reveal a reality that is so much bigger than we know. When that happens, those claustrophobia-stricken cosmologists will finally be able to breathe easy.

Just how big is the universe?

It is 13.7 billion years since the big bang, so light now reaching us cannot have started its journey longer ago than that. Yet the most distant object we could conceivably see today lies further away than 13.7 billion light years. That's because throughout the life of the universe, space has been expanding. Taking this into account, cosmologists calculate that the edge of our observable universe is now approximately 45 billion light years away.

Beyond that, who knows? The inflation theory of cosmology predicts that the universe grew from a bubble. Just how big that bubble has now become depends on how long inflation lasted. If it continued for a very long time - in this context "very long" is still only a fraction of a second - then the edge of our universe might lie far beyond the 45-billion-light-year limit of our vision. That could also rule out the possibility of observing the influence of other universes on our own. As physicist Matthew Kleban of New York University puts it: "It's totally possible that we live in a multiverse and we'll never know because there's been so much inflation."

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