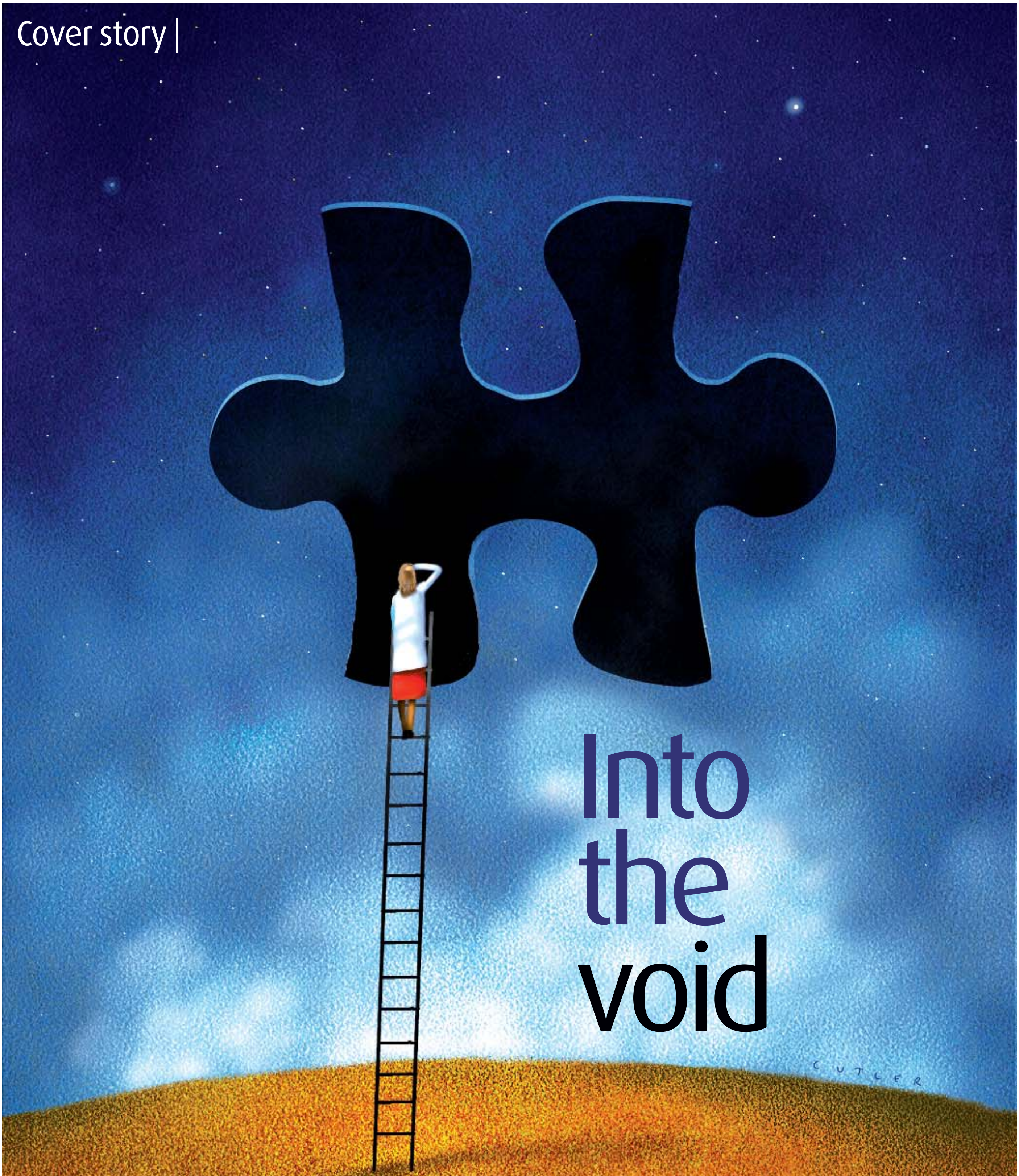


Into the void

Could a vast empty hole in space be the imprint of another universe? **Marcus Chown** investigates

DAVE CUTLER

IN AUGUST, radio astronomers announced that they had found an enormous hole in the universe. Nearly a billion light years across, the void lies in the constellation Eridanus and has far fewer stars, gas and galaxies than usual. It is bigger than anyone imagined possible and is beyond the present understanding of cosmology. What could cause such a gaping hole? One team of physicists has a breathtaking explanation: "It is the unmistakable imprint of another universe beyond the edge of our own," says Laura Mersini-Houghton of the University of North Carolina at Chapel Hill.

It is a staggering claim. If Mersini-Houghton's team is right, the giant void is the first experimental evidence for another universe. It would also vindicate string theory, our most promising understanding of how the universe works at its most fundamental level. And it would do away with the anthropic arguments that have plagued string theorists in recent years because they say we are the reason the cosmos is the way it is. The hole in the universe is a big deal.

The giant void first showed up in maps of the afterglow of the big bang. In 2004, NASA's WMAP satellite made the most detailed measurements to date of the temperature of the cosmic background radiation. This microwave radiation gains a small amount of energy when it passes through a region of space populated by matter, making it appear slightly warmer in that direction. In contrast, radiation passing through an empty void loses energy, and so it appears cooler.

The WMAP team noticed an abnormally large cold spot where the temperature was between 20 and 45 per cent lower than the average for the rest of the sky, suggestive of a void. The spot covers a few degrees of the sky – many times more than the full moon. However, without knowing how far away the void was, it was difficult to tell its size.

Things began to change as researchers analysed the Sloan Digital Sky Survey, the largest 3D map of galaxies made so far. Once they knew how far away various galaxies were, they were able to calculate that the WMAP cold spot coincides with an enormous void that has grown to around 900 million light years across. Located about 8 billion years away, the void contains about 20 to 45 per cent fewer galaxies than you would expect.

This was confirmed in August by Lawrence Rudnick, Shea Brown and Liliya Williams of the University of Minnesota in Minneapolis, who were analysing a survey of radio-emitting galaxies carried out by the Very Large Array of telescopes at the National Radio Astronomy Observatory near Socorro, New Mexico.

A mere 5 per cent of the universe is filled with galaxy clusters, the other 95 per cent is mysterious voids. There are plenty of small voids, but the bigger they get the rarer they become. No one expected one 900 million light years across.

A void so big is virtually impossible to explain within standard cosmology. According to our best theories, the seeds of galaxy clusters and voids were sown shortly after the big bang, when the universe was a roiling vacuum of quantum fluctuations that were then magnified by a period of superfast expansion called inflation. Fluctuations of all sizes are possible, though larges ones are rare. "Any fluctuation leading to a void as big as the WMAP cold spot is exceedingly unlikely, according to standard cosmology," says Mersini-Houghton.

> "Standard cosmology cannot explain such a giant cosmic hole"

There are other explanations for the WMAP cold spot. For example, some researchers speculate that it is due to a giant knot in space called a topological defect, predicted in certain theoretical models (*New Scientist*, 13 July, p 12). However, Mersini-Houghton's explanation could have greater significance.

Entangled universes

She and her colleagues looked for an explanation outside of standard cosmology. They turned to string theory, the leading contender for a "theory of everything" that unites the laws of physics to explain how all matter and energy behaves. The theory holds that the ultimate building blocks of matter, such as quarks and leptons, are tiny strings of mass-energy vibrating in a 10-dimensional space-time.

String theory's selling point had always been that it could make unique predictions about the properties of our universe. This made it more aesthetically pleasing than anthropic arguments, which say that certain aspects of the universe – like the constants that characterise the laws of physics – are the way they are because otherwise we wouldn't be here to wonder about them.

Yet string theory does not just describe one universe. It describes 10^{500} universes, each one a quantum vacuum with different physical properties. So why was ours the universe that grew large? "String theorists, who so much hoped to avoid the anthropic principle, have now been forced to invoke it to explain why our vacuum was selected out from the 10^{500} other string vacuums," says Mersini-Houghton.

Anthropic arguments leave many physicists queasy. They would prefer an explanation for the universe's properties that has nothing to do with our existence. Rather than abandon string theory completely, however, Mersini-Houghton was convinced there must be a way to thin down the forest of string vacuums without using the anthropic principle. She and her collaborator Richard Holman of Carnegie Mellon University in Pittsburgh, Pennsylvania, had a hunch that matter and gravity might have some kind of dynamic effect that whittles down the number of vacuums to a small bunch that eventually grows into our universe and its neighbours.

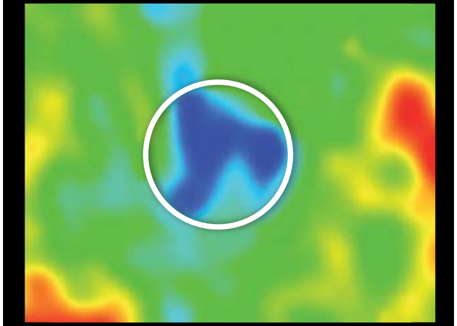
According to string theory, each possible universe has different conditions. If a patch of vacuum is to lead to a universe like ours, the important thing is that it must grow large. This means something must oppose gravity, which tends to suck together the mass-energy of the vacuum and shrink it.

That something can only be the vacuum itself. If the vacuum has an enormous negative pressure, Einstein's theory of gravity says it will generate repulsive gravity that blows rather than sucks. "A patch of vacuum's repulsive gravity therefore overwhelms the attractive gravity of its matter," says Mersini-Houghton. "For the patch of vacuum that led to our universe, this happened during the first split second of its existence in a period called inflation."

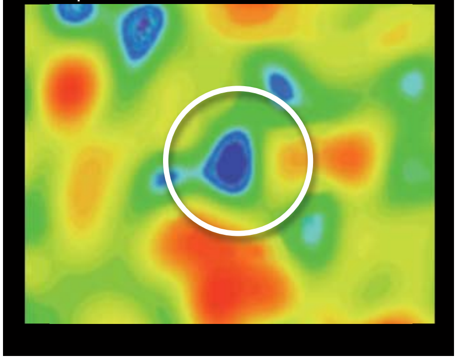
According to Mersini-Houghton and ▶

SENSING THE VOID

The WMAP picture of the cosmic microwave background shows a cold spot that is much larger than expected



The Very Large Array, which measurs radio emissions from galaxies, shows that the cold spot also has far fewer galaxies than expected



Holman, the dynamic effect of matter and gravity would have weeded out the majority of string vacuums, leaving only our patch and close neighbours in the string landscape. "It's a much more scientific and legitimate way of picking out a universe like ours than the anthropic principle," she says. "But it has extraordinary consequences."

Mersini-Houghton and Holman's calculations show that the patch of vacuum that led to our universe must have interacted with neighbouring patches very early on. Because these interactions are between tiny patches of quantum vacuum, they would leave the universes in an entangled state and give them a ghostly connection that allows them to sense and affect each other from afar. "Such an entangled state remains for all time," says Mersini-Houghton. "So although inflation quickly pushed our region beyond the reach of neighbouring regions, it should still retain the imprint of its quantum entanglement with its neighbours."

The question is: where should we look for the imprint and what form might that imprint take? Because of the expansion of the universe, no light or signals can reach us from beyond the cosmic horizon, about 42 billion light years away. On a far smaller scale, the messy process of galaxy formation has effectively erased any trace of the early interaction between our universe and neighbouring ones. However, on scales comparable to the cosmic horizon itself, there ought to remain an imprint from the time closest to the beginning of inflation when there was an interaction. "In today's universe, it should manifest itself at a red shift of less than 1, corresponding to a time when the universe was about half its present age, says Mersini-Houghton."

Smoking gun

Mersini-Houghton and Holton say their dynamical theory can describe the form of the imprint too. The vacuums of neighbouring patches effectively push on our universe, they say. According to relativity, such squeezing produces repulsive gravity. Where we can see the squeezing act – on scales comparable with the size of the universe – the repulsive gravity should dramatically thin out matter and make it harder for galaxies to form. "We predict the existence of a giant void about 500 million light years across," says Mersini-Houghton. By cosmology's standards this forecast ties in pretty well with astronomers' observations of a void 900 million light years across at a red shift of 1. "We are amazed that the void is there just as we predicted," she says.

Working with Tomo Takahashi of Saga University in Japan, Mersini-Houghton and Holman go further. They predict that there should be not one such giant void but two: one in the northern hemisphere corresponding to the WMAP cold spot and one in the southern hemisphere. "We are hoping that a southern void will turn up in the data soon," she says.

So far the work has had a mixed reception. "It is one of the most interesting ways to relate observations in our universe to the vastly larger string landscape," says physicist Leonard Parker of the University of Wisconsin, Milwaukee. Others are more cautious. "It's interesting," says David Spergel of Princeton University. "However, it is very speculative."

Mersini-Houghton and her team make a further prediction that could soon be tested – what they call the "smoking gun" of their idea. In standard cosmology, the temperature variations of the big bang radiation are the direct result of the distribution of matter in the universe. This means the pattern of galaxies should exactly match the temperature features in the big bang radiation.

That won't be the case, says Mersini-Houghton. Her team's work shows that the entanglement between our universe and neighbouring universes changes the density of matter on the largest scales. If they are right, the interaction will leave a subtle mark on observations. "We predict that correlation between matter and temperature will be found to be much less than 100 per cent."

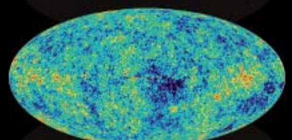
The test could come as soon as next year, when the European Space Agency launches its Planck microwave background probe. Planck should be able to both confirm the existence of the cold spot and improve the precision of the WMAP sky map.

Planck isn't the only test. Mersini-Houghton also makes a prediction about what will be seen – or rather not seen – at the Large Hadron Collider (LHC) near Geneva, Switzerland, when it switches on next year. Many particle physicists believe that the LHC will uncover the first experimental evidence for supersymmetry, a popular theory that posits that every particle has a heavier superpartner. None of the particle accelerators

AXIS OF EVIL

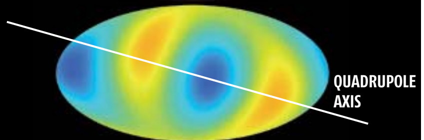
COSMIC MICROWAVE BACKGROUND

The cosmic microwave background as imaged by NASA's WMAP spacecraft. Minute variations in temperature reveal the nature of the universe just after the big bang



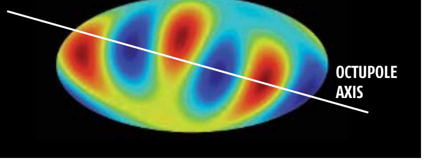
QUADRUPOLE

Astronomers break down the temperature variations into broad components, one of which is the quadrupole

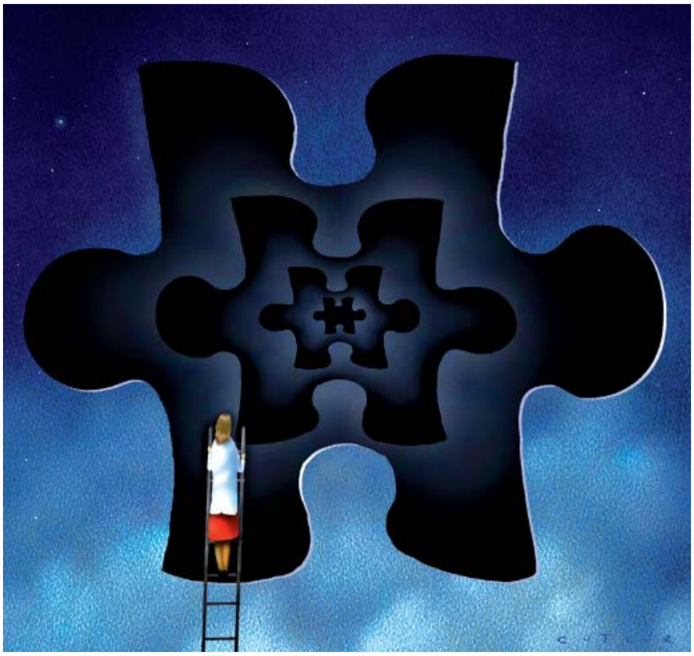


OCTUPOLE

Another component is the octupole, a pattern of three pairs of hot and cold regions. Both the quadrupole and the octupole are aligned along an "axis of evil" which standard cosmology cannot explain. Laura Mersini-Houghton and her collegues say it exists because our universe is interacting with another one



> “Our evidence points to string theory being on the right track”



DAVE CUTLER

built so far has had enough energy to create supersymmetric particles, but physicists believe that the collision energy at the LHC will produce fireballs with sufficient energy to recreate conditions in the early universe.

They hope to test what happened when the universe cooled below a certain temperature and underwent a phase transition, which broke supersymmetry. According to string models, the energy released during the phase transition drove inflation, and went on to create supersymmetric particles. Since the energy had to be sufficient to ensure the growth of our piece of vacuum, Mersini-Houghton and her colleagues can make an estimate of the energy scale of supersymmetry breaking. “We find it is about 100,000 times greater than generally believed,” she says. “Therefore we predict that the LHC will not detect supersymmetry.”

String theory’s saviour

It is a controversial result and many physicists disagree. “The string landscape is quite dense and it is most likely that vastly different physical parameters may give rise to quite similar universes,” says Orfeu Bertolami of the Instituto Superior Técnico in Lisbon, Portugal. “Nevertheless, I find their work very interesting.”

Despite the disagreement, the latest work is emblematic of a recent U-turn in theoretical physics. When the first WMAP results were made public in 2002, cosmologists claimed that the findings confirmed the standard model of the universe. Nobody expected anomalies to emerge and, if they did, nobody expected they would threaten to turn the standard picture of cosmology on its head.

Worse, some physicists have started to turn their backs on string theory in recent years, fearing that it is a dud, incapable of making any testable predictions. Some have even gone as far as declaring string theory dead. “I think our evidence points to string theory being on the right track,” says Mersini-Houghton. Now, with the discovery of the hole in the universe, it seems it could be a case of string theory is dead, long live string theory. ●

Marcus Chown is the author of *Quantum Theory Cannot Hurt You* (Faber, 2007)

Further Reading: “Extragalactic radio sources and the WMAP cold spot” by Lawrence Rudnick, Shea Brown and Liliya Williams, www.arxiv.org/abs/0704.0908

Is the evidence warmer?

If the cosmic cold spot was all that Laura Mersini-Houghton and her colleagues had chalked up in the way of a prediction, it might be possible to dismiss it as a fluke. However, they claim they can explain two other anomalies in the WMAP measurements of the cosmic microwave background too.

Both puzzles concern the way the map’s pattern of temperature can be broken down into simpler components known as multipoles (see Diagram, left). The simplest, or “dipole”, consists of one hot region and one cold region and is due to the Milky Way’s motion rather than any cosmological reason. The quadrupole consists of two hot spots and two cold spots; the octupole three hot spots and three cold spots.

The standard model of cosmology cannot explain why the hot and cold spots of the quadrupole and octupole are much closer in temperature than they are in other multipoles. But Mersini-Houghton says that the squeezing of our universe by neighbouring ones in her team’s model leads to repulsive gravity and suppresses the quantum fluctuations that seeded matter. “This is turn depresses the temperature variations at the quadrupole scale, exactly as WMAP has seen,” she says.

Standard cosmology also predicts that the hot and cold spots should be randomly distributed over the sky. Yet the WMAP results appear to show a curious alignment between the quadrupole and octupole’s hot and cold spots, dubbed the “axis of evil”. While many cosmologists dispute the existence of the axis of evil, others have suggested its origin. The alignment might be down to our universe being smaller in one direction than in others, perhaps shaped like a CD or a ring doughnut. This would suppress temperature variations in the short direction, leading to the kind of alignment observed.

Mersini-Houghton and her colleagues say their model has an axis too. It explicitly predicts that interactions between our universe and neighbouring patches should lead to correlations between matter on the largest scales. This in turn would lead to an alignment in the temperature features.

Physicist Orfeu Bertolami of the Instituto Superior Técnico in Lisbon, Portugal, has also looked at the possibility of neighbouring universes interacting with each other, and is impressed with the idea. “The idea of looking for long-wavelength effects as a smoking gun of the string landscape is a quite clever one, and clearly relevant.”