Embrace the lumpiverse: How mess kills dark energy

- 25 June 2014 by **Stuart Clark**
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GHOST BUSTERS

The universe is full of dark spectres -- but could a simple change to our cosmological outlook exorcise them, asks Stuart Clark

A DOOR flies open but no one's there. A vase levitates from the mantelpiece and hurls itself across the room. The furniture starts moving around of its own accord.

The universe today is a little like one of those ghost movies. Galaxies whirl around in unexplained ways. Groups of stars race across space, pulled by forces from beyond the visible universe. The fabric of space is inexplicably elastic, expanded ever faster by an inscrutable energy all of its own.

Not an overly superstitious bunch, cosmologists invent names for the poltergeists responsible -- dark matter, dark flows, dark energy -- and invest a lot of effort in proving they are real. But might they, too, be chasing ghosts? That's what some of their ilk say. They argue that the standard model of the universe is based on an oversimplification of Einstein's general relativity -- the theory that underpins all of cosmology -- and contains an unwarranted assumption about how stuff is distributed in the universe. Strip away these misconceptions and we can exorcise the cosmos of its uninvited manifestations. Is this for real?

Arguments today about the nature of the cosmos begin and end with Einstein. His equations of general relativity describe how matter curves space and time around it, causing the local accelerations we interpret as the force of gravity and, on the grandest scale, guiding the universe's evolution. Over the past century, cosmologists have plugged their improving observations into Einstein's equations and, little by little, refined the standard model. So here we are, in a universe that began some 13.8 billion years ago as an unimaginably hot, dense pinprick that has since been uniformly expanding and cooling in all directions.

To make Einstein's fiendishly complex equations tractable and arrive at such conclusions, however, a few simplifying assumptions must first be hard-wired into the model. One has a particularly distinguished pedigree. When Nicolaus Copernicus laid out the Copernican principle in the 16th century, it was to say that Earth was not the centre of the universe. In modern cosmology, it has morphed into the cosmological principle: that Earth is nowhere special at all. We see the universe from a representative standpoint, and draw conclusions that can apply everywhere else, too. This amounts to two related assumptions. First, that the universe is homogeneous, looking roughly the same in all locations. Second, it is isotropic, looking roughly the same in all directions from any standpoint.

For some, this is a leap of faith. In the universe today, galaxies exist in clusters and filaments of matter distributed around the boundaries of huge, bubble-shaped voids. These voids have roughly one-tenth of the clusters' matter density, but account for more than 60 per cent of the universe's volume. "Everyone knows that the universe is inhomogeneous," says Thomas Buchert of the University of Lyon in France. "To idealise such a complex structure with a homogeneous solution is a bold idealisation."

The mismatch is generally brushed aside using the concept of statistical homogeneity: that the sort of universe we are looking for exists if we zoom out far enough. On scales of about 400 million light years, bigger than all the structures we see, voids and galaxy clusters average into uniformity.

The problem is, we don't have a bird's-eye view of the universe on such scales. David Wiltshire, a cosmologist at the University of Canterbury in New Zealand, thinks that what is going on right in front of our eyes might be distorting our view.

He has been looking at the cosmic microwave background (CMB), light produced when photons scattered off the first atoms formed some 380,000 years after the big bang. This light has since been travelling with the cosmos, expanding and cooling along with it. In a uniform universe, the same amount of expansion and cooling should have taken place wherever we look at the CMB in the sky.

In fact, it appears overwhelmingly hotter in one direction than the other. This "dipole anisotropy" is well known, and it is generally explained by Earth's movement through space. Thanks to the Doppler effect, anything with a relative motion towards us looks hotter than it actually is and anything moving away looks cooler. Earth orbits the sun, the sun orbits the centre of the Milky Way, the Milky Way moves through our Local Group of galaxies and the Local Group is hurtling towards a massive concentration of more distant galaxies. Take account of the Doppler shifts created by all these motions, and the CMB's hot and cold patches melt away. Maps of the CMB, such as that produced last year by the European Space Agency's Planck satellite, the most detailed yet, present a picture that is uniform over the wide sweep of the sky, with variations only on much smaller scales.

Wiltshire takes issue with the last of the motions used to make the dipole anisotropy disappear: a movement at a speed of 635 kilometres per second of the entire Local Group towards a "great attractor" somewhere in the distant Hydra-Centaurus supercluster of galaxies. Without making any assumptions about how the universe is expanding or how the Local Group itself is moving, he and his colleagues have analysed the distance and apparent movement of over 4500 galaxies out to four times the distance of the putative great attractor (Physical Review D, vol 88, p 083529).

They claim the galaxies' movements make most sense if the Local Group isn't moving at all. Instead, the greater density of matter towards Hydra-Centaurus is slowing the universe's expansion along our line of

sight, giving us the impression of such a movement. A comparative void in the other direction, meanwhile, is producing the opposite effect, causing an area of faster expansion behind us. The effects of the inhomogeneities along this axis are comparatively local, occurring on scales up to about 300 million light years, and only alter the universe's expansion rate by some 0.5 per cent. But they are sufficient to account for nearly all of the dipole anisotropy -- and so colour our view of the entire universe (see diagram, right).
Wiltshire emphasises that this is all just Einstein's relativity. "Differential expansion is what you should expect in Einstein's theory," he says. "It is not controversial, it is not surprising, it is the norm, but it is just not the standard model."
He thinks his interpretation could also banish a cosmic spectre raised in 2008 by Alexander Kashlinsky of NASA's Goddard Spaceflight Centre in Greenbelt, Maryland, and some colleagues. Their analysis of 700 galaxy clusters showed that they were being pulled through space in approximately the same direction as the Local Group was supposedly moving.
Kashlinsky's own explanation for this "dark flow" was the gravitational influence of objects created in the very first moments of the big bang and driven far over the horizon of our observable universe by the subsequent period of runaway expansion known as inflation. In Wiltshire's view, the coincidence may be a consequence of us adding in the motion of the Local Group that wasn't there in the first place.

Can of worms

Kashlinsky is unconvinced. "I think that David Wiltshire's study is very important, but in my opinion the data he analyses becomes too noisy to prove his hypothesis," he says.
Physicist Paul Halpern at the University of the Sciences in Philadelphia, Pennsylvania, thinks such studies are worth pursuing, but warns of far-reaching consequences. "Until recently no one doubted that the universe was homogeneous, so everyone just used the simplest models," he says. "Once you say that the universe can be very different in other parts of space, then you open up a can of worms. It would just be incredibly more complex to do cosmology."

Buchert thinks that's precisely the point. His Skype status message, "Dark energy was yesterday", leaves no doubt which dark spectre he is gunning for. He thinks he can kill it off with the same weapon Wiltshire is wielding: inhomogeneity.
Dark energy was invented to explain the puzzling fact that, some 7 billion years ago, the universe's expansion seemingly began to accelerate. This conclusion is intimately tied up with the assumption of uniformity, and how cosmologists use it to extract predictions from Einstein's equations about the history and ultimate destiny of the universe.
Matter causes space and time to curve. Too much matter, and space-time curves so much that it closes in on itself like a four-dimensional sphere, and will eventually crunch back down to nothingness in a reverse of the big bang. Too little matter, and space-time curves outwards, forming an open geometry that expands forever.

Before the 1990s, our universe was thought to contain enough matter to place it almost perfectly between these two extremes. The universe is more or less "flat": its average matter density makes it free from curvature either in or out. In this case, Einstein's equations predict that the universe's expansion will continue forever, though it will be gradually slowed by gravity's attractive effects.
It came as something of a shock in the late 1990s when two groups of astronomers independently trying to measure this slowdown discovered the exact opposite. Dark energy patched things up: an extra term in Einstein's equations representing an additional anti-gravity force to speed the expansion up. Where it came from, and why it waited 7 billion years to make its presence known, we don't know.

Perhaps it came from nowhere -- because it isn't actually there. Buchert has developed models of an inhomogeneous universe that start from the self-same equations of Einstein's that everyone agrees on, but he assumes that the universe is fundamentally divided into voids and clusters of matter. Rather than assuming one average space-time curvature for the whole universe, as the standard model does, Buchert computes the curvature by averaging over this inhomogeneous distribution of matter.
"This is where the elephant jumps into the water," he says. The universe no longer expands equally in all directions. Just as in Wiltshire's picture, a near void on one side of the sky makes the fabric of space in that region expand faster, whereas the gravity of a rich cluster of galaxies will make that area expand more slowly.

Time's ticking

Crucially, though, as the universe has aged and gravity has clumped matter into ever larger galaxies and galaxy clusters, the voids between clusters have grown, and the universe has begun to unfurl ever faster in those regions. The result is an accelerating effect rather like that credited to dark energy -- but without a hint of the stuff (Journal of Cosmology and Astroparticle Physics, vol 10, p 043). "It is not a question of whether this effect is there. There is no doubt about it," says Buchert. "It is a very natural physical theory because it is based on Einstein, but it is not in the standard model."

Natural it might be, but an inhomogeneous, lumpy universe would work very differently to the one we think we know. For a start, Einstein showed that space and time are conjoined entities, so if you allow space to expand at different rates in different places, you must accept that clocks will tick at different speeds, too. That means even such a fundamental property as the age of the universe is not a constant all across the cosmos. Measure it from within a dense cluster and you will get one answer; measure it from within a void and you will get another.

Wiltshire countenanced this possibility in earlier work on a theory he calls the "timescape". This suggests that the age of the universe could be as much as 18.6 billion years in places where a low density of matter means the clock has ticked particularly fast. Our own smaller estimate of the universe's age is a natural consequence of sitting in an area of unusually high density: a galaxy. "The fact that every galaxy appears to have clocks that keep time with ours doesn't mean that the universe has a single age," says Wiltshire. "We just haven't sat down to think what it is about galaxies that makes them special and different."
It's not just the universe's age: depending on whether or not there is any scale on which some sort of "average" universe exists, we may have to accept we have no secure handle on its fate, either. Depending on how much matter might exist in other parts, all possible fates -- a coasting universe, a perpetually expanding one, or one that pulls itself back into a big crunch -- are back on the table.

For Kashlinsky that would be too bitter a pill. He argues that the peerless agreement between the standard-model predictions and observations of how galaxies form, for instance, mean it must be something close to the truth. And the factor of 10 difference in matter density between galaxy clusters and voids isn't enough to justify jettisoning the standard model. "The inhomogeneities are at such a low level that the overall description of the homogeneous universe that we use is a very good assumption," he says. He would rather keep things like dark energy and dark flows -- even if to explain them we must look to theories that leap beyond Einstein.

Buchert, for his part, sees in such resistance an entrenched way of thinking. "The over-simplified model of homogeneity has been around for over 100 years," he shrugs. "In all other disciplines of physics, if you came up with a problem like dark energy, you would improve the model. This has not been done in cosmology. The standard model is believed rather too rigidly, I would say."

Cosmologist John Peacock from the University of Edinburgh, UK, errs on the side of the traditionalists, but concedes there is an open question. "I wish this debate could be put to bed," he says. "In a mathematical science you should be able to home in on the questionable parts and decide who is right. It is disappointing and worrying that we have not been able to do this." Until we do, or until we constrain the nature of cosmology's dark spectres, they will continue to roam free.

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