Zombie physics: 6 baffling results that just won't die

To celebrate Halloween, *Nature* brings you the undead results that physicists can neither prove — nor lay to rest.

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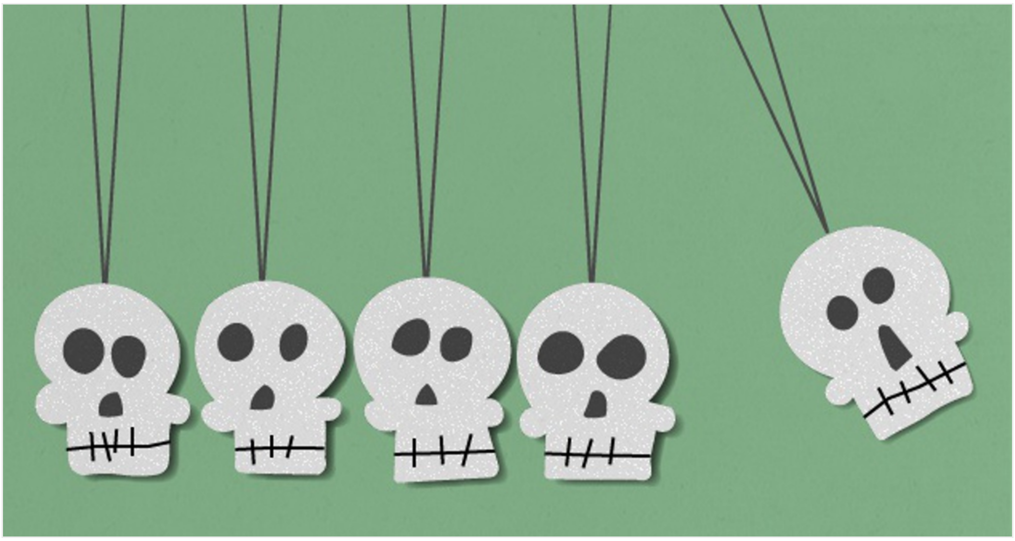
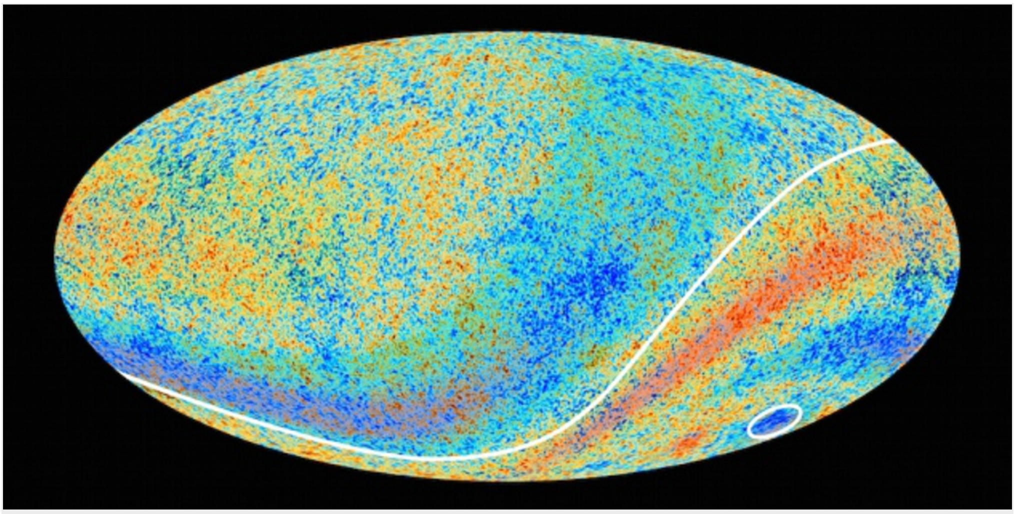


When a scientific result seems to show something genuinely new, subsequent experiments are supposed to either confirm it — triggering a textbook rewrite — or show it to be a measurement anomaly or experimental blunder. But some findings seem to remain forever stuck in the middle ground between light and shadow. Even efforts to replicate these results — normally science's equivalent of Valyrian steel — have little effect. Welcome to the realm of undead physics.

Ahead of Halloween, *Nature* guides you through some findings in physics, astronomy and cosmology that researchers have repeatedly left for dead — only to find that they keep coming back.

Axis of evil

The dim afterglow of the Big Bang, known as the cosmic microwave background (CMB), is virtually uniform in all directions. From one point to another, its temperature varies by less than one part in 100,000. Cosmologists expected these tiny temperature differences to be distributed at random, but in 2003, when NASA's Wilkinson Microwave Anisotropy Probe (WMAP) satellite surveyed the CMB and mapped the fluctuations at different scales, some unexpected patterns emerged[1, 2]. A mysterious cold spot lurked in the southern sky; fluctuations between large areas of the sky were even smaller than expected; and fluctuations at some scales seemed to align along a preferred direction, forming what has been dubbed an 'axis of evil'.



ESA-Planck collaboration

Planck satellite's map of the Cosmic Microwave Background should be blandly uniform but an 'axis of evil' courses through it, and a cold spot lurks in its southern hemisphere.

Some scientists have suggested that these features could be artefacts of WMAP's measurements. But with further observations from WMAP and later by the European Space Agency's Planck mission, the anomalies have refused to go away. "The subject has been in a zombie state for, I guess, ten years," says Kendrick Smith, a cosmologist at the Perimeter Institute for Theoretical Physics in Waterloo, Canada, and a member of the Planck science team.

Some, including Smith, say that the chance of the features occurring randomly might be higher than intuition would suggest because those observed represent just a few of the large number of all possible oddities. Others are searching for phenomena that could explain the unexpected patterns: in particular, the cold spot has been linked to a giant cosmic void[3]. Future experiments that measure the CMB's polarization with higher precision could reveal who is right, Smith says.

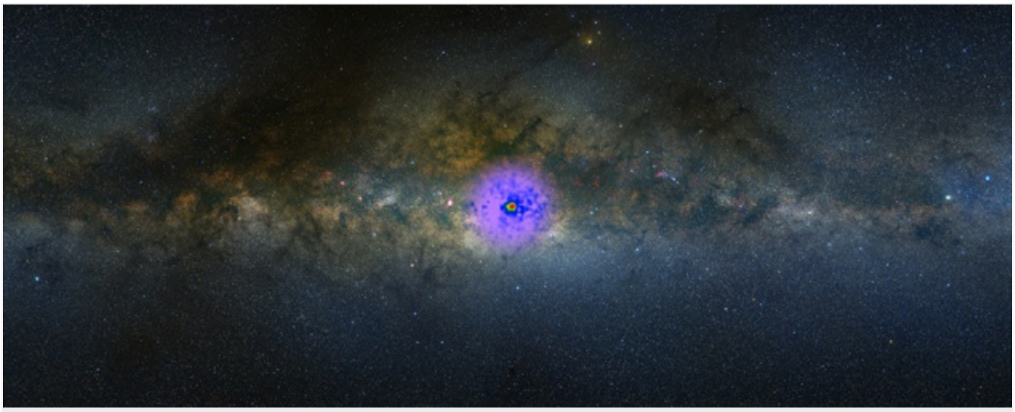
Seasonally spooky dark matter

Like a ghostly wind that can blow through walls, dark matter in the Galaxy should stream through Earth — and even our bodies — continuously from all directions. Thought to make up around 85% of the Universe's matter, the stuff has never been definitively detected. Since the late 1990s, however, physicists on the DAMA experiment, which is situated in a cavernous underground laboratory nestled below Italy's Gran Sasso massif, have been detecting what could be the interactions of dark matter with crystals of sodium iodide. The strength of these signals varies according to a seasonal pattern, which was expected because Earth's velocity should change relative to the surrounding dark matter as it revolves around the Sun [4].

However, there are other phenomena that vary with the seasons that could have created a spurious result, and follow-up experiments all but slayed the DAMA detections — researchers found either no dark matter signals at all[5] or mere hints[6] that many found unconvincing [7]. Still, the DAMA project continues to amass evidence, keeping alive the idea that dark matter has been detected.

No one disputes that the experiment is detecting a seasonal ebb and flow. Whether the variations are caused by dark matter or something else, however, remains unclear. "Nobody has been able to come up with a conclusive argument as to what they're seeing," says Reina Maruyama, a physicist at Yale University in New Haven, Connecticut. Two planned experiments in the southern hemisphere, where the seasons are reversed, could bring a resolution: one called DM-Ice will be embedded in the ice of the South Pole; the other will be in the Stawell Underground Physics Laboratory in Australia, which is currently being built.

Glowing galactic saga



A. Mellinger, CMU; T. Linden, Univ. of Chicago/NASA Goddard

A gamma ray excess at the centre of the Milky Way is freaking out physicists.

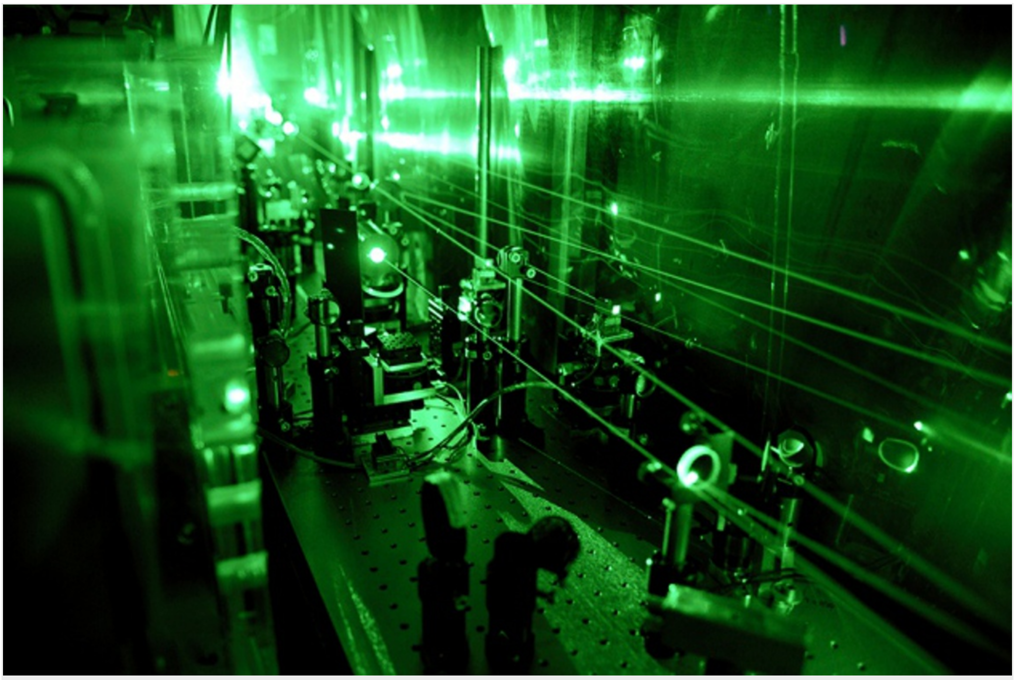
More dark-matter drama has unfolded in space. In 2009, two physicists discovered[8] a mysterious glow in data from NASA's Fermi Gamma-Ray Space Telescope. They say that the electromagnetic radiation, which took the form of γ-rays and seemed to exceed what known sources should produce, could be the result of dark-matter particles concentrating near the centre of the Milky Way and then colliding with and annihilating each other.

Since then, several teams have posited alternative, non-dark-matter explanations for the γ-rays — most recently pulsars[9–12], the remnants of dead stars — only to see dark-matter claims crawl back into existence soon after. In the past few months, Christoph Weniger, a theoretical astrophysicist at the University of Amsterdam in The Netherlands, co-authored papers that presented evidence both for[13] and against[11] a dark-matter source. "I want just to figure out what's going on," he says, adding that he now leans slightly more towards the pulsar explanation.

A long-awaited official analysis by the Fermi team itself, presented in October 2014 and yet to be published, left the matter undecided, says Simona Murgia, a physicist at the University of California, Irvine, who led the analysis. "In the end, we observe an excess, too," she says, "although we cannot say if it's dark matter." [Update 12 November: a paper by the Fermi mission scientists has now been posted on the arXiv online repository and accepted for publication in *Astrophysics Journal*.]

Diabolical proton discrepancy

Given that protons are among the most common and well-studied particles in the Universe, one would expect physicists to have a solid grasp of their size. But in 2010, Randolf Pohl of the Max Planck Institute of Quantum Optics in Garching, Germany, and his team measured the radius of the proton and found it to be 4% smaller than previous estimates[14]. The team used a novel technique that involves replacing the electrons in hydrogen atoms with negatively charged particles called muons, and then measuring subtle shifts in the energy that is required to bump a muon into a higher-energy orbit around the single-proton nucleus. This shift is sensitive to the proton's radius, and muons — which some 200 times more massive than electrons — make it millions of times easier to measure.



PSI/A. Antognini und F. Reiser

The green glow of laser light produced by a facility that measures the radius of the proton.

In 2013, a second study[15] using the muon technique confirmed the discrepancy with previous estimates of proton size, which had come from determinations involving electrons rather than muons. Researchers tried to find flaws in the muon technique, but have now given up. “Nobody questions this experiment,” says Krzysztof Pachucki, a theoretical physicist at the University of Warsaw.

At the same time, no one can work out what could be wrong with the electron-based measurements either. The next suite of experiments, some of which are already running, could potentially solve the problem, says John Arrington, a physicist at the Argonne National Laboratory in Illinois. “It’s a zombie we hope to be able to put back in the ground soon.”

Devilish OMG particles

Tens of millions of times more energetic than particles produced by the most powerful human-made accelerators, ultra-high-energy cosmic rays are a mystery — there is no known phenomenon in the Universe that could create them. In 2007, the Pierre Auger Observatory, with detectors spread over 3,000 square kilometres of Argentina’s Pampas, seemed to be on its way to chasing down the source of these unholy monsters, sometimes nick-named ‘Oh-My-God’ particles. They found[16] that the rays seemed to concentrate in 'hotspots' in the vicinity of particular galaxies, suggesting that they might originate in the overheated matter surrounding supermassive black holes at the galaxies' centres. But as the observatory accumulated more data, the link waned.

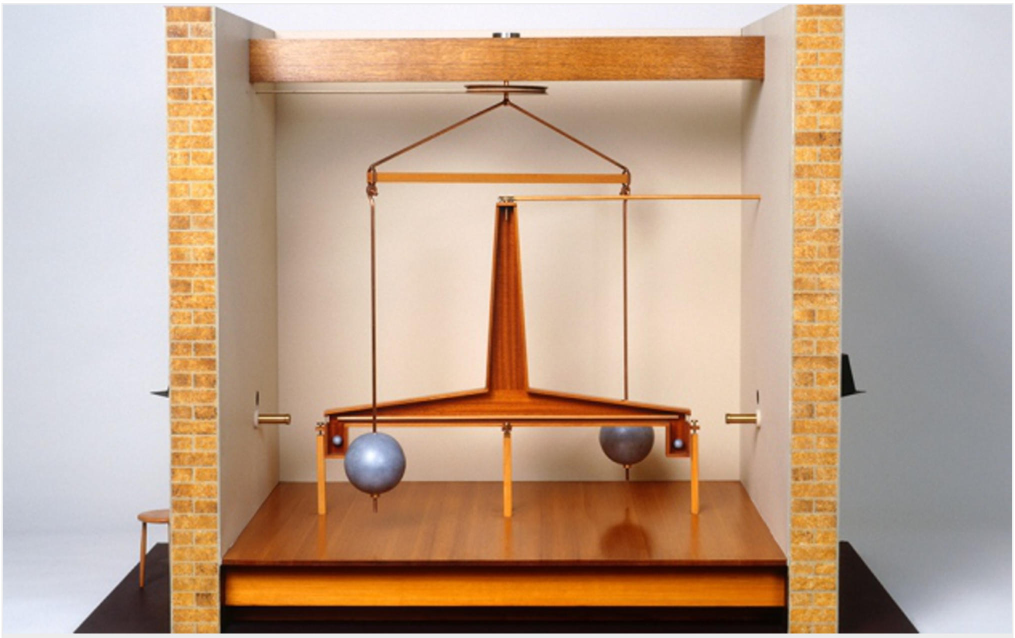
NASA Goddard/A. Mellinger/T. Linden

A black hole at the centre of the galaxy Centaurus A is a potential source of ultra high energy cosmic rays...or is it?

Just as the idea that there might be hotspots of OMG particles seemed left for dead, a fresh hotspot in the Northern Hemisphere was detected by a smaller, Japanese-led experiment in Utah called the Telescope Array. At this stage, the concentration is more phantom than fully-fledged zombie because its statistical significance is low[17]. And the experiment sees only two or three events each year, so it could take some time to find a resolution. To speed things up, the collaboration plans to nearly quadruple the size of the array to fill about 2,500 square kilometres, a project expected to take three years.

Eternal fluctuations of Big *G*

What exactly is the strength of gravity? Surprisingly, physicists still can't agree on the value of the 'big *G*' constant that features both in Isaac Newton's law of gravitation — which dates back to the year 1687 — and in Albert Einstein's general theory of relativity. Different experimental techniques have found contradictory values for it. And the entrance of experiments based on quantum physics that exploit the wave-like aspects of matter have only made the discrepancy worse.



DK/UIG/SPL

In 1798, British natural philosopher Henry Cavendish used an instrument like this to measure Big G, but physicists still can't agree on its true value.

An initiative to get labs from around the world to join forces to find a solution is under way. But fresh ideas are needed, says John Gillaspy, who heads the Atomic, Molecular, and Optical Experimental Physics Program at the US National Science Foundation (NSF). The NSF will sponsor a brainstorming session next year at which researchers from different branches of physics will spend a week trying to come up with a strategy to solve the discrepancy. "Or, people could end up saying that they don't know how to solve this problem. That's a possible outcome we don't want," Gillaspy says.

It is also possible that the discrepancy points not to a measurement problem but to something completely new. Some physicists have suggested that different techniques give different results because the physics of gravity itself needs to be revised. If so, this zombie could be a beautiful new life form in disguise.

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Updates

Updated: The article 'Glowing galactic saga' has been updated to mention that the Fermi collaboration's results are now due to be published.

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