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Our World may be a Giant Hologram

by Marcus Chown

New Scientist / January 15, 2009



Driving through the countryside south of Hanover, it would be easy to miss the **GEO600 experiment** (<http://geo600.aei.mpg.de/>). From the outside, it doesn't look much. In the corner of a [field](#) stands an assortment of boxy temporary buildings from which 2 long trenches emerge at a right angle to each other covered with corrugated iron. Underneath the metal sheets, however, lies a [detector that stretches for 600 meters](#).



The gravitational wave detector GEO600 in Ruthe near Hannover. In the front, the central building for the laser and the vacuum tanks can be seen. The tubes (600 m in length) run in covered trenches at the edge of the field upwards and to the right. Buildings for the mirrors are situated at the end of each tube.

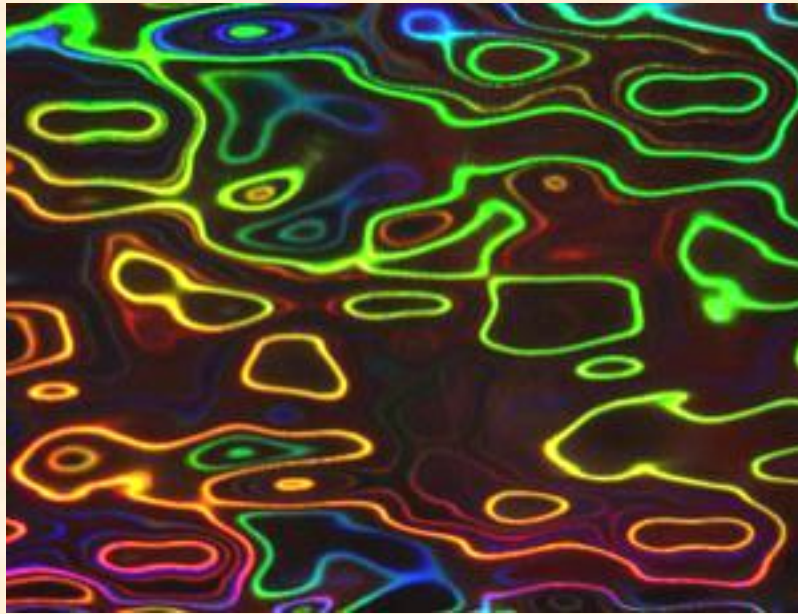
Credit: Albert Einstein Institute Hannover

For the past 7 years, this German set-up has been looking for **gravitational waves** -- ripples in space-time thrown off by super-dense astronomical objects such as neutron stars and black holes. GEO600 has not detected any gravitational waves so far. But it might inadvertently have made the most important discovery in Physics for half-a-century.

For many months, the GEO600 team-members had been scratching their heads over inexplicable noise that is plaguing their giant detector. Then out of the blue, a researcher approached them with an explanation. In fact, he had even predicted the noise before he knew they were detecting it.

According to Craig Hogan (a physicist at the Fermilab particle physics lab in Batavia, Illinois), GEO600 has stumbled upon the fundamental limit of space-time -- i.e., the point where space-time stops behaving like the smooth continuum Einstein described and instead dissolves into "grains" just as a newspaper photograph dissolves into dots as you zoom in. "It looks like GEO600 is being buffeted by the microscopic quantum convulsions of space-time," says Hogan.

If this doesn't blow your socks off, then Hogan -- who has [just been appointed](#) director of Fermilab's Center for Particle Astrophysics -- has an even bigger shock in store. "If the GEO600 result is what I suspect it is, then we are all living in a giant Cosmic Hologram."



Could our 3 dimensions be the ultimate cosmic illusion? A German detector is picking up a hint that we are all mere projections. (Image: Ledomira/Stock.xchng)

The idea that we live in a hologram probably sounds absurd. But it is a natural extension of our best understanding of black holes and something with a pretty firm theoretical footing. It has also been surprisingly helpful for physicists wrestling with theories of how the Universe works at its most fundamental level.

The [holograms](#) that you find on credit cards and banknotes are etched on 2-dimensional plastic films. When light bounces off them, it recreates the appearance of a 3-D image. In the 1990s, physicists Leonard Susskind and Nobel prizewinner Gerard 't Hooft suggested that the same principle might apply to the Universe as a whole. Our everyday experience might itself be a holographic projection of physical processes that take place on a distant 2-D surface.

The "Holographic Principle" challenges our sensibilities. It seems hard to believe that you woke up, brushed your teeth, and are reading this article because of something happening on the boundary of the Universe. No one knows what it would mean for us if we really do live in a hologram. Yet theorists have good reasons to believe that many aspects of the Holographic Principle are true.

Susskind and 't Hooft's remarkable idea was motivated by ground-breaking work on black holes by Jacob Bekenstein of the Hebrew University of Jerusalem in Israel and [Stephen Hawking](#) at the University of Cambridge. In the mid-1970s, Hawking showed that black holes are in fact not entirely "black" but instead slowly emit radiation which causes them to evaporate and eventually disappear.

This poses a puzzle because Hawking radiation does not convey any information about the interior of a black hole. When the black hole has gone, all the information about the star that collapsed to form the black hole has vanished, which contradicts the widely affirmed principle that information cannot be destroyed. This is known as the "[black hole information paradox](#)".

Bekenstein's work provided an important clue in resolving the paradox. He discovered that a black hole's entropy -- which is synonymous with its information content -- is proportional to the surface area of its "event horizon". This is the theoretical surface that cloaks the black hole and marks the point of no return for infalling matter or light. Theorists have since shown that microscopic quantum ripples at the

event horizon can encode the information inside the black hole. So there is no mysterious information loss as the black hole evaporates.

Crucially, this provides a deep physical insight. The 3-D information about a precursor star can be completely encoded in the 2-D horizon of the subsequent black hole -- not unlike the 3-D image of an object being encoded in a 2-D hologram.

Susskind and 't Hooft extended the insight to the Universe as a whole on the basis that the Cosmos has a "horizon" too (i.e., the boundary from beyond which light has not had time to reach us in the 13.7-billion-year lifespan of the Universe).

What's more, work by several string theorists -- most notably [Juan Maldacena](#) at the Institute for Advanced Study in Princeton -- has confirmed that the idea is on the right track. He showed that the physics inside a hypothetical universe with 5 dimensions and shaped like a Pringle is the same as the physics taking place on the 4-dimensional boundary.

According to Hogan, the Holographic Principle radically changes our picture of space-time. Theoretical physicists have long believed that quantum effects will cause space-time to convulse wildly on the tiniest scales. At this magnification, the fabric of space-time becomes grainy and is ultimately made of tiny units rather like pixels but a hundred billion billion times smaller than a proton. This distance is known as the Planck length (a mere 10^{-35} meters. The Planck length is far beyond the reach of any conceivable experiment. So nobody dared dream that the graininess of space-time might be discernable.

That is, not until Hogan realized that the Holographic Principle changes everything. If space-time is a grainy hologram, then you can think of the Universe as a sphere whose outer surface is papered in Planck length-sized squares, each containing one bit of information. The Holographic Principle says that the amount of information papering the outside must match the number of bits contained inside the volume of the Universe.

Since the volume of the spherical Universe is much bigger than its outer surface, how could this be true? Hogan realized that in order to have the same number of bits inside the Universe as on the boundary, the world inside must be made up of grains bigger than the Planck length. "Or to put it another way, a holographic universe is blurry," says Hogan.

This is good news for anyone trying to probe the smallest unit of space-time. "Contrary to all expectations, it brings its microscopic quantum structure within reach of current experiments," says Hogan. So while the Planck length is too small for experiments to detect, the holographic "projection" of that graininess could be much, much larger at around 10^{-16} meters. "If you lived inside a hologram, you could tell by measuring the blurring," he says.

When Hogan first realized this, he wondered if any experiment might be able to detect the holographic blurriness of space-time. That's where GEO600 comes in.

Gravitational wave detectors like GEO600 are essentially fantastically sensitive rulers. The idea is that if a gravitational wave passes through GEO600, it will alternately stretch space in one direction and squeeze it in another.

To measure this, the GEO600 team fires a single laser through a half-silvered mirror called a beam splitter. This divides the light into two beams, which pass down the instrument's 600-meter perpendicular arms and bounce back again. The returning light beams merge together at the beam

splitter and create an interference pattern of light and dark regions where the light waves either cancel out or reinforce each other. Any shift in the position of those regions tells you that the relative lengths of the arms has changed.

"The key thing is that such experiments are sensitive to changes in the length of the rulers that are far smaller than the diameter of a proton," says Hogan.

So would they be able to detect a holographic projection of grainy space-time? Of the 5 gravitational wave detectors around the World, Hogan realized that the Anglo-German GEO600 experiment ought to be the most sensitive to what he had in mind. He predicted that if the experiment's beam splitter is buffeted by the quantum convulsions of space-time, this will show up in its measurements ([*Physical Review D*, vol 77, p 104031](#)). "This random jitter would cause noise in the laser light signal," says Hogan.



In June, he sent his [prediction](#) to the GEO600 team. "Incredibly, I discovered that the experiment was picking up unexpected noise," says Hogan.

GEO600's principal investigator Karsten Danzmann of the [Max Planck Institute for Gravitational Physics](#) in Potsdam, Germany and also the University of Hanover admits that the excess noise -- with frequencies of between 300 and 1500 Hertz -- had been bothering the team for a long time. He replied to Hogan and sent him a plot of the noise.

"It looked exactly the same as my prediction," says Hogan. "It was as if the beam splitter had an extra sideways jitter."

No one -- including Hogan -- is yet claiming that GEO600 has found evidence that we live in a holographic Universe. It is far too soon to say. "There could still be a mundane source of the noise," Hogan admits.

Gravitational-wave detectors are extremely sensitive. So those who operate them have to work harder than most to rule out noise. They have to take into account passing clouds; distant traffic; seismological rumbles and many, many other sources that could mask a real signal.

"The daily business of improving the sensitivity of these experiments always throws up some excess noise," says Danzmann. "We work to identify its cause, get rid of it and tackle the next source of excess noise."

At present, there are no clear candidate sources for the noise GEO600 is experiencing. "In this respect, I would consider the present situation unpleasant, but not really worrying."

For a while, the GEO600 team thought the noise that Hogan was interested in was caused by fluctuations in temperature across the beam splitter. However, the team worked out that this could account for only one-third of the noise at most.

Danzmann says several planned upgrades should improve the sensitivity of GEO600 and eliminate some possible experimental sources of excess noise. "If the noise remains where it is now after these measures, then we have to think again," he says.

If GEO600 really has discovered holographic noise from quantum convulsions of space-time, then it presents a double-edged sword for gravitational wave researchers. On one hand, the noise will handicap their attempts to detect gravitational waves. On the other, it could represent an even more fundamental discovery.

Such a situation would not be unprecedented in Physics. Giant detectors built to look for a hypothetical form of radioactivity in which protons decay never found such a thing. Instead, they discovered that neutrinos can change from one type into another. It is arguably more important because it could tell us how the Universe came to be filled with matter and not anti-matter ([*New Scientist*, 12 April 2008, p 26](#)).

It would be ironic if an instrument built to detect something as vast as astrophysical sources of gravitational waves inadvertently detected the minuscule graininess of space-time. "Speaking as a fundamental physicist, I see discovering holographic noise as far more interesting," says Hogan.

Small Price To Pay

Despite the fact that if Hogan is right and holographic noise will spoil GEO600's ability to detect gravitational waves, Danzmann is upbeat.

"Even if it limits GEO600's sensitivity in some frequency range, it would be a price we would be happy to pay in return for the first detection of the graininess of space-time," he says. "You bet we would be pleased! It would be one of the most remarkable discoveries in a long time."

However, Danzmann is cautious about Hogan's proposal and believes that more theoretical work needs to be done. "It's intriguing," he says. "But it's not really a theory yet -- more just an idea."

Like many others, Danzmann agrees that it is too early to make any definitive claims. "Let's wait and see," he says. "We think it's at least a year too early to get excited."

The longer the puzzle remains, however, the stronger the motivation becomes to build a dedicated instrument to probe holographic noise. **John Cramer** of the University of Washington in Seattle agrees. It was a "lucky accident" that Hogan's predictions could be connected to the GEO600 experiment, he says. "It seems clear that much better experimental investigations could be mounted if they were

focused specifically on the measurement and characterization of holographic noise and related phenomena."

One possibility according to Hogan would be to use a device called an **atom interferometer**. These operate using the same principle as laser-based detectors but use beams made of ultra-cold atoms rather than laser light. Because atoms can behave as waves with a much smaller wavelength than light, atom interferometers are significantly smaller and therefore cheaper to build than their gravitational-wave-detector counterparts.

So what would it mean if holographic noise has been found? Cramer likens it to the [discovery](#) of unexpected noise by an antenna at Bell Labs in New Jersey in 1964. That noise turned out to be the cosmic microwave background (i.e., the afterglow of the 'Big Bang' fireball). "Not only did it earn Arno Penzias and Robert Wilson a [Nobel prize](#). But it also confirmed the 'Big Bang' and opened up a whole field of [Cosmology](#)," says Cramer.

Hogan is more specific. "Forget 'Quantum of Solace'. We would have directly observed the quantum of [time](#)," says Hogan. "It's the smallest possible interval of time -- the Planck length divided by the speed-of-light."

More importantly, confirming the Holographic Principle would be a big help to researchers trying to unite Quantum Mechanics and Einstein's Theory of Gravity. Today, the most popular approach to quantum gravity is **string theory** which researchers hope could describe happenings in the Universe at the most fundamental level. But it is [not the only show in town](#).

"Holographic space-time is used in certain approaches to quantizing gravity that have a strong connection to string theory," says Cramer. "Consequently, some quantum gravity theories might be falsified and others reinforced."

Hogan agrees that if the Holographic Principle is confirmed, it rules out all approaches to quantum gravity that do not incorporate the principle. Conversely, it would be a boost for those that do including some derived from string theory and something called **matrix theory**. "Ultimately, we may have our first indication of how space-time emerges out of quantum theory."

As serendipitous discoveries go, it's hard to get more ground-breaking than that.

[StealthSkater note: more on holographic perceptions of Reality is archived on the "[Science#Emergent](#)" page at => [doc](#) [pdf](#) [URL](#)]

Readers' Comments

1. How Many D-s Are We Talking About?

by Marek / Wed Jan 14, 2009 23:17:06 GMT

So our World (the hologram) has 4 dimensions and the actual information is encoded in 3-D?
Or should time be discounted here?

2. by whipster / Thu Jan 15, 2009 13:37:45 GMT

I don't know. But I imagine that time shouldn't be discounted. So I'd be inclined to agree with you.

Would all of this mean that it is in fact possible that the entirety of our Universe is inside a black hole with each 'bit' being encoded as a 'bit' on the event horizon as quantum fluctuations of the black hole that contains it? (as per the analogy in the article describing a sphere covered in paper containing bits)

That would mean that there is in fact an infinite amount of universes all holographically projected from black holes in a sort of fractal arrangement.

Imagine when a black hole is formed from a collapsing star, a holographic 'Big Bang' is occurring with the only observable part to us being the encoded bits on its event horizon.

I'm nowhere smart enough to draw conclusions like that. But if that were the case, how interesting would that be!

3. Not So Sure

by JoJo McGillicuddy / Thu Jan 15, 2009 02:13:53 GMT

Fascinating stuff. But somehow I don't feel I know any more now than I did before reading this article. Seems that we are ALWAYS on the verge of some huge, totally earth-shattering theoretical advancement. But all I ever seem to read are articles talking about some scientist out there who is feverishly working on proof that just never seems to come.

What I want to read is the story about the BIG breakthrough. The one that changes everything and the big splashy parade for the guy who proved it -- this one theory that is actually proven and accepted and every bit as shattering as predicted and I want it to affect every facet of my daily life.

Somehow, I don't expect to ever hear that these ideas have been proven or that anything has come of it. But hey! I'm an idiot, I admit it, so what do I know? I just have no use at all for anything that's still just an interesting possibility. It's really starting to irritate me. I'm frustrated because Science literally OWES US another big revelation (and I mean a BIG, BIG ONE!)

C'mon, Poindexters! Make with the breakthroughs or I'm going back to taking your lunch money and beating you up during recess!

4. The Author Has Not Interpreted The Best Part.

by Alex / Thu Jan 15, 2009 08:24:56 GMT

While I don't understand how discovering the fundamental graininess of the space/time union that allows our World to exist and us to make sense of it, what would it imply if our Universe IS a hologram?

5. Nonsense

by Slobodan / Thu Jan 15, 2009 10:22:07 GMT

What nonsense! Are those guys paid to invent such stupidities? With the increasing entropy of the Universe, it seems that the Mankind stupidity entropy is also increasing.

Hawking evaporation is so far just a mathematical abstraction with some leaks and flaws in the theory. Besides, this theory is based also on some artificially-constructed assumptions and generalizations in order to be proven. There are some serious concerns that point against his theory.

So, the most probable, black holes are stable and do not lose their mass due to the Hawking radiation. Besides, although there were a lot of efforts to observe potential Hawking radiation around suspected black holes, none of the measurements ever confirm its existence.

What a waste of time and resources that could be used to make a real breakthrough in our Science!

Hawking radiation could be --maybe -- confirmed or discarded if LHC succeed to produce MBH (microscopic black holes). If Hawking radiation exists like he predicts, microscopic black holes are evaporating very fast comparing to normal types.

So if scientists in CERN on the LHC really succeed to make MBH, they will evaporate faster than create matter from Earth, thus making no treat to the Planet. If Hawking is wrong, than MBH (if produced in LHC) will not evaporate faster or not evaporate at all. And what's more, they should possibly have to low momentum to leave Earth's gravitational pool. Some of MBH will fall down to the Earth's core, continuing to create matter from the core, swallowing Earth gradually until we get sucked.

And of course, all of this mentioned counts only in the case that LHC can really produce MBH as some of CERN scientists predict it could!

This "Holographic Universe" theory is a complete nonsense, pseudo-scientific garbage, a handful of abstractions based on unconfirmed theories on the very edge of science, more metaphysical than physical. They got some strange noise in their very sensitive instruments and thus getting an idea about holographic Universe??? WOW! What an imagination of the SF writers.

It seems that entropy is not applicable only on physical world, it could also be applied also in human thinking giving us more entropy, more chaos in scientific world with a large number of mindless ideas.

6. Confusing or Not Confusing?? You Tell Me!!

by Alex Morbach / Thu Jan 15, 2009 13:43:20 GMT

I just don't know what to believe anymore. First, there comes the Loop-Quantum Theory and now this Theory. What are we supposed to believe??

It's like that with every new issue of *New Scientist* comes a new theory about the Universe is created. I'm asking myself what theory is correct and if we are ever going to get somewhere with all this theories of the Universe!!!

What do you think?? Tell me, please!!

7. by 2smrt4u / Thu Jan 15, 2009 15:12:46 GMT

Both theories can be correct. I believe that it was discussed in an earlier paper. If the quantum loops are at the boundaries of the Universe and their interplay is what causes the hologram, then both theories can be correct just the interpretation. Or one theory could be held within the other. (For example, if the loops are due to the boundary pixel interactions.)

Quantum fluctuations could be the result of the blurriness discussed in this paper.

8. Wave-Particle Duality

by ian / Thu Jan 15, 2009 14:07:28 GMT

This ties in with wave-particle duality. Real point particles also have a fundamental wave nature. Much like a hologram image of any solid article. Articles looks like a solid but are actually a space full of light waves from a 2-D surface.

This may also tie in with recent maths which showed that space time must be 2-D at very small scales and 4-D at "normal" scales.

9. Dead Pixels

by x / Thu Jan 15, 2009 14:21:03 GMT

What if the screen gets a dead pixel? Or if the equivalent to a mercury light bulb that is projecting matter through the Universe blows?

Was the 'Big Bang' somebody changing the bulb?

10. What Does The Projecting, then??? No Physics Below 10nm if this is correct

by Punter / Thu Jan 15, 2009 14:45:26 GMT

If the Universe is a hologram, then just what is doing the projecting to make it real?

I see the argument of the analogy that somehow the Universe is a big black hole. And they account for what goes on in the inside by what goes on at the boundary. But I have trouble with this boundary. Is it 3-D?

Then what of this Planck scale? If the boundary is $4\pi r^2$ and the volume is $4/3\pi r^3$, then the 'voxels' (i.e., 3-D pixels) would scale linearly with Universe size. And being some 14 billion lightyears across, we would see no physics smaller than the Planck length * 14 billion light years (i.e., about 10nm).

Seems bogus.

11. Bits Encoded

by 2smrt4u / Thu Jan 15, 2009 15:05:48 GMT 2009

"The Holographic Principle says that the amount of information papering the outside must match the number of bits contained inside the volume of the Universe."

Each bit of information on the outside (or "pixel") could be used to encode several internal bits. So the actual amount of information papering the outside does not need to be the same as the bits inside.

The end result is that nothing changes for us. We still breathe, eat, sleep, etc. So what difference to our lives will this make? None. The only thing it will change is how we describe our Universe and the laws of Physics within it. Nothing else will change.

12. Experiments In Space

by Billy / Thu Jan 15, 2009 15:32:41 GMT

They need to conduct these experiments in Space to eliminate the passing clouds, distant traffic, seismological rumbles and many, many other sources that could mask a real signal to get a better reading.

13. Our World May Be A Giant Hologram

by R Thomson / Thu Jan 15, 2009 15:39:03 GMT

Is this the answer to the biblical "*In my Father's house, there are many mansions*"? I think we should be told.

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