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The holographic secret of black holes

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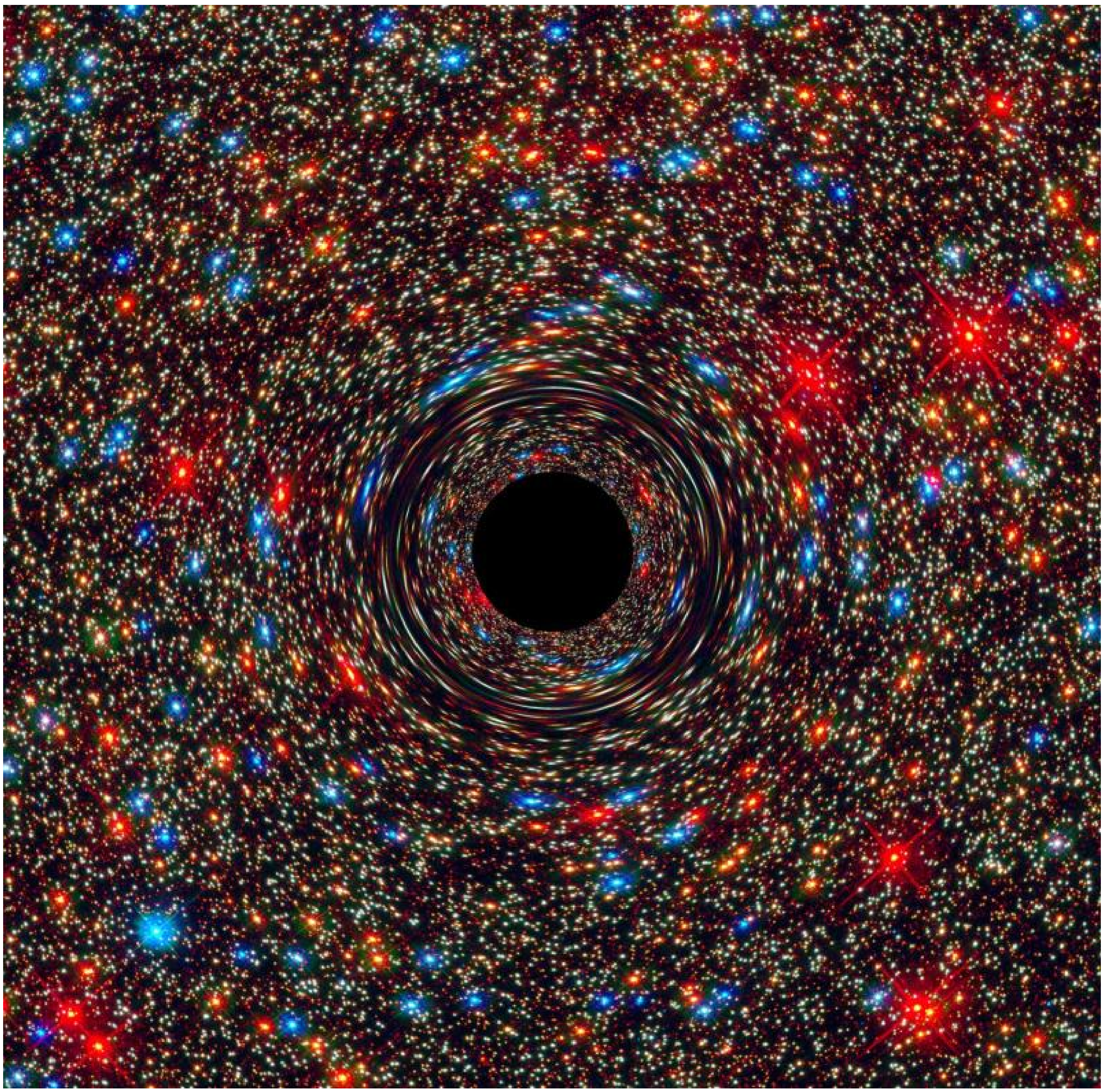

This computer-simulated image shows a supermassive black hole at the core of a galaxy. The black region in the center represents the black hole's event horizon, where no light can escape the massive object's gravitational grip. The black hole's powerful gravity distorts space around it like a funhouse mirror. Light from background stars is stretched and smeared as the stars skim by the black hole. Credit: NASA, ESA, and D. Coe, J. Anderson, and R. van der Marel (STScI)

As weird as it might sound, black holes appear to be holograms.

In the 1980s physicist Jacob Bekenstein was able to calculate exactly how much a black hole grew. If you add a single bit of information to a black hole, its surface area increases by exactly one Planck unit.

A Planck length the smallest possible measurable distance, roughly 10^{-35} meters, and is important because it's right around that scale where our understanding of physics completely breaks down. Specifically, it's at that scale that we believe that we require a quantum theory of gravity to understand what's going on. A Planck area is this length squared, and it's by this amount that a black hole grows. It could have been literally any other number in the cosmos, but instead it's this specific one.

When we add information to a black hole, it responds in a uniquely quantum gravitational way, unlike any other system in the cosmos.

It seems as if the information entering a black hole is tied more to its surface than to its volume. Its two-dimensional surface. Whatever information we pour onto the event horizon seems to stay there, responding directly to that information. It seems as if we are encoding all the three-dimensional information about what constructed and what fell into black holes on their two-dimensional surfaces.

It seems as if black holes are holograms.

What in the world do black holes have to do with holograms? Why are the only accessible places in the universe where quantum mechanics and gravity meet—namely, black hole event horizons—operating counterintuitively where their surfaces respond to information more than their volumes do? Nature is trying to teach us something, but we can only discern the lesson in faint whispers.

So let's take nature's hand and see where this trail goes. If black holes are holograms, and black holes are quantum gravity made manifest, then perhaps we are beginning to dimly see, through a hazy and shifting glass like Galileo when he first trained his homespun optics on the sky, that a quantum theory of gravity must be holographic in nature, and that holography has tremendously powerful implications for not just how we view arcane mathematical physics, but the extent of reality itself.

This is the line of reasoning behind the holographic principle, and a statement containing no more than three words that completely and utterly decimates our understanding of space, time, matter, and energy: we live in a hologram.

The next, and perhaps the last, gravitational revolution is upon us. It starts with the observation that black holes are regions of maximum entropy in the universe, and that their consumption of information content causes their surface areas, not their volumes, to grow in proportion. And it ends with a completely new understanding of gravity.

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