Scientists find a new way to see inside black holes

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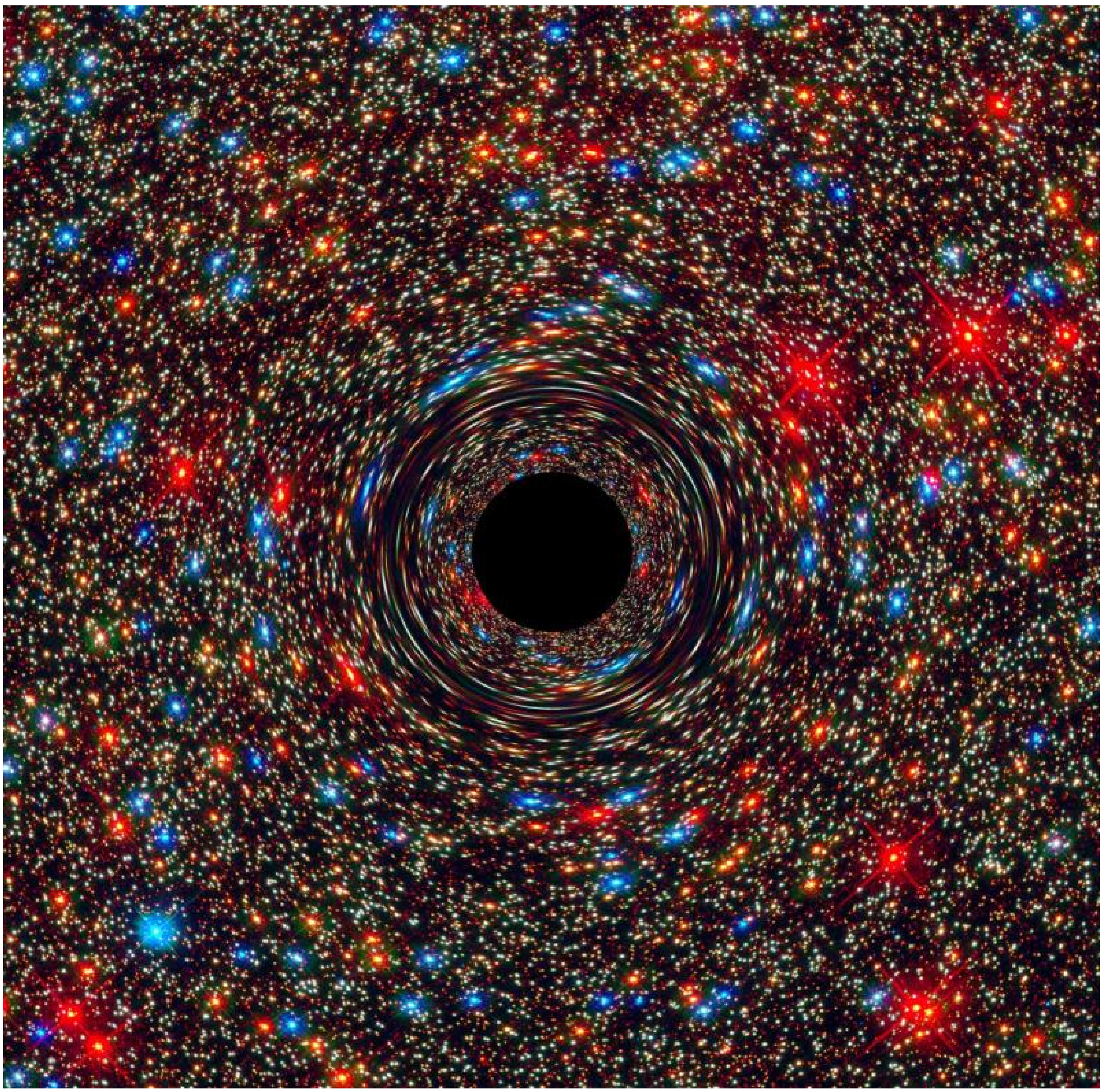

This computer-simulated image shows a supermassive black hole at the core of a galaxy. The black region in the center represents the black hole's event horizon, where no light can escape the massive object's gravitational grip. The black hole's powerful gravity distorts space around it like a funhouse 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)

Scientists at Towson University and the Johns Hopkins University are reporting a new way to peer through the event horizons around black holes and visualize what lies beneath. Their results could rewrite conventional ideas about the internal structure of spinning black holes. Current approaches use special coordinate systems in which this structure appears quite simple, but quantities that depend on an observer's choice of coordinates can give a distorted view of reality, as anyone knows who has compared the size of Greenland and the USA on a map.

The new approach focuses exclusively on mathematical quantities known as invariants, which have the same value for any choice of coordinates. Expressed in terms of these quantities, black hole interiors reveal a much more intricate and complicated structure than usually thought, with wild variations in curvature from place to place.

These new findings are timely for two reasons, according to Towson University's Kielan Wilcomb, who presented the team's results yesterday at the 228th meeting of the American Astronomical Society in San Diego. First, 2016 is the centennial year of the publication of the theory that first predicted the existence of black holes: Einstein's general theory of relativity. Second, the existence of these objects is no longer a matter of theory, but observational fact. Last September astronomers at the LIGO gravitational-wave observatory detected the first ripples in spacetime from a collision between giant black holes in a distant galaxy.

But while we now know they exist, we will never be able to look inside them, notes team member James Overduin, also of Towson University, since no information can emerge from beyond a black hole's event horizon. Their interiors are, by definition, places that can only be explored mathematically. The new results are thus important in a unique sense. Scientists usually observe first, and then attempt to classify and understand their observations using theory. With black holes this usual course of discovery is reversed: we have a satisfactory theory, but are still groping for the best way to visualize it.

The physical significance of the curvature invariants calculated by Wilcomb, Overduin and Richard C. Henry of the Johns Hopkins University is not yet clear. For the most general black holes (those with mass, spin and electric charge) there are seventeen of these quantities altogether, but they can be related to each other mathematically so that only five are truly independent. Explicit mathematical expressions for some are presented here for the first time. The simplest, known as the Ricci scalar, lies at the heart of general relativity theory. Another, the Weyl invariant, plays an analogous role in one of the few serious alternatives to Einstein's theory, known as conformal gravity. For black holes with no electric charge (as expected for the vast majority of real, astrophysical black holes, since they will tend to neutralize themselves with time) this invariant is equivalent to another quantity known as the Kretschmann scalar.

The team's results confirm that the wild fluctuations in the value of this quantity near the singularity inside a spinning black hole include regions of negative curvature, which are associated physically with a phenomenon known as gravitomagnetism (the gravitational analog of ordinary magnetism). Gravitomagnetic fields, fed by rotational energy, are believed to be responsible for generating the tremendous jets which emanate from the poles of supermassive black holes at the centers of some galaxies. A clearer map of curvature inside the horizon, Henry emphasizes, could enable astronomers to understand why such jets exist in some galaxies and not others (including our own).

More information: "A New Way to See Inside Black Holes," R. C. Henry, J. M. Overduin & K. Wilcomb, 2015, Bridges Baltimore 2015: Mathematics, Music, Art, Architecture, Culture (Phoenix, AZ: Tessellations Publishing, 2015) and presented at the 228th meeting of the American Astronomical Society in San Diego, Calif. aas.org/meetings/aas228, *Arxiv*: arxiv.org/abs/1512.02762

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