New law implies thermodynamic time runs backwards inside black holes

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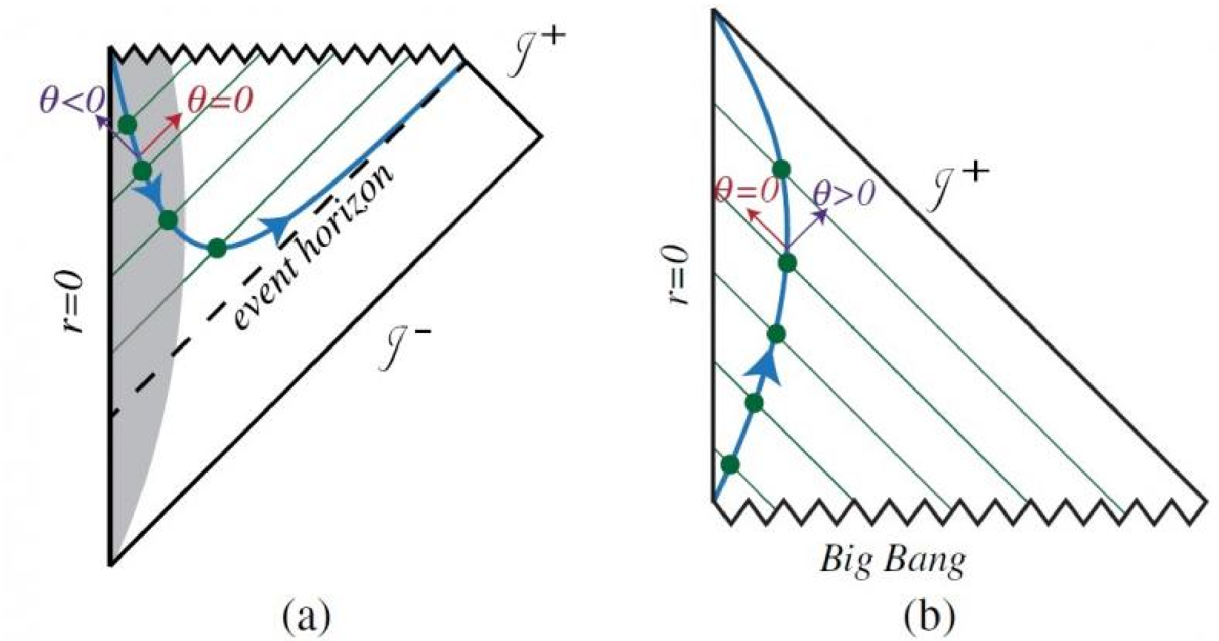

The new area law states that the area of a future holographic screen (the solid blue line in [a]) is always increasing in one direction, while the area of a past holographic screen (the solid blue line in [b.]) is always increasing in a different direction. Credit: Bousso and Engelhardt. ©2015 American Physical Society

(Phys.org)—Black holes are known to have many strange properties, such as that they allow nothing—not even light—to escape after falling in. A lesser known but equally bizarre property is that black holes appear to "know" what happens in the future in order to form in the first place.

However, this strange property arises from the way in which black holes are defined, which has motivated some physicists to explore alternative definitions.

In a new paper published in *Physical Review Letters*, Raphael Bousso, a professor at the University of California, Berkeley, and Lawrence Berkeley National Laboratory, and Netta Engelhardt, a graduate student at the University of California, Santa Barbara, have reported a new area law in general relativity that is based on an interpretation of black holes as curved geometric objects called "holographic screens."

"The so-called teleology of the black hole event horizon is an artifact of the way in which physicists define an event horizon: the event horizon is defined with respect to infinite future elapsed time, so by definition it 'knows' about the entire fate of the universe," Engelhardt told *Phys.org*. "In general relativity, the black hole event horizon cannot be observed by any physical observer in finite time, and there isn't a sense in which the black hole as an entity knows about future infinity. It is simply a convenient way of describing black holes."

As Engelhardt explained, one reason why holographic screens are so interesting is that they are defined in a way which depends on more local properties and does not require information about future infinity.

"This is one property that makes objects like holographic screens so appealing: they do not suffer from such bizarre properties in the way in which they are defined," she said.

In their paper, the physicists report a new area law that tells in which direction the area of a holographic screen increases, which depends on whether the screen is a "future holographic screen" or a "past holographic screen." As the scientists explain, these two types of screens correspond to different types of gravitational fields.

"Holographic screens are in a sense a local boundary to regions of strong gravitational fields," Engelhardt said. "Future holographic screens correspond to gravitational fields which pull matter together (e.g., black hole, big crunch), whereas past holographic screens correspond to regions which spread matter out (e.g., big bang, white hole)."

The new area law states that the area of a future holographic screen is always increasing in one direction, while the area of a past holographic screen is always increasing in a second (different) direction. This law has some intriguing interpretations when viewed from a thermodynamic perspective and using the idea that spacetime is a hologram. According to the holographic principle, the amount of information or entropy in a given area is related to the surface area. So by interpreting the area as a bound on the entropy, the area law can reveal the direction of thermodynamic time (which, as the scientists note, is not the same as mathematical time).

Because the area of future and past holographic screens increases in different directions, the direction of time is different for the two types of screens. In past screens, time moves forward. Expanding universes, such as ours, involve past holographic screens, and so we naturally perceive thermodynamic time as running forward. In contrast, time runs backward in future holographic screens. In a sense, this interpretation has the odd result that thermodynamic time runs backward inside black holes and collapsing universes.

The scientists also note in their paper that this is the first new broadly applicable area law in general relativity since 1971, when Stephen Hawking showed that a black hole's event horizon (and therefore its total surface area) never gets smaller. Later, however, Hawking showed that, in the presence of quantum effects, black holes emit radiation. This emission causes a black hole's event horizon, surface area, and mass to decrease over time, so that the black hole eventually evaporates. In the absence of quantum effects, however, the Hawking area law still holds.

This is also one area of future research for Bousso and Engelhardt—to investigate how the new area law may hold up in the presence of quantum effects.

"Our area law holds in the absence of quantum effects, and we hope in the future to prove a more generalized area law which will hold more generally in the presence of certain quantum effects," Engelhardt said.

More information: Raphael Bousso and Netta Engelhardt. "A New Area Law in General Relativity." *Physical Review Letters*. DOI: 10.1103/PhysRevLett.115.081301