Study finds flaw in emergent gravity

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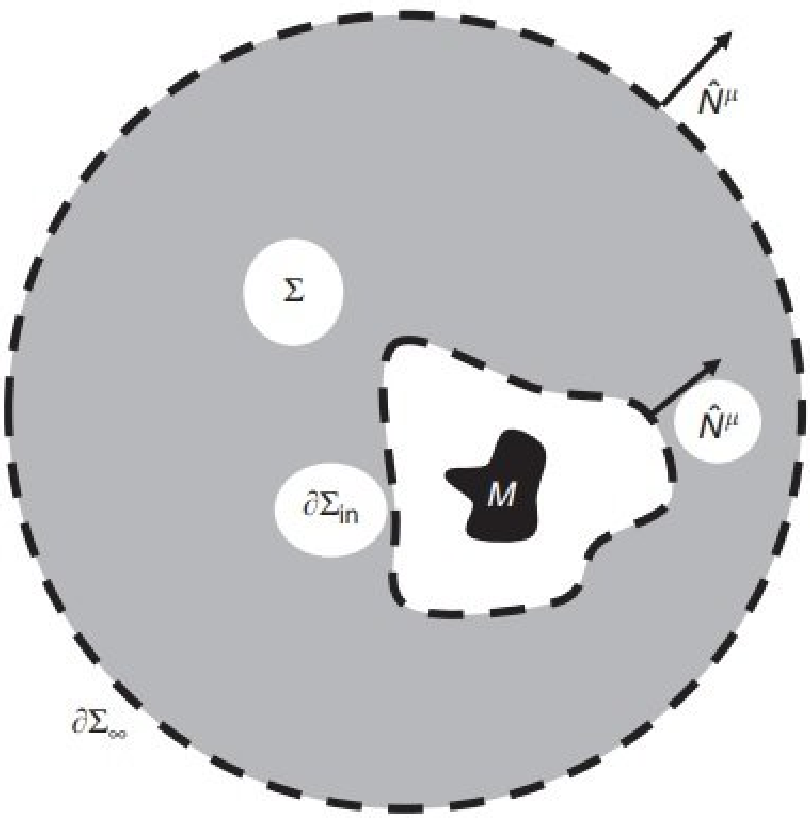

Illustration of a three-dimensional hypersurface. Credit: Wang and Braunstein. Published in *Nature Communications*

In recent years, some physicists have been investigating the possibility that gravity is not actually a fundamental force, but rather an emergent phenomenon that arises from the collective motion of small bits of information encoded on spacetime surfaces called holographic screens.

The theory, called emergent gravity, hinges on the existence of a close connection between gravity and thermodynamics.

Emergent gravity has received its share of criticism, however, and a new paper adds to this by showing that the holographic screen surfaces described by the theory do not actually behave thermodynamically, undermining a key assumption of the theory.

Zhi-Wei Wang, a physicist at Jilin University in Changchun, China, and Samuel L. Braunstein, a professor of quantum computational science at the University of York in the UK, have published their paper on non-thermodynamic surfaces in a recent issue of *Nature Communications*.

"Emergent gravity has very strong claims: that it can explain things like dark matter and dark energy, but also reproduce the decades of work coming out of regular general relativity," Wang told *Phys.org*. "That last claim is now knocked on its head by our work, so emergent gravity proponents will have their work cut out for themselves in showing consistency with the huge canon of observational results. We've set them back, not necessarily knocked them out."

In the cosmological context, surfaces refer generally to any two-dimensional area in spacetime. Some of these surfaces, such as the horizons of black holes and other objects, are confirmed to be thermodynamic. For black hole horizons, this has been known since the 1970s, since the very laws that define black hole mechanics are directly analogous to the laws of thermodynamics. This means that black hole horizons obey thermodynamic principles such as energy conservation and having a positive temperature and entropy.

More recently, surfaces that are not horizons have been conjectured to obey the laws of thermodynamics, with the holographic screens in the emergent gravity theory being one example. However, so far these conjectures have not been fully justified.

In the new paper, the scientists tested whether different kinds of surfaces obey an analogue of the first law of thermodynamics, which is a special form of energy conservation. Their results reveal that, while surfaces near black holes (called stretched horizons) do obey the first law, ordinary surfaces—including holographic screens—generally do not. The only exception is that ordinary surfaces that are spherically symmetric do obey the first law.

As the scientists explain, the finding that stretched horizons obey the first law is not surprising, since these surfaces inherit much of their behavior from the nearby horizons. Still, the scientists caution that the results do not necessarily imply that stretched horizons obey all of the laws of thermodynamics. On the other hand, the finding that ordinary surfaces do not obey the first law is more unexpected, especially as it is one of the key assumptions of emergent gravity. Going forward, researchers will work to understand what this means for the future of emergent gravity, as well as explore other possible implications.

"We spent a large amount of time working out how to reproduce the original results for black holes from the 1970s," Braunstein said. "Although the methods from the 1970s were extremely tedious to replicate in detail, we found them very powerful and are thinking now about whether there is any way to generalize these results to other scenarios. Also, we think that our formula for the deviation away from the first law as one moves away from horizons will have important implications for quantum gravity."

More information: Zhi-Wei Wang and Samuel L. Braunstein. "Surfaces away from horizons are not thermodynamic." *Nature Communications*. DOI: 10.1038/s41467-018-05433-9