How well can information be stored from the beginning to the end of time?

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(Phys.org)—Information can never be stored perfectly. Whether on a CD, a hard disk drive, or a piece of papyrus, technological imperfections create noise that limits the preservation of information over time. But even if you had a perfect storage medium with zero imperfections, there would still be fundamental limits placed on information storage due to the laws of physics that govern the evolution of the universe ever since the Big Bang. But what exactly these fundamental limits are is still unclear.

In a new paper published in the *New Journal of Physics*, Stefano Mancini and Roberto Pierini at the University of Camerino and INFN in Italy, along with Mark M. Wilde at Louisiana State University, have investigated these fundamental limits to preserving information on a literally cosmic scale.

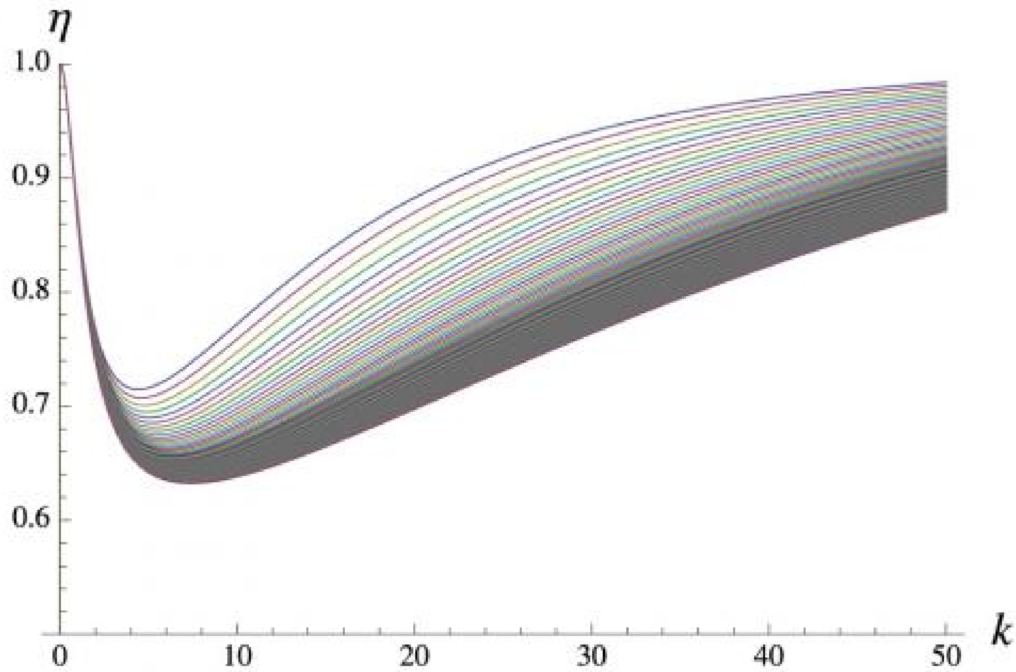
Specifically, they wanted to know how well a given amount of information can be preserved from the beginning to the end of time, with limitations only from physical laws and not technological imperfections in the specific storage medium.

"The motivation that has led us to consider this goal, though it may appear unrealistic, was the discovery of ultimate limitations in information processing," Mancini told *Phys.org*. "Above all, we want to try to understand if and how spacetime dynamics affects information storage."

To do this, they modelled information transmission over a "channel" that is essentially spacetime itself, described by the Robertson-Walker metric. Their model combines the theories of general relativity and quantum information by considering the quantum state of matter (specifically, spin-1/2 particles) as the universe expands. In this model, the evolution of the universe creates noise which, in the context of quantum communication, acts like an amplitude damping channel.

The physicists' main result is that, the faster the universe expands, the less well the information can be preserved. To deal with this "problem" of the expanding universe on information preservation, the researchers investigated strategies for preserving as much information as possible over billions of years of expansion. Doing this involved using a communication-theoretic paradigm in which information is encoded at the beginning of the universe's evolution and decoded at the end of its evolution. This model allowed the scientists to develop a strategy for preserving both classical and quantum information, which use different storage techniques and so require a trade-off.

So to answer the original question of how much information can be stored from the beginning to the end of time, the results suggest "not very much."



Plot of the transmissivity, η, of the channel where information travels, shown as function of the momentum, k, of the matter field where information is encoded. Credit: Mancini, et al. CC-BY-3.0

"I would say that, for most cases (except when particles are at rest or moving very fast), the impact of spacetime dynamics would be large, so little information can be preserved," Mancini said. "However, a quantitative answer could be provided by using a more accurate evolution model of the universe. This is left as work for the future."

There are a number of other interesting future directions that this work could take. For instance, implementing correction measures at various times during the evolution of the universe could reduce the degradation of the stored information. More speculatively, future research might focus on entanglement-assisted communication in Einstein-Rosen bridges—better known as wormholes—and even entanglement between different eras in the universe. This research could have implications for understanding dark energy and the evolution of the universe overall.

More information: Stefano Mancini, et al. "Preserving information from the beginning to the end of time in a Robertson-Walker spacetime." *New Journal of Physics*. DOI: 10.1088/1367-2630/16/12/123049