Cosmologically speaking, diamonds may actually be forever

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If you've ever wondered about the ultimate fate of the universe, Lawrence Krauss and Robert Scherrer have some good news - sort of. In a paper published online on April 25 in the journal *Physical Review D*, the two physicists show that matter as we know it will remain as the universe expands at an ever-increasing clip. That is, the current status quo between matter and its alter ego, radiation, will continue as the newly discovered force of dark energy pushes the universe apart.

"Diamonds may actually be forever," quips Krauss, professor of physics and astronomy at Case Western Reserve University (CWRU) who is spending the year at Vanderbilt. "One of the only positive things that has arisen from the dark-energy dominated universe is that matter gets to beat radiation forever."

This viewpoint runs contrary to conventional wisdom among cosmologists. Today, there is more matter than radiation in the universe. But there were periods during the early universe that were dominated by radiation due to particle decays. The generally accepted view of the distant future has been that ordinary matter particles – protons and neutrons in particular – will gradually decay into radiation over trillions upon trillions of years, leaving a universe in which radiation once again dominates over matter; a universe lacking the material structures that are necessary for life.

It is only in the last decade that the existence of dark energy has been recognized. Before that Krauss and collaborators argued for its existence based on indirect evidence, but the first direct evidence came in 1998 when a major survey of exploding stars, called supernovae, revealed that the universe is apparently expanding at an increasing rate. Dark energy acts as a kind of anti-gravity that drives the expansion of the universe at large scales. Because it is associated with space itself, it is also called "vacuum energy." A number of follow-up observations have supported the conclusion that dark energy accounts for about 70 percent of all the energy in the universe.

"The discovery of dark energy has changed everything, but it has changed the view of the future more than the past. It is among the worst of all possible futures for life," says Krauss, who has spent the last few years exploring its implications. In an eternally expanding universe there is at least a chance that life could endure forever, but not in a universe dominated by vacuum energy, Krauss and CWRU collaborator Glenn Starkman have concluded.

As the universe expands, the most distant objects recede at the highest velocity. The faster that objects recede, the more that the light coming from them is "red-shifted" to longer wavelengths. When their recessional velocity reaches light speed, they disappear because they are traveling away faster than the light that they emit. According to Krauss and Starkman, the process of disappearance has already begun: There are objects that were visible when the universe was half its present age that are invisible now. However, the process won’t become really noticeable until the universe is about 100 billion years old. By ten trillion years, nothing but our local cluster of galaxies will be visible.

From the perspective of future civilizations, this process puts a finite limit on the amount of information and energy that will be available to maintain life. Assuming that consciousness is a physical phenomenon, this implies that life itself cannot be eternal, Krauss and Starkman argue.

"Our current study doesn’t change the process, but it does make it a little friendlier for matter and less friendly for radiation," says Scherrer, professor of physics at Vanderbilt.

In their paper, Krauss and Scherrer analyzed all the ways that ordinary matter and dark matter could decay into radiation. (Dark matter is different from dark energy. It is an unknown form of matter that astronomers have only been able to detect by its gravitational effect on the ordinary matter in nearby galaxies. At this point, the physicists have no idea whether it is stable or will ultimately decay like ordinary matter.) Given known constraints on these various decay processes, the two show that none of them can produce radiation densities that exceed the density of the remaining matter. This is counter-intuitive because, when matter turns into energy, it does so according to Einstein’s equation, E=mc2, and produces copious amounts of energy. "The surprising thing is that radiation disappears as fast as it is created in a universe with dark energy," says Krauss.

The reason for radiation’s vanishing act involves the expansion of space. Expanding space diminishes the density of radiant energy in two ways. The first is by increasing the separation between individual photons. The second is by reducing the amount of energy carried by individual photons. A photon’s energy is contained entirely in its electromagnetic field. The shorter its wavelength and the higher its frequency, the more energy it contains. As space itself expands, the wavelengths of all the photons within it lengthen and their frequency drops. This means that the amount energy that individual photons contain also decreases. Taken together, these two effects dramatically reduce the energy density of radiation.

Protons and neutrons, by contrast, only suffer from the separation effect. Most of the energy that they carry is bound up in their mass and is not affected by spatial expansion. In an accelerating universe, that is enough of an advantage to maintain matter’s dominance - forever.

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