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Big Bang light reveals minimum lifetime of photons

If particles of light have mass, a small but distinct possibility, they may not live forever — and some fundamental theories would have to be modified, too.

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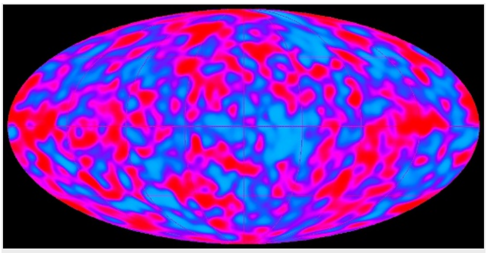

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REMNANT OF THE BIG BANG, the cosmic microwave background radiation as measured by COBE, reveals temperature fluctuations of the early universe.

The notion of the speed of light as the cosmic speed limit is based on the assumption that particles of light, called photons, have no mass. But astrophysical observations cannot rule out the slim chance that photons do have a tiny bit of mass — a prospect with wide ramifications in physics. For instance, if photons weigh nothing at all, they would be completely stable and could theoretically last forever. But if they do have a little mass, they could eventually decay into lighter particles. Now, by studying ancient light radiated shortly after the Big Bang, a physicist has calculated the minimum lifetime of photons, showing that they must live for at least one billion billion years, if not forever.

That lifetime may sound like an eternity, but to a photon traveling at light speed, it passes in a relative blink. Because of the time-dilation effect predicted by Einstein's special theory of relativity, a billion billion years on Earth feels like only three years to a photon, because it's traveling so fast.

If physicists ever do discover that photons have nonzero mass, and therefore limited lifetimes, then “the notion of light-speed obviously wouldn't make much sense anymore," says study author Julian Heeck, a PhD student at the Max Planck Institute for Nuclear Physics in Heidelberg, Germany." There would still be an absolute limit on velocities, but the photons would have to obey that law, too, and travel below the speed of light." Photons’ speed would then depend on their wavelengths, and blue light would travel faster than red light. Photons released simultaneously from distant stars would arrive at Earth at different times, depending on their wavelengths.

A photon with mass would also necessitate modifications to the Standard Model of particle physics (which posits a massless photon), the Maxwell equations that describe electromagnetic waves and fields (photons are the carrier particles for electromagnetic force) and the laws describing interactions between charged particles. Because of this latter effect, observations of the sun’s magnetic field have already proved that the photon, if it weighs anything at all, must be extremely light. The current experimental limit on the possible mass of the photon is 10^{-54} kilogram.

To find the limit on the photonic lifetime, Heeck analyzed observations of the cosmic microwave background radiation—light pervading the universe that dates from a few hundred thousand years after the Big Bang—gleaned from the now defunct NASA's Cosmic Background Explorer (COBE) satellite, launched in 1989. This light fits a very specific pattern—called blackbody radiation, that tells scientists how intense the light should be, based on its wavelength. If any photons were decaying as they traveled across the universe, however, COBE would see less low-energy (redder) light than predicted by the blackbody radiation law, because red light would be expected to decay sooner than blue light. "If the photons come from very far away, say from the beginning of the universe, then they might have had enough time to decay on their way here," says physicist Emanuele Berti of the University of Mississippi, who has studied the mass of the photon but was not involved in Heeck's research. "That's the idea, which I think is very elegant."

But according to COBE's measurements, the cosmic microwave background appears to behave like a perfect blackbody. No low-energy light seems to be missing, indicating that very few photons, if any, have decayed since the Big Bang some 13.7 billion years ago. This analysis enabled Heeck to calculate that the minimum lifetime of a photon is 10^{18}, or one billion billion, years.

Although the simple model of a massless photon may turn out to be correct, the prospect of one with mass raises some intriguing possibilities. For instance, if photons do decay, what do they decay into? "That's, of course, the key question," Heeck says. Gluons, another particle in the same category as photons (namely, force-carrying particles called gauge bosons), are also thought to be massless and could represent the end states of photon decay. So might particles called neutrinos, which come in several varieties, or flavors: "If the lightest neutrino were massless, then that would be the most obvious final state" for the photon, Heeck says. A photon "could also in principle decay into other unknown particles."

Heeck's paper, published July 11 in *Physical Review Letters*, represents the first calculation of the minimum lifetime of a photon, but it relies on some simplifying assumptions, he says. Most important, it neglects interactions of photons and matter after the cosmic microwave background formed, which could have a strong effect if photons have very small masses. For example, photons may be absorbed by interstellar matter and reemitted, changing their properties. Berti agrees that the assumptions complicate things. "The calculation in principle is very interesting," he says. "But then the devil is in the details."

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If these matter interactions can be better understood and taken into account, Heeck says he could calculate tighter limits on the photon’s lifetime. More precise data about the cosmic microwave background would also help, although the reason Heeck didn't use measurements from more recent spacecraft than COBE, such as the Wilkinson Microwave Anisotropy Probe, is because those newer observations lack the necessary temperature data to understand the light's blackbody spectrum.

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