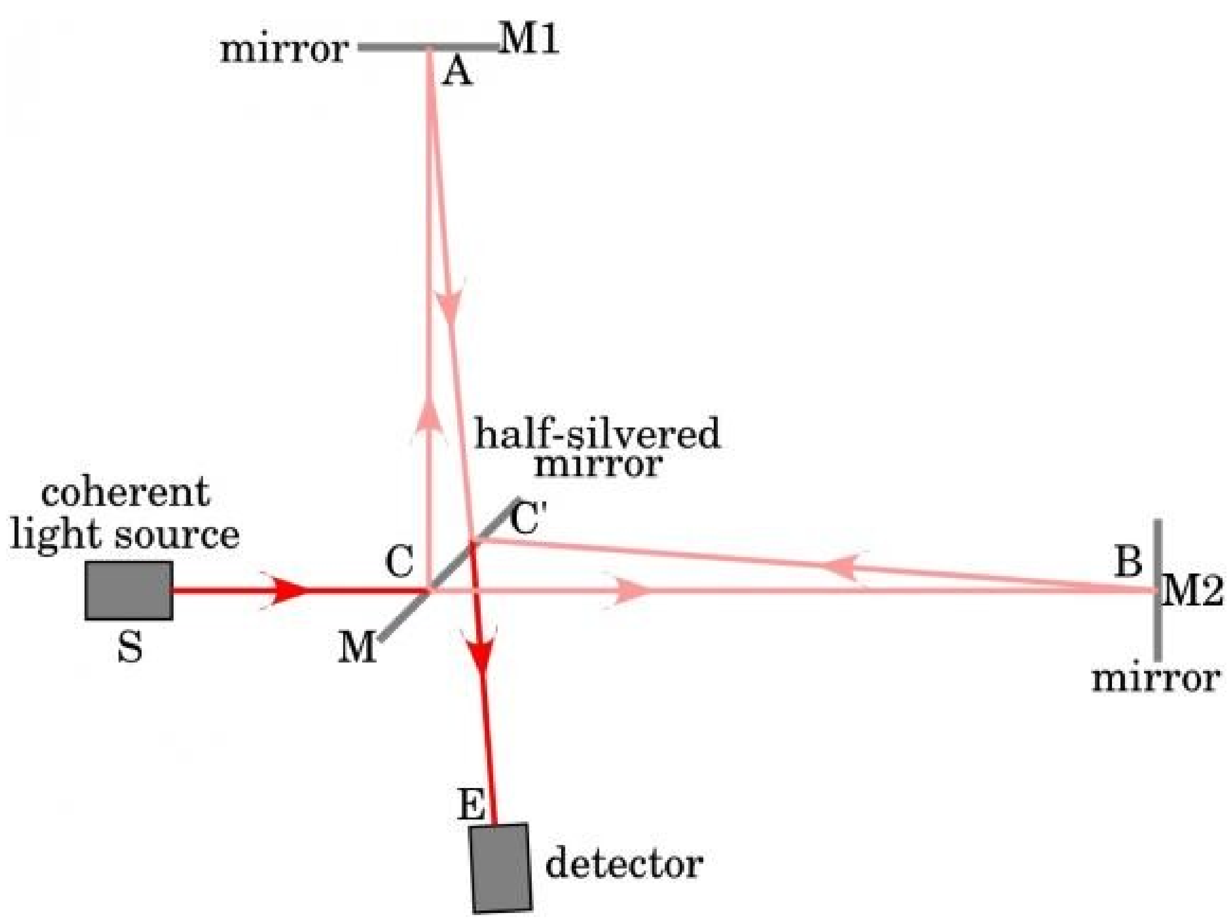
There's no way to measure the speed of light in a single direction

January 11 2021, by Brian Koberlein



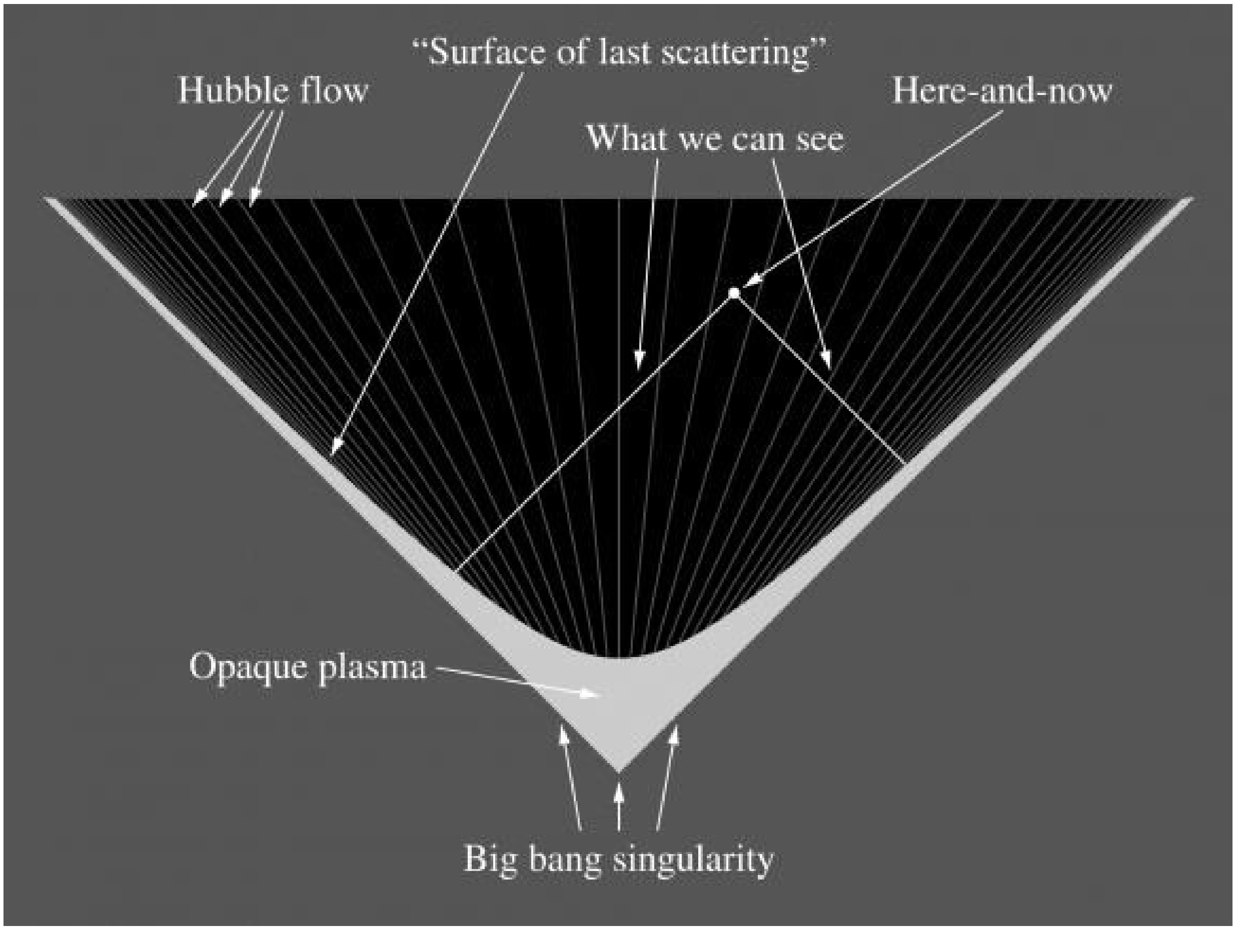
How to measure the round-trip speed of light. Credit: Wikipedia user Krishnavedala

Special relativity is one of the most strongly validated theories humanity has ever devised. It is central to everything from space travel and GPS to our electrical power grid. Central to relativity is the fact that the speed of light in a vacuum is an absolute constant. The problem is, that fact has never been proven.

When Einstein proposed the theory of relativity, it was to explain why light always had the same speed. In the late 1800s, it was thought that since light travels as a wave, it must be carried by some kind of invisible material known as the "luminiferous aether." The reasoning was that waves require a medium, such as sound in air or water waves in water. But if the aether exists, then the observed speed of light must change as the Earth moves through the aether. But measurements to observe aether drift came up null. The speed of light appeared to be constant.

Einstein found that the problem was in assuming that space and time were absolute and the speed of light could vary. If instead, you assumed the speed of light was absolute, space and time must be affected by relative motion. It's a radical idea, but it's supported by every measurement of light's constant speed.

But several physicists have pointed out that while relativity assumes the vacuum speed of light is a universal constant, it also shows the speed can never be measured. Specifically, relativity forbids you from measuring the time it takes light to travel from point A to point B. To measure the speed of light in one direction, you'd need a synchronized stopwatch at each end, but relative motion affects the rate of your clocks relative to the speed of light. You can't synchronize them without knowing the speed of light, which you can't know without measuring. What you can do is use a single stopwatch to measure the round trip time from A to B back to A, and this is what every measurement of the speed of light does.



A Milne universe with anisotropic light would look uniform. Credit: Wikipedia user BenRG

Since all the round-trip speed of light measurements give a constant result, you might figure you can just divide the time by two and call it a day. This is exactly what Einstein did. He assumed the time there and back was the same. Our experiments agree with that assumption, but they also agree with the idea that the speed of light coming toward us is 10 times faster than its speed going away from us. Light doesn't have to have a constant speed in all directions, it just has to have a constant "average" round-trip speed. Relativity still holds if the speed of light is anisotropic.

If the speed of light varies with its direction of motion, then we would see the universe in a different way. When we look at distant galaxies, we are looking back in time because light takes time to reach us. If distant light reached us quickly in some direction, we would see the universe in that direction as older and more expanded. The faster light reaches us, the less "back in time" we would see. Since we observe a uniform cosmos in all directions, surely that shows the speed of light is constant.

Well, not quite, as a new study shows. It turns out that if the speed of light varies with direction, so does length contraction and time dilation. The team considered the effects of anisotropic light on a simple relativistic model known as the Milne universe. It's basically a toy universe similar in structure to the observed universe, but without all the matter and energy. They found that the anisotropy of light would cause anisotropic relativity effects in time dilation and cosmic expansion. These effects would cancel out the observable aspects of a varying light speed. In other words, even if the universe was anisotropic due to a varied speed of light, it would still appear homogeneous.

So it seems simple cosmology isn't able to prove Einstein's assumption about the speed of light either. Sometimes, the most basic ideas in science are the most difficult to prove.

More information: The One-Way Speed of Light and the Milne Universe. arXiv:2012.12037v1 [gr-qc] arxiv.org/abs/2012.12037

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