How can space travel faster than the speed of light?

February 23 2015, by Vanessa Janek

Light speed is often spoken of as a cosmic speed limit… but not everything plays by these rules. In fact, space itself can expand faster than a photon could ever hope to travel.

Cosmologists are intellectual time travelers. Looking back over billions of years, these scientists are able to trace the evolution of our Universe in astonishing detail. 13.8 billion years ago, the Big Bang occurred. Fractions of a second later, the fledgling Universe expanded exponentially during an incredibly brief period of time called inflation.

Over the ensuing eons, our cosmos has grown to such an enormous size that we can no longer see the other side of it.

But how can this be? If light's velocity marks a cosmic speed limit, how can there possibly be regions of spacetime whose photons are forever out of our reach? And even if there are, how do we know that they exist at all?

The Expanding Universe

Like everything else in physics, our Universe strives to exist in the lowest possible energy state possible. But around 10-36 seconds after the Big Bang, inflationary cosmologists believe that the cosmos found itself resting instead at a "false vacuum energy" – a low-point that wasn't really a low-point. Seeking the true nadir of vacuum energy, over a minute fraction of a moment, the Universe is thought to have ballooned by a factor of 1050.

Since that time, our Universe has continued to expand, but at a much slower pace. We see evidence of this expansion in the light from distant objects. As photons emitted by a star or galaxy propagate across the Universe, the stretching of space causes them to lose energy. Once the photons reach us, their wavelengths have been redshifted in accordance with the distance they have traveled.

This is why cosmologists speak of redshift as a function of distance in both space and time. The light from these distant objects has been traveling for so long that, when we finally see it, we are seeing the objects as they were billions of years ago.

The Hubble Volume

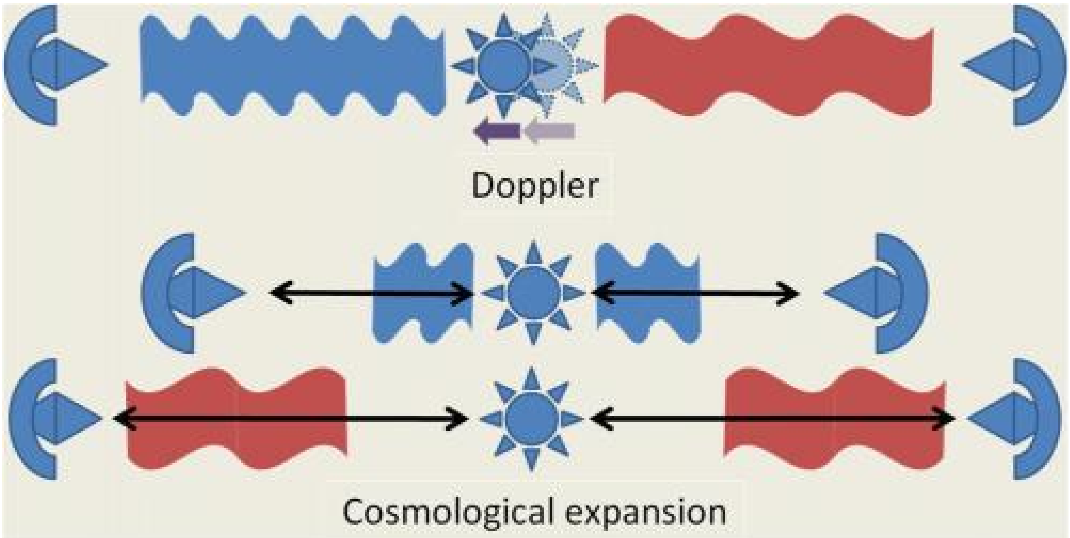
Redshifted light allows us to see objects like galaxies as they existed in the distant past; but we cannot see all events that occurred in our Universe during its history. Because our cosmos is expanding, the light from some objects is simply too far away for us ever to see.

The physics of that boundary rely, in part, on a chunk of surrounding spacetime called the Hubble volume. Here on Earth, we define the Hubble volume by measuring something called the Hubble parameter (H0), a value that relates the apparent recession speed of distant objects to their redshift. It was first calculated in 1929, when Edwin Hubble discovered that faraway galaxies appeared to be moving away from us at a rate that was proportional to the redshift of their light.

Dividing the speed of light by H0, we get the Hubble volume. This spherical bubble encloses a region where all objects move away from a central observer at speeds less than the speed of light. Correspondingly, all objects outside of the Hubble volume move away from the center faster than the speed of light.

Yes, "faster than the speed of light." How is this possible?

The Magic of Relativity



Two sources of redshift: Doppler and cosmological expansion; modeled after Koupelis & Kuhn. Bottom: Detectors catch the light that is emitted by a central star. This light is stretched, or redshifted, as space expands in between. Credit: Brews Ohare

The answer has to do with the difference between special relativity and general relativity. Special relativity requires what is called an "inertial reference frame" – more simply, a backdrop. According to this theory, the speed of light is the same when compared in all inertial reference frames. Whether an observer is sitting still on a park bench on planet Earth or zooming past Neptune in a futuristic high-velocity rocketship, the speed of light is always the same. A photon always travels away from the observer at 300,000,000 meters per second, and he or she will never catch up.

General relativity, however, describes the fabric of spacetime itself. In this theory, there is no inertial reference frame. Spacetime is not expanding with respect to anything outside of itself, so the the speed of light as a limit on its velocity doesn't apply. Yes, galaxies outside of our Hubble sphere are receding from us faster than the speed of light. But the galaxies themselves aren't breaking any cosmic speed limits. To an observer within one of those galaxies, nothing violates special relativity at all. It is the space in between us and those galaxies that is rapidly proliferating and stretching exponentially.

The Observable Universe

Now for the next bombshell: The Hubble volume is not the same thing as the observable Universe.

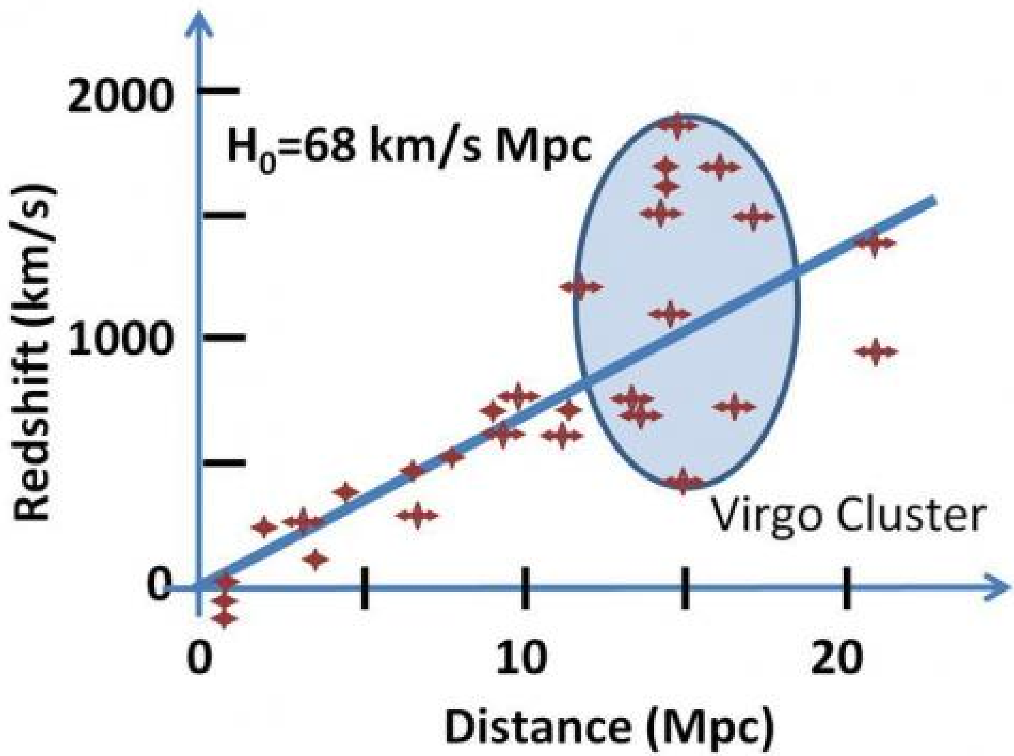
To understand this, consider that as the Universe gets older, distant light has more time to reach our detectors here on Earth. We can see objects that have accelerated beyond our current Hubble volume because the light we see today was emitted when they were within it.

Strictly speaking, our observable Universe coincides with something called the particle horizon. The particle horizon marks the distance to the farthest light that we can possibly see at this moment in time – photons that have had enough time to either remain within, or catch up to, our gently expanding Hubble sphere.

And just what is this distance? A little more than 46 billion light years in every direction – giving our observable Universe a diameter of approximately 93 billion light years, or more than 500 billion trillion miles.

(A quick note: the particle horizon is not the same thing as the cosmological event horizon. The particle horizon encompasses all the events in the past that we can currently see. The cosmological event horizon, on the other hand, defines a distance within which a future observer will be able to see the then-ancient light our little corner of spacetime is emitting today.

In other words, the particle horizon deals with the distance to past objects whose ancient light that we can see today; the cosmological event horizon deals with the distance that our present-day light that will be able to travel as faraway regions of the Universe accelerate away from us.)



Fit of redshift velocities to Hubble's law. Credit: Brews Ohare

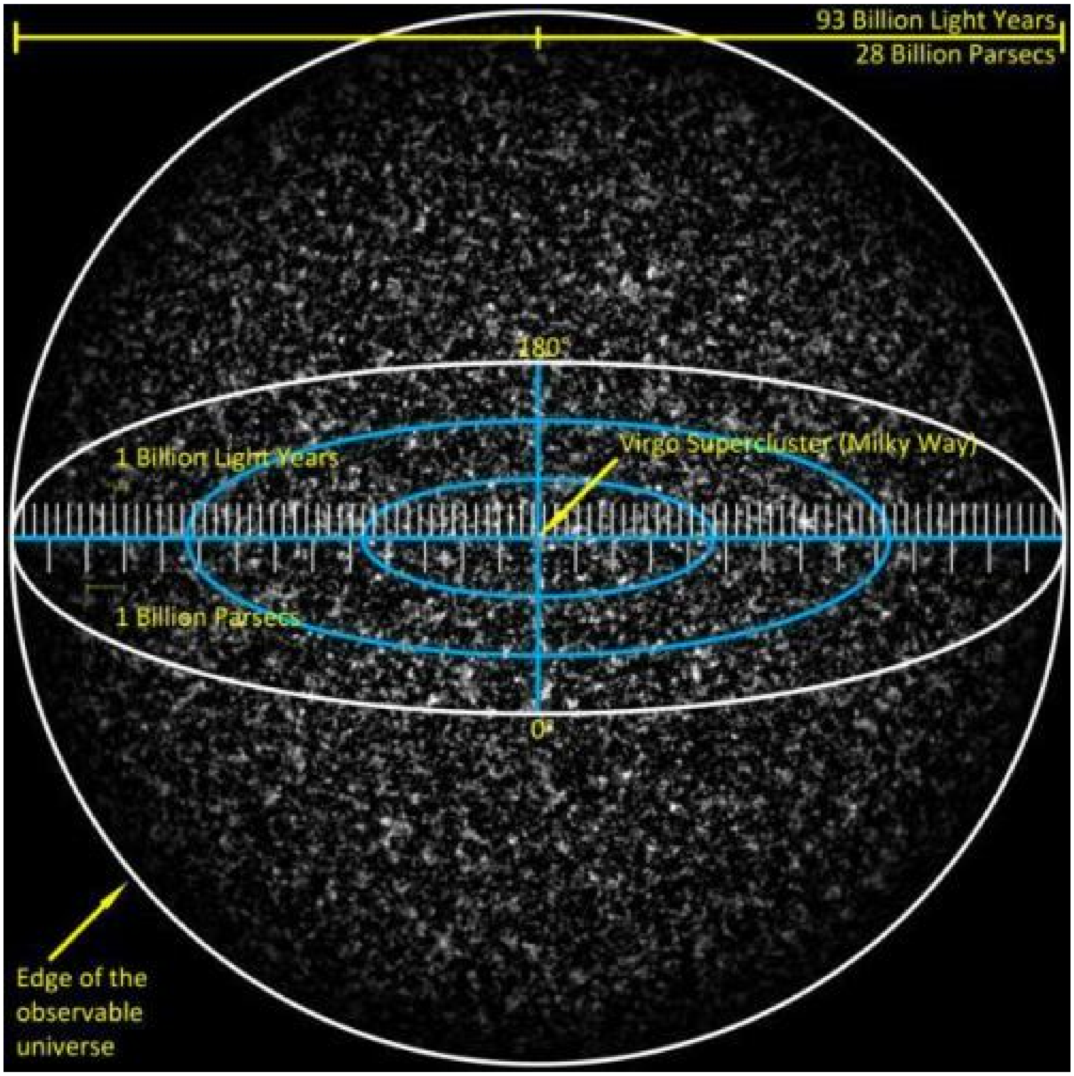
Dark Energy

Thanks to the expansion of the Universe, there are regions of the cosmos that we will never see, even if we could wait an infinite amount of time for their light to reach us. But what about those areas just beyond the reaches of our present-day Hubble volume? If that sphere is also expanding, will we ever be able to see those boundary objects?

This depends on which region is expanding faster – the Hubble volume or the parts of the Universe just outside of it. And the answer to that question depends on two things: 1) whether H0 is increasing or decreasing, and 2) whether the Universe is accelerating or decelerating. These two rates are intimately related, but they are not the same.

In fact, cosmologists believe that we are actually living at a time when H0 is decreasing; but because of dark energy, the velocity of the Universe's expansion is increasing.

That may sound counterintuitive, but as long as H0 decreases at a slower rate than that at which the Universe's expansion velocity is increasing, the overall movement of galaxies away from us still occurs at an accelerated pace. And at this moment in time, cosmologists believe that the Universe's expansion will outpace the more modest growth of the Hubble volume.



The observable universe, more technically known as the particle horizon.

So even though our Hubble volume is expanding, the influence of dark energy appears to provide a hard limit to the ever-increasing observable Universe.

Our Earthly Limitations

Cosmologists seem to have a good handle on deep questions like what our observable Universe will someday look like and how the expansion of the cosmos will change. But ultimately, scientists can only theorize the answers to questions about the future based on their present-day understanding of the Universe. Cosmological timescales are so unimaginably long that it is impossible to say much of anything concrete about how the Universe will behave in the future. Today's models fit the current data remarkably well, but the truth is that none of us will live long enough to see whether the predictions truly match all of the outcomes.

Disappointing? Sure. But totally worth the effort to help our puny brains consider such mind-bloggling science – a reality that, as usual, is just plain stranger than fiction.

Source: Universe Today

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