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MEMORANDUM

To: Science Council

From: Peter Fisher

Subject: Transluminal velocities, relativity and cosmology

Date: Sunday, March 20, 2016

Hydrogen formed 380,000 years after the Big Bang, releasing light with a wavelength of 1.4 μm. In 1963, this light from just after the Big Bang was detected with a wavelength of 1.5 mm, a redshift of z =1,100. Hubble's law relates distance to an astronomical object with its recession velocity. The Hubble Space Telescope measured 69 km/s/Mpc for the proportionality constant, known as the Hubble Constant. The hydrogen that emitted the light we observe now must be moving away from us with a velocity of 950,000 km/s, about three times the speed of light, an apparent violation of Einstein's idea of the limiting nature of the velocity of light. This memorandum explains why this transluminal recession velocity does not violate Einstein's theory of relativity.

Two postulates form the basis of the Special Theory of Relativity: 1) the velocity of light, c, is the same in all inertial frames and 2) the laws of physics are the same in all inertial frames. The idea of an inertial frame provides the key to question above. An inertial frame moves at constant velocity (speed and direction) relative to an observer's frame. The Lorentz Transformation relates the coordinates in two inertial frames and enforces the constancy of light in both frames.

A final postulate extends Einstein's reasoning to situations influenced by mass or energy: around any free falling observer, it is possible, at some level of approximation, to define inertial frames. An observer that moves in such a way that they do not feel any gravitational force is a freely falling observer. Consider an astronaut falling toward the Earth along a radius. The astronaut would feel weightless – an object placed a meter away from the astronaut would appear to be stationary. However, another astronaut ten miles away, falling along a different radius, would appear to move slowly towards the first astronaut as their radii converge. The motion between the two astronauts is a gravitational force acting between them. One can always choose a region around a free falling object small enough so objects in that region do not appear to feel gravitational forces larger than a certain amount.

In relativity, measurements are always carried out in freely falling frames. Around any freely falling frame, one can define inertial frames and it is in these frames that an object must never exceed the speed of light. The emitter of the light from the formation of hydrogen may be traveling much faster than the speed of light, but to a freely falling observer, the astronomer observing the light through a telescope[1], the light appears as a photon moving at c in their frame. What has

[1]The astronomer and telescope are subject to the gravitational force on Earth, so one may argue that the telescope is not a freely falling frame. This is true, but the gravity on Earth is so weak that for most observations, the telescope may be treated as being in a freely falling frame.

happened to the emitter over the intervening 13.7 billion years has no bearing. Like all politics, all relativity is local.

There is the big picture: the universe is expanding, driven by the energy content. The hydrogen that emitted the light 13.7 billion years ago that we see now was 12 Mly from us and moving away at 2% the speed of light at the time the light was emitted. The universe expanded as the photons traveled towards us and by our reckoning, moved more slowly than the speed of light, dragged backwards by the expansion of spacetime. In the end, it took them 13.7 billion years to reach us.

The free faller does not need to know any of this: all the free faller knows is that they see light in the form of radio waves with a frequency of around 200 GHz. What the emitter has done since emitting the light can only be discerned by constructing a model based on General Relativity and informed by observations. We can interpret the photons we see as being redshifted light from the formation of hydrogen 13.7 billion year ago.

The short answer is that, because the expansion rate of the universe increases with time, the emitter is not an inertial frame when viewed from Earth, so it does not need to respect the postulates of Special Relativity. The emitter may move faster than the speed of light and may be subject to forces not observed in our frame. The photons from the emitter travel through the universe to our local freely falling frame and there they must travel at the speed of light, consistent with the postulates above.