Does the Velocity of Light Decrease?

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Assuming that the velocity of light changes with time we attempt to determine what rate of deceleration of light speed might explain the cosmological redshift. The proposed deceleration rate of $a_c \approx 2.3\,m/s$ in 100 years ($H_o \approx 75\,km\ s^{-1}\ Mpc^{-1}$) is very small, but might be observed if measurements at present-day accuracy are repeated over a few decades. Speculations as to the consequences of the hypothetical effect of a light speed deceleration are given.
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Introduction

In recent years the Big-Bang theory has encountered various difficulties (Arp, *et al.* 1990) such as the horizon problem and the extreme homogeneity of the 2.7° K cosmic background radiation (CBR) (Barrow 1982). These problems could be partially overcome with the assumption of an inflationary phase in the early universe (Guth 1981, Hawking 1982). However, Big-Bang cosmology suffers from an increasing complexity of its assumptions, including extended and hyperextended (Steinhardt 1990, Accetta 1991) or extended chaotic inflation (Linde 1990). Non-Doppler interpretations of the Hubble redshift have also been considered in order to support non-expanding ("steady state") models of the universe, most of them based on "tired light"-mechanisms (Arp 1990). On the other hand, the idea that a decrease of the velocity of light with time may be responsible for Hubble redshift has hardly been discussed, because it appears to contradict special relativity. Calculations show that such an effect is too small to have been measured in the past; however, it may be measurable in the forseeable future.

A hypothetical decrease in the velocity of light

The following assumptions are made. A decreasing light velocity must not result from conventional gravitation. Gravitational effects according to General Relativity are described by the photon's loss (or gain) of energy. The principle of special relativity remains valid, in the sense that there is no speed greater than c. The mechanism of deceleration is presumed to be, in detail: (1) the velocity of light remains the highest possible speed for transmission of photons and information and the relativistic addition theorems remain valid; (2) the value of c is the same everywhere in the universe at a given time (in the meaning of Robertson-Walker metrics) and (3) the deceleration parameter is very small and equal everywhere in the universe at a given time. The proposed mechanism must not contradict the theory of relativity based on the constancy of light; it is regarded as an intrinsic effect of nature not subject to the usual addition of velocities. The acceleration parameter $a_c = 0$ for classical and relativistic physics is regarded as a special case of $a_c \neq 0$. In other words, some hundred years of modern physics have not been long enough to reveal possible time-dependencies of the fundamental constants of nature, as Dirac (1974) has pointed out (varying cosmological constants were recently considered by Abdel-Rahman 1990 and Berman 1991).

Determination of the deceleration parameter

If there exists a light deceleration, how large must it be to replace the Doppler interpretation of the Hubble redshift? In the following, photons emitted by a radiation source will be regarded as bullets leaving a machine gun with a constant frequency *resp.* time interval T_o. We assume that for an unknown reason photons slow down with a constant deceleration rate $|a|$ in such a way that the *nth* bullet is emitted with the present speed of its predecessor, n–1. Let the muzzle speed of bullet n be v_{on}. Defining a zeroth bullet this speed can be written

$$v_{on} = v_{oo} - anT_o \tag{1}$$

At time $t > nT_o$ the speed of the *nth* bullet (= photon) is

$$v_n(t) = v_{on} - a(t - nT_o) = v_{oo} - at \tag{2}$$

where Eq. (1) has been used. At time t photon n has travelled a distance

$$r(t)=\int_{nT_o}^{t} v_n(t')dt' = v_{oo}t-\frac{a}{2}t^2-v_{oo}nT_o+\frac{a}{2}(nT_o)^2 \quad (3)$$

from the muzzle. This equation can be solved for the time $t_r^{(n)}$ at which photon n has travelled distance r:

$$\begin{aligned} t_r^{(n)} &= \frac{1}{a}\left(v_{oo}-\sqrt{v_{oo}^2+a^2(nT_o)^2-2av_{oo}nT_o-2ar}\right) \\ &= \frac{1}{a}\left(v_{oo}-(v_{oo}-anT_o)\sqrt{1-\frac{2ar}{(v_{oo}-anT_o)^2}}\right) \end{aligned} \quad (4)$$

where the positive root is excluded because one must have $t_r^{(n)}=nT_o$ for $r=0$. The time interval $T_r^{(n)}$ between the arrival of two photons n and $n+1$ at the observer at distance r is

$$T_r^{(n)}=t_r^{(n+1)}-t_r^{(n)}$$

which is given by

$$T_r^{(n)}=-\frac{1}{a}\left\{\begin{aligned} &(v_{oo}-a[n+1]T_o)\sqrt{1-\frac{2ar}{(v_{oo}-a[n+1]T_o)^2}} \\ &-(v_{oo}-anT_o)\sqrt{1-\frac{2ar}{(v_{oo}-anT_o)^2}} \end{aligned}\right\} \quad (5)$$

where T_o is the time interval between emission of the two photons. This expression can be expanded in powers of $2ar\big/(v_{oo}-anT_o)^2 \ll 1$:

$$T_r^{(n)}\approx-\frac{1}{a}\left\{-aT_o-ar\left(\frac{aT_o}{v_{oo}^2\left[1-\frac{a(2n+1)T_o}{v_{oo}}+\frac{a^2n(n+1)T_o^2}{v_{oo}^2}\right]}\right)\right\} \quad (6)$$

Under the additional assumption $v_{oo}\gg anT_o$ this expansion leads to

$$T_r^{(n)}\approx\frac{1}{a}\left(-aT_o-\frac{a^2rT_o}{v_{oo}^2}\right)=T_o\left(1+\frac{ar}{v_{oo}^2}\right) \quad (7)$$

Because the observed frequency is given by $\nu_r=T_r^{-1}$ one has

$$\nu_r\approx\frac{\nu_o}{1+\frac{ar}{v_{oo}^2}} \quad (8)$$

It should be noticed that the time-dependence represented by nT_o vanishes under the second assumption. What do those two assumptions mean physically? After substitution of r by Eq. (3) the first assumption $2ar \ll (v_{oo}-anT_o)^2$ can be written as

$$v_{oo}\gg at \quad (9)$$

A small a_c in relation to the speed of light was already the precondition of these calculations (see section 2, assumption 3). The approximation remains valid, as long as t does not approach the Hubble time H^{-1}, as Eq. (11) implies. Because $t>nT_o$ [see Eq. (3)] the first assumption contains the second assumption ($v_{oo}\gg anT_o$).

The classical Doppler effect for the frequency of light escaping from a source moving with velocity v is approximately given by

$$\nu=\frac{\nu_o}{1+\frac{v}{c}}$$

According to Hubble's law we can replace v by Hr and get:

$$\nu=\frac{\nu_o}{1+\frac{Hr}{c}} \quad (10)$$

The resemblance with Eq. (8) is obvious. Now, if the Doppler interpretation of the Hubble redshift is to be substituted by light retardation, Eq. (8) and (10) must always give the same value for ν. For $v_{oo}=c$, this is the case if $ar/c=Hr$ or

$$a_c=Hc \quad (11)$$

As mentioned above, Eq. (11) is correct only in a confined part of spacetime and for a small deceleration parameter a_c.

There is also a fundamental consideration that leads to the result of Eq. (11): Conventional cosmology interprets the Hubble redshift as Doppler recession and therefore has $H=\dot{R}/R$. In order to explain Hubble's observation by light retardation, the Hubble constant (*resp.* "parameter") could be defined by $H=\dot{c}/c$, so that

$$\dot{c}=a_c=Hc \quad (12)$$

It is remarkable that the calculated value of a_c [Eq. (11)] equals its formal definition [Eq. (12)]. Furthermore, the value of light retardation we have found confirms the independent argumentation of Zeng Xinchuan (1990), whose estimation of Δc is based on the postulate $c(t)=\dot{R}(t)$.

Could a light speed deceleration rate a_c be measured? According to the uncertain value of $50\le H\le 100\ km\ s^{-1}\ Mpc^{-1}$ the result will vary by about a factor of 2. With $H=75\ km\ s^{-1}\ Mpc^{-1}$, which is still higher than most of the observationally determined values for H (Fukugita 1990, Sandage and Tamman 1990, Tonry 1991, Peacock 1991, Salucci and Sciama 1991) we obtain

$$a_c\approx 2.3\ ms^{-1}\ \ per\ \ 100\ years \quad (13)$$

This is indeed a very small value, but large enough to be measured directly with the accuracy achieved today. The velocity of light has been measured quite often and very precisely within the last decades with different frequencies and experimental procedures. To determine whether there exists a deceleration rate a_c of the predicted magnitude it will be necessary to measure accurately over a period of about 20 years. One of the most precise values of the light velocity available is still Baird's (1979) result of c = 299792458.8 ms^{-1} with Rowley's (1980) corrected uncertainty of $\pm 0.2\ ms^{-1}$. This means that a definite answer to the question whether c decreases should be obtainable within a reasonable number of years. (A crucial experiment has been proposed by Zeng Xinchuan [1990]).

Consequences of light speed deceleration

Light deceleration would have an inestimable advantage: it could mediate between expanding and non-expanding models of the universe. If there was, for example, no other measure for the (cosmic) distance between two fixed points P_1P_2 than the travel time of light, the retardation effect would make this distance appaear to increase with time. If light travelled with nearly infinite speed, it would reach all points almost at the same time - with the consequence that space would shrink almost to the size of a point. On the other hand, if speed of light were very slow, it would take almost infinite time to get from one point to another, which is indistinguishable from an almost infinite space. Light retardation therefore can be regarded as "virtual expansion", dilating space between two fixed points—namely two astronomical objects without proper motion. As further calculations indicate, the suggested model reveals properties of an "inflationary expansion"; it also avoids the problem of the origin of the tremendous amount of energy, which would have been necessary to give the universe a "real" expansion (Big Bang). However, it does not—at least in the present state—avoid a singularity at the "moment of creation". It also allows isotropy / homogeneity of cosmic background radiation and matter distribution in the universe; thus there would not be any horizon problem. The "retarded light" effect would have repercussions for all fields of physics. A host of new insights could be expected if it should happen to be verified.

Conclusions

It has been found that with a deceleration rate of $a_c = Hc$, which is barely measurable at the present time, it is possible to explain the cosmological redshift presently attributed to the expansion of the Universe. Observing a retarded light effect might be somewhat difficult. A calculation has been made for a maximum effect replacing the Doppler shift completely by light retardation. It is also possible that both Doppler shift and a decreasing c (among other mechanisms like "tired light") contribute to the observed spectral redshift, each to an unknown extent. However, a few decades of measurements of c could reduce the part attributable to a retarded light hypothesis, so that its possible role would be determined.

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