

# On the Possibility of Variable Speed of Light in Vacuum

Qinghua Cui

Department of Biomedical Informatics, Peking University, Beijing, China

Email: cuiqinghua@hsc.pku.edu.cn

**How to cite this paper:** Cui, Q.H. (2022) On the Possibility of Variable Speed of Light in Vacuum. *Journal of High Energy Physics, Gravitation and Cosmology*, 8, 927-934.

<https://doi.org/10.4236/jhepgc.2022.84063>

**Received:** June 24, 2022

**Accepted:** September 26, 2022

**Published:** September 29, 2022

Copyright © 2022 by author(s) and Scientific Research Publishing Inc. This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).

<http://creativecommons.org/licenses/by/4.0/>



Open Access

---

## Abstract

We previously revealed a quantitative relation by which the fine-structure constant  $\alpha$  can be described by the temperature  $T$  of cosmic microwave background (CMB) with several other fundamental constants, including the elementary charge  $e$ , the Boltzmann constant  $k$ , the Planck constant  $h$ , and the light of speed in vacuum  $c$ . Given that the value of  $\alpha$  is quite conserved but  $T$  is variable across CMBs, we propose that  $c$  changes with  $T$  and can be given by  $T$ , the present CMB temperature  $T_0$  and the present light speed  $c_0$ . As  $T$  is continuously decreasing,  $c$  is thus predicted to decrease at a rate of  $\sim 2.15$  centimeters/second (cm/s) per year. Moreover, we provide a lot of evidence to support this finding. In conclusion, this study suggests a possibility of variable speed of light in vacuum.

## Keywords

Speed of Light in Vacuum, Fine-Structure Constant, Cosmic Microwave Background, Earth-Moon Distance

---

## 1. Background on the Constant Speed of Light in Vacuum

Light in vacuum always travels at the constant speed, which is one of the key insights of relativity theory and modern physics. Given the big success of relativity theory in many areas, it is widely accepted that speed of light in vacuum  $c$  is a constant of our nature, and thus, it is no surprise that its value has not been measured for  $\sim 40$  years since the latest measurement (299,792,458 meters/second, m/s) by National Bureau of Standards in 1983 [1]. However, a number of researchers proposed hypothesis of variable speed of light in vacuum. For example, Moffat had investigated two models of variable speed of light [2] [3] [4], which proposed the possibility of variable speed of light in vacuum.

## 2. Possibility of Variable Speed of Light in Vacuum

We previously revealed that the fine-structure constant  $\alpha$  can be precisely described by the temperature  $T$  (or expected average frequency  $f$ ) of cosmic microwave background (CMB) as the following equation [5],

$$\begin{cases} \alpha = \beta \frac{e^2 f}{hc} \\ \alpha = \beta \frac{e^2 kT}{h^2 c} \end{cases} \quad (1)$$

where  $e$  is the elementary charge,  $k$  is the Boltzmann constant,  $h$  is the Planck constant, and  $c$  is the light of speed in vacuum.  $\beta$  is  $1 \text{ kg}\cdot\text{m}^3\cdot\text{s}^{-1}\cdot\text{Coulomb}^{-2}$ , which was introduced to make the dimension consistence. In addition, it is important to give a physical reason for the introduction of  $\beta$ . It is known that  $\alpha$  is a constant, and  $e$ ,  $k$ ,  $h$ , and  $c$  are also constants but  $T$  is variable across CMBs. That is, changing  $T$  should result in variation of  $\alpha$ . Strikingly, however, it was recently reported that the measured value of  $\alpha$  is quite stable along the observed-scale of space-time and temperature of CMBs [6] [7]. This finding triggers us to conclude that some other constant(s) in Equation (1) is (are) not real constant but linearly changes with  $T$ . According to Boltzmann's theory, its constant  $k$  was presented for linking energy and temperature  $T$  of blackbody radiation, and thus obviously  $k$  does not change with  $T$ . Moreover,  $h$  is equivalent with  $k$  as they are all used to calculate energy [5], then  $h$  does not change with  $T$ . For  $e$ , it is not affected by whether it is in vacuum or not, and thus does not change with  $T$ . Based on the above observations, we propose that the speed of light in vacuum,  $c$ , has to be variable with and proportional to  $T$ . Thus, the speed of light in vacuum  $c_T$  at some temperature of CMB  $T$  (at some space-time) is proportional to the speed of light  $c_0$  in vacuum at the current temperature of CMB  $T_0$  (at present space-time) as the following formula.

$$c_T = \frac{T}{T_0} c_0 \quad (2)$$

where  $c_0$  is the speed of light in vacuum at present CMB (that is, at the present space-time,  $c_0 = 299,792,458 \text{ m/s}$ ). As our universe is continuously cooling, the speed of light in vacuum thus could be timely decreasing along the temperature  $T$  of CMB. It is known that the cosmic redshift  $z$  is defined as

$$z = \frac{\Delta f}{f_T} = \frac{f_0 - f_T}{f_T} = \frac{v}{c_0} \quad (3)$$

where  $f_T$  is the expected average frequency of CMB at temperature  $T$  and  $v$  is the recession velocity of one given galaxy. It should be noted here that CMB frequency is related to the CMB temperature but not frequency of light emitted by a galaxy. In addition, because the Hubble constant and recession velocity are both calculated based on  $c_0$ , it also should be noted that the speed of light in vacuum of Equation (3) is  $c_0$  but not the speed of light in vacuum at other space-time (e.g.  $c_T$ ). Moreover, it is known that the Hubble constant is around  $H$

= 70 km/s/Mpc [8], here 1 Mpc is the distance of light travelling in ~3.26 million years. Therefore, the recession velocity of galaxy at 1 Mpc will be  $v = 70$  km/s. As  $f = kT/h$ , then Equation (3) can be re-described as

$$z = \frac{\nabla f}{f_r} = \frac{T_0 - T}{T} = \frac{v}{c_0} \quad (4)$$

Then, the temperature  $T$  of CMB after ~3.26 million years will be  $T = 0.9997666 T_0$ . Then, the speed of light in vacuum at that space-time ( $T = 0.9997666 T_0$ ) will be

$$c_T = \frac{T}{T_0} c_0 = 0.9997666 c_0 \quad (5)$$

Given the above observations, it is not difficult to obtain that currently the speed of light in vacuum decreases as the following rate:

$$\frac{c_0 - c_T}{3261563.7771674528} = 2.15 \text{ cm/s per year}$$

Here we use  $c_0 = 299,792$  km/s and  $v = 70$  km/s. As a result, we predict the speed of light in vacuum to decrease at a rate of ~2.15 cm/s per year.

### 3. Evidence for Variable Speed of Light in Vacuum

In the above section, we infer a variable speed of light in vacuum and find that the speed of light in vacuum decreases at a rate of ~2.15 cm/s per year at present space-time. Although it seems unbelievable that the speed of light in vacuum is variable, we try to present some clues to confirm this finding. As the speed of light in vacuum has not been measured for ~40 years, we have to find some other evidence to support this finding, as follows.

#### 3.1. Evidence from the Recession Rate of Moon from Earth

We noted that the total CMB energy in a space (e.g. Earth-Moon system) at CMB temperature  $T$  can be given by

$$E_T = kT \left( \frac{4}{3} \pi r^3 \right) \quad (4)$$

where  $\frac{4}{3} \pi r^3$  is the volume of the sphere with a radius of  $r$  (e.g. the Earth-Moon distance,  $3.844 \times 10^8$  meters). Based on the law of conservation of energy, that is,  $E_T = E_{T_0}$ , we can obtain the following equation,

$$\frac{4}{3} \pi k T r_T^3 = \frac{4}{3} \pi k T_0 r_{T_0}^3 \quad (5)$$

As a result, according to the Hubble's law and Hubble constant (70 km/s/Mpc), it is not difficult to predict that the recession rate of Moon from Earth is 0.92 centimeters per year (0.92 cm/yr), which is quite close to the value ( $1.24 \pm 0.71$  cm/yr) derived from the analysis of sedimentary cyclic rhythmites of tidal origin [9]. However, National Aeronautics and Space Administration (NASA) reported a recession rate of 3.8 cm/yr [10] based on the laser beams reflected between Earth and Moon. If we consider the decreasing rate of speed of light, both our

data and sedimentary cyclic rhythmites data will match the NASA data quite well (**Table 1**), suggesting that the speed of light in vacuum could indeed decrease at a rate of  $\sim 2.15$  cm/s/year.

### 3.2. Evidence from the Temperature of Phanerozoic Oceans

As the speed of light  $c$  continuously decreases, it is thus expected that equal numbers of photons from Sun will produce less and less energy on Earth. As a result, the temperature of the Earth system is expected to continuously decrease although it may increase at some time scale due to some reasons like volcano. Indeed, it was reported that the temperature of phanerozoic oceans do globally decrease as time by the measurement of oxygen isotopes [11]. However, it should be noted this evidence is not so solid enough as the Earth is moving far away from the Sun, which would also decrease the temperature of the Earth.

### 3.3. Evidence from Thought Experiments

Besides the above evidence, we also have some evidence from thought experiments.

Firstly, according to Equation (2), the speed of light in vacuum  $c$  will be bigger/smaller at a space-time with higher/lower  $T$ . Thus,  $c$  would be zero when  $T$  decreases to 0 K in a future space-time according to this study, however,  $c$  is constant in classical theory. We think that in a zero temperature of CMB, a zero speed of light in vacuum is more reasonable than a constant one, that is,  $c_0 = 299,792,458$  m/s. But a universe with 0 K CMB would be another singularity opposite with the one before the Big Bang.

Secondly, according to the Big Bang theory, our universe comes from a singularity, which is a dimensionless point where all the mass of the universe concentrated. It seems quite bizarre for such a huge mass of our universe concentrated in such a small dimensionless point. Current physics cannot explain it well. According to our finding, the mass-energy equation  $E = mc^2$  should be re-written as

$$E_T = mc_T^2 = m \frac{T^2}{T_0^2} c_0^2 \quad (6)$$

**Table 1.** The recession rate (cm/yr) of Moon from Earth by this paper prediction, by analysis of sedimentary cyclic rhythmites of tidal origin (SCRT), and by NASA's laser reflection measurement **with** or **without** considering decreasing speed of light in vacuum. Given that the Earth-Moon distance is  $3.844 \times 10^8$  meters and the speed of light in vacuum decreases at a rate of 2.15 cm/s/yr, the measurement by laser will increase the Earth-Moon distance at a rate of 2.76 cm/yr, which could be a pseudo-recession rate.

Methods	With (true)	Without
This paper	0.92	3.68
SCRT	$1.24 \pm 0.71$	$4.00 \pm 0.71$
NASA	1.04	3.80

where  $m$  is the mass of the object and  $E_T$  is the equivalent kinetic energy of the object at temperature of CMB  $T$ . According to the conservation law of energy, the total energy in our universe should be conserved. Using the new mass-energy Equation (6), it is thus not difficult to predict the mass of universe at the singularity. The temperature of our universe at the Planck time was estimated to be  $\sim 100$  million trillion trillion ( $T_p = \sim 10^{32}$ ) Kelvins [12] and one estimation of the mass of the present universe is  $m_0 = \sim 1.6 \times 10^{60}$  kg. Based on the new mass-energy equation and the conservation law of energy, we can obtain

$$\begin{cases} E = E_0 = m_0 c_0^2 \\ E = E_p = m_p c_p^2 = m_p \left( \frac{T_p}{T_0} c_0 \right)^2 \end{cases} \quad (7)$$

As a result, the mass of our universe at the Planck time (almost the time in singularity) is predicted to be  $m_p = \sim 1.438 \times 10^{-3}$  kg. That is, the mass of our universe around the Big Bang singularity is only  $\sim 1.438$  gram, which is thus much more reasonable.

Thirdly, according to relativity theory, nothing can move faster than light. However, it was observed that there are indeed something moving faster than light, e.g. universe expansion and jets of material moving away from the black hole [13]. Currently, no physical theories can interpret faster-than-light, however, the proposed Equation (2) can easily explain it.

#### 4. Conclusion and Discussion

In summary, we have revealed and quantified the relation of the temperature  $T$  of cosmic microwave background (CMB) with the speed of light in vacuum. As  $T$  is variable, we suggest a possibility of variable speed of light in vacuum and predicted it to decrease at a rate of 2.15 cm/s per year at present space-time. It should be noted that the definition of meter is based on the measured value ( $c = 299,792,458$  m/s) of speed of light in vacuum by the National Bureau of Standards in 1983. What we proposed in this paper is a possibility of variable speed of light in vacuum across space-time. A personal definition of meter by the speed of light in vacuum at that space-time (Earth in 1983) does not conflict with different speeds of light in vacuum at other space-time. Moreover, we provide a lot of evidence to support variable speed of light in vacuum. It should be noted that in a given specific space-time, the speed of light is the maximum speed, which is still consistent with the relative theory. What we revealed in this study is that in different space-time (that is, different CMB temperatures), the speed of light would vary as CMB temperature  $T$ . The definition of the speed of light is the speed at which light travels in a vacuum. Both Maxwell's theory and relative theory take it as a constant as it is determined by vacuum permittivity and vacuum permeability, which were both considered to be constant. It is well known that  $c_0 = 1/\sqrt{\epsilon_0 \mu_0}$  and vacuum permittivity and vacuum permeability are constant, however, which should be in the same space-time. According to our finding, different space-time should have different values of vacuum permittivity and vacuum permeability, and thus different speeds of light. We previously inferred that

vacuum permittivity  $\epsilon_0 = \frac{1}{2f}$  [5] and thus vacuum permeability  $\mu_0 = \frac{2}{f\lambda^2}$ .

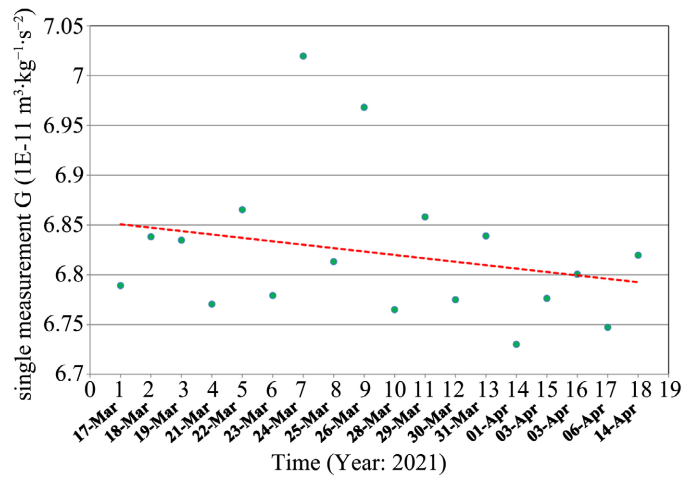
With the continuously cooling and expansion of our universe, the vacuum will become more and more ‘bare’, and thus the speed of light in the universe at different space-time will be quite different from  $c_0$ , which matches Dicke’s opinion well [14]. In addition, it should be noted that the parameters (e.g. galaxy redshift, Hubble constant) used in this study are based on the Big Bang cosmology model, parameters from other cosmology models [15] need to be addressed as well. Moreover, it should be noted that CMB contributes to gravitational force and charge force as some “stimulus” but NOT as pressure of radiation [5]. The exact explanation of the roles of CMB in gravitational force and charge force should be investigated in the future.

However, more evidence, especially direct high-precise measurement of the speed of light under the same condition across years (or one year), is required to support the above findings. In addition, some indirect measurements may be also helpful. For example, according to Equation (2), the gravitational force and the gravitational constant  $G$  in our previous study [5] at a space-time of CMB temperature  $T$  should be re-described as

$$F_T = \gamma \frac{k^3 T^2 T_0}{2\pi c_0 h^2} \frac{Mm}{r^2} \tag{8}$$

$$G_T = \gamma \frac{k^3 T^2 T_0}{2\pi c_0 h^2} \tag{9}$$

where  $\gamma$  is 1 unit  $\text{m}^3 \cdot \text{kg}^3 \cdot \text{s}^{-1}$ , which was introduced to make the dimension consistency. That is, the gravitational constant  $G$  is also predicted to be decreasing as time. Very recently, Brack *et al.* at ETH Zurich had measured 13 values of  $G$  on Mar-2021 and 5 values of  $G$  on Apr-2021 [16]. We re-analyzed these  $G$  values. As a result, there is a clear tendency of decreasing  $G$  along time ( $R = -0.25$ ,  $p = 0.32$ , Pearson’s correlation) (Figure 1), suggesting that the  $G$  value could be



**Figure 1.** The value of gravitational constant  $G$  (y axis) in 18 single measurements from 17-March-2021 to 14-April-2021 (x axis) from Brack *et al.*’s study at ETH Zurich. There is a clear tendency of decreasing  $G$  along time ( $R = -0.25$ ,  $p = 0.32$ , Pearson’s correlation).

indeed decreasing. However, this measurement is in a short period and a small number of samples, continuous large-scale and high-precise measurements [17] of the gravitational constant  $G$  across years (or sampling measurements in one year) would get more significant results and thus could confirm whether the gravitational constant  $G$  is decreasing or not, which thus can indirectly confirm the possibility of variable speed of light in vacuum.

### Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

### References

- [1] (1984) Documents Concerning the New Definition of the Metre. *Metrologia*, **19**, Article No. 163. <https://doi.org/10.1088/0026-1394/19/4/004>
- [2] Moffat, J.W. (1993) Superluminary Universe: A Possible Solution to the Initial Value Problem in Cosmology. *International Journal of Modern Physics D*, **2**, Article No. 351. <https://doi.org/10.1142/S0218271893000246>
- [3] Moffat, J.W. (2002) Variable Speed of Light Theories.
- [4] Moffat, J.W. (2002) Bimetric Gravity Theory, Varying Speed of Light and the Dimming of Supernovae.
- [5] Cui, Q. (2022) Possible Relations of Cosmic Microwave Background with Gravity and Fine-Structure Constant. *Journal of Modern Physics*, **13**, 1045-1052. <https://doi.org/10.4236/jmp.2022.137058>
- [6] Hees, A., *et al.* (2020) Search for a Variation of the Fine Structure Constant around the Supermassive Black Hole in Our Galactic Center. *Physical Review Letters*, **124**, Article ID: 081101. <https://doi.org/10.1103/PhysRevLett.124.081101>
- [7] Wilczynska, M.R., *et al.* (2020) Four Direct Measurements of the Fine-Structure Constant 13 Billion Years Ago. *Science Advances*, **6**, No. 17. <https://doi.org/10.1126/sciadv.aay9672>
- [8] Chen, H.Y., Fishbach, M. and Holz, D.E. (2018) A Two Percent Hubble Constant Measurement from Standard Sirens within Five Years. *Nature*, **562**, 545-547. <https://doi.org/10.1038/s41586-018-0606-0>
- [9] Williams, G.E. (2000) Geological Constraints on the Precambrian History of Earth's Rotation and the Moon's Orbit. *Reviews of Geophysics*, **38**, 37-59. <https://doi.org/10.1029/1999RG900016>
- [10] NASA. <https://nssdc.gsfc.nasa.gov/planetary/factsheet/moonfact.html>
- [11] Veizer, J. and Prokoph, A. (2015) Temperatures and Oxygen Isotopic Composition of Phanerozoic Oceans. *Earth-Science Reviews*, **146**, 92-104. <https://doi.org/10.1016/j.earscirev.2015.03.008>
- [12] Deziel, C. (2017) The Temperature of the Universe During the Big Bang. <https://sciencing.com/temperature-universe-during-big-bang-4822.html>
- [13] Watzke, M. and Porter, M. (2020) MAXI J1820+070: Black Hole Outburst Caught on Video. [https://www.nasa.gov/mission\\_pages/chandra/news/maxi-j1820070-black-hole-outburst-caught-on-video.html](https://www.nasa.gov/mission_pages/chandra/news/maxi-j1820070-black-hole-outburst-caught-on-video.html)
- [14] Dicke, R.H. (1957) Gravitation without a Principle of Equivalence. *Reviews of*

*Modern Physics*, **29**, 363-376. <https://doi.org/10.1103/RevModPhys.29.363>

- [15] Traunmüller, H. (2018) Towards a More Well-Founded Cosmology. *Zeitschrift für Naturforschung*, **73**, 1005-1023. <https://doi.org/10.1515/zna-2018-0217>
- [16] Brack, T., Zybach, B., Balabdaoui, F., Kaufmann, S., Palmegiano, F., Tomasina, J.C., Blunier, S., Scheiwiller D., Fankhauser, J. and Dual, J. (2022) Dynamic Measurement of Gravitational Coupling between Resonating Beams in the Hertz Regime. *Nature Physics*, **18**, 952-957. <https://doi.org/10.1038/s41567-022-01642-8>
- [17] Westphal, T., *et al.* (2021) Measurement of Gravitational Coupling between Millimetre-Sized Masses. *Nature*, **591**, 225-228. <https://doi.org/10.1038/s41586-021-03250-7>