How to Relieve the Hubble Constant Tension? (Earth’s Gravitational Redshift + Earth’s Diurnal Aberration)

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Abstract — There were published very precise experimental values of the Hubble constant $H_0$ in the range 66-74 km/s/Mpc during the last decade. There is a very active discussion in the $H_0$ community how to relieve this Hubble constant tension. In our model we have described the cosmological redshift as the expansion of old photons in the Earth’s gravitational field: the joint effect of the Earth’s gravitational redshift and the Earth’s diurnal aberration. This model predicts the value of the Hubble constant on the surface of the Earth $H_{\text{Earth}} = 66.71$ km/s/Mpc and on the board of the Hubble Space Telescope (HST) $H_{\text{HST}} = 72.34$ km/s/Mpc. The value $H_0$ determines the expansion of old photons in the Earth’s gravitational field and not the age of the Universe or the age of that old photon. In order to falsify this model in the spirit of Karl Popper we predict the value of $H_0$ for the surface of the Moon as $H_{\text{Moon}} = 6.62$ km/s/Mpc. This experiment for the determination of the value $H_0$ on the Moon’s surface is technically possible with the existing technology during this decade while several advanced countries have plans to realize experiments on the surface of the Moon. This proposed experiment on the surface of the Moon might open a new epoch in the description of our cosmological models.

Keywords — Hubble constant values, Hubble constant tension, expansion of old photons, Earth’s gravitational field, Moon’s gravitational field, Hubble constant interpretation.

I. INTRODUCTION

Edwin Hubble in 1929 [1] introduced the experimentally determined slope between the observed cosmological redshift and the distance of those objects – the Hubble constant with the dimension km/s/Mpc. Today’s physical interpretation of the Hubble constant is based on papers of Alexander Friedmann [2] and Georges Lemaître [3] as the measure of the expansion of the Universe and its age, e.g., [4]-[5].

There were published many valuable experimental studies with the aim to determine this Hubble constant, e.g. [6] - [8] with hundreds of inspirational references.

During the last decade the experimental determination was significantly improved and almost all values of the Hubble constant $H_0$ lay in the range 66-74 km/s/Mpc. The most statistically significant tension is the determination of the Hubble constant $H_0$ found by the Planck mission based on the cosmic microwave background $H_0 = (67.27\pm0.60)$ km/s/Mpc and the value $H_0 = (74.03\pm1.42)$ km/s/Mpc based on the analysis of the Hubble Space Telescope observations, e.g., [9]-[13].

Eleonora Di Valentino together with the $H_0$ community [12] analyzed the state of the art of the determination of the Hubble constant and surveyed proposals for the new physics models that could solve this Hubble constant tension and discussed how the next decade experiments will be crucial in the development of cosmological models., e.g., [14]-[29].

The gist of the contribution is to present a new model based on the expansion of old photons in the Earth’s gravitational field as a combination of the Earth’s gravitational redshift and the Earth’s diurnal aberration. This model can be falsified in the spirit of Karl Popper on the surface of the Moon where the predicted value should be one order smaller in compare with the value on the surface of the Earth.

Can we find a new road leading to the interpretation of the Hubble constant?

II. DETERMINING THE HUBBLE CONSTANT IN THE LAST DECADE

The experimental determination of the Hubble constant made a significant progress during the last decade as it is given in Fig. 1.
Fig. 1. The experimental values of the Hubble constant in the last decade (data from [6]).

Multiple methods have been used to determine the Hubble constant. Fig. 2 shows the evolution in the determination of the Hubble constant using three types of measurements.

Values of the Hubble constant given by Fig. 2 were measured using three different techniques. The first method is based on the cepheids -SN Ia distance ladder calibrated by the Hubble Space Telescope $H_0 = (73.3 \pm 1.4)$ km/s/Mpc [30]. The second method is based on the tip of the red-giant branch (TRGB) distance indicator (HST + Gaia EDR3) with the value $H_0 = (69.8 \pm 1.7)$ km/s/Mpc [29]. The third method is based on data from the Planck mission investigating the cosmic microwave radiation with the value $H_0 = (67.4 \pm 0.5)$ km/s/Mpc [31].

The discrepancy between the “late universe” measurements with the value $H_0 = (73.3 \pm 1.4)$ km/s/Mpc and the “early universe” value $H_0 = (67.4 \pm 0.5)$ km/s/Mpc is called the Hubble tension.

Our model is based on the interaction of old photons with the Earth’s gravitational field – the Earth’s gravitational redshift + the Earth’s diurnal aberration.

The Planck satellite was operated in the Earth/Sun L2 point but the instruments were calibrated using the “geocentric” kelvin for the Earth’s surface. Therefore, we will assume that those redshifted data were calibrated for the Earth’s surface conditions.

The Hubble Space Telescope took data at the average altitude 538.950 km and the cepheid- SN Ia distance ladder was calibrated at this altitude.

The distance ladder based on the tip of the red-giant branch was calibrated as a “mixture” of the Earth’s surface data and the data valid for the Hubble Space Telescope. We will assume that the “calibration altitude” was 269.475 km.
III. DETERMINING THE HUBBLE CONSTANT AT THE EARTH’S SURFACE

In our model, we assume that old photons, from far distance of the Universe, interact with the Earth’s gravitational field. The joint co-operation of the Earth’s gravitational redshift and the Earth’s diurnal aberration leads to the observed photon expansion and could be described by the Hubble constant for the Earth’s surface $H_0$ as:

$$H_0^{\text{EARTH}} = \frac{G M_{\oplus}}{R_{\oplus} c^2} \frac{v_{\oplus \text{rot}}}{360 \cdot 60 \cdot 60 \text{ parsec}} \frac{1 \text{ parsec}}{2\pi}$$  \hspace{1cm} (1)

All parameters in (1) are given in Table I.

| TABLE I: THE EARTH’S PARAMETERS IN EQUATION 1 |
|---------------------------------------------|
| Newtonian gravitational constant $G = 6.67430 \times 10^{-11} \text{ m}^3 \text{kg}^{-1} \text{s}^{-2}$ |
| Mass of the Earth $M_{\oplus} = 5.9722 \times 10^{24} \text{ kg}$ |
| Radius of the Earth $R_{\oplus} = 6.378137 \times 10^6 \text{ m}$ |
| Speed of light $c = 299792458 \text{ m s}^{-1}$ |
| Angular speed of the Earth’s rotation $\omega = 7.2921159 \times 10^{-5} \text{ rad s}^{-1}$ |
| Earth’s equatorial speed $v_{\oplus \text{rot}} = 465.10 \text{ m s}^{-1}$ |
| Parsec $pc = 3.085677758 \times 10^{16} \text{ m}$ |

$$H_0^{\text{EARTH}} = \frac{G M_{\oplus}}{R_{\oplus} c^2} \frac{v_{\oplus \text{rot}}}{360 \cdot 60 \cdot 60} \frac{1 \text{ parsec}}{2\pi} = 2.161 \cdot 10^{-18} \left[ \text{s}^{-1} \right] = 66.70 \left[ \text{km s}^{-1} \text{ Mpc} \right]$$  \hspace{1cm} (2)

IV. DETERMINING THE HUBBLE CONSTANT ON THE HUBBLE SPACE TELESCOPE

The orbital parameters of the Hubble Space Telescope are: perigee altitude 537.0 km, apogee altitude 540.9 km, the average altitude is 538.950 km. The rotation speed of the Earth’s gravitational field at the HST is $v_{\oplus \text{HSTrot}} = 504.4 \text{ m s}^{-1}$:

$$H_0^{\text{HST}} = \frac{G M_{\oplus}}{R_{\oplus} c^2} \frac{v_{\oplus \text{HSTrot}}}{360 \cdot 60 \cdot 60} \frac{1 \text{ parsec}}{2\pi} = 2.344 \cdot 10^{-18} \left[ \text{s}^{-1} \right] = 72.34 \left[ \text{km s}^{-1} \text{ Mpc} \right]$$  \hspace{1cm} (3)

V. JOINT CALIBRATION: HST AND THE EARTH’S SURFACE

The calibration method based on the tip of the red-giant branch (TRGB) distance indicator (HST + Gaia EDR3) with the value $H_0 = (69.8 \pm 1.7) \text{ km/s/Mpc}$ [29] is based on the data of the HST and the Earth’s surface. We assume that the “average altitude” for this calibration is 269.950 km with the rotation speed of the Earth’s gravitational field $v_{\oplus \text{HSTrot}}/2 = 484.75 \text{ m s}^{-1}$:

$$H_0^{\text{HST/2}} = \frac{G M_{\oplus}}{R_{\oplus} c^2} \frac{v_{\oplus \text{HSTrot}/2}}{360 \cdot 60 \cdot 60} \frac{1 \text{ parsec}}{2\pi} = 2.253 \cdot 10^{-18} \left[ \text{s}^{-1} \right] = 69.52 \left[ \text{km s}^{-1} \text{ Mpc} \right]$$  \hspace{1cm} (4)

VI. DETERMINING THE HUBBLE CONSTANT AT THE MOON’S SURFACE

In order to falsify this model in the spirit of Karl Popper we propose to realize the measurement of the Hubble constant on the surface of the Moon because this model predicts the value of the Hubble constant one order lower in compare with the value on the surface of the Earth. The advanced countries might perform this experiment on the surface of the Moon during this decade.
TABLE I: THE MOON’S PARAMETERS IN EQUATION 5

| Parameter                          | Value                      |
|------------------------------------|----------------------------|
| Newtonian gravitational constant   | $G = 6.67430 \times 10^{-11} \, m^3 \, kg^{-1} \, s^{-2}$ |
| Mass of the Moon                   | $M_{\text{MOON}} = 7.34767 \times 10^{22} \, kg$ |
| Radius of the Moon                 | $R_{\text{MOON}} = 1.7374 \times 10^6 \, m$ |
| Speed of light                     | $c = 299792458 \, m \, s^{-1}$ |
| Moon’s average orbital speed       | $v_{\text{MOON orb}} = 1022 \, m \, s^{-1}$ |
| Parsec                             | $pc = 3.085677758 \times 10^{19} \, m$ |

\[
H_0^{\text{MOON}} = \frac{G \, M_{\text{MOON}}}{R_{\text{MOON}} \, c^2} \frac{360 \cdot 60 \cdot 60}{2\pi} = 2.1455 \cdot 10^{-19} \left[ s^{-1} \right] = 6.620 \left[ km \, s^{-1} \, Mpc \right] \quad (5)
\]

VII. REDSHIFT DEPENDENCE ON THE AGE OF OLD PHOTONS

There are many valuable experimental data with the redshift dependence $z_{(\text{EARTH})}$ on the luminosity distance $d_L$ or the age of old photons $t$:

$$t = \frac{d_L}{c} \quad (6)$$

where $d_L$ is the luminosity distance measured by the very sophisticated techniques, e.g. [32].

In our model the observed redshift $z$ of old photons at the surface of the Earth can be expressed as:

$$z_{\text{EARTH}} = \frac{H_0^{\text{EARTH}} \, t}{\left( 1 + H_0^{\text{EARTH}} \, t \right)^{\frac{1}{3}} \, \left[ s^{-1} \right]} \quad (7)$$

Fig. 3 shows a typical dependence of the observed redshift of old photons in experiments done on the surface of the Earth. The volume of old photons expands in the Earth gravitational field.

![Graph showing redshift vs age of photons](image)

Fig. 3. The experimental values of the observed redshifts of old photons observed on the surface of the Earth ([4], [5]).

VIII. CONCLUSION

We might open a new road leading towards the interpretation of the Hubble constant as the old photon expansion in the gravitational field of a planet. In this model the Hubble constant with the dimension $s^{-1}$
does not describe the age of the photon or of the Universe but the ability of a planet gravitational field to expand the photon volume. This model can be easily falsified by the measurement of the Hubble constant on the surface of the Moon. The poetic conclusion: the Slavic goddess SLAVIA [33] predicts the $H_0 = 6.620 \text{ km/s/Mpc}$ and the Moon goddesses ARTEMIS, CHANG’E, LUNA, and SELENÉ might experimentally falsify this prediction during the coming decade.

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