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Hubble Tension

Vladimir S. Netchitailo

Biolase Inc., Irvine, USA
Email: netchitailov@gmail.com

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Abstract

The results of measurements of the Hubble constant H_0, which characterizes the expansion rate of the universe, show that the values of H_0 vary significantly depending on Methodology. The disagreement in the values of H_0 obtained by the various teams far exceeds the standard uncertainties provided with the values. This discrepancy is called the Hubble Tension. In this paper, we discuss Macrostructures of the World (Superclusters and Galaxies); explain their Origin and Evolution in frames of the developed Hypersphere World-Universe Model (WUM), which is an alternative to the prevailing Big Bang Model (BBM) [1]; and provide the explanation of the Hubble Tension. The main difference between WUM and BBM is: Instead of the Infinite Homogeneous and Isotropic Universe around the Initial Singularity in BBM, in WUM, the 3D Finite Boundless World (a Hypersphere) presents a Patchwork Quilt of different Luminous Superclusters (10^3), which emerged in various places of the World at different Cosmological times. In WUM, the Medium of the World is Homogeneous and Isotropic. The distribution of Macroobjects in the World is spatially Inhomogeneous and Anisotropic and temporally Non-simultaneous.

Keywords

Macrostructures of the World, Hubble Constant, Spatially Inhomogeneous and Anisotropic Distribution of Macroobjects, Hypersphere World-Universe Model, Homogeneous and Isotropic Medium

1. Introduction

E. Conover in the paper "Debate over the universe's expansion rate may unravel physics. Is it a crisis?" outlined the following situation with the measurements of an expansion rate of the universe [2]:

- *Scientists with the Planck experiment have estimated that the universe is expanding at a rate of* 67.4 *km/s Mpc with an experimental error of* 0.5 *km/s*

Mpc;

- *But supernova measurements have settled on a larger expansion rate of* 74.0 *km/s Mpc*, *with an error of* 1.4 *km/s Mpc*. *That leaves an inexplicable gap between the two estimates. Now* "*the community has started to take this* [*problem*] *extremely seriously*," *says cosmologist Daniel Scolnic of Duke University*, *who works on the supernova project led by Riess*, *called SH*0*ES*;
- *It is unlikely that an experimental error in the Planck measurement could explain the discrepancy. That prospect is* "*not a possible route out of our current crisis*," *said cosmologist Lloyd Knox of the University of California*, *Davis*;
- *So*, *worries have centered on the possibility that the supernova measurements contain unaccounted for systematic errors—biases that push the SH*0*ES estimate to larger value.*

L. Verde, T. Treu, and A. G. Riess gave a brief summary of the "Workshop at Kavli Institute for Theoretical Physics, July 2019" [3].

Table 1 summarizes the results of measurements of the Hubble constant H_0 in 2019-2021 [4]. Observe that the values of H_0 vary significantly depending on Methodology. The disagreement in the values of H_0 obtained by the various teams far exceeds the standard uncertainties provided with the values. The average values of H_0 vary from 67.4 to 76.8 km·s^{-1}·Mpc^{-1}. This discrepancy is called the Hubble tension [5]. A. Mann gave a summary of the situation with the measurements of H_0 in "One Number Shows Something Is Fundamentally Wrong with Our Conception of the Universe" paper [6]. It is not clear whether the discrepancy in the observations is due to systematics, or indeed constitutes a major problem for the Standard model.

W. L. Freedman in the paper "New analysis by UChicago astronomer finds agreement with standard model in ongoing Hubble tension" outlined the following situation with the measurements of an expansion rate of the universe [7]:

- Our universe is expanding, but our two main ways to measure how fast this expansion is happening have resulted in different answers. For the past decade, astrophysicists have been gradually dividing into two camps: one that believes that the difference is significant, and another that thinks it could be due to errors in measurement;
- One way to measure the Hubble constant is by looking at very faint light left over from the Big Bang, called the cosmic microwave background. Scientists can feed these observations into their 'standard model' of the early universe and run it forward in time to predict what the Hubble constant should be today; they get an answer of 67.4 kilometers per second per megaparsec;
- The other method is to look at stars and galaxies in the nearby universe and measure their distances and how fast they are moving away from us. Freedman has been a leading expert on this method for many decades; in 2001, her team made one of the landmark measurements using the Hubble Space Telescope to image stars called Cepheids. The value they found was 72;

Table 1. Measurements of Hubble constant H_0. Adapted from [4].

Date Published	H_0 km·s^{-1}·Mpc^{-1}	Observer	Remarks/Methodology
2021-12-08	73.3 ± 1.4	SH0ES	Cepheid-SN distance ladder (HST + Gaia EDR3 + Pantheon Plus SN Ia).
2021-09-17	69.8 ± 1.7	W. Freedman	Tip of the red-giant branch (TRGB) distance indicator (HST + Gaia EDR3).
2020-12-16	72.1 ± 2.0	Hubble Space Telescope and Gaia EDR3	Combining earlier work on red giant stars, using the tip of the red-giant branch (TRGB) distance indicator, with parallax measurements of Omega Centauri from Gaia EDR3.
2020-12-15	73.2 ± 1.3	Hubble Space Telescope and Gaia EDR3	Combination of HST photometry and Gaia EDR3 parallaxes for Milky Way Cepheids, reducing the uncertainty in calibration of Cepheid luminosities to 1.0%. Overall uncertainty in the value for H_0 is 1.8%, which is expected to be reduced to 1.3% with a larger sample of type Ia supernovae in galaxies that are known Cepheid hosts.
2020-12-04	73.5 ± 5.3	E. J. Baxter, B. D. Sherwin	Gravitational lensing in the CMB is used to estimate H_0 without referring to the sound horizon scale, providing an alternative method to analyze the Planck data.
2020-11-25	$71.8^{+3.9}_{-3.3}$	P. Denzel, *et al.*	Eight quadruply lensed galaxy systems are used to determine H_0 to a precision of 5%, in agreement with both "early" and "late" universe estimates. Independent of distance ladders and the cosmic microwave background.
2020-11-07	67.4 ± 1.0	T. Sedgwick, *et al.*	Derived from 88 $0.02 < z < 0.05$ Type Ia supernovae used as standard candle distance indicators. The H_0 estimate is corrected for the effects of peculiar velocities in the supernova environments, as estimated from the galaxy density field. The result assumes $\Omega m = 0.3$, $\Omega\Lambda = 0.7$ and a sound horizon of 149.3 Mpc, a value taken from Anderson *et al.* (2014).
2020-09-29	$67.6^{+4.3}_{-4.2}$	S. Mukherjee, *et al.*	Gravitational waves, assuming that the transient ZTF19abanrh found by the Zwicky Transient Facility is the optical counterpart to GW190521. Independent of distance ladders and the cosmic microwave background.
2020-06-18	$75.8^{+5.2}_{-4.9}$	T. de Jaeger, *et al.*	Use Type II supernovae as standardisable candles to obtain an independent measurement of H.
2020-02-26	$73.9^{+3.0}_{-3.0}$	Megamaser Cosmology Project	Geometric distance measurements to Megamaser-hosting galaxies. Independent of distance ladders and the cosmic microwave background.
2019-10-14	$74.2^{+2.7}_{-3.0}$	STRIDES	Modelling the mass distribution & time delay of the lensed quasar DES J0408-5354.
2019-09-12	$76.8^{+2.6}_{-2.6}$	SHARP H0LiCOW	Modelling three galactically lensed objects and their lenses using ground-based adaptive optics and the Hubble Space Telescope
2019-08-20	$70.3^{+1.36}_{-1.35}$	K. Dutta, *et al.*	This is obtained analyzing low-redshift cosmological data within ΛCDM model. The datasets used are Type-Ia Supernova, Baryon Acoustic Oscillations, Time-Delay measurements using Strong-Lensing, measurements using Cosmic Chronometers and growth measurements from large scale structure observations.
2019-08-15	$73.5^{+1.4}_{-1.4}$	M. J. Reid, D. W. Pesce, A. G. Riess	Measuring the distance to Messier 106 using its supermassive black hole, combined with measurements of eclipsing binaries in the Large Magellanic Cloud.
2019-07-16	$69.8^{+1.9}_{-1.9}$	Hubble Space Telescope	Distances to red giant stars are calculated using the tip of the red-giant branch (TRGB) distance indicator.

Continued

2019-07-10	$73.3^{+1.7}_{-1.7}$	H0LiCOW collaboration	Updated observations of multiply imaged quasars, now using six quasars, independent of the cosmic distance ladder and independent of the cosmic microwave background measurements.
2019-07-08	$70.3^{+5.3}_{-5.0}$	LIGO and Virgo detectors	Uses radio counterpart of GW170817, combined with earlier gravitational wave and electromagnetic data.
2019-03-28	$68.0^{+4.2}_{-4.1}$	Fermi-LAT	Gamma ray attenuation due to extragalactic light. Independent of the cosmic distance ladder and the cosmic microwave background.
2019-03-18	$74.03^{+1.42}_{-1.42}$	Hubble Space Telescope	Precision HST photometry of Cepheids in the Large Magellanic Cloud (LMC) reduces the uncertainty in the distance to the LMC from 2.5% to 1.3%. The revision increases the tension with CMB measurements to the 4.4σ level (P = 99.999% for Gaussian errors), raising the discrepancy beyond a plausible level of chance. Continuation of a collaboration known as Supernovae, for the Equation of State of Dark Energy (SHoES).
2019-02-08	$67.78^{+0.91}_{-0.87}$	Joseph Ryan, *et al.*	Quasar angular size and baryon acoustic oscillations, assuming a flat LambdaCDM model. Alternative models result in different (generally lower) values for the Hubble constant.

- The value of the Hubble constant Freedman's team gets from the red giants is 69.8 km/s/Mpc—virtually the same as the value derived from the cosmic microwave background experiment.

In the article "Measurements of the Hubble Constant: Tensions in Perspective," W. L. Freedman provides an excellent review of the Hubble Constant measurements [8]:

- As apparent fissures in the standard model have been emerging, there are also indications that there may be cracks that need attention in the local distance scale as well. For example, the Tip of the Red Giant Branch (TRGB) method and the Cepheid distance scale result in differing values of $H_0 = 69.6 \pm 1.9$ km/sec/Mpc (Freedman, *et al.* 2019, 2020) for the TRGB and 73.2 ± 1.3 (Riess *et al.* 2021) for the Cepheids;
- In contrast, (early-time) estimates of H_0 based on measurements of fluctuations in the temperature and polarization of the cosmic microwave background (CMB) from Planck and ACT+WMAP (Planck Collaboration *et al.* 2020; Aiola *et al.* 2020) consistently yield lower values of $H_0 = 67.4 \pm 0.5$ and $67.6 \pm 1.1\ \text{km}\cdot\text{s}^{-1}\cdot\text{Mpc}^{-1}$, respectively, both adopting the current standard ΛCDM model;
- High values of H_0 were initially obtained from time-delay measurements of strong gravitational lensing (Suyu *et al.* 2017; Wong *et al.* 2020), with $H_0 = 73^{+1.7}_{-1.8}\ \text{km}\cdot\text{s}^{-1}\cdot\text{Mpc}^{-1}$, apparently consistent with the Cepheid measurements. However, recent detailed consideration of the assumptions in the modeling of the lens mass distribution (Birrer *et al.* 2020; Birrer & Treu 2020) leads to a much lower value of the Hubble constant, as well as a significantly larger value of the uncertainty $H_0 = 67.4^{+4.1}_{-3.2}\ \text{km}\cdot\text{s}^{-1}\cdot\text{Mpc}^{-1}$, currently consistent with the CMB and TRGB measurements;

- This TRGB calibration was updated slightly in (Freedman *et al*, 2020), yielding a value of $H_0 = 69.6 \pm 0.8(\text{stat}) \pm 1.7(\text{sys})\,\text{km}\cdot\text{s}^{-1}\cdot\text{Mpc}^{-1}$. To date, the TRGB is the only method with comparable numbers of galaxies in its calibration relative to Cepheids; the H_0 calibration of Riess *et al.* (2016, 2019), is based on the Cepheid distances to 19 galaxies. Ten of the galaxies in the (Freedman *et al*, 2019) and (Freedman *et al*, 2020) TRGB sample also have independent Cepheid distances, an order of magnitude greater number than for Miras (Huang *et al.* 2020) or the maser technique (Pesce *et al.* 2020), in both cases for which only a single galaxy is available for comparison with Cepheids;
- The updated TRGB calibration applied to a distant sample of Type Ia supernovae from the Carnegie Supernova Project results in a value of the Hubble constant of $H_0 = 69.8 \pm 0.6(\text{stat}) \pm 1.6(\text{sys})\,\text{km}\cdot\text{s}^{-1}\cdot\text{Mpc}^{-1}$. No statistically significant difference is found between the value of H_0 based on the TRGB and that determined from measurements of the cosmic microwave background.

2. Macrostructures of the World

Laniakea Supercluster (LSC) is a galaxy supercluster that is home to Milky Way (MW) and approximately 100,000 other nearby galaxies (see **Figure 1**). It is known as one of the largest superclusters with estimated binding mass $10^{17} M_{\odot}$ [9]. The neighboring superclusters to LSC are the Shapley Supercluster, Hercules Supercluster, Coma Supercluster, and Perseus-Pisces Supercluster. Distance from the Earth to the Centre of LSC is 250 Mly, Redshift—0.0708 (center).

The mass-to-light ratio of the Virgo Supercluster is about three hundred times larger than that of the Solar ratio. Similar ratios are obtained for other superclusters [10]. In 1933, F. Zwicky investigated the velocity dispersion of Coma cluster and found a surprisingly high mass-to-light ratio (~500). He concluded: "*If this would be confirmed, we would get the surprising result that dark matter*

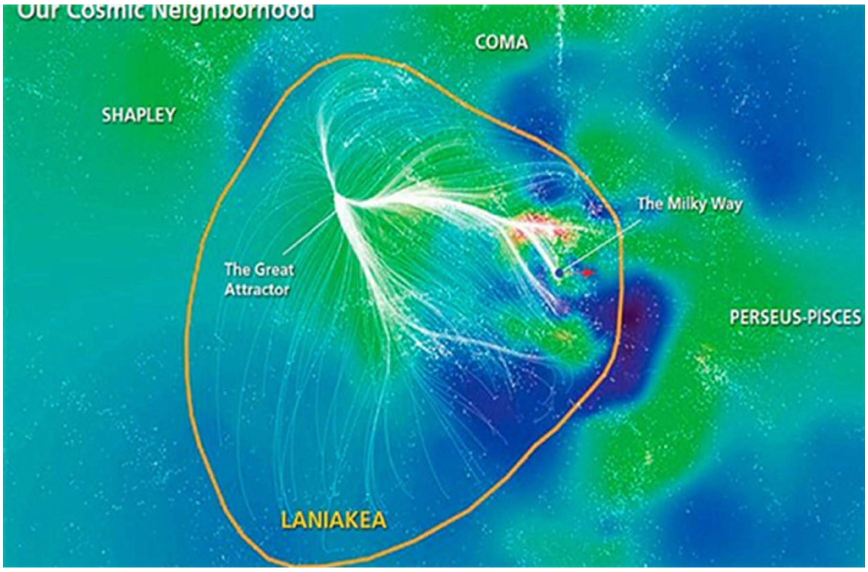

Figure 1. Laniakea supercluster. Adapted from [13].

is present in much greater amount than luminous matter" [11]. These ratios are one of the main arguments in favor of presence of substantial amounts of Dark Matter in the World.

We emphasize that about 100,000 nearby galaxies are moving around Centre of Laniakea Supercluster. They belong to LSC. All these galaxies did not start their movement from the "Initial Singularity". The neighboring superclusters have the same structure (see **Figure 2** and **Figure 3**). It means that the World is, in fact, a Patchwork Quilt of different Luminous Superclusters ($\gtrsim 10^3$) [12].

According to R. B. Tully, *et al.*, "*Galaxies congregate in clusters and along filaments, and are missing from large regions referred to as voids. These structures are seen in maps derived from spectroscopic surveys that reveal networks*

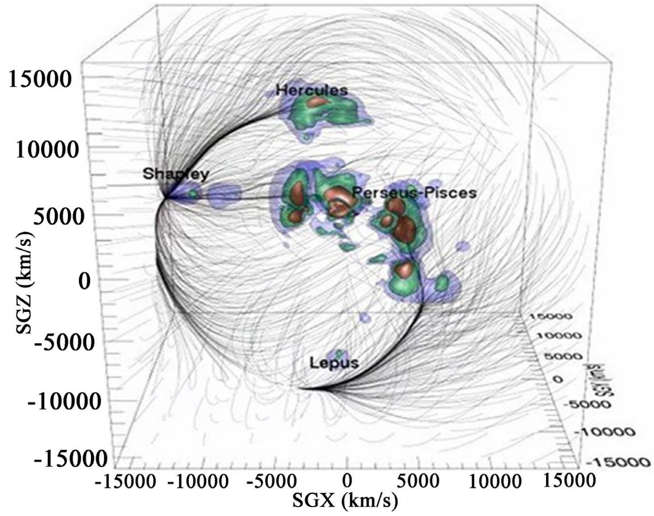

Figure 2. Structure within a cube extending 16,000 km·s^{-1} (~200 Mpc). Adapted from [13].

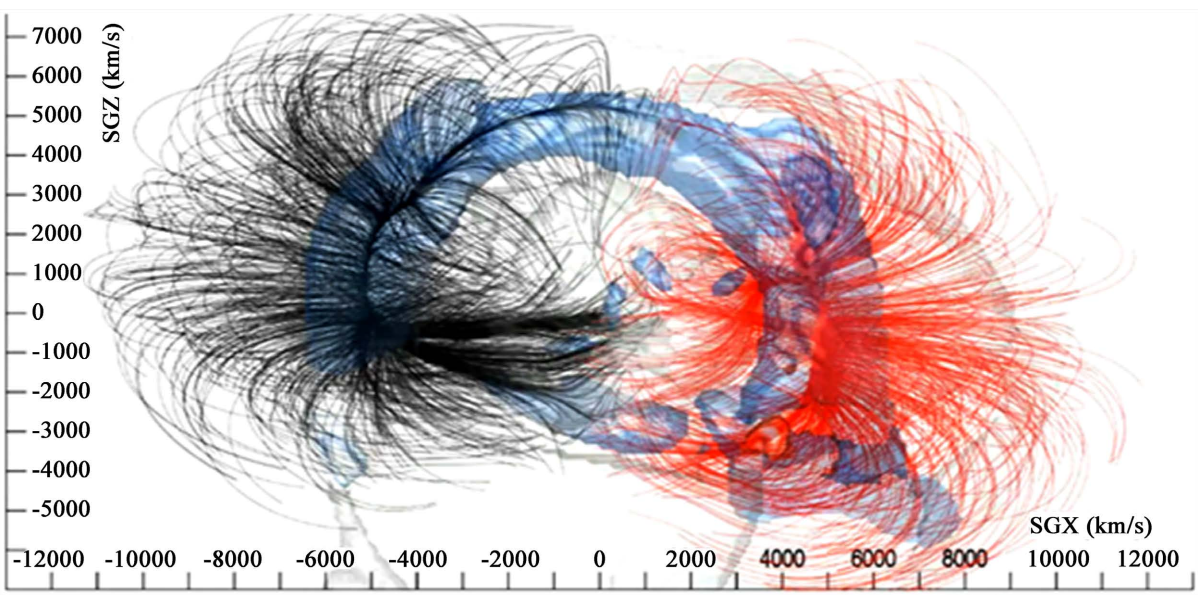

Figure 3. A representation of structure and flows due to mass within 6000 km·s^{-1} (80 Mpc). Adapted from [13].

of structure that are interconnected with no clear boundaries" [13].

P. Wang, *et al.* made a great discovery: "*Most cosmological structures in the universe spin. Although structures in the universe form on a wide variety of scales from small dwarf galaxies to large super clusters, the generation of angular momentum across these scales is poorly understood. We have investigated the possibility that filaments of galaxies—cylindrical tendrils of matter hundreds of millions of light-years across, are themselves spinning. By stacking thousands of filaments together and examining the velocity of galaxies perpendicular to the filament's axis (via their red and blue shift), we have found that these objects too display motion consistent with rotation making them the largest objects known to have angular momentum. These results signify that angular momentum can be generated on unprecedented scales*" [14].

A. Lopez reported about the discovery of "*a giant, almost symmetrical arc of galaxies—the Giant Arc—spanning* 3.3 *billion light years at a distance of more than* 9.2 *billion light years away that is difficult to explain in current models of the Universe. This new discovery of the Giant Arc adds to an accumulating set of (cautious) challenges to the Cosmological Principle. The growing number of large-scale structures over the size limit of what is considered theoretically viable is becoming harder to ignore. Can the standard model of cosmology account for these huge structures in the Universe as just rare flukes or is there more to it than that?*" [15].

WUM. These latest observations of the World can be explained in frames of the developed WUM only [1]:

- "*Galaxies do not congregate in clusters and along filaments.*" On the contrary, Cosmic Web that is "*networks of structure that are interconnected with no clear boundaries*" is the result of the Explosive Volcanic Rotational Fission of Dark Matter (DM) Cores of neighboring Superclusters;
- "*Generation of angular momentum across these scales*" provide DM Cores of Superclusters through the Explosive Volcanic Rotational Fission;
- "Spinning cylindrical tendrils of matter hundreds of millions of light-years across" are the result of spiral jets of galaxies generated by DM Cores of Superclusters with internal rotation;
- The Giant Arc is the result of the intersection of the Galaxies' jets generated by the neighboring DM Cores of Superclusters;
- 13.77 Gyr ago, when the Laniakea Supercluster emerged, the estimated number of DM Supercluster Cores in the World was around ~10^3 [12]. It is unlikely that all of them gave birth to Luminous Superclusters at the same cosmological time being far away from each other. The 3D Finite Boundless World presents a Patchwork Quilt of different Luminous Superclusters, which emerged at different Cosmological times.

3. Hubble Tension Explanation

The experimental observations of galaxies in the universe show that most of them are disk galaxies [16]. It is well-known, that while observing spiral galaxies, a side spinning toward us has a slight blueshift relative to the center of the galaxy whereas the side spinning away from us has a slight redshift. Therefore, there is a meaning of a redshift of a Center of galaxy only. The redshift of the Centre of LSC is 0.0708. But it does not mean that LSC is moving away from MW. On the contrary, MW is moving away from the Centre of LSC. In LSC, some galaxies are moving toward MW, and the other are moving away (see **Figure 1**). Then redshift depends on the position and movement of a particular galaxy in LSC against MW. More complicated situation with redshift is when galaxies belong to neighboring superclusters, which emerged at different cosmological times.

According to WUM, the value of the Hubble parameter H depends on the cosmological time: $H = \tau^{-1}$. It means that a value of H should be measured based on Cosmic Microwave Background (CMB) radiation only. **Figure 4** illustrates recent H_0 determinations using only CMB data.

The calculated value of Hubble constant in 2013 [18]: $H_0 = 68.733\ \text{km/s} \cdot \text{Mpc}$ is in excellent agreement with the most recent measured value in 2021: $H_0 = 68.7 \pm 1.3\ \text{km/s} \cdot \text{Mpc}$ using only CMB data [17].

In frames of WUM, the Hubble tension can be explained the following way:

- All measurements of Hubble constant are model-dependent;
- Statistics of these measurements is not sufficient to yield reliable conclusions;
- Hubble's law in Standard Cosmology is valid for the Big Bang Model (BBM) only when all galaxies start their movement from a single point named "Initial Singularity" that is not the case in WUM;
- There are observations of Galaxies, which belong to different Superclusters;

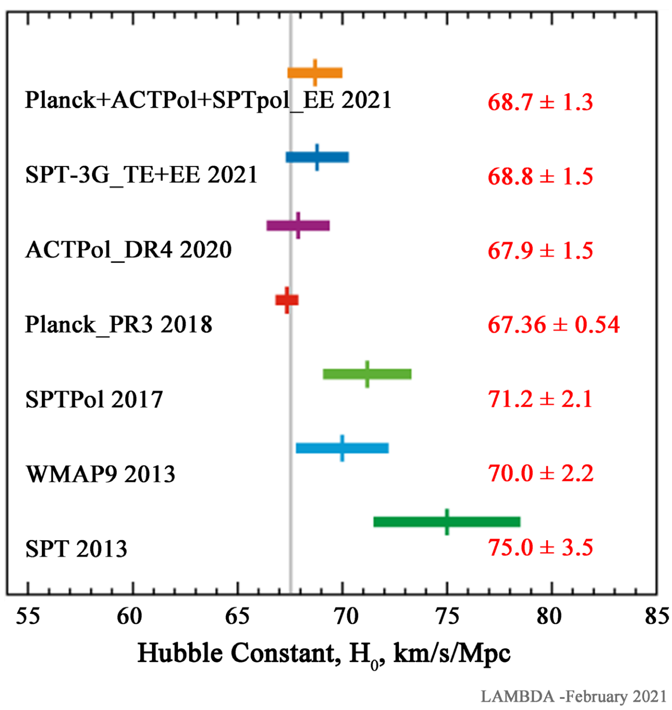

Figure 4. H_0 determinations using only CMB data. Adapted from [17].

- The value of H depends on the cosmological time $H = \tau^{-1}$ and is higher for the earlier Epoch of the World. It means that the value of H should be measured for each Galaxy separately depending on a distance to it and corresponding cosmological time. We must not calculate average values of H depending on Methodology as it is done in Table 1;
- The value of H should be measured based on Cosmic Microwave Background Radiation only.

This explanation is in good agreement with the experimental results provided by W. L. Freedman who belongs to the camp that believes that the difference could be due to errors in measurement. I belong to the camp that believes that the difference is significant.

The main differences between BBM and WUM are:

- Mainstream scientists, following BBM, measure the values of the Hubble constant based on various characteristics of Macroobjects, the distribution of which in the World is spatially Inhomogeneous and Anisotropic and temporally Non-simultaneous;
- WUM suggests that the value of the Hubble constant should be measured based on Cosmic Microwave Background Radiation only, which depends on the characteristics of the Medium of the World. The Medium is Homogeneous and Isotropic. Its parameters do not practically depend on Macroobjects, which can create some fluctuations in the Medium.

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Conflicts of Interest

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

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