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FUNDAMENTAL PROBLEMS OF METROLOGY

COSMOLOGICAL DISTANCE SCALE. PART 14: "HUBBLE BUBBLE" AND THE GRAVITATIONAL DIPOLE

S. F. Levin

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Drawing on astronomical discoveries made in the past 25 years, the paper discusses possible causes of the phenomenon perceived as the "accelerated expansion of the universe." In 1998, to confirm the "accelerated expansion of the universe," the High-Z SN Search Team tested and rejected the hypothesis about the effect produced by a local void — Hubble bubble — using data on 44 Type Ia supernovae (SNe Ia), which was believed to be an alternative to the positive cosmological constant. Also in 1998, the present author and specialists of the Computing Center of the Academy of Sciences (CC RAS) discovered divergent dipole anisotropy in the redshift of 383 quasars and radio galaxies along the Virgo – Leo ↔ Eridanus – Aquarius axis when testing the MCM-stat M program for multivariate statistical analysis using standard reference data. In 2007, the issues associated with anisotropy caught the attention of cosmologists, while in 2016, the High-Z SN Search Team and the Carnegie–Chicago Hubble program initiated a discussion about the impasse in cosmology. An additional analysis revealed that the dipole anisotropy in the redshift of SNe Ia, as well as radio galaxies, is inversely oriented with respect to the dipole anisotropy of quasars.
Keywords: *redshift, cosmological distance scale, quasars, radio galaxies, Type Ia supernovae, SN Ia, supercluster, supervoids, Hubble bubble, gravitational dipole.*

Introduction. In 2016, divergent estimates of the Hubble constant[1] H_0 obtained by the Planck Collaboration $H_{0PC} = (66.93 \pm 0.62)$ km·s^{-1}·Mpc^{-1} [3] and the High-Z SN Search Team $H_{0HZ} = (73.23 \pm 1.74)$ km·s^{-1}·Mpc^{-1} [4] prompted a discussion about the impasse in cosmology [1].

The H_{0PC} estimate was obtained by interpreting cosmic microwave background (CMB) data from the Planck cosmology probe according to the standard ΛCDM model at a redshift of $z > 10^3$. The estimation of H_{0HZ} used measurement data for Cepheids and Type Ia supernovae (SNe Ia) at $z < 0.2$, with the data statistically processed via the 3rd-order Taylor expansion of the Friedmann–Robertson–Walker model without the zero term, with the Hubble radius c/H_0 (c – speed of light), as well as the deceleration q_0 and jerk j_0 parameters [5].

When the "accelerated expansion of the universe" was discovered in 1998, the High-Z SN Search Team obtained a different estimate that was close to H_{0PC}, i.e., $H_0 = (63.8–65.2) \pm 1.3$ km·s^{-1}·Mpc^{-1} [6]. However, the complete Friedmann–Robertson–Walker model was applied then, using the parameters of dark matter Ω_m and energy[2] Ω_Λ at a curvature of $\Omega_k = 0$ to factor in the CMB angular power spectrum drawing on the Planck project measurements as per the ΛCDM model [7]. In addition, it was noted that "for any value of the Hubble constant less than $H_0 = 70$ km·s^{-1}·Mpc^{-1}, the implied age of the universe is greater than 13 Gyr, allowing enough time for the oldest stars in globular clusters to evolve" [8].

The Carnegie–Chicago Hubble program was the first to draw attention to the 3.4σ discrepancy between the H_{0PC} and H_{0HZ} estimates in terms of the normal law [9]. Its leader, Wendy Freedman, suggested that everything was great in the early 2000s, but then a true statistical discrepancy was observed [10]. A way out of this impasse she saw in bringing the accuracy of the extragalactic distance scale to one percent, admitting that we may be dealing with a new physics [10]. The

[1]As a function of time, the Hubble constant is called the Hubble parameter [2].
[2]Perhaps the terms "dark substance" and "dark field" would be more appropriate.

Moscow Institute of Expertise and Testing, Moscow, Russia; e-mail: miei-metrolog@yandex.ru. Translated from Izmeritel'naya Tekhnika, No. 2, pp. 4–11, February, 2023. Original article submitted December 11, 2022. Accepted December 17, 2022.

High-Z SN Search Team and its leader, Adam Riess, also believed that the divergent estimates were the evidence of this new physics outside the ΛCDM model. Subsequently, they obtained "stronger evidence," i.e., a more accurate estimate of $H_0 = 74.03 \pm 1.42 (1.91\%)$ km·s^{-1}·Mpc^{-1} [11]. However, despite an increase in the accuracy of astrophysical measurements, the reasons for the discrepancy between the Hubble constant estimates in the Friedmann–Robertson–Walker metric remain unknown while the discussion continues [12].

Meanwhile, the anisotropy in the redshift of the spectra of extragalactic sources has pushed the discussion about the impasse in cosmology to explore an alternative explanation of the "acceleration" without involving any new physics.

The paper aims to consider a series of observations allowing for a different interpretation of the phenomenon perceived as the "accelerated expansion of the universe."

Hubble Bubble.[3] In a 1998 paper [6], which became the basis for drawing a conclusion about the "accelerated expansion of the universe," a small yet fundamental aspect is considered — the effect of a local void. It is noted that SNe Ia exhibit a 6% higher expansion rate at a distance[4] of up to 7000 km·s^{-1} than that measured for more distant objects. "The significance of this peculiar monopole … is not inconsistent with the upper limit of ~10% for the difference between the local and global values of H_0 … The implication is that the volume out to this distance is underdense relative to the global mean density. This effect appears as an excess redshift … and can be seen with both the MLCS method and the template-fitting method ... Mistaking this inflated rate for the global value would give the false impression of an increase in the low-redshift expansion rate relative to the high-redshift expansion rate. This outcome could be incorrectly attributed to the influence of a positive cosmological constant Ω_Λ.[5] In practice, only a small fraction of our nearby sample is within this local void, reducing its effect on the determination of the low-redshift expansion rate. As a test of the effect of a local void on our constraints for the cosmological parameters, we reanalyzed the data ... The result was a reduction in the confidence that $\Omega_\Lambda > 0$ from 99.7% (3.0 σ) to 98.3% (2.4 σ) for the MLCS method and from more than 99.9% (4.0 σ) to 99.8% (3.1 σ) for the template-fitting approach. The tests for both methods excluded the unclassified SN 1997ck and included the snapshot sample ... As expected, the influence of a possible local void on our cosmological conclusions is relatively small." [6].

In this connection, the following was noted earlier in [14]. "We analyze … Type Ia supernovae (SNe Ia) to test for a local void. … with distances, deduced from light-curve shapes, accurate to ~6%. Assuming $\Omega_m = 1$ and $\Omega_\Lambda = 0$, the most significant deviation we find from the Hubble law is an outward flow of 6.5% ± 2.2% …, as would be produced by a void of ~20% underdensity surrounded by a dense shell. This shell roughly coincides with the local great walls. Monte Carlo analyses, using Gaussian errors or bootstrap resampling, show the probability for chance occurrence of this result out of a pure Hubble flow to be ~2%. The void … would be more significant if one outlier is removed from the sample ... This putative void is not in significant conflict with any of the standard cosmological scenarios. It suggests that the Hubble constant … could be overestimated by ~6%, and the local value of Ω may be underestimated by ~20%."

The data sample [6] contains one outlier that raises suspicion — the SN 1997ck supernova at $z = 0.97$. The parameters of dark matter Ω_m and dark energy Ω_Λ were estimated using the MLCS and template fitting methods (TFM) [6, Table 8] with and without taking SN 1997ck into account. Since the results were contradictory [15], the hypothesis about the Hubble bubble as an alternative cause of "accelerated expansion" in [6] was eventually rejected.

An "unexpected coincidence" remained unnoticed: the equatorial coordinates of SN 1997ck are right ascension $\alpha = 16^h53^m$, declination $\delta = +35^o03'46.4''$. This is the constellation of Hercules containing the solar apex, with the North Galactic Pole P_N located nearby on the celestial sphere in Coma Berenices [$\alpha = 12^h40^m$; $\delta = +28^o$]. Galactic poles coincide with the centers of transparency windows; what is more, the dipole of CMB anisotropy is associated with them. The background temperature in the direction of P_N (Dipole$^+$ CMB) at the border of Leo and Crater exceeds the average by 3.5 mK, whereas in the Sculptor constellation toward the South Galactic Pole P_S (Dipole$^-$ CMB), it is lower by 3.5 mK [16]. With the Sun moving toward the Virgo and Leo at a speed of about (370 ± 3) km·s^{-1} toward $\alpha = 11^h38^m$, $\delta = -3^o25'$, the temperature maximum is interpreted as the Doppler effect. In the area of the South Galactic Pole P_S [$\alpha = 0^h40^m$; $\delta = -28°$], the temperature minimum is observed, near which quasars on average have greater redshifts than those found in the area of the temperature maximum [17].

An example of Hubble bubble is the Boötes Void, i.e., a large, almost spherically symmetric region of space containing a small number of galaxies centered at $\alpha = 14^h\ 50^m$, $\delta = 46^o$ [18]. In this connection, the participant of the

[3]Astronomical term — departure of the local value of the Hubble constant H_0 from its globally averaged value, a local void in the matter distribution [13].

[4]According to Hubble's law $cz = H_0 r$, a speed of about 7000 km·s^{-1} corresponds to $z \sim 0.02$ or a distance of $z \sim 108$ Mpc.

[5]In the Friedmann-Robertson-Walker model, Ω_Λ is called the dark energy density parameter.

Supernova Cosmology project [8], an American astronomer Greg Aldering believed that we would not have known about the existence of other galaxies until the 1960s if the Milky Way had been at its center [19].

In 1997, I. Karachentsev and D. Makarov identified a local Hubble ellipsoid for the Local Group, whose major axis (81 ± 3; 62 ± 3; 48 ± 5) km·s^{-1}·Mpc^{-1} is oriented to a point in the Virgo constellation with equatorial coordinates of $\alpha \approx 13^h$, $\delta = -15^o$ [20]. In this case, an increase in the local Hubble parameter H_0 to 95 km·s^{-1}·Mpc^{-1} by a distance of 2 Mpc was recorded, with a decrease to 65–70 km·s^{-1}·Mpc^{-1} by a distance of 8 Mpc.

In 1998, on the eve of discovering the "accelerated expansion of the universe," the MCM-stat M program [21] was tested as per RRT 507-98[6] using data on 383 radio galaxies and quasars [22], generally revealing anisotropic dipoles in the redshift of quasars and radio galaxies along the right ascension of the Leo and Virgo constellations [23]. The first of these dipoles explained the distribution of quasars across the celestial sphere, which was noted back in 1967 by D. Wilkinson and R. Partridge [17]. In terms of the Doppler effect, these dipoles were accepted as a matter of course, as redshift anisotropy was also characteristic of galaxies. At the 10th Gravity Conference, when this result was reported at the section chaired by Vladimir Braginsky, Prof. Braginsky strongly recommended continuing research in this direction. However, at the 15th International Meeting Physical Interpretations of Relativity Theory, the participants were rather surprised by a report [24] on the dipole anisotropy in the redshift of radio galaxies and quasars as a gravitational dipole of the large-scale heterogeneous structure of the universe in the centers of the Milky Way's transparency windows. However, the deeper meaning of this "unexpected discovery" became clear only after a detailed study of the data [22]: the anisotropic dipoles of radio galaxies and quasars on average proved to be divergent [25].

Alternative to dark energy. The reasons for the discussion initiated about the impasse in cosmology can also be explained in other ways. In general, these are problems of statistical inference logic in the identification of cosmological models. With respect to the calibration of the cosmological distance scale, this is the issue of inadequacy; the same problem is typical of measuring instrument calibration [26]. The new physics is understood here as either a discrepancy between cosmological models and astrophysical measurement data, or an unknown physical mechanism behind dark energy. However, in both cases these are model inadequacy errors.

The discussion continued with an analysis [27] of the hypotheses about the "accelerated expansion of the universe" due to "cosmic jerks" at $z = 0.46 \pm 0.13$ [6] and $z = 0.763$ [8], which showed that these predictions correspond to the "discrepancies" in scale models at $z = 0.44$–0.48 and $0.763 \le z \le 0.828$. However, already in 2018, it was concluded that the SN Ia-based DL(z) scale is not metric due to "discrepancies" and rank inversions [28]. Thus, the question remained open as to whether this conclusion confirms the hypotheses or whether "discrepancies" are mistaken for "jerks." Furthermore, at least two "jerks" were observed.

The "unexpected discovery" of the divergent anisotropic dipoles of radio galaxies and quasars [25] required an explanation at the level of physics underlying the local void effect [6, 14].

This phenomenon implies that the apex of the Sun's motion relative to the CMB at the border of Leo and Crater in the Dipole$^+$ region at $\Delta T \approx 3$ mK coincides with the direction to a group of superclusters: Shapley, Virgo, Vela, Coma Berenices, Hydra, Great Attractor, and Leo. The solar antapex corresponds to the Dipole− region at $\Delta T \approx -3$ mK of the CMB in Aquarius and a supervoid of over 3 Gpc in Eridanus [29]. Special attention was paid to the fact that a system of supervoids (Eridanus and Aquarius) is located in the direction of the South Galactic Pole [30]. During a lecture on the Big Bang at the Bauman Moscow State Technical University, Roger Penrose did not comment on these facts when he was asked about "unexpected coincidences" [31] of solar apex, CMB anisotropic dipoles, deceleration parameter, redshift of extragalactic objects, as well as violet shift, with the galactic polar axis, the largest structural element of the observable part of the universe in the northern direction and the system of Eridanus and Aquarius in the southern direction. This "dipole coincidence" is observed for the Hubble dipole formed by the Hubble Deep and Ultra-Deep Fields [27] and is attributed to the polar direction of motion of the Milky Way Galaxy, which is accompanied by the rotation of its spiral structure around this axis, similar to the swirling of water at the gutter drop outlet [32]. Seven years later, the "dipole coincidence" was attributed to the "Dipole Repeller" [33].

Since the 1980s, it has been known that the Local Group is moving at (366 ± 125) km·s^{-1} toward the Centaurus constellation — this region contains the Shapley Supercluster comprising a large number of clusters and groups of galaxies with a redshift of $0.040 \le z \le 0.055$ spanning less than 500 million light years across [34]. An analysis of the CMB dipole anisotropy revealed in the 1970s and its source known at the time, motion toward the constellation of Leo, indicated that

[6]RRT 507-98. GSI. Measurement Problems. Solution Methods. Terms and Definitions.

the Local Group and the Virgo Supercluster were moving at about 600 km·s^{-1} toward the Hydra constellation relative to the CMB. This led to the discovery of the Great Attractor.

The twenty-first century saw a series of astronomical discoveries.

In 2005, an X-ray examination revealed that the Great Attractor actually has only one-tenth of the initially assumed mass, confirming that the Local Group is, in fact, being pulled toward a much more massive supercluster of galaxies located behind the Great Attractor [35]. According to recent data, the Great Attractor constitutes a gravitational anomaly having a mass of about 105 Milky Way masses, located at about 75 Mpc, roughly 250 million light years away in the Norma constellation. Due to its gigantic size, the mass of the Great Attractor is so great that the Virgo Supercluster and several nearby superclusters have peculiar velocities directed at it, forming a huge stream of galaxies in a stretch of space spanning several hundred million light years.

On August 24, 2007, the so-called CMB Cold spot (or Eridanus Supervoid) was discovered. According to conservative estimates, its width is 150–500 million light years, its depth is 6–10 billion light years (the entire universe is estimated to extend 93.5 billion light years), its radius is about 5^{o}, and its center is the point $\alpha = 03^{h}15^{m}05^{s}$, $\delta = -19^{o}35'02''$ at $z \approx 1$ [36]. In 2013, the Planck probe updated CMB maps and confirmed the existence of the CMB Cold spot, which was larger than previously thought, measuring up to two billion light years in diameter. Further research showed that the void is not entirely empty: it has 20–30% less matter than the rest of the universe. In 2007, the issue of redshift anisotropy was raised [37]. For 40 galaxy clusters and 36 supernovae as compared to 57 galaxy clusters with $z < 0.08$ at angular scales of (10–20)^{o}, M. McClure and C. Dyer found variations of $H_0 \approx 9$ km·s^{-1}·Mpc^{-1} resulting from the cellularity of the large-scale structure of the universe and the reason for the discrepancy between Hubble constant estimates [38].

In November 2013, an unusually large gamma-ray burst cluster revealed the Hercules-Corona Borealis Great Wall — the largest structure in the observable part of the universe, spanning approximately 10 billion light years at $z = 1.6$–2. This massive structure is located in the Northern hemisphere, centered on the border of the constellations of Draco and Hercules, extending into the constellations Lyra, Boötes, and Draco [39].

In October 2014, the Laniakea Supercluster (Hawaiian for "open skies") was discovered, which measures about 520 million solar years in diameter and comprises about a hundred thousand galaxies. It includes the Virgo Supercluster together with the Local Group and the Milky Way, as well as the Great Attractor, which contains the center of gravity of Laniakea, whose proper mass is about 100 times the mass of the Virgo Supercluster. Laniakea's neighbor is the Perseus–Pisces Supercluster from the Perseus–Pegasus chain of the Pisces–Cetus Supergroup Complex [40].

On January 30, 2017, the center of effective repulsion in the large-scale stream of galaxies near the Milky Way, the Supervoid Dipole Repeller, was discovered at a distance of 220 Mpc. The attraction created by the Shapley Supercluster, which is located in the opposite direction and enhanced by the position of Dipole Repeller, makes the main contribution to CMB dipole anisotropy [33].

The contribution of the Great Attractor to the velocity of the Local Group is estimated at only 44%. The rest is attributed to the global flow in which a large part of the local universe, including the Great Attractor, is moving toward an even stronger center of attraction near the Shapley Supercluster — the Shapley Attractor. The Shapley Supercluster is four times more massive than Laniakea and the Great Attractor, as well as about 10,000 times more massive than the Milky Way Galaxy. It is the most massive supercluster of galaxies in the observable universe. It is observed in the direction of the constellation of Centaurus and is located at a distance of 200 Mpc (about 650 million light years); it has an elongated, oval shape, and its angular diameter is several times the size of the lunar disk.

The specified discoveries made in the 21st century are characterized by a significant prior underestimation of the gravitational masses of superclusters and the size of supervoids. In addition to this factor, we should consider the issue of the fundamental gravitational constant G. As early as 1986, the Committee on Data for Science and Technology (CODATA) recommended the estimate $G = 6.67259(85)\cdot10^{-11}$ m^3·s^{-2}·kg^{-1}. However, by the end of the 20th century, it was found that the confidence intervals of three of the four best G estimates did not overlap [41], while the problem of incorrect confidence intervals arose in neutrino oscillation experiments [42]. In 1998, CODATA recommended a new estimate of the gravitational constant $G = 6.673(10)\cdot10^{-11}$ m^3·s^{-2}·kg^{-1}. Subsequently, new estimates were adopted, in the same units: 6.67428(67) — 2008; 6.67384(80) — 2010; 6.67408(31) — 2014. In 2014, another estimate $G = 6.67191(99)\cdot10^{-11}$ m^3 s^{-2}·kg^{-1} was obtained via precision atomic interferometry [43]. At a special meeting of the British Academy of Sciences, Terry Quinn (International Bureau of Weights and Measures) called this increasing discrepancy between G estimates a metrological and scientific dead end [44].

In the case of the fundamental gravitational constant G, the same tendency emerged as was the case with the impasse existing in cosmology, i.e., a higher measurement accuracy increased the discrepancy between the estimates obtained via different methods.

However, doubts arose about the insignificance of gravitational effects [6, 14] on acceleration in galaxy streams.

Anisotropic dipoles in the redshift of quasars and SNe Ia. The main drawback of cosmological models representing redshift in the emission spectra of extragalactic objects is isotropy. Adopted by the High-Z SN Search Team in 2016, the isotropic Friedmann–Robertson–Walker model approximated using the 3rd-order Taylor formula proved to be redundant for the data presented in [6, 8] according to the minimum inadequacy error criterion as compared to the anisotropic model, with an estimate of H_0 = 60.8 km·s^{-1}·Mpc^{-1} [45, 46]. However, it was shown in [25] that the requirements of [10] for the accuracy of extragalactic distance scales with a redshift of about 1% are unattainable due to errors in the application of statistical methods with varying accuracy of measurements [47]. The actual errors, factoring in inadequacy errors, were an order of magnitude higher. In addition, the data from [6, 8] did not constitute a compositionally homogeneous sample.

However, the anisotropic model of the cosmological distance scale [46] proved to be more feasible in terms of the minimum inadequacy error criterion, as well as providing a means to establish that, strictly speaking, the photometric distance is not a redshift metric function. Otherwise, we would have to admit that for SNe Ia [6, 8], redshift measurement data and the results of determining distances, underlying the conclusions about the discovery of the "accelerated expansion of the Universe," are problematic. Also, the anisotropic model of the cosmological distance scale [46] is based on data from [6, 8], supplemented with information on angular coordinates [48]. Furthermore, these works violate at least one of the conditions for the applicability of regression analysis — nonconfluence [49, 50].

In other words, the anisotropy and rank inversions of the cosmological distance scale mean that this model is a random function, a spatiotemporal trend, and that the photometric redshift distance estimates are average estimates.

This leads to the paradox of divergent anisotropic dipoles in the redshift of quasars and SNe Ia.

A standard Hubble diagram [21] contains extragalactic objects of different morphological types: galaxies, radio galaxies, and quasars. For these objects, the characteristics of the diagram have the same slope in logarithmic scale, while differing in the zero points and scatter. Therefore, we can assume that the Hubble diagram gives an indication of the average distances to these objects.

On average, the distances to quasars, due to their greater redshift, are larger than for radio galaxies and for host galaxies that contain SNe Ia. Furthermore, the redshift of quasars contains gravitational and Doppler contributing components, while the anisotropic dipole of their redshift is located approximately on the galactic axis, with its maximum pointing to the Eridanus Supervoid. However, this means that the Milky Way Galaxy is generally moving relative to quasars from the constellations of Aquarius and Eridanus toward Leo and Virgo. The maximum of the anisotropic dipole in the redshift of SNe Ia, and hence their host galaxies, is oriented in the direction of Leo and Virgo, i.e., relative to the Local Group, the Milky Way galaxy is generally moving in the opposite direction — toward the constellations of Aquarius and Eridanus. This raises an obvious question as to how this is possible.

This gives rise to the "unexpected coincidence" [29–31] or the Dipole Repeller effect [32]. It consists in the fact that the North (Coma Berenices) and South (Sculptor) Galactic Poles are near the centers of the transparency windows. In the same directions, we can find the largest structural objects in the observable part of the universe. To the south is the Aquarius + Eridanus supercluster system, while to the north is the Great Attractor + Shapley + Centaurus + Leo + Coma Berenices + Virgo supercluster system of galaxies, where the Local Group is moving.

If we adopt the CMB as an absolute frame of reference, the radiation anisotropy will indicate that the Milky Way Galaxy is also moving in the direction of Leo and Virgo having the eponymous superclusters, which hide a gravitational anomaly. The Doppler correction for the Sun's motion relative to the CMB at 390 km·s^{-1} toward a point on the border between Leo and Crater ($\alpha \approx 11^h 12^m$; $\delta = -7.1^\circ$) amounts to 0.0013 [50].

This is consistent with anisotropic dipoles in the redshift of galaxies and radio galaxies; for them, the high-value region of the local Hubble parameter $H_0 > 80$ km·s^{-1}·Mpc^{-1} is oriented toward the constellation of Virgo, while the low-value region of the local Hubble parameter $H_0 < 50$ km·s^{-1}·Mpc^{-1} is oriented toward the constellation of Eridanus [31]. However, the anisotropic dipole maximum in the redshift of SNe Ia in the sample from [6, 8] corresponds to the Sun's general motion in the opposite direction toward the Aquarius + Eridanus supervoid system.

Thus, a chain of interacting objects emerges: gravitational anomaly in the Shapley Supercluster → Great Attractor + Shapley + Centaurus + Leo + Coma Berenices + Virgo supercluster system → Local Group → Milky Way galaxy → Aquarius + Eridanus supervoid system. As this chain approaches the gravitational anomaly, the speed of motion increases, the chain stretches, and, as a result, the Milky Way galaxy "lags behind" the supercluster system at an increasing rate. Therefore, in the Local Group, which is the host galaxy for SNe Ia [6, 8], the redshift dipole maximum is also oriented toward the North Galactic Pole [25].

Conclusion. The isotropy of cosmological models inevitably resulted in the averaged streams of extragalactic objects moving around the sphere, which can first be interpreted as the "expansion of the universe", then translating the accelerations of these motions into the "expansion of the universe." However, this means only that the isotropic models representing the dependence of photometric distance on redshift in the emission spectra of extragalactic sources according to their fitting to astrophysical measurements should not be considered as conclusive proof validating cosmological theories.

The issue regarding the relation between gravitational "dipole inhomogeneity" and the cellular structure of the universe requires special consideration.

Conflict of interest. The author declares no conflict of interest.

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