

Cosmological expansion rate - Various measurement results and interpretation

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Abstract

Different values of the Hubble constant for extragalactic objects are not considered here. We give a number of examples of the extreme accordance of expansion rates of different fields of knowledge with the cosmological expansion rate. The coincidence of the expansion rates means that a common cause is almost inevitable. All these examples are gravitationally bound in themselves and in this case are subject to cosmological expansion. According to standard theory, this should not happen. We therefore question the common boundary of gravity and expansion for both theoretical and observational reasons and conclude that all gravitationally dominated objects participate in cosmological expansion or scale drift, contrary to general doctrine. The space expands with its contents while numerically maintaining distance, radius, rotation time and density. What is generally interpreted as an expansion is obviously a scale drift with a drift rate that corresponds to the size of the Hubble constant. The Earth is subject to expansion and scale drift. This results in numerically constant measured values. This drift apparently also applies to distant galaxies and other objects. The cosmological red shift is not interpreted here as a Doppler effect and numerical increase in distances, but in accordance with standard theory as an expansion or drift of the space-time scale. The expansion of the radii of galaxies makes the assumption of dark matter superfluous. The continents and our everyday environment are not subject to expansion or scale drift.

1. Introduction

A number of accordances with the Hubble relation or expansion rate of the universe ($72 \text{ km} \times \text{s}^{-1} \times \text{Mpc}^{-1} \cong 2.4 \times 10^{-18} \text{ s}^{-1}$) were found in areas connected by gravity. A causal connection was already ruled out by Einstein and Straus in 1945 [1]. This was certainly a reason to ignore the counter-arguments, some of which lay in areas of knowledge other than astrophysics. However, there are reasons not to do so. Therefore, some relevant terms will be explained in particular. These terms are described in more detail in sections 2 - 4. Section 5 briefly describes the origin and nature of counter-arguments and section 6 contains some resulting conclusions. Basic conclusions on which others build are:

Cosmological expansion is also present in areas dominated or defined by gravity. Cosmological expansion does not correspond to a relative velocity according to special relativity (STR). We therefore assume that cosmological expansion does not lead to a relative velocity and therefore to no change in the number of distance units (!). However, there is an expansion of these units, i.e. a scale drift. With this drift, any distance defined by gravity expands.

2. Expansion of space and the relative velocity

In the spectra of extragalactic objects, redshift values occur which correspond to a recession velocity greater than the speed of light (c). The cosmological recession velocity cannot therefore be a relative velocity in the sense of special relativity (STR) [2]. Numerical changes in distances (relative velocities) are therefore different from cosmological recession velocities. The numerical distance only changes if there is a relative velocity. Relative velocities between light source and observer corresponding to the STR are therefore ruled out as the cause of the cosmological redshift, provided peculiar velocities are neglected.

The expansion of the universe or space is therefore **not a numerical** increase in the growing distances in space. The distances and radii **expand with space**, so they do **not expand into space**. This leads to the unusual situation that the distances increase but not the number of distance units. The distance units are subject to the same rate of expansion as the distances. We therefore assume: Not the number of distance units, but their scale value expands or drifts. The space expands with its objects while numerically maintaining distance, radius, rotation time and density. A numerical increase of the distance or relative velocity according to STR therefore does not exist due to cosmological expansion ! With the expansion of space, the numerical distance does not change, but space with its dimensions expands (Mpc, light year, AU, kilometre, second etc.). The expansion of space with the Hubble parameter means that 1 Mpc has grown about 72 km after one second [3]. An object at a distance of 1 Mpc does not move away with a relative velocity of 72 km/s, but with this recession velocity. The numerical distance of an object after any time remains constant 1 Mpc and the expansion corresponds to an enlargement (drift) of the unit of measurement Mpc.

3. The lower limit of cosmological expansion or scale drift

The lower limit of cosmological expansion postulated by Einstein and Straus [1] is found today by comparing (difference-formation) the respective potential of a gravitating mass with the potential of cosmological expansion.

Here, a substantial incorrectness is committed: The potential of a gravitational mass leads to a change in the relative velocities of objects in the area of influence. In contrast, cosmological expansion does not result in a relative velocity according to STR but something else. So two different phenomena are being compared. Such a comparison is inadmissible ! Through this inadmissible comparison, one comes to the assumption: Gravitationally bound objects are not subject to cosmological expansion. We consider this assumption to be incorrect. With a few exceptions (e.g. [24]), it is widely agreed that gravitationally bound objects do not expand cosmologically. On the other hand, despite the redshift of the Virgo cluster, the so-called Virgo infall exists [4]. In addition to this obvious contradiction, expansion effects of the size of the Hubble constant are repeatedly found in much smaller areas. As a result of different assumptions about the lower limit of cosmological expansion, we hold our own view:

The lower limit is not formed by the Einstein/Straus relationship, nor by comparing the potentials of gravitation and expansion. We assume that the lower limit of the cosmological expansion is found by comparing the effects of the gravitational potential with the effects of the electromagnetic potential. If one compares the shape of planets with the shape of small planetoids or even smaller objects, it becomes apparent that the shapes are differently shaped or dominated. Obviously, the expansion behaviour of low-mass objects is not influenced by their gravity. The inner bond is primarily formed by other forces (electromagnetism). We conclude that the lower expansion limit is in the transition region. With increasing mass, the shapes become rounder and more shaped by gravity. Smaller and lower-mass objects show crystalline and molecular shapes. The shape-forming properties are less or not dominated by gravity. For example, overhanging parts of a construction (bridges) do not obey gravity. The distance Earth - Moon is determined by gravity and is subject to expansion. A large rock plate does not become a sphere in free space due to its own gravity. The internal electromagnetic forces are stronger than the gravitational forces. Although gravity determines the structure of space, this plays a subordinate role in this case. Molecular / crystalline forces dominate the shape of the rock slab. The shape of water drops is not formed by the gravitation of their mass, but by surface tension. The spatial properties determined by gravity are subordinate to the internal electromagnetic properties when the mass is small. Cosmological expansion or scale drift is a property of gravitationally dominated space. This property is not relevant for low mass. Through this subordination, objects of our daily environment and smaller ones do not show cosmological expansion effects. The relation (1) used below loses its meaning. Although the Earth as a whole is subject to cosmological scale drift (expansion), this does not apply to continents and smaller structures. Objects or phenomena bound by their own gravity are listed in Table 1. According to standard theory, these should not show any cosmological expansion.

4. Coincidences

Random numerical equality of two different phenomena in 18 (!) powers of ten and the same dimension are very rare coincidences. The occurrence of such a rare coincidence becomes even rarer when another phenomenon of the same size and dimension is added. The probability or better improbability is then to be exponentiated. The coincident rates from terrestrial tidal friction (rotational deceleration) and cosmological expansion rate are a coincidence of two different phenomena. A coincidental coincidence of this coincidence with the delay rate from the Pioneer anomaly is already an almost impossible coincidence. As other phenomena (see Table 1) are added, we exclude coincidental accordance and assume causal accordance. The phenomena mentioned have a common rate because they have a common cause ! This cannot be tidal friction. Causal accordance cannot be based in the Earth's sphere because, for example, even the most distant galaxies are obviously subject to this rate of expansion (Table 1,[6,12]). As the cause of this common rate we see the still unknown cause of cosmological expansion or scale drift. However, their lower limit then lies in the area in which gravity is dominant over other basic forces, i.e. in the area of gravitationally bound objects.

5. Measured values versus standard theory

The occurrence of the rate $\sim 3 \times 10^{-18} \text{ s}^{-1}$ in all ranges mentioned in Table 1 from the Earth's radius to the astronomical horizon is remarkable. In these two extreme cases, relative velocities are excluded as the cause of the existing rate. For the Earth's radius, the exclusion is due to measurement results by X. Wu et al [7] and for the universe because recession velocities at large distances are greater than the speed of light ($v > c$). If there is a common cause, the relative velocities are also to be rejected for intermediate values. This is true for lunar orbit and solar orbit in the Galaxy, among others. If no relative velocities occur as a result of cosmological expansion, the corresponding distances are numerically constant despite this expansion. The cosmological expansion manifests itself as recession speed or scale drift. For the distance of the earth's radius it is approx. $0.05 \text{ cm} / \text{a}$ [5]. For the lunar orbit, the result is approx. $3 - 4 \text{ cm} / \text{a}$, depending on the type of measurement [8, 9, 10]. The distance of the solar orbit in the Galaxy results in a recession velocity of about $4 \times 10^{15} \text{ km} / \text{orbit}$ or $18 \times 10^6 \text{ km} / \text{a}$ and for the Andromeda Nebula it is about $50 \text{ km} / \text{s}$. However, the recession velocity of the Andromeda Nebula is superimposed by a larger, opposite relative velocity. The values given are obtained by using the rate $\alpha = 2.5 \times 10^{-18} \text{ s}^{-1}$ and relation (1). The values obtained from this agree with the measured values (if measurable).

$$\alpha = \Delta r / (t \times r) \quad (1)$$

(α = expansion rate \equiv recession rate, Δr = distance difference or recession value, t = period, r = distance)

The value $\alpha \cong 2.5 \times 10^{-18} \text{ s}^{-1}$ is found several times in the solar system, but also in other gravity-bound systems. α should not be confused with the cosmological scaling factor α . Below are some examples of the occurrence of the

cosmological expansion rate in gravitationally bound objects. Further examples are partly included in Table 1.

5.1. Earth radius

X.Wu et al investigate the expansion behaviour of the Earth in [7]. Among other things, the relative velocity between the centre of mass and the Earth's surface was measured. It was concluded that there was serious evidence of expansion of the Earth's radius. However, the measurements using ITRF 2008 + Grace + OMCT + ECCO showed maximum values ~ 0.1 mm/a or smaller, i.e. insignificant or non-existent at present. Here the found scale drift or origin drift is of interest. Their size is not particularly certain due to insufficient data and, depending on the parameters used, amounts to approx. 0.5 mm / year for the earth's radius. We set the corresponding values equal and get : $0.05 \text{ cm} / (31.56 \times 10^6 \text{ s} \times 6370 \times 10^5 \text{ cm}) = 2.5 \times 10^{-18} \text{ s}^{-1}$. The cosmological expansion rate and the scale drift rate of the Earth have the same value. The deceleration rate of the Earth's rotation is of approximately the same value. According to Section 6, other authors ([23]) and we assume tidal friction to be only part of the cause of the rotational lag. The rotational deceleration should lead to the pirouette effect if the earth mass is approximately constant and the moment of inertia is valid. The Earth's radius should expand according to the rotational deceleration. The radius difference (Δr) results as (2).

$$\Delta r = r [(1 + \Delta t / t)^{0.5} - 1] \quad (2)$$

(Δr = radius difference (cm), r = Earth radius (cm), t = rotation time (s), Δt = Length of day (LoD) change (s / 100 a)

$$\Delta r = 6371 \times 10^5 [(1 + 0.0016 / 86400)^{0.5} - 1] = 5.9 \text{ cm} / \text{cy} = \underline{0.059 \text{ cm} / \text{a.}}$$

The value 0.0016 / 86400 refers to the lengthening of the day per 100 years.

Since the radius difference results according to the cosmological expansion rate, there is no expansion of the **numerical** Earth radius according to Section 2. The increase of the value by 0.059 cm / (a \times r) results from the scale drift at numerically constant earth radius published in [7]. The value of scale drift of approx. 0.5 mm / year given in [7] is therefore acceptable. If it is a continuous drift, smaller drift values are obtained for smaller distances and periods and larger drift values for larger distances and periods. The expansion of the lunar orbit and other distances can also be explained by scale drift.

5.2 Inner core of the Earth

S.K. Runcorn gives a growth of 243 km / 10^9 years (0.024 cm / a) for the inner core of the Earth [16]. With relation (1), this corresponds to an expansion rate or drift rate of $\sim 3 \times 10^{-18} \text{ s}^{-1}$ and thus approximately the cosmological expansion rate or Hubble constant.

5.3 Lunar distance

The distance to the moon is about 60 times greater than the radius of the earth. The drift value or recession value is 60 times greater than expected for the Earth's radius. The scale drift is then ≈ 3 cm per year and orbital radius of the moon. With relation (1) and rate α ($2.4 \times 10^{-18} \text{ s}^{-1}$) one obtains the recession value or drift value $\Delta r = 2.9 \text{ cm/a}$. This is in agreement with values measured during solar eclipses. Sediment data also indicate an expansion or drift of $2.9 \pm 0.6 \text{ cm/year}$ [8]. Measurements with LLR give the larger value $3.82 \pm 0.07 \text{ cm / a}$ ($3,15 \times 10^{-18} \text{ s}^{-1}$). However, it is possible that a relative velocity (e.g. from tidal friction) and the recession velocity or scale drift complement each other. In the case of the Andromeda Nebula, a (negative) relative velocity must also be added to the recessional velocity.

5.4. Pioneer anomaly

The Pioneer anomaly describes an anomalous delay of the Pioneer X and XI space probes. The delay value is $8.74 \times 10^{-8} \text{ cm/s}^2$ [15]. It results from a frequency shift of the radio signals assuming the Doppler effect. Dividing the deceleration value by the speed of light yields a deceleration rate of $2.91 \times 10^{-18} \text{ s}^{-1}$. This value agrees exactly with the Earth's rotational deceleration and corresponds approximately to the Hubble parameter (!). Shortly after the discovery of the pioneer anomaly, cosmological expansion was considered a possible cause. This possibility was rejected by cosmology [22]. The argumentation: Cosmological expansion only leads to redshift and also only outside gravitationally bound systems. We contradict these assumptions in sections 2 and 3. If, contrary to standard theory, the universe is also expanding in the solar system, the units of measurement of space (metre, light year, second etc) were smaller at the time of the probe launches than they are today. Due to the expanded units of measurement since the launch of the probes, the current measured distance is numerically smaller than expected. This manifests itself as a delay and a blue shift. With a numerically constant speed of light, the second was also shorter in the past. The time scale corresponds to the course of UT time defined by gravity. This deviates secularly from the electromagnetically defined SI time at a rate of $2.91 \times 10^{-18} \text{ s}^{-1}$.

5.5 Size evolution of galaxies

The effective radius of large galaxies decreases with increasing distance and the inner density and dynamics increase. There are a number of studies on this subject, e.g. in [6,12,21]. P. v.Dokkum et al [6] describe galaxies located at a distance of $z \sim 2.2$ ($\sim 10.7 \times 10^9$ Ly). We see these galaxies as they were after 20% of the present world age. The radii are about 0.9 kpc, i.e. 20% of the radius of galaxies of the same type and mass as today. Such galaxies do not exist in today's nearby universe. An explanation other than expansion does not seem possible. Let us assume that today's galaxies began at this size and density. In this case, the expansion rate results from the difference of the radius per radius and the expansion time (1).

$$\alpha = \frac{\Delta r}{r \times t} = \frac{5 - 1}{5 \times 10.7 \times 10^9 \times 31.56 \times 10^6 \text{ s}} = \frac{4}{1.688 \times 10^{18} \text{ s}} = 2.37 \times 10^{-18} \text{ s}^{-1} \quad (1)$$

α = required expansion rate, Δr = difference between present radius(5) and emission radius(1), r = adequate present radius (5), t = distance in light time (SI-s).

This expansion rate corresponds to a Hubble constant of 73.2 (km / s) / Mpc. The objects are gravitationally bound objects. They expand according to the cosmological expansion. This contradicts standard cosmology. I. Trujillo makes a similar observation when he writes: "Consequently, the very dense nature of our objects at high z could reflect the much denser state of the universe at the time of their formation" [21]. We see that these studied objects exhibit the same effect and rate of expansion as observed today as scale drift on Earth (see above: Earth radius).

5.6 Orbital expansion of Saturn's moon Titan

Measurements taken by the Cassini probe show that the orbit of Saturn's moon Titan is expanding by 11.3 ± 2.0 cm/year. This value could be caused by tidal friction. However, this is clearly too large for normal tidal friction without additional assumptions as described by V. Lainey et al in [25]. However, according to F.R. Stephenson et al [23], the orbital expansion of our Earth's moon measured by LLR is also too large to be caused by tidal friction. Taking into account the measured value, the annual length and the orbital radius of Titan of 1.22×10^{11} cm, an expansion rate α of

$$\alpha = 11.3 \text{ cm} \times (31.56 \times 10^6 \text{ s} \times 1.22 \times 10^{11} \text{ cm})^{-1} = 2.93 \times 10^{-18} \text{ s}^{-1}.$$

It should be noted that the closeness to the cosmological expansion rate has already caused discussion [26].

6. Conclusions

The multiple occurrence of the cosmic recession rate $2 - 3 \times 10^{-18} \text{ s}^{-1}$ in gravitationally bound systems suggests that the expansion of space is also present in full magnitude in these objects. Section 2. shows that the expansion or recession is not a relative velocity in the sense of the STR. There is therefore no numerical change in distances due to the occurrence of this rate. The work of X Wu [7] and NASA confirms in the case of the Earth that the above rate is caused by scale drift and not by a relative velocity between the centre of the Earth and the surface. The recession rates listed in Table 1 suggest that there is a common cause for the listed phenomena. The scale drift appears as an expansion or recession. The length of day (LoD) grows at approximately the same rate and accordingly with the same cause. An increase in the LoD due to tidal friction is assumed here in addition to scale drift. Tidal friction theory, however, demands a much faster increase in LoD (2.3 ms / cy) than observation allows (1.6-1.8 ms / cy) [23]. This points to deficiencies in the theory of tidal friction. In Table 1, the LLR measurements with $\alpha \sim 3.15 \pm 0.06 \times 10^{-18} \text{ s}^{-1}$ give the highest value for scale drift or recession near the Earth. We therefore assume that the difference to the Hubble constant is caused by tidal friction. Only this fraction would then correspond to a relative velocity between the Earth and the Moon. The numerical distance of the moon in early times is then only insignificantly smaller than today. A destruction of the Moon by the Earth's Roche boundary is therefore not to be assumed.

If one assumes that cosmic recession is not a relative velocity corresponding to the STR and occurs in gravitationally bound objects, further consequential phenomena must have to occur or be present, for example:

- 1 According to paragraph 2, a relative velocity does not exist due to cosmological recession. Orbiting objects thus maintain their numerical distance from the centre of gravity during this recession. With the numerically constant orbital radius, the orbital velocity also remains numerically constant despite recession. This results in an outwardly flat level of orbital velocity. The flat course of the orbital velocities in galaxies [14] does not require dark matter. Modified Newtonian Dynamics (MOND) is also not required.
- 2 The Earth and gravitationally bound objects expand according to scale drift. The numerical radii remain constant, however, since relative velocities between the centre of the Earth and the surface do not exist [7].
- 3 The Moon moves away from the Earth at approximately the same recession rate as by Hubble constant. We conclude that the measured recession is primarily not a relative velocity and that the distance is numerically approximately constant.
- 4 According to section 5.5. it can be assumed that radii and distances of spiral galaxies used to be smaller during cosmic expansion, but were numerically constant according to section 2. In the process, the outer areas move away faster than areas near the inertial centre. We observe the same with time-delayed measurements of the Earth's radius (Sections 5.1. and 5.2.).
- 5 The continents and our everyday environment do not participate in the expansion or scale drift. These objects

as well as e.g. small moons and planetoids are obviously dominated and shaped by electromagnetic forces and not by gravity (section 3 and [5]).

- 6 The lower limit of the cosmic expansion is not removed. However, it is at a smaller distance than in the standard theory. This makes this value interesting for space travel (pioneer anomaly), geophysics (LoD), time determination (leap seconds) and other fields.
- 7 Using the brightness of supernovae, it was found that the Hubble constant was smaller at great distances (in space or time) than it is today. The cosmological recession velocity or scale drift has increased less per Mpc at great distances than in the near universe ($<72 \text{ km} \times \text{s}^{-1} \times \text{Mpc}^{-1}$). According to Section 2, gravitationally defined dimensions (radii, distances, time periods) are subject to expansion or scale drift. The Hubble constant relates a recession velocity ($\text{km} \times \text{s}^{-1}$) to a distance (Mpc). The smaller Hubble constant measured for large distances refers to the smaller Mpc there. The expansion rate therefore remains constant ($\cong 2.4 \times 10^{-18} \text{ s}^{-1}$). This contradicts the increase in the Hubble constant due to dark energy.
- 8 The deceleration rate of the Earth's rotation is of the same magnitude as the expansion rate of the universe. The delay corresponds to a drift of the (SI) time scale. Since time and space have approximately the same scale drift rate ($\sim 2.5 \times 10^{-18} \text{ s}^{-1}$), the **numerical** constancy of the speed of light is ensured. The galaxies mentioned in section 5.5. have a distance of about $10.7 \times 10^9 \text{ Ly}$ according to the current scale value. Since this distance is numerically constant according to section 2 and had smaller scale values at the beginning, the number of spatial and temporal distance units results in (3).

$$\Sigma = 0,5n (x_1 + x_n) \quad (3)$$

(Σ = Sum of the past distance units since emission, n = number of distance units defined today, x_1 = scale value of the first unit after emission (=1), x_n = scale value of the unit in the observation (=5)).

The light that reached us was therefore not 10.7×10^9 years but 32.1×10^9 years on the way. If one observes objects whose distance is close to the world age, the light travel time is close to ∞

- 9 The value of the cosmological recession can be calculated with relation (1). For the distance Earth - Sun (AU), this results in a recession value of approx. $11 \text{ m} \times \text{a}^{-1} \times \text{AU}^{-1}$. This recession velocity is not a relative velocity according to section 2. The latter is not present and therefore not measurable. X.Wu et al find in [7] that a relevant relative velocity of the distance earth centre - surface (earth radius) is also not present. However, a scale drift corresponding to the expected recession speed was measured ($\sim 0,5 \text{ mm} \times \text{a}^{-1} \times \text{earth's radius}$).

The determined recession value of the AU of $0.15 \text{ m} \times \text{a}^{-1} \times \text{AU}^{-1}$ is obviously a relative velocity with a cause other than cosmological expansion. A decrease in the mass of the sun, for example, results in a low relative velocity of the increasing distance earth - sun (AU).

Objects bound by their own gravity are subject to cosmological expansion (scale drift), contrary to standard theory. This is not the case for other objects. The former include massive objects such as fixed stars, pulsars, Earth, galaxy clusters. Other objects include, for example, smaller, low-mass planetoids and moons ($< 200 \text{ km}$), continents and objects in our environment.

Hilgenberg, Carey, Scalera and many others assume that the Earth is expanding. It seems that this assumption is partially justified. X.Wu et al. [7] and NASA confirm this assumption by stating : The measured number of units of the Earth's radius remains almost constant. However, the size of these units expands according to scale drift rate !

Table 1

1	2	3	4	5
Row	Example	Rate	Possible other causes	References*
1	Expansion-rate of the universe	$2.33 \pm 0.26 \times 10^{-18} \text{s}^{-1}$	-	[3]
2	Expansion of galaxies	$2.37 \times 10^{-18} \text{s}^{-1}$?	[6,12]
3	Pioneer anomaly	$2.91 \pm 0.44 \times 10^{-18} \text{s}^{-1}$	Thermal radiation pressure	[15]
4	Expansion of moon's orbit (LLR-Technology)	$3.15 \pm 0.06 \times 10^{-18} \text{s}^{-1}$	Tidal friction	[9]
5	Expansion of moon's orbit (Eclipse)	$2.32 \times 10^{-18} \text{s}^{-1}$	Tidal friction	[8,10]
6	Delay of the Earth's rotation	$2.93 \times 10^{-18} \text{s}^{-1}$	Tidal friction	[11]
7	Distribution of rotational delay of pulsars	$2.7 \pm 0.4 \times 10^{-18} \text{s}^{-1}$?	[18]
8	Surface relation oceans/continents	$3.0 \times 10^{-18} \text{s}^{-1}$?	[5]
9	5-dimensional field theory	$3.6 \times 10^{-18} \text{s}^{-1}$	Scale effect	[19]
10	Polar diameter of Earth	$2.5 \pm 0.95 \times 10^{-18} \text{s}^{-1}$	Post glacial uplift	[17]
11	Inner Earth's core	$3.0 \times 10^{-18} \text{s}^{-1}$	Growth by phase-conversion	[16]
12	Expansion of the orbit of Saturn's moon Titan	$2.93 \pm 0.52 \times 10^{-18} \text{s}^{-1}$	Tidal friction on Saturn	[25]
13	Origin drift CM ITRF2008+GRACE+OMCT	$2.5 \pm 1.0 \times 10^{-18} \text{s}^{-1}$	Networksparseness	[7]
14	Expansion of galaxies	$2.33 \pm 0.26 \times 10^{-18} \text{s}^{-1}$	DM in Bose–Einstein condensate	[13]

*Values contained in column 3 were calculated by the author. Calculation basis is information from column 5.

No explanation was found for the difference between the expansion rates $2.3 \times 10^{-18} \text{s}^{-1}$ and $2.9 \times 10^{-18} \text{s}^{-1}$.

However, the latter value was found predominantly at cosmologically short distances.

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