Analogy of space time as un elastic medium - Estimation of a thermal expansion coefficient of space from the cosmological constant Lambda

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Abstract

This study explores the analogy of general relativity with the theory of elasticity by considering the cosmological constant Λ as an additional curvature of the structure of space due to a thermal gradient coming from the cosmic web and the cold vacuum. It follows from this analogy and from the supposed space model consisting of thin sheets of Planck's thickness curved by this thermal gradient a possible coefficient of thermal expansion of the equivalent elastic medium modeling the space of the order of $\alpha_{space-QFT}$=1.16 x 10^{-6} K^{-1}

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1. Introduction

1.1 Measured strains of space and analogy of the general relativity theory with the elasticity theory

Einstein's theory of general relativity is over 100 years old and is now widely verified. Thus, spacetime is according to this theory a deformable elastic physical object. Gravitation is thus a manifestation of the geometric deformation of space-time under the effect of the masses or energy density therein. The manifestations of the deformations of this space-time are now known and measured with great precision. We can cite the apparent position variation of stars placed behind the sun during an eclipse measured by Edington **[1]**, the frame dragging of space-time by angular distortion by the rotation of the earth (experiment prob B, Lense-Thirring and frame dragging effects) **[2]**, the simultaneous lengthening and shortening deformations in each of the arms of Ligo/Virgo type interferometers during the passage of gravitational waves **[3][4]**, gravitational lenses or substantial masses located between a galaxy and our field sighting on earth distorts space to the point of making it appear to us in the shape of a circle (a bit like a candle placed behind the flat circle of a stemmed wine glass appears circular by its transparency reflection), and finally the expansion of the universe where the galaxies are "fixed" in a space which expands in an increasingly accelerated way characterized by Hubble's law. All these manifestations of the deformations of space time have led many physicists like A Sakharov **[5]**, J.L Synge **[6]**, C. B Rayner **[7]**, R. Grot **[8]**, V.V Vasilev and L.V Fedorov **[9] [10]**, J.D Brown **[11]**, T.G. Tenev and M.F. Horstemeyer **[12]**, P.A Millette **[13]** and many others as T. Damour in its conferences and books consider

that the theory of general relativity is a kind of theory of the elasticity in 4 dimensions of a deformable elastic space-time medium. We then speak of “elastic metric” or “elastic theory of gravitation”. It is within the framework of this analogy that we place ourselves in this paper.

If by analogy, therefore, space-time is considered as an equivalent deformable elastic medium, they are two consequences. We will study it in the next two paragraphs.

1.2 The mechanical characteristics of the equivalent elastic medium in the field of the analogy of the elasticity theory with the General Relativity – review of the state of the art

This equivalent elastic medium must therefore be characterized with the usual parameters linked to all elastic mediums and to the elasticity theory (Young’s modulus Y, Poisson’s ratio ν, density ρ, etc.). Thus, various authors have sought to establish an equivalent Young's modulus of the space noted Y_{space} . We can quote R. Weiss during his Nobel prize speech I quote *«In other words, it takes enormous amounts of energy to distort space. One way to say it is, the stiffness (Young’s modulus) of space at a distortion frequency of 100 Hz is 10^{20} larger than steel»*.

T.G Tenev et M.F Horstemeyer **[12]** who propose by considering the space-time made up of thin elastic sheets of the thickness of Planck the following formulation (1) giving Y_{space} = 4.4× $10^{113} N/m^2$

$$Y_{space} = \frac{6c^7}{2\pi\hbar G^2} = \frac{24}{l_p^2 \kappa} \quad (1)$$

In this expression, c is the speed of light, G is the gravitational constant, $\hbar$ is Planck's constant, l_p is the Planck's length (thicknesses of the thin sheets supposed to constitute the space fabric in **[12]**) and κ is the Einstein's gravitational constant ($\kappa = \frac{8\pi G}{c^4}$).

M. Beau proposes a space bulk modulus **[14]** and arrives at K_{space} =1.64× $10^{109} N/m^2$.

K. McDonald **[15]** proposes another expression of the Young's modulus (2) based on dimensional equations and obtain:

$$Y_{space} = \frac{c^2 f^2}{G} \quad (2)$$

Where f is the frequency of the gravitational wave. He thus obtains for a gravitational wave of 100 Hz Y_{space} =10^{20} Y_{steel} so, Y_{space} =$4.5 \times 10^{31} Pa$ as R. Weiss.

D. Izabel in **[16]** arrives at an expression similar to K. Mc Donald by studying the elastic deformations in space dynamics located in the arms of the Ligo/Virgo laser interferometers and by studying the elastic deformations of a space cylinder twisted by the rotation of two black holes. He thus obtains the expression (3) of the Young's modulus of space similar to K. Mc Donald at the factor π close:

$$Y_{space} = \frac{\pi f^2 c^2}{G} \quad (3)$$

This leads by considering a density ρ from quantum field theory (hypothesis similar to T.G Tenev and M.F Horstemeyer **[12])** at Y_{space} = 1 at $4.0 \times 10^{113} Pa$

A.C. Melissinos **[17]** considers vibrating plates in the planes of the arms of the interferometers and arrives at the following expression (4) of the Young's modulus of space:

$$Y_{space} < \frac{\pi c^2 f^2}{4G} \times \frac{c\Delta\tau}{\Delta z} \quad (4)$$

In this expression, Δτ is the length of the Gravitational Wave burst and the total path length traversed by the GW is designated by Δz. The numerical application is done with Δτ ≈ 1 s and Δz ≈ 400 Mpc and leads it to a next value of Young's modulus Y_{space} < 2.5× 10^{-17}(c^2f^2/G).

Finally, let us quote S.R. Hwang in **[18]** which by comparing the energy of gravitational waves for different frequencies (35 to 100 Hz and different GW) with the deformation energy of a spring modeling the lengthening and shortening of the arms of the interferometers arrives at values of the Young' modulus of space time $Y_{space} = 1.0 \times 10^{36}\ at\ 1 \times 10^{54}$ Pa.

Another key parameter of any elastic medium is of course the coefficient of transverse deformation, the space Poisson's ratio ν. Again, many authors have proposed values. From the simultaneous deformations of the arms of the Ligo/Virgo interferometers (while one arm is shortened by a deformation by shortening of the order of -10^{-21} the other lengthens by the same amount of $+10^{-21}$) T.G Tenev and M.F Horstemeyer **[12]** propose ν=1 which presupposes a certain anisotropy of space which behaves like a kind of thousand leaves during the passage of a gravitational wave , each plane deforming successively according to the polarizations A^+ and $A^\times$. The Poisson's ratio being close to zero in the direction of propagation of the wave and being equal to 1 in the plane perpendicular to the direction of propagation.

D. Izabel in **[16]** arrives at the same conclusion on this Poisson's ratio.

Concerning the equivalent density of the medium space ρ, A Sakharov **[5]** shows that quantum considerations of space (quantum field theory) make it possible to go back to an elastic theory of space (5). We quote it below:

"In Einstein's theory of gravitation, it is postulated that the action of space-time depends on the curvature (R is the invariant of the Ricci tensor):

$$S(R) = -\frac{1}{16\pi G}\int (dx)\sqrt{-gR} \tag{5}$$

The presence of action (1) results in a "metric elasticity" of space, that is, the generalized forces that oppose the curve of space.

T.G Tenev and M.F Horstemeyer **[12]** and D. Izabel **[16]** also follow this path which leads them by considering the minimum non-zero energy of the vacuum to the following expression (6):

$$\rho = \frac{Y_{space}}{4c^2} = 1.3 \times 10^{96}\frac{kg}{m^3} \tag{6}$$

P.A Millette in **[13]** formula 19.36 proposes the following expression (7) for the density of space:

$$\bar{\rho}_0 = \frac{32c^5}{\hbar G^2} = 1.7 \times 10^{98} kg/m^3 \tag{7}$$

Finally concerning the shear modulus of the middle space P.A Millette always in **[13]** formula 19.14 and 19.22 proposes the following expression (8a):

$$\bar{\mu}_0 = \mu = G = \frac{Y}{2(1+\nu)} = \frac{32c^7}{\hbar G^2}1.5 \times 10^{115} N/m^2 \tag{8a}$$

For bulk modulus (formula 19.21 of **[13]**):

$$\bar{\kappa}_0 = K = \frac{\bar{\mu}_0}{32} = \frac{c^7}{\hbar G^2} = \lambda + \frac{2}{3}\mu = \frac{Y}{3(1-2\nu)} = 0.046875 \times 10^{115} N/m^2 \tag{8b}$$

That concludes this review of the characteristics of space following the analogy of it as an equivalent elastic medium. Two conclusions emerge from this state of the art. Firstly, all space is absolutely not in this elastic analogy an "equivalent elastic material" like the others classically known on Earth, given the orders of magnitude of the deformations (10^{-21}), of the Young's modulus ($10^{113}Pa$), the Poisson's ratio outside the usual standards (ν=1), the density of the medium ($10^{98}kg/m^3$) and its associated anisotropy linked to the Poisson's ratio if it is 1 in a direction perpendicular to the propagation of the wave and 0 in the direction of propagation. Secondly, and this is partly the subject of this paper, no publication to our knowledge deals with a possible coefficient of expansion α of this space medium. We are therefore going to propose an original and innovative approach in this paper to try to propose a mechanical expression and a numerical value of this possible expansion coefficient α of the equivalent space fabric.

1.3 Analogy about the behaviour law of the space following the general relativity with the Hooke's law in elasticity without and with cosmological constant – thermal gradient implication about the different curvatures that have to be considered

The second aspect about this analogy is the law governing this equivalent elastic medium, this very special space fabric. Indeed, it is well known that Einstein's equation of general relativity without cosmological constant Λ relates the curvature of space $G_{\mu\nu}$ to the density of energy which deforms it $T_{\mu\nu}$(9).

$$G_{\mu\nu} = R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = -\frac{8\pi G}{c^4} T_{\mu\nu} \quad (9)$$

In this expression $R_{\mu\nu}$ is the Ricci tensor resulting from the contraction of the Riemann tensor, R is the scalar curvature resulting from the contraction of the Ricci tensor and $T_{\mu\nu}$ the momentum energy tensor. μν varying from 0 for time to 3 for the 3 dimensions of space.

D. Izabel showed in **[16]** that the equation of general relativity in 4 dimensions presents an analogy with the expressions in 1 and 2 dimensions of the curvature of beam (10, 11) and plate (12) in pure bending under two moments applied at each extremity (see Figure 1.) according to the Timoshenko's strength of materials theory issued of the elasticity theory.

$$\frac{1}{R^2} = \frac{2}{EI}\left(\frac{W_{ext(total)}}{L}\right) = K\left(\frac{W_{ext(total)}}{L}\right) \quad (10)$$

In analogy with:

$$G^{\mu\nu} = -\frac{8\pi G}{c^4}(T^{\mu\nu}) = -\kappa(T^{\mu\nu}) \quad (11)$$

In these expressions, R is the radius of curvature of a beam of span L, inertia I and Young's modulus E=Y associated with a work of the external forces W. K is the mechanical coupling constant between the curvature and the strain energy U of the beam which is equal to the work applied external forces W.

Or in theory of the plates of thickness h following **[25]**:

$$\left[\left(\frac{1}{R_x}\right)^2 + \left(\frac{1}{R_y}\right)^2 + 2(1-\nu)\left\{\left(\frac{1}{R_{xy}}\right)^2\right\} + 2\nu\left\{\frac{1}{R_x}\frac{1}{R_y}\right\}\right] = \frac{24(1-\nu^2)}{Eh^2} \times \frac{\Delta U}{h\Delta x\Delta y} \quad (12)$$

T.G Tenev et M.F Horstemeyer **[12]** but also T. Damour in his book "if Einstein was told to me " showed this analogy from a tensor point of view in terms of Hooke's law (13) and (14):

$$\sigma^{kl} = \frac{Y}{1+\nu}\left(\frac{\nu}{1-2\nu} g^{ij} g^{kl} + g^{ik} g^{il}\right) \varepsilon_{ij} \quad (13)$$

$$T_{\mu\nu} = \frac{1}{\kappa}\left(R_{\mu\nu} - \frac{1}{2}R g_{\mu\nu}\right) \quad (14)$$

In the space fabric model of T.G Tenev et M.F Horstemeyer **[12]**, space is assumed to be made up of ultra-thin sheets of Planck thickness, having an elastic behavior. It is in this space model that we will place ourselves in the rest of this publication.

But the tensorial equation of Einstein (9) can be also written by considering this time the cosmological constant Λ as a materialization of a certain repulsive dark energy. It is written as follows:

$$R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R = \frac{8\pi G}{c^4}T_{\mu\nu} - \boldsymbol{\Lambda} g_{\mu\nu} \quad (15)$$

Or by factoring Einstein's constant κ :

$$R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R = \frac{8\pi G}{c^4}\left[T_{\mu\nu} - \frac{c^4\boldsymbol{\Lambda}}{8\pi G}g_{\mu\nu}\right] \quad (16)$$

But the Einstein's tensorial equation (9) considering the cosmological constant can be also written as an additional curvature present in all space (frame of this paper). It is written as follows:

$$G_{\mu\nu} = R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R + \boldsymbol{\Lambda} g_{\mu\nu} = -\frac{8\pi G}{c^4}T_{\mu\nu} \quad (17)$$

If we follow completely the analogy of the beam or the plate in elasticity describes before it exists not one but two sources of curvature (see chapter 3): one under the applied masses developed in **[12]** and **[16]** and one under the temperature gradient, hence our idea of associating the second with the cosmological constant if our analogy is correct, the first one having already been partially demonstrated in **[16]**.

So, we come to the subject of this publication. In the same way that we have shown that Einstein's constant κ, by analogy with an elastic medium made of thin sheet of thickness l_p, (plate theory) could be expressed in terms of mechanical constants **[12] [16]** ($\frac{24(1-\nu^2)}{Eh^2} \rightarrow \kappa \rightarrow Y = \frac{24}{l_p^2\kappa}$), the cosmological constant Λ which is generally associated with a dark energy **[19]** opposed to gravitation (15 and 16), can it not also be expressed in terms of mechanical parameters as an additional curvature present in all space (17) due at a thermal gradient?

This constant Λ generally associated with an expansion of space **[20]**, can it not be correlated with a hidden mechanical behaviour of space via a parameter missing from the state of the art cited above in the analogy of space as an elastic medium, namely a coefficient of thermal expansion α of it? The phenomenal temperature difference between the cosmic web that fills the entire universe and the icy vacuum at -2.73 K does not constitute such a thermal gradient sufficient to impose on the sheets **[12]** constituting the space of a thickness of Planck in the framework of our model an additional source curvature of this cosmological constant? It is these hypotheses that we will study in this paper, thus placing ourselves in the continuity of the publications and theoretical models of T.G Tenev and M.F Horstemeyer **[12]** and D. Izabel **[16]**.

2. Methods

The following methodology has been implemented to estimate, within the framework of the analogy of space as an equivalent elastic medium, the value of a possible coefficient of thermal expansion α of space in line with the cosmology constant Λ associated with an additional thermal space curvature in the framework of a Planck thickness sheet space model as considered by T.G Tenev and M.F Horstemeyer **[12]**:

1) Within the framework of the analogy of an elastic medium to model the deformations of space in the presence of mass energy, restructure the simplified and appropriate mechanical model among those already developed to evaluate a possible generalized thermal curvature of this one,

2) Search for certain scientific data that can feed this mechanical model of curved space under the effect of a thermal gradient between the cosmic web and the space vacuum,

3) Consider the cosmological constant Λ not as a gravitationally repulsive dark energy (if placed to the right of equations (15) and (16) but as an additional curvature present in all space (if placed to the left of the equation (17)) and analysis of the consequences of this approach,

4) Extract from the mechanical model of curvature of space under thermal gradient and from the scientific data available in connection with this model by considering the cosmological constant Λ, a possible coefficient of expansion of the medium space α,

5) Discuss the representativeness of this model by varying the assumptions (value of Λ) and seeing the consequences on the value of the thermal expansion coefficient of the elastic medium modeling space,

6) Discuss the additional verifications necessary to confirm this approach,

7) Presentation of the possible consequences of this model concerning the interpretation of dark energy.

3. Search for a simplified mechanical model of space allowing to represent a thermal curvature of this one

3.1 Analogy of the thermal curvature of an elastic medium with a simplified approach of resistance of materials in one dimension - beam under thermal gradient

In the strength of materials, two phenomena and only 2 can create curvature: masses supported by the object, a thermal gradient applied to the object (beam, plate, shell).

We studied the first in **[16]** and showed that masses placed on a beam create curvature (18). Thus, we have shown in **[16]** that the curvature of a beam in pure bending (solicited by two moments M at each end) (18) takes a form similar to Einstein's equation from the point of view of the analogy of space as an elastic medium in the form curvature =K x a linear strain energy density U/L:

$$\frac{1}{R^2} = \frac{2}{EI}\left(\frac{U}{L}\right) \tag{18}$$

With U the strain energy of the beam (See Figure.1).

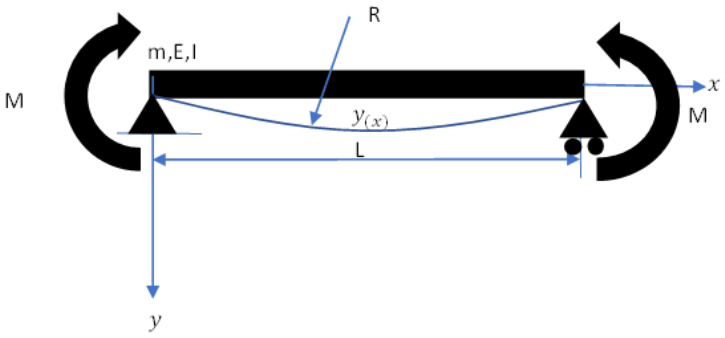

Figure 1: Definition of a Timoshenko's beam in pure bending –

The second, we study it in this article, it is the curvature created by the difference in temperature between the two extreme fibers of the beam. The beam is then subjected to a thermal gradient ΔT which leads to an elongation of the heated fibers and a shortening of the cooled fibers. These differences in elongation create a curvature without internal forces of the beam if this one is not constrained in displacement somewhere along its surface.

T. Damour tells us in his various conferences and publications **[9] [11]** that curvature in the sense of Einstein is an angle divided by a surface (see also C. F Gauss work **[21]**). We will show that is indeed the case of a beam requested by a thermal gradient (temperature difference T between the lower and upper fibers of the beam $\Delta_T = T_{ext} - T_{int}$)

Let us now consider the case of an identical beam in pure bending undergoing a thermal gradient (Cf. figure. 2):

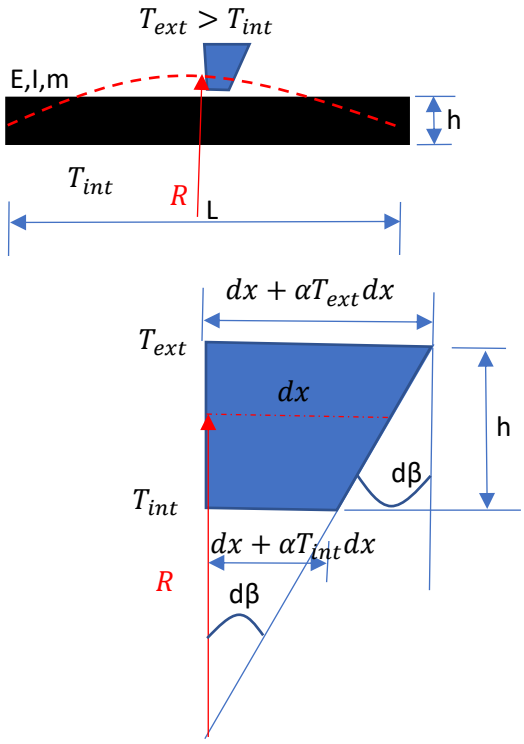

Figure 2: Strain of a beam in bending under a thermal gradient ΔT –

The strain energy U is always with M a bending moment for a beam of span L and rigidity EI:

$$U = \frac{1}{2}\int_0^L \frac{M^2}{EI}dx \quad (19)$$

Figure 2 and formula (20) allows us to write the following geometric relations between the angle β (radiant) and the curvature (1/R) of the beam with h the height of the beam, α its expansion coefficient and ΔT the thermal gradient applied to this beam:

$$tan(d\beta) = \frac{dx}{R} = \frac{(dx+\alpha T_{ext}dx)-(dx+\alpha T_{int}dx)}{h} = \frac{(\alpha T_{ext}-\alpha T_{int})dx}{h} = \frac{\alpha \Delta T dx}{h} \quad (20)$$

Given the figure. 2, from the relation between the curvature of a beam under a thermal gradient and the second derivative of its deformation $y(x)$, we obtain the expression (21):

$$\frac{d^2y}{dx^2} = \frac{M}{EI} = \frac{1}{R} = \frac{tan(d\beta)}{dx} = \frac{d\beta}{dx} = \frac{\alpha \Delta T}{h} \quad (21)$$

Considering the new expression of the moment M from (21):

$$M = EI\frac{d\beta}{dx} \quad (22)$$

By replacing the moment M by its expression above (22) in the expression of the strain energy U of the beam (19), we then obtain:

$$U = \frac{1}{2}\int_0^L \frac{\left(EI\frac{d\beta}{dx}\right)^2}{EI}dx \quad (23)$$

So, after simplification (EI =constant along the beam):

$$U = \frac{EI}{2}\left(\frac{d\beta}{dx}\right)^2 L \quad (24)$$

After some mathematical calculations:

$$\left(\frac{\boldsymbol{d\beta}}{\boldsymbol{dx}}\right)^{\mathbf{2}} = \frac{\mathbf{2}}{\boldsymbol{EI}}\frac{\boldsymbol{U}}{\boldsymbol{L}} \quad (25)$$

That can be compared with the expression recalled above in the case of the beam in pure bending (18).

We therefore have an angle on a surface as the definition of the curvature (1/R) squared of the beam (26).

$$\left(\frac{\boldsymbol{d\beta}}{\boldsymbol{dx}}\right)^{\mathbf{2}} = \frac{\boldsymbol{d\beta^2}}{\boldsymbol{dx}\times\boldsymbol{dx}} = \left(\frac{\mathbf{1}}{\boldsymbol{R}}\right)^{\mathbf{2}} \quad (26)$$

This corroborates the expression of T. Damour from the differential geometry of Gauss developed by Riemann **[21]** and given again in the formula (27):

$$Curvature = \frac{\alpha+\beta+\gamma-180^\circ}{Area} \quad (27)$$

The strain energy of a beam of span L, rigidity EI=YI for a constant thermal gradient ΔT is given by formula (28):

$$U_{\Delta T} = \frac{EI}{2}\left(\frac{d\beta}{dx}\right)^2 L = \frac{EI}{2}\left(\frac{\alpha \Delta T}{h}\right)^2 L \quad (28)$$

So:

$$\left(\frac{\boldsymbol{\alpha\Delta T}}{\boldsymbol{h}}\right)^{\mathbf{2}} = \frac{\mathbf{2}}{\boldsymbol{EI}}\frac{\boldsymbol{U_{\Delta T}}}{\boldsymbol{L}} \tag{29}$$

As we are in elasticity, we can superimpose the load cases and thus superimpose the case of the beam in pure bending (due to the 2 moments M at each extremity see Figure1.) with the case of the beam under thermal gradient uniform constant ΔT see Figure 2.), we then obtain the formula (30) of the generalized curvature of a beam under load and thermal gradient:

$$\frac{1}{R^2} + \left(\frac{\boldsymbol{\alpha\Delta T}}{\boldsymbol{h}}\right)^{\mathbf{2}} = \frac{2}{EI}\left(\frac{U_M}{L}\right) + \frac{\mathbf{2}}{\boldsymbol{EI}}\left(\frac{\boldsymbol{U_{\Delta T}}}{\boldsymbol{L}}\right) = \frac{2}{EI}\left(\frac{W_{ext(total(M+\Delta T)}}{L}\right) \tag{30}$$

This expression is compatible from the point of view of the elastic analogy with the expression (17) of the Einstein field equation with cosmological constant according to the correspondences (31) and (32) if one assumes (hypothesis of this article) that the cosmological constant is by analogy correlated with a thermal gradient applied in all space:

$$R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R \to \frac{1}{R^2} \tag{31}$$

$$\Lambda g_{\mu\nu} \to \left(\frac{\boldsymbol{\alpha\Delta T}}{\boldsymbol{h}}\right)^{\mathbf{2}} \tag{32}$$

About the formula (31), indeed, for memory, it can be proven that the Ricci tensor for a classical 2sphere is $2/R^2$ (see book what is space-time made of? of D. Izabel).

3.2 Analogy of space as an elastic medium with the thermal curvature of a thin plate associated according to Timoshenko's theory

Considering space as a fabric made up of thin sheets has already been explored as we have said above by many authors. Let us quote Melissinos **[17]**, T.G Tenev and M.F Horstemeyer **[12]** D. Izabel **[16]**, H A Perko **[22]**.

It is therefore quite natural that we take up this hypothesis on the structure of the fabric of space.

Moreover, if we take a piece of the universe locally, its surface will be considered almost flat according to the value of k=0 obtained by measurements from the Planck satellite **[23]**. In these publications, it is proven that the joint constraint with BAO measurements on space curvature is consistent with a flat universe,

Ωk=$-kc^2(r_0H_0)^{-2}$ = -0.0010 +0.0018 / -0.0019."

As a reminder, the space expansion scale factor is written $a_{(t)} = \frac{r_{(t)}}{r_0}$. r_0 is the radius of reference and the radius of the 3sphere in the metric of Friedmann-Lemaitre-Robertson Walker.

The Hubble constant (1/s²) squared is: ${H_0}^2 = \frac{8\pi G}{3}\rho_c$ with ρ_c the critical density of the medium.

So, the curvature k (unit 1/m²) of the universe can be considered as flat (33).

$$\Omega_k = -kc^2(r_0H_0)^{-2} = -\frac{3kc^2}{8\pi G\rho_c a^2} \tag{33}$$

$\Omega_k$is therefore the dimensionless curvature parameter of space (34):

$$\frac{\frac{1}{m^2}\times\frac{m^2}{s^2}}{\frac{m^3}{kgs^2}\times\frac{kg}{m^3}\times 1} = 1 \tag{34}$$

It is therefore not absurd to consider space as an infinitely long thin plate superposition given the very large radius of curvature of the universe associated with its gigantic size **[24]**.

In this case the curvature of a thin plate under a thermal gradient is well known and is given in S. Timoshenko in his book **[25]** in chapter 14 formula 50. We give the expression below (formula 35) similar to that obtained in the case of a beam:

$$\frac{\alpha \Delta T}{e} = \frac{1}{R} \tag{35}$$

Or squared to stay consistent with the previous paragraph regarding beam theory (36):

$$\left(\frac{\alpha \Delta T}{e}\right)^2 = \left(\frac{1}{R}\right)^2 \tag{36}$$

In these two expressions the curvature of the plate $\left(\frac{1}{R}\right)^2$ is therefore linked to the thickness of the considered plate e, to the coefficient of thermal expansion α associated with the elastic material and to the thermal temperature gradient ΔT between the extreme fibers of the plate.

It is therefore this model that we will consider later in the continuity of the authors cited above **[12]**, **[16]**. We must therefore establish the different parameters involved in this model. Namely, what thickness e of the sheets? what intensity of the thermal gradient ΔT? what value of the curvature 1/R? This is what we will study in the next chapter.

4. Search for certain scientific data that can feed this mechanical model of thermal curvature of the fabric of space

4.1 What plate thickness consider?

We know from A. Sakharov **[5]** that the potential quantum nature of vacuum can generate an elastic metric of space. T.G Tenev and M.F Horstemeyer in **[12]** consider Planck's thickness sheets. D. Izabel in **[16]** manages to find the Young's moduli of the different authors by considering a Planck's length P.A Millette **[13]** does the same.

Consequently, we will consider within the framework of this publication a thickness e of plate or fiber of the elastic fabric of space equal to l_p the Planck's length (35).

$$e = e_p = l_p = \sqrt{\frac{\hbar G}{c^3}} \tag{35}$$

4.2 Which thermal gradient consider?

New data show a temperature gradient between the absolute vacuum at 2.73 K and the cosmic web see **[26]** "The Cosmic Thermal History Probed by Sunyaev–Zeldovich Effect Tomography". In this article we can read:

*"We estimate Te, the density-weighted electron temperature of the universe, which goes from 7 × 10^5 K at z=1 to 2 × 10^6 K today" The cosmic thermal history probed by Sunyaev-Zeldovich effect tomography YI-KUAN CHIANG , RYU MAKIYA, BRICE MÉNARD ET EIICHIRO KOMATSU **[26]**.*

In this paper, the authors therefore highlight a certain thermal gradient between the cold zones of the universe and the very hot zones at the level of the cosmic web. So, this recent article suggests that the

average temperature of the gas present in the large structures of the observable Universe has been multiplied by 10 during the last ten billion years. to reach about two million Kelvin today.

We will therefore retain this hypothesis*: ΔT=2,000,000 °K*

4.3 What curvature of space associated with this thermal gradient consider?

P. J. E. Peebles in his paper **[19]** reviews the different approaches for linking the cosmological constant and dark energy.

Emilio Santos in **[20]** his paper studies the dark energy induced by the curvature of space-time by quantum vacuum fluctuations.

On the basis of his two articles in particular, we will therefore postulate that the cosmological constant is the source of a curvature of space linked to a thermal gradient acting on the thin sheets of space of quantum thickness equal to the Planck's length.

To be consistent with the approaches of A. Sakharov **[5]** and T.G Tenev and M.F Horstemeyer **[12]**, we consider in this study the cosmological constant resulting from vacuum fluctuations (quantum field theory). We will see in chapter 6 to explore all the scientific options, what gives the other value of the cosmological constant Λ- resulting from cosmological observations.

We make this hypothesis based on quantum field theory taking into account all of the previous paragraphs:

1) The analogy of the fabric of space as an elastic medium works well with the general relativity equation for mass/energy **[5]** to **[17]**,

2) The elastic analogy suggests two possible curvatures and only two: one resulting from the masses/energy acting in the medium and one resulting from the thermal gradient acting on the medium **[16]**,

3) There is obviously a thermal gradient present in space **[26]**,

4) Many authors **[12]**,**[16]**,**[22]** and gravitational waves **[3] [4]** suggest plane deformations of elastic media (spatial fabric),

5) A. Sakharov **[5]** showed that general relativity is correlated with an elastic metric resulting from quantum fluctuation of space.

4.4 Final model retained to estimate a coefficient of thermal expansion of the fabric of the equivalent space

Considering the previous paragraphs, we therefore arrive at the simplified model given in Figure 3 below.

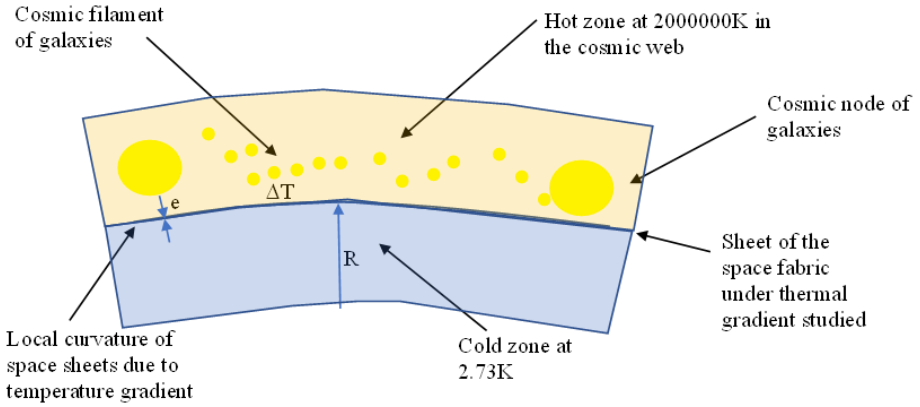

Figure 3: Simplified mechanical model of elastic space undergoing a curvature by a thermal gradient between a very hot zone and a very cold zone of the universe–

Thus, the almost flat thin sheets of space (k=0, T of space curvature tending towards infinity **[12]**,**[23]** and **[24]**) of Planck's thickness (L_p) according to the reasoning by A. Sakharov **[5]** T.G Tenev and M.F Horstemeyer **[12]** undergo a thermal gradient resulting from the differences in average temperature between the cosmic web and the space vacuum, **[26]** this causes their curvature. It is this curvature that the cosmological constant Λ **[19] [20]** can represent. By placing ourselves in the analogy of space functioning as a medium, an elastic fabric, the mechanics of continuous media by the theory of plates of Timoshenko **[25]** allows us to model its behavior in a simplified way and to extract a coefficient of thermal expansion α of the space fabric.

5. Consequence of considering the cosmological constant as a generalized thermal curvature

5.1 Determination of the coefficient of expansion of the space fabric

From the expression (36) of Timoshenko **[5]** of the curvature of a spatial plate (k=0) see **[23]** and **[24]** in pure bending requested by a thermal gradient ΔT **[26]** and in considering the cosmological constant Λ as an additional curvature (and not a dark energy) associated with the thermal gradient acting in space **[19] [20]** we postulate:

$$\left(\frac{\alpha\Delta T}{e}\right)^2 = \left(\frac{1}{R_0}\right)^2 = \Lambda \tag{37}$$

We deduce from the above expression the coefficient of thermal expansion α of the spatial fabric:

$$\alpha = \frac{e\sqrt{\Lambda}}{\Delta T} \tag{38}$$

By definition of the cosmological constant:

$$\frac{c^4\Lambda}{8\pi G} = \rho_{vacuum}c^2 \tag{39}$$

So:

$$\Lambda = \frac{8\pi G \rho_{vacuum}}{c^2} \tag{40}$$

By transferring this expression to the formula for the coefficient of thermal expansion of the fabric of space (38), we obtain the expression for the coefficient of thermal expansion of space α from the density of the vacuum:

$$\alpha = \frac{\boldsymbol{e}\sqrt{\frac{\boldsymbol{8\pi G \rho_{vacuum}}}{\boldsymbol{c^2}}}}{\boldsymbol{\Delta T}} = \frac{\boldsymbol{e}\sqrt{\Lambda}}{\boldsymbol{\Delta T}} \tag{41}$$

If we consider a space plate thickness e of Planck dimension (35) like Tenev and Horstemeyer **[12]** and the associated vacuum energy, we obtain a first approximation of this coefficient of thermal expansion α.

$$\alpha = \frac{\sqrt{\frac{hG}{2\pi c^3}}\sqrt{\frac{8\pi G \rho_{vacuum,QFT}}{c^2}}}{\Delta T} \tag{42}$$

So, all calculations performed:

$$\alpha = \frac{\boldsymbol{2G}\sqrt{\frac{\boldsymbol{\hbar \rho_{vacuum,QFT}}}{\boldsymbol{c^5}}}}{\boldsymbol{\Delta T}} \tag{43}$$

With $\hbar$ the reduced Planck constant (h/2π), ρ the quantum vacuum density according to quant um field theory, G the gravitational constant, c the speed of light and ΔT the thermal gradient applied to these sheets of space.

Consider the expression of the coefficient of thermal expansion α:

We check that the dimensional equation is satisfied:

$$\alpha = \frac{\frac{m^3}{kgs^2}\sqrt{\frac{\frac{kgm^2}{s}\times\frac{kg}{m^3}}{\frac{m^5}{s^5}}}}{K} = K^{-1} \tag{44}$$

Numerical application using the constants of physics and using the same assumptions as P.A Millette **[13]** and T.G Tenev and M.F Horstemeyer **[12]** gives:

G =6.6743015 × 10^{-11} m^3/kg.s^2

h = 6.62607004 × 10^{-34} m^2.kg/s

$\rho_{vacuum,QFT}$ =1.11×10^{96} kg/m^3

$\Delta T = 2000000\ K$

c = 299,792,458 m/s

We obtain:

$$\alpha_{QFT}=1.16317 \text{ x } 10^{-6}\ K^{-1}$$

For the record, the coefficient of expansion of steel is worth 12x10^{-6} K^{-1}

We therefore obtain a result that seems realistic since the space is rather rigid if we refer to the value of κ which represents the flexibility (1/rigidity) of the space and which is equal to 2.076610^{-43} N^{-1}.

We find this result directly from equation (41) with the following data by considering Λ from quantum field theory:

Λ_{QFT}=2.0717x10^{70} m^{-2}

$e = l_p$ =1.61626x10^{-35} m

$\Delta T = 2000000\ K$

6. Discussion of the representativeness of the mechanical model of thermal curvature of space

It is well known that one of the greatest challenges of physics today is this problem of the cosmological constant which, depending on the hypothesis adopted to establish it (vacuum energy resulting from quantum fluctuations in the ground state provided by quantum field theory or cosmological observations via the Planck's satellite in particular) leads to a ratio of 10^{120} between the two values of Λ! We do not claim in this paper to solve this problem, simply from a scientific point of view it is important to explore what these two values of the cosmological constant imply on the coefficient of potential thermal expansion of the fabric of space.

In this case, the application of formula (41) with the following numerical values:

$l_p = e$ =1.61626x10^{-35} m

Λ= 1.088 × 10^{-52}m^{-2}

$\Delta T = 2000000\ K$

Leads to an extremely small coefficient of thermal expansion…

$$\alpha_{astrophysics}=8.42936\text{x}10^{-68}\text{K}^{-1}$$

7. Discussion of the additional verifications necessary to validate or not this model

To really validate our model, it would of course be necessary to solve this problem of the possible variation of values of the cosmological constant. A model of the universe reproducing the construction of the cosmic web from general relativity and observations exists, however these models do not integrate any mechanical behavior such as the analogy of space as a deformable elastic medium suggests.

It would undoubtedly be necessary to model the space, containing and contained in a structure in sheets, to set up the cosmic web and to impose the thermal gradient between the hot and cold zones to check or not if a curvature of thermal origin appears curving in mean the whole universe, what is its intensity and thus took advantage of it to evaluate the true value of the cosmological constant Λ and therefore the true value of the coefficient of thermal expansion of the fabric of space.

8. Presentation of the possible consequences of this model concerning the interpretation of dark energy

The publications of **[19]** and **[20]** in particular and many others seem to indicate that the dark energy source of expansion of the universe is connected to the cosmological constant in particular when this one is positioned on the right of the equations (15) and (16). We are interested in this article in a cosmological constant placed on the left of the equation (17) that is to say in an additional curvature present in all space. This more mechanistic approach makes it possible to no longer have recourse to an energy of unknown origin and is closer to a functioning of the universe as a structure "charged" within it by the cosmic web and undergoing the thermal gradient of this one. But raises other questions (which thermal gradient considered? does space really have a sheets structure deforming relative to each other as the deformations associated with the polarizations $\boldsymbol{A}^{+}$ and $\boldsymbol{A}^{\times}$ seem to suggest gravitational waves? What is the real thickness of these sheets? how to integrate the anisotropy of space suggested by a Poisson's ratio of 1? The quantum field theory approach seems more coherent because it leads to a coefficient of thermal expansion compatible with materials on Earth, nevertheless the difference with the astrophysical value of the cosmological constant raises a real fundamental question. Moreover, the values of the Young's moduli that we recalled at the beginning of the article of on the one hand and the vacuum energy densities on the other hand being so outside the usual values of elastic materials on Earth that it is advisable to be particularly careful with respect to this "quasi-normal" value of the coefficient of expansion thermal that we propose in this study.

Einstein said God isn't playing dice when talking about quantum mechanics, but maybe God is playing structural engineer with dark energy acting throughout the universe—at least that's the question this article likes to ask.

9. Conclusions

We explore in this study the analogy of space as an elastic medium by focusing on one of the mechanical parameters associated with any elastic fabric, its coefficient of thermal expansion α. The state of the art is rather poor or even non-existent on its definition and its intensity within the framework of an elastic model of space. By taking inspiration from models of space fabric in the form of thin sheets, placing ourselves within the framework of quantum field theory both on the value of the cosmological constant Λ and on the thickness of these sheets of the order of the Planck length, considering the recent measurements making it possible to establish the orders of magnitude of the thermal gradients between the hot and cold zones of the universe and finally considering that these sheets bend under this thermal gradient by analogy with mechanics plates, we propose a formulation and a value of the expansion coefficient of the fabric constituting the space. This study remains a first approach which somehow clears this path given the great variability of the intensity of the cosmological constant depending on whether one considers its value from quantum field theory or its value from cosmological measurements. Other models are certainly necessary to fine-tune the value of this coefficient of thermal expansion of the spatial fabric and this study remains only a first approach. The potential impact of this thermal approach on time (because Einstein's equation requires considering space-time and not just space) should also be studied.

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References

F.W. Dyson, A. S. Eddington and C. Davidson, *Phil. Trans. Of. The. R. Soc. Lond.* **220** 291 (1929)

C.W. F. Everitt, *Phys. Rev. Let.* **106** (2011) 221101

Collective and al, *Phys. Rev. Let.* **116** (2016) 061102

Collective and al, *Phys. Rev. Let.* **119** (2017) 161101

A. D. Sakharov, *Sov. Phys. Dokl.* **12** (1968) 1040

J. L. Synge, *Math. sch. of. phy. sc.* **72** (1959) 82

C. B. Rayner and R. Proc, *Soc. A. Math. Phys. And. Eng.* **272** (1963) 44

R. Grot and A. Eringen, *Int. J. Eng. Sc.* **2** (1966) 1

V. V. Vasiliev and L. V. Fedorov, *Mech. of. Sol.* **53** (2018) 256

V.V. Vasilev and L.V. Fedorov, *Mech. of. Sol.* **56** (2021) 404

J. D. Brown, *Class. And. Quan. Grav.* **38** (2021) 085017

T. G. Tenev and M. F. Horstemeyer, *Int. J. Of. Mod. Phy.* D **27** (2018) 1850083

P. A. Millette, *Elastodynamic of the space time continuum* (NewMexico, USA, STCED, American, Research, Press, NewYork, 2019)

K. McDonald, *What is the Stiffness of Spacetime* (Princeton, J, Henry, Lab, Princ, Univ, 2018)

M. Beau, *On the acceleration of the expansion of a cosmological medium* (Boston, US, Univ, Massachusetts, Boston, 2018)

D. Izabel, *Pram. J. Of. Phys.* **94** (2020) 119

A. C. Melissinos, *Upper limit on the Stiffness of space-time* (Rochester, Dept, Phys, Astro, Univ, Rochester, 2018)

S. R. Wang, *Estimation of spacetime stiffness based on LIGO observations* (Taiwan, ,Keelung, univ, 2003)

P. J. E. Peebles and B. Ratra, *Rev.of. Mod. Phys.* **75** (2003) 559

E. Santos, *Astr. Sp. Sc.* **332** (2011) 423

C. F. Gauss, *Disquisitiones generales circa superficies curvas* (Gottingen, Societate, Regiae, Oblatae, D, Gottingae, 1828)

H. A. Perko, *J. Phy. Conf. series.* **1956** (2021) 1

Collectif and al, *Astron. And. Astrop. Rev.* **571** (2014) 1

D. Izabel, *What is space time made of?* (Paris, Edp, sciences, 2021)

S. Timoshenko and J.N. Goodier, *Theory of elasticity* (NewYork, McGraw, Hill, 1951)

Y. K. Chiang, R. Makiya, B. Ménard and E. Komatsu, *Astr. J.* **902** (2020) 56