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# Solved anomalies prove a shear-thickening vacuum

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## Abstract

By using the Lorentz factor as a viscosity term in Stokes's law for objects moving in a vacuum, Mercury's perihelion precession (classical test of general relativity) and the Pioneer anomaly are directly and exactly solved, demonstrating that the physical vacuum is a shear-thickening fluid. The modified Stokes's equation also correctly indicates that planetary orbits are stable over billions of years. Furthermore, relativistic kinetic energy is revealed as the necessary energy to oppose a shear-thickening vacuum. Consequences on aerospace engineering are eventually discussed.

## Introduction

Some authors considered the possibility that the physical vacuum may be a superfluid, a special Bose-Einstein condensate (1–8). Here, by exactly solving two known anomalies, along with other correct results, it is demonstrated that the physical vacuum rather behaves as a dilatant fluid, as shear stress increases. Sect. 1 introduces a modified Stokes's formula for motion in a shear-thickening vacuum. In Sect. 2, by applying this formula, the Pioneer anomaly, the orbital stability of the planets and Mercury's perihelion precession are correctly calculated. The Pioneer anomaly is currently considered solved after thermal simulations, whose results, approximate and based on various assumptions and scenarios (9, 10, 16), are now challenged by the simpler, direct and precise result presented in Sect. 2.1, which *exactly corresponds to the*

*acceleration of  $-8.74 \times 10^{-10} \text{m} \cdot \text{s}^{-2}$  measured by the NASA.* The modified Stokes's formula, put into Newton's second law of motion, says that due to the large masses of planets (unlike the case of the Pioneer probes), planetary orbits are stable over billions of years, averting what would be otherwise a major objection to the existence of a shear-thickening vacuum, i.e. its effect on orbital stability. Sect. 2.3 shows that vacuum's apparent (shear-dependent) viscosity emerges as the real cause of the anomalous precession of perihelia, suggesting that the quantum foundations of relativity are situated in a fluid, shear-thickening quantum vacuum. In fact, it is shown that Einstein's formula for the precession of perihelia is directly derived from the modified Stokes's formula. In Sect. 3, we see that the relativistic formula for kinetic energy corresponds to particle rest energy multiplied by the term of vacuum dilatancy. Relativistic mass is therefore reinterpreted as the work necessary to oppose the shear-thickening vacuum, which becomes solid-like as a body approaches the speed of light. Also time dilation and the Lorentz-Fitzgerald contraction are shown to depend on vacuum dilatancy, as they depend on the Lorentz factor, which the solved anomalies in Sect. 2 demonstrate to be the rheogram of a shear-thickening vacuum. Eventually, in Sect. 4, from the result presented in Sect. 2.1 as regards the Pioneer anomaly, the consequences of the modified Stokes's law for a dilatant vacuum in the field of aerospace engineering are discussed.

## **1 Methods: modified Stokes's law for a dilatant vacuum**

Stokes' law, derived in 1851, to calculate the viscous force acting on a body traveling through a viscous, Newtonian fluid (*11*) reads

$$F_v = -6\pi r v \eta \quad (1)$$

where  $v$  is the translational velocity,  $r$  the radius of the object (the law refers to spherical shape) and  $\eta$  is a coefficient of dynamic viscosity expressed in  $\text{Pa} \cdot \text{s}$ . However, for a shear-thickening

vacuum, the coefficient of linear viscosity,  $\eta$ , in Eq. (1), is not appropriate, since it is valid only for Newtonian fluids. In the present investigation it is demonstrated (Sect. 2) that the correct mathematical behavior of vacuum's apparent viscosity is expressed by the Lorentz factor, therefore reinterpreted as the rheogram of physical vacuum, in which the asymptote at the speed of light consequently refers to a solid-like condition of the vacuum by approaching a certain level of shear stress. Let us then multiply  $\eta$  by the Lorentz factor in the expression  $\gamma - 1$ . We arrive to a modified Stokes's law

$$F_{v(vac)} = -6\pi r(\eta\gamma - 1)\kappa = -6\pi r \left( \frac{\eta}{\sqrt{1 - \left(\frac{v}{c}\right)^2}} - 1 \right) \kappa \quad (2)$$

where  $\eta$  and  $\kappa$  are a unitary constants expressed in  $\text{Kg} \cdot \text{m}^{-1} \cdot \text{s}^{-1}$  and  $\text{m} \cdot \text{s}^{-1}$  (respectively). Let us define

$$D = \eta\gamma - 1 \quad (3)$$

as the term of vacuum dilatancy. The formula is simply written  $F_{v(vac)} = -6\pi r D \kappa$ . If we use this formula for bodies traveling in a vacuum, such as probes or planets, the viscous force it refers to is of course that of the physical vacuum, so Eq. (2) is the formula for the viscous force exerted by a dilatant vacuum and its applications and validity are presented in the following sections, by precisely solving two known anomalies and by obtaining other correct results, such as the stability of planetary orbits.

## 2 Results: shear-thickening vacuum proven

### 2.1 Exact value for the Pioneer acceleration

Being the anomalous negative acceleration of the Pioneer spacecrafts 10 and 11 well-known (concrete investigations of the anomaly started in 1994 (12)), it is not necessary to summarize here this issue. In the light of the exact result presented below, it appears evident that this

problem has not been correctly solved yet, despite copious investigations, based on thermal simulations (9, 10, 12–16), which gave approximate results based on several assumptions and different scenarios. In 2012 (9) a value of  $-7.4(\pm 2.5) \times 10^{-10} \text{ m} \cdot \text{s}^{-2}$  was proposed. On the contrary, the exact solution (without models and assumptions) is directly produced by Eq. (2), that is, via the interaction of the Pioneer probes with a shear-thickening vacuum. Let us put Eq. (2) in Newton’s second law, using the known data of the Pioneer probes and *we directly obtain the exact negative acceleration of the Pioneer ( $a_P$ ) detected by the NASA*

$$\begin{aligned}
 a_P = \frac{F_{v(vac)}}{m_P} &= - \frac{6\pi r_P \left( \frac{\eta}{\sqrt{1 - \left(\frac{v_{max}}{c}\right)^2} - 1} \right) \kappa}{m} = \\
 &= - \frac{6\pi \cdot 1.371 \text{ m} \cdot \left( \frac{1 \text{ kg} \cdot \text{m}^{-1} \cdot \text{s}^{-1}}{\sqrt{1 - \left(\frac{36737 \text{ m} \cdot \text{s}^{-1}}{299792458 \text{ m} \cdot \text{s}^{-1}}\right)^2} - 1} \right) \cdot 1 \text{ m} \cdot \text{s}^{-1}}{222 \text{ kg}} = \\
 &= -8.74 \times 10^{-10} \text{ m} \cdot \text{s}^{-2}.
 \end{aligned} \tag{4}$$

where  $m_P = 222 \text{ kg}$  is the mass of the spacecrafts (258 kg) minus that of the burned fuel (36 kg hydrazine) after the Jupiter flyby;  $r_P = 1.371 \text{ m}$  is the radius of the antenna (diameter is 9 ft) and  $v_{max} = 36737 \text{ m/s}$  is the maximum speed of the probe, *as indicated* by the NASA’s Scientific and Technical Information Office (17) after the swing-by caused by Jupiter. This exact and direct result cannot be ignored and the Pioneer issue has to be reopened. Moreover, the NASA should now consider to Doppler track other probes. Unfortunately this was not the case of the New Horizons spacecraft, for which data are missing. Testing other probes (maybe a dedicated probe) with Eq.(2) is definitely recommended.

## 2.2 Stability of planetary orbits

The existence of a shear-thickening vacuum lets immediately arise an objection as regards orbital stability. However, considering the second law of motion in the form  $a = F/m$  and putting

the large mass of a planet in the denominator and vacuum's viscous force (2) in the numerator, we see that, despite the existence of a dilatant vacuum, planetary orbits are stable over billions of years. For instance, the deceleration of the Earth corresponds to the following negligible value

$$a_{\oplus} = \frac{F_{v(vac)}}{m_{\oplus}} = -1.557 \times 10^{-32} \text{m} \cdot \text{s}^{-2}. \quad (5)$$

using the mean radius and the mean orbital velocity of the Earth in Eq. (2) (numerator) and the mass of the Earth in the denominator. Subscript  $\oplus$  refers to the Earth. Such a negative acceleration corresponds to a decrease in orbital speed of only  $-4.9 \times 10^{-16} \text{m/s}$  per billion years. For Jupiter, orbital deceleration is  $-6.59 \times 10^{-28} \text{m/s}^2$ , that is a reduction of  $2 \times 10^{-11} \text{m/s}$  in orbital speed over one billion years. One therefore concludes that planetary orbits are stable despite the presence of a shear-thickening vacuum.

### 2.3 Deriving Einstein's formula for the precession of perihelia

Net of classical gravitational contributions, perihelia precessions show an anomalous positive contribution, which is particularly evident for the planet Mercury. The correct calculation of this anomaly is one of the classical tests for general relativity (GR). Here Einstein's formula for the precession of perihelia is differently derived via the modified Stokes's formula presented above (2). In this way, it is demonstrated that the long-awaited quantum foundations of general relativity are situated in a shear-thickening quantum vacuum. In GR (18), the anomalous perihelia precession is represented by a formula which can be observed in three equivalent forms

$$\Delta\phi = \frac{24\pi^3 a^2}{T^2(1-e^2)c^2} = 6\pi \left(\frac{v}{c}\right)^2 \frac{1}{1-e^2} = 6\pi \frac{GM}{a(1-e^2)c^2} \quad (6)$$

where  $\Delta\phi$  expresses the relativistic contribution to perihelia precessions in radians per revolution corresponding, using the data of Mercury, to the known value of 42.98" per century (or  $5.0186 \times 10^{-7} \text{rad/rev.}$ ),  $a$  is the semi-major axis,  $T$  the orbital period and  $e = 0.205$  the

orbital eccentricity. The expression in the center of Eq. (6) is obtained via the equivalence  $T^2 = 4\pi^2 a^2 / v^2$ , resorting to mean orbital velocity, and in the expression on the right the stable second cosmic velocity,  $v = \sqrt{GM/a}$ , is used, putting the radius  $r = a$ . As for the case of the Pioneer, the modified Stokes's formula for a dilatant vacuum (2) is now used. In this case, the treatment of the planet as a point mass is respected, so the direct proportionality to planetary radius is not taken into account and by resorting to the nondimensionalized norm of Eq. (2) we obtain

$$6\pi \left( \frac{1}{\sqrt{1 - \left(\frac{v}{c}\right)^2}} - 1 \right) = 6\pi (\gamma - 1) \quad (7)$$

which can be expressed in radians. Resorting to Taylor, let us proceed via the approximation

$$2(\gamma - 1) \approx \left(\frac{v}{c}\right)^2 \quad (8)$$

and Eq. (7) now reads

$$3\pi \left(\frac{v}{c}\right)^2 = 3\pi \frac{GM}{ac^2} \quad (9)$$

where, on the right, we see again the stable second cosmic velocity, as in the rightmost expression in Eq. (6). Since we are considering an elliptic orbit, we have to use the elliptic parameter, correcting  $a$  into  $a(1 - e^2)$  and we obtain a formula which exactly gives 1/2 the result of GR (6)

$$\Delta\phi = 3\pi \frac{GM}{a(1 - e^2)c^2} = 3\pi \left(\frac{v}{c}\right)^2 \frac{1}{1 - e^2} \quad (10)$$

This 1/2 result can be also considered as the precession occurring in a semi-orbit and is due to the use of mean orbital velocity. Indeed, in the elliptic orbit, orbital speed actually varies as in Fig. 1 on the left side. Since the mean orbital velocity is given as  $v_{max}/2 + v_{min}/2$ , Let us adopt the reduced model on the right side of Fig. 1, i.e. one semi-orbit at maximum orbital speed and one at minimum speed. The full precession (6) is therefore given by

$$\Delta\phi = 3\pi \left(\frac{v_{max}}{c}\right)^2 \frac{1}{1 - e^2} + 3\pi \left(\frac{v_{min}}{c}\right)^2 \frac{1}{1 - e^2} = 6\pi \left(\frac{v}{c}\right)^2 \frac{1}{1 - e^2} = \frac{24\pi^3 a^2}{T^2(1 - e^2)c}$$

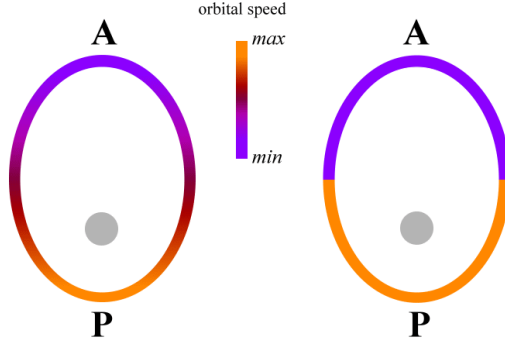


Figure 1: Left: variable orbital velocity in the elliptic orbit (P and A refer to perihelion and aphelion, respectively). Right: the reduced model used in the present study which considers half an orbit at maximum orbital velocity and the other one at minimum velocity.

where  $v_{max}$  and  $v_{min}$ , each referring to a semiorbit, recombine in the mean orbital velocity  $v$  and the rightmost equivalence comes from Eq. (6). Now, by merging in a single formula the steps presented in this subsection, we can now look at the relationship between Eq. (2), which expresses the viscous force in a dilatant vacuum, and the contribution to the precession of perihelia derived in general relativity. The formula reads

$$\Delta\phi \equiv \left\| \frac{2F_{v(vac)}}{\kappa\eta r(1-e^2)} \right\| = \frac{12\pi D}{\eta(1-e^2)} \quad (11)$$

where  $D$  is the term of vacuum dilatancy (3). By testing Eq.(11) with the parameters of the planet Mercury, we see that *it exactly gives the well-known value of general relativity*

$$\begin{aligned} \Delta\phi &= \frac{12\pi D}{\eta(1-e^2)} = \frac{12\pi \left( \frac{\eta}{\sqrt{1-\left(\frac{GM}{ac^2}\right)} - 1} \right)}{\eta(1-e^2)} = \\ &= \frac{12\pi \left( \frac{1 \text{ Kg}\cdot\text{m}^{-1}\cdot\text{s}^{-1}}{\sqrt{1-\frac{(6.67408 \times 10^{-11} \text{ m}^3\cdot\text{kg}^{-1}\cdot\text{s}^{-2})(1.98847 \times 10^{30} \text{ kg})}{(5.7909 \times 10^{10} \text{ m})(299792458 \text{ m}\cdot\text{s}^{-1})^2}} - 1} \right)}{(1 \text{ Kg}\cdot\text{m}^{-1}\cdot\text{s}^{-1})(1-0.20563^2)} = \\ &= 5.018649 \times 10^{-7} \text{ rad/rev.} \Rightarrow 42.98''/\text{century} \end{aligned} \quad (12)$$

where, in  $D$ , the equivalences  $r = a$  and  $v = \sqrt{GM/a}$  are used, as in Eq. (6). The positive contribution to the precession of perihelia treated in general relativity is in this way revealed as



a phenomenon driven by a shear-thickening vacuum. We see that nothing in the present study contradicts general relativity: this investigation, by rederiving Einstein's formula for perihelia precession, only highlights that the quantum foundations of relativity are in a dilatant quantum vacuum and that Einstein's formula can be rewritten by revealing the role of the shear-thickening vacuum (11). After all, this is compatible with the stress-energy tensor of the field equation, in which  $T^{00}$  is vacuum's energy density ( $\rho_{vac}$ ), also present in the cosmological constant  $\Lambda = \kappa\rho_{vac}$ , and the remaining components of the tensor can be as well hydrodynamically interpreted, being pressure, shear stress, momentum flux and momentum density. Interestingly, also an investigation by Conti and Marcucci (19), following the present findings (20), shows that the interaction at Planck-scale with a quantum fluid may be cause of precession.

### **3 Particle acceleration in a shear-thickening vacuum: revisiting relativistic mass**

Since the three exact solutions discussed above indicate the existence of a shear-thickening vacuum, it becomes clear that, if bodies traveling in a vacuum undergo a nonlinear negative acceleration due to the viscous force exerted by the dilatant vacuum, relativistic mass increase should be reinterpreted as actually the braking action of the vacuum, i.e. something that occurs in the vacuum, leaving particle mass actually unaffected. This agrees with Taylor and Wheeler (21), who state that the increase of energy originates not in the accelerated object but in the geometric properties of space-time itself. We say now in the properties of the physical vacuum, which is fluid and dilatant. While Okun (22) reflects that it is more appropriate to refer to relativistic momentum instead of relativistic mass.

In general relativity, the kinetic energy of an accelerated particle is given by

$$E_k = -mg_{tt}u^t u_{obs}^t - mc^2 = mc^2 \sqrt{\frac{g_{tt}}{g_{tt} + g_{ss}v^2}} - mc^2 \quad (13)$$

factoring out the rest energy

$$E_k = mc^2 \sqrt{\frac{g_{tt}}{g_{tt} + g_{ss}v^2}} - 1. \quad (14)$$

According to the present investigation, and especially as regards the case of Mercury's perihelion, curved space-time is actually the mathematical expression of the hydrodynamics of a fluid, dilatant vacuum and space is flat. Under this condition, we can substitute  $g_{tt} = -c^2$  and  $g_{ss} = 1$  and after some simple algebra Eq. (14) reads

$$E_k = mc^2 \left( \frac{1}{\sqrt{1 - \left(\frac{v}{c}\right)^2}} - 1 \right), \quad (15)$$

that is, particle rest energy,  $mc^2$ , multiplied by the term of vacuum dilatancy  $D$  (3) nondimensionalized. We are therefore actually observing the energy corresponding to the work done by the synchrotron on the accelerated particle to oppose vacuum dilatancy,

$$W = E_0 \frac{D}{\eta}, \quad (16)$$

where  $E_0 = mc^2$  is rest energy (with  $m$  rest mass). As accelerated bodies approach the speed of light, the work to be done becomes infinite, since the vacuum becomes solid-like. Further solidification is not possible, so we observe an asymptote. As shown in Fig. 2, as the modulus of the negative tangential acceleration  $|a_{T_{vac}}|$  due to the presence of a shear-thickening vacuum equals that of the tangential acceleration  $|a_{T_{syn}}|$  made possible by the synchrotron, a particle reaches its maximum speed ( $v_{max}$ , black dotted line in Fig. 2), depending on the maximum energy of the synchrotron and anyway lower than  $c$ . The more powerful the accelerator, the closer to the speed of light the black dotted line (Fig. 2). As we see, by putting Eq. (2) in the second law of motion, the tiny mass of a particle exposes it to a huge deceleration. On the contrary, due to its large mass, if the Earth traveled at 99% the speed of light it would undergo a negative acceleration of just  $-1.22 \times 10^{-16} \text{m/s}^2$ . For the same reason, we have

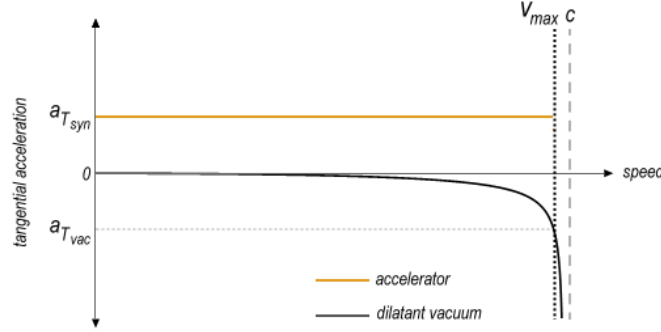


Figure 2: Total tangential acceleration of a particle in a synchrotron is zero when the negative nonlinear acceleration due to the presence of a dilatant vacuum equals the acceleration caused by the synchrotron,  $|a_{T_{vac}}| = |a_{T_{syn}}|$ . Particles reach in this way maximum speed ( $v_{max}$ ).

seen (Sect. 2.2) that planetary orbits are stable. This leads to the considerations below, as regards unexpected aerospace engineering applications, which are already possible with current technology. But before that, in addition to relativistic mass and to quickly complete the list of relativistic phenomena in the light of a shear-thickening vacuum, it is interesting to reflect that also time dilation is due to vacuum dilation, it depends, indeed, on the Lorentz factor, which is proven to be the rheogram of the physical vacuum, via the exact results of the modified Stokes's equation (2). Basically, traveling clocks are slowed down by the increased viscosity of the physical vacuum (apparent viscosity) with respect to another observer who is not subject to the apparent flow, or is subject to a weaker apparent flow. Now, as regards gravitational time dilation, we know it is linked to time dilation in a flat space-time via the second cosmic velocity.

Let us write

$$\Delta t' = \frac{\Delta t}{\sqrt{1 - \frac{v^2}{c^2}}} = \frac{\Delta t}{\sqrt{1 - \frac{R_S}{r}}} \quad (17)$$

hence  $\frac{v^2}{c^2} = \frac{R_S}{r} \Rightarrow v^2 = \frac{2GM}{r}$ , that is  $v = \sqrt{2V}$ , where  $V$  is the gravitational potential. The action of gravity is equated to that of speed. To understand this, it is enough to consider the flux in Gauss's law for gravity,  $F_g = \oint_S \mathbf{g} \cdot \mathbf{n}(\mathbf{r})dS$  (equivalent to Newton's law of universal gravitation), as a real flow of fluid, dilatant vacuum, to realize that time dilation is due both to

speed and to gravity, since a gravitational field is actually an inflow of fluid, dilatant vacuum, as hypothesized by Cahill (23), who considers a quantum foam inflow. In both cases, a body is subject to an apparent flow, which causes apparent viscosity and consequently time dilation, according to vacuum's rheogram (Lorentz factor). To complete the picture of relativistic effects in special relativity, one can declare that the Lorentz-Fitzgerald contraction also depends on vacuum dilatancy, as it directly depends on time dilation. In short, every relativistic effect, in which Lorentz factor (vacuum's rheogram) is at stake, is directly reinterpretable as due to vacuum's dilatancy.

## 4 New prospects in aerospace engineering?

Since in  $a = F_{v(vac)}/m$  the negative acceleration due to the shear-thickening vacuum nonlinearly decreases by taking into account greater masses, the case of heavier accelerated objects is different from what we observe in synchrotrons, where the mass of the accelerated particles is tiny and vacuum dilatancy prevails. A fact which aerospace engineering and space research were currently unaware of. Not by case, we see that it is much more difficult to maintain at  $v_{max}$  electrons than protons, when both are accelerated in a synchrotron, due to the considerable difference in their masses. The lighter the more difficult. For this reason, Hawking's and Milner's nanocrafts (24) could not be a good idea and this experience could confirm an unexpected deceleration due to the dilatant vacuum, as in the case of the Pioneer spacecrafts (2.1) but much greater. In short, it seems we already possess the correct technology for quasi-luminal flight of large spacecrafts being unaware of that. For instance, a hypothetical spherical spacecraft with the same mass of the International Space Station (ISS) and radius 6 m (i.e. of a sphere whose volume is equal to the pressurised volume in the ISS) traveling at 0.9999991  $c$ , that is at the maximum speed a proton achieves in the LHC, would undergo a negative acceleration due to the shear-thickening vacuum of just  $-0.2 \text{ m/s}^2$ , which even reduces to only

$-0.002 \text{ m/s}^2$  by increasing 100 times the mass of the spacecraft. Space exploration at quasi-luminal speed using large spacecrafts would therefore be possible, if not for different reasons such as those concerning propulsion etc. However, transporting great quantities of fuel would increase the mass, reducing the braking action of the vacuum. Another aspect of what we might call vacuum-applied aerodynamics (*vacuodynamics?*) emerging from Eq. (2) once put into Newton's second law, is that the smaller the section of the accelerated body perpendicular to the direction of motion, the weaker vacuum's viscous force. Cylindrical shapes would be therefore advantageous. Progressive in-orbit assembly of large-mass spacecrafts with very capacious tanks is therefore indicated as a future correct strategy for deep space exploration directed toward other stars at quasi-luminal speed. Also, being the deceleration of large masses due to shear-thickening vacuum so small, if compared that of subatomic particles in synchrotrons, the question whether superluminal speed is possible comes back on the table. Vacuum's quasi-lattice (solid-like condition) could indeed collapse under the action of large-mass objects trying to overstep the speed of light.

## Conclusion

The modification of Stokes's law, obtained by multiplying its viscosity coefficient  $\eta$  by the Lorentz factor (in the form  $\eta\gamma - 1$ ) and therefore reinterpreting the latter as the rheogram of a fluid, shear-thickening vacuum, has produced a new formula expressing the viscous force exerted by physical vacuum. This formula has been confirmed valid by solving two well-known anomalies, the relativistic contribution to perihelia precession, rederiving Einstein's equation, and the Pioneer anomaly, for which a direct and exact result has been obtained, to be therefore preferred to the more approximate and complicate solutions sofar presented. Deriving Einstein's formula for the precession of perihelia from the viscous force of the vacuum, along with the presence of the term of vacuum dilatancy in the relativistic formula for kinetic energy and the

dependence of time dilation and length contraction on vacuum's rheogram, indicate that the quantum foundations of relativity are rooted in the existence of a shear-thickening quantum vacuum, whose hydrodynamics is mathematically interpreted as curved space-time. We can conclude by reflecting that this fluid, dilatant vacuum likely corresponds to the dark sector, i.e. to 95% of the universe's mass-energy, in which diffused particle dark matter (a granular component) could play the role of a dopant in superfluid dark energy, determining vacuum dilatancy. For sure, the shear-thickening aspect of the physical vacuum now helps us to better understand its nature, along with that of dark energy and dark matter. In this investigation, we have finally seen that the more massive a body the less deceleration it undergoes when it travels through the dilatant vacuum and this indicates that the use of very massive spacecrafts is the correct direction to interstellar space exploration. After this investigation, Einstein's relativity remains quantitatively correct and its equations only needs to be reinterpreted in the light of a shear-thickening quantum vacuum, paving the way to a theory of quantum relativity.

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