DOI 10.59277/RoAJ.2024.1-2.01

HUBBLE'S LAW IN THE LOCAL FLAT SPACETIME

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Abstract. On the road towards observational (and experimental) validation of the DEUS cosmological model we will cross the boundary between theory and observation with the help of Hubble's law for the Universe evolution, expressed as function of quantities as redshift z (measured through Doppler-shift observations) and local time *T*. In the book by Popescu (2007) we gave a theoretical method for computing the Hubble constant H_0. Now, in the light of the new acquired knowledge that followed Popescu (2020) paper's results, after defining what is the local time for the flat spacetime and how it relates to the FLRW spacetime, we will be able to derive the Hubble's law *H (T)*. The theoretical meaning of the redshift parameter contained by it will diverge from the one given by the classical expansion cosmological models, not being directly dependant on the time *T* (or age of the Universe), but rather on the way the entropy evolved in the Universe, at some particular location, with the t_{FLRW} time.

Key words: cosmology, redshift, large scale structure.

1. INTRODUCTION

Knowing how the local spacetime evolves as function of time, the relative velocities between objects (as galaxies and clusters of galaxies) as function of the moment of observation, represents a very strong mean to differentiate between models of Universe. In 1929 Edwin Hubble published his paper (Hubble, 1929) which described the relation between the recession velocities of "extra–galactic nebulae" and the cosmic distances. This became the foundation stone for the modern cosmology ideas, confirming Lemaitre's theory about the expanding Universe (Lemaitre, 1927) and the existence of an initial moment ("primeval atom" or "Cosmic Egg"), mocked by Fred Hoyle, adept of the "Steady State" Universe, as the "Big Bang" (Hoyle, 1949).

In this new understanding of the Cosmos, Hubble gave a relation, known now as Hubble's law, describing the way in which distant galaxies recede, relative to us, faster than nearby galaxies. As would be expected for the case of a Universe without an apparent curvature (a flat Universe), for relative small distances and spacetime volumes, the relation between velocity and distance is linear, their ratio giving a constant value: the Hubble Constant. As we move towards higher spacetimes volumes, this recession velocity would become sensitive to the type of space geometry the Universe has, implicitly on its curvature and, so, on its metric. At this point, we would reach to the domain of curved spaces (with positive or negative curvature), out of which the FLRW bubble Universe is one of the possibilities.

In the present, one of the most successful tools in testing the proposed cosmological models through observations is by seeing what is the Hubble Constant and how it starts (or not) to vary at higher distances in the Universe. Out of these observations I can mention few phenomena currently used as "standard candles" and whose evolution across the Universe should only be influenced by the spacetime itself: SN Ia (Brout *et al.*, 2022), SN II (de Jaeger *et al.*, 2020), CMB (Aghanim *et al.*, 2018), gravitational lensing in the CMB (Baxter *et al.*, 2021), gravitational waves (Mukherjee *et al.*, 2020), gravitational waves data combined with electromagnetic data (Hotokezaka *et al.*, 2019), precision photometry of Cepheids (Riess *et al.*, 2019), etc. These events can describe the relative recession velocities for the specific period from the Universe's history in which they manifest, or can cover a more consistent part of this history, while observing them all the way from the present towards the beginning of time (local time). Even that these phenomena should agree in giving at least the same Hubble Constant, this doesn't happen. One reason might be this "clustering" of a particular type of phenomena used for the computation of the expansion rate (as, for example, of the SN Ia or the CMB would be) in a specific and relatively narrow domain of cosmic times, or, as also the change from linearity in the case of Hubble's law would imply, a hint about the transition towards a curved spacetime. In tune with the last idea, we come with a proposal for the Hubble's law and, through it, with an invitation for an experimental checkup which could elucidate DEUS model's validity at local flat spacetime scale and its implications towards the immersion of this local flat spacetime in a larger FLRW spacetime. At the same time, looking at the reverse problem, it could give a better understanding of the reasons for observational discrepancies and find a consistent value for the Hubble Constant in the given cosmological model.

As part of the current research, while we were looking to pinpoint a more reliable Hubble Constant value (in the limits of observational cosmology measured values) through numerical simulations performed with our derived Hubble's law, we clearly observed a behavior similar with an accelerated expansion of the size of our dummy model of the Universe, that kept occurring in all possible domains of H_0.

Last but not least, we propose a selection factor for different possible values of H_0 given in the literature by studying the slight differences existing in this accelerated expansion at different scales of the Universe. Still, this selection remains to be made in a dedicated, rigorous manner in a future research, by comparing the variation curves of our N parameter (obtained at different H_0 values) with the observational acceleration rates for different epochs of the Universe.

2. TIMES AND SCALES

In DEUS model, in the description of the BHIG manifold (in Chapter "I: Five-Dimensional Manifolds and World-Lines" of Popescu, 2007), we use the coordinate system (t_k, ϕ_k), where t_k has a "time" meaning (hypertime), while ϕ_k has a "space" meaning (hyperspace), while both being dimensionless.

These coordinates of the BHIG manifold transform to global FLRW coordinates (in chapter "II: Self-Similarity and Implications in Cosmology" of Popescu, 2007) as:

$$r = a\sqrt{\mathrm{t}_k^2 + \phi_k^2}\ , \tag{1}$$

where *a* is the scale factor of the Universe, and:

$$\mathrm{t}_{FLRW} = \arctan\left(\frac{\mathrm{t}_k}{\phi_k}\right)\ . \tag{2}$$

In Popescu (2020) we saw that, for obtaining the same entropy through information dispersion on each degree of freedom (on our hypertime and hyperspace), we should have:

$$\mathrm{t}_k = -\frac{1}{\phi_k}\ . \tag{3}$$

With (3) in (2) results that:

$$\mathrm{t}_{FLRW} = \arctan\left(-\frac{1}{\phi_k^2}\right)\ . \tag{4}$$

From the same paper (Popescu, 2020) we know also that:

$$\phi_k^2 = \frac{\ln\left(\frac{d}{a}\right) + iT}{\ln\left(\frac{d}{a}\right) - iT}\ , \tag{5}$$

gives the relation between the BHIG manifold's coordinates and the local Minkowski flat spacetime, as part of the global FLRW spacetime (Popescu, 2007a). In (5), *d* is the distance, *T* is the local time in the Minkowski flat spacetime and *i* stands for the imaginary unit. If we replace (5) in (4) we will get the relation between the local Minkowski spacetime and the global FLRW spacetime containing it:

$$\mathrm{t}_{FLRW} = \arctan\left[-\frac{\ln\left(\frac{d}{a}\right) - iT}{\ln\left(\frac{d}{a}\right) + iT}\right]\ . \tag{6}$$

Now, if we also consider that the information in the Universe propagates with the speed of light, meaning that the distance will be defined by $d = cT$:

$$\mathrm{t}_{FLRW} \quad = \quad \arctan\left[-\frac{\ln\left(c\,\frac{T}{a}\right)-iT}{\ln\left(c\,\frac{T}{a}\right)+iT}\right]. \tag{7}$$

The recessional velocity of different objects in the local flat Universe will be given as multiples *N* of the velocity with which the considered objects cover the local “meter” of the Universe, and by “meter” we will refer to the scale factor *a* of the local flat spacetime of time *T*:

$$v \equiv N\,\frac{a}{T}. \tag{8}$$

With (8) convention back in (7), we will obtain:

$$\mathrm{t}_{FLRW} \quad = \quad \arctan\left[-\frac{\ln\left(N\,\frac{c}{v}\right)-iT}{\ln\left(N\,\frac{c}{v}\right)+iT}\right]. \tag{9}$$

Because of the entropy increase, the FLRW bubble/sphere’s matter, initially in isotropic and uniform distribution of the zero entropy state, and traveling on the spiral trajectory computed and represented in Popescu (2007b) with the theoretical formalism described in Popescu (2007a), will suffer dispersion around this trajectory towards $S > 0$. This dispersion can be visualized through the traditional image of the cosmological expansion of the Universe, from the $S = 0$ moment to the present, with all except one $S = 0$ points from the t_{FLRW} spiral trajectory seen as spacelike from the present moment of *T* time. This singular event with $S = 0$ could be easily mistook for the “Big Bang”, while the true “Big Bang” event lies at $t_{FLRW} = 0$, the sphere pole from where the matter “enters” the FLRW sphere (or, from the point of view of spacetime itself, at the moment where the FLRW spacetime is created from BHIG manifold; see Popescu, 2007).

Towards $S = 0$ (the beginning of the local spacetime), the distorted “surface unit” (of area a^2) of the $S > 0$ matter on the FLRW sphere will look as having an apparent increase in the scale factor. In reality, as the time *T* is tangent to the spiral trajectories, an observer from the flat spacetime will have to see around the curvature of the FLRW spacetime to perceive the real change of the scale factor with the t_{FLRW} time, this being impossible.

At the same time, as the information will propagate with the light and it will follow the path of time, an observer in the FLRW bubble will never perceive any event occurring on neighboring spirals (see Popescu, 2007b), of different scale factors. The first conclusion resulting from this is that no phenomenon that takes place in the FLRW spacetime will be directly observable, but only through the time *T* perspective. This is expressed also by the (9) relation, where $t_{FLRW} \propto i\,T$. The second conclusion that summarizes all the above discussion is that, in the local flat Universe defined by the time *T*, the scale factor neither increase nor decrease. Instead, the scala factor is "distorted" by the increase of the entropy. This will be useful later, when we will derive the Hubble's law and where it will make $da/dT = 0$. Also, because we will have to convert $H(t_{FLRW}) \rightarrow H(T)$ as a flat spacetime measure of a curved spacetime quantity, we will have to redefine the FLRW changes to *a* as:

$$\dot{a} \equiv \pm i \frac{da}{dt_{FLRW}} \; . \tag{10}$$

Now, we could ask ourselves from where the different values of velocities that takes us to the conclusion of having an accelerated expansion in the flat Universe? First of all we should notice that, in our model, the distant matter disappears from the flat spacetime not because the velocity of the spacetime in which they dwell is, relative to our velocity as observers, higher than the velocity of light, but because they cross the "horizon" of the flat spacetime, disappearing over the curvature of the FLRW spacetime.

First lets define the t_{FLRW} time as the time needed by the matter on the spiral trajectory to complete a full loop around the FLRW sphere (*i.e.*, the FLRW sphere is the "clock" and the spirals are its "seconds"), while considering the FLRW sphere stationary or expanding/contracting with a speed negligible compared to the matter revolution speed. Lets suppose now that our flat Universe's matter, in its evolution around the FLRW spacetime, crossed already the sphere's equator. As the t_{FLRW} time will be equal for a loop close to the equator and a circumpolar one, the matter that is, in its spread, closer to the equator will rotate faster than the matter with $S = 0$ (in the same flat spacetime of the FLRW spiral trajectory), which, in turn, will rotate faster than the matter on the $S > 0$ spread closer to the FLRW pole (the "Big Crunch" location). If the local flat Universe hasn't yet crossed the FLRW equator, the situation of the relative velocities will repeat itself, the only difference being given by the observer's location. In this way, if we are in the $S > 0$ vantage point closer to the FLRW equator, our $z = 0$ location will move faster relative to the other two considered locations (the $S = 0$ location and the one with $S > 0$ closer to the pole), while if we are at the $S > 0$ closer to the FLRW pole, everything else will move faster than us. However, without an absolute observable reference frame, we will never be able to differentiate between these two scenarios. We would only know that the relative velocity is higher when our motion is compared to those of objects at higher distances than when compared to those of objects at smaller distances, in the local flat spacetime.

Now, everything that is faster in the local Universe will leave behind the rest of the matter which, gradually and in function of their relative velocities, will cross the FLRW sphere's horizons. And here is only a mater of perspective if we, as observers, are the ones left behind by some other matter crossing the forward horizon, or if, as the fastest moving region of the flat spacetime, we will see everything else disappearing from view over the backward horizon.

3. HUBBLE'S LAW

From all the above reasonings we can infer that we will have a "fake" Hubble's law, giving not the Universe's expansion rate but, through its definition, an expression of the scale factor distortion in the $S > 0$ flat spacetime:

$$H(t_{FLRW}) \equiv \frac{\dot{a}}{a} \; . \tag{11}$$

While considering also (10) and doing a bit of term rearrangements, the definition (11) will give:

$$\frac{dt_{FLRW}}{da} = \pm i \, \frac{1}{aH(T)} \; , \tag{12}$$

taking also into account the transformation $t_{FLRW} \propto iT$.

Now, deriving (7) relative to *a* we obtain:

$$\frac{dt_{FLRW}}{da} = i\left(\frac{T}{a}\right)\frac{1}{\ln^2\left(c\,\frac{T}{a}\right) - T^2} \; . \tag{13}$$

From the equality of (12) with (13), in our perspective of the local Universe, we will have:

$$H(T) = \frac{1}{T}\left|T^2 - \ln^2\left(c\,\frac{T}{a}\right)\right| \; , \tag{14}$$

or, when employing (8):

$$H(T) = \frac{1}{T}\left|T^2 - \ln^2\left(N\,\frac{c}{v}\right)\right| \; . \tag{15}$$

We know that the redshift for the Minkowski spacetime can be expressed (for radial expansion or line of sight motion) as:

$$1 + z = \sqrt{\frac{1 + \frac{v}{c}}{1 - \frac{v}{c}}} = \frac{\lambda_{observed}}{\lambda_{emitted}} \; , \tag{16}$$

which gives:

$$\frac{v}{c} = \frac{(z+1)^2 - 1}{(z+1)^2 + 1} \; . \tag{17}$$

With (17) in the Hubble's law (15):

$$H(T) = \frac{1}{T}\left|T^2 - \ln^2\left[N\,\frac{(z+1)^2+1}{(z+1)^2-1}\right]\right|, \tag{18}$$

or, expressed in wavelength observables:

$$H(T) = \frac{1}{T}\left|T^2 - \ln^2\left[N\,\frac{\lambda^2_{observed}+\lambda^2_{emitted}}{\lambda^2_{observed}-\lambda^2_{emitted}}\right]\right|. \tag{19}$$

In our opinion, formula (19) could be extremely useful for the observational cosmology, as with it our flat Universe can be mapped not relative to us (or, better said, with us as the "center of the Universe"), but relative to what is considered to be the "Big Bang" moment. This is because *T* isn't the time that light needs to travel from the observed galaxy or cluster of galaxies to us, but is the age (time) at which this object is located relative to the zero entropy trajectory (from the "Big Bang", in its modern cosmological acceptance). Having our perspective of the Universe constructed with the frame of reference on the $S = 0$ state (the "local Big Bang"), instead of having it on Earth or on our Galaxy, might mean a huge leap towards finding the non-inertial frame of reference, the Holy Grail of knowledge. Next step from there would be finding the location in which the matter and the local Universe is on the $S = 0$ FLRW spiral, relative to the true "Big Bang" and relative to the center of this expanding (and later contracting) FLRW bubble. But, by then, the path of knowledge and its acceptance is long and difficult.

Another test which can be done with our Hubble's law would be to check its validity for nearby cosmic objects. Because the third parameter, *N* from (19), gives the number of scale factors across which a cosmic object travels in the course of the flat spacetime's history, it would be a good measure for the velocity with which it moves relative to us. In principle, if we are certain that an object is in our cosmic neighborhood then, as we know its redshift (from wavelengths shifts) and the time T (same as ours), we could compute its value of *N*. We can then check this value for consistency with another nearby cosmic object.

4. NUMERICAL SIMULATIONS, COSMIC VELOCITIES AND SPACE EXPANSION

Our simulations focused mainly on the way the parameter *N* from (18) evolves for a cosmic object, trying to obtain possible values and a law of evolution for it. In the classic view, the recession velocity will change because of the change in the scale factor, contained in the definition of the Hubble's law. We will use the *N* parameter from our (18) Hubble's law, having its roots in the way the local time and space evolves as consequence of the geometry of DEUS spacetime, and see if we can mimic the traditional scapegoat's (the scale factor) behavior.

For our first simulation we took the dimensionless value we obtained in Popescu (2007) for the Hubble constant $H_0 = 72.33 \pm 0.02$ and a variation step $\Delta H = 10^{-3}$. For *T* we used as initial value and step the limit for which we can determine the Hubble constant, more precisely $1Mpc$ (which, in our code, translates to 3.261563×10^6), while the final value was chosen to be the supposed age of the Universe, $T_{max} = 13.7 \times 10^9$ (while omitting the units, as time and space are derived from the dimensionless BHIG's hyperspace and hypertime; see Popescu, 2020). Having the purpose of placing ourselves in the Universe's region for which we are confident that the spacetime is flat and the Hubble's law doesn't deviate from linearity, setting at the above mentioned Hubble constant's value for the present Universe, we took the maximal value for the redshift as $z_{max} = 1$. Because it was found (Brout *et al.*, 2022) that for $z < 0.01$ the sensitivity to peculiar velocities would be very large, giving unreliable results for the construction of the "Hubble diagram" through a SN Ia survey, we also had to limit our initial value and the step for the redshift z at 0.01.

In this run we found that, since the start of our simulation, at a Universe size of T $\sim$ 1M pc, a exhibits an accelerating change (equivalent to the "dark energy" effect or to an "inflation"), with our cosmologic test object covering much smaller N fractions of scale factor a units for each successive ΔT time interval of T incrementation. This variation for *N* is of the form 10^{-s}, with s initially being of the order of tens, fast evolving to hundreds and, even faster, to thousands. This can be illustrated as in Figure 1, where, for simplicity, we kept $z = 0.5$ and $H_0 = 72.33$. Because of the rapid "deflation" of *N* with *T*, we had to represent it in logarithmic scale. Same behavior but with irrelevant changes to *N* can be observed while varying H_0 in the above given limits or by assigning other values to *z*. We observed that, by comparison with its variation with *T*, the *N* variation with *z* (in the considered domain) is negligible. We should also mention that $N \in (0, 1)$.

Contrary to appearances, this won't mean that the velocity in (8) decreases. Lets look at an object moving with constant velocity through the local spacetime, as it would in absence of any external interaction. As we defined *N* as the number of scale factors crossed by the object in its motion, this just means that the scale factor "explodes" in size (or, as we already explained for our model, is distorted by the entropy increase).

Another valuable realization that came with this first simulation was that, as the evolution from flat spacetime towards FLRW should manifest as change in the perception of the time *T*, its flow being deviated from "uniformity", so the change in the Hubble's law should be reflected by a departure from the linear behavior (given by the first term *T* in (18)), towards a slightly non-linear behavior, the second term from (18) playing the role of a small perturbation to linearity. In conclusion, the "true" Hubble's law describing the differences in expansion velocities in our neighboring

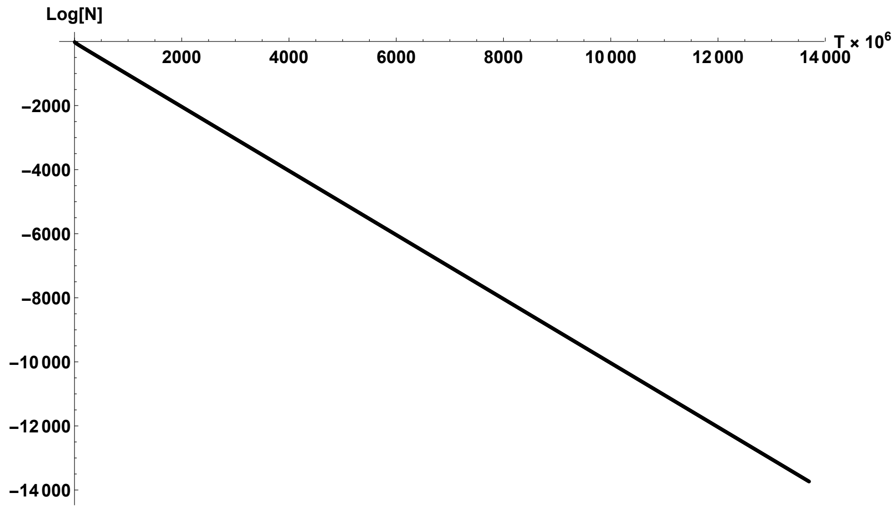

Fig. 1 – The variation of *N* as function of the local cosmologic time *T*, for fixed H_0 and *z* values. This behavior of *N*, points out towards an exponential deformation (expansion) of the local spacetime's scale factor.

spacetime of time *t* and relative to us, is this small perturbation:

$$H(t) = \frac{1}{t}\ln^2\left[N\frac{(z+1)^2+1}{(z+1)^2-1}\right] . \tag{20}$$

In a second simulation we varied H_0 in the domain defined by the values obtained through different types of measurements, meaning $H_0 \in [67, 80]$, with a step $\Delta H = 0.01$ (as *N* shown some discontinuities for $\Delta H = 10^{-3}$ in this particular simulation). To check if indeed the variation of redshift has a negligible influence on *N*, we also took a wider range of redshifts: $z_{max} = 1000$. We kept the *T* values as in the previous simulation and we used the same (18) law.

From this simulation we obtained that all the above H_0 gave continuous values (on intervals of $H_0 \pm F$, with $F = 0.02$, same as for the error range of the previous simulation's $H_0 = 72.33$ value) for the parameter *N* variation. We also confirmed that *z* had a negligible effect on *N*'s variation. It resulted again $N \in (0, 1)$.

5. DISCUSSION

As one of the new and important model quantities, we should have a very clear image on the meaning and the properties of *N*. For this, in the first instance, we should emphasize that, for the FLRW spacetime, we have a scale factor *a* which is varying with the t_{FLRW} time and leads to a Hubble parameter $H(t_{FLRW}) \equiv \dot{a}/a$ which, in the local Minkowski spacetime, part of the global FLRW spacetime, metamorphoses to $H(T)$ as function of the local time *T*. On the other hand, by definition, in the Newtonian or Minkowski spacetimes we will have a constant scale factor which will give a definite unique value for the Hubble constant H_0 for these local spacetimes (which, as mentioned, is only a small instance of the FLRW global spacetime). So, locally, the scale factor *a* doesn't vary with the local time *T*.

In this local spacetime, the factor *N* doesn't express a variation of the scale factor, but the variation of time needed by a moving object of constant velocity to cover one scale factor unit. If we consider that, initially, after Big Bang, this object can cover the scale factor in some specific time interval ΔT, as the age of the Universe grows, there will increase also the needed time interval in which it covers the same scale factor.

For the moment being, as far as we are concerned, the law describing this temporal variation associated to *N* is unknown. Aside from the potential necessity of determining it from observations, we might still try to define it theoretically. The physics behind it is the increase of entropy with the cosmological time (the age of the Universe) and, so, the increase in the "distortion" of the spacetime grid of a^2 unit area. Here, for a better picture of the phenomenon, we could use the analogy of a boat moving on a sea. If, initially, the sea is calm and the boat moves between two points *A* and *B* in a Δt time, on a wavy, agitated sea, even if it moves with the same velocity as before, it will need a bigger time interval (or spend more energy) to cover the same distance as before. In conclusion, we can see the entropy's related "distortion" of the scale factor as (initially quantum) fluctuations in this spacetime that, subsequently, amplify as the Universe ages.

Now, in the (15) formula describing the behavior of $H(T)$, we see that the logarithm should be in time units, meaning that also *N* must be in time units (as c/v is dimensionless), fact that transpires also from the above physical interpretation. In this way, accommodating for a time-energy relation that should be valid at any level, from quantum to macroscopic, we should have:

$$N(T) \equiv -\hbar \frac{\partial T}{\partial E_{\Lambda}(T)} \, , \tag{21}$$

where $\hbar$ is the reduced Planck constant and $E_{\Lambda}(T)$ is the vacuum energy at a moment of time in the history of the local Universe. As described in Popescu (2007) (chapter IX, page 123; see the (59)-(73) formulas), this vacuum energy will have two possible expressions, $E_{\Lambda,-}(T)$ and $E_{\Lambda,+}(T)$. Moreover, as we want this energy as function of the local Minkowski spacetime quantities and not as function of the *r* of the FLRW global spacetime, we should express *r* as in Popescu (2007b) and t_{FLRW} as in (9). With these in (21) we will have an equation with *N* in the left side and a complex expression of *T* and $\ln\left(N\,\frac{c}{v}\right)$ in the right size, solvable for *N* at any moment of time T and as function of the parameters c_2 and c_1 (whose dependence on the local quantities T, N and v will be the topic of another paper).

6. CONCLUSIONS

In this work we characterized the meaning of some important cosmologic quantities as perceived from the flat Minkowski spacetime, immersed as part of the FLRW global spacetime, this one being the result of "reshaping" the BHIG manifold of the DEUS model as a four-dimensional surface of space and time. Connecting the dots with the results obtained in Popescu (2020) for the entropic evolution of the local spacetime (and by its close correlation with the flow of time direction), we were able to shape the local time in the context of the global FLRW time. This, naturally, meant that we were given a tool through which we were able to study the evolution of the local's Universe scale in the context of the local time and, also, characterize the motions of different objects dwelling in this local spacetime. Finally, the dynamics of objects inside the local spacetime gave us its Hubble's law.

We saw in Popescu (2007) that we can't convert the BHIG helicoidal manifold to a FLRW spacetime without considering also an inertial dynamics of this spacetime, between "Big Bang" and "Big Crunch", this motion being perceived by the FLRW observer as "dark energy" effect. Now, as an observer of the Minkowski flat spacetime (part of FLRW spacetime), we observed, through simulations, an accelerated behavior for the spacetime itself, as a smoking gun pointing towards "dark energy", a reinterpretation of the global FLRW perspective.

Our new expression for the Hubble's law comes with the opportunity of new Large Scale Structure simulations of the Universe, by having them centered not on our position in the present Universe, but on the origin of the local flat spacetime. Its confirmation through observations and its validation as a viable law in the description of our local Universe are also imperative desiderates and will be the topic of other research. Through this observational and simulated validation we hope for an indirect proof of the DEUS model, from its local consequences.

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Received on 1 March 2023