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Photons and their Different Speeds: a possible New Theorem

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ABSTRACT
A fundamental mathematical implication of the Maxwell Electromagnetism is represented by the constant speed of all electromagnetic waves (EMW$_s$). However, many experimental tests carried out by Lenard or Feynman, for example, show unequivocally that light rays of violet or blue colour always travel faster than yellow or red light. But not only that!
Speed differences emerge between all waves in the electromagnetic (EM) spectrum, as seen in the study of Gamma Ray Bursts (GRB$_s$). The GRB is a very violent cosmic explosion that mostly lasts a few seconds.
The strange peculiarity of such emissions is that the EM signals do not arrive at Earth all at once, but always first the more energetic EMW$_s$ such as the γ-rays, and then gradually those of lower frequency, often several days or weeks later (as evidenced by numerous satellite surveys).
Regardless of the cause, dispersion phenomenon or different photons momenta, the fact remains that, even in the infinite intergalactic spaces, the EMW$_s$ do not all travel at the same speed.
Key words*: Photon (P); Electromagnetic Waves (EMW$_s$); Electromagnetic Radiation (EMR); Planck constant (h); Electromagnetic (EM).*

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I. INTRODUCTION

As is known the photon [1], or *light quantum* [2] or *quantum* of the electromagnetic radiation [3] travels with electromagnetic waves (EMW$_s$), so it has primarily wave-like behaviour.

Moreover, after several years of research, Planck succeeded in solving the enigma of the spectral distribution of *black body radiation*, as shown in his *communication* to the Meeting of the German Physical Society, in Berlin, on December 14, 1900.

To be exact, the central assumption presented by Planck was the supposition (or *Planck's Postulate*) that the electro-magnetic radiation (EMR) could only be emitted in *quantized* form; as to say that the energy could only be a multiple of an elementary energetic unit: the *Energieelement* [3].

Furthermore, it is important to emphasise that, beyond its wave-like behaviour, the photon (P) also has a corpuscular nature, which is amply documented by various practical or experimental evidences, of which we mention e.g. the photo-electric effect (PEE) [4],[5],[2], the Compton effect [6],[7] or the Raman effect [8].

Just about the *even corpuscular or particle nature* of P, this is what Feynman said in his lectures: "I want to emphasise that light comes in this form: particles. It is very important to know that light behaves like particles, especially for those of you who have gone to school, where you were probably told something about light behaving like waves. I'm telling you the way it DOES behave: like particles. Light is made of particles. One could argue that it is the photomultiplier that reveals light in the form of particles. But no: every measurement made with any instrument (sensitive enough to detect very faint light) has always led to the same conclusion: **light is made of particles.** I have spoken of the photomultiplier to illustrate an essential aspect, which you may not have known as well, namely that light is made of particles, but I hope there is now no longer any doubt about that either" [9].

So, ultimately, P travels like a wave, but also behaves like a particle.

In this regard, Fermi expressed himself as follows: 'In the present state of science, it may be said that there is a lack of a theory that satisfactorily accounts for optical phenomena, for while the *wave theory* is perfectly suited to the explanation of interference, diffraction, polarisation and all that complex of phenomena that constitute the so-called classical optics, it appears insufficient to account for what happens every time the action of light on a single atom is examined. Thus, the *quantum theory of light* was constructed just to explain this last class of phenomena. Whenever an atom or molecule absorbs light energy, the amount of energy (E) that is absorbed cannot take just any value, but is related to the frequency (v) of the light absorbed by the relation:

$$E = h\,v \qquad (1)$$

where h is Planck's constant (= 6.54 x 10^{-27} erg sec). Thus, *light quanta* have a content of energy (E) directly proportional to frequency (v)" [10].

In this regard, Planck expressed himself as follows: "Considering that - and this is the crucial point of the whole calculus - the energy, oscillator energy, is made of a defined number of finished and same parts; we can use to this purpose the natural constant h = $6.55 \cdot 10^{-27}$ [erg·sec]. If this constant is multiplied for the normal oscillators' oscillating frequency, (υ), we get the *Energieelement (*the element of energy), ε, expressed in erg·sec" [3].

According to subsequent measurements and calculations, the exact value of h corresponds to $6.626 \cdot 10^{-27}$ [erg · sec].

The following year, in 1901, Planck further specified: 'The essential point is to consider Energy, at each frequency, as made of a certain number of *energy* elements (*Energieelements*), all equal to each other, indistinguishable and indivisible' [11].

As is well known, that represented by Eq.(1) is *Planck's formula*, also known as "the *Planck's Law of Radiation*" [12], which shows us the possible energy value (E) carried by a *quantum of electro-magnetic radiation* (EMR) [3],[11] or *light's quantum* [2].

To this purpose, Atkins points out: 'In 1900 Max Planck proposed that the exchange of energy between matter and radiation took place by *discrete* quanta or *packets of energy* (E). The fundamental concept of his theory was that a charged particle, oscillating at a frequency v, could only exchange energy with the environment in the form of *packets* of magnitude $E = h\,v$. If the oscillating atom gives up an amount of energy to the environment, an EMR of frequency $\nu = E/h$ will be detected. In 1905, Einstein proposed that the EMR consists of particles (light quanta), later called photons (P_s). Each P, or light quantum, can be regarded as a *packet of energy* (E) that depends on the frequency (v) of the radiation, since $E = h\,v$. For example, ultaviolet photons (UV P_s) are more energetic than the P_s of visible light, which correspond to lower frequencies.

It is important to note that the radiation *intensity* indicates the number of P_s present, i.e. carried by the electromagnetic wave (EMW) considered, while the expression $E = h\,v$ measures the *energy* of each individual P.

So, let us calculate the energy of a P of blue light, frequency $6.4 \cdot 10^{14}$Hz: then from $E = h\,v$ we have E=h· $6.4 \cdot 10^{14}$ Hz = $4.2 \cdot 10^{-19}$J (Joule)'' [13], i.e.= $4.2 \cdot 10^{-12}$ [erg].

Again with reference to Planck's Law of Radiation, shown by Eq.(1), it may result particularly interesting to quote
from a seminar by Rinaudo, who asks: "What is there to understand about Planck's relation $E = h\,v$?

This *formula* links energy (E) to frequency (v) with a proportionality coefficient h, or *quantum of action*, which is a
natural constant.

Energy and frequency are concepts that belong to different phenomena, because *energy* is a property which, in Classical
Physics, we usually associate with a material body, well located in space-time, to which, however, it is difficult to
associate a *frequency*.

In turn, *frequency* is characteristic of a periodic phenomenon, to which, however, it is difficult to associate a well-localised *energy* in space-time" [14] and likewise a possible mass value.

Likewise, one cannot overlook the notion that "in Classic Physics, *energy* often plays a role marginal (compared to other concepts); however, in Quantum Mechanics, *energy* is the crucial quantity: *in* this case, *energy* is to be traced
back to its role as a 'state variable' and, as such, descriptor fundamental and unifying phenomena.

Moreover, Planck's relationship *is revolutionary* because it expresses a link between energy and Frequency of an electromagnetic field (EMF): *energy* is typical of 'material corpuscles', while the *frequency* represents a characteristic
property of 'a wave'.

According to Einstein's interpretation, the energy of an EMF is 'quantised'. The value of an elementary *quantum of energy*

(E), of frequency v, will be: $E = h\,v$. The quantisation of energy does not occur at the moment of interaction with matter,
but it is EMF itself that behaves like a particle (the quantum of light, or photon), which has both corpuscular (E) and wave (v) aspects" [14].

II. MATERIAL AND METHODS

2.1 PHOTO-ELECTRIC EFFECT (PEE)

At the beginning of last century, as Asimov reminds us, "Lenard had discovered that when light hit certain metals it caused the emission of electrons from their surface, just as the light had the power to push out the electrons from the atoms" [15]. In this respect, even a single photon (P), if provided with sufficient energy, is capable of overpowering the *binding-energy* that keeps the electron bound to the metal and, thus, pushing it away, ejecting it from the metal!

In fact, as Fermi reminds us, "The results of the study of the absorption of light energy by matter can be summarised in the following Einstein's Law, which finds application in a very large number of phenomena; to recall only the main ones, we will mention the photo-electric effect (PEE), which consists in the fact that a metal surface, illuminated with light of sufficient frequency, emits electrons. Now, it is found experimentally that **the** maximum **kinetic energy** (w) **of the emitted electrons is related to the frequency** (v) by the relation:

$$w = h\,v - w_0 \qquad (2)$$

where w_0 represents the energy required to extract an electron from the metal. Therefore, in accordance with Einstein's Law represented by Eq.(2), the total energy communicated to the electron by the light is precisely equal to $w + w_0 = h\,v$ " [10].

To this end, Fermi points out: "For photoelectric emission to occur, it is necessary that the energy communicated to the electron is sufficient to extract it from the metal, i.e. it must be $h\,v \geq w_0$. This is the interpretation of the fact that only light with a frequency (v) above a certain limit is effective to produce photoelectric effect (PEE)" [10].

Also with reference to the PEE, one cannot overlook a very important result that emerged from Lenard's experiments [5].

At this regard, Asimov says: "When physicists started to do experiments on this phenomenon (PEE) they realised, with great surprise, that if they raised the light *intensity*, the energy of the emitted electrons did not increase" [15].

To this purpose, it may be interesting to point out that this appeared to be at odds with Maxwell's wave theory of light, which predicted that the electron energy would be proportional to the *intensity of* the radiation.

On the contrary, Lenard observed that the energy of individual emitted electrons increased with the *frequency* (which is related to the colour) of light [5].

In this respect, indeed, Lenard found that the calculated maximum electron *kinetic energy* (E_{Kin}) is determined by the *frequency* of light.

In other terms, an increase in frequency results in an increase in the maximum E_{Kin} calculated for an electron upon release. For example, ultraviolet radiation would require a higher applied stopping potential to stop current in a phototube than blue light [16].

To this purpose, Asimov specifies: "What influenced the energy of the emitted electrons were the different colours of the wavelength of light used: for instance, the blue light gave the electrons a bigger speed than the yellow light. A blue weak light caused the emission of fewer electrons than an intense yellow light, however the few electrons pushed out by the blue light had a bigger speed than any electron pushed out by the yellow light" [15].

Thus, what do we learn from the Lenard's experiment?

We learn that the electromagnetic radiations (EMR_s) having a greater frequency of oscillation (v), that is the more energetic radiations, transmit a greater speed to the hit particles, compared to what the less energetic EMR_s can do. Hence, Lenard's experimental demonstration represents an enormous leap, which gives a significant turning point to Mechanics [16].

In short, Lenard demonstrated for the first time to the scientific community that the more energetic photons (P_s) give a greater and faster thrust to the particles they hit.

Thus, similarly to Planck's Communication of 1900 [3], Lenard's experimental proofs of 1902 also proved to be ((*doubly*)) *revolutionary*. For Lenard, too, presented the scientific community with two absolute novelties for the first time.

Thanks to the Lenard's experiments, indeed, from the early 1900s it was known that: 1) *the energy*, or more

specifically the E_{Kin} of photoelectrons increases with increasing *frequency* of incident light; and: 2) this *energy*, contrary to Maxwell's concepts and conclusions, is independent of the *intensity* of the light.
Even Einstein predicted that the *energy* of individual ejected electrons increases linearly with the *frequency* of the light [2].
At this regard, Asimov points out: 'A red light of any intensity did not cause at all the emission of electrons in certain metals. None of these phenomena could be explained by the old theories of light. Why ever the blue light was able to do something which the red light was not able to do? Einstein found the answer: an electron had to be hit by a quantum of energy higher than a minimum value in order to absorb enough energy to abandon the surface of the metal" [15], that is higher than the energy which keeps the electron linked to the atom: *threshold value* or *shearing value*, as shown by Eq.(2).
Asimos adds: 'Anyway, the higher the energy of the light's quantum, the higher was also the speed of the electron pushed out from the metal" [15].
In short, we have that those photons (P_s) carrying a larger energetic charge, and at the same time with a higher frequency (i.e. the blue P), give a higher speed to the electron they hit.
On the contrary, less energetic P_s (such as red P_s) push out electrons with a lower speed [17].
Furthermore, we also know that the P is a corpuscle, a "grain" [3],[11], the *Planck's grain*, which is a very small sphere which, just like a billiard small ball thrown with the right energy, pushes away the electron (the opponent ball). It could be a suitable example, since the E_{Kin} of the small ball is given 100% to the pushed ball.
In fact, as Fermi reminds us, 'When an atom is struck by a quantum of light it absorbs all its energy. The P too, like other particles, is a corpuscle, a *light's quantum* and has a its own *impulse* or *momentum* (***p***), through which transfers all its energy to the hit particle" [10].
At this regard, we can read from d'Alambert: 'We distinguish between *impulse* and impact because the *conservation of kinetic energy* (E_{Kin}) takes place in the movement of bodies which are being pushed, insofar as these movements change only by minute degrees or infinitely small amounts rather than if it occurs in *elastic* bodies which impact each other, even in the case where a spring would act in an indivisible time and would pass them and would allow them to continue without any gradual motion from one to the other.
Mr. Huyghens appears to have been the first to notice that this Law of the Conservation of E_{Kin} was contained in the collision between *elastic bodies*. It also appears that Mr. Huyghens was familiar with the E_{Kin} Conservation Law during the motion of bodies which are animated by forces" [18].
In this respect, Feynman adds: 'It is possible to make the colliding bodies from high elastic materials, such as steel, with carefully designed spring bumpers, so that the collision generates very little heat and vibration. In these circumstances the velocities of rebounds are practically equal to the initial velocities; such a *collision* is called *elastic.*
That the velocities *before* and *after* an *elastic collision* are equal is not a matter of conservation of *momentum*, but a matter of conservation of *Kinetic Energy* (E_{kin}).
That the speeds of the bodies rebounding after a symmetrical collision are equal to *each other*, however, is a matter of conservation of *momentum*'' [19].
At this regard, Feynman says: "Elastic collisions are especially interesting for systems that have no internal 'gears, wheels, or parts'. Then when there is a collision there is nowhere for the energy to be impounded, because the objects that move apart are in the same condition as when they collided. Therefore, between very elementary objects, the collisions are always *elastic* or very nearly elastic. As an interesting example, let us consider an *elastic* collision between two objects of *equal mass*. If they come together with the same speed, they would come apart at that same speed, by symmetry.
But now look at this in another circumstance, in which one of them is moving with velocity v and the other one is at rest. What happens? We find that if a stationary body is struck *elastically* by another body of exactly the same mass, the moving body stops, and the one that was standing still now moves away with the same speed that the other one had; the bodies simply exchange velocities. This behaviour can easily be demonstrated with a suitable impact apparatus. More generally, if both bodies are moving, with different velocities, they simply exchange velocity at impact" [19].
This last case just described by Feynman, is precisely what occurs with the *photo-electric effect* (PEE), as amply demonstrated and verified by Lenard.
Hence, if the electrons pushed away by a blue photon (P) travel with a higher speed than those hit by a red P [5], we can infer that they have been given a different E_{Kin} by the respective incident photons (P_s) [20].
In other words, it should be inferred that **blue P_s travel with a higher speed than red ones**!
In short, this is the most astonishing, truly revolutionary scientific novelty (of almost equal importance to Planck's discoveries [2]): electro-magnetic waves (EMW_s), and thus the P_s , do not all travel at the same speed, but at different speeds, in a ratio directly proportional to the energy they carry!

Yet, even this most important scientific acquisition provided to Humanity by Lenard, confirmed over time by various experimental evidences, now as then (except for a few exceptions) has never been given proper consideration by the international scientific community.

On the other hand, it should be mentioned that Newton had already hypothesised what Lenard later proved experimentally, namely that P_s of different colours travel at different speeds!

In fact, in his 'Lectiones opticae' (1670), Newton showed a completely new hypothesis. He establishes, indeed, a completely different relationship between light and colours: white light is a mixture of luminous rays, having different degrees of speed, that is of different colours, which are therefore not generated ex novo by mixing, but only by separation from the mixture in which they are already present. In other words, when differently fast light rays are separated from mixing (through refraction) and hit the optic nerve, they cause the sensations corresponding to the various colours. Thus, the action of the prism consists solely in separating, through the refraction, slower rays from the faster ones, and this is possible precisely because they have different speeds within a mixture that can be indifferently white, grey or black [21].

In short, for Newton light is intrinsically a mixture of rays having a different degree of speed [17].

Moreover, as early as 1664, Newton had stated: "Because of refraction, the light beam slowly moved is separated from the fast ones, two kinds of colours arise, namely: the slow ones, the fast ones and the ones that are moved neither too fast nor slow" [22].

In agreement with Newton and Lenard, Feynman writes: "In the partial reflection from two glasses surfaces the variation circle between 0 and 16% repeats more rapidly with the blue light than with the red one. In fact, the rotation speed of the hand of the imaginary chronometer changes with the colour of the light. The blue light, in the same unity of time, has formed 5 waves, whereas the red light formed only 3: that is the blue light covers a longer distance than the red light, in the same time. **That is the blue light travels with a higher speed of the red light (which is less frequent than the blue light**)" [9].

Well, this is a very authoritative and detailed confirmation, which fully seals the experiments of Lenard. Unfortunately, however, even this very important experimental report has been ignored by the scientific community.

Feynman points out: "The reflection cycles repeat with different intervals because the hand of the imaginary chronometer has to go more quickly when it follows a blue P, than when it follows a red P. In fact, the rotation speed of the hand is the only difference between a red P and a blue one, or a P of any other colour, including X-rays and radio waves" [9].

Hence, it comes out that the blue colour travels with a higher speed than the red one, in the same time. That is, in full compliance with Lenard, a P with a higher frequency (the blue P) travels with a higher speed than another P with a frequency just a bit lower (the red one).

That is, the higher the frequency of a P, the higher its speed, compared to P_s with lower frequency.

Let's analyse now how P_s reflect, that is how they behave in a diffraction reticule. "This particular reticule is made to measure for the red light, it would not work with the blue light because the hand of the imaginary chronometer has to go more quickly when it follows a blue P than when it follows a red P" [9].

Thus, we had already under our eyes that the blue light, more frequent and more energetic, travelled more quickly than a P with a lower frequency and energy, such as the red P.

So, if we have a difference of speed between two P_s of the visible band, that is with little difference in frequency, we can imagine how much bigger the difference of speed will be when the difference in frequency increases, such as with an X ray or a γ ray, and the visible light itself, or even if compared to the radio waves [17].

In this respect, we read: 'Nature has made several types of diffraction reticules, under the shape of crystals. A salt crystal reflects, only for some angles, X rays, which are light for which the hand of the imaginary chronometer rotates with very high speed, even ten thousand times higher than the visible light' [9].

This may be the further proof of the different propagation speed of the electromagnetic waves (EMW_s), that is of the different kind of P_s.

In short, in agreement with Lenard's experiments, the more energetic P_s give a greater and faster thrust to the particles they hit. Therefore, it is easy to infer that the EMW_s with greater frequency transmit a greater E_{Kin} to the struck particles, compared to the less energetic EM radiations (EMR_s).

Consequently, it is possible to indirectly infer that the more energetic P_s travel faster than the less energetic ones [23].

Feynman adds: 'There is a *probability amplitude* also for propagation speeds higher or lower than the visible light. We have seen that the light does not propagate only on a straight line, now we find that it does not always travel with the speed of light! It could be surprising that to the propagation of a P with different speeds from the conventional one, correspond probability amplitudes which are not null. These amplitudes are very small if we compare them with the one of the contribute with *c* speed, rather they annul each other when the

light travels on long distances. But when the distances are short, as in many cases that we will see, these other possibilities become essential and we need to take them into account' [9].
In other terms, it is likely that the speed of the P_s is lower or higher than *c* (the speed of light in *vacuum*: 299792.458 Km/sec), and in short distances these probabilities become 'essential'.

For example, according to the Variable Speed of Light Theory (Albrecht-Magueijo) [24] the speed of light was greater in the primordial universe. To this purpose, related to the Inflationary Theory [25], there is no satisfactory physical explanation to justify expansion speed of the *inflationary phase*, much larger than the speed of light.

Thus, at this regard, we presented and discussed a paper at the Electromagnetics Symposium held in Cambridge (Massachusetts) [26], where we stated that the *inflationary* expansion of the Universe was probably conducted by very energetic P_s , since the Big Bang represents a source of very high electromagnetic (EM) emission.

We think, indeed, that the P_s emitted with the Big Bang had an energy significantly bigger than the more energetic γ P_s (~10^{27} Hz) thus having a bigger *momentum* than the visible light, enough to justify the superluminal speed in the expansion of the primordial Universe, according to Maguejo and Albrecht on one hand [24] and to Guth [25] on the other.

Moreover, Feynman states: 'To deflect the high-speed electrons in the synchrotron that is used here at Caltech, we need a magnetic field that is 2000 times stronger than would be expected on the basis of Newton's laws. In other words, the mass (*m*) of the electrons in the synchrotron is 2000 times as great as their normal mass, and is as great as that of a proton! That *m* should be 2000 times equal to the electron rest mass (m_o). It means that 1- v^2/c^2 (where *c* is the light speed in the vacuum and *v* its speed in a medium) must be 1/ 4,000,000, and that means that v^2/c^2 differs from 1 by one part in 4,000,000, or that *v* differs from *c* by one part in 8,000,000, so the electrons are getting pretty close to the speed of light. If the electrons and the light were both to start from the synchrotron (estimated at 700 feet away) and rush out to Bridge Lab, which would arrive first? The **electrons would actually win the race versus visible light** because of the index of refraction of air. **A gamma (γ) ray would make out better**' [19].

2.2 ČERENKOV PHENOMENON

This last sentence by Feynman brings to mind the *Čerenkov Phenomenon* or *Čerenkov Effect*, a peculiar effect induced in the Earth's upper atmosphere by γ-rays.
Čerenkov, in fact, was the first to underline the *effect* generated by the impact of γ-rays on the upper layers of the terrestrial atmosphere [27]. As we all know, the most energetic γ rays hitting the Earth are emitted by intense electromagnetic (EM) sources represented mainly by explosions of supernovae or by the collision of two neutron stars.
Čerenkov pointed out that γ radiations, hitting the molecules of the high atmosphere, can make them free electrons.

What surprised Čerenkov was that electrons hit by γ rays travelled with a speed higher than the visible light in the air, and that at this speed they could emit EM radiations (EMR_s) which wavelength (λ) moved from brilliant blue to violet, and in bigger quantity to ultraviolet (UV): these EM frequencies represent the so-called *Čerenkov Radiation* or *Čerenkov Light*.

To this purpose, Feynman points out: 'Any object moving through a medium faster than the speed at which the medium carries waves will generate waves on each side. This is simple in the case of sound, but it is also occurs in the case of light. It is possible to shoot a charged particle of very high energy through a block of glass such that the particle velocity is close to the speed of light in vacuum, while the speed of light in the glass may be only 2/3 the speed of light in vacuum. A particle moving faster than the speed of light in the medium will produce a conical wave of light with its apex at the source, like the wave wake from a beat. By measuring the cone angle, we can determine the speed of particle. This light is called Çerenkov Radiation" [19].

This can easily be explained by considering that the atmospheric refraction index (*n*) is larger than the vacuum refraction index: n_o . If we consider n_o =1, we have that the atmospheric refraction index is: 1.000293, carbon dioxide's is 1.00045, water's is 1.333 [17].

Thus, common visible light going through the atmosphere travels with a speed lower than in vacuum (*c*). In fact, when the light goes through a mean different from vacuum its spreed is given by the ratio *c/n*. Hence, as the light goes through the water its speed is 299792.458/1.333= 224000 m/sec, that is it travel ≈1/3 slower than in vacuum. That is why a small particle as an electron can travel in the atmosphere ($n>1$, namely $n=1.000293$) with a speed bigger than common visible light. Besides, the particles we are considering (electrons) are the lightest elementary particles, thus the *impulse* or *momentum* (***p***) they receive by γ rays can make them accelerate till a relativistic speed [28].

But what is most interesting, and scientifically very intriguing at the same time, is that the *Čerenkov phenomenon,* or *Čerenkov effect*, occurs exclusively if molecules in the upper layers of the Earth's atmosphere are hit by gamma photons (γ P_s).
That is, only the impact induced by γ P_s on such molecules proved capable of driving the electrons away from the atoms in the upper atmosphere with sufficient speed to emit the *Čerenkov Light* or *Čerenkov Radiation* (ČR).
The obvious question arises: why only γ P_s induce the *Čerenkov effect*? [29].
Why doesn't it happen with P_s with lower frequency?
It is useful to underline that the *Čerenkov effect* seems to us very similar to the *photoelectric effect* (PEE) [4],[5],[2], or to the Compton effect [6],[7]. In these cases too the electrons are thrown out from the struck atom by a sufficient energetic EM radiation (EMR).
The only difference is that for the PEE it is necessary just the visible light, in the case of Compton effect it is necessary the force, the *radiation pressure*, given by X P_s to throw out electrons from graphite, whereas in order to have the *Čerenkov Effect* it are needed exclusively the γ rays [30].
Why? A possible explanation can be found in the different EM frequencies used.
As it is known, indeed, our atmosphere is constantly bombarded by EMR_s of several types. Just as γ rays, X radiation too, or the UV radiation hit the atoms of the atmospheric molecules, throwing away electrons from them. However, and this is the crucial point, in these cases the electron will not be able to emit the *Čerenkov radiation*. Why?
For the fact that an *X photon* (*x P*) does not manage to give the hit electron a sufficient E_{Kin} , as to say a speed similar to the one given by a *gamma photon* (*γ P*).
This may be the difference and the explanation [29]. However, this explanation doesn't seem exhaustive, satisfactory.
What is the intimate physical mechanism so that, in the atmosphere, an electron hit by an *xP* does not emit *Čerenkov light*? We can say because it has not been sufficiently accelerated, as a *γP* is able to do instead.
We wonder then: why a *γP* manages to accelerate the electron with a speed greater than a *xP* is able to do, or a less energetic P?
It hasn't been explained properly, however it is what happens with the photo-electric-effect (PEE). Therefore, what we learn from the Lenard's experiments [5], or from the Čerenkov's observations [27]?
We learn that EMR_s having a greater frequency of oscillation (*ν*), that is the more energetic, transmit a greater E_{Kin} to the affected particles, compared to what the less energetic EMR_s can do. These are the facts.
This is the essential concept proposed with this article, a concept that, in the Euclidean manner [31], can be the *foundation* for *the construction of* a new *Theorem*: 'P_s of different energies do not travel at the same speed'.
In other words, the more energetic P_s give a greater and faster thrust to the particles they hit.
Hence, it is precisely this different E_{Kin} transmitted that can make us understand why only electrons affected by γ P_s can generate the *Čerenkov radiation* (ČR) [29].
And yet, just the ČR, and its induction mechanism, provide us with another very important piece of information: γ P_s , i.e. the particles capable of striking the electrons so violently (so as to generate the ČR), receive at their origin, from their own EM source, a very high energy and thrust (proportionally greater than the EMR_s belonging to the other less energetic bands) which likewise they transmit to the affected particles.
These collisions, in fact, are *elastic collisions* and, therefore, the E_{Kin} is preserved [17].
In short, as has been repeatedly demonstrated by facts and experiments, we deduce that **it is the amount of energy given to P_s by EM source to determine their specific speed.**
Namely, we think that the real cause, the deeper reason behind the different propagation speeds of the emitted EM signals, lies in the different EM sources: the more energetic the source, the more energetic the *push*, the acceleration given to the P_s produced [16].
This concept results in full accordance with what emerges from Feynman's chronometer with blue light and red light [9], with the relative clarifications of Fermi previously reported [10], with Lenard's experiments [5] and *Photo-Electric Effect* (PEE) [4],[5,[2], with the Compton [6],[7] and Čerenkov effects [27], vith the *Inflationary Phase* [25],[26] etc...
Well, all these experimental tests, carried out, described and proven by eminent scientists, in our opinion they can at the same time represent (following the criteria adopted by Euclid for the *construction of* Theorems [31]) the *axioms* and *logical deductions* necessary for the *formulation* of a possible *New Theorem*: 'Different EMW_s do not travel at the same speed'!
In the last example above, describing the possible unfolding of the *Inflationary Phase*, it is plain for all to see that only the huge and unparalleled explosion triggered by the Big Bang could have accelerated the first P_s emitted in the Universe to an incredible superluminal speed, commonly estimated to be between 20 and 50 times the value of *c*.

As Margaret Hack reminds us, with *Inflation* there was, in an infinitesimal period of time, a very rapid expansion of space, which would increase the scale of the Universe by a factor of 10^{50} [32].
We are therefore talking about unimaginable speeds in our day and age, which can only be achieved when the EMR$_s$ is issued from a formidable and unrivalled EM source, which is was the one represented by the Big Bang!
In this respect, however, no valid and meaningful physical explanation, real, concrete and plausible, seems to emerge from the literature to justify these truly astonishing speeds reached by light in those infinitesimal fractions of a second attributable to the *Inflationary Phase* [25].
In our opinion (Big Bang *docet*), the energy value of the emitted P$_s$ should have been directly proportional to the energy of the EM source: the greater the power of the energy source, the greater the E_{Kin} and the momentum (***p***) carried by the emitted P$_s$ and transmitted more or less in full [10] from each individual P to the particle hit.
Moreover, we cannot omit a particular and high-energy astrophysical phenomenon: we are talking about Gamma Ray Bursts (GRB$_s$) [33].

2.3 GAMMA RAY BURSTS (GRB$_s$)

As it is known, GRB$_s$ represent the most energetic and luminous electromagnetic (EM) events since the Big Bang. In fact, "GRB$_s$ can release more energy in 10 seconds than our Sun will emit in its entire 10-billion-year expected lifetime! By exploring the Universe at these high energies, scientists can search for new physics, testing theories and performing experiments that are not possible in Earth-bound laboratories" [34].

The energetic power emitted by a GRB is second only to the Big Bang!

In fact, a GRB can vaporise everything it meets in a radius of 200 light years. Fortunately there is no such a menace for our planet [35].

GRB$_s$ can last from ten milliseconds to several hours. Thus, GRB$_s$ are phenomenologically classified into 3 families: 1) *Short* GRB$_s$ (time duration < 2 seconds); 2) *Long* GRB$_s$ (time duration > 2 seconds); 3) *Ultra-Long* GRB$_s$ (time duration > 10,000 seconds).

There are several theoretical models for GRB$_s$ as well, according to the most reliable theories, GRB$_s$ are generated by the increase of matter on a black hole [17]. This accretion disk around a black hole can be caused by different phenomena, such as the gravitational collapse of a very massive rotating star, or the coalescence of two neutron stars or a neutron star and a black hole [36].

In this respect, the most energetic γ radiations hitting the Hearth are emitted by intense electro-magnetic (EM) sources represented mainly by explosions of supernovae or by the collision of two Neutron Stars, creating a GRB.

It should be noted that GRB$_s$ represent very powerful sources of EM emission. GRB$_s$ have a much more intense energy than common γ rays, though the latter represent the most energetic radiation in the entire EM spectrum: their greater energy is due to the different sources. The sources of GRB$_s$ are much more energetic than the common γ sources (atomic nuclei).

It is impressing to note that though a GRB is very short (referring to the time we can detect it), it is often followed by an EM signal which lasts for many days. This signal, this *Afterglow*, is made of several EM radiations (EMR$_s$), with different frequencies [17].

2.3.1 GAMMA RAY BURST'S *AFTERGLOW*

One of the most interesting surprises comes out by analysing the EMR$_s$ released with a GRB, which affect the whole EM spectrum. So, studying the GRB$_s$ coming for instance from a distance of 11-12 billion light years, it can be seen that the EM signals reach us with peculiar modalities.
That is, these EMR$_s$, although of different frequencies, do not reach us all together in about twenty seconds, that is the duration corresponding to their emission time. No!
In fact, once at their destination, the photons (P$_s$) released with the GRB do not run out in some twenty seconds, but they continue to arrive there for several days, even for a month or more, as an *EM swarm*: the so-called *Afterglow*. It
is truly amazing!
In fact, the EMW$_s$, although of different frequencies, should all move at the same speed, so they should all arrive together! But it is not so [16].

At this regard, we read: 'The detection of delayed emission at X-ray, optical and radio wave-lengths (*afterglow*) following GRB suggests that the relativistic shell that emitted the initial GRB as the result of internal shocks decelerates on encountering an external medium, giving rise to the *afterglow*. We explored the interaction of a relativistic shell with a uniform interstellar medium up to the nonrelativistic stage. We demonstrated the importance of several effects that were previously ignored and must be included in a detailed radiation analysis. At a very early stage (a few seconds), the observed bolometric luminosity increases as t^2 . On longer timescales (more than ~10 s), the luminosity drops as t^{-1}. If the main burst is long enough, an intermediate stage of constant luminosity will form. In this case, the afterglow overlaps the main burst; otherwise there is a time separation between the two. On the long timescale, the flow decelerates in a self-similar way, reaching nonrelativistic velocities after ~30 days" [37].

The intense radiation of most observed GRB_s is thought to be released during a supernova or a superluminous supernova (*hypernova* [32]) as a high-mass star implodes to form a neutron star or a black hole.

In brief, from an EM source emitting in just a few seconds, the signals arrive to us scattered even in 30 days. It is really surprising!

Several models for the origin of GRB postulated that the initial burst of γ rays should be followed by slowly fading emission at longer wavelengths created by collisions between the burst ejecta and interstellar gas (*dispersion phenomenon*). This fading emission would be called the *afterglow*. Then, on February 28, 1997 the satellite Beppo SAX detected a GRB (970228) and when the X-ray camera was pointed towards the direction from which the burst had originated, it detected fading X-ray emission [32]. The William Herschel Telescope identified a fading optical counterpart 20 hours after the burst. Once the GRB faded, deep imaging was able to identify a faint, distant host galaxy at the location of the GRB as pinpointed by the optical *afterglow*.

From the Astronomical Observatory of Palermo it is reported: 'The Burst in the γ band does not last long, but thanks to BeppoSAX it was possible to observe also the subsequent signal, the *afterglow*, which existence had been predicted by the fireball model, accepted by the majority of scientists. *Afterglows* are believed to originate from the impact of the matter, thrown away by the explosion, with the interstellar medium in which it propagates. This sort of *echo* of the initial gamma-ray explosion fades a lot as time goes by and shows itself at different wavelengths (in X-rays, ultraviolet, optics and radio). Considering therefore this fast decay, it is necessary that the observations begin as soon as possible, immediately after the GRB, in order to obtain data when the *afterglow* is still easily observable" [38].

Moreover, the typical GRB's EM *swarms* detected with Beppo-SAX have been later widely and repeatedly confirmed by the Swift satellite.

In short, '**After an initial *flash* of γ rays, a longer-lived *afterglow* is usually emitted at longer wavelengths: X-ray, ultraviolet, optical, infrared, microwave and radio**" [39].

In fact, as repeatedly detected by various satellites, or as described by the Observatory of Palermo [38], this just reported [39] is the exact EM sequence that characterises GRB's *afterglows.*

Therefore, the most interesting and extremely intriguing thing that characterises these extremely violent cosmic explosions, in our opinion, is the fact that the EM signals emitted do not all travel at the same speed, since the most energetic EM radiations (EMR_s), i.e. the photons (P_s) with the highest frequency (γ P_s), arrive before the less energetic ones, even a month earlier, although they have been issued simultaneously!

In short, these concepts are the cornerstone, the summary of this article, since the numerous experimental observations, coupled with multiple satellite surveys, show without a shadow of a doubt that across long intersidereal distances, as evidenced by the typical *Afterglows*, the different EMW_s do not all propagate at the same speed, but in a ratio directly proportional to the energy charge carried!

In our opinion, indeed, the *dispersion phenomenon* is not in itself the cause of different propagation speed of the EMR_s, as detected for long distances, but it is simply the mirror, the picture of the phenomenon. It just shows it, without influencing it [17].

To this purpose, indeed, contrary to what is proposed by the *dispersion* theory, one wonders: why, along the way, only lower frequencies interact with particles, i.e. with those electrons in the intergalactic medium?

Why should higher frequencies not likewise interact?

Why can't we explain, instead, this phenomenon as a dilatation of the time the radiation takes to reach us, regardless of interactions with the intergalactic medium? [33]. We mean, because of huge distances - sometimes longer than 11-12 billions light years - the waves of the EM spectrum, released all together from the same source and at the same time of the GRB (this is an important particular), reach us at different times. Though with very little staggering, because of the different energy related to their frequencies, and thus with different propagation speeds [35].

It would explain why, among all the different EMR_s emitted simultaneously with the GRB, γ-rays reach the Earth a bit earlier than other EMW_s . The latter, on their hand, still because of the different frequencies and energies carried, would travel with a slightly different speed among them. For this reason, though they all left at the same time, land on Earth separately, staggered with some days.

All this is in perfect agreement with what emerges from Feynman's chronometer [9] and Lenard's experiments [5], with the photoelectric [4],[5],[2], Compton [6],[7] and Çerenkov effects [27], etc...

In short, **based on numerous experimental evidences**, we think that **it is the amount of energy given to photons (P_s) by EM source to determine their specific speed.**

2.3.2 GRB's *AFTERGLOW* and UNCERTAINTY PRINCIPLE

On the other hand, these concepts can be arrived at independently, by another route, namely by considering the Heisenberg Uncertainty Principle (HUP) [40]:

$$\Delta_E \cdot \Delta_t \geq \frac{h}{2\pi}$$

(3)

where h is the Planck's constant, that is a *fixed* number given by nature; Δ_E and Δ_t represent the two *densities of probability* related to energy and time.

Since the right member of the inequation (3) contains fixed, stable values, it is obvious that in order to keep the result of the inequation unchanged, the product of the *densities* must also not vary.

In fact, being two *complementary parameters*, "it comes out that as one of the two parameters increases the other will decrease proportionally. If we apply the HUP to the EMW_s we have that the higher the energy an EMW carries, the shorter its time of travelling and hence the higher the speed of the wave" [35].

Likewise, through HUP, one could explain the peculiar GRB's *afterglow*: "Few day long *EM swarm*, related to the EMW_s and emitted by GRB_s in about 20 seconds, may represent a demonstration of the different propagation speeds of EMW_s depending on the different energy they carry" [35].

So, we asked ourselves in 2005: why cannot we consider the GRB's *afterglow* a precise evidence and natural application of the HUP to EMW_s?

"Maybe in a short future it will be possible, using the appropriate equipment, to detect if the waves carrying a high energy reach us first" [35].

On the subject of the HUP, Hawking put it this way: 'HUP is a fundamental, inescapable property of the world' [41]. Feynman in turn adds: 'No one has ever found (or even thought of) a way around the HUP. So we must assume that it describes a basic characteristic of nature" [42].

Since that time (2005), very sophisticated equipment has been built, starting with the Swift satellite. From the numerous GRB's *aftreglows* examined, this EM sequence was detected: **γ photons always arrive first, immediately after X-rays, then UV-rays, then visible light, infrared-rays, microwaves and, finally, radio waves.** This EM sequence corresponds to those described e.g. by the Observatory of Palermo [38], by Sari [37], or by Vedrenne [39].

We recently read from the Max Planck Institute in Heidelberg: 'Gamma-ray bursts (GRB_s) are bright X-ray and gamma-ray flashes observed in the sky, emitted by distant extragalactic sources. They are associated with the creation or merging of neutron stars or black holes. The initial flashes, which last a few seconds, are followed by a long-lived *afterglow phase* that can be detectable for several days in X-rays, and often weeks or even months in the optical and radio bands"[43].

We take great comfort in the fact that these are valid confirmations of our hypothesis, which dates back to 2005, according to which, in summary, **more energetic photons (P_s) travel faster than less energetic ones** [35]**.**

On the other hand, what we claim, as mentioned above, has already been tested and verified by very eminent scientists, e.g. Lenard [5] and Feynman [9], but their extraordinary scientific achievements have not been given due prominence.

III. RESULTS

3.1 LIGHT DELAY in MEANS OTHER THAN *VACUUM*

It is well known that when light passes through a medium other than *vacuum* it slows down its speed significantly; e.g. in water, light loses about 1/3 of its speed. In this respect, it may be useful to bear in mind a passage from a Mariotti seminar: "We know that **photons can behave like massive particles**: this happens when they travel in a medium other than empty space. The physical reason for this is that the propagation of the electric and magnetic field (i.e. the photon) interacts with the medium.

The resulting effect is **the 'slowing down' of the propagating wave**, which **is the equivalent of an effective mass for the propagating photon**" [44].

Consequently, it follows from Mariotti's lecture that we have the physical effects of the actual photon (P) slowing down, i.e. the typical effects of a massive P, continuously before our eyes! In fact, a completely massless P should not slow down at all either in glass or in water, or in other media with refraction index, $n_o > 1$.

In other words, the most common natural events, such as light passing through glass or water, prove unequivocally that P behaves *kinematically* as a particle, and a massive one at that!

In this respect, indeed, Feynman writes: 'Newton thought that light was made of particles, which he called *corpuscles*, and he was right. Today we know that the light (meaning all the EMW_s) is made of particles, because if we take a very sensitive tool, making a clicking when hit by the light, if we make the light dimmer, the intensity of every single click remains unchanged: they are just less frequent. Light is made of photons. We use the photomultiplier to detect a single photon. When the photon hits a small plate it causes the emission of an electron from one of the atoms of the plate" [9]. Thus, as Feynman describes, even a single P is capable of ejecting an electron from its atom, consequently revealing that the P_s, although considered massless particles, exert real *mechanical actions*, i.e., as the Mechanics dictate, *actions* attributable purely to massive particles!

3.2 MASS-ENERGY EQUIVALENCE PRINCIPLE (MEEP)

Actually, it seems more likely that the P behaves, first and foremost *kinematically*, as a body having a mass; as if to say that the P also carries a mass: to be precise, a mass (m) *equivalent to* the energy (E) it carries, as the Mass-Energy Equivalence Principle (MEEP) of Einstein [2], a milestone of modern Physics, authoritatively dictates:

$$E = m\,c^2 \qquad (4)$$

where c is the light speed in *vacuum.*

In this respect, Einstein wrote to his friend Conrad Habicht: 'It has come to my mind a consequence of the study of Electrodynamics. The Principle of Relativity, in association with Maxwell fundamental equations, requires that the mass is a direct measure of the energy contained in a body; ***the light carries a mass***" [45]. Galison goes on: 'Einstein was unsatisfied: he was not satisfied with the analyses of the light. **Einstein stated that *to any kind of energy is associated a mass***' [45]. Hence, in agreement with Einstein, there must also be a mass associated with the P [46].

According to Planck, as Galison reminds us, it seemed that a hot pot was heavier than a cold one, although exactly the same size. It was a new idea: in Newtonian Physics there was nothing suggesting a variation in mass as a consequence of the energy. Planck stated that also the transfer of *heat* adds a mass [45].

Yet, what is heat made of? As it is known, the *heat* is made of electromagnetic radiations (EMR_s), that is P_s. Thus, in agreement with Planck, a transfer of radiation from A to B will cause an increase in the mass of B [28].

But the opposite can also happen, whereby a physical system, losing energy, in perfect accordance with MEEP, also loses mass, as could occur with Black Holes [47].

In this regard, one cannot overlook the famous hypothesis of the *Evaporation* of Black Holes proposed by Hawking. He writes: "It seems that any black hole will create and emit particles such as neutrinos or photons....As **a black hole emits this thermal radiation one would expect it to lose mass**" [48].

With such a prediction, Hawking provides further prestigious confirmation of the profound concept of *mass-energy equivalence*, with all the implied consequences and the various related mechanical phenomena [28].

Moreover, as reported by Galison, "Einstein adds that based on the calculations of his article containing the equation $E=mc^2$, it emerges that a body that emits EMR_s necessarily loses mass" [45], just as would happen with the *evaporation* of Black Holes [48].

In short, wherever there is a body, or particle, having energy, there should be in a way (visible or *hidden*, concealed) a certain mass too, and *vice versa*: this is what comes from Eq.(4).

Furthermore, with reference to the MEEP formula, Einstein makes a further clarification: "It follows that, considering a particle at rest, **mass and energy are essentially similar, i.e. they are only expressions of the same thing. The mass of a body** is not a constant, but **varies as its energy varies**" [49].

To this end, Feynman points out: "*The mass of the object which is formed when two equal objects collide must be twice the mass of the objects which come together.* You might say, 'Yes, of course, that is the conservation of mass'. But not 'Yes, of course,' so easily, because *these masses have been enhanced* over the masses that they would be if they were standing still, yet they still contribute to the total mass (M), not the mass they have when standing still, but *more.*

Astonishing as that may seem, in order for the conservation of *momentum* to work when two objects come together, the

mass that they form must be greater than the rest masses of the objects, even though the objects are at rest after the collision!"[19].

In other words, the *momentum* of a particle in motion also increases its mass. This is like saying that its *kinetic energy* (E_{Kin}) is stored in the particle as mass at the end of the ride! [28]

At this regard, Feynman adds: "Suppose that our two equally massive objects that collide can still be 'seen' inside M. Then, athough we might at first expect the mass M to be $2m_0$, we have found that it is not $2m_0$, but $2m_w$. Since $2m_w$ is what is put in, but $2m_0$ are the rest masses of the things inside, the *excess* mass of the composite object is equal to the E_{Kin} brought in. This means, of course, that ***energy has inertia***" [19]: it would be a bit like saying, arguably, that the energy of the particle, through its *linear momentum* (***p***), also incorporates, transports, a mass, whether *inertial* or *dynamic*, and in full compliance with MEEP [28].

Of course, this also applies to the particle of light, which is endowed with energy and *momentum.*

To this purpose, indeed, Feynman says: 'That light carries energy we already know. We now understand that it also carries *momentum*, and further, that the *momentum* carried is always *1/c* times the energy... The energy (E) of a light-particle is h (the Planck constant) times the frequency (ν): $E = h\,\nu$. We now appreciate that light also carries a *momentum* equal to the energy divided by *c*, so it is also true that these effective particles, these *photons*, carry a *momentum* (***p***) :

$$\boldsymbol{p} = \frac{E}{c} = \frac{h\,\nu}{c} \qquad (5)$$

The direction of the *momentum* is, of course, the direction of propagation of the light'' [19].
In this respect, Feynman writes: "It is still true that the mass is the total energy that has been put in. So we see that **the conservation of mass** which we have deduced above **is *equivalent to* the conservation of energy**... **Because of the E_{Kin} involved in the collision, the resulting object will be *heavier***; therefore it will be a different object... So, necessarily, the conservation of energy must go along with the conservation of *momentum* in the theory of relativity"[19].
Thus, the example given by Feynman, in full agreement with Einstein [49], emphasises that adding energy to a particle makes it '*heavier*', i.e. increases its mass!
At this point, we feel it is right and necessary to make an important clarification. Since the photon (P) is known to have its own energy density value, according to MEEP it must also somehow carry a mass density value. This, however, according to the dictates of Special Relativity, implies a different interpretation concerning the propagation mode of the P_s, related to the different electromagnetic waves (EMW_s).

3.3 SPEEDS of ELECTROMAGNETIC WAVES (EMW_s)

As it is known, the Special Relativity was developed by Einstein as a consequence of the constancy of the velocity of light in *vacuum*, indicated with *c*. In fact, a fundamental implication of the Maxwell Electromagnetism is represented by the constant speed of all EMW_s.
However, it implies that P appears to be massless.
But not everyone was convinced of this. On the contrary, several of the most eminent physicists and mathematicians experimentally tried to identify a value for the possible *photon's rest-mass* (m_γ).
They examined the P_s of the optical band, indicating its value in *grams* (g).
We mention just a few of them and without going into technical details.
The first research on this subject dates back to 1769, with Robison, who highlighted a limit to the *photon's rest-mass* (m_γ), corresponding to $\leq 4\cdot10^{-40}$[g] [50]. Just incidentally, in the same year Robison announced that balls with like electrical charges repel each other with a force that varies as the inverse-square of the distance between them, anticipating Coulomb's law of 1785 [51].
Coulomb also tried to measure the value of m_γ , which turned out to be $\sim10^{-39}$ [g] [52]. Maxwell himself tried to measure the possible *photon's rest-mass* (m_γ), finding a value of 10^{-41}[g] [53].
In his turn, de Broglie (1940) estimated that "the m_γ could not exceed 10^{-48} [g]" [54].
Skipping many other authors, we arrive at the research carried out in 1983 by the Crandall *team*, which obtained an m_γ equal to $8 \cdot10^{-48}$ [g] [55], or the research carried out by Fulcher's *team*, which showed an m_γ equal to $1.6 \cdot10^{-47}$[g] [56]. Nevertheless, in order for the accounts to add up, and to confirm the absolute validity, in all its aspects, of the entire mathematical construction of Electromagnetism, brilliantly worked out by Maxwell [53], the mass of P must be absolutely zero.
And why? Even Schrödinger, rather perplexed, asked: "Must the photon mass be zero?" [57].
But it is clear: with a photon (P) not massless, crucial concepts of the electromagnetic theory (EMT) resulting from Maxwell's equations would collapse.
In fact, the first and most resounding consequence of the existence of a massive P would refute and disprove *ex abrupto* one of the best-known mathematical conclusions derived from EMT: EMW_s does not they could absolutely all travel at the same speed. No!
How so? It is Mathematics itself that rejects one of the most acclaimed and most entrenched concepts of electromagnetism. Which is? Yet, a **P not massless imposes that the *EMW_s speed* is not a unique constant; on the contrary, it is a *function of frequency***!
It seems very important to underline that these conclusions are not only arrived through mathematics, but also through the careful observation and in-depth study of various natural phenomena, or through the analysis of experimental data, which, as widely reported, have unequivocally shown that EMW_s characterised by different colours do not travel at the same speed at all. Moreover, this also occurs with the different bands of the EM spectrum: GRB's Afterglow *docet*.
Therefore, if a massive P, just by applying Mathematics, dictates that EMW_s of different frequencies must travel at different speeds, let us examine the *photon's rest-mass* (m_γ), already measured by many eminent scientists with results to be considered positive, although these were truly infinitesimal mass values, of no value in our macroscopic world and without the slightest meaning in our daily life [58].

However, despite showing infinitesimal values, these very reliable *photon mass* measurements were all different from zero, so it can assume, in our opinion, a its value, a its role, both in the sub-atomic world and in the mathematical formalism [59].
In our case, however, we do not perform this investigation through sophisticated laboratory research, but simply through Mathematics alone.

3.3.1 PHOTON's REST-MASS (m_γ)

To this purpose, let's consider the Eq.(4), $E=mc^2$, which as is known expresses the Mass-Energy Equivalence Principle (MEEP). As Galison reminds us, that's how Einstein commented upon his MEEP: "The value of the considered mass refers to the value of an *inertial mass*" [45], as to say: the *rest-mass.*
Let's now apply the Eq.(4) to the photon (P), keeping in mind that one of the three parameters is well known, that is *c*, the speed of light in the *vacuum*, corresponding to 299792.458 (±0.4) Km/sec [60] The 2nd parameter, *E*, is the *energy* of the P, which is described by Eq. (1): $E=h\,\nu$, where *h* is the Planck's constant, corresponding to $6.626\cdot 10^{-27}$ $[erg \cdot \sec]$ and ν indicates the frequency of oscillation (10^n) of the P considered, where *n* indicates the number of oscillations per second [c/s] [61].
If we want to consider the *energy* of the P in its *inertial state*, indicated with E_o, we should have:

$$E_o = h\cdot \nu = h\cdot 10^n\,[\text{c/s}] \tag{6}$$

$$E_o = 6.626\cdot 10^{-27}[\text{erg}\cdot \text{s}]\cdot 10^n[\text{c/s}] \tag{7}$$

$$E_o = 6.626\cdot 10^{-27+n}\,[\text{erg}] \tag{8}$$

Moreover, as the *erg* value is expressed in [g· cm/s² ·cm], that is in [g· cm²/s²], we have:

$$E_o = 6{,}626\cdot 10^{-27+n}\left[\text{g}\cdot\frac{\text{cm}^2}{s^2}\right] \tag{9}$$

This should be the Energy value of a P at an *inert state*.
Thus, in the case of a P at the *inertial state*, that is when it interacts with another particle, so it stops running, at least for that infinitesimal moment it will oscillate much less. However, we will never be able to know how much! That is, we will never be able to know with *accuracy* how much an interacting P can oscillate, i.e. what could be the number of oscillations [c⁄s] in that instant [62].
In short, the P stops running when hitting another particle, so it will not oscillate as when it was running, although it will never stop moving completely: it is the *Heisemberg Uncertainty Principle* (HUP) to deny it, since in this case we would know simultaneously the *position* and the *momentum* of the P [40]. Therefore, a P which does not oscillate is a motionless P, and in this case we would know simultaneously *2 complementary parameters* of the same particle: its position and *momentum*.
Thus, also in the *inertial state* the oscillating frequency (ν) of the P can never be 0, but always ≥1/s, that is ≥ one oscillation per second (if not even ½ oscillation per s., or a fraction of its).
Thus, from Eq.(9) we can obtein information with a fair approximation about the 2nd parameter of Eq.(4), referred to the
P. Hence we can easily have the 3rd parameter, the *equivalent inertial mass* or *equivalent rest-mass* (m_γ) of the P, i.e.
precisely that *photon's rest-mass* (m_γ) already researched and measured with commitment and accuracy by many prestigious scientists:

$$m_\gamma = \frac{E_o}{c^2} = \frac{h\,\nu}{c^2} = \frac{6.626\cdot 10^{-27+n}[\text{g}\cdot\frac{\text{cm}^2}{s^2}]}{(2.9979\cdot 10^{10})^2[cm/s]^2} \tag{10}$$

$$m_\gamma = \frac{6.626\cdot 10^{-27+n}}{(2.9979)^2}\cdot 10^{-20}\cdot\frac{[\text{g}\cdot\frac{\text{cm}^2}{s^2}]}{\frac{\text{cm}^2}{s^2}} \tag{11}$$

$$m_\gamma = \frac{6.626}{(2.9979)^2}\cdot 10^{-27-20+n}\cdot\left[\text{g}\cdot\frac{\text{cm}^2}{s^2}\right]\cdot\frac{\text{s}^2}{cm^2} \tag{12}$$

$$m_\gamma = \frac{6.626}{(2.9979)^2}\cdot 10^{-47+n}\,[\text{g}] \tag{13}$$

and we have:

$$m_\gamma = 7.372\cdot 10^{-48+n}\,[\text{g}] \tag{14}$$

What we get is that the *inertial mass*, or *rest mass* of the P corresponds to 10^{-48+n} grams.
Hence, if the value of *n* was 10^0, that is one oscillation per second, m_γ would be 10^{-48} [g]. Whereas if *n* was 10^3 oscillation per second, we would have $m_\gamma = 10^{-45}$[g]. Of course in all cases it is an extremely small value, but it

is ≠ 0, in agreement with Quantum Mechanics, i.e. according to HUP [40] and in line with the scrupulous and accurate measurements carried out by many famous physicists and mathematicians, as reported in section **3.3.**
Precisely in this respect, it can be seen that our results do not deviate significantly from these measurements, indeed in some cases they are even completely superimposable, as is clear from de Broglie's research and calculations ("m_γ could not exceed 10^{-48} [g]" [54]), or from the measurements made by Crandall's *team*: $m_\gamma = 8{\cdot}10^{-48}$ [g] [55].
Also in this regard, what Penrose writes may be very interesting. In fact, in his masterful volume, "The Road to Reality", he points out: "The mass of photon, if not 0, should be $<10^{-20}$ electronic masses **for good observational motives**" [63].
Well, the mass of the electron is $9.1{\cdot}10^{-28}$ grams, so if the photon is $<10^{-20}$ electronic masses, we have: $9.1{\cdot}10^{-28-20}$ [g]. Thus, in accordance with Sir Roger Penrose a light quantum, i.e. a photon (P), which is not massless must have a mass very close to $< 9.1{\cdot}10^{-48}$ [g].
Penrose's calculations, among the greatest living mathematicians (and Nobel Prize in Physics, 2020), are completely superimposable on ours: $7.372{\cdot}10^{-48}$ [g], as shown in Eq.(14).
This is of great honour for us and greatly comforts us.
So far, we have mainly analysed the photon (P) in its state of minimum energy and minimum motion [64], but it certainly has not escaped our minds that the main theme of our article is the study of the speed of EMW_s .
Therefore, we must examine P in its most conventional state, i.e. when it is in motion, when it is thrown at full speed. In this case, therefore, the parameter that best describes the peculiarities and characteristics of the running P must be investigated: that is the *momentum* (***p***).
To this purpose, indeed, we find it very important to highlight that the propagation speed of a wave (i.e. an EMW) or of a particle can also be calculated from the analysis of its *momentum* (***p)***.

3.3.2 PHOTON's *MOMENTUM* (*p*)

As it is known, indeed, one of the main characteristics of the P is to travel most of the time, so it also carries a *momentum* ***(p)***. At this regard, Fermi writes: 'The photon too, like other particles, is a corpuscle and has an its own *momentum*, through which tranfers all its energy to the hit particle" [10]. Besides, in accordance with Quantum Mechanics, Feynman adds: 'A photon is like a particle, in that it carries an energy and a momentum. The energy of a photon is a certain constant, called Planck's constant, times the frequency of the photon: $E=h\nu$. Such a photon also carries a momentum, and the momentum (***p***) of a photon is *h* divided by the wavelength (λ)" [19]:

$$\boldsymbol{p} = \frac{h}{\lambda} \qquad (15)$$

It is common knowledge that Eq.(15) represents the *de Broglie formula.*
In fact, taking inspiration from Einstein's intuitions about the particle behaviour of *light's quanta* [2], in 1923 de Broglie
proposed a similar process, in reverse, to be applied to particles. So, without experimental data, he suggested to give particles the same property as waves.
Hence, He gave each particle an its own wavelength,(λ), depending only on the *momentum* (***p***) of the particle itself [65], just as the Eq.(15) shows.
Thus, "any particle seems to be something periodic, like a wave, with a universal relation between the wavelength of the particle, indicated by λ, and the modulus ***p*** of its *momentum*" [63].
And interesting' to emphasise that Eq.(15) shows a fundamental charateristic, valid for any particle, including the P: ***p*** and λ are inversely proportional! It is therefore obvious that, taking the entire *EM spectrum* into consideration, as the wave length (λ) decreases, the corresponding *momentum* (***p***) will also increase proportionally.
Hence, let's now calculate the *momenta* of photons (P_s) depending on the EMW examined.
According to Weinberg, it is known that the mean wave length of a P in the optical band corresponds to about $5{\cdot}10^{-5}$ [cm] [66] and in agreement with *de Broglie's formula* its ***p*** is:

$$\boldsymbol{p} = \frac{h}{\lambda} = \frac{6.626\cdot10^{-27}[erg\cdot s]}{5\cdot10^{-5}[cm]} \qquad (16)$$

$$\boldsymbol{P} = \frac{6.626\cdot10^{-27}[g\cdot \frac{cm^2}{s}]}{5\cdot10^{-5}[cm]} \qquad (17)$$

$$\boldsymbol{p} = 1.325\cdot10^{-22}\ [g\cdot\frac{cm}{s}] \qquad (18)$$

As is shown by Eq.(18), it is clear that the *momentum* (***p***) of a visible photon (P), expressed in grams, should carry out a *hidden dynamic-mass*. Moreover, this *hidden dynamic-mass* carried by the *momentum* of an optic P is larger than the *rest mass* of 100 protons.
No surprise! At this regard, Feynman points out: 'The *momentum*, as a mechanical quantity, is difficult to *hide*. Nevertheless, momentum *can* be *hidden*, in the electro-magnetic field, for example. This case is another effect of relativity" [19]. It is like saying that the *momentum* carries, albeit *hidden*, also a *dynamic-mass*, of which it manifests its *pushing effect*, i.e. a clear mechanical action only when it interacts with another particle.
Instead, as the Complementarity Principle dictates, the *Planck's grain*, when in motion, can never show us its *corpuscular dress*, but always and only its *undulatory dress*! This is a rule of nature, ingeniously intuited by Bohr [67].
In this respect, indeed, Penrose chases: 'The particle aspect of the wave-particle object shows itself only to the detector, when the *measurement* is finally performed. The *measurement* makes clear the holistic nature of the Wave Function of the measured particle, in the sense that the particle always appears and only at one point" [63].
Hence, only when the motion almost stops (and its *wave aspect* disappears) will the light quantum be able to show its *corpuscular aspect*. Only then, as a corpuscle, the P will show us, at last, its probable mass: maybe indirectly, showing us the probable mass-effects or mechanical effects [68]. To this purpose, Feynman writes: "Finally, associated with the relativity theory, there is a modification of the laws of kinetic energy, or whatever you wish to call it, so that kinetic energy is combined with another thing called *mass energy*. An object has energy from its sheer *existence*" [19]. Likewise, it is deduced that the object itself also possesses mass, to be exact a proportional *equivalent mass energy*'' [2],[69].
In fact, Penrose points out: "The famous formula from Einstin's Special Relativity, $E= mc^2$, tells us that **mass (*m*) and energy (*E*) are interchangeable**. To give an astonishing example, in which the effect of Einstein's mass-energy relation is present in an extreme form, let us consider the decay of a subatomic particle, the π^o meson. It is a *material particle* with a well-defined (positive) mass. After about 10^{-16} seconds, it almost always disintegrates into just *two photons*.
For an observer at rest with respect to the π° meson**, each photon takes** half the energy and, **de facto**, **half the mass of the π^o meson with it**. Yet, this mass of the photon is of the most impalpable kind: it is pure energy"[12], which is why this mass appears to be *hidden*, contributing to no mass being assigned to P!
According to *de Broglie's formula*, let's now calculate the ***p*** value of photons (P_s) with different wave length (λ). To this purpose, let's analyse the ***p*** of radio waves with different λ. Therefore, we consider a radio wave with $\lambda=10^{-3}$ [cm]:

$$\boldsymbol{p} = \frac{6.626 \cdot 10^{-27}\ [g \cdot \frac{cm^2}{s}]}{10^{-3}\ [cm]} \tag{19}$$

$$\boldsymbol{p} = 6.626 \cdot 10^{-24}\ [g \cdot \frac{cm}{s}] \tag{20}$$

Let's consider now a radio wave with a wavelength (λ) of two higher orders of magnitude, i.e. with $\lambda= 10^{-1}$ [cm] and calculate its ***p:***

$$\boldsymbol{p} = \frac{6.626 \cdot 10^{-27} [g \cdot \frac{cm^2}{s}]}{10^{-1} [cm]} \tag{21}$$

$$\boldsymbol{p} = 6.626 \cdot 10^{-26}\ [g \cdot \frac{cm}{s}] \tag{22}$$

Well, Eq. (22) clearly shows that also the ***p*** value changed by two orders of magnitude, but less, according to the de Broglie formula, where it can be easily inferred that ***p*** and λ are inversely proportional [17].
Let's consider then, an X photon with $\lambda=10^{-10}$ [cm]:

$$\boldsymbol{p} = \frac{6.626 \cdot 10^{-27} [g \cdot \frac{cm^2}{s}]}{10^{-10} [cm]} \tag{23}$$

$$\boldsymbol{p} = 6.626 \cdot 10^{-17}\ [g \cdot \frac{cm}{s}] \tag{24}$$

In this case, the difference compared to a radio wave is 7-9 orders of magnitude greater.

Finally, we find it very important to emphasise that, as evidenced by numerous satellite survays [37],[38],39].[43], the fundamental characteristic of Gamma Ray Bursts (GRB_s) is that the first elecromagnetic (EM) signals to arrive on Earth are those that carry the γ photons (γP_s).
Thus, let's try to understand why. To this purpose, let's consider a γP with a $\lambda=10^{-12}$ [cm]:

$$\boldsymbol{p} = \frac{6.626 \cdot 10^{-27} [g \cdot \frac{cm^2}{s}]}{10^{-12} [cm]} \tag{25}$$

$$\boldsymbol{p} = 6.626 \cdot 10^{-15} \; [g \cdot \frac{cm}{s}] \tag{26}$$

We have, in other words, that the ***p*** value of a γP is 2 orders of magnitude bigger than that of an X photon (XP), of 7 orders of magnitude bigger than that of an optic P and even 11 orders of magnitude bigger than of a radio wave, as Eq.(22) shows.

IV. DISCUSSION

According to the belief of the scientific community, as the EM signals emitted by GRB_s pass through the cosmic *vacuum*, the lower frequencies of these *packets* remain somewhat further behind the higher frequencies, as the lower frequencies interact with the particles they meet.

The effect is small, but the distances are enormous, so the phenomenon is able to be underlined. Its intimate mechanism is set by the so-called *wave absorption*, through which an *attenuation* due to collisions appears.

"If this effect is quite small, the phase constant is practically the same as that obtained without collisions. The *attenuation* shows that a part of the EM energy of the wave is dispersed, i.e. dissipated and sold to the plasma in the form of heat. Plasma behaviour at high frequencies is similar to that of a dielectric with losses.
It is useful to note that the *attenuation constant* (α) is directly proportional to the number of collisions and that, other conditions being equal, it decreases with the increasing of the wave frequency (υ)" [70]:

$$\alpha = \frac{1}{\upsilon^2} \tag{27}$$

as to say that in these circumstances the *dispersion measure*, indicated by the *dispersion value* (α), is inversely proportional to the frequency(υ) of the considered wave. This is why among the EMW_s, although belonging to the same *wave packet*, those having a greater oscillation frequency (υ) suffer very little from the *slowing down* of their
propagation speed, slowing down induced by the free electrons of the interstellar medium [17].
"The *dispersion phenomenon* has been observed for over 50 years by Pulsar scholars, who have found that the greater the *dispersion*, the farther away the source of the impulses is" [71].
On the contrary, in our opinion, they are precisely these ***p*** value differences, in relation to the different considered wavelengths, that represent the only valid explanation to justify the characteristic *EM swarm* that goes with the GRB_s, just like a tail of a comet.
In fact, if we compare the equations (20) and (22), we easily notice that, as the λ of a radio wave increases, its ***p*** value and its speed will decrease. This explains why, regardless of the *dispersion phenomenon*, in a packet of radio waves carried by a Fast Radio Burst (FRB), the more energetic radio waves arrive on Hearth before the less energetic ones.
As it is known, FRB_s are one of the most tantalizing mysteries of the radio sky. FRB_s are very brief (milliseconds) bursts of radio photons, and have been detected at frequencies ranging between 400MHz-8GHz by a number of ground-based radio telescopes. FRB_s are manifested as an intense flash of *radio pulses* that exhibits the characteristic *dispersion* sweep of radio pulses [17].
These events are detected with high intensity. A FRB in a few thousandths of a second, indeed, can even reach the energy of 500 million Suns, emitted in the form of radio waves.
As the Keane*'s team* reminds us, 'The longest radio waves arrive on Heart a fraction of time later than shorter radio waves" [72], in perfect agreement with our calculations.
This phenomenon is even more evident in GRB_s. In our opinion, **the *EM swarm*** that characterises a GRB, meaning what its *Afterglow*, **represent a clear proof of the different EMW_s propagation times, in a ratio inversely proportional to the respective wavelengths (λ), but in a ratio directly proportional to the respective *momentum* (*p*)**.

Therefore, as is clear from all the above, and as is evident from our calculations, the speed of an EMW is closely related to the value of its *momentum* (***p***).
The question naturally arises: what is this all about? What is the cause? And what deep correlation is there between ***p*** and the speed of an EMW?
Feynman makes it clear: '**Velocity and *momentum* are proportional**" [19].
That is why, as Feynman reminds us, "the **blue light travels with a higher speed than the red light** (which is less frequent than the blue light)" [9].
At this regard Asimov points out: "A violet light quantum has double energy of a quantum of red light, and of course **it takes more heat to produce a violet quantum than to produce a red quantum**" [15]. We have a confirmation if we calculate the value of the *momenta* of respective photons (P_s).
Thus, let us calculate the *momentum* (***p***) of a P of the violet band, close the blue, with λ ≈ 390 nanometers, that is ≈ 3.9 ·10^{-5} [cm]:

$$\boldsymbol{p} = \frac{h}{\lambda} = \frac{6.626 \cdot 10^{-27} [\text{g} \cdot \frac{\text{cm}^2}{s}]}{3.9 \cdot 10^{-5} [cm]} \tag{27}$$

$$\boldsymbol{p} = 1.7 \cdot 10^{-22} [\text{g} \cdot \frac{cm}{s}] \tag{28}$$

Let's consider now a photon travelling with red light, whose wavelength (λ) corresponds to about 780 nanometers, that is≈ 7.8 ·10^{-5} [cm]. Let us calculate its ***p*** value:

$$\boldsymbol{p} = \frac{6.626 \cdot 10^{-27} [\text{g} \cdot \frac{\text{cm}^2}{s}]}{7.8 \cdot 10^{-5} [cm]} \tag{29}$$

$$\boldsymbol{p} = 0.85 \cdot 10^{-22} [\text{g} \cdot \frac{cm}{s}] \tag{30}$$

This is the *momentum* (***p***) of a red photon.
Thus, as shown by Eq.(28), we have that the ***p*,** that is the impulse, the *power* with which the violet photon hits a particle is exactly double of the power with which the ***p*** of the red photon impacts on the electron, as it is clear from Eq.(30). In fact, this occurs with the photo-electric effect (PEE).
These are the facts and results, as confirmed by various experimental tests. Therefore, we do not should be any more surprising that 'The blue light travels with a higher speed than the red light' [9], or that blue light travels faster than
yellow light [15].
Moreover, it is of particular relevance that the so-called *momentum* (or *linear momentum*) was introduced by Newton himself, in order to calculate how much a body in motion weighs.
In fact, Newton was the first one to fully deal with this topic.
In the first pages of 'Philosophiae Naturalis Principia Mathematica' (1687), Newton also reported the following definition: '*Quantitas motus est mensura ejusdem orta ex Velocitate et quantitate Materiæ conjunctim*", that is, the quantity of motion (*momentum*) is a measure in itself, since it depends conjuctly on both the *speed* and the *quantity of matter* [73].
Namely, the sole mass or speed do not therefore describe what happens in real cases.
Newton then referred to what we call ***momentum*: something that originates <u>jointly</u> from the speed and quantity of matter** of the particle considered. Newton defined this vector magnitude in the following way:

$$\vec{p} = m \cdot \vec{v} \tag{31}$$

Eq.(31) describes the *quantity of motion* (***p***) of a body having a mass *m* and moving at a speed (***v***) [73,Newton,1687]**.**
Hence, the *momentum* (***p***) of a particle is the product of two quantities: the particle's mass and its velocity. *Momentum* is a vector quantity: it has both magnitude and direction, and direction and line coincide with those of the velocity (***v***)**.** In fact, the vector ***p*** has the same direction and the same line of ***v*** and its module is the mass times the speed module.
Thus, it is of particular significance, as well as rich in meaning and potential, to point out that, in line with Newton [73], **the *momentum* of a particle is directly proportional to its mass and to its speed too**. Moreover, as can be seen from Eq.(31), the characteristics and properties of the *momentum* described by Newton are perfectly matched, on the one hand, by the experiments performed by, e.g., Lenard, or Feynman, and, on the other hand, are in full agreement with the ***p*** values emerging from Eq.(16) to Eq.(30).
All these equations, in turn, are corroborated in natural events, through the examination of numerous Gamma Ray Bursts (GRB_s) [37],[38],[39],[43] whose *Afterglows* confirm, beyond any doubt, that the most energetic

photons (P_s) such as the γP_s always arrive first on Earth, as opposed to the least energetic, i.e. radio waves, which arrive last.
In fact, with a GRB travels all the EM spectrum, which comes to us as an *Afterglow*, that is, out of phase in an *EM swarm*, which can last even for 30 days, or more.

V. CONCLUSIONS

It is obvious that in agreement with Newton ($\vec{p}=m\cdot\vec{v}$ [73]) and in accordance with Feynman ("Velocity and *momentum* are proportional"[19]) and on the basis of the *de Broglie formula* ($\boldsymbol{p}=h/\lambda$), the more energetic P_s, and therefore with greater *momentum*, such as blue light compared to red light, will travel at greater speed, as Lenard's experiments [4], or Feynman's chronometer [9] show.
Obviously, this will be even more pronounced with X-rays and γ P_s. This is confirmed, without a shadow of a doubt, by examining the peculiar GRB's *Afterglows*, as evidenced e.g. by the numerous satellite detections carried out [37],[38],[39],[43].
At this point, it is natural and spontaneous to ask the question: what is the reason for all these considerable differences between the values of the various photon's *momenta* (related to the wavelength of the various EMW_s), and what do they mean, what do they imply?
If it were true that the EMW_s all travel at the same speed (Maxwell *docet*), the *momenta* (each related to a different EM frequency band) should also all be the same.
Instead, as our equations unequivocally demonstrate, what is more in total agreement with Newton ($\vec{p}=m\cdot\vec{v}$[73]) and de Broglie ($\boldsymbol{p}=h/\lambda$[65]), and as evidenced by numerous satellite surveys, this is not the case at all! And why?
It will be said that this occurs due to the *dispersion phenomenon*. At this regard, in the opinion of the astronomers the EMW_s emitted by a GRB have to go through gases released by the Supernova and through the interstellar medium whose electrons tend to *attenuate* the propagation speed of the EM signals in a different way, in accordance with the type of wave. According to astronomers this mechanism is set by the *wave absorption*, which decreases with the increasing of the wave frequency (υ), as shown in Eq.(27) [33]. This is the so-called *dispersion phenomenon* of the EM signals.
On the contrary, in our opinion, this *dispersion phenomenon* is not in itself the cause of different propagation speed of the EM signals, as detected for long distances, but it is simply the picture of this phenomenon. We think that it just shows it, without influencing it [17].
Therefore, we believe that a greater scientific meaning should be given to what comes from the very peculiar GRB's *Afterglow*.
In short, we think that the real cause, the deeper reason behind the peculiarity of GRB_s and FRB_s - represented essentially by the different propagation speeds of the emitted EM signals - lies in the different EM sources: the more energetic the source the more energetic the *push momentum* [74] and consequently (since $\boldsymbol{p}=m\mathbf{v}$) the greater the acceleration given to the photons (P_s) produced.
In fact, this mechanical effect exerted by the photon's *momentum* ($\boldsymbol{p}$) [75] is confirmed by Heisenberg, who defines it as "the mechanical *impulse* $\boldsymbol{p}$ of the individual corpuscular radiations" [76].
In fact, there are numerous physical events supporting what we claim.
As discussed above, the first and most striking event was the Big Bang which, without a shadow of doubt, has so far been the greatest electromagnetic source. According to Guth [25], Albrecht and Magueijo [24], indeed, we believe that the photons (P_s) emitted with the hypothesized Inflationary *Phase* had an energy significantly bigger than the more energetic γP_s ($\approx 10^{27}$ Hz), thus having a *momentum* and a *kinetic energy* greater than the visible light and γ-rays, and enough to justify the superluminal speed in the expansion of the primordial Universe [26].
Another example is represented by the electrons (of the atmospheric molecules) hit by cosmic and γ-rays at high altitude, and accelerated at superluminal speed, thus emitting EM radiations (EMR_s) which wavelength (λ) moved from brilliant blue to Ultra-Violet. These EM frequencies represent the so-called *Çerenkov Light* [27].
To this purpose, we find it very important to emphasise that only γP_s manage to give electrons such a speed to be able to emit the *Çerenkov Light.*
On the contrary, being less energetic than γ rays, all other EMR_s are unable to accelerate the affected particles at a speed sufficient to generate the *Çerenkov Light* [29].
At this regard, Heisenberg points out: "**The speed (*s*) value of a particle it is the same as saying: the energy (*E*) value of the same particle**" [76] and *vice versa*!
According to Feynman, indeed, "the P is a particle" [9]. Consequently, the **more energetic P_s travel faster than the less energetic ones**!
In our comfort, we read from the Astronomical Observatory of Brera: 'Today we know that the entire Gamma-Ray Burst explosion does not end with the emission of *gamma rays* but, within a month, it is possible to observe

it in other bands of the electromagnetic spectrum: in *X-rays*, in the *optic*, in the *infrared* as well as in the *radio*. This *emission tail* is called *afterglow*" [77].
Furthermore, in agreement with the *mathematical formalism*, it is of fundamental importance to also keep in mind that a nonzero mass P, as shown in Eq.(14), categorically dictates that the speed of EMW_s cannot be represented by a unique constant, since in this circumstance the **EMW**'s **speed (*s*) is a *function* (*f*) *of frequency* (*v*)**:

$$s = f(v) \tag{32}$$

where it is clearly stated that the *dependent variable* (*s*) varies in a directly proportional ratio to the varying values of the *independent variable* (*v*). This is in full agreement with what emerges from the various experimental observations and our equations concerning the *momenta* (***p***) of different P_s, which also turn out to be directly proportional to the oscillation frequency (*v*) of each EMW considered. If we then add what Feynman reported, 'speed and *momentum* are proportional' [19], then we can truly say that *the circle is closed*!
These are the facts, moreover proven by numerous experiments and as evidenced by numerous satellite surveys. So, either the cause lies in the *dispersion phenomenon*, or it depends on different EM sources (the more energetic the source the greater the acceleration given to the P_s emitted), ultimately the truth is that **EMW_s do not travel at the same speed**!
Well, this is precisely the theme of the Theorem that we want to propose, and since, no matter what the cause, it is an established truth, according to Eucidean *Logic* it can be a *demonstration* (of the Theorem) for all intents and purposes.
In fact, unlike his predecessors, Euclid does not simply state that a certain theorem is true, but also provides a *proof of* it. And what is a *proof*, for Euclid? "It is a kind of mathematical tale, in which each step is a *logical consequence of* some of the previous steps. Each *statement* must be justified in relation to the preceding ones, and *proved* as a *logical consequence of* them" [31].
We, too, with our *account*, even mathematically, think we have proceeded *step by step*, following the Euclidean procedure of the *logical construction of* a new *Theorem*, and probably also providing the *proof*.

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