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Fast Radio Burst And Gamma Ray Burst: Hidden Causes Of Their Peculiar Propagation Times

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Abstract: We analyze the peculiar propagation times of Fast Radio Bursts and Gamma Ray Bursts. The main feature of these peculiar and high-energy astrophysical phenomena lies precisely in the different speeds with which the different electro-magnetic (EM) signals, carried by the Bursts, propagate. Surprisingly, in fact, instead of travelling all at the same speed (Maxwell *docet*), the satellites unequivocally recorded first the arrival of the most energetic EM signals, i.e. of greater frequency, and then the less energetic ones (bigger wavelength). According to astrophysicists, the interstellar medium acts as a brake, slowing down the EM radiations (EMR_s) with bigger wavelength. We believe that the real cause, the deeper reason behind the different EMR_s propagation speeds, lies in the different EM sources: the more energetic the source is the more energetic the acceleration given to the photons produced will be.

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1. Introduction

As it is known the Fast Radio Bursts (FRB_s) and Gamma Ray Bursts (GRB_s) are peculiar and high-energy astrophysical phenomena.

1.1 Fast Radio Bursts (Frb_s)

FRB_s are one of the most tantalizing mysteries of the radio sky; their progenitors and origins remain unknown. FRB_s are characterized by one or multiple very bright (~ Jy) and 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. It is known that the *Jansky* (Jy) is the unit of the *spectral flux density*, or spectral irradiance. In the *cgs* metric system 1 Jy = 10^{-23} erg·s^{-1}·cm^{-2}·Hz^{-1}.

FRB_s are manifested as an intense flash of *radio pulses* that exhibits the characteristic *dispersion* sweep of radio-pulsars. These events are of extremely short duration, typically lasting for less than a few milliseconds, but are detected with high intensity. Suffice it to say that a FRB in a few thousandths of a second can even reach the energy of 500 million Suns, emitted in the form of radio waves. Usually, FRB are detected by large radio telescopes at 1.4 GHz.

As for the distance from us, from which a FRB can be *turned on*, "experts are convinced that in the vicinity of the Milky Way the FRB_s are few, but their number grows rapidly as the distance increases: the peak is reached at the distance about 7 billion light years and then begins to be more rare "(MEDIA INAF 2019).

Little is known about the origins of the FRB_s. It should be kept in mind, however, that since radio impulses have a duration of about one thousandth of a second, very short, then the celestial source that generates it must not be very large, indeed it must have a fairly narrow diameter, such as that of a Neutron Star, equal to 10-12 Km (Puccini 2018, a) (Michilli), which only rarely reaches 20 Km. Furthermore, a Neutron Star is a fairly compact object (Puccini 2019, b). "The only known repeating FRB source –FRB 121102- has been localized to a star-forming region in a dwarf galaxy at redshift 0.193 and is spatial coincident with a compact, persistent radio source. The origin of the bursts, the nature of the persistent source and the properties of the local environment are still unclear. We report observations of FRB 121102 that show almost 100 per cent linearly polarized emission at a very high and variable Faraday rotation measure in the source frame and narrow (below 30 microseconds) temporal structure. The large and variable rotation measure demonstrates that FRB 121102 is an extreme and dynamic magneto-ionic environment, and the short duration of the bursts suggest a Neutron Star origin" (Michilli). Subsequently a second repeating FRB source was highlighted. Possenti points out: "In fact, the nature of the FRB_s is currently unknown. In the confusion of hypotheses, 3 today seem to carve out some favor in the scientific community. One concerns the Magnetars, that is Neutron Stars with an ultra-intense magnetic field: sudden adjustments of this magnetic field could trigger the emission of a FRB. A second possibility is that the FRB_s represent an extreme form of *giant impulses* (emitted by a Neutron Star) much more energetic - and therefore much rarer - than those normally observed in the Pulsars of our galaxy. A variation of these models postulates that the FRB_s originate from young Neutron Stars, which are surrounded by a bubble of ionized gas generated by the Supernova that formed them "(Possenti).

1.2 Gamma Ray Bursts (Grb_s)

Phenomenologically, GRB_s are traditionally classified in two families: 1) *Long* GRB (time duration > 2 seconds); 2) *Short* GRB (time duration < 2 seconds).

GRB_s are very high energy photons emissions.

There are several theoretical models for GRB_s as well: according to the most reliable theories they are generated by the increase of matter on a black hole (BH). This accretion disk around a BH 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 BH.

As it is well-known, in fact, the most energetic gamma (γ) radiations hitting the Hearth are emitted by intense electromagnetic (EM) sources represented mainly by explosions of supernovae or by the collision of two Neutron Stars, creating GRB. Generally, in the first case the emission lasts ≈20 seconds (only rarely it lasts a few minutes); in the second case the EM emission mostly lasts about 1-5 seconds. It should be noted that GRB_s represent very powerful sources of EM emission. GRB_s, indeed, have a much more intense energy than γ rays, though the latter represent the most energetic radiation in the entire EM spectrum. On the other hand, their greater energy is due to the different sources: the sources of GRB_s are much more energetic than the common γ sources. Namely, a GRB emission represents the most energetic phenomenon which can happen in the universe second only to the Big Bang. As known, in fact, in an extremely short lapse of time (some seconds) a GRB can emit the same radiant energy emitted simultaneously, in the same lapse of time, by all the stars of all the galaxies of the universe.

Nowadays it is recorded in average a GRB a day mainly coming from the most remote ends of the universe (the farthest has been located at a distance of over 13 billion light years from the Earth) and from all directions: isotropic distribution.

Besides, it is impressing to note that although the sources can be at the ends of the universe, these kind of GRB_s manage to reach us still very luminous: the power and the energy released must be dreadful. One more curiosity comes from the fact that though a GRB is very short (referring to the time we can see it, or 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, with different frequencies (Puccini,2019 d) (Hongxuan and Yiping).

2. Discussion

2.1 Electromagnetic Signals *Dispersion*

Another peculiar phenomenon related to FRB and GRB, if not quite the most characteristic, it is that of their EM signals *dispersion*. "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. In the case of FRBs, the *dispersion* is much higher than the maximum that can be imputed within our galaxy. As for the FRB reported by Keane et al. (Nature, 2016), covering the 6 billion light years that separate it from us, the EM pulse was *dispersed* by the material present in the galaxies, with the effect of slowing down the lower radio-frequencies more than the higher ones "(Possenti).

In fact, "the burst with the smallest wavelength dispersion seems to have reached us after passing through some 5.5 billion light-years of space; the burst with the largest dispersion appears to be from nearly twice as far out, originating some 10.4 billion light-years away. One of the four bursts also bears the likely imprint of turbulence in the intergalactic medium, a subtle stretching out of its pulse shape probably caused by electron scattering. If we can trace an FRB to a specific galaxy, we can then independently measure the distance to that galaxy. Comparing the FRB's *dispersion measure* with that galactic distance would yield the average electron density between Earth and that other galaxy." (Thoronton et al.). And because all those electrons come from baryons - subatomic particles such as protons and neutrons- they would be a proxy measurement of the amount and distribution of unseen ordinary matter that exists between and even within far-distant galaxies (Chun-xuan).

One of the primary observables of an FRB is the delay in the arrival time between different frequency components of the burst. This delay is proportional to the *dispersion measure* (DM). Moreover, DM indirectly provides us with new on the column density of free electrons along the line of sight from the source to the observer. "For an extragalactic FRB the DM is expected to be the sum of contributions from the Milky Way's disc and halo, the intergalactic medium, the disc and halo of the host galaxy, and the local environment of the FRB progenitor, while the DM of a galactic FRB must be entirely accounted for by the Milky Way and/or the local environment of the progenitor. Of the FRB so far observed at high galactic latitude, most have large DM that is difficult to account for with gas in the Milky Way, and so point toward and extragalactic origin. The presence of excess DM contributed by Hα filaments. Since all but one FRB consist of a single pulse with no observable counterparts, they have not been sufficiently localized on sky to be associated with any astronomical object, and thus their distance is unknown. However, if one assumes that the dominant contribution the DM is due to diffuse gas in the intergalactic medium, one can estimate their distance/redshift. These estimates suggest a cosmological origin"(Platts et al.).

In recent years, millisecond duration radio signals originating from distant galaxies appear to have been discovered in the FRB. "These signals are *dispersed* according to a precise physical law and this *dispersion* is a key observable quantity which, in tandem with a redshift measurement, can be used for fundamental physical investigations. While every FRB has a DM, none before now have had a redshift measurement, due to the difficulty in pinpointing their celestial coordinates. Here we present the discovery of a FRB and the identification of a fading radio transient lasting ~6 days after the event, which we use to identify the host galaxy; we measure the galaxy's redshift to be z=0.492±0.008. The DM and redshift, in combination, provide a direct measurement of the cosmic density of ionized baryons in the intergalactic medium of ΩIGM=4.9±1.3%, including all of the so-called "missing baryons". The ~6-day transient is largely consistent with a *Short* GRB *radio afterglow*, and its existence and timescale do not support progenitor models such as giant pulses from pulsars, and supernovae. This contrasts with the interpretation of another recently discovered FRB, suggesting there are at least two classes of bursts"(Keane et al.).

We read: "For at least 15 years, radio pulses have been coming from space. They come from far away, even beyond our galaxy. Their characteristics are surprising. First of all they are elusive phenomena: they last a few milliseconds, they come from different directions. A mystery concerns the size of the emitting sources: at most a few hundred Km, which is the size of a planet, or a satellite, rather than a star. Each pulse is formed by a series of signals at frequencies close to 1.3 Giga Hertz, similar to the operation frequencies of a microwave oven. The package of radio waves, emitted with a FRB, at the beginning very compact, *breaks up* along the way, since the highest frequencies arrive first, i.e. the most energetic, and then the lowest ones. Analyzing the collected data, it is also possible to reconstruct their path: these radio impulses arrive from far away, as if from billions of light-years away. The first FRB was picked up on 24/7/2001 by the Radio Telescope of Parkes (Australia), but went unnoticed. Only now, that a higher number of cases is available, does a certain order seem to emerge, which does not seem to be random, as Michael Hippke (Institute for Data Analysis for Kernphysik, Germany), Wilfried Domainko (Max Planck Institute, Germany) and John Learned (University of Hawaii, USA) recently argued. And not only. It seems that the analysis of the signals of 11 FRBs (of which 9 collected by the Parkes radio-telescope, one by the Green Bank Telescope and another by Arecibo) reveals a suspicious *regularity*; for each FRB the *delay* in the arrival times of the lower frequencies is, with a good approximation, a *multiple* of a precise number: 187.5, multiplied by 2,3,4,5,6 and 9. Why? However, as Andrea Possenti (Cagliari's Radio-Telescope chief of Sardinia) explains: "Our group has identified new FRB_s, not yet published, where, however, there is no more *regularity*, that is the recurrence of the number 187.5. Moreover, it is difficult for such signals to come from an alien civilization: if they come from billions of light-years away, at the start these signals must have had a very high energy (equal to that emitted by the Sun in a month) so it is difficult to imagine a technology capable of producing such high energy". So what generates these signals? Extreme phenomena, so far only hypothesized: a *blitzar*, that is a hyper-compact star that once its rotation energy has been exhausted collapses becoming a *Black Hole* (BH). Or the explosion of primordial BH_s, formed shortly after the *Big Bang*. Or a *magnetar*, that is a star with one of the most intense magnetic fields in the Universe (millions of billions more than the Earth's one), and from whose superficial regions can be emitted, every now and then, very violent energy emissions" (Bernagozzi).

Huang and Geng noted that there are four main stages of detecting FRB: "First, the radio telescopes are uniformly pointing toward the sky at the time of the detections. Second, for the multi-beam receiver system, usually the signal was recorded only in very few beams, typically less than four, especially by adjacent beams. Third, FRB_s are characterized by large DM values, significantly larger than terrestrial sources of interference. Fourth, the observed behaviors of time delay and frequency evolution of FRB strongly indicate that cold-plasma dispersion should have been engraved in the radio signal"(Huang). The astronomers noted also that FRB cannot be quickly followed up to catch the counterparts in other wavelengths (as instead happens with GRB), as they are generally screened out from archive data, as was done by Huang and Geng in their research.

Thus, the absence of counterparts poses great difficulties in understanding the true nature of FRB.

As giant pulses from radio pulsars like the Crab, the first FRB detection, or *Lorimer FRB*, was extremely intense (30 Jy peak flux) and observed across a 288 MHz radio band. The DM of the radio burst was 375 pc cm^{-3} and was near the location of the Small Magellanic Cloud. In fact, Lorimer *team* points out: "Transient radio sources are difficult to detect, but they can potentially provide insights into a wide variety of astrophysical phenomena. Of particular interest is the detection of *short radio bursts*, which lasts no more than a few milliseconds, that may be produced by exotic events at cosmological distances, such as merging neutron stars or evaporating BH_s. Pulsar surveys are currently among the few records of the sky with good sensitivity to radio bursts, and they have the necessary temporal and spectral resolution required to unambiguously discriminate between short-duration astrophysical bursts and terrestrial interference. Indeed, they have recently been successfully mined to detect a new galactic population of transients associated with rotating neutron stars. The burst we report has a substantially higher inferred energy output than this class and has not been observed to repeat. This burst therefore represents an entirely new phenomenon. Pulsar surveys offer a rare opportunity to monitor the radio sky for impulsive burst-like events with millisecond durations. The burst was discovered during a search of archival data from a 1.4-GHz survey of the Magellanic Clouds using the multibeam receiver on the 64-m Parkes Radio Telescope in Australia. We found a 30-jansky dispersed burst, less than 5 milli-seconds in duration, located 3° from the Small Magellanic Cloud. The burst properties argue against a physical association with our Galaxy or the Small Magellanic Cloud. Current models for the free electron content in the universe imply that the burst is less than 1 gigaparsec distant. No further bursts were seen in 90 hours of additional observations, which implies that it was a singular event such as a supernova or coalescence of relativistic objects"(Lorimer).

In this event a particular effect was observed attributed to the *dispersion* produced by the diffuse plasmas that fill the interstellar and intergalactic space: what has just been described consists in the fact that "the detected radio signal is *dispersed*, that is its high frequency waves arrive before those at low frequency. The DM allows us to have an idea of the remoteness of the source that emitted the lightning, in fact the more the signal is distributed, the more plasma has crossed and therefore the more distant its source is. Analyzing the data, Lorimer and his colleagues estimated that the explosion could be located a few billion light year away from the"(Del Puppo).

Therefore, examining in more detail the data from the Parkes Radio Telescope (Australia), Lorimer and colleagues found something curious in the *dispersion* of the burst's wavelengths. Its short wavelength components arrived at the telescope a fraction of a second before longer wavelengths. In fact, the radio-signal that streamed into the Parkes dish was curiously smeared out, with **its** high frequency waves arriving a fraction of second earlier than its low-frequency counterparts, an effect that can be caused by longer-wavelength light moving ever so slightly slower through electrons in clouds of cold plasma that suffuse the space between stars and galaxies. The longer the delay between the arrival of a burst's short and long wavelength, the more intervening electrons it passed through and the greater the distance it traveled. These results suggested the burst had come from as much as a few billion light-years away (Lorimer et al.).

2.2 Possible Causes Of Em *Dispersion*

"The phenomenon that the *index of refraction* (*n*) depends upon the frequency (ω) is called the phenomenon of *dispersion*, because it is the basis of the fact that light is *dispersed* by a prism into a spectrum" (Feynman1965a). The *n* value determines how much the speed and the wave length of the radiation are reduced with respect to their vacuum values. As we know, the *n* of a material (Young) is a dimensionless value describing *how fast light travels* through the material. It is defined as:

$$n = \frac{c}{v_p} \qquad (1),$$

Where c is the speed of light in vacuum and *vp* is the phase velocity of light in the medium. The phase velocity is the speed at which the crests or the phase of the wave moves (which may be different from the group velocity), i.e. the speed at which the pulse of light or the envelope of the wave moves. From Eq. (1), the speed of light in a medium is v = c/n; which implies that the vacuum has *n* = 1.

Feynman points out: "*n* is higher for blue light than for red light. That is the reason why a prism bends the light more in the blue than in the red. So *n* rises slowly with the frequency (ω) of the light.

We have a formula for *n* in terms of the properties of the atoms of the material and of the ω of the light:

$$n = 1 + \frac{N q_e^2}{2\epsilon_o m(\omega_o^2 - \omega^2)} \qquad (2),$$

where ω_o is the *resonant frequency* of an electron bound in an atom, ω is the frequency (angular) of the radiation, *N* is the number of charges per unit volume, ϵ_o the dielectric constant vacuum, *m* and q_e the mass and the charge on an electron.

Why should there be charges moving? We know that all material consists of atoms containing electrons.

When the electric field of the *source* acts on these atoms it drives the electrons up and down, because it exerts a force on the electrons. And moving electrons generate a field — they constitute new radiators. These new radiators are related to the source, because they are driven by the field of the source. The total field is not just the field of the source, but it is modified by the additional contribution from the other moving charges.

The equation (2) gives the explanation of the *index of refraction* (*n*) that we wished to obtain. In the above process we obtained something very interesting. For we have not a number for *n*, which can be computed from the basic atomic quantities, but we have also learned how *n* should vary with the frequency (ω) of the light"(Feynman 1965, a).

We read: "The discovery of repeating bursts from one source, and its subsequent localization to a dwarf galaxy at a distance of 3.7 billion light years, confirmed that the population of FRB_s is located at cosmological distances. However, the nature of the emission remains elusive. We found 20 FRB_s, none of which repeated during follow-up observations between 185-1,097 hours after the initial detections. The sample includes both the nearest and the most energetic bursts detected so far. The survey demonstrates that there is a relationship between burst *dispersion* and brightness and that the high-fluence bursts are the nearby analogues of the more distant events found in higher-sensitivity, narrower-field surveys"(Shannon et al.). Regarding the FRB_s, in fact, we can read: "The component frequencies of each burst are delayed by different amounts of time depending on the wavelength. This delay is described by a value referred to as a *dispersion* measure(DM) This results in a received signal that sweeps rapidly down in frequency, as longer wavelengths are delayed more"(Wikipedia). It appears even more evident with GRB_s.

Indeed, the most surprising thing, in our opinion, about FRB_s and GRB_s is precisely in their peculiar propagation modes. "As these signals emitted by a FRB pass through the cosmic vacuum, the lower frequencies of this *packet* 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" (Bernagozzi), so the phenomenon is able to be highlighted. 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 electromagnetic (EM) energy of the wave is dispersed, i.e. dissipated and sold to the plasma in the form of heat. Plasma behavior 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 (ω) of the wave frequency" (Bosia):

$$\alpha = \frac{1}{\omega^2} \quad (3),$$

as to say that, in these circumstances, in full agreement with Feynman (1965, a), the DM, indicated by the *dispersion value* (α), is inversely proportional to the frequency (ω) of the involved wave.

This is why among the EM waves, although belonging to the same *wave packet*, those having a greater oscillation frequency (ω) suffer very little from the *slowing down* of their propagation speed, slowing down induced by the free electrons of the interstellar medium. One wonders: why, along the way, only lower frequencies interact with particles? Why higher frequencies should not likewise interact? And yet, as can be seen from the literature, a similar explanation is provided by astronomers also with regard to GRB_s.

2.3 Grb'S *Afterglow*

Well, the most interesting thing, in our opinion, comes out by studying the electromagnetic radiations (EMR_s) released with a GRB, which affect the whole EM spectrum. Thus, analyzing 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 particular modalities. That is, these EM waves (EMW_s), although of different frequencies, do not reach us all together in about twenty seconds, that is the duration corresponding to their emission time, as the Equivalence Principle requires. No! Once at their destination, EMW_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!

As we all know, 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. Thus, though a GRB is very short (referring to the time we can see it, or detect it), it is often followed by an EM signal which can last for many days. This signal, this "afterglow", is made of several EMR_s, with different frequencies. To this purpose, 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 (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"(Sari). So, from an EM source emitting in just a few seconds, the signals arrive to us scattered even in 30 days!

As it is known, in fact, "several models for the origin of GRB postulated that the initial burst of gamma rays should be followed by slowly fading emission at longer wavelengths created by collisions between the burst ejecta and interstellar gas. This fading emission would be called *the Afterglow*. Then, in February 1997 when 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. 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. Well, later another major breakthrough occurred with the next event registered by BeppoSAX, GRB 970508. This event was localized within four hours of its discovery, allowing research teams to begin making observations much sooner than any previous burst. The spectrum of the object revealed a redshift of z = 0.835, placing the burst at a distance of roughly 6 billion light years from Earth"(Wikipedia,2018).

Therefore, "the *Burst* in the gamma 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 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 "(Astronomical Observatory of Palermo).

The typical GRB's EM *swarms* detected with Beppo-SAX have been later widely and repeatedly confirmed by the *Swift* satellite, using a secret technology borrowed from the US military industry.

As Chincarini reminds us "the feature that makes *Swift* irreplaceable in the study of GRB_s is its ability to observe many *wavelengths*, as well as its incomparable pointing speed. There are three instruments on the satellite: BAT (Burst Alert Telescope) sensitive to radiation between 15 and 200 keV, XRT an X-ray Telescope sensitive to radiation between 0.3 and 10 KeV, and UVOT operating in the ultraviolet and visible at wavelengths between 1700 and 6000 Å. Like a *sentinel*, BAT is able to observe a vast area of the sky at the same time. From the moment in which BAT sees a γ Flash, to the moment the XRT and UVOT instruments are positioned in the direction of the GRB, they are at most 100 seconds. Considering the fact that the previous satellites required hours to be able to point the instruments in the direction of the lightning, it is possible to state that *Swift* really represents a turning tool in the study of the GRB_s. Its speed has allowed us to deepen our knowledge about the first phases of the lightning, key moments for understanding the physical phenomenon.

Thanks to *Swift* – besides - it is now possible for the entire scientific community to access the observations collected by the instruments on the satellite even in "dead" moments, i.e. when there is no GRB observation in progress. In this way the satellite also contributes to the study of galaxies, supernovae and all those astronomical phenomena involving high energies, in particular rapidly varying *X-ray* sources (also called *X transients*) "(Chincarini).

At this regard,: astronomers who analysed the intensity of the frequencies got to the conclusion that this depends on the fact that the GRB, often, has first to go through gases released by the supernovae (if this was the source), gas containing mainly iron.

Why can't we explain, instead, this phenomenon as a dilatation of the time the radiation take to reach us from the EM spectrum? 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 GRB (this is an important particular), reach us in different times. Though with very little staggering, because of the different energy related to their frequencies, and thus with different propagation speeds. If this was true, it would explain why a GRB, which has the most energy of all (and likely the highest propagation speed, after the Big Bang), reaches us 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, (and simultaneously to GRB), land on earth separately, staggered with some days. Mathematics shows us how the *dispersion phenomenon* of the EMR slows down EMW_s with minor oscillation frequency, as shown in equations (2) and (3).

These are the facts! And yet, in everyday life, we had never noticed it.

2.4 Propagation Speed Of Electromagnetic Waves (Emw_s)

Of course, in the cases mentioned above we refer to infinitesimal differences, with no significance from a practical point of view, with any effect and any advantage on the everyday life. Why these possible differences have never been observed? The reason is that they are so minimal, imperceptible, that they are not shown in the distances we know, but they may be very interesting from a scientific point of view, since the *assumption* that all EMW_s travel at the same speed, (corresponding to that of visible light: 299792.458 (± 0.4) Km/sec, in vacuum – Achenbach -) would fail. One could immediately reply: the various EM spectrum waves actually travel all at the same speed. However, when they do not travel in the vacuum, but through a medium, it is the specific *refractive index* (n) of the medium to slow down the different EMW_s emitted by the source: radio waves (even if of different wavelengths) in the case of FRB_s, or the entire EM spectrum in the case of GRB_s. Well, we must keep in mind that, as we know, the intergalactic and interstellar spaces are not completely *empty*, but they have an average of 3-6 atoms per cubic meter, as confirmed, among other things, by the constant presence of the interstellar medium that, precisely, slows down the EMR_s (mostly the less energetic ones). As known, in the description of physic systems, *vacuum* is considered as the minimum energy state, or *Zero Point Energy* (Chandrasekhar) (Puccini, 2011, c) which only in some cases corresponds to the *almost* total absence of particles or waves.

"It was thought that the interstellar and inter-galactic spaces were expanses of vacuum, but then with the *theory of quantum fields* (QFT) it was stated that space is never really empty, but is pervaded by quantum fields present everywhere: the various particles are, in fact, *excited states* of these fields. Space appears empty when the fields are at the lowest energy level, whereas space comes alive with visible matter and energy when the fields are excited. Wheeler said: empty space is not empty, but it is the kingdom of the richest and most surprising Physics"(Ferris).

Barrow states: "The quantum revolution has shown us why the old concept of vacuum as an empty box was unsustainable. From then on, the vacuum was simply the state that remained when everything that could be removed from the box had been removed. This state was by no means the absence of anything: it was only the lowest possible energy state. There was always something remaining: an energy of emptiness that permeated every fiber of the universe. It is never possible to achieve a perfect vacuum. A concept confirmed by the evident impossibility of extracting all the atoms from the vessel to the last. Any small perturbation or attempt to intervene on the vacuum would increase its energy. Newton was convinced that a means "more rare and thin than air" must still be present in the vessel in which the void was made: Newton was ahead of his time.

The Uncertainty Principle (UP) and Quantum Theory have revolutionized the concept of vacuum. Saying that in a box there are no particles, that it is completely free from any mass and energy, is in contrast to the UP, as it assumes to have complete information on the motion at any point and on the energy of the system at a given instant of time. With Quantum Theory it emerged that the last surprise offered by the UP was shown as what was called Zero Point Energy (ZPE)"(Barrow), meaning that it will never be possible to completely empty a container, but there will always remain "an irreducible fundamental energy, which can never be completely eliminated. This limitation reflects the reality of the UP, since if we know the position of an oscillating particle, its motion and therefore its energy are uncertain"(Barrow). He adds: "The entity of the *uncertainty* is precisely the ZPE. This means that the concept of vacuum must be reconsidered in some way, since it can no longer be associated with the idea of null or empty space"(Barrow).

Thus the so-called speed of light in the *vacuum*, represented by c, could represent just a theoretical, hypothetical value, since it is not obtained even in the so-called *cosmic void*, in the more sparse sidereal spaces. Moreover, *absolute vacuum* does not exist, nor can it be created. Therefore, also the intergalactic spaces probably have a value of $n \neq 1$.

In its turn, Feynman says: “In the partial reflection from two glass 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 of the blue light). The reflection cycles repeat with different intervals because the hand of the imaginary chronometer has to go more quickly when it follows a blue photon, than when it follows a red photon. In fact, the rotation speed of the hand is the only difference between a red photon and a blue one, or a photon of any other colour, including X rays and radio waves” (Feynman 1985). It comes out then, that the blue colour travels with a higher speed than the red one, in the same time. That is a photon with a higher frequency (the blue photon) travels with a higher speed than another photon with a frequency just a bit lower (the red one). That is the higher the frequency of a photon, the higher its speed, compared to photons with lower frequency. Let's analyse now how photons 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 photon than when it follows a red photon"(Feynman 1985).

We had already under our eyes that the blue light, more frequent and more energetic, travelled more quickly than a photon with a lower frequency and energy, such as the red photon. Thus, if we have a difference of speed between two photons 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 a X ray or a γ ray, and the visible light itself, or even if compared to the radio waves. We quote: "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"(Feynman 1985). This may be the further proof of the different propagation speed of the EMW_s, that is of the different kind of photons. Indeed one of the frequencies of the X rays is 10000 times higher than the visible light. We can infer from this that the hand of the imaginary chronometer goes with a speed directly proportional to the frequency. In fact the frequency of the blue light is higher than the red one's (the hand of the chronometer of the blue photon goes with a higher speed than the one of the red photon), just as, on their turn, X rays have a much higher frequency than the blue light (the hand of the imaginary chronometer of the X rays has a speed 10000 times higher than the chronometer of the blue light). In the same way if we consider the γ rays, more frequent and more energetic than X rays, we will probably have that the hand of their imaginary chronometer has a speed higher than the hand of the chronometer of X rays. As a confirmation of these deductions we read: "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 photon 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 in account" (Feynman 1985). That is, it is likely that the speed of the photons is lower or higher than *c*, and in short distances these probabilities become "essential".

In his "Lectiones opticae" (1670), Newton showed a completely new hypothesis. He establishes a completely different relationship between light and colors: white light is a mixture of luminous rays, having different degrees of speed, that is of different colors, which therefore are not generated *ex novo* by mixing, but only by separation from the mixture in which they are already present. That is, when differently fast light rays are separated from mixing (through refraction) and hit the optic nerve they cause the sensations corresponding to the various colors. The action of the prism, therefore, 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, gray or black. In short, for Newton light is *intrinsically* a mixture of rays having a different degree of speed (Newton 1670).

As early as 1664, Newton had stated: "Because of refraction, the light beam slowly moved is separated from the fast ones, two kind of colors arise, namely: the slow ones, the fast ones and the ones that are moved neither too fast nor slow" (Newton 1664).

In accordance with what Feynman pointed out, at the beginning of last century, as Asimov reminds us "Lenard had discovered that when the 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. When physicists started to make experiments on this phenomenon (photoelectric effect) they realized, with great surprise, that if they raised the light intensity, the energy of the emitted electrons did not increase. What influenced them instead, were the different colours of the wavelength of the 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. 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"(Asimov), that is higher than the energy which keep the electron linked to the atom: 'threshold value or shearing value'.

"Anyway, the higher the energy of the quantum, the higher was also the speed of the electron pushed out from the metal"(Asimov).

Thus we have that those photons carrying a bigger energetic charge, and at the same time with a higher frequency (i.e. the blue photon), give a higher speed to the electron they hit. Whereas, less energetic photons (such as red photons) push out the electrons with a lower speed. This is certain. However we also know that the photon is a corpuscle, a "grain", a very little sphere which, just as a billiard small ball thrown with the right energy, pushes away the electron (the opponent ball). It could be a suitable example, since the *kinetic energy* (K_E) 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" (Fermi 1926). Therefore, for this reason, if the electrons pushed away by a blue photon travel with a higher speed than those hit by a red photon (Feynman 1985), we can infer that they have been given a different K_E by the respective incident photons (Puccini 2005, b).

It should be inferred that the blue photons travel with a higher speed than the red ones!

According to the *Variable Speed of Light Theory* (Albrecht-Magueijo 1999) the speed of light was greater in the primordial universe. To this purpose, related to the Inflationary Theory of Alan Guth (1981), there is no satisfactory physical explanation to justify expansion speed of the *inflationary phase*, much bigger than the speed of light. Thus, we presented and discussed a paper (Puccini 2010) at an Electromagnetics Symposium held in Cambridge (Ma), where we stated that the *inflationary expansion* of the Universe was probably conducted by very energetic photons, since the Big Bang (*BB*) represents a source of very high electromagnetic (EM) emission.

We think, in fact, that the photons emitted with the *BB* had an energy significantly bigger than the more energetic γ photons (~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 and to Guth on the other.

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 un mezzo) 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" (Feynman 1965, a).

In short, Feynman' s statement, one of the most expert in the secrets of light, implies that gamma rays travel faster than *visible* light! This represents a very authoritative confirmation of our concepts, of our hypothesis. This is of great honor for us and greatly comforts us.

2.5 Çerenkov Light

Moreover, it is not surprising that electrons may travel faster than visible light, since we are referring to the speed of light in a mean different from the *vacuum*. Thus, no physical theory or law are violated. In 1934 the Russian physicist Pavel Alekseeviç Çerenkov (Nobel Prize for Physics, 1958) was the first to highlight the effect generated by the impact of γ radiation and the layers of high terrestrial atmosphere (Çerenkov). As is well-known, the most energetic γ radiations hitting the Earth are emitted by intense electromagnetic (EM) sources represented mainly by explosions of supernovae or by the collision of two neutron stars (creating GRB_s). Çerenkov pointed out that γ radiations, hitting the molecules of the high atmosphere, can make them free electrons.

As Feynman remind us "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*" (Feynman, 1965, a).

Namely, what surprised Çerenkov was that electrons hit by γ radiations travelled with a speed higher than the visible light in the air, and that at this speed they could emit 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 *Çerenkov Light* (*ÇL*). This can be explained easily considering that the atmospheric *refraction index* (*n*) is bigger than the vacuum refraction index: n_v. If we consider n_v =1, we have that the atmospheric refraction index is: 1.000293, carbon dioxide's is 1.00045, water's is 1.333. Thus, common visible light going through the atmosphere travels with a speed lower than in vacuum (*c*). In fact, as known when the light goes through a mean different from vacuum its speed 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 are the lightest elementary particles, thus the impulse they receive by γ photons can make them accelerate till a relativistic speed.

This is the crucial point, in our opinion, when considering the *ÇL* (Puccini 2012, a). *ÇL*, in fact, is emitted only if the hit particle is also accelerated sufficiently. *Conditio sine qua non*: within EM Spectrum only γ photons manage to give electrons such a speed to be able to emit the *ÇL*. Why doesn't it happen with EMR_s with lower frequency (*ω*)? It is useful to underline that *ÇL*, or *Çerenkov Effect*, seems to us very similar to the photoelectric effect or to the Compton effect. In these cases too the electrons are thrown out from the struck atom by a sufficient energetic EMR.

The only difference is that for the photoelectric effect it is necessary just the visible light, in the case of Compton effect it is necessary the force, the *radiation pressure*, given by X photons to throw out electrons from graphite, whereas in order to have the *Çerenkov Effect* it is necessary exclusively the γ photon. Why? An explanation can be found in the different EM frequencies used.

As is well-known, our atmosphere is constantly bombed 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 in these cases the electron will not be able to emit the *ÇL*.

Why? The X photon does not manage to give the hit electron a sufficient *kinetic energy* (K_E), that is a speed similar to the one given by a γ photon (Puccini 2012, a). This may be the difference and the explanation. However this explanation seems to us not sufficient.

What is the intimate physical mechanism so that, in the atmosphere, an electron hit by a X photon does not emit *ÇL*? We can say because it has not been sufficiently accelerated, as a γ photon is able to do instead. We wonder then: why a γ photon manages to accelerate the electron with a speed bigger than a X photon is able to do, or a less energetic photon? It hasn't been explained properly, however it is what happens with photoelectric effect. As Lenard first pointed out, when some metals are struck by EMR_s with different wavelength (λ), electrons are pushed out with different velocities, in a rate inversely proportional to the value of λ and directly proportional to the frequency (*ω*) of the EM wave (EMW) (Lenard). Therefore, what we learn from the Lenard's experiment?

We learn that the EMR_s having a greater frequency of oscillation (ω), that is the more energetic, transmit a greater speed to the hit particles, compared to what the less energetic EMR_s can do. It is unmistakable! These are the facts. That is, the more energetic photons 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 K_E to the struck particles, compared to the less energetic EMW_s (it is possible to indirectly infer that the more energetic photons travel faster than the less energetic ones). It is precisely this different K_E transmitted that can make us understand why only the electrons affected by γ rays can generate the *ÇL*. And yet, just the *ÇL*, and its induction mechanism, provide us with another very important piece of information: the particles capable of striking the electrons so violently (so as to generate the *ÇL*), i.e. γ photons, receive at their origin, from their own EM source, a very high energy and thrust (proportionally greater than the photons 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 K_E is preserved.

In brief, this is the keystone of our paper. The *dispersion phenomenon* is not in itself the cause of different propagation speed of the EMW_s, as detected for long distances, but it is simply the mirror, the picture of the phenomenon. In our opinion it just shows it, without influencing it. On the contrary, we believe that the real cause, the deeper reason behind the peculiarity of FRB_s and GRB_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*, the acceleration given to the photons produced.

All this is in perfect agreement with what emerges from Feynman's chronometer with blue light and red light, with the relative clarifications of Fermi previously reported (Fermi 1926), with Lenard's experiment, with the photoelectric effect, with the Çerenkov effect, etc...

In short, we believe that it is the amount of energy given to photons by EM source to determine its specific speed.

2.6 Different Photon'S *Momenta*

As Feynman (1965, a) reminds us, "Between very elementary objects, the collisions are always *elastic* or very nearly elastic". He adds: "That the velocities *before* and *after* an elastic collision are equal is a matter of conservation of K_E"(Feynman 1965, b).

The propagation speed of a wave, or of a particle, can be also calculated from the analysis of its *momentum* (***p***). Fermi writes: "The photon too, as other particles, is a corpuscle, a *light's quantum* and has a its own *momentum* (***p***), through which transfers all its energy to the hit particle"(Fermi 1926). Feynman (1965, a) adds: "Each photon has an energy and a *momentum* (***p***)". As known, the *momentum*, indeed, was introduced in order to calculate how much a body in motion "*weighs*".

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 *momentum* is a measure in itself, since it depends on both the speed and the quantity of matter" (Newton, 1687).

The only mass or speed do not therefore describe what happens in real cases. Newton then referred to what we call *momentum*: something that originates jointly from the speed and quantity of matter. Newton therefore defined this vector magnitude in the following way:

$$\vec{p} = m \cdot \vec{v} \qquad (4).$$

Eq. (4) describes the *quantity of motion* (***p***) of a body having a mass *m* and moving at a speed *v*.

Well, the *momentum* of a particle is the product of 2 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 $\boldsymbol{v}$. In fact, the vector ***p*** has the same direction and the same line of the speed *v* and its module is the mass times the speed module.

We therefore find it of particular value, as well as rich in meaning and potential, to point out that the momentum module of an object, i.e. a *quantum object*, is directly proportional to the mass of the object, and to its speed too!

Briefly, greater ***p*** greater the *velocity* of the considered particle, just in a directly proportional rate!

Since momentum has a direction, it can be used to predict the resulting direction and speed of motion of objects after they collide. Below, the basic properties of momentum are described in one dimension. The vector equations are almost identical to the scalar equations. The unit of ***p*** is the product of the units of mass and velocity. In *cgs* units, if the mass is in grams and the velocity in centimeters per second, then the momentum is in gram centimeters per second (g·cm/s).

Feynman points out: "In Newtonian physics ***p*** value is given by: ***p*** = *m***v**. But since ***p*** is related to the *wave number* (***K***), there exists in nature still another way to measure the ***p*** of a particle –photon or otherwise- which has no classical analog, because it uses the formula:

$$\boldsymbol{p} = \hbar \boldsymbol{K} \qquad (5),$$

where $\hbar$ is the *rationalized* Planck's constant and ***K*** indicates the quantity of waves carried with the considered *momentum* (***p***)"(Feynman 1965, b). This parameter (***K***) is similar to the frequency. He adds: "Now in Quantum Mechanics (*QM*) it turns out that ***p*** is a different thing—it is no longer *m*v. It is hard to define exactly what is meant by the velocity of a particle, but ***p*** still exists. In spite of the differences, the law of conservation of ***p*** holds also in *QM.* In *QM* the difference is that when the particles are represented as particles, ***p*** is still *m*v, but when the particles are represented as waves, ***p*** is measured by the number of waves per centimeter (equation 5): the greater this number of waves, the greater ***p***"(Feynman 1965, a). In short, the Eq. (5) shows the deep bond in a wave between ***p*** and the *wave number* (***K***): these values are directly proportional, as to say that greater the wave frequency (ω), the greater ***p***.

Moreover, in *QM* the particle may be also considered as a wave. As we know, in fact, without experimental data, de Broglie suggested to give each particle an its own wave length (λ) depending only on the *momentum* (***p***) of the particle itself:

$$\boldsymbol{p} = \frac{h}{\lambda} \qquad (6),$$

where *h* is the Planck's constant (de Broglie). Therefore, according to the de Broglie formula, any particle seems to be something periodic, oscillating as a wave, with a universal relation between the λ of the particle and modulus ***p*** (Puccini 2011, a) (Puccini 2017).

Let's to analyse de Broglie's formula. As known, the Planck's constant (*h*) is equal to $6.626 \cdot 10^{-27}$ [erg·s] and λ is the wave length of the considered photon (or other particles). The mean wave length of a photon in the optical band corresponds to $\approx 5 \cdot 10^{-5}$[cm] (Weinberg 1977) and its ***p*** is:

$$\boldsymbol{p} = \frac{6.626 \cdot 10^{-27}[erg \cdot s]}{5 \cdot 10^{-5}[cm]} \qquad (7).$$

Since 1 *erg* = g·cm^2/s^2, we have:

$$\boldsymbol{p} = \frac{6.626 \cdot 10^{-27}[g \cdot \frac{cm^2}{s}]}{5 \cdot 10^{-5}[cm]} \qquad (8)$$

$$\boldsymbol{p} = 1.3252 \cdot 10^{-22} \, [\frac{g \cdot cm}{s}] \qquad (9).$$

As Eq. (9) shows, the momentum (***p***) of a visible photon carries out a *dynamic-mass*, a *pushing* *momentum* bigger than the *rest mass* of 100 protons. No surprise! At this regard, Feynman states: "The *momentum*, as a mechanical quantity, is difficult to hide. Nevertheless, momentum *can* be hidden –in the electro-magnetic (EM) field, for example. This case is another effect of relativity" Feynman (1965, b). It's like saying that *momentum* carries, albeit *hidden*, a dynamic-mass (Puccini,2018, b). Briefly, other than photons massless! It is the opposite: with these masses carried out by photons we can better understand, and justify the *light pressure* action or *'photonic pressure'* or *radiant pressure* (Puccini 2019, c).

Feynman (1965, a) adds: "In the Einstein Relativity Theory, anything which has energy has mass—mass in the sense that it is attracted gravitationally. Even light, which has en energy, has a *mass*.

When a light beam, which has energy in it, comes past the sun there is an attraction on it by the sun. Thus the light does not go straight, but is deflected".

In short, it is incontrovertible that the EM radiation (EMR) exerts a compressive action on the hit object: the so-called *Radiation Pressure.* It was first pointed out by Iohanne Keplero in 1619 the concept of *Radiation Pressure* to explain the observation that a tail of a comet always points away from the Sun (Keplero). In fact, Feynman writes: "I want to emphasize 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 particle"(Feynman 1985). He points out: "When light is shining on a charge and it is oscilling in response to that charge, there is a driving *Force* in the direction of the light beam. This *Force* is called *Radiation Pressure* or *Light Pressure* (*F*). Let us determine how strong the *Radiation Pressure* is. Evidently it is that the light's force (*F*) on a particle, in a magnetic field (*B*), is given by:

$$F = q\boldsymbol{v}\boldsymbol{B} \quad (10),$$

and it is at right angles both to the field and to velocity (**v**); q is the charge. Since everything is oscillating, it is the time average of this,$\langle F\rangle$. We know that the strength of the magnetic field is the same as the strength of the electric field (***E)*** divided by c (the velocity of light in vacuum), so we need to find the average of the electric field, times the velocity, times the charge, times $1/c$:

$$F = q\,\frac{\boldsymbol{vE}}{c} \quad (11).$$

But the charge q times the field E is the electric force on a charge, and the force on the charge times the velocity is the work dW/dt being done on the charge! Therefore the force, the *Pushing Momentum*, that is delivered per second by the light, is equal to $1/c$ times the *energy absorbed* from the light per second! That is a general rule, since we did not say how strong the oscillator was, or whether some of the charges cancel out. *In any circumstance where light is being absorbed, there is a Pressure.* The *momentum* that the light delivers is always equal to the energy that is absorbed, divided by c:

$$F = \frac{\frac{dW}{dt}}{c} \quad (12).$$

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's constant) times the frequency (ω):

$$E = h\,\omega \quad (13).$$

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***):

$$\boldsymbol{p} = \frac{E}{c} = \frac{h\omega}{c} \quad (14).$$

The direction of the *momentum* is, of course, the direction of propagation of the light. So, to put it in the vector form:

$$\mathrm{E} = h\,\omega\;\boldsymbol{p} = \frac{h\omega}{c} \quad (15).$$

We also know, of course, that the energy and the *momentum* of a particle should form a *four-vector.* Therefore It is a good thing that the latter equation has the same constant (h) in both cases; it means that the Quantum Theory and the theory of Relativity are mutually consistent"(Feynman 1965, a).

Let's now analyze the ***p*** value of photons with different wave length (λ) (Abdel Raouf et al.), with reference to the de Broglie formula. To this purpose, let's calculate the ***p*** of radio waves with different λ, as happens with FRB_s and, beyond the *dispersion phenomenon.* Let's try to verify if the different arrival times (on the Hearth) of different radio waves can be attributable, first of all, to their *momenta*. Thus, we consider a radio wave with $\lambda=10^{-3}$[cm]; then let's calculate its ***p***:

$$\boldsymbol{p} = \frac{6.626\cdot10^{-27}[g\cdot\frac{cm^2}{s}]}{10^{-3}[cm]} \quad (16),$$

we have:

$$\boldsymbol{p} = 6.626\cdot10^{-24}\,[g\cdot\frac{cm}{s}] \quad (17).$$

Let's consider now a radio wave with a wavelength (λ) of an higher order of magnitude, i.e. with $\lambda = 10^{-2}$[cm] and calculate its ***p***:

$$\boldsymbol{p} = 6.626\cdot10^{-25}\,[g\cdot\frac{cm}{s}] \quad (18).$$

Eq. (18) shows clearly that also the ***p*** value changed of an order of magnitude, but less, according to the de Broglie formula (Eq.6), where it can be easily inferred that ***p*** and λ are inversely proportional (Puccini 2019, a). However we must also consider that, according to ***p*** =*m* **v** (Eq. 4), ***p*** and **v** (speed) are directly proportional: as to say that greater ***p*** greater **v** (Puccini 2012, a). If we compare the equations (4) and (6), we easily notice that, as the λ of any particle (or of a particle/wave such as the photon) 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 FRB, the longest radio waves arrive on Heart a fraction of time later than shorter radio waves. This is, in our opinion, the intimate mechanism, the deepest reason behind the peculiar propagation times of the EMW_s, both in the FRB_s and in the GRB_s. In fact, this is even more evident in the GRB_s. To this purpose, as known, unlike the FRB_s, 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. In our opinion, the EM swarm that characterizes a GRB, its Afterglow, represent a clear proof of the different EMW_s propagation times, in a ratio inversely proportional to the respective wavelengths (λ). What we argue is clearly confirmed by the calculation of the ***p*** values related to the different λ In fact, when considering equation (9), concerning the wavelength of the visible light, we notice a difference of 2-3 order of magnitude bigger than the ***p*** values concerning the radio waves.

X rays too are carried by a GRB. Let's consider then, an X photon with λ= 10^{-10} [cm]:

$$\boldsymbol{p} = \frac{6.626\cdot 10^{-27}[g\cdot \frac{cm^2}{s}]}{10^{-10}[cm]} \quad (19),$$

$$\boldsymbol{p} = 6.626\cdot 10^{-17}\,[g \cdot \frac{cm}{s}] \quad (20).$$

In this case, the difference compared to a radio wave is 7-8 orders of magnitude greater. Finally, a fundamental characteristic of the GRB_s is that the first EMW_s to arrive on Earth are those that carry the γ photons: let's try to understand why. Let's to consider a γ ray with a λ = 10^{-12}[cm]:

$$\boldsymbol{p} = \frac{6.626\cdot 10^{-27}[g\cdot \frac{cm^2}{s}]}{10^{-12}[cm]} \quad (21),$$

$$\boldsymbol{p} = 6.626\cdot 10^{-15}\,[g \cdot \frac{cm}{s}] \quad (22).$$

We have, in other words, that the ***p*** value of a γ photon is 2 orders of magnitude bigger than that of an X photon, of 7 orders of magnitude bigger than that of an optic photon and, even, 9-10 orders of magnitude bigger than a radio wave.

In short, they are precisely these ***p*** value differences, in relation to the different considered wavelengths, that represent the only valid explanation, in our opinion, to explain the characteristic *EM swarm* that goes with the GRB, just as a tail of a comet.

2.7 Uncertainty Principle Applied To Electromagnetic Radiations

As is well-known, the Heisenberg's Uncertainty Principle (UP) states that energy (Δ_E) and time (Δ_T) are two *complementary parameters*, just as the position and the *momentum* of a particle.

From Heisenberg's equation we learn:

$$\Delta_E \cdot \Delta_T \geq \frac{h}{2\pi} \quad (23),$$

where *h* is the Planck's constant. Therefore, from UP concerning time and energy, it comes out that as one of the two parameters increases the other will decrease proportionally (Heisenberg 1927) (Heisenberg 1930).

If we apply the UP to the different Electromagnetic Radiations (EMR_s) we have that the higher the energy an EMR carries, the shorter its time of travelling and hence the higher the speed of the considered radiation (Puccini 2005, a). This is in perfect agreement with what happens with the peculiar propagation times of the EMR_s carried both by GRB_s, and by FRB_s, where it is very evident the delay in arrival time between different frequency component of the burst.

With regard to FRB_s, in fact, it always emerges that its high frequency radio waves arriving a fraction of second earlier than its low frequency radio waves.

These are the facts: they unquestionably demonstrate that the higher the frequency (or the energy) of an EMR, the higher its propagation speed in the space. Therefore, this is the real and deepest cause, in our opinion, of the different propagation velocities of the EMR_s, as it clearly emerges both for long distances (as with FRB_s and GRB_s), as for short distances (as with the blue and red light in the glass).

Well, in all honesty, we consider the so-called *dispersion phenomenon* of the EM signals (presumably caused by free electrons in the intergalactic space, without explaining why even the most energetic signals are not slowed down) simply and only a consequence of a different propagation speed of the EMR_s, directly proportional to their frequency, or energy.

This is in perfect agreement with the *dispersion* measure (DM) which, as Feynman reminds us "the fact that light is *dispersed* depends upon its frequency"(Feynman 1965, a).

This phenomenon is much more pronounced in the GRB. Indeed, the few day long *EM swarm*, related to the different EMR_s emitted by a GRB in just 20 seconds, may represent a demonstration of the different propagation speeds of EM waves (EMW_s) depending on the different energy they carry.

3. Conclusions

It is the name itself to tell us that the *momentum* (***p***) of a particle is related to its speed (**v**) too.

In fact, the ***p*** value indicates the *quantity of motion* of a particle, photon included, in a unit of time (generally the second). It is as saying how much space the particle travels in that time unit. If the value of this quantity of motion performed by the particle varies, i.e. increases, it means that the particle has traveled more space in the same time unit. But if we leave the time parameter fixed, when the space crossed is greater (compared to a previous measurement), it means that the considered particle moved faster. So, if a particle, or a photon (P), shows a higher ***p*** value than another P, it means that it is going faster.

We can find in Physics itself a confirmation of what we are stating. To this purpose, we learn from Fermi: "The quantum of light is given an *energy* (*E*) proportional to their *frequency* (*ω*), and expressed precisely by:

$$E = h\,\omega \qquad (24),$$

where *h* is the Planck's constant. As for the light quantum it is necessary to give it a quantity of motion, or *momentum* (***p***) too. So, the *electromagnetic momentum* (*E/c*) is linked to the propagation of light energy (*E*). We must therefore also give the ***p*** to a *quantum of energy* (*h ω*):

$$\boldsymbol{p} = \frac{h\,\omega}{c} \qquad (25),$$

where *c* is the speed of light in vacuum"(Fermi 1926) (Fermi 2009).

The Eq. (25) can also be written as follows:

$$\boldsymbol{p} = \frac{E}{c} \qquad (26),$$

Besides we have the famous equation related to the Einstein *Mass Energy Equivalence Principle* (1905):

$$E = m\,c^2 \qquad (27),$$

thus Eq. (26) can be represented as follows:

$$\boldsymbol{p} = \frac{mc^2}{c} = m\,c \qquad (28).$$

The Eq. (28) is completely superimposable to Eq. (4), ***p*** =***mv***, indeed it is exactly identical in the case of the photon (P).

We can conclude that velocity (*v* or *c*) and *momentum* (***p***) are closely linked, in a directly.

proportional relationship, so that in our opinion it can be affirmed, without any doubt, that a particle with a higher ***p*** value also implies a higher speed, compared to an analogous particle, i.e. two P_s of different wavelength (*λ*) (Puccini2011d, 2019d). A clear confirmation is provided by the numerous equations concerning the *momenta* of the various EMW_s analyzed, and where the greater ***p*** value corresponds exactly to the γ rays, i.e. those arriving before the others with the GRB.

Finally, it seems interesting to point out some considerations by Tullio Regge in the field of the Quantum Mechanics (*QM*) (Regge) (Hongbao). In an essay about *QM* by Regge, we find: "if we consider a very wide and uniform wave, it represents a particle of which we do not know exactly the position, it can exist with the same probability anywhere. On the other hand we can measure with accuracy the frequency of this kind of wave and thus the energy of the particle. Therefore the speed too, which is directly related to the energy" (Regge).

Thus, along with Regge, why can't we think then that a radio wave which propagates with a greater frequency than another, and so carrying a greater quantity of energy, can travel with a speed slightly higher than a less energetic radio wave? It is precisely what emerges from the FRB! This comes, and even more strikingly, also from the analysis of GRB in which, after the detection of the first γ photons, many other EM frequencies can be recorded, detectable even for a few days, giving rise to the typical *EM swarm*, or *Afterglow* which so characterizes the GRB (Puccini, 2005a). As it has been repeatedly recorded, in fact, the GRB_s are often followed by an EM signal which can last for many days. This signal, this *Afterglow*, is made of several EMR_s, with the main characteristic that we progressively get, in days or weeks, first the most energetic EMR_s and later the least energetic ones.

These time sequences are irrefutably recorded by satellites, i.e. these are the facts. Over long distances it clearly emerges that more energetic P_s propagates faster, in the same *medium*, than less energetic ones. No matter what the cause may be, or the different refractive index of the medium crossed, or the different EM source, more or less energetic, of the considered P_s.

Moreover, it should be kept in mind that, according to Feynman, "the index of refraction varies with frequency"(Feynman 1965, a), as shown in the Eq. (2). Furthermore, as known, EMW_s with higher frequency are the most energetic. Indeed, energy (E) and frequency (ω) of an EMW, of a P, or of any other *quantum object*, are closely related by the well-known Planck-Einstein formula: E = hω, as shown in Eq. (24).

Hence, we can infer that, it is the *frequency* (ω) to really determine the propagation speed of EMR_s, rather than the refractive index (*n*) of the medium.

In addition, going deeper, we must keep in mind that the value of ω depends exclusively on the intensity, on the energy of the EM source: the greater the acceleration given to the P by its EM source, the greater its propagation speed. Moreover, as can be seen from the various equations describing the *momenta* of the various EMR_s, it clearly emerges that the momentum (***p***) of a γP shows a value greater than that of a less energetic P. In his turn, as Feynman reminds us "velocity and *momentum* are proportional" (Feynman,1965a), namely: *directly* proportional.

Thus a more energetic P, provided with a remarkable *momentum* like that of a γ P (see Eq. 22), will travel faster than an optic P or a radio wave.

In short, it is of considerable importance to bear in mind that, what happens in reality by analyzing the propagation times of the EMR_s emitted with FRB and GRB, is also confirmed by the *QM* applying the UP to EMW_s, from which it clearly emerges that the more energetic EM signals travel faster than the less energetic ones (Puccini, 2011d). To this purpose, we read: "Today we know that the entire GRB 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 EM spectrum: in *X-rays*, in the *optic*, in the *infrared* as well as in the *radio*. This *emission tail* is called *afterglow*"(Astronom. Observ. of Brera).

In conclusion, in our opinion, a greater scientific meaning should be given to what comes from these peculiar *Afterglows*.

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