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The emission mechanism of gamma-ray bursts from supernovae

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The connection between gamma ray bursts and supernovae is studied using a temperature-dependent vacuum model. A harmonically bound particle-antiparticle system is consistent with both Hawking radiation and Casimir effect, therefore, the Maxwell-Sellmeier model correlates the speed of light to temperature. According to quantum field theory, Lorentz invariance is violated only for temperatures larger than 4×10^9 K. Introducing in the temperature distribution of a 2D simulation for a type Ia supernova the speed of light temperature dependence proposed in this article, results a speed of light distribution. A theoretical snapshot of this distribution at an arbitrary distance is consistent with photon photo finish resulted from experiments. Variable speed of light shows that supernova could be accompanied by gamma-ray bursts.

Keywords: vacuum model; gamma ray bursts; supernovae.

1. Introduction

After the discovery of the connection between the supernova 1998bw and the gamma-ray bursts (GBRs),[11] a theoretical model was proposed, but not able to describe bursts with energy a thousand times higher. GBRs from stellar explosions reveal variations in the speed of light, distinguishable in photon photo finish.[6] Moreover, recently detected long GRBs 160509A, is intriguing and matches with an energy-dependent speed of light due to Planck scale effects.[25]

Recently, the most detailed map of the distribution of dark matter[22] shows that the universe is smoother and more spread out than Einstein's theory of general relativity predicts.

In analogy to the situation a shorter wavelength leads in a optical medium to a lower speed of light, Einstein assumed the clocks in gravitational field run slower, the corresponding frequencies being influenced by the gravitational potential.[10] Einstein went through several versions of light speed theory, eventually concluding that speed of light cannot be regarded as constant in a changing gravity field, and he intended to described the light-speed as a vector. Later, Bergmann wrote that light-speed might change direction but not the modulus.[3] Born agreed Einstein and established that both the speed and the modulus of light change in a gravitational field.[4] Compared to Einstein, Dicke assumed that both frequencies and wavelengths are varying.[8] Considering the increase of the horizon, more and more masses contribute to the refractive index, Dicke proposed a cosmology in which the speed of light decreases in time, providing an alternative explanation to the cosmological redshift.

To explain the cosmic inflation, were introduced several theories. In the field equation, the so-called Einstein constant is defined as $\chi = -8\pi G/c^2$. Petit kept the Einstein's constant as an absolute constant, but assumed the speed of light c and the gravitational constant G change in time.[21] Moffat postulated speed of light passes at a critical time through a first order phase transition, associated with the spontaneous Higgs breaking of local Lorentz invariance.[19] Albrecht and Magueijo postulated breaking Lorentz invariance, proposing $\hbar c$ variable in time, assumed energy nonconservation.[1]

Current theories introduce arbitrary constants to explain experimentally measured values, but are unable to explain these values. To understand the significance of these values, we must look at the evolution of the cosmos in time. A truth universally accepted in physics is the lifetime of matter, consequently everything has a finite existence. All studied systems are without choice connected to external reservoirs, and their parameters initially considered constant, actually evolve in time. Even mathematics, built on definitions, accepts the constants as an idealization. The failure of the concept of absolute value of infinity, led to the creation of transfinite numbers, and consequently, to modern set theory.[5]

The environment influences the propagation of light, which in turn is influenced by temperature. The idea of vacuum being dependent on temperature is not new: vacuum, like any other system, must satisfy the third law of thermodynamics and, therefore, at absolute zero, vacuum oscillations are frozen. This suggests us to see vacuum as a propagation environment.

In this paper, using a classical description of vacuum fluctuations, we evaluate the dependence of the speed of light on temperature: applying the Maxwel-Sellmeier model for a harmonically bound particle-antiparticle system, we obtain the dependence of polarization on frequency and, using the heat theory, we link this frequency to temperature. The dependence of the speed of light on temperature must come from the quantum theory and, therefore, we expect to find more information in the propagators. The results are consistent with the data collected from a type Ia supernova, and the light curve measured in GRBs.

The variable speed of light, as presented in this paper, does not invalidate the theory of general relativity, it actually adds to it. As long as the temperature is low compared to the mass of elementary particles, we can consider the speed of light to be constant. The rise in temperature changes the real concept on the constancy of the speed of light and gives us new insights into the puzzle of the universe.

2. The model

We begin to describe the model knowing that the properties of vacuum are given by its internal fluctuations, which are interpreted as a phenomenon of creation and annihilation of particles. We know for a fact that electrostatics is also there when charges are in constant motion, and therefore we want to describe vacuum fluctuations in analogy with the electrostatics of macroscopic environments. Consequently, we model a semi-classic vacuum where we link vacuum permittivity to temperature. To explain the entropy of black holes, Hawking assumed that, after the process of creating the particle-antiparticle pair found near the horizon of a black hole, a particle is absorbed by the black hole, while the other is spared becoming real, which is another way of seeing vacuum fluctuations as real.[12]

At a certain moment in time, the electrical charges inside a certain vacuum volume are in random positions. If we maintain a constant temperature, the average charge value at a given moment in time is the same as an average value made at a different moment in time. As long as we are dealing with equal average quantities, we are right to consider static both the field and the charges. In conclusion, mediation can be achieved by taking into account fixed charges, i.e., considering a single moment in time.

In electrostatics problems, the average charge density is divided into two parts: one is the average charge density of the particle-antiparticle pairs and the other is the induced density, given by the polarization of charges. In absence of an electric field, dipoles have their dipolar moments randomly oriented, but in the presence of an electric field they tend to align with the field, contributing to the average charge density.

In multipolar development, the charge is energetically associated with the electric potential, the dipole with the electric field and the quadrupole with the electric field gradient. As long as macroscopic variations of the electric field occur on long distances compared to the fluctuation distances of the particle-antiparticle pair, the term corresponding to the quadrupole can be disregarded in relation to the dipolar term.

In all the analyzes performed, we consider vacuum to be homogeneous, isotropic, and non-dissipative. The electric flux density $\mathbf{D}$ is related to the $\mathbf{E}$ field intensity by the so-called constitutive relationship. Starting from this assumption we have $\mathbf{D} = \epsilon_0\mathbf{E}$, and consequently $\epsilon_0(T_0)\mathbf{E} = \epsilon_0'(T)\mathbf{E} + \mathbf{P}$, with $T_0 \geq T$ (see pages 103-109 in[13]). It is true that today $\mathbf{P}$'s contribution is negligible, and we have $\epsilon_0' = \epsilon_0 = 8,9 \times 10^{-12}$ F·m^{-1}, but with the significant increase in temperature we expect $\mathbf{P}$ to play an increasingly important part in the equation.

We consider a simple harmonic model of a particle-antiparticle system, which we describe using the Maxwell-Sellmeier-Lorentz model, resulting that the induced dipole moment has the value $\mathbf{P} = \gamma\mathbf{E}$ (see pages 119-121 in[13]). The $\gamma = q^2/(m\omega_0^2)$

quantity is called polarizability, where q is the charge, m is the mass of the charge and ω_0 is the frequency of oscillation about equilibrium. In fact, not all particle-antiparticle pairs move apart at the same distance and, consequently, for a total number of N pairs, we can write that $\gamma = \sum_i^N q^2/(m_i\omega_i^2)$. The model agrees with the statistical mechanics where the probability distribution of particles in the space of phases is proportional to the Boltzmann factor $e^{-H/(k_\mathrm{B}T)}$, where H is the Hamiltonian, T temperature and k_B the Boltzmann constant. The average value of a quantity over a canonical distribution is defined in[14] and the sketch of this proof may be found in[13] on page 122.

Casimir force is understood as the interaction of virtual particles with two non-electrically charged parallel conducting plates found are in vacuum and depends on the distance between the plates. Consequently, assigning the separation distance of virtual particles is a known fact. We can talk about a confinement of virtual particles within a finite range of action, which also assigns them velocity.

In the static description of semi-classical vacuum, the kinetic energy of the oscillations of the particle-antipar-ticle pairs around the equilibrium point is proportional to temperature.[14] Mathematically we write that $3k_\mathrm{B}T/2 = \hbar\omega_0$. Up to a proportionality factor, this dependence is true in finite temperature field theory, where the statistical behavior of the quantum system is studied by means of an appropriate statistical assembly. Therefore, we can write $\epsilon_0(T) = \epsilon_0' + \kappa_\mathrm{P}'/T^2$, where κ_P' is a constant that can be determined. Measurements show that today we have $\epsilon_0(T_0) = \epsilon_0'$ or $\kappa_\mathrm{P}' \approx 0$.

We want to correlate permittivity to a certain marker, where temperature had the highest value in the history of the universe. Hence, we write that

$$\epsilon_0(T) = \epsilon_\mathrm{BB} + \frac{\kappa_\mathrm{P}}{T^2}\,, \tag{1}$$

where ϵ_BB is permittivity at big-bang moment. Therefore, at high temperatures vacuum changes its properties with temperature. Further on we determine the value from which this equation is valid.

The lowest possible value of $\epsilon_0(T)$ is at the BB moment, where we also have the highest temperature. Because temperature decreases over time, it results from Eq. (1) that the value of $\epsilon_0(T)$ is maximum when $T \to 0$. Using the relationship between the speed of light and permittivity $c = 1/\sqrt{\epsilon_0\mu_0}$, we conclude that the speed of light decreases from $c = 1/\sqrt{\epsilon_\mathrm{BB}\mu_0}$ to 0.

As we have mentioned right from the start, semi-classical vacuum has a certain lifetime. When temperature decreases, the speed of light decreases, and the electromagnetic field exhibits variations over distances comparable to the distances between particle-antiparticle pairs. At this point the field gradient becomes important and therefore the quadrupole as well. The transition between classical and quantum phenomenology takes place at this temperature.

We expect the dependence of light on temperature to be related to the propa-

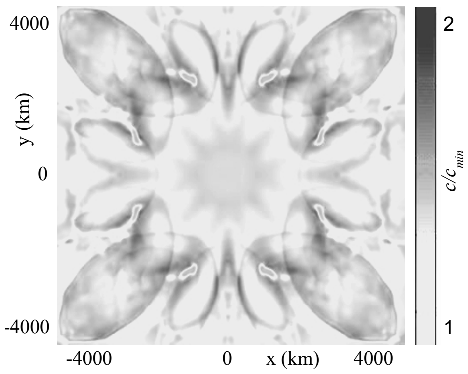

Fig. 1. The adimensional speed of light dependence with distance in a 2D simulation of a supernova explosion.[16] c_{min} corresponds to a temperature of $2.5{\times}10^9$ K. The simulation is consistent with photon photo finish.[6]

gator

$$\Delta(k) = 1/\left(\mathbf{k}^2 - \frac{\omega^2}{c^2} + \frac{m^2c^2}{\hbar^2} - i\epsilon\right) . \tag{2}$$

Temperature must have a positive contribution to the particle energy m in the propagator, so we have to replace $\frac{m^2c^2}{\hbar^2} \to \frac{m^2c^2}{\hbar^2} + \frac{9}{4}\frac{k_B^2T^2}{\hbar^2c^2}$. It must be said that, in the finite temperature field theory developed by Matsubara, we have a similar dependence on temperature (see pages 10-14 in[7]).

The scattering section is related to the propagator and, as a result, a smaller propagator means weaker interaction. Once temperature increases, the propagator decreases and consequently the scattering section. At an infinite temperature, the scattering section is zero and therefore nothing interacts. This is consistent with the case where a particle with $M > m$ interacts less than the particle with mass m. In the given situation, the propagator shows major corrections when temperature is in the order of $T_c = 2mc^2/(3k_B) = 4 \times 10^9$ K. We should notice that this value is close to the energy for producing the electron-positron pair. Since there are not many places in the universe with such high temperatures, the general theory of relativity is valid almost everywhere.

The electron is the stable elementary particle with the smallest mass, being therefore convenient to use it as a test particle for interaction. The fact that in our model we consider electrons to be bosons does not change the order of magnitude of temperature and allows us to make an analogy with the Matsubara formalism.

We try to estimate the value of the constant κ_P considering that up to a critical temperature T_c, the permittivity value remains approximately constant. Using Eq. (1), we can express the κ_P constant based on BB permittivity, i.e.

$$\kappa_P \approx T_c^2(\epsilon_0' - \epsilon_{BB}) . \tag{3}$$

From our classical model we conclude that $\epsilon_0' \gg \epsilon_{BB}$, which allows us to estimate

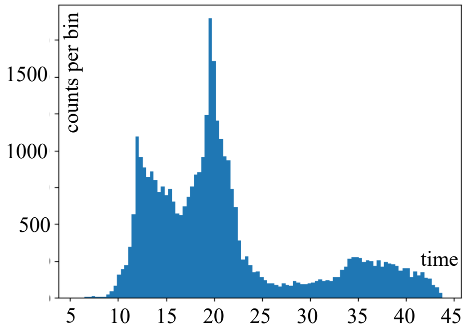

Fig. 2. The pattern of the light curve for the supernova explosion simulated in Fig. 1, at an arbitrary distance. The graphic representation is consistent with the GRB light curve.[25]

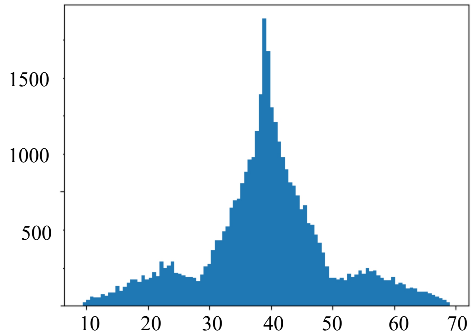

Fig. 3. The same setup as in Fig. 2, but for the speed of light independent of temperature.

$\kappa_{\mathrm{P}} \approx 1.4 \times 10^8$ F·m^{-1}·K^2.

3. Type Ia supernova and emitted GRB

We consider a binary system consisting of a star orbiting a white dwarf made up of carbon and oxygen. The thermonuclear explosion of the white dwarf is called type Ia supernova. By definition, the Chandrasekhar mass is the maximum mass for which a white dwarf is stable. In this paper we consider a simulation of a type Ia supernova, using the model of turbulent deflagration with a deflagration-to-detonation transition for a white dwarf whose mass is close to the Chandrasekhar mass.

In this paper we consider a white dwarf with central carbon ignition at a temperature of 1×10^8 K. Central density is 3×10^9 g cm^{-3} while mass is $1.38 M_{\odot}$. Further on we consider that the white dwarf has the metallicity of the sun and that the carbon-oxygen mass ratio has an isotherm profile. Fortunately, this simplified approximation was successfully compared to several realistic evolutionary models.[15]

Both the turbulent deflagration process and the deflagration-to-detonation process were simulated using a 2D code.[16] As a matter of fact, this hydrodynamics code solves the 2D Euler equations in cylindrical coordinates with subgrid turbulence and a moving grid. After carbon deflagration and detonation, the explosion decomposes the white dwarf by quickly dispersing its material. Once temperature has dropped, matter cools down ending all thermonuclear reactions.

In the simulation process we consider certain special symmetries, e.g. that the most likely place where the first flame appears is the center of the white dwarf. Compared to the 3D model, the 2D model has some disadvantages. First of all, due to the symmetries considered, the movements of the flames near the edge are overestimated, leading to Rayleigh-Taylor instabilities. These turbulent behaviors exaggerate both flame propagation and the transition time. Second, due to detonation, the shock wave reflected by colliding with the axis of symmetry interacts with the wave approaching the center, thus creating incandescent spots and, consequently, temperature rises unnaturally, which is not described in a 3D model.

With the 2D model shown above, we obtain the distribution of temperature with distance. Eq. (1) together with the definition of the speed of light $c = 1/\sqrt{\mu_0 \epsilon_0}$ give us the dependence of the speed of light with temperature, and in Fig. 1 we represent the dependence of the speed of light on distance. Both Fig. 1 and A. Cho's photon photo finish[6] share the same pattern: from the center of the figure towards the extremity, both figures show a reduction in intensity distributed in a ring shape. This suggests that the photons arrive at different moments of time implying that their speed is different. Superimposing photon photo finish on the temperature distribution given by Fig. 1, we considered that the speed of light depends on the temperature. If the speed of light is constant, and not dependent on temperature, the photographic plate will no longer present a ring-shaped intensity reduction.

BATSE (Burst and Transient Source Experiment) was the first instrument to underline that GRBs are evenly distributed in the sky, which led to the conclusion that events occur in the distant universe.[18] Later on, BeppoSAX showed that GRBs have a cosmological origin.[23] The same satellite established a connection between Ic supernova 1998bw and GRBs, leading to the construction of a theoretical model.[17] Unfortunately, the mechanism of understanding GRBs has remained unclear due to the energy differences between supernova 1998bw and other distant GRBs with much higher energies.

In Fig. 2, we represent the light curve for the explosion of the supernova simulated in Fig. 1. The image is seen at some distance from the supernova explosion and is consistent with the GRB curves in the literature.[25] About two weeks after the explosion, the supernova becomes transparent to GRBs. Therefore, the same mechanism, that of variable speed of light, could be responsible for the supernova 1998bw and much more powerful GRBs found in the distant universe.

In Fig. 3, we represented the same set of parameters as the one in Fig. 2, but for constant speed of light, independent of temperature. The profile of Fig. 2 changes significantly, Fig. 3 showing only a central peak, which does not correspond to the measurements from.[25]

Due to the expansion of the universe, photons coming from quasars or extremely distant gas clouds have an extremely long wavelength and are therefore extremely redshifted. When measurements are being made, redshift must be considered very seriously because there are many systematic errors.

Moreover, galaxies have a much smaller redshift than the corresponding quasars, although both objects should have the same redshift.[2] This leads us to the idea that redshift is not just about the physical movement of objects, and that it must have an intrinsic origin, and temperature is an intrinsic variable.

The work[24] describes the results of a search for time variability of the fine structure constant using absorption systems in the spectra of distant quasars, and the authors conclude that they do not know any systematic effects that could explain the result. In the paper,[20] using variable light speed, the author stated that the model fits the spectral line data and can also lead to a solution of the initial value problems in cosmology. The temperature dependent light speed can be a solution to the redshift problem, and we intend to develop this aspect in future works, to confirm from the perspective of another cosmic phenomenon that the speed of light is dependent on temperature. It seems that the photon photo finish analysis could be a viable solution in the speed of light variation analysis, eliminating the redshift problem.

The value of dimensional constants differs from one unit choice to another, and therefore only dimensionless constants are fundamental and represent a legitimate subject of the speed of light variation.[9] Fig. 1 shows dimensionless quantities measured with the same device.

4. Conclusions

In this paper, we wondered if a variable speed of light could explain the data collected from a type Ia superova. A consistent theory accepts that in it phenomena are not preferential and according to quantum mechanics if a phenomenon happens once, it can occur at any time. If the inflationary period characterized by high temperatures were influenced by a variable speed of light, then we must find today the same effect in cosmic phenomena at extremely high temperatures.

In this paper, physics models already accepted by the scientific community that have been used support the claims made. Using the Maxwell-Sellmeier-Lorentz model, we approached the virtual particle-antiparticle pairs as having real contributions in modeling the optical properties of vacuum. Similarly, according to Hawking, the horizon of black holes breaks the virtual particle-antiparticle pair, creating real particles. And the Casimir effect treats virtual pairs as real, moreover, also assigning them speed (confinenment).

Analysis of data collected from a type Ia superova, more precisely photon photo finish, support the dependence of light speed on temperature. Moreover, the graphical representation of the simulated speed of light from a supernova explosion Ia is consistent with the data collected for GRBs from the literature, which allows us to conclude that the mechanism of variation of light speed with temperature is a candidate for the production of GRBs with supernova explosions.

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