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Analogies Between Spectroscopic Properties of Laser And The Universea

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ABSTRACT

In this paper we present a comparative analysis of the coherent properties of laser radiation and the birth of the universe, which took place as a result of quantum fluctuations. Six quantities have been brought under consideration for comparison. They are Entropy, Time, space-time, origin, Temperature and vacuum fluctuation.

KEYWORDS Laser, Universe

Introduction

When a problem is compared with something identical in a different field but which one understands reasonably, comparative ideas are created. This is one way of looking at the problem. In many ways some phenomena in physics appearing in different domains are quite analogous. Recently it has been illustrated in the case of squeezed state, multiple reflection and spatial Hole- Burning [1] and also in the case of dispersion curves of semi classical theory of laser and electromagnetically induced transparency [2]. In an earlier paper the phenomenon of spatial and its analogy with some non physics context have been worked out [3], by us. In the present paper we proceed to show such an analogy which concerns the characteristic properties of laser radiation and a model of the universe involving space time and quantum cosmology.

Special Theory of Relativity

Electromagnetic waves of all frequencies travel with constant speed in vacuum. It is surprising and also unexpected that this does not depend on the relative velocity of the source and observer. This fact led Einstein to formulate the special theory of relativity and concluded that space and time are not separate but belong to the same space-time continuum of the four dimensional universe. It is worthwhile to note here that in the world of electromagnetism light was propagated at a constant speed which could not be surpassed, but there seemed to be little connection with Newtonian mechanics in which the speed of the object might be indefinitely increased by adding more energy to it. What Einstein now proposed that the velocity of light is a constant and maximum in the electromagnetic and mechanical world and that light thus could travel with a constant velocity that was independent of bodies emitting or receiving it [4]. Minkowski not only gave a new mathematical formalism to the special theory but also enabled Einstein to solve the problems of gravitation by means of the General Theory. Thus according to Minkowski an event which takes place in three dimensional space at a specific time is described as a "world point" while a series of consecutive events is described as a "world line". More significantly time is described as "the fourth dimension". We may appropriately say that this "dimension" signifies for a mathematician a forth variable, apart from length, breadth or thickness which must naturally enough be inserted into any equation concerning events since these occur not only in space but at a certain instant of time.

The Direction of Time

It is now worthwhile to consider the problem of the direction or arrow of time in cosmology as discussed by Hawking [5] several decades ago. In this paper Hawking has shown that the usual proof of CPT theorem does not apply to theories which include the gravitational field. Nevertheless, he has shown that CPT invariance still holds in these cases provided that the quantum state of the universe is defined by a path integral over compact four- matrices without boundary [6-8]. The observed asymmetry or arrow of time defined by the direction of time in which entropy increases is shown to be related to the cosmological arrow of time defined by the direction of time in which the universe is expanding. It arises because in the proposed quantum state the Universe would have been smooth and homogeneous when it was small but irregular and inhomogeneous when it was large. Why do the three arrows of time known as the psychological, thermodynamic and cosmological- all seem to point in the same direction and is thus this necessarily be always true throughout the evolution of the universe. Psychological arrow of time is always the way time appears to flow in the human mind- that is, the way we experience the unstoppable aging of our bodies, remember the past and have no direct vision of the future.

The thermodynamic arrow of time refers to the fact that as entropy increases time increases (according to the second law of thermodynamics). The cosmological arrow of time is concerned with the evolution of the universe currently expanding and accelerating from the "big bang". The connection between the psychological and the thermodynamic arrow of time can be discussed from an analogy with computers [9]. When a computer records something in memory, that is, when it records digitally in bits or q-bits (quantum beats) the total entropy increases. Thus computer remembers things in the direction of time in which entropy increases. It is reasonable to assume that we remember in the same direction of time that computers do. This means that psychological arrow of time our subjective sense of time is the same as the thermodynamic arrow of time, the direction in which entropy increases. So the second law of thermodynamics is the repetition of the same thing. Entropy increases with time because we define the direction of time in which entropy increases. In 1985 paper [5] Hawking put forth the controversial conjecture that although the arrows all point in the same direction, the thermodynamic arrow would reverse during a contracting phase or inside black holes. Hawking believed that the no boundary proposal (which used closed universe doomed to eventually collapse in on themselves) would predict that when the universe began to contract, the thermodynamic arrow of time (and so by the earlier argument the psychological arrow of time as well) would reverse. He proposed that entropy would decrease rather than increase. This would mean that the things would become more ordered rather than more random. Thus it would also defy Budha's last words to his disciples, "Behold O Bhikkhus, now I speak to you, Transient are all conditioned things, strive on with diligence". Hawking's proposal would also mean that one would remember the future and have no knowledge of the past. However Hawking finally admitted that he had been wrong about the reversal of the thermodynamic and psychological arrows of time in a contractor universe. Hawking and Collins [10] connected the fact that the overall distribution of matter in the universe is remarkably similar in all direction we observe (isotropic) to the density perturbations in the early universe (which led to the creation of galaxies) and found that the balance to be highly unlikely. They came to the conclusion that we have observed the universe to be isotropic is therefore only a consequence of our own existence. If it were otherwise galaxies would not exist and presumably we would not exist. With these concepts in mind Hawking pondered the problem of the three arrows of time came to the conclusion that although the psychological and thermodynamic arrows did not reverse during contracting phase of the universe, it was only when the three arrows of time pointed in the same direction the intelligent life could not exist who could contemplate the problem. Hawking further stated that "the fact that we are around to observe the universe means that we must be in the expanding, rather than the contracting phase". Although Hawking had no problem involving this principle (anthropic principle) to explain the "fine tuning" (or detuning?) of the universe there are others who do not support these views. "It smells of religion... and like religion it cannot be disapproved [11]".

Coherent Properties of Laser Radiation

In the earlier sections we have brought under discussion two well known topics. The first is the Special Theory of Relativity formulated by Einstein and extended by Minkowski, involving space and time. Special theory of relativity tells us about the four dimensional universe. The fourth dimension (or variable) time is naturally to be introduced in any equation concerning events since they occur not only in space but also at a certain instant of time. Secondly we have also considered the direction of the fourth dimension (or variable)"time" as discussed by Hawking. In the present section we specifically bring forth the coherent properties of laser radiation for a possible analogy with the so called "world point" and "world line" in the space time continuum of the special theory of relativity. We must indicate here that the topics set forth above in the earlier sections have helped us to draw some analogy with the coherent properties of laser radiation. How this analogy appears is apparent from the following discussion.

Laser radiation is both space and time coherent. A source of radiation may have little time coherence but still has perfect space coherence. Example of such coherent source is the light from a distant star.

Spatial coherence: If at a particular instant of time the radiation has the same phase across the uniphase wavefront it is said to be completely spatial coherent. The directional property of a laser beam is due to its space coherency.

Temporal coherence: If the phase of the light of one uniphase wavefront at a particular time is the same with its displaced wavefront after it has travelled a distance in a time t, and if the phase agrees for all time intervals, the light is said to be perfectly time coherent. Extreme monochromaticity is the manifestation of the property of this temporal coherence.

High Intensity: The usual optical radiation has an intensity characterized by an effective temperature of the order of few thousands of degrees only. On the other hand the laser output can be described as having an effective temperature of 10^{18}K or more.

The Analogy:

It is appropriate that we term this section as Analogy because of the nature of the comparative study. The basic facts and principles relating to the special theory of relativity as formulated by Einstein with the three arrows of time articulated by Hawking [8] have been expounded in the earlier sections. We have also discussed the coherent properties of laser radiations in order to correlate them with the earlier topics of space-time continuum and as well as the arrows of time.

In this context it should be worthwhile to discuss the quantum theory of laser and the process of build up of laser photon from vacuum as formulated by Lamb Jr. and co-workers [12-14]. Laser is basically created inside a resonating cavity and as it emerges out of the partially reflecting dielectric mirror it appears as a unidirectional strong beam of monochromatic radiation having the properties of spatial and temporal coherence. In this case spontaneous emission is the driving force which acts as the platform for the laser radiation to be built up. The interesting consequence of the quantization of radiation field is the fluctuation associated with the zero point energy or the so called vacuum fluctuations. These fluctuations are responsible for many interesting phenomena in quantum physics including spontaneous emission. The mechanism of spontaneous emission- an isotropic perturbation always present and attributed in connection with the quantum theory to the all pervading zero point fluctuations of the electromagnetic field. The light excites the atoms, the zero point fluctuations de excite them, resulting in re radiation of light.

We recall the treatments of the quantum theory of laser by Lamb and co-workers [13] to emphasize the role of spontaneous noise in the process of build up of laser photon from vacuum. To do this we note that the average photon number is given by

$$\langle n(t)\rangle = \sum n\rho_{nn}(t)$$

And it may be shown that the equation of motion for the average photon number $\langle n(t)\rangle$ is given by

$$\frac{d}{dt}\langle n(t)\rangle = \left(\mathcal{A} - \frac{\nu}{Q}\right)\langle n\rangle + \mathcal{A} - \mathcal{B}\left[\langle n^2\rangle + 2\langle n\rangle + 1\right]$$

Where the linear gain is co-efficient in quantum theory of laser, is the lowest order saturation coefficient in quantum theory of laser, ν is the laser oscillation frequency in radians/sec (not Hertz) and Q is the cavity quality factor. The above equation has been used to investigate the process of build up of laser photon from vacuum [13]. It may be noted that the lone term in the equation represents the spontaneous noise originating from vacuum fluctuations.

From what has been discussed above one can safely infer that laseroriginates from a highly chaotic environment of atomic or molecular system which is converted into an uniform and coherent (in space and time) beam of light. It is quite reasonable to state that the entropy increases with time as the laser beam propagates through space. This is due to the fact that the concepts of space and time coherency will not be valid for any practical laser after it has travelled a huge distance, resulting in increase in disorder. Thus the direction of the laser beam is the direction of the thermodynamic arrow of time. How the entropy (or disorder) increases as the laser beam propagates can be visualized in terms of the distance through which the beam maintains the constant phase relationship. This length is known as coherence length and is given approximately by the relationship

$$\ell = \frac{c}{\Delta\nu}$$

where c is the velocity of light and $\Delta\nu$ is the bandwidth of the source. Thus the reduction of the laser frequency bandwidth significantly increases the coherence length or coherence time. As the laser radiation travels through space, the beam-spread increases which is also a measure of the increase of the disorder (or entropy).

We speculate here that laser evolves from a big chaos analogous to the evolution of the universe currently expanding (and accelerating) from the big bang. The temperature at a time of 10^{-12} second from big bang is estimated to be at 10^{15} K (present day microwave cosmic background corresponds to about 2.7K). The laser output can also be described as having an unbelievable high value with an effective temperature of 10^{18}K or more.

That the universe began in a big bang is one of the great theories of modern cosmology. This theory is presumably a scientific theory supported by numerous evidences. But there still remains an enigma. What caused the big bang itself? For many years cosmologists have relied on the idea that the universe formed spontaneously, that the big bang was the result of quantum fluctuations in which the universe came into existence from nothing. In 1973, Tryson [15] published a paper in Nature where he proposes a model supporting the theory that our Universe is a large scale fluctuation of vacuum, where "vacuum fluctuation" is to be understood in the sense of quantum field theory. In a very recent paper Dongsham et. Al [16] have come up with the first rigorous proof that the Big Bang could indeed have occurred spontaneously because of quantum fluctuations. How Dongsham et. Al [16] showed rigorously that the birth of the early universe completely depends on the quantum nature of the theory and created spontaneously can be briefly described as follows. According to them with the Lambda- cold dark matter (ΛCDM) model and all available observations such as cosmic microwave background, abundance of light elements it has been widely accepted that the universe was created in a big bang. However there are still some puzzles, such as problems of flatness, the horizon, the monopole and the singularity [17]. In particular, inflation theories which suggest that the universe experienced an exponential expansion period were proposed to solve puzzles of the early universe [18-20]. In quantum cosmology theory, the universe is described by a wave function rather than the classical space time. The wave function of the universe should satisfy the Wheeler-Dewitt equation (WDWE) [21]. With the development of quantum cosmology theory, it has been suggested that the universe can be created spontaneously from nothing, where nothingness means there is neither matter nor space or time [22], and the problem of singularity can be avoided naturally. Although the concept of the universe created spontaneously from nothing has emerged for a long time, a rigorous mathematical foundation for this is still missing. According to Heisenberg's uncertainty principle, a small empty space, also called a small true vacuum bubble can be created by quantum fluctuations of the metastable false vacuum. But if the small bubble cannot expand rapidly, it will disappear soon due to quantum fluctuations. In this case early universe would disappear before it grows up. On the other hand, if the small bubble expands rapidly to a large enough size, the universe can be created irreversibly. In 2014, paper Dongshan et.al. obtained analytic solutions of the WDWE of the true vacuum bubble. With the de Broglie- Bohm quantum trajectory theory, they prove that once a small true vacuum bubble is created, it has the chance to expand exponentially when it is very small, that is a<<1. The exponential expansion will end when the size of the true vacuum bubble becomes very large, that is, a>>1. It is shown that the quantum potential of the bubbles is the driving force for the exponential expansion and it also plays the role of cosmological constant. This definitely shows that the universe can be created spontaneously originating from quantum mechanism.

It is now appropriate that we include all the considerations set forth in the earlier sections in a tabular form so that a worthwhile analogy between the coherent properties of laser radiation and the evolution of the universe can be made. The analogy is summarized in Table1.

Table-1
(Summary of Comparison between the Laser and Evolution of the Universe)

Parameter	LASER	UNIVERSE
Entropy	Entropy increases as laser propagates through space.	Entropy increases as the universe is expanding (and currently accelerating).
Time	Thermodynamic arrow of time is directed along the laser axis.	According to Hawking [5] the universe that we live in does not appear time symmetric. One can identify a number of different "arrows of time" that explains the asymmetry of the universe. The psychological arrow of time, thermodynamic arrow of time and the cosmological arrow of time all point in the same direction.
Origin	Originates from a highly chaotic environment.	Origin of the universe took place as a "Big Bang".
Temperature	Laser output can be described as having an effective temperature of~10^{18}K.	Temperature at a time of 10^{-12}sec. After Big Bang is estimated at 10^{15}K.
Space-Time	Laser radiation is both space and time coherent.	In special theory of relativity time is the fourth dimension, and an event occurs not only in space but also at a certain instant of time. They are known as "world point" and the line linking events are "world lines".
Vacuum Fluctuations	The mechanism of spontaneous emission is attributed in connection with the quantum theory to the all pervading vacuum fluctuations of the electromagnetic field. Laser builds up from spontaneous noise and laser photon builds up from vacuum fluctuations [13, 14].	In quantum theory of cosmology the universe can be created spontaneously from nothing by virtue of vacuum fluctuations [15, 16].
Exponential Growth	Laser photon grows exponentially in the initial stage as it created from vacuum.	The true vacuum bubble expands rapidly and the universe can be created irreversibly [16].

6. Discussion and Conclusion

In summary, we have presented a comparison between the laser and the universe. Seven topics which are quite analogous are included in Table1. It must be emphasized that the characteristic features as shown for laser and the universe are already well established in literatures. As may be inferred from Table 1, in many ways the physics of the laser is analogous to that of the evolution of the universe. It is reasonable to believe that they will be analogous in many other ways. The root of the analogy is the fact that both the laser and the early universe depend completely on the quantum nature of the theory. In conclusion, it is worthy of remark that there has been strong sense of disapproval from some workers [23, 24] of the idea that the universe could create itself from spontaneously from nothing –from vacuum fluctuations. Therefore without entering into these controversies we have concerned ourselves with analogies only.

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