Abstract

On the basis of the results of some experiments dealing with the violation of Local Lorentz Invariance (LLI) and on the formalism of the Deformed Special Relativity (DSR), we examine the connections between the local geometrical structure of space-time and the foundation of Quantum Mechanics. We show that Quantum Mechanics, beside being an axiomatic theory, can be considered also a deductive physical theory, deducted from the primary physical principle of Relativistic Correlation. This principle is synonym of LLI and of a rigid and flat minkowskian space-time. The results of the experiments mentioned above show the breakdown of LLI and hence the violation of the principle of Relativistic Correlation. The formalism of DSR allows to highlight the deep meaning of LLI breakdown in terms of the geometrical structure of local space-time which, far from being rigid and flat, is deformed by the energy of the physical phenomena that take place and in this sense it has an active part in the dynamics of the whole physical process. This perspective has a far reaching physical meaning that extends its consequences to the foundations of Quantum
Mechanics according to the interpretation of Copenhagen. It provides a 'real' explanation and description of quantum phenomena enriching, by the concept of deformed space-time, the realistic interpretation in terms of pilot wave and hence it uncovers the reality hidden below the probabilistic interpretation and dualistic nature of quantum objects.

1 The principle of relativistic correlation

The study of the laws of Nature has always found in the cause-effect relationship (causality), between two events, a very powerful method of investigation. Causality stands on the principle of relativistic correlation which establishes the temporal order of events. Before the experimental disclosure of the deep link between electricity and magnetism and its formalisation in terms of Maxwell’s equations and before the understanding that these equations described the interactions among elementary particles (that had just been discovered), physics relied on the not-physical concept of "action at a distance". Maxwell’s equations formalised the concept of field as conveyor of the electromagnetic interaction among bodies and being its propagation speed the speed of light, it became possible to establish causality at a finite speed. However, a further step forward had to be moved before defining the principle of relativistic correlation. This step had to be moved through the whole process that brought from Galilean Relativity to Special Relativity or, rather, to the Einsteinian Relativity. The postulate of relativity and the postulate of a universal limiting speed by Einstein, contain, as direct consequences, both Lorentz transformations and the flat and rigid Minkowski space-time. The former implies that the speed of light is the limiting speed for physical phenomena, the latter implies that c is the maximal causal speed. From these two points of view, it turns out that the causal velocity is not just finite (i.e. not infinite), but also limited (i.e. it cannot be bigger than a certain value), unique (i.e. valid for any interaction and energy independent), constant (i.e. time independent in an inertial reference system), invariant and coinciding with the numerical value of the light speed in vacuum and in this last sense maximal.

2 Quantum Mechanics as deductive theory

Quantum Physics relies on the proposal of three new phenomenological models based on revolutionary concepts: quantization of energy exchanges between

---

1Of the two postulates, the latter has been the crucial one for the development of Quantum Mechanics and for the following development of whole Physics, both theoretical and experimental until nowadays. It is also called "postulate of the constancy of the speed of light" but "because special relativity applies to everything not just light, it is desirable to express it in terms that convey its generality" [1]. This is how J.D.Jackson expresses the importance of this postulate, but it reflects also the point of view of a young Einstein who, moved by idealism, aimed at making universal experimental evidences, that despite their strong accountability, were strictly true only for electromagnetism.
radiation and matter, by Max Planck; quantization of the electromagnetic radiation and indivisibility of space and time by Albert Einstein; quantization of the energy of atomic electrons by Niels Bohr. From these assumptions, as stated by M. Jammer in [2], in the initial years, Quantum Physics had developed as a "deplorable patchwork of hypotheses, principles, theorems and computational rules" that allowed to match the predictions, obtained through classical methods, with experimental data. Several theoretical works were developed in order to systematize this empirical methods. In 1924 de Broglie showed the wave nature of material particles, in 1925 Heisenberg developed together with Born and Jordan a formalism to face quantum problems known as Matrix Mechanics and a few months later Dirac came out with his formalism called quantum algebra which produces the same results as Heisenberg's. Eventually, in 1926, it appeared the formalism developed by Schrödinger which initiated the version of Quantum Physics known as Wave Mechanics. The conference held in Como in September 1927 may certainly be considered as the conclusion of the first period of theoretical construction of the Quantum Theory and as the birth of Quantum Mechanics as an axiomatic theory according to the "Copenhagen Interpretation". From an historical perspective the process of development of Quantum Mechanics went on in the following years when the first steps towards a quantum electrodynamics began to be moved. In 1928 Dirac published the first relativistic wave equation for the electron and in the same year Jordan and Wigner wrote the relativistically invariant commutation relations for the electromagnetic field. This is the most important result of this formalism, from a theoretical point of view, because they are considered the quantization relations and from an experimental and epistemological point of view because from them the indeterminacy relations can be inferred. Despite the important results, the formalism of quantum electrodynamics presented several considerable problems like divergences and negative energy states. These difficulties produced several doubts about the soundness of the formalism. Because of these problems, several physicists, who had contributed to the foundation of the formalism, like Heisenberg, Bohr and Rosenfeld, wanted, some years later, to deeply experimentally analyse the predictions of the theory in order to prove its soundness. Above all Bohr and Rosenfeld wanted to test the predictions of the Quantum Mechanics with infinite degrees of freedom, where Spacial Relativity has to be explicitly used. They focused their attention on the analysis of complementarity and on the commutation relations. From the commutation relations for the electromagnetic field, in which the field components refer to precise spacial points and hence do not possess a clear and straight physical meaning, they designed some Gedankenexperimente, that, despite this, were perfectly realisable. In these experiments, they considered only the mean values of the fields over finite regions

\[ ^2\text{This statement means that Quantum Mechanics is not based on any prime physical principle, but only on a coherent set of postulates from which operative conditions can be extrapolated and predictions matching experiments can be obtained. These are the postulates about the wave functions, the observables, the Hermitian operators, the probability interpretation, the complete set of independent eigenfunctions, the expectation values, the time evolution of the wave function.} \]
of space-time. From these experiments, they obtained the same indeterminacy relations that can be obtained from the commutation relations of the formalism, and hence provided a physical foundation to the theory. This process of deeper reanalysis of the experimental foundations of the formalism of Quantum Electrodynamics, that was carried out by the founding fathers of this theory, is a precious work as it discloses new aspects of the existing relation between the relativistic and the quantum-mechanical descriptions of physical phenomena and moreover it sheds a possibly clarifying light on the heart of Quantum Mechanics that makes clear its limits of validity. By considering the book by Heisenberg [3] and some papers by Bohr and Rosenfeld [4] in which they describe their process of reanalysis, mentioned above, it clearly emerges that all their Gedankenexperimente and hence the indeterminacy relations they get to have a common physical foundation: the primary principle of relativistic correlation. Without giving too many details of the Gedankenexperimente that these physicists imagine in order to determine the mean values of the components of the electromagnetic fields and their indeterminacy relations, we will only sketch their main ideas and show that they are clearly always compatible with the relativistic correlation. Heisenberg is convinced that the classical concepts of particle (position and velocity) and wave need to be used in the description of a quantum experiment too and he shows by Gedankenexperimente that in the quantum world these two concepts are inadequate to achieve a cause-effect relation and that their concomitant application to the same microscopical experiment brings about the indeterminacy relations. It is evident that these concepts (corpuscle and wave) were stably related, since their birth, to an isotropic and homogeneous space (the Euclid space) and then they were generalized, after the advent of Special Relativity, to continue to be valid in the flat and rigid minkowskian space-time. In his Gedankenexperimente, he chooses cubic volumes and right angles, where to evaluate the energy and intensity of the electromagnetic field which, of course, is expressed by the Maxwell’s equations or expressions derived from them (Poynting vector, energy density, Liénard–Wiechert potentials or, equivalently, the fields obtained by a Lorentz boost applied to a Coulomb electric field). It goes without saying that all of these ideas are deeply rooted in the relativistic correlation. Similar kinds of considerations are used by Bohr. He is convinced that the physically meaningful statements of the theory are those regarding the average values of the components of the electromagnetic field and, hence, that the mathematical formalism is an idealization that acquires physical meaning when integrated over space-time. With regards to the Gedankenexperimente, he states several times that they have to be treated from a classical point of view considering only classical concepts. He considers extended bodies, not point charges, in order to reduce to zero the radiation emitted by them (radiation reaction) during the measurement of their momentum and he states

---

3We remind again that these indeterminacy relations are equal to those obtained from the commutation relations of the mathematical formalism and that this equality established the physical foundations of this formalism.

4From the previous paragraph, it is clear that this principle is synonym of Special Relativity and of flat and rigid Minkowskian space-time
that due to the finite (not infinite) speed of light the body cannot be considered rigid, but it must be made of many parts interconnected with each other by springs. He bases his considerations and measurements on the classical formalism of Maxwell’s equations (flat and rigid minkowskian space-time) and on the classical concepts. Then, he considers the electromagnetic field as a quantum object, i.e. made up of photons and hence, he considers its corpuscular nature. Photons are emitted according to the Poisson distribution which foresees their probability of being emitted. He shows that the mean value of this distribution coincides with the field measured in classical conditions in the Gedankenexperiment and that the distribution possesses fluctuations which never cancel even when the distribution is identically zero. Exactly as Heisenberg did, he also shows that the results of the Gedankenexperiments are the indeterminacy relations for the components of the field that are precisely compatible with those obtained by integrating, over a minkowskian space-time, the commutation relations of the theoretical formalism. It is clear that both the experimental part and the integrating part have the relativistic correlation as their groundwork. From the perspective gained through the deep revisions made by Heisenberg and Bohr about the physical foundations of Quantum Mechanics, it becomes possible to consider it, not only an axiomatic theory, but also a deductive theory deduced from the principle of relativistic correlation.

3 Relativistic correlation, Local Lorentz Invariance and Space-Time structure

After showing the physical foundation of the formalism of Quantum Mechanics, its founders were no longer worried about the paradoxes that still remained in it like the instantaneous collapse of the wave function, the ontological meaning of indeterminacy, the wave-corpuscle dualism and the contrast between reality and locality. On the contrary, some other physicists, like Einstein, de Broglie, Schroedinger, Dirac, and some years later Bohm continued to be deeply dissatisfied with a theory that, despite its capacity to produce predictions in agreement with the results of the experiments, was only capable to calculate the probability to obtain a result and could not say anything about the description of the physical phenomenon which ended up to be considered ontologically indeterminate until the actual measurement. It will now be illustrated that, by looking at the relativistic correlation (which we have seen to be at the basis of Quantum Mechanics) from the point of view of the Local Lorentz Invariance (LLI) and the local geometrical structure of space-time, new interesting and far reaching

5 As to these indeterminacy relations, it is interesting to know that, at the beginning, Heisenberg called them uncertainty relation and only later Bohr changed their name to indeterminacy. While the word uncertainty is a probabilistic concept with no ontological meaning, the word indeterminacy is an epistemological concept which states the impossibility of knowledge.

6 The formalism of Quantum Mechanics (the commutation relations) which comes from axiomatic assumptions, was proved to be physically sound because the results obtained by it could be obtained as well by realisable experiments.
physical perspectives on Quantum Mechanics will open up, which will provide physical explanations to the paradoxes and a new and physically rich insight of the wave-corpuscle dualism.

3.1 LLI breakdown and Deformed Special Relativity

As above said, the final step for the birth of the principle of relativistic correlation was moved through the process that brought from the relativity of Galilei to the Einsteinian Special Theory of Relativity. In other words, it is not limiting at all to focus the attention on the two postulates of Special Relativity rather than on the principle of relativistic correlation. In particular, the attention has to be concentrated on LLI\(^7\) and its possible breakdown. The concept of LLI comes from Einstein’s relativity theories which state that physical phenomena occur in a space-time whose structure is globally curved (Riemannian) and locally flat (Minkowskian). The local flatness of space-time means that the laws of physics can be locally written in the language of Special Relativity (SR) and hence physical phenomena are locally invariant under Lorentz transformations. The controversial point at issue (from both the theoretical and the experimental side) is whether the validity of local Lorentz invariance (LLI) is preserved at any length or energy scale. It is worth mentioning that a great deal of attempts, both theoretical and experimental, have been conducted so far from different perspectives to predict LLI limits or measure them in order to find out some possible signature of a new physics \([5, 6, 7, 8, 9]\). However, in order not to drift away from the track that has been followed so far, they will not be mentioned. The point of view, from which LLI breakdown is looked at and dealt with in the theoretical and experimental research conducted so far, is metrical. In other words, the questions to be addressed are ‘how does the Lorentz invariant Minkowskian Space-Time get deformed if LLI is broken?’ and ‘can this Space-Time deformation somehow affect the evolution of the physical phenomena that take place in it?’\(^8\). Two of the present authors, Cardone and Mignani, started from the profound connection between the breakdown of LLI and Space-Time geometry and parametrised the minkowskian metric tensor by replacing the constant coefficients of \(\text{diag}(1,-1,-1,-1)\) with coefficients depending on a phenomenological parameter \(E\) as in \(\text{diag}(b_0^2(E), -b_1^2(E), -b_2^2(E), -b_3^2(E))\). The parameter \(E\) has the dimension of energy and has to be interpreted as the energy exchanged during the non-Lorentz invariant process\(^9\). In order

\(^7\)It will be defined more precisely soon, but here it can be considered as the synthesis of the two postulates mentioned above.

\(^8\)It is necessary to clarify the meaning of the words “a parameter with the dimension of energy which is considered to be the energy exchanged during the non-Lorentz invariant process”. A physical process which is not invariant under Lorentz symmetry (in the local sense) takes places in or, more precisely, involves a locally non flat spacetime. In order to detect the effects due to a non-flat spacetime (either curved or deformed) it is necessary to perform two measurements and then subtract their results. This is how Eddington operated when he measured the deflection of the light of a distant star around the Sun by subtracting two measured angles and this is how one operates with geodesic deviation to determine the intrinsic curvature of a manifold. In our case, the parameter \(E\) parametrizes the local deformation of
to determine the features of this parameter, the analytical forms of the metric coefficients and other phenomenological details of this theory, this formalism was used to analyse the experimental set-up and the results of two experiments carried out in Cologne [10] and Florence [11] where LLI was broken in the sense that superluminal propagation of electromagnetic waves was observed. From this analysis, it was possible to extrapolate the energy function of the metric parameters, as it is shown in [12, 13]. However, for our purpose, that is to show the results of an experiment in which some photons anomalously interact with other photons (not according QED), it is sufficient to state that the analysis of the results of these two experiments found out, first of all, an energy value of $4.5 \mu eV$ which is the threshold value over which the local Space-Time becomes again minkowskian and second, the space extension and the angles over which it is possible to make out the deformed space-time effects of LLI breaking.

### 3.2 The experiments

Since we wanted to measure effects due to LLI breakdown, we designed the experimental set-up according to the energy and space threshold mentioned above. Moreover, since we were looking at LLI breakdown from the point of view of the effects brought about by the locally deformed spacetime on the propagation of photons, we had to search for these effects in a difference of two measurements according to what has been explained in the previous Section. Besides, since we wanted the results to shed new light on Quantum Mechanics and, in particular, on the wave-corpuscle dualism, we decided to design an experimental set-up where there would be the presence of the de Broglie wave, i.e. a double slit like experiment. In the last decade we carried out three experiments involving photon systems in the near infrared range. Before moving on to the description we refer to Fig.1 where the lay-out of the set-up is reported. The distances between sources and detectors and in particular the distances $L$ and $s$ were fixed in the same proportion as those of the Florence experiment [11] where LLI breakdown showed up in the sense of superluminal propagation of electromagnetic waves in the microwave range between two horn antennas. A strong hypothesis was made here as to the independence of LLI breakdown from the range of frequency (microwave to infrared).

### 3.3 Experimental set-up

The apparatus employed in all experiments (schematically depicted in Fig.1) consisted of a Plexiglas box with wooden base and lid. The box (thoroughly

---

---

---
Figure 1: Experimental set-up. The box contains two near infrared sources S1 and S2 and three detector A, B and C. The panels divide the room into several vanes, some of them connected by apertures F1, F2 and F3.

screened from those frequencies susceptible of affecting the measurements) contained two identical infrared (IR) LEDs, as (incoherent) sources of light, and three identical detectors (A, B, C). The two sources S1, S2 were placed in front of a screen with three circular apertures F1, F2, F3 on it. The apertures F1 and F3 were lined up with the two LEDs A and C respectively, so that each IR beam propagated perpendicularly through each of them. The geometry of this equipment and the absorbing material of the internal walls were designed so that no photon could pass through aperture F2 on the screen. The wavelength of the two photon sources was $\lambda = 8.5 \times 10^{-5}$ cm. The apertures were circular, with a diameter of 0.5 cm, much larger than $\lambda$. We therefore worked in the absence of single-slit (Fresnel) diffraction. However, the Fraunhofer diffraction was still present, and its effects were taken into account in the background measurements. Detector C was fixed in front of the source S2; detectors A and B were placed on a common vertical panel. Let us highlight the role played by the three detectors. Detector C destroyed the eigenstates of the photons emitted by S2. Detector B ensured that no photon passed through the aperture F2. Finally, detector A measured the photon signal from the source S1. In summary, detectors B and C played a controlling role and ensured that no spurious and instrumental effects could be mistaken for the anomalous effect, which had to be revealed on detector A. The design of the box and the measurement procedure were conceived so that detector A was not influenced by the source S2 according to the known and commonly accepted laws of physics governing electromagnetic phenomena: classical and/or quantum electrodynamics. In other words, with regards to detector A, all went as if the source S2 would not be there at all or would be kept turned off all the time. In essence, the experiments just consisted in the measurement of the signal of detector A (aligned with the source S1) in two different states of source lighting. Precisely, a single measurement on detector A consisted of two steps: (1) Sampling of the signal on A with source S1
switched on and source $S_2$ off; (2) sampling of the signal on $A$ with both sources $S_1$ and $S_2$ switched on. Analogous measurements have been taken on detectors $B$ and $C$. A possible non-zero difference $\Delta A = A(S_1 \text{ on } S_2 \text{ off}) - A(S_1 \text{ on } S_2 \text{ on})$ in the signal measured by $A$ when source $S_2$ was off or on (and the signal in $B$ was strictly null) has to be considered as evidence for the searched anomalous effect. Following all previous discussions, let us explicitly notice once again that the geometry of the box was strongly critical in order to reveal the anomalous photon behaviour.

3.4 The results

Three experiments were carried out by different sources, detectors, power supplies and multimeters. The results of the first and second experiments are reported in [14, 15, 16]. Only the results of the third experiment is reported here. The third experiment was repeated several times over a whole period of four months, in order to collect a fairly large amount of samples and hence have a significant statistical reproducibility of the results. Thanks to this large quantity of data, it was possible to study the distribution of the differences of signals on detector $A$. We considered two types of differences: the differences containing the anomalous signal $\Delta A = A(S_1 \text{ on } S_2 \text{ off}) - A(S_1 \text{ on } S_2 \text{ on})$ and the blank differences $\Delta A' = A(S_1 \text{ on } S_2 \text{ on}) - A(S_1 \text{ on } S_2 \text{ on})$. In Fig.2 we show that the second type of differences are all compatible with zero (inside the zero compatibility interval $[-1; 1]$ µV).

In Fig.3 conversely, we show the differences of the first type ($A(S_1 \text{ on } S_2 \text{ off}) - A(S_1 \text{ on } S_2 \text{ on})$) not compatible with zero after having discarded those difference whose error bar was too much inside the interval $[-1; 1]$ µV.

These data are apparently at variance with electrodynamics which expects that all of the differences of the two types should be compatible with zero. This should be the case because, by the actual design of the experimental box, detector $A$ should not be affected by the state of lighting of the source $S_2$. $\Delta A'$ is indeed compatible with the prediction of electrodynamics. The situation is quite different for the differences $\Delta A$. Actually, only some values (73/180) are inside the null interval, which were discarded, while most of them (107/180) lie outside the null interval. As it is clear from Fig.2, the differences $A(S_1 \text{ on, S}_2 \text{ off}) - A(S_1 \text{ on, S}_2 \text{ on})$ are positive and shifted upwards (needless to say, the stability of power supplies was constantly checked) which means that $A(S_1 \text{ on, S}_2 \text{ off}) > A(S_1 \text{ on, S}_2 \text{ on})$. In other words, despite the greater number of photons in the box when both sources are on, detector $A$ sees less photons than those seen when only $S_1$ is on. Let us stress that it is impossible to account for this systematic effect by a destructive interference between photons from the two sources, because the LEDs are incoherent sources of light. We performed statistical analysis [17, 18] of the data and found out that there is no compatibility between the $\Delta A'$ set and the $\Delta A$ set non compatible with zero as

\footnote{The detectors and the detecting circuitry were so that the higher the $\mu V$, the higher the number of photons collected by the detector.}
Figure 2: Values of the differences $\Delta A'$ obtained by subtracting two sets of signal samples measured on the detector $A$ with both sources on. The differences are clearly compatible with zero.
Figure 3: Values of the differences $\Delta A$ obtained by subtracting two sets of signal samples measured on the detector A with different lighting conditions of the sources: $S_1\text{on}S_2\text{off}$ and $S_1\text{on}S_2\text{on}$. The differences are clearly incompatible with zero.
Figure 4: Gaussian curves (normal frequency vs. signal difference in µV) for the signal differences $\Delta A$ and $\Delta A'$ (dashed and solid curve, respectively). The instrumental drift has been taken into account. It is $\Delta A = 2.411$ µV ($\sigma_{\Delta A} = 0.601$ µV); $\Delta A' = 0.116$ µV ($\sigma_{\Delta A'} = 0.602$ µV). $\Delta A - \Delta A' = 3.81\sigma_{\Delta A'}$

shown in Fig. 4. In particular the mean values of the two gaussian distributions are $3.81\sigma$ apart.

4 Interpretations

Some not exhaustive interpretations are presented here in order to sketch the far reaching consequences of the results of this experiment. Although the experiment was designed so that the detector A should not be affected by the lighting condition of the source $S_2$, the differences (A ($S_1$ on $S_2$ off)-A ($S_1$ on $S_2$ on)) are convincingly incompatible with zero. This evidence, which has been ascertained to be true beyond any reasonable doubt, can be raised from the level of mere evidence to the rank of physical effect if a physical cause is clearly spotted. This experiment was explicitly designed in order to study LLI breakdown in terms of space-time deformation and hence measures the effects of this deformation. In this sense we can imagine that the energy of the photons emitted by $S_2$ locally deforms (electrically, not gravitationally) space-time and that this deformation expands through the aperture $F_2$, reaches the photons emitted by $S_1$ and steers (pilots) their propagation before they are detected.

\footnote{For extensive interpretations you can refer to [19, 20].}
A similar kind of interpretation in terms of something, other than photons, moving through the aperture $F_2$ can be given in terms of Bohmian Mechanics and pilot wave. In this case, it is possible to imagine that the pilot waves of the photons emitted by $S_2$ propagate through the aperture $F_2$ and steer the photons emitted by the source $S_1$ before they reach the detector $A$. According to this interpretation, this is the first experiment ever in which a direct evidence of pilot waves is achieved. The similarity between these two interpretations allows to put forward the intriguing hypothesis of a possible connection between them. In particular we can say that what is called pilot wave is nothing but a deformation of the local space-time geometry, intimately bound to the quantum entity considered (photon) which, in this sense, becomes a much more complex object than the quantum mechanical picture. In particular, with regards to the photon we can say that most of its energy is concentrated in a tiny extent (complying with electrodynamics, relativity and Minkowski space-time) and the rest of the energy is used to deform the space-time surrounding it (violating electrodynamics, not complying with relativity and hence possessing real non-local and superluminal features). This second part of the energy is stored in the local deformation of space-time just as the Riemann curvature of space-time in General Relativity possesses its own energy momentum pseudo-tensor. According to the last sentence about energy stored in the deformation, it is possible to state that pilot waves cannot be hollow waves any longer.

5 Conclusions and remarks

The change of the number of photons detected by $A$ can be read as well in terms of the modification of the photon-photon cross section due to the deformed space-time associated to each photon. With this last picture of modified cross section, we report that compatible results with ours were obtained in crossed photon-beam experiments both in the microwave range [21, 22] and with a CO2 laser [23, 24]. Crossed laser beams are certainly a much simpler experimental set-up, however, it goes without saying that, despite the apparent simple and very common appearance of the equipment, the features of LLI breakdown are so peculiar, as we have extensively pointed out, that require subtle care in tuning all the experimental features in order to make out the anomalous effect due to deformed space-time. However the intersecting of laser beam is a very suitable set-up to deepen the study of different features: spatial extension by varying horizontally and vertically the crossing region of the beams; timing of the deformation by applying different chopper frequencies and sampling time procedures; investigating the effects of deformed space-time on the frequency of photons; attempts to work as close as possible to the single photon; drawing interesting similarities between the nonlinear and non-local effects studied by

\[\text{Just like the curved spacetime around the Sun curves the trajectory of the photons from a distant star. However, while the concept that energy can affect the geometry of space-time is the same as that in General Relativity, this deformation has nothing to do with gravitation.}\]

\[\text{For more extensive interpretations refer to [19, 20].}\]
non linear optics in nonlinear media (liquid crystals) and non linear non local effects of space-time; visualize by CCD the deformation of the laser beam spot which is the unmistakable evidence of deformed space-time through which photons propagate as already tried and reported in [21].

References

[1] J. D. Jackson, *Classical Electrodynamics*, Hamilton Ripinting Company (1998).

[2] M. Jammer, *The Conceptual Development of Quantum Mechanics*, McGraw-Hill, New York, 1966.

[3] W. Heisenberg, *The Physical Principle of Quantum Theory*, Dover Publication Inc. (1949).

[4] N. Bohr, *Niels Bohr Collected Works: Volume 7, Foundations of Quantum Physics II (1933-1958)*, Elsvier Science Ltd. June, (1996).

[5] C. M. Will, *Theory and Experiment in Gravitational Physics*, Cambridge Univ. Press, 1993, and references therein.

[6] D. Mattingly, *Living Rev. Relativity*, 8, 5, (2005).

[7] A. Kostelecky (Ed.), *CPT and Lorentz Symmetry*, vols. I and II, World Scientific, Singapore, (1999 and 2002), and references therein.

[8] G. Amelino Camelia, *arXiv:gr-qc/0207049*, (2000).

[9] G. Amelino Camelia, *Phys. Rev. D* 64, 036005, (2001).

[10] A. Enders, G. Nimtz, *Phys. Rev. E* 48, 632, (1993).

[11] A. Ranfagni, P. Fabeni, G.P. Pazzi, D. Mugnai, *Phys. Rev. E* 48, 1453, (1993).

[12] F. Cardone, R. Mignani: Energy and Geometry – An Introduction to Deformed Special Relativity (World Scientific, Singapore, 2004).

[13] F. Cardone, R. Mignani: Deformed Spacetime – Generalizing Interactions in Four and Five Dimensions (Springer, Dordrecht, 2007).

[14] F. Cardone, R. Mignani, W. Perconti and R. Scrimaglio, *Phys. Lett. A* 326, 1 (2004).

[15] F. Cardone, R. Mignani, W. Perconti, A. Petrucci and R. Scrimaglio, *Int. J. Mod. Phys. B* 20, 85 (2006).

[16] F. Cardone, R. Mignani, W. Perconti, A. Petrucci and R. Scrimaglio, *Int. J. Mod. Phys. B* 20, 1107 (2006).
[17] F. Cardone, R. Mignani, Int. J. Mod. Phys. B Vol.21, no.26, 4437-4471 (2007).

[18] F. Cardone, R. Mignani, W. Perconti, A. Petrucci and R. Scrimaglio, Annales de la Fondation Louis de Broglie, Vol.33, no.3, (2008).

[19] R. Mignani, A. Petrucci, F. Cardone, Proceedings of CASYS’09 - Ninth International Conference On Computing Anticipatory Systems Session On Electromagnetism And Quantum Field Theory (invited) Liège, Belgium, August 3-8, (2009).

[20] F. Cardone, R. Mignani, A. Petrucci, Proceedings of SOPO2012 - International Symposium on Photonics and Optoelectronics Shanghai, China, May (2012).

[21] A. Ranfagni, D. Mugnai and R. Ruggeri, Phys. Rev. E 69, 027601 (2004).

[22] A. Ranfagni and D. Mugnai, Phys. Lett. A 322, 146 (2004).

[23] F. Cardone, R. Mignani, Int. J. Mod. Phys. B Vol.21, no.26, 4437-4471 (2007).

[24] F. Cardone, R. Mignani, W. Perconti and R. Scrimaglio, Phys. Lett. A 326, 1 (2004).