Planck scale still safe from stellar images

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Abstract

The recent paper of Lieu and Hillman [1] that a possible, (birefringence like) phase difference ambiguity coming from Planck effects would alter stellar images of distant sources is questioned. Instead for *division of wavefront* interference and diffraction phenomena, initial (lateral) coherence is developed simply by propagation of rays (cf. van Cittert-Zernike theorem). This case is strongly immune to quantum gravity influences that could tend to reduce phase coherence. The phase ambiguity, if actually present, could reduce any underlying polarization of the light rays.

However, we argue that, as expected since any inherent quantum discreetness of space should become increasingly negligible over larger distances, such a phase ambiguity is rapidly cancelled if a more realistic constantly fluctuating quantum "buffeting" occurs.

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1.0 Introduction

In a recent paper Lieu and Hillman [1] have suggested that the presence of interference effects in stellar interferometers is contrary to what should be expected if time fails to be defined below the Planck time $t_{pl} \sim 10^{-44} sec$. These results, if true, would have profound consequences for quantum gravity research as emphasized in press accounts of this work, including *The Times* of London (8th Feb, 2003).

In their analysis they consider the phase change of waves that occur on propagating through space from distant objects. Because of quantum uncertainties in time, this phase can become so uncertain (to $\sim 2\pi$) after travelling vast distances $\sim Mpc$ in space that clear interference patterns should no longer be possible. However we shall argue that the authors have neglected an opposing property of waves they they simply gain coherence by propagating, which counteracts against any loss of phase caused by quantum gravitational fluctuations.

However, rather than affecting interference or diffraction patterns significantly this phase could alter the possible polarization state of any observed light. Although this alone would be extremely important we find little justification for such a random phase term being present due to quantum gravity discreteness alone.

2.0 Michelson Interferometer

To clarify some of these issues we first consider, at face value, the phase ambiguity outlined in ref.[1]. This would actually be relevant for a Michelson interferometer -see eg[2-4] . Recall there that a light source is split by means of a partially reflecting mirror. These beams are then reflected back and depending on the relevant phase difference between the beams, interference fringes are seen. In the language of ref.[2] this is an example of *division of amplitude* interference phenomena . Such an arrangement was originally used to rule out motion through the "ether". Presumably if the arms of the interferometer were of $\sim Mpc$ scale then an uncertainty in phase would prevent longitudinal coherence and such fringes would no longer be present. Of course this arrangement is impossible to make, and has merely theoretical interest in placing an upper bound on allowed coherence. However, future generations of space born gravitational wave (of Michelson type) interferometers, with ultra high frequency lasers together with the possibility of a low energy quantum gravity scale $\sim Tev$ means this effect might possibly be amenable to investigation - see ref.[5] for more detailed discussion of this

possibility.

3.0 Stellar interferometry

The later developed Michelson stellar interferometer or its electronic Hanbury-Brown and Twiss versions works on a different principle [2,3]. It is an example of a *division of wavefront* interference effect [2]. The lateral coherence between the telescope's two apertures is the quantity now measured. The diameter of the circular coherent area is given by $\sim 0.16\lambda/\alpha$, where λ is the wavelength and α the angle subtended at the aperture [2,3]. For a finite size star this coherence only extends a finite distance which can be measured by moving the mirrors/ receiving dishes until the presence of interference fringes (or their electronic analogues) are no longer present. For the sun this distance is only $\sim 0.019mm$ while for the star Betelgeuse it is $\sim 2.5m$ [2,3]. From this can be deduced the diameter of the source, typically stars or bright galaxies. For a point source the interference pattern is always present regardless of how far apart the mirrors are placed. The calculation in this case is then the same as that for Fraunhofer diffraction through two circular holes [2]. The underlying phase is not important since the sources can be assumed to be incoherent and any temporal or longitudinal coherence is never required .

Now the only way this argument could be prevented is if the initial transverse or spatial coherence is never present across the two collecting mirrors. This is easily seen to be unreasonable by means of the van Cittert-Zernike theorem which roughly is the principle that an electromagnetic wave becomes spatially coherent simply by the process of propagation [2-4]. Technically the calculation now depends of differences between path lengths between points on an incoherent source and at a far distance receiving surface. Without providing the messy details the required sum over path differences is rather immune to any underlying fuzzy Planck scale cf. section 10.4.2 in ref.[2]. Any underlying phase differences cancel out in the calculation since we sum over a large number of paths. As mentioned, the sun, although an incoherent source, develops spatial coherence albeit only over a small scale by the time is reaches earth. Young's fringes can still be produced provided the two slits are very close within the region of spatial coherence. The fact that this coherence develops at all means that any quantum effect causing decoherence is subdominant and counteracted. Since any possible path through space can be split up into a series of shorter ones cf. Huygen's principle [2,3] , the classical effect necessarily dominates.

If quantum gravity had dominated it would be analogous to placing a finely ground glass plate in front of the slits in Young's experiment using a coherent beam-broadened laser source [4,6] . This introduces an irregular phase variation producing a fragmented interference pattern . If the glass plate is then slowly moved, to produce an ensemble average, the usual Airy disc interference pattern is made fuzzy due to a reduction in the *mutual coherence function* [2-4,6]. However, on propagation through space the classical effect must dominate if coherence from the sun or nearby stars is actually produced - corresponding to an overall growth in the *mutual coherence function*.

4.0 Optical Birefringence of the vacuum

We now wish to consider the work of ref.[1] more directly but first we wish to review a number of issues that seem relevant before proceeding, particularly optical birefringence - see eg.[2].

Recall that some crystals are birefringent which allows the speed of propagation to takes two values. This produces two orthogonal beams: ordinary and extraordinary. A well known consequence is the double image seen when viewing an object through a slab of Iceland Spar ($CaCO_3$). The phase difference that gradually evolves between the two beams can alter any initial polarization . This is the principle of the quarter wave or half wave plate that is used to alter the polarization of say an initially vertically polarized beam e.g.[2]. There are a number of related phenomena like the Kerr and Pockels effects where applied electric fields actually alter the indices of refraction [2]. One can also set up a *division of amplitude* interference effect between the ordinary and extraordinary rays. This is the phenomena of *interference figures* as seen in a polarizing microscope [2]. Because the two beams are orthogonal one cannot directly set up the interference effect . Rather one uses an *analyzer* involving a Nicol Prism to finally obtain the interference figure [2] . These and other general forms of optical activity generally just involve polarization effects, as first passing a laser through some crystal to rotate its polarization has no effect on any subsequently Airy disc diffraction pattern.

Studies in Lorentz violations in Electrodynamics have considered the possibility that the vacuum itself is birefringent so that polarization changes or pulse dispersion might occur as waves pass through space [7]. If such phenomena exist then initially polarized light will gradually change as a phase shift develops between the ordinary and extraordinary rays. In theory it

might, like in crystals, be possible to create a interference figure between the two rays although the type of analyzer now required is unclear. Now the sort of analysis done by Lieu and Hillman, would suggest that quantum gravity would make this phase difference uncertain for large propagation lengths so that polarization is eventually lost and any future interference figure impossible to produce. One might have argued that the still present polarization in the Microwave background radiation is at odds from these expected Planck scale degradation effects.

However there are a number of assumptions that can be questioned before we could reach such a conclusion even if vacuum birefringence is present. Assume that the two modes, travelling in the z direction, have differing phase velocities v_p so that the relative phase $\Delta\phi$ between the x direction and y direction of the Electric field changes by

$$\Delta\phi = 2\pi\Delta v_p L/\lambda \tag{1}$$

where L is the distance travelled and λ the wavelength. So far this is deterministic and would simply alter any initial polarization present. What we really require is for $\Delta\phi$ to become random which would signify that polarization is becoming arbitrary after passing large distances. Can the quantum gravity discreteness produce this required randomness ? It is unclear why the phase velocity in say the x component should always receive positive fluctuations $(+ + + + +....)$ while those in the other y component only negative fluctuations $(- - - - -....)$. One should rather expect each ray to receive a random sequence e.g. $(+ - + + -....)$. [1] It isn't clear how often one should consider a measurement to be made if at all. If we consider N such measurements then the random sequence will typically take the normalized value $\pm N^{-1/2}$. Note that unlike a random walk the velocity cannot keep wandering further from its standard value but is instead anchored, to within the confines of the uncertainty principle, around c. In the limit $N \to \infty$ the positive and negative fluctuation components cancel out and no random phase component would be present. However, in this notation ref. [1] have assumed $N = 1$ so that the rays either have a constantly smaller or greater than c velocity throughout their journey. Although this is one possible description of presently unknown Planck scale physics it does not seem

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[1]The actual size of the fluctuation determined by the parameters a and α in refs.[1,8]is not crucial for the following argument.

plausible. In ref.[8] they have pointed out that if instead one takes a more reasonable $N = L/\lambda \sim 10^{30}$ any corresponding effect is $\sim 10^{15}$ times smaller. But one could even envision taking the Planck length to be the relevant scale of quantum "buffeting" so that the effect would now be around $\sim 10^{30}$ times smaller. Note that unless $N = 1$ increasing the distance L reduces the cumulative effects of quantum discreteness as more sampling is done. Especially since any actual image is made up from large numbers of photons. Only in the birefringent limit $N = 1$ does the fluctuation (phase difference) grow with distance as in eq.(1). We would contend that a reasonable interpretation of the effects of quantum foam is that a large number of small buffetings occur during the passage through space. Provided that this number $N >> 1$ the effects of random fluctuations are rapidly cancelled out and don't accumulate in a linear way with distance.

If one is prepared to consider that the two components of the electric field should be treated independently during their travels then it wouldn't be necessary to require that the vacuum itself be birefringent. However since the two electric field components are commuting variables this is difficult to envision and again any effect is rapidly reduced for $N >> 1$.

7.0 Conclusion

In conclusion the authors of ref.[1] have neglected an opposing property of propagating waves that tends to counteract any phase decoherence caused by underlying quantum gravitational effects.

Evading this principle with quantum gravity is difficult since it now depends on summing over all path length differences between emitter and receiver, not a simple accumulation of phase along some path length as in birefringence. The presence of sharp diffraction patterns from Hubble telescope images is not incompatible with at least simple notions of Planck scale physics.

If there is some birefringence of the vacuum, that some approaches to quantum gravity allow, it could have had a dramatic effect on any underlying polarization of light. However, a more realistic treatment for the effects of being constantly buffeted by quantum gravity fluctuations shows no evidence for random phase effects even with a underlying "birefringence of the vacuum" structure. Instead the larger the path length of propagation the more the effects, of any underlying discreteness of time, are weakened. There still remains a deterministic possible alteration in the polarization that is being actively searched for - see e.g. [7]. This makes any observation, of the random

quantum gravity influence on electromagnetic radiation from distant sources, more difficult to envision. Some other possible means of probing this Planck regime are recently reviewed in ref. [9].

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