Measuring the Scale of Quantum Gravity with MAGIC

Javier López[1], Oscar Blanch[1], Manel Martínez[1] for the MAGIC Collaboration
(1) Institut de Física d'Altes Energies, UAB, Bellaterra 08228, Spain

Abstract

Any quantum theory of gravitation leads unavoidably to quantum fluctuations in the gravitational vacuum. In this scenario, an energy-dependent propagation speed for electromagnetic waves emerges. Therefore gammas of different energies being emitted simultaneously by an extragalactic source should reach the human observatories at different times. Despite the propagation speed correction should be very small, the time delay might become measurable for gamma rays traversing cosmological distances.

Active Galaxy Nuclei have shown to be sources with a fast and intense variability at TeV energies which should allow to use them as probes to search for Quantum Gravity effects. The first generation of ground based Cherenkov Telescopes already placed some limits on the effective scale of Quantum Gravity using the data from a single Mkn 421 flare. The new generation of IACTs expects to improve it. They should see many more AGNs and they also expect to see other extragalactic sources with high variability at the GeV-TeV range, such as Gamma Ray Burst. Considering the characteristic time scales of flaring AGN and GRB at all redshifts, the range of the effective Quantum Gravity scale accessible to MAGIC has been studied using Monte Carlo simulations.

1. Introduction

An energy-dependent speed for the propagation of gamma rays in the gravitational vacuum is a natural consequence of any formulation of Quantum Gravity. The speed dispersion relation however, might be rather different for each Quantum Gravity approach. Nevertheless, in all possible models the actual effects are expected to be rather small and for this reason, Quantum Gravity effects can be studied from a pure phenomenological point of view just using the leading orders of an expansion of any model formulation. From this approach a general expression for the delay in the arrival time of a gamma ray can be cast in the following equation 1.

$$\Delta t \sim \eta \cdot \left(\frac{E}{E_{QG}} \right)^{\alpha} \tag{1}$$

pp. 1669–1672

where E_{QG} is an effective energy scale of Quantum Gravity (which might be close to the Planck scale $E_{planck} \sim 10^{-19} GeV$), α is the first non zero leading order and η must be proportional to the gamma-ray path from the source to the observer and, for low redshift sources, should be in good approximation just proportional to the source's distance to us.

Imagining Air Cherenkov Telescopes (IACTs) were proposed since some time ago as good candidates for observing Quantum Gravity effects through the speed dispersion of gammas at high energies [1]. The most important advantage of the IACTs for this purpose is the fact that they are the detectors observing the most energetic gamma rays coming from cosmological objects. Hence the ones which might provide the larger expected time delay between gammas of different energies. At present several studies and proposals about using present and future IACT data for the study of possible Quantum Gravity effects have been presented [2].

2. Quantum Gravity with IACTs

There is at present a direct limit for the effective Quantum Gravity scale given by the Whipple collaboration [3] using propagation time delays. The new generation of IACTs is expected to provide better results in these kind of measurements due to their lower energy threshold and higher sensitivity.

One of the key points will be the possibility of observing sources at higher redshifts than with the present Cherenkov Telescopes due to the improvement in lowering the energy threshold, which provides a much more distant gamma ray horizon. Nevertheless looking at larger distances requires to introduce consistently the role of the Gamma Ray Horizon [4,5] in decreasing the flux of the gamma-rays arriving to us for the measurement of time delays due to Quantum Gravity.

The existence of a gamma ray horizon is due to the fact that high energy gammas are absorbed through the $\gamma\gamma \rightarrow e^+e^-$ interaction with the extragalactic background light while traversing cosmological distances. This absorption limits the observability of very high energy gammas for very far away sources.

Quantum Gravity effects modify not only the propagation speed of gamma-rays in vacuum but also the kinematics of the above process and hence its threshold energy, and therefore modify also the gamma ray horizon [5]. Both effects must be treated simultaneously and consistently for the prediction of the Quantum Gravity phenomenology for IACTs.

A detailed study about the Quantum Gravity scenario for new IACTs [6], shows that looking at farther away sources has two opposite effects on the time delay: on the one hand the propagation from more distant sources leads to larger time delays but on the other hand, because of the absorption due to the the gamma ray horizon, looking at very distant sources, limits the observation to lower energy gammas and, therefore, lower time delays. This two competing

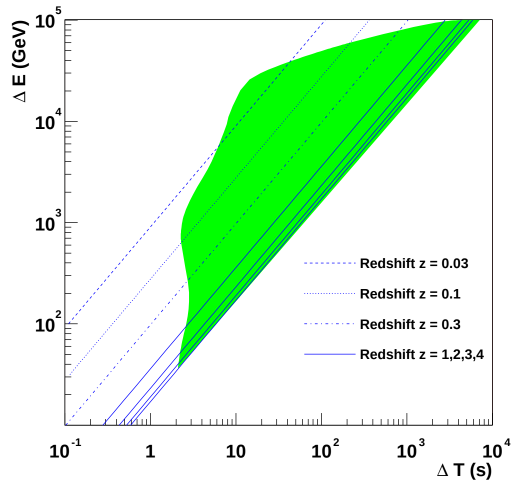

Fig. 1. Expected time delay as function of the gamma ray energy for different redshift sources (*QG parameters*: $E_{QG} = E_{Planck}$ and $\alpha = 1$). The shadow area is the projection of the Gamma Ray Horizon where a lack of gammas is expected due to their interaction with the extragalactic diffuse background light. Figure extracted from reference [6].

effects compensate each other leading to a time delay rather independent on the distance to the observed source. In figure 1. the expected time delay can be seen as function of the gamma ray energy for sources at different redshift. This figure illustrates that the time delay expected to test an effective scale for Quantum Gravity of the order of the Planck Mass is of around few seconds for sources at basically any redshift due to the existence of the gamma ray horizon. Another interesting effect that can be gleaned for this figure and that is due to the peculiar energy spectrum of the extragalactic background light is that for a range of very high energy gammas the universe becomes transparent again: for $E_{gamma} \sim 100\,TeV$ a window in the GRH starts to appear.

Although these time delays do not increase very much by looking at more distant sources it will be mandatory to observe the energy dependence of the gamma arrival times for sources at a wide range of different redshifts in order to disentangle Quantum Gravity effects from any source-dependent delay emission phenomena. Hence the importance of the new generation Cherenkov Telescopes for this measurement since very likely only them may be able to do a redshift dependent analysis.

3. Quantum Gravity with the MAGIC Telescope

The MAGIC Telescope is an Imaging Air Cherenkov Telescope of new generation whose main goal is to reduce the gamma energy threshold below 30

GeV in order to close the gap in the electromagnetic spectrum from 30 to 300 GeV still unexplored [7,8].

A Monte Carlo analysis on the capability of MAGIC to observe Quantum Gravity effects looking into the energy dependence of gamma arrival times has been carried out.

This analysis is based on a rather realistic framework assuming simple Gaussian-like flares with the typical strength and duration of the ones already observed for AGNs like Mkn 421 and the observed AGN energy spectrum. On the other hand also the possibility of observing much faster flux changes detecting GRB at MAGIC energies is been studied now. Several techniques for the analysis of the the arrival time delays have been compared in order to find the one providing the highest accuracy in the determination of the energy-dependent shifts in the time structures for different gamma energies.

Preliminary results show the capability of MAGIC to observe the effective energy scales of Quantum Gravity up to around one hundredth of the Planck Mass scale ($E_{QG} \sim E_p/100$). A full study covering the complete Quantum Gravity parameter space accessible by MAGIC will be presented in this conference based on the Monte Carlo analysis described above.

4. Conclusions

MAGIC is a new Cherenkov Telescope with a very low energy threshold which will allow the study of a region of the Quantum Gravity parameter space unaccessible for previous IACTs. A complete study based on Monte Carlo about the feasibility for MAGIC to observe Quantum Gravity effects through the measurement of the energy dependence of the gamma arrival times will be presented in the ICRC.

References

1. S. D. Biller et al. 1999 Phys.Rev L83, 2108
2. A. Camelia et al. 1998 Nature 393, 763
3. S. Sarkar 2002 Mod.Phys.Lett. A17, 1025
4. V. Vassiliev, 2000 Astropart.Phys. 12, 217
5. F. W. Stecker and O. C. De Jager, Space Sci.Rev. 75, 401
6. O. Blanch et al. 2003 Astropart.Phys. 19, 245
7. M. Martinez for the MAGIC collaboration, these proceedings
8. J. A. Barrio et al, 1998 Preprint MPI-Phe/18-5