Measuring Cosmological Parameters with MAGIC

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Abstract

The physics potential of MAGIC in exploring the Gamma Ray Horizon is discussed. It is shown that the reduction in the Gamma Ray detection threshold might open the window to use precise determinations of the Gamma Ray Horizon as a function of the redshift to obtain relevant independent constraints in some fundamental cosmological parameters.

1. Introduction

Imaging Čerenkov Telescopes (ČT) have proven to be the most successful tool developed so far to explore the γ-ray sky at of energies above few hundred GeV. A pioneering generation of installations has been able to detect a handful of sources and to start a whole program of very exciting physics studies. Nowadays a second generation of more sophisticated Telescopes is about to provide new observations. One of the main characteristics of some of the new Telescopes is the potential ability to reduce the gamma ray energy threshold below ~ 30 GeV.

In the framework of the Standard Model of particle interactions, high energy gamma rays traversing cosmological distances are expected to be absorbed through their interaction with the diffuse background radiation fields, or Extragalactic Background Field (EBL), producing e^+e^- pairs. Then the flux is attenuated as a function of the gamma energy E and the redshift z_q of the gamma ray source. It can be parameterized by the optical depth $\tau(E, z_q)$, which is defined as the number of e-fold reductions of the observed flux as compared with the initial flux at z_q. This means that the optical depth introduces an attenuation factor $\exp[-\tau(E, z_q)]$ modifying the gamma ray source energy spectrum.

The optical depth can be written with its explicit redshift and energy dependence [8] as

$$\tau(E,z) = \int_0^z dz' \frac{dl}{dz'} \int_0^2 dx \, \frac{x}{2} \int_{\frac{2m^2c^4}{Ex(1+z')^2}}^{\infty} d\epsilon \cdot n(\epsilon, z') \cdot \sigma[2xE\epsilon(1+z')^2] \qquad (1)$$

where $x \equiv 1 - \cos\theta$ being θ the angle between the photon directions, ϵ is the energy of the EBL photon and $n(\epsilon, z')$ is the spectral density at the given z'.

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For any given gamma ray energy, the Gamma Ray Horizon (GRH) is defined as the source redshift for which the optical depth is $\tau(E,z) = 1$.

In practice, the cut-off due to the Optical Depth is folded with the intrinsic spectrum of the γ-ray source. Nevertheless, the suppression factor in the gamma flux due to the Optical Depth depends only (assuming a specific cosmology and spectral EBL density) on the gamma energy and the redshift of the source. Therefore, a common gamma energy spectrum behaviour of a set of different gamma sources at the same redshift is most likely due to the Optical Depth.

2. Cosmology with MAGIC

Quantitative predictions of the Gamma Ray Horizon have already been made, but so far no clear confirmation can be drawn from the observations of the previous generation of Gamma Ray Telescopes.

The fact that the next generation of ČT will have a considerably lower energy threshold than the present one should be of paramount importance in improving the present experimental situation for, at least, two reasons:

- Lower energy points will allow to disentangle much better the overall flux and spectral index from the cutoff position.
- Sources at higher redshift should be observable, giving the possibility to gather plethora of new sources that will allow disentangling the intrinsic spectrum and the shape of gamma absorption.

To understand the capability of MAGIC [1,7] to measure the GRH, the fluxes for several of the best extragalactic candidates has been extrapolated to the MAGIC energy range [2]. Then the spectra, which will be measured, is obtained using the MAGIC Montecarlo. And this is used to compute the precision of the GRH determination at several redshifts.

Moreover, some fundamental cosmological parameters such as the Hubble constant and the cosmological densities play an important role in the calculation of the GRH:

$$\frac{dl}{dz} = c \cdot \frac{1/(1+z)}{H_0[\Omega_M(1+z)^3 + \Omega_K(1+z)^2 + \Omega_\Lambda]^{1/2}} \tag{2}$$

Therefore the measurement of the GRH for sources at several redshifts will open the possibility to obtain constraints in some fundamental cosmological parameters [3].

The GRH behaviour with the redshift does not depend only on the cosmological parameters but also on the EBL. The fact that the EBL is not well known at the relevant energy range [4,5,6] will produce large uncertainties in the determination of these cosmological parameters. These uncertainties are quoted as the main systematic errors for the measurements.

3. Results

As a first guess one can assume sources with a similar spectrum to the current TeV extragalactic sources (Mkn501 and Mkn421): $dF/dE = f_o \cdot E^{-\alpha}$, where $f_o \simeq 9 \cdot 10^{-11} cm^{-2} s^{-1} TeV^{-1}$ and $\alpha \simeq 3.0$. We did not consider any energy cutoff since it comes from the GRH predictions and any intrinsic cutoff is neglected. Then, it is extrapolated at lower energy and higher redshift. Under these conditions MAGIC should be able to measure the GRH up to high redshifts with a reasonable significance.

These measurements of the GRH can be used to fit the cosmological parameters. A first estimation of their systematic error due to the EBL has been done in this scenario leading to uncertainties at the level of 30-70% for H_o, Ω_M and Ω_Λ. Waiting for results from a more realistic assumption it already indicates that an effort to reduce them are mandatory.

More realistic predictions based on the first candidate sources to be observed with MAGIC are underway and will be shown in the ICRC conference.

4. Discussion and Conclusions

Before discussing the impact of the cosmological measurements, we would like to see how the observables that will be measured (Optical Depths and GRH) depend on the redshift z. For that we have plotted the prediction for their z evolution in Figure 1. For comparison, the z variation of the Luminosity-Distance, used for the determination of the cosmological parameters using Supernova 1a and of the Geodesical-Distance are shown. One can see that each observable behaves differently with z. Hence, any measurement done with the GRH or the Optical Depth is complementary with the current ones.

MAGIC will be able to measure the GRH for sources in a large redshift range, if their spectra is similar to the one of the TeV emitters already observed. The dependence on the cosmological parameters gives a method to calculate them that is independent on the current ones but a better understanding of the EBL is mandatory to reduce the systematic error.

To understand the actual capability of MAGIC to measure cosmological parameters, a realistic study based on its performance and the list of first targets [2] is being done. The conclusions from this study will be shown in the ICRC conference.

5. References

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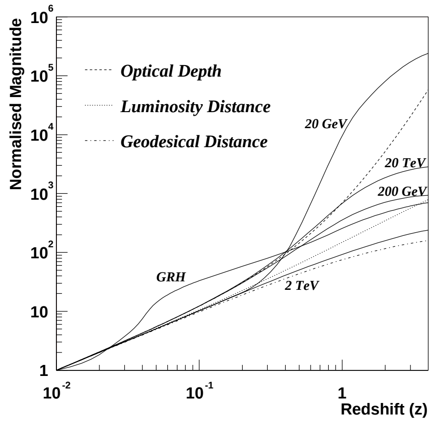

Fig. 1. Redshift dependence of different observables. The predictions are normalized to their value at $z = 0.01$. The solid lines correspond to the Optical Depth prediction for gamma rays of different energies (20 GeV to 20 TeV) while the dashed line is the prediction for a flat νI_ν EBL spectrum. The GRH curve gives the z dependence of the inverse of the GRH energy.

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