Predicted sensitivity of the MAGIC telescope for gamma ray pulsars

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Abstract

Gamma ray pulsars constitute some of the most brilliant sources of the GeV sky as seen by EGRET. Nevertheless, none of them has been detected up to now by ground based Cherenkov telescopes. The reduced energy threshold and big effective area of the MAGIC Cherenkov telescope will offer the possibility to change this situation. In this report, predictions based on EGRET data and Monte Carlo simulations of MAGIC performance are combined to study the sensitivity of this telescope for gamma ray pulsars.

1. Introduction

The first generation of ground-based Cherenkov γ-ray telescopes has not detected pulsed emissions in the energy domain above 300 GeV. This might show that the EGRET pulsed spectra should have a cutoff in the GeV domain, as it is expected from both Polar Cap and Outer Gap γ-ray emission models [1]. In addition there are several hard-spectrum unidentified EGRET sources which are thought to be γ-ray pulsars for which the EGRET statistics are too small to resolve the periodicity [2]. Recently, some young radio pulsars have been proposed as counter parts for unidentified EGRET sources, but detailed periodicity analyses fail to confirm these associations [3]. Therefore, it is of great interest the observation of such sources with the second generation of γ-ray telescopes.

The MAGIC telescope, with its large reflective area of 234 m^2, is expected to be able to capture pulsed γ-rays in the GeV domain in the non-imaging mode [4,5]. In this paper we present the detection time estimated for a selected list of pulsed γ-ray sources, given the information obtained by EGRET, and the

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results of Monte Carlo simulations corresponding to a flat distribution on $cos\theta$ with bins of $\Delta(cos\theta) = 0.01$, being θ the zenith angle, for two different azimuth angles $\phi_1 = 0$ degrees (North) and $\phi_2 = 90$ degrees (West) to see the effect of the geomagnetic field. The Monte Carlo simulations used represent the present estimate of the telescope performance in its foreseen final configuration but no use of the γ/hadron separation methods has been made.

2. Methods

The expected rate of triggers of pulsed Cherenkov showers is obtained from the convolution of the collection area $A(E)$ and the differential spectra dN_γ/dE:

$$R_p = \int A(E)\,(dN_\gamma/dE)\,dE \tag{1}$$

The differential spectra can be obtained in a generic model (polar cap and/or outer gap) for the tails of pulsed differential spectra as

$$dN_\gamma/dE = K\cdot(E/E_n)^{-\Gamma}\exp\left(-\left(E/E_0\right)^b\right) + K_1\cdot(E/E_n)^{-\Gamma_1}\exp\left(-\left(E/E_1\right)^c\right) \tag{2}$$

The second component would be absent in the case of pure polar cap γ-ray emitters, with a super exponential cutoff ($b \geq 1$ and $K_1 = 0$) due to the magnetic pair production in the superstrong magnetic field. An outer gap origin can be interpreted in terms of a non-zero K_1, but with a slower roll-over ($b < 1$ and $c < 1$) compared to polar cap models, since the outer gap absorption process is controlled by photon-photon pair production, which has a weaker energy dependence than magnetic pair production above the polar cap. In order to be conservative in our estimations, we assume a typical polar cap scenario, with $b = 2$ and cutoff energy $E_0 = 20$ GeV for all the sources except those from which b and E_0 have been determined [6]. We fix the normalising energy E_n at 1 GeV so that K is the monochromatic flux at 1 GeV. Γ is the spectral index of the source.

The selected sources are both confirmed EGRET γ-ray pulsars and unidentified EGRET sources compatible with the pulsar hypothesis. All of them should comply with the following criteria: *i*) to be observable from La Palma, *ii*) to have an unidentified EGRET source associated to a known pulsar, *iii*) to have an spectral index within the range $1.4 - 2.3$, typical for pulsar spectra, and *iv*) to have a high value of $log\dot{E}/d^2$ ($\dot{E}$ being the spin-down luminosity and d the distance) and of the efficiency of converting the rotational energy of a neutron star into γ-rays. Table 1 shows the assumed pulsed spectral parameters for the objects considered. K and Γ have been obtained from the third EGRET catalogue [7]. The observation time required is given by $T = x^2 \cdot (R_p + R_b)/R_p^2$, where $R_b = 400Hz$ is the background rate obtained from the Monte Carlo software of the MAGIC

Table 1. Gamma-ray spectral parameters above 1 GeV and associated pulsars.

Object	Associated pulsar	$K(\times 10^{-8})$ ($\mathrm{cm^{-2}s^{-1}GeV^{-1}}$)	Γ	E_0 (GeV)	b
Crab		24.0	2.08	30	2
Geminga		73.0	1.42	5.0	2.2
PSR B1951+32		3.80	1.74	40	2
3EG J0222+4253	PSR J0218+4232	1.9	2.01	20	2
3EG J1837-0604	PSR J1837-0606	5.5	1.82	20	2
3EG J1856+0114	PSR J1856+0113	7.4	1.93	20	2
3EG J2021+3716	PSR J2021+3651	11.5	1.86	20	2
3EG J2227+6122	PSR J2229+6114	4.8	2.24	20	2

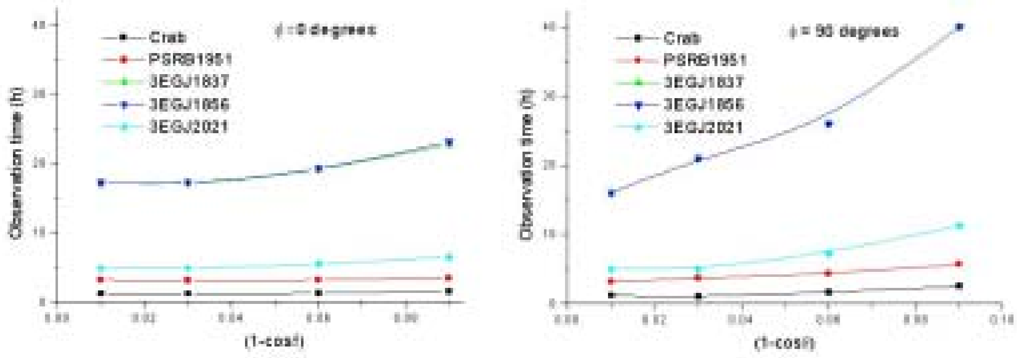

Fig. 1. Observation time vs $(1 - \cos\theta)$ for an azimuth (ϕ) angle of 0 degrees and 90 degrees.

collaboration. This time has been calculated for a $x = 5\sigma$ significance following the description by de Jager [8].

3. Results

The observation time obtained varies from 1 hour in the case of the Crab at low zenith angles to 943 h for the 3EG J0222+4253 source at $\theta = 25$ degrees. We have chosen the sources with an observation time lower than 20 hours for some zenith angles as those that might be candidates for observation at this preliminary stage. The observation time for these sources is plotted versus $(1 - \cos\theta)$ in Fig. 1 for azimuth angles of 0 degrees and 90 degrees.

4. Discussion and conclusions

Looking at the observation time, we see that the pulsed spectra of Crab, PSR B1951+32 and the unidentified EGRET source 3EG J2021+3716 should be detected in few hours with MAGIC telescope. In addition, the unidentified EGRET sources 3EG J1837-0604 and 3EG J1856+0114 might be also detectable with MAGIC if clever cuts are applied to reject the background, taking also into account that we have been conservative in both the spectrum shape ($b = 2$) and cutoff energy (20 GeV).

The obtained results show that for all the γ-ray sources considered the observation time increases with the zenith angle, as it would be expected. However, we also see that this increase is different for the two azimuth angles considered. This result shows the effect of the geomagnetic field which distorts the shower development in the atmosphere and makes the observation time longer for ϕ_2 than for ϕ_1. The two values of azimuth angle could represent the average (90 degrees) and optimal (0 degrees) observation conditions with respect to the geomagnetic field. According to Fig. 1, the relative increase in the observation time when comparing ϕ_1 with ϕ_2 is greater for high zenith angles, reaching a $\sim 40\%$ value for $\theta = 25$ degrees ($(1 - \cos\theta) = 0.09$). In all the sources considered, the relative increase ranges from 40% to 43% at this zenith angle.

5. Acknowledgements

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6. References

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