Detectability of γ-ray from Millisecond Pulsars with MAGIC

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Abstract

Beside the so called canonical pulsars, a sample of radio pulsars, the millisecond pulsars, have been detected with rotational periods in the range from 1 ms to 10 ms. These pulsars are rather old, and most probably have been recycled by some external mechanism (usually a binary system). The surface magnetic fields are lower than that of canonical pulsars, with $B_s \sim 10^9$ G. Given such a low magnetic field, the cut-off energy of curvature photons due to pair production shifts to higher energies since the condition for pair production on the perpendicular component of the fiel is $E_\gamma B_\perp \geq 10^{18.6}$ [3]. Moreover, millisecond pulsars are expected to radiate mostly in the range between 10 GeV and 1.5 TeV, as discussed in the paper. The Cherenkov telescope MAGIC with the energy threshold of $\sim$ 30 GeV will therefore be able to determine the nature of these objects.

The detection rates discussed in this paper make no assumption about hadron rejection capability.

1. Introduction

A catalogue of radio pulsars [7] with rotational periods faster that 30 ms has been investigated to establish if MAGIC [1,8] will be able to detect their γ-ray emission at energies between 30 GeV and 1 TeV, within the context of polar cap emission from rotationally powered pulsars. A total of 73 millisecond pulsars was used to calculate the expected γ-ray rate and the required time to detect a signal, assuming a 3σ sensitivity for the detection.

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2. Method

For these studies we restrict ourself to the polar cap model: it is generally accepted that an inherent feature in polar cap is a very sharp, super-exponential cutoff at the high energy end of the pulsar spectrum [4], resulting from the exponential term in the 1γ-$B_\perp$ optical depth. A generic model for pulsed differential spectra is given by:

$$E^2\frac{dN}{dE} = K \cdot E^\alpha \cdot exp(-(\frac{E}{E_o})^2) \tag{1}$$

where E_o is the cutoff energy. Being conservative we take the slope of the spectrum α as 0 for E> 10 GeV, instead the more optimistic α = -2/3 [6], for unabsorbed curvature radiation in the absence of any pair production. On the other hand, the cutoff energy E_o can be calculated with the expression given by Bulik et al [2] from the known pulsar parameters:

$$E_o = 10^2(\frac{P}{10^{-3}s})^{1/2}(\frac{B_{pc}}{10^9G})^{-1}(\frac{R_{ns}}{10^6cm})^{-1/2}(1+\frac{h}{R_{ns}})^{5/2}GeV \tag{2}$$

To calculate the value of K, we take into account the relation given by Harding et al. [5], which predicts that the high energy luminosity L_γ is $\sim$ 5% of the pulsar spindown power $\dot{E} = 4\pi^2 I\dot{P}/P^3$, whereas the maximum efficiency of conversion is 10%.

$$L_\gamma = \int_0^\infty E\frac{dN}{dE}dE \sim \int_{E_{min}}^{E_o} K \cdot E^{-1}dE = Kln(E_o/E_{min}) = 0.05\dot{E} \tag{3}$$

where E_{min} is 10 GeV. Once the spectrum is known it is possible to infer the expected rate of photons by:

$$Rate_\gamma = T_{obs}\int_{10GeV}\frac{dN}{dE}A_{eff}(E)dE \tag{4}$$

A_{eff} is the telescope effective area at this energy, from MC simulation [5] and T_{obs} is the observation time required for a 3σ detection.

3. Results

We have selected the millisecond pulsars using the following criteria : P<30 ms from the ATNF Pulsar Catalogue. For each pulsar the expected integral rate of high energy photons (between 10 GeV and 1 TeV) was then calculated. With the known rate of hadrons ($\sim$ 400 Hz) and the MAGIC effective area we can infer the observation time to have a detection of 3σ.

Table 1 shows the preliminary results about ms pulsars which MAGIC can detect with 3σ in 65 hours. No γ/hadron discrimination is applied, that is, the so-called quality factor Q is equal to 1:

$$T_{obs} = (\frac{\sigma}{Q})^2\frac{R_p}{R_\gamma^2} \tag{5}$$

Table 1. List of ms pulsars detectable with MAGIC within less than 65 hours.

Pulsar name	P(s)	$\log(B_{sp})$ (G)	$\log(\dot{E})$ $(erg \cdot s^{-1})$	E_o (GeV)	dist (kpc)	z(°)	$T_{obs}^{\alpha=0}$	$T_{obs}^{\alpha=2/3}$
J0437-4715	0.00576	8.76	34.08	418	0.142	75	11 s	0.0015 s
J1744-1133	0.00407	8.28	33.72	1058	2.0	39	136 s	0.009 s
J2124-3358	0.00493	8.50	33.83	698	0.248	61	364 s	0.032 s
J1807-2459	0.00306	9.16	35.98	119	3.27	52	455 s	0.184 s
J1824-2452	0.00305	9.35	36.35	79	5.5	52	764 s	0.452 s
J1909-3744	0.00295	8.32	34.35	826	0.553	65	839 s	0.064 s
J1959+2048	0.00161	8.21	35.20	770	1.53	8	1414 s	0.136 s
J0030+0451	0.00487	8.34	33.54	1000	0.235	24	0.4 h	0.080 s
J1300+1240	0.00622	8.93	34.27	296	0.624	16	0.5 h	0.384 s
J1024-0719	0.00516	8.49	33.73	730	0.354	35	0.7 h	155 s
J2129+1209D	0.00480	9.86	36.58	30	10	16	1.9 h	10 s
J0034-0534	0.00188	7.99	34.48	1405	0.98	33	1.5 h	0.26 s
J1012+5307	0.00526	8.44	33.60	828	0.517	25	6 h	1.584 s
J1823-3021A	0.00544	9.63	35.92	54	8	58	8.7 h	26 s
J1939+2134	0.00156	8.61	36.04	308	9.65	7	10.7 h	7.7 s
J1623-2631	0.01108	9.47	34.36	112	1.8	54	20.7 h	32 s
J0218+4232	0.00234	8.62	35.37	365	5.85	14	26.9 h	16 s
J1730-2304	0.00812	8.61	33.17	703	0.506	51	36.3 h	11 s
J2322+2057	0.00481	8.33	33.54	1013	0.782	8	62 h	17 s

Table 1 lists: the value of the period P, magnetic field at the pulsar surface B_{sp}, spindown power $\dot{E}$, cutoff energy E_o using equation (2), distance d, zenith angle at culmination at the MAGIC site in La Palma $\mid l - \delta \mid$ (where l is the geographical latitude at La Palma and δ is the pulsar declination) and the detection time for pulsars, assuming α=0 and α=2/3, which can be detected in less than 65 hours. There is a total of 19 pulsars selected. Since in the most pessimistic scenario a minimal value of Q $\sim$ 3 is expected from MC, this number would increase to 32 millisecond pulsars. The effect of the zenith angle at the MAGIC site was also taken into account on the time calculation, but they should be still confirmed with further MC simulation.

4. Discussion

Due to the lower magnetic field in the polar cap of ms pulsars, $B_{sp} \sim 10^8$ to 10^9G in contrast to the range of $B_{sp} \sim 10^{11}$ to 10^{13} G for canonical pulsars, the ms pulsar cutoff energies are shifted to higher values [9], reaching values of $\sim$ TeV. Such a high energy cutoff favors the detection with MAGIC even when the γ ray flux would be low, since the telescope reaches its large collection area $\sim 10^4$ m^2 at energies above 30 GeV.

Assuming a flux of γ-rays from only curvature radiation in absence of any pair production, that is, a spectral index of α=2/3, the observation times $T_{obs}^{\alpha=2/3}$

become much smaller. In a more realistic point of view, using a spectral index α=0, time increases. From the times given in table 1, we can select the best ms pulsars to be observable by MAGIC.

To select the best targets, we also have to take into account the zenith angle range of the source at the MAGIC site. Therefore PSR J1959+2048 and PSR J1939+2134, with cutoff energies of $\sim$ 770 GeV and $\sim$ 310 GeV, would be our best choice for MAGIC during phase I.

5. References

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