Astrophysics and Space Science manuscript No.
(will be inserted by the editor)

Massimiliano Razzano · Alice K. Harding
on behalf of the GLAST LAT Collaboration

Pulsar Sensitivity Studies of the GLAST Large Area Telescope

Received: date / Accepted: date

Abstract In this contribution we present our preliminary investigation on pulsar sensitivity of the Large Area Telescope, the main instrument aboard the GLAST mission. In particular we concentrated our attention to pulsars located at low galactic latitudes. We created a set of simulated pulsars having different fluxes in an array of galactic coordinates separated by a distance greater than the LAT Point Spread Function in order to avoid confusion between adjacent sources. Galactic gamma-ray sky background as used during the second LAT *Data Challenge* (DC2) is also included. We then run an automatic routine for testing periodicity for all the pulsars considering an opportune timing solution. In this way we can obtain a map of the sensitivity of the periodic searches for different fluxes and for various Galactic latitudes. Some assumptions have been made by simulating the pulsar sources, but this study is a first step toward an estimate for pulsed emission sensitivity of the GLAST LAT. The pulsed flux sensitivity profile we generate could also be input to a population synthesis code of Galactic pulsars in order to obtain more accurate predictions of the number of expected pulsar detections by GLAST.

Keywords Pulsars · GLAST · Gamma-rays

PACS 97.60.Gb · 95.85.Pw · 95.55.Ka

1 Introduction

Pulsars are among the most exciting gamma-ray sources presently known in the Universe. According to our current knowledge pulsars emit in a wide range of the electromagnetic spectrum, from radio up to gamma-rays. Presently seven high-confidence and three low-confidence gamma-ray pulsars are known, among them the Vela, Crab and Geminga gamma-ray pulsar, which have been recognized as the brightest sources of the gamma-ray sky well before the launch of the Compton Gamma Ray Observatory (CGRO). During the CGRO era four other pulsars were discovered with high-confidence, PSR B1706-44, PSR B1055-52, PSR B1509-58 and PSR B1951+32 [7].

The number of known gamma-ray pulsars should increase significantly after the launch of the Gamma-ray Large Area Space Telescope (GLAST), an international space mission entirely devoted to the exploration of the gamma-ray sky up to hundreds of GeV. Planned for launch in autumn 2007, GLAST will carry a main instrument, the Large Area Telescope (LAT), a pair conversion telescope designed for detection of photons from about 30 MeV up to 300 GeV, and the GLAST Burst Monitor (GBM), specifically designed for GRB observations. Based on sophisticated detectors from High Energy Physics, GLAST will have a much higher resolution and sensitivity than its predecessor EGRET, one of the CGRO experiments.

One of the scientific objectives of GLAST is the capability to study gamma-ray emission from pulsars with unprecedented detail and to discover a large number of new pulsars. An important way of understanding the LAT capabilities for pulsar science is to study the sensitivity to pulsed emission. In this first study we investigate the sensitivity of the GLAST LAT for pulsars that have a counterparts in other wavelengths, so that we have a set of ephemerides available. In order to do that we set up an array of simulated pulsars with properties consistent with young rotation-powered pulsars and with a simple phase profile. We then analyze each of these pulsars to determine whether it is possible to establish if the gamma-rays have the same periodicity as the radio counterparts. In this case we assume the pulsar is detected using timing information, since the gamma-rays have the same modulation of radio counterparts, and then the flux

M. Razzano
Universitá di Pisa and Istituto Nazionale di Fisica Nucleare, 56100 Pisa, Italy Tel.: +039-050-2214400
Fax: +039-050-2214317
E-mail: massimiliano.razzano@pi.infn.it

Alice K. Harding
Laboratory for High Energy Astrophysics,
Code 663, NASA Goddard Space Flight Center, Greenbelt, MD 20771 E-mail: harding@twinkie.gsfc.nasa.gov

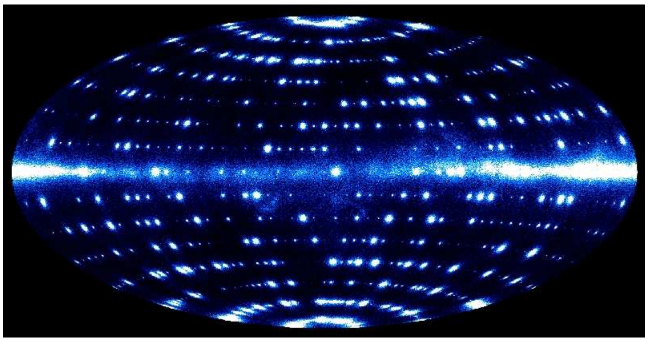

Fig. 1 Skymap that displays the distribution in galactic coordinates of the simulated pulsars used in this study. The sample consists of 900 simulated pulsars. The galactic center is at the borders of the picture

is considered. A study of sensitivity for blind search of Geminga-like pulsars is beyond the scope of this work.

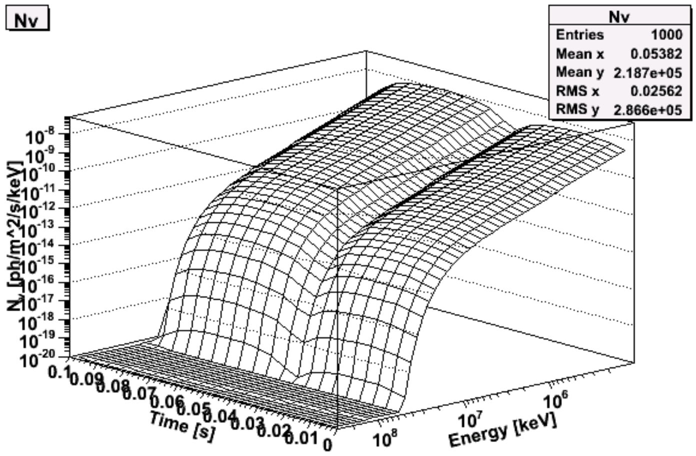

Fig. 2 An example of a photon distribution of a simulated pulsar of the sample simulated by *PulsarSpectrum*. The normalization depend on the total flux

2 Simulations

The simulations are the first step of our investigation. We simulated a set of pulsars distributed in a fixed grid of galactic coordinates. We expect that the LAT Point Spread Funtion (PSF) above 100 MeV is of the order of $\sim 3^\circ$, then we decide a spacing between pulsars at least twice this value. In order to reach a good compromise between good spacing and number of pulsars we choose a separation of 6° in l and 12° in b, with a resulting sample of 900 pulsars, distributed as in Fig. 1 The fluxes F of the simulated pulsars have been chosen to span a range from 5×10^{-9} ph cm^{-2}s^{-1}to 5×10^{-6} ph cm^{-2}s^{-1}, where the flux is intended to be for photons above 100 MeV, in order to be compatible with the 3^{rd} EGRET catalog [6]. The simulated fluxes have been obtained from a uniform distribution in $\log_{10}$(F), and each decade in flux is divided in two flux bins. The flux is integrated above 100 MeV.
Every pulsar from this sample has been simulated using *PulsarSpectrum*[8], a pulsar simulator developed within the GLAST LAT Collaboration and able to simulate pulsar gamma-ray emission with high detail. With *PulsarSpectrum* it is possible to simulate gamma-rays from pulsars according to different scenarios, by specifying the spectrum and the lightcurve. Also the timing effects due to motion of GLAST through the Solar System and to the period change with time is taken into account.
The spectral shape we adopt is a power-law with super-exponential cutoff, as in [2]:

$$\frac{dN}{dE} = K_0(\frac{E}{E_n})^a exp(\frac{E}{E_0})^{-b} \quad (1)$$

This form is particularly interesting since it can be used to roughly model the high-energy behaviour of the spectrum according to basic Polar Cap (b>1) [4] or Outer Gap scenarios (b=1) [1,5].

We decided to maintain fixed spectral parameters for every pulsar in our sample, in order to compare the same pulsar at different fluxes and different galactic coordinates. Since we know that the present high-confidence gamma-ray pulsars are young, strongly-magnetized pulsars, we use for every pulsar in our sample a set of spectral parameters similar to the ones derived for the Vela pulsar (PSR B0833-45) by fitting its spectrum at high energies [2]. We then fix the parameters to be E_0=10 GeV, a=-1.8. The E_n is an energy scale-factor that is fixed to 1 GeV. The value of b is strongly dependend on the emission model, and we fix it to 2.0, as it is derived for EGRET pulsars by fits in [2].
Regarding the phase distribution of the simulated photons, that here we will refer to as *lightcurve*, we have chosen a simple shape in order to allow us the possibility in future studies to find also potential flux upper limits for detections. We chose a double peaked profile in which each peak has the form f(t) = $|\sin\phi(t)|$, but we impose that the second peak of the sine function has height that is double that of the first peak.
According to these prescriptions on spectrum and lightcurve a two-dimensional model of the phase-energy distribution has been derived for each pulsar. An example of such model is shown in Fig. 2 In order to simulate the LAT observations of our pulsar sample, we use *Observation Simulator*, a fast simulator that is part of the LAT *Science Analysis Environment* (SAE), a suite of analysis tools designed by the LAT Collaboration for analyzing incoming LAT data. With *Observation Simulator* we can fold with the LAT response functions the photons generated by a gamma-ray source, in our case a pulsar, in order to obtain a distribution of the photons reconstructed by the LAT. We run a simulation of a 2-months observation of the LAT in scanning mode, that will be the normal LAT operating mode in orbit.

3 Analysis

The goal of the analysis is to find the lowest pulsar flux that can be detected by the LAT for different galactic coordinates, in the presence of the gamma-ray background. In order to do this, we must apply the barycentric corrections to the reconstructed photons and then test the periodicity of the photons in a region near the position of the radio counterpart. For every simulated pulsar there is a correspondent set of ephemerides, generated by *PulsarSpectrum* itself and stored in a database.
We use the LAT SAE tools specifically devoted to pulsar analysis for doing barycentering, testing periodicity and assigning phases, as well as for selecting the sky region of interest.
We decided to investigate a region of 3 degrees around the position of every pulsar, since this is compatible with a PSF 68% containment radius. We also select photons that have reconstructed energies above 100 MeV and we apply these cuts for every pulsar in our sample.
Since we are doing a study on the pulsars with some radio counterparts, we use the database of the simulated pulsars for retrieving timing information to be tested.
We then manage a separate analysis for each pulsar through a suite of Python classes capable to do analysis by interfacing with the LAT SAE tools, so that for each pulsar the region of the sky is selected, the photons are barycentered and then the periodicity is tested. We use here a χ^2-Test for periodicity. In order to decide whether a pulsar is "detected" or not, we adopt a threshold on the chance probability given by the χ^2-Test, and we decide to take only the pulsars that have a Chance Probability less that 5×10^{-9}, in order to be approximately in agreement with the gamma-ray high-confidence detections made by EGRET [3]

4 Low-latitude sources

There are some effects that reduce the sensitivity of our instrument to pulsar detection, mainly due to contamination with photons coming from background and not from the pulsar we are analyzing. First there is a contribution due to the gamma-ray background and also a possible contribution due to sources nearby the pulsar under study. In order to better study the first effect, we put our simulated pulsars at angular spacing comparable with the LAT PSF, in order to avoid confusion between adjacent sources. We present here the study for low-latitude pulsars, that are mainly affected by the galactic gamma-ray background, and we show also some preliminary medium-latitude sources. We study first the minimum detectable flux as a function of the distance from the galactic plane for different observation time. In Fig. 3 is shown the minimum flux for an observation of 1 month. Is is clearly visible that on the galactic plane the minimum flux is increased, since the sensitivity is limited

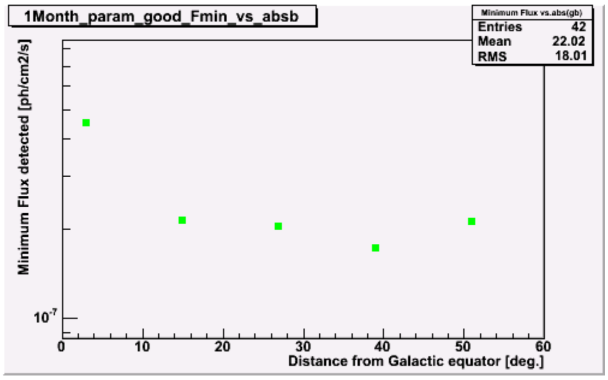

Fig. 3 Plot showing the minimum detected flux in function of the distance from the galactic plane for the simulated pulsars of the sample

Table 1 Values of minimum flux detectable F_{min} for different observation times t_{obs}in case of a pulsar on the galactic plane and at b=24≃°. Fluxes are expressed in ph$cm^{-2}s^{-1}$ for photons with E>100 MeV

t_{obs}	Galactic Plane	Low Galactic Latitude
1 Day	4.3×10^{-6}	3.5×10^{-7}
1 Week	1.6×10^{-6}	6.7×10^{-7}
1 Month	4.5×10^{-7}	2.0×10^{-7}
2 Months	3.0×10^{-7}	1.3×10^{-7}

by the gamma-ray galactic background. We compare the minimum fluxes F_{min} for different observation times and in case of pulsar on the plane (b=0°) and off the plane at galactic latitute b≃24°. For different observation time we obtain the values reported in Table 1. We decided to use these two galactic latitudes in order to highlight the effect of the gamma-ray background near the Galactic plane and a little bit off of the plane. We can see that after 1 month the minimum detectable flux can be lowered roughly by an order of magnitude in the Galactic Plane.
The next step we do is to look for the behaviour of F_{min} with the observation time for different galactic latitudes. The results are shown in Fig. 4 In this plot there are displayed the F_{min} for pulsars on the galactic plane (red squares) and at distance of 24° degrees from the galactic plane . From this plot we derived that the points can be fitted with an inverse square-root law, as we expected. This part of the study can be extended in order to try to extrapolate to the sensitivity at longer observation times, e.g. over a timescale of 1 year, and this will be the scope of our future work.

5 Discussion and conclusion

Gamma-ray pulsars will be a major component of the scientific program of the GLAST mission, in particular of its main instrument, the Large Area Telescope. In or-

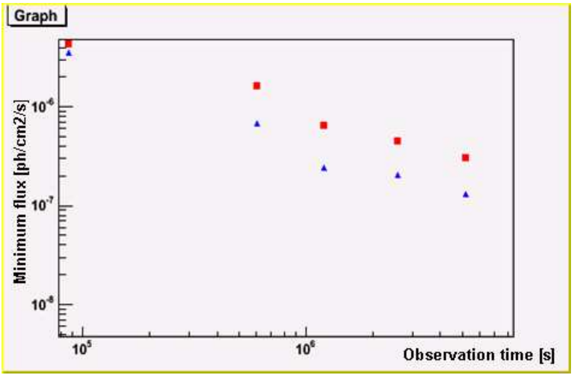

Fig. 4 Plot of F_{min} with the observation time for sources on the galactic plane (red squares) and at out of the plane (blue squares)

der to better address the scientific issues to be studied with the LAT it is useful to know the instrument response and the sensitivity of the LAT to pulsars.
In this work we begin a study on the LAT sensitivity to pulsed gamma-ray signal from pulsars. This first analysis shows some preliminary results on LAT sensitivity for pulsars using timing informations from a radio counterpart. We gave some estimates of minimum detectable flux for different galactic latitudes near the Galactic plane.
Indeed this first study has some limitations that are under consideration in continuing the work. First of all the sensitivity depends on many pulsar parameters, so it would be good to explore more deeply the phase space of pulsar parameters, e.g. periods, lightcurve shape, etc... Regarding analysis it is possible to implement the H-test, since it is less dependent on the profile of the lightcurve. In that case a better estimate that is not dependent on the phase distrubution of photons can be given. A better and customized choice of the region of the sky around a pulsar and of the minimum energy of the analyzed photons will also lead to a more realistic detection procedure, with a consequent increase in detected pulsars. All these issues have been implemented and will be included in a new study.
Hovewer, there are many issues that can be better addressed and the work can be extended. In particular a study with finer spacing between pulsars will give a better-defined sensitivity behaviour, and also a study in galactic longitude can be made, especially for studying the zone near the galactic center. Another important issue is to make longer simulations, in order to give some estimates of the sensitivity for a time scale of a year or more. A possible extention and goal of this type of study can be the use of the sensitivity maps in a population synthesis code, in order to better estimate the number of gamma-ray pulsars that GLAST will discover.

Acknowledgements The authors would like to thanks the GLAST LAT Collaboration for having provided the tools of the LAT Science Analysis Environment and members of the LAT Science Working Group on Pulsars/Plerions/PWN/SNR for the very interesting and useful discussions and suggestions.

References

1. Cheng, K. S. et al.: Energetic radiation from rapidly spinning pulsars. I - Outer magnetosphere gaps. II - VELA and Crab. ApJ **300**, 500-539 (1986)
2. Nel, H.I. and De Jager, O.C.: Gamma-Ray Pulsars: Polar CAP or Outer Gap Emission?. APSS, **230**, 299-306 (1995)
3. Ramanamutrhy, P.V. et al.: EGRET Detection of Pulsed Gamma Radiation from PSR B1951+32. ApJL **447**, L109 (1995)
4. Daugherty, J.K and Harding, A.K.: Gamma ray pulsars: Extended polar CAP cascades from nearly aligned rotators. AAPS **120**, C107+ (1996)
5. Romani, R.W.: Gamma-Ray Pulsars:Radiation in the Outer Magnetosphere. ApJ **470**, 469 (1996)
6. Hartman, R.C. et al: The Third EGRET Catalog of High-Energy Gamma-ray Sources. ApJS, **123** , 79-202 (1999)
7. Kanbach, G.: Gamma-ray Pulsars. Proceedings of the 270 WE-Heraeus Seminar on Neutron Stars, Pulsars, and Supernova Remnants, MPE Report 278. Edited by W. Becker, H. Lesch, and J. Trmper. Garching bei Mnchen: Max-Plank-Institut fr extraterrestrische Physik, 91 (2002)
8. Razzano, M. et al.: PulsarSpectrum, simulating gamma-ray pulsars for the GLAST mission. In Proocedings of the third Workshop on Physics with the new generation of High-Energy Experiments, Cividale del Friuli, May 2005, Wiley (2005), also as astro-ph/0510181