Gamma-ray Pulsar Simulations

for the Gamma-ray Large Area Space Telescope (GLAST)

Massimiliano Razzano, Università di Pisa & INFN Pisa

on behalf of the GLAST LAT collaboration

Gamma-ray pulsars in the GLAST era

A short timetable

1961 - Explorer XI detects first cosmic gamma rays

1967 - Jocelyn Bell discovers the first pulsar (PSR 1919+21)

1968 - Discovery paper on Nature (Hewish et al. *Nature* 1968)

1969 - Goldreich and Julian paper on pulsar electrodynamics (*ApJ*, 1969)

1970 - first Crab gamma-ray resolved curve from Groom data (Thiller et al. *ApJ* 1970)

1972 - Launch of SAS-2 mission ; detection of gamma rays > 35 MeV from Crab (Kniffen et al. *Nature* 1974)

1973 - Detection of Geminga with SAS-2

1975 - First SAS-2 observations of gamma rays from Vela (Thompson et al. *ApJ* 1975); launch of COS-B mission

1981 - Paper on gamma-ray emission from Polar Cap model (Harding *ApJ* 1981)

1986 - Outer gap model for pulse gamma rays emission (Cheng, Ho Ruderman *ApJ* 1986)

1991 - Launch of the Compton Gamma Ray Observatory

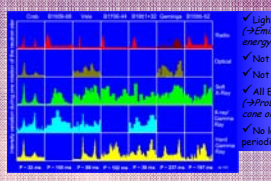
1992 - EGRET discovery of PSR B1706-44 (Thompson et al. *Nature* 1992)

1993 - EGRET discovery of PSR B1055-52 (Fierro et al. *ApJ* 1993); BATSE discovery of PSR B1509-58 (Wilson et al. 1993)

1995 - EGRET discovery of pulsar PSR B1951+32 (Ramanamurthy et al. *ApJ*, 1995)

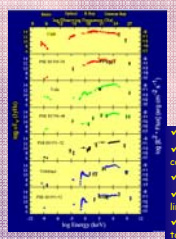
2000 - End of CGRO mission

2007 *- Launch of the Gamma ray Large Area Space Telescope*

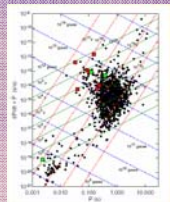


- ✓ Lightcurves depends on the energy band *(->Emission mechanism and geometry should be energy dependent)*
- ✓ Not all are observed at highest energies
- ✓ Not all have radio counterparts
- ✓ All EGRET pulsars shows double peaks *(->Probably emission takes place along a cone or surface)*
- ✓ No longer time variability except from the periodicity

Plots from D.J.Thompson 2003



Observational picture



- ✓ Maximum power output is in gamma rays
- ✓ For some pulsars there is a thermal component in X rays
- ✓ Power law of spectral index ~2
- ✓ No pulsed emission > 30 GeV (~EGRET upper limit)
- ✓ Spectrum variation with phase, probably due to different emission components and geometry

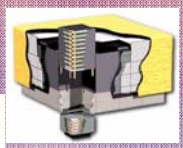
7 high confidence gamma-ray pulsars

Low confidence gamma-ray pulsars

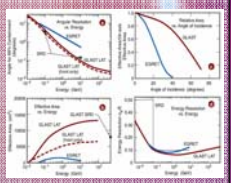
- ✓ Concentrates in high B region
- ✓ Young ages
- ✓ One msec pulsar candidate: need confirmation

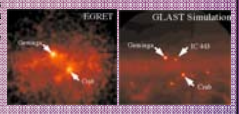
Gamma-ray pulsars: what GLAST can say

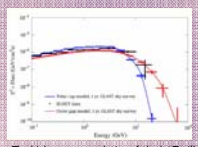
Thanks to its superior sensitivity, its greater effective area and better time and energy resolution, GLAST will be a powerful instrument to study the gamma ray emission from pulsars



The Large Area Telescope (LAT) is the main GLAST instrument. The LAT is a pair conversion telescope like EGRET, but is equipped with new high-level performances detectors. A key subsystem of the LAT is the high precision silicon tracker, assembled under the responsibility of the Italian collaboration.



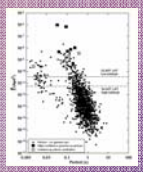




(From LAT Science Document and LAT proposal)

The high energy resolution of the LAT will permit to distinguish between different emission scenarios (here for example between Polar Cap or Outer Gap)

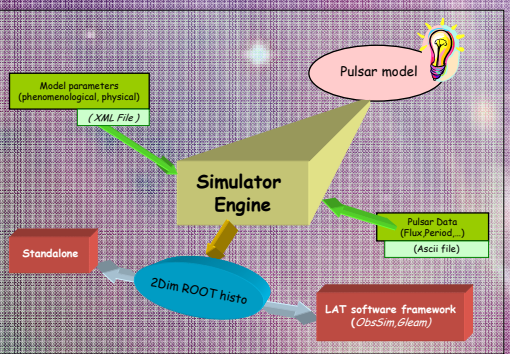
The dead time ‹ 100 μs and the large effective area will permit better phase-resolved studies in order to reveal emission components



- Higher sensitivity of the LAT with respect to the previous gamma-ray telescope: GLAST might detect a number of pulsars between few tens to few hundreds depending where the pulsars are located in the galaxy.
- In addition new gamma-ray pulsars could be detected with unknown period searches.

The PulsarSpectrum simulator

PulsarSpectrum is a software that can simulate gamma-ray emission from pulsars starting from a pulsar model.



How it works?

Starting from a pulsar model, e.g. phenomenological, the simulator builds lightcurves and spectra of the simulated pulsar.

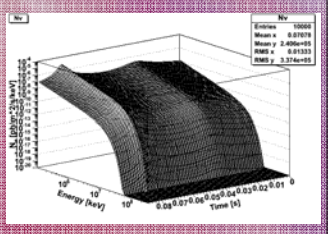
The parameters of the pulsar are divided in 2 categories:

- *Model parameters* (like spectral indexes, etc.),located in the XML source file;
- *Pulsar general parameters* (period, period derivatives, ephemerides, etc.) located in a *PulsarDataList* ASCII file;

The simulator then creates a 2-dim ROOT histogram (ph/m²/keV/s vs. energy vs. time)

Major features:

- **Simple usage:** every user can easily create his own pulsar source
- **Flexibility:** Different pulsar models can be implemented
- The effects due to the **period change** with time is taken into account
- The **barycentric corrections** for arrival times due to lightTravel delay and Shapiro delay are taken into account
- The pulsar general parameters can be referred to **specific ephemerides**
- The simulator can be used **standalone** or can be plugged in the **LAT simulation framework** (*Gleam*or *ObservationSim*)



Example of a TH2D ROOT histogram created by PulsarSpectrum

The basic model for simulations

The default model is a phenomenological one. We use an analytical form for the spectrum, based on (Nel & De Jager,1995)

Flux normalisation based on 3rdEGRET catalog (ph/cm²/s, E>100MeV) for known gamma-ray pulsars, and in the EGRET band for fake simulated pulsars

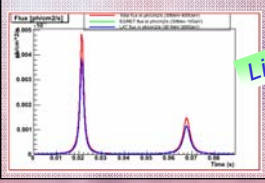
There are several lightcurve options:

- Generates random curve (1 or 2 peaks with Lorentz profile)
- Read profile from a template (useful for reproducing existing pulsars);

Analytical spectral shape: (Nel and De Jager, 1995):

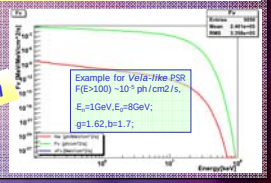
$$\frac{dN_\gamma}{dE} = K \left(\frac{E}{E_n}\right)^{-g} exp\left(\frac{-E}{E_0}\right)^{+b}$$

- Description of the high energy cutoff;
- Parameters are obtained from fits on the known gamma-ray pulsars (Ref. Nel, DeJager'95), and DeJager '03);
- Flux normalisation based on 3rdEGRET catalog (ph/cm²/s, *E>100MeV-30 GeV* ~EGRET band);
- By changing values of the parameters we can simulate different pulsars;



Lightcurve

Spectrum

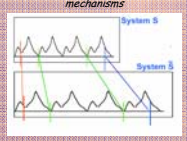


Accurate timing corrections

From the 2-dimensional ROOT histogram created by the simulator the photons are extracted according to the flux and to poissonian distribution, but the arrival times at the spacecraft must be corrected in order to keep into account several timing effects:

Pulsar period change

due to energy loss caused by radiation mechanisms



The ROOT histogram refers to a system S where the period derivatives P' and P'' are 0. According to a P' and P'' we can transform the arrival times to a system S' where period change.

Barycentric corrections

due to use of Barycentric Dynamical Time for arrival times

The arrival times of the photons extracted are referred to the Solar System Barycenter (SSB), and must be "de-corrected" to Terrestrial Time (TT) at the spacecraft. This because the data reduction begins with the barycentric corrections from TT to Barycentric Dynamical Time (TDB)

Corrections:

- Conversion from TT to TDB;
- Geometrical delay due to light propagation time;
- Relativistic correction due to gravitational field of the Sun (Shapiro delay);

Pulsars ephemerides

In order to assign a phase to each photon, a set of ephemerides is needed. The ephemerides P_0,P'_0,P''_0 are referred to a specific epoch t_0 (e.g. $P_0=P_{t=t_0}$). *PulsarSpectrum* takes into account the ephemerides and they validity range in order to correctly compute the period change corrections.

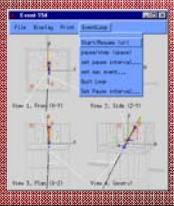
An screenshot of the **LAT pulsar database**, that is intended to contain the timing solutions of the pulsars targeted by GLAST

Pulsar simulations during the LAT Data Challenge 2

The LAT Data Challenges (DC) are important milestones for developing and testing LAT simulation and analysis software. During the DC2 a full simulation of 55 days of LAT observation in scanning mode has been produced and scientists will analyze these data in order to validate LAT MonteCarlo, study LAT response functions, refine sky simulations and test analysis tools and algorithms. The LAT DC2 started at the beginning of March and will end at the end of May. The DC2 sky should resemble what LAT will see during its first months of observations.

The sky model of DC2 contains all EGRET sources and a lot of more simulated sources. **PulsarSpectrum has been used to simulate the pulsar population that constitutes the DC2 sky.**

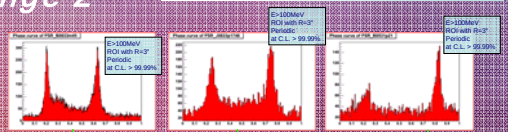
The LAT response has been simulated with Gleam, a full MonteCarlo of the instrument. Gleam takes into account all the physical processes that occur when a photon or a charged particle enter the LAT

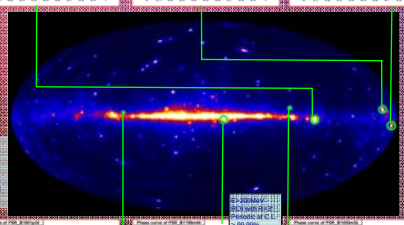


Here we show **the lightcurves of EGRET pulsars** that have been simulated and then analyzed. The basic analysis consisted in the barycentering, the periodicity test (Chi2) and then the phase assignment in order to build the phase distribution of the photons reconstructed by the LAT.

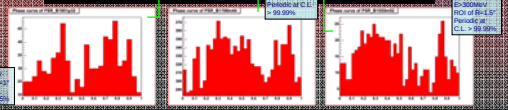
All these procedures have been conducted using the pulsar tools from the LAT Science Analysis Environment controlled to a Python-based interface.

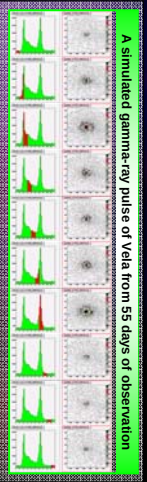
The EGRET pulsars in the DC2 data





All-sky count map of the simulation of 55 days for DC2





A simulated gamma-ray pulse of Vela from 55 days of observation