Observation of the Crab Pulsar and Nebula with the Fermi Large Area Telescope

M.-H. Grondin, M. Lemoine-Goumard, F. Loparco and M. N. Mazziotta

for the Fermi-LAT Collaboration and the Pulsar Timing Consortium

Abstract

The Crab Pulsar and Nebula are the remnants of the explosion of supernova SN 1054, which was observed by Chinese astronomers. Previously detected by EGRET, the Crab Pulsar and Nebula have been extensively observed in the gamma-ray energy band by the Large Area Telescope (LAT) onboard the Fermi satellite. The data collected by the LAT during its early operation stage have allowed a detailed measurement of the fluxes and of the energy spectra of both sources. The pulsar spectrum is consistent with the EGRET measurement in the low energy region below 1 GeV and is well described by a power law with an exponential cut-off at a few GeV. The nebula spectrum is well modeled by a sum of two power laws, identified as the falling edge of the synchrotron and the rising edge of the inverse Compton components, and is in agreement with the observations from Earth-based telescopes.

Fermi-LAT data analysis

Event selection:

- Region of Interest (RoI) of 20° centered on the Crab pulsar radio position
- 8 months data with Fermi operating in survey mode
  - ✓ data from August 2, 2008 to April 7, 2009
- P6 ''diffuse'' class events

Temporal analysis:

- ephemeris built from the Nancay and Jodrell radiotelescope data
- 698 Times of Arrival (ToA) used for the analysis:
  - ✓ 210 observations at 1.4GHz
  - ✓ 488 observation at 600MHz

Maximum likelihood spectral analysis

- A parametric model is assumed for the source spectrum and for the background components
  - ✓ All the nearby sources already detected by Fermi are modeled using simple power law spectra with spectral index 2.0 and free prefactors
  - ✓ The spectrum of the Crab nebula is modeled by the sum of two simple power law spectrum
    - The nebula spectrum is reconstructed from off-pulse events, i.e. events with phases in the range from 0.52 to 0.87
  - ✓ The spectrum of the Crab pulsar is modeled by a power law with exponential cutoff
    - The pulsar spectrum is evaluated from on-pulse events, i.e. events with phases less than 0.52 or larger than 0.87
    - The background has been evaluated off-pulse
- The search of the set of parameters that maximize the likelihood is performed (unbinned analysis)
- The maximum likelihood analysis is also performed in individual energy bins (binned analysis)
- An unfolding analysis that takes energy dispersion introduced by the instrument response function into account has been also implemented and the results are consistent with the ones from the maximum likelihood analysis

Crab Nebula spectrum

The Crab Nebula spectrum is well described by the sum of two simple power laws, identified as the falling edge of the synchrotron component and the rising edge of the inverse Compton component:

$$dN/dE=k_{sync}(E/E_0)^{-\Gamma sync}+k_{IC}(E/E_0)^{-\Gamma IC}$$

with E_0=1GeV. The values of the parameters are:

- $k_{sync}=(9.1\pm2.1_{stat}\pm0.7_{sys})\times10^{-13}cm^{-2}s^{-1}MeV^{-1}$
- $\Gamma_{sync}=3.99\pm0.12_{stat}\pm0.08_{sys}$
- $k_{IC}=(6.4\pm0.7_{stat}\pm0.1_{sys})\times10^{-12}cm^{-2}s^{-1}MeV^{-1}$
- $\Gamma_{IC}=1.64\pm0.05_{stat}\pm0.07_{sys}$
- $\Phi(E>100MeV)=(9.8\pm0.7_{stat}\pm1.0_{sys})\times10^{-7}cm^{-2}s^{-1}$

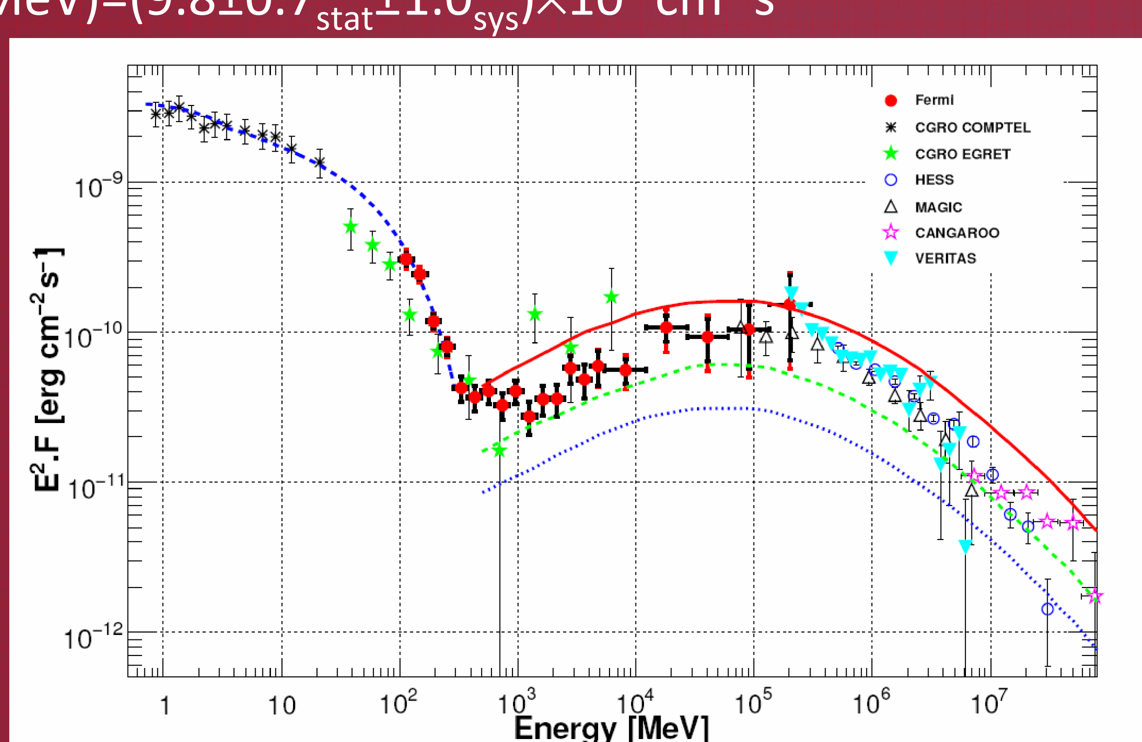
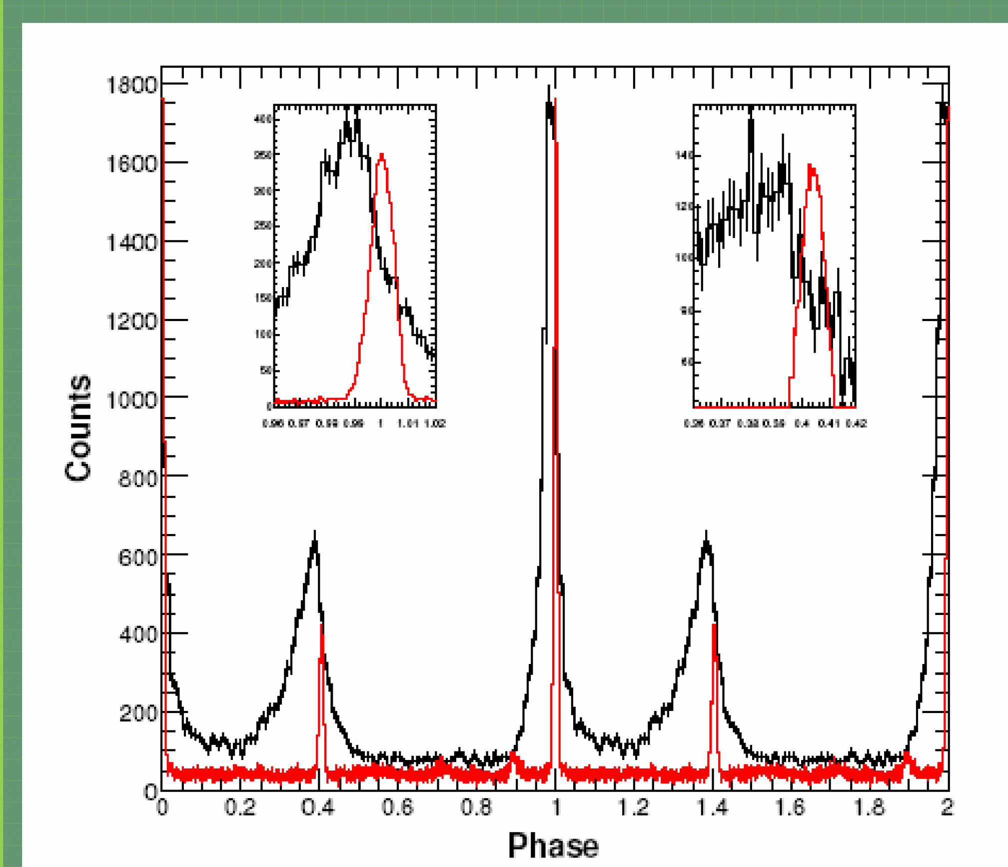


Figure 4: Crab Nebula spectral energy distribution. The Fermi-LAT data points (red dots) are obtained from the binned maximum likelihood analysis and are compared with the observations from CGRO and some earth-based telescopes.

Crab Light curves

The Crab pulsar has a rotation period of 33ms. The light curve obtained with Fermi-LAT data exhibits two peaks, P1 and P2, at the phases $\phi_1=0.9915\pm0.0005$ and $\phi_2=0.3894\pm0.0022$. The ratio P1/P2 decreases with increasing energy.



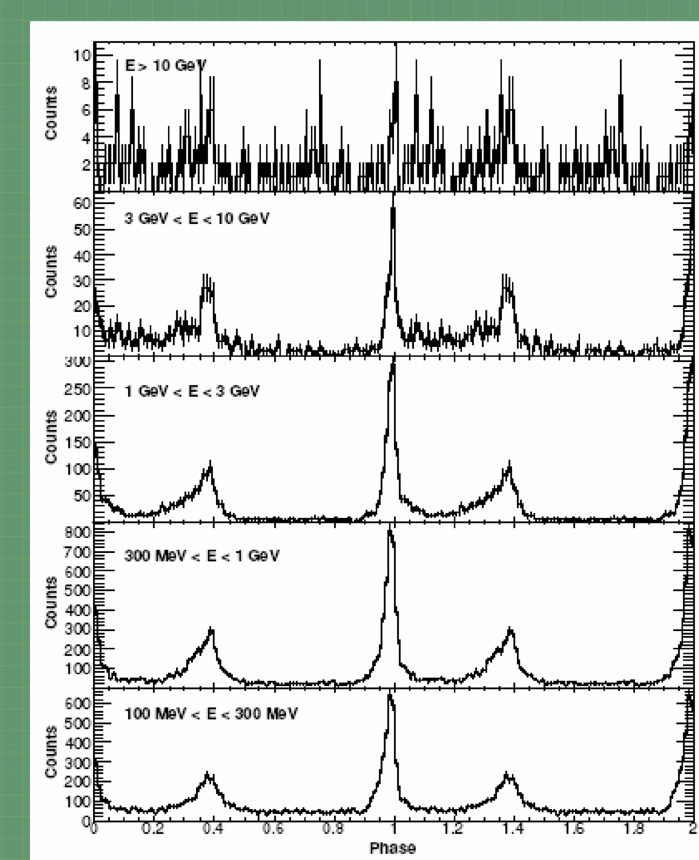


Figure 1: Light curve obtained with the Fermi-LAT photons above 100 MeV (black) compared with the radio light curve (red)

Figure 2: Fermi-LAT light curves in different energy bands

Crab Pulsar spectrum

The Crab Pulsar spectrum is well modeled by an exponential cutoff power law:

$$dN/dE=k(E/E_0)^{-\Gamma}\exp(-E/E_{cut})$$

with E_0=1GeV. The values of the parameters are:

- $k=(2.36\pm0.06_{stat}\pm0.15_{sys})\times10^{-10}cm^{-2}s^{-1}MeV^{-1}$
- $\Gamma=1.97\pm0.02_{stat}\pm0.06_{sys}$
- $E_{cut}=(5.8\pm0.5_{stat}\pm1.2_{sys})$ GeV
- $\Phi(E>100MeV)=(2.09\pm0.03_{stat}\pm0.18_{sys})\times10^{-6}cm^{-2}s^{-1}$

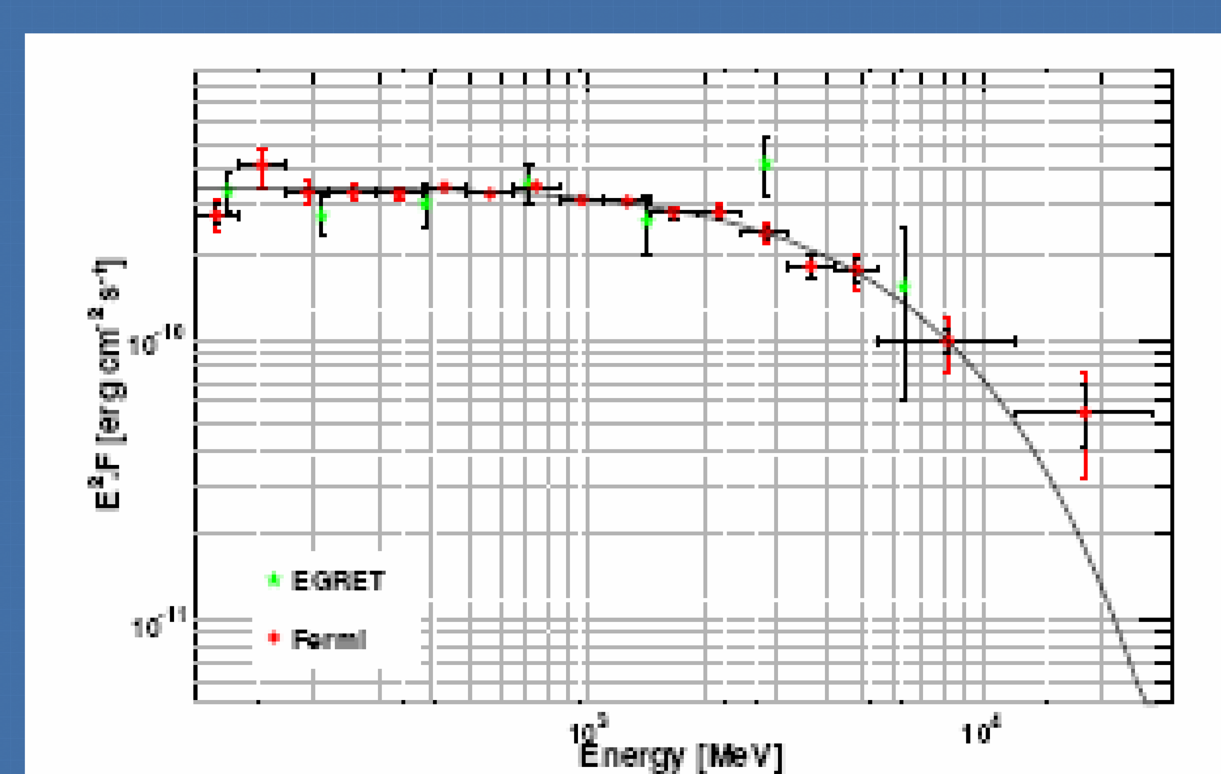


Figure 3: Crab Pulsar spectral energy distribution. The Fermi-LAT data points are obtained from the binned maximum likelihood analysis and are consistent with the EGRET observations.

Conclusions

The Crab Pulsar and Nebula are being widely investigated by the Fermi LAT:

- The pulsar spectrum exhibits a cutoff at a few GeV
- The tail of the synchrotron component and the rise of the inverse Compton component are observed in the nebula spectrum

The spectra of the pulsar and of the nebula are in good agreement with the results from other experiments

- the low energy region of the pulsar spectrum is consistent with EGRET data
- the nebula spectrum is in agreement with EGRET data in the 200 MeV – 1 GeV region and with data from Cerenkov telescopes in the high energy region