High-energy gamma-ray observations of Geminga with the Fermi Large Area Telescope

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The Geminga pulsar is the second brightest persistent source in the GeV gamma-ray sky. We report on the preliminary results obtained on the analysis of the first year of observations.

Abstract

Geminga is the second brightest persistent source in the GeV gamma-ray sky. Discovered in 1975 by SAS-2 mission, it was identified as a pulsar only in the 90s, when ROSAT detected the 237 ms X-ray periodicity, that was later also found by EGRET in gamma rays. Even though Geminga has been one of the most intensively studied isolated neutron star during the last 30 years, its interest remains intact especially at gamma-ray energies, where instruments like the Large Area Telescope (LAT) aboard the Fermi mission will provide an unprecedented view of this pulsars. We will report on the preliminary results obtained on the analysis of the first year of observations. We have been able to do precise timing of Geminga using solely gamma rays, producing a timing solution and allowing a deep study of the evolution of the light curve with energy. We have also measured and studied the high-energy cutoff in the phase-averaged spectrum and produced a detailed study of the spectral evolution with phase.

The chase for Geminga

A short history

1975 **Discovery by SAS-2**
(Fichtel et al. 1975)

1981 **Observations by COS B**
(Swanenburg et al. 1981)

1983 ***Einstein* X-ray source 1E 0630+178 proposed as a possible counterpart for "Geminga"**
(Bignami et al. 1983)

²The reader may be puzzled about the origin of the name "Geminga": this source is in the constellation of *Gemini* and it is a *gamma*-ray source. Pronounced with both G's as in "get," the word means "does not exist" or "it's not there" in Milanese dialect.
(From Bignami et al. 1983)

1987 **Detection of the optical counterpart**
(Bignami et al. 1987, Halpern & Tytler 1988)

1992 **Detection of 237 ms periodicity in X-ray by ROSAT**
(Halpern & Holt 1992)

Detection of gamma-ray periodicity by EGRET aboard CGRO
(Bertsch et al. 1992)

Gamma-ray periodicity found in archival data of COS B and SAS-2
(Bignami & Caraveo 1992, Mattox et al. 1992)

1993 **Detection of proper motion of the optical counterpart**
(Bignami et al. 1993)

1994 **Detailed analysis by EGRET**
(Mayer-Hasselwander et al. 1994)

1998 **Improved position by Hipparcos and subsequent improved timing solution**
(Caraveo et al. 1998, Mattox et al. 1998)

2003 ***XMM-Newton* Discovery of bow-shock trailing Geminga's motion (the Geminga's "tail")**
(Caraveo et al. 2003)

2004 **XMM-Newton phase-resolved spectroscopy**
(Caraveo et al. 2004)

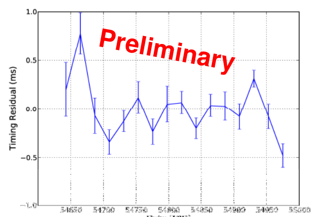
2009 **AGILE observations**
(Pellizzoni et al. 2009)

Fermi-LAT observations
(Abdo et al. 2009, in prep.)

Fermi-LAT observations

- Data collected from **2008 June 25 to 2009 June 15**
- Spectral analysis based on subsample beginning on 2008 August 4
- Removed photons at zenith angles > 105º
- Used "**diffuse**" event class (lowest background contamination)

- **Using gamma rays only**, a set of 16 TOAs have been obtained
- **Timing solution** based solely on gamma rays have been derived
- Residuals to the model have a rms of 251 μs

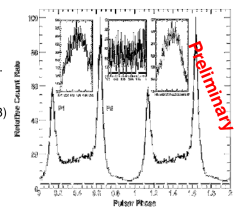


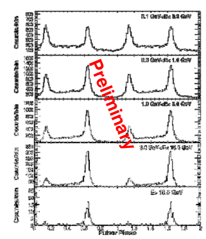
Timing solution of Geminga obtained solely from gamma rays.
(The Y-scale is chosen to highlight the timing noise residuals, that corresponds to only ~0.001 in phase)

Geminga pulse profile

Light curve at E> 0.1GeV

- Gamma rays selection:
  - At θ <Max[1.6-3log$_{10}$(E_{Gev})] deg.
  - E>0.1 GeV
- 61219 pulsed photons
- 2 peaks (0.141±0.002; 0.638±0.003)
- 789 photons in off-peak [0.9-1.0]

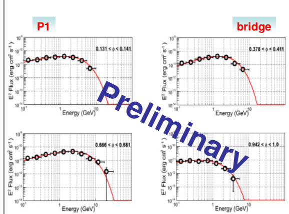




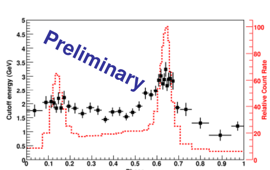
Energy-dependent light curve

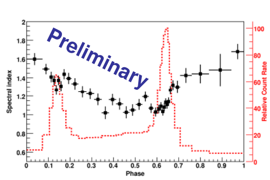
- P1 disappears at high energies
- P2 present up to ~18 GeV
- P1/P2 decreasing
- No 3rd peak at ~GeV energies

Phase-resolved spectroscopy



- 36 phase bins with 2000 counts each
- Fit with power law with exponential cutoff
- Here 4 sample spectra extracted from P1, P2, bridge and off-peak





Phase-resolved scans

- P2 is the hardest component
- Bridge emission very hard
- Off-peak emission compatible with magnetospheric emission

Discussion and Summary

Light curve and beam geometry

- No radio emission → Favored outer magnetospheric emission
- Pulsed emission ~18 GeV → Emission at > ~2.7 R_* *(Baring 2004)*
- Using gamma-ray pulsars 'Atlas' of Watters et al. 2009:

Model	α	ζ	f_Ω
TPC	30 – 80, 90	90, 55 – 80	0.7 – 0.9, 0.6 – 0.8
OG	10 – 25	85	0.1 – 0.15

Inclination angles and Beaming factor for Geminga, from Watters et al. (2009)

Gamma-ray luminosity and efficiency

- F(>100 MeV)=4.11± 0.02 ± 0.27 erg cm^{-2} s^{-1}
- Assuming distance 250^{-62}_{+120} (Faherty et al. 2007), gamma-ray luminosity L_γ ~ 3x10^{34} erg s^{-1}
- Gamma-ray efficiency η_γ ~ 0.15(d/100pc)^2 (~7% for Outer Gap models, ~38%-43% for Two Pole Caustics model)
- Uncertainty in the distance limits the conclusions
- Spectral variation explained by caustics models

Summary of key points

- ✓ Timing solution based **solely on gamma-rays**
- ✓ **High-detailed light curve** and profile evolution with energy
- ✓ Detailed **phase-resolved spectroscopy**
- ✓ Magnetospheric origin for the **off-peak emission** (thus no longer "offpulse" as for many other gamma-ray pulsars)
- ✓ **Outer magnetospheric emission** models are favored

Some useful references:

Full results in Abdo et al. (in preparation)

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Bertsch, D.L., et al. 1992, Nature, 357, 306
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