Gamma-ray flares from the Crab Nebula

Rolf Buehler, Roger Blandford, Stefan Funk, Marco Ajello, Eric Grove, Liz Hays, Luca Mazziotta, Damien Parent for the LAT Collaboration
The *star* of the play

- Remnant from 1054 AD supernovae at 2 kpc
- Standard candle in X-rays and VHE
- Yearly variable in X-rays ~3.5% , 1-150 MeV on ~40%

Fermi measures Nebula transition between components

Measurement in Off pulse to avoid pulsar foreground
Nebula synchrotron flux

Monthly variations

Two flares:

- Flux increase of factor ~4 during ~16 days (26 Jan 11 to Feb. 2009)
- Flux increase of factor ~6 during ~4 days (18 to 22 Sep. 2010)

AGILE
Atel: 2855

LAT ToO observations

No variation (<5%) nebula IC component
Flares spectrum

- Second flare has hard spectrum and extends >1 GeV at >3 \( \sigma \)
- Energy release small compared to pulsar spin down (\( \sim 5 \cdot 10^{38} \) erg s\(^{-1} \))
Where does it come from?

- Not resolvable with LAT localization accuracy (~2')
- Causality: $L < D \cdot t \cdot c < 4 \cdot 4 \text{days} \cdot c = 0.014 \text{ pc} < 1.5''$
- Structures this small only in inner nebula (<15'' around pulsar)
Where does it come from?

- Nothing unusual detected in Chandra and Hubble observations after the flare (Atels: 2882, 2903)
- Future simultaneous observations may reveal location
From the pulsar?

- Nothing unusual during the flares in the timing residual
- Pulsar light curve constant within 5%

Crab Pulsar Daily Timing Residuals (model up to F2)
How are particles accelerated?

Basic conclusions:

- Radiation is synchrotron emission (fast variability and SED)
- Electrons have $\geq$ PeV energies for magnetic field $0.2-2$ mG

Highest energy particles associated to a discrete source. Difficult for diffusive shock acceleration:

$$\frac{\text{larmor radius}}{\text{cooling length}} \approx 2 \times 10^{-2} \varepsilon_{\text{peak}} \approx 4 \quad \text{(for } \varepsilon_{\text{peak}} = 200 \text{ MeV)}$$

→ Acceleration might be related directly to the pulsar

DC component or mag. reconnection of striped Wind
Summary

Synchrotron component of the Crab Nebula is variable on monthly time scales in gamma-rays. Two strong flares with daily variations.

Several conclusions:

- The flare emission is *synchrotron radiation* from a *small region*, likely in the *inner Nebula*

- The acceleration of electrons to $\geq$ PeV poses difficulties to diffusive shock acceleration

  $\rightarrow$ perhaps acceleration in the pulsar electric field

Motivates future theoretical and experimental work. Multi-wavelength observations may soon pin down the gamma-ray emission site.

Paper submitted, see astro-ph/1011.3855
Backup slides
Weekly TS of flaring component
Crab with Fermi

Pulsar spectrum index = 1.97 ± 0.02 with exp. cutoff ~6 GeV

Sych. index: 3.99 ± 0.12

IC index: 1.64 ± 0.05