9th AGILE Science Workshop
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@ESRIN, Frascati (Rome) Italy

Fermi Gamma-ray Space Telescope

The Crab seen by Fermi

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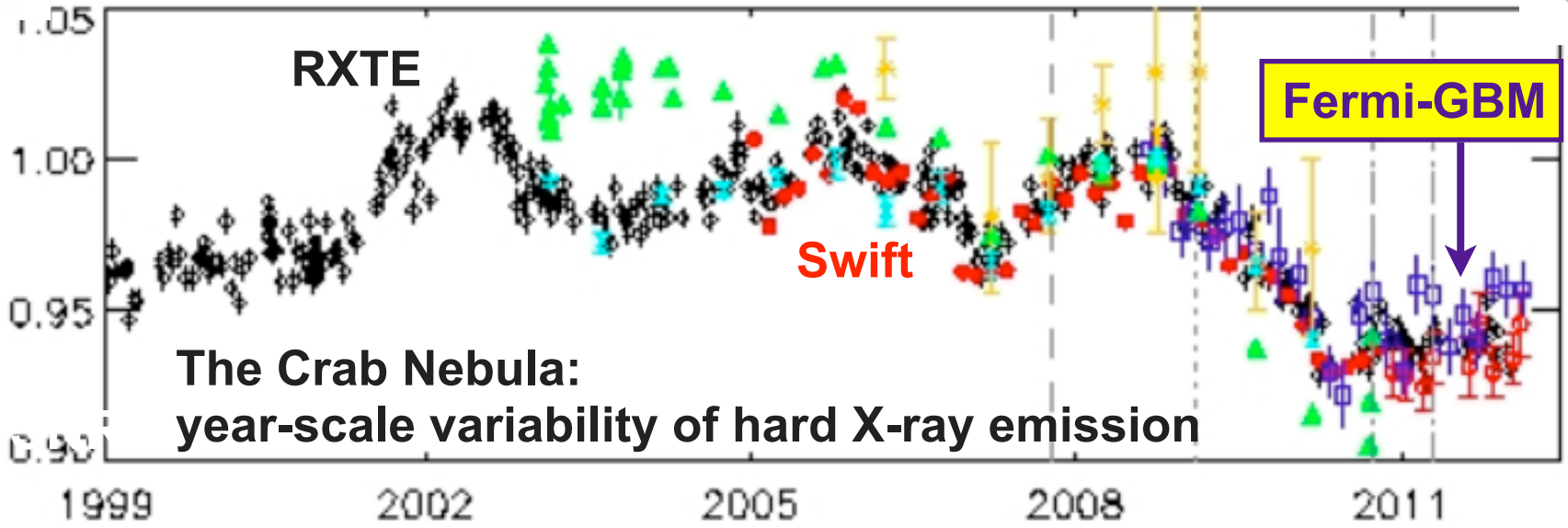
for the Fermi LAT Collaboration

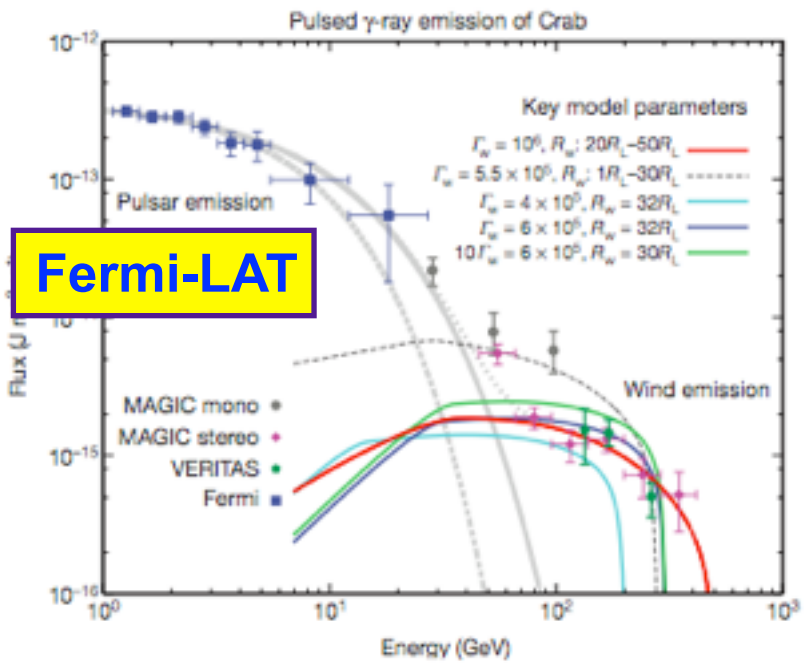
Based on the work done by
Rolf Buehler (SLAC) et al.

The Crab: Full of Surprises?

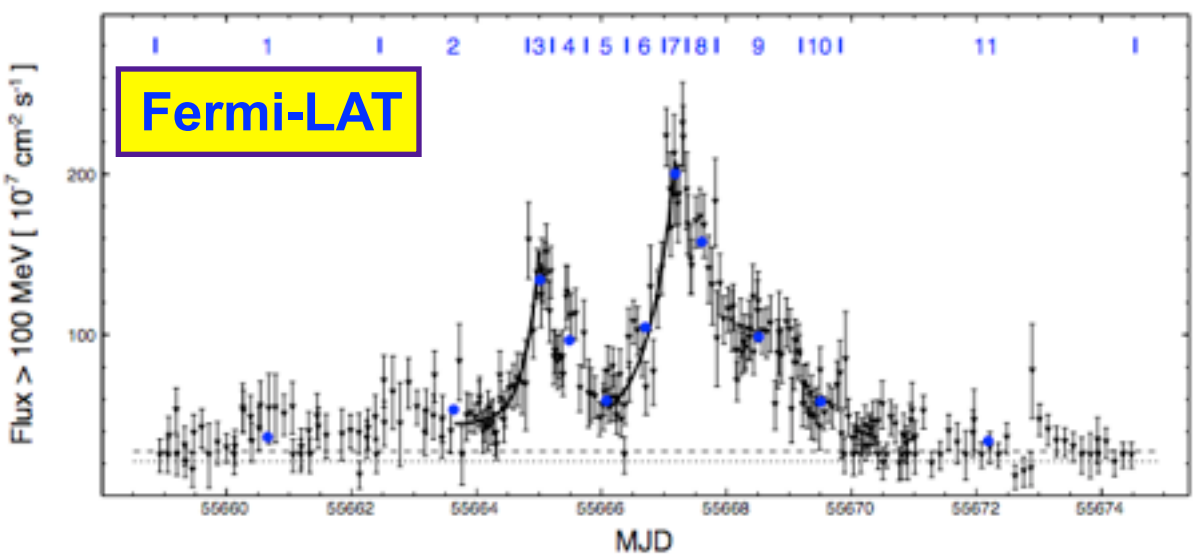


The Crab Nebula:
year-scale variability of hard X-ray emission

The Crab pulsar: extra TeV emission



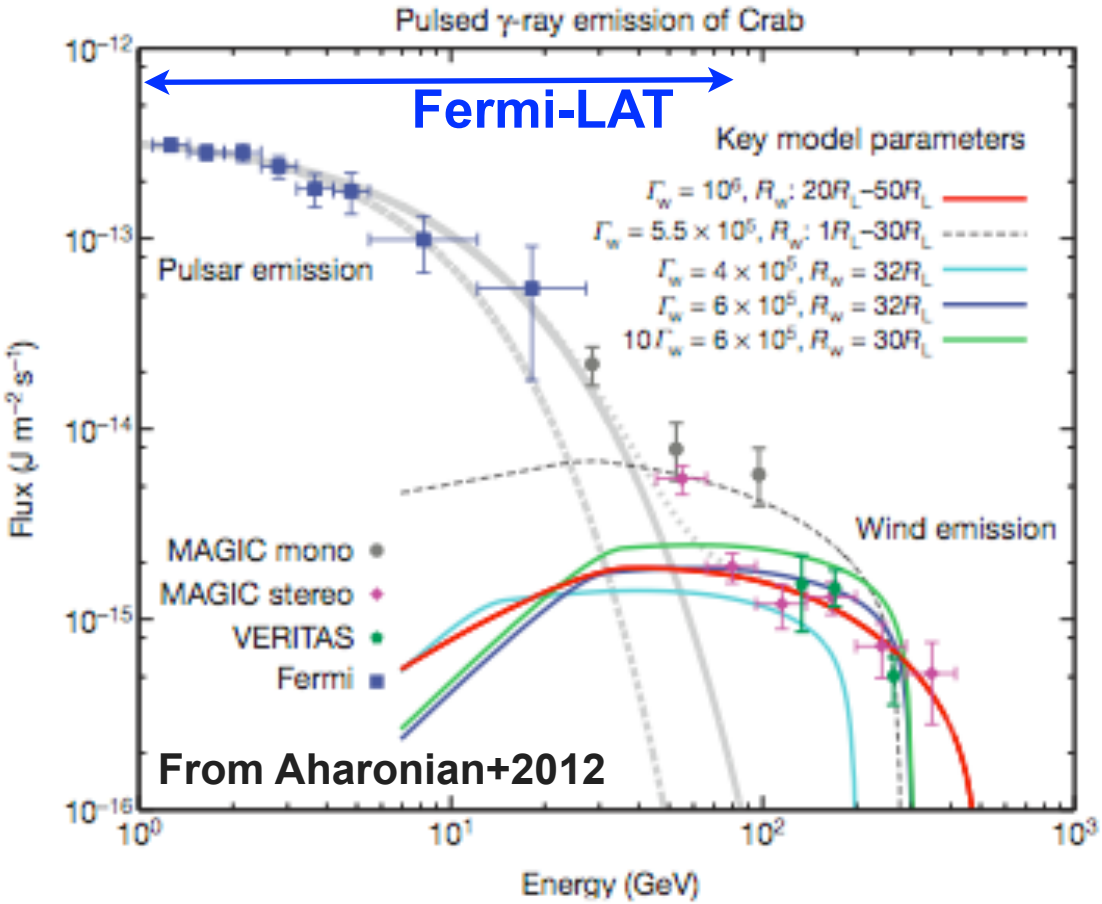
The Crab Nebula: GeV flares

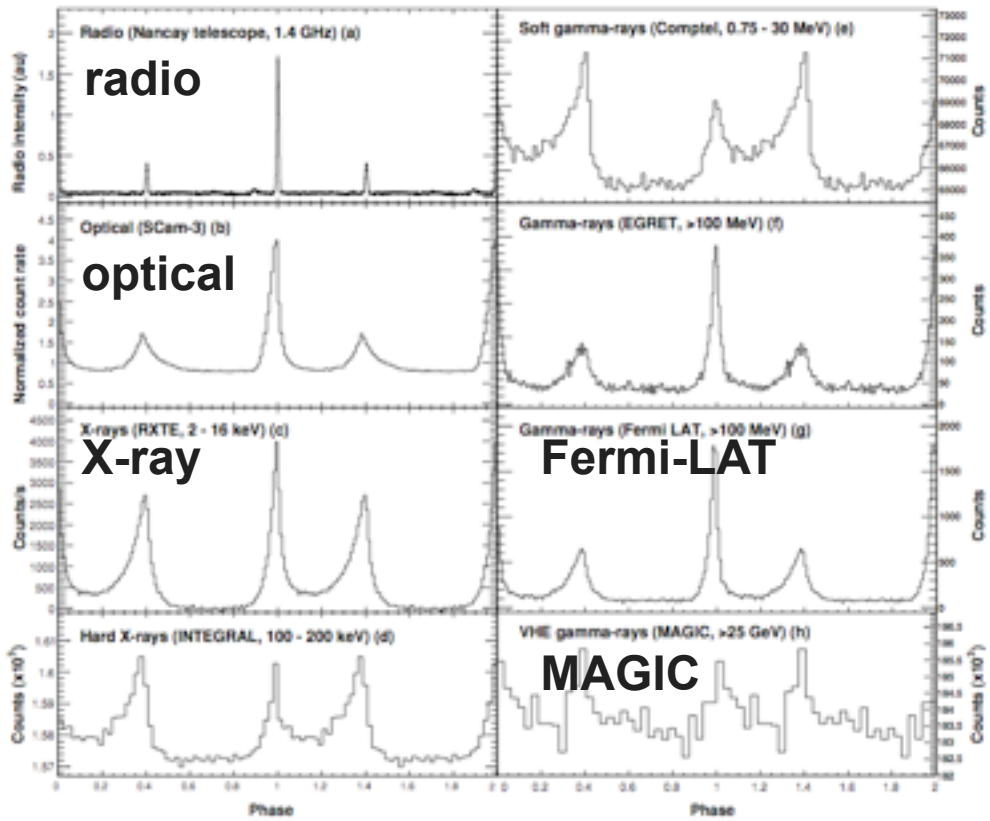


Pulsed GeV-TeV Emission

Fermi-LAT spectrum: Curvature radiation

$\Gamma = 1.97 \quad \varepsilon_c = 5.8$ GeV (Abdo+2010) where $dN/d\varepsilon = K\,\varepsilon^{-\Gamma} \exp(-\varepsilon/\varepsilon_c)$



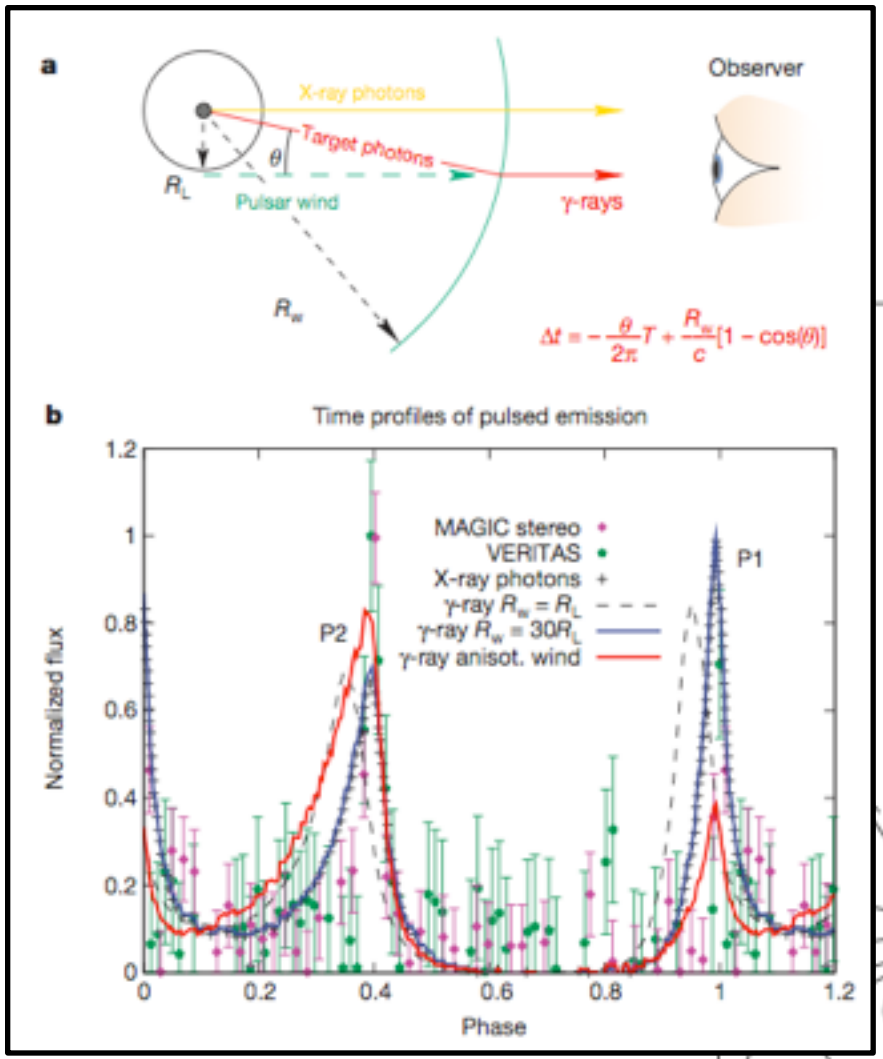


Abdo+2010: 8 months of data
➜ Now 43 months accumulation!

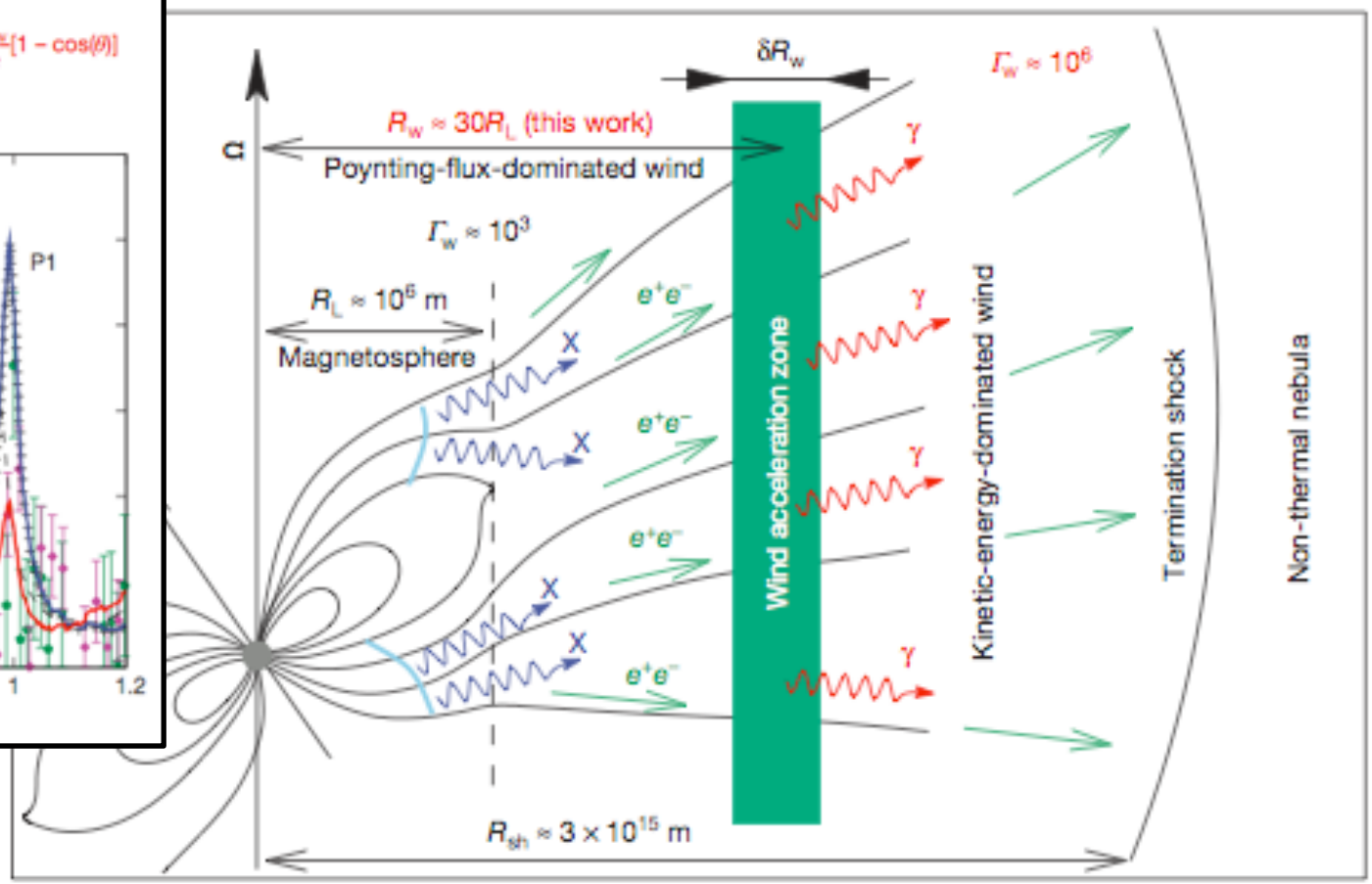
Lightcurves at different wavelengths (Abdo+2010)

A Model for Extra TeV Component

Aharonian, Bogovalov, & Khangulyan 2012:
Pulsed TeV gamma-rays = Inverse Compton of (pulsed) X-rays by pulsar wind

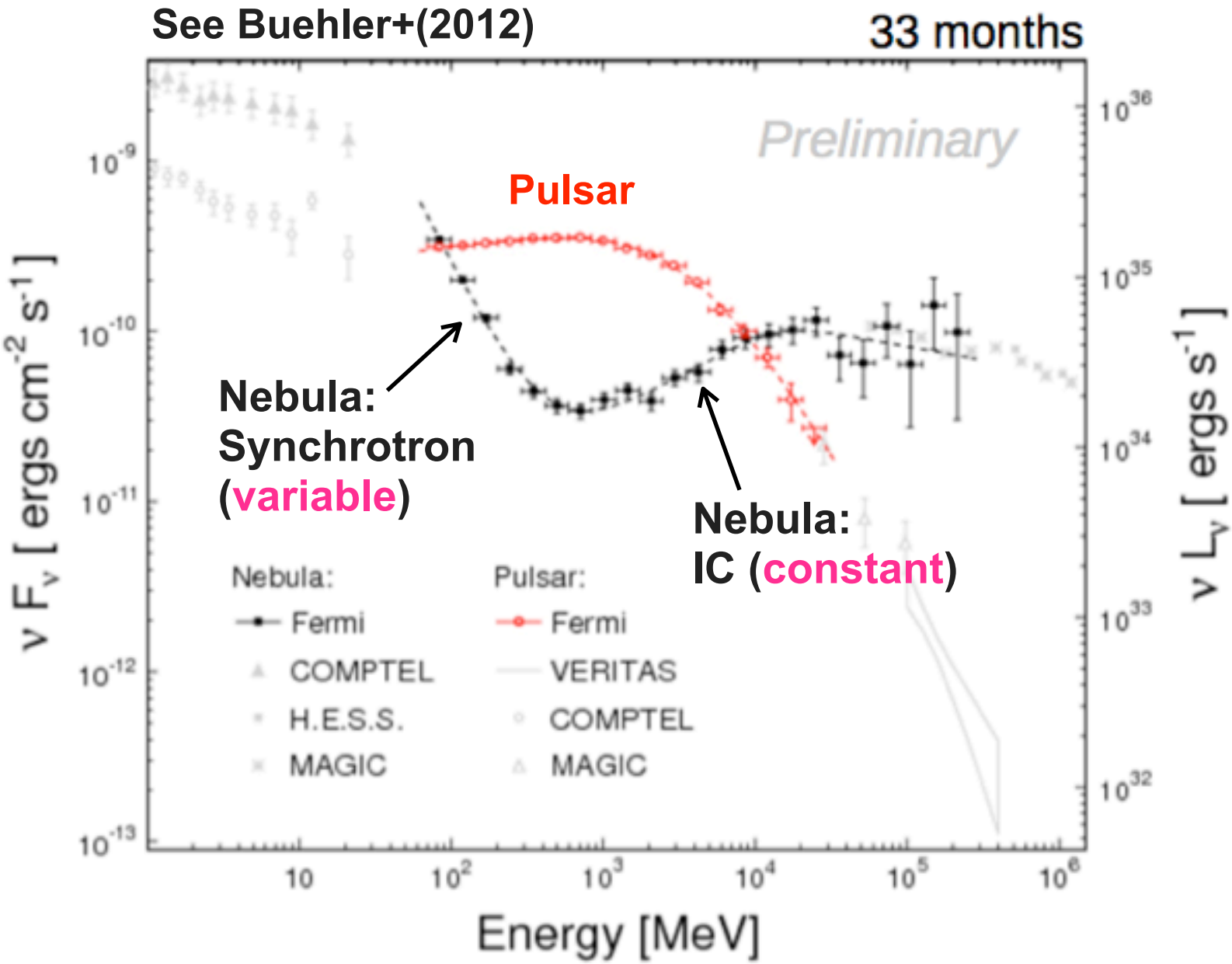


- Poynting-flux dominated ➜ Kinetic-energy dominated wind at 20-50 R_L
- Wind Lorentz factor : (0.5-1)x10^6

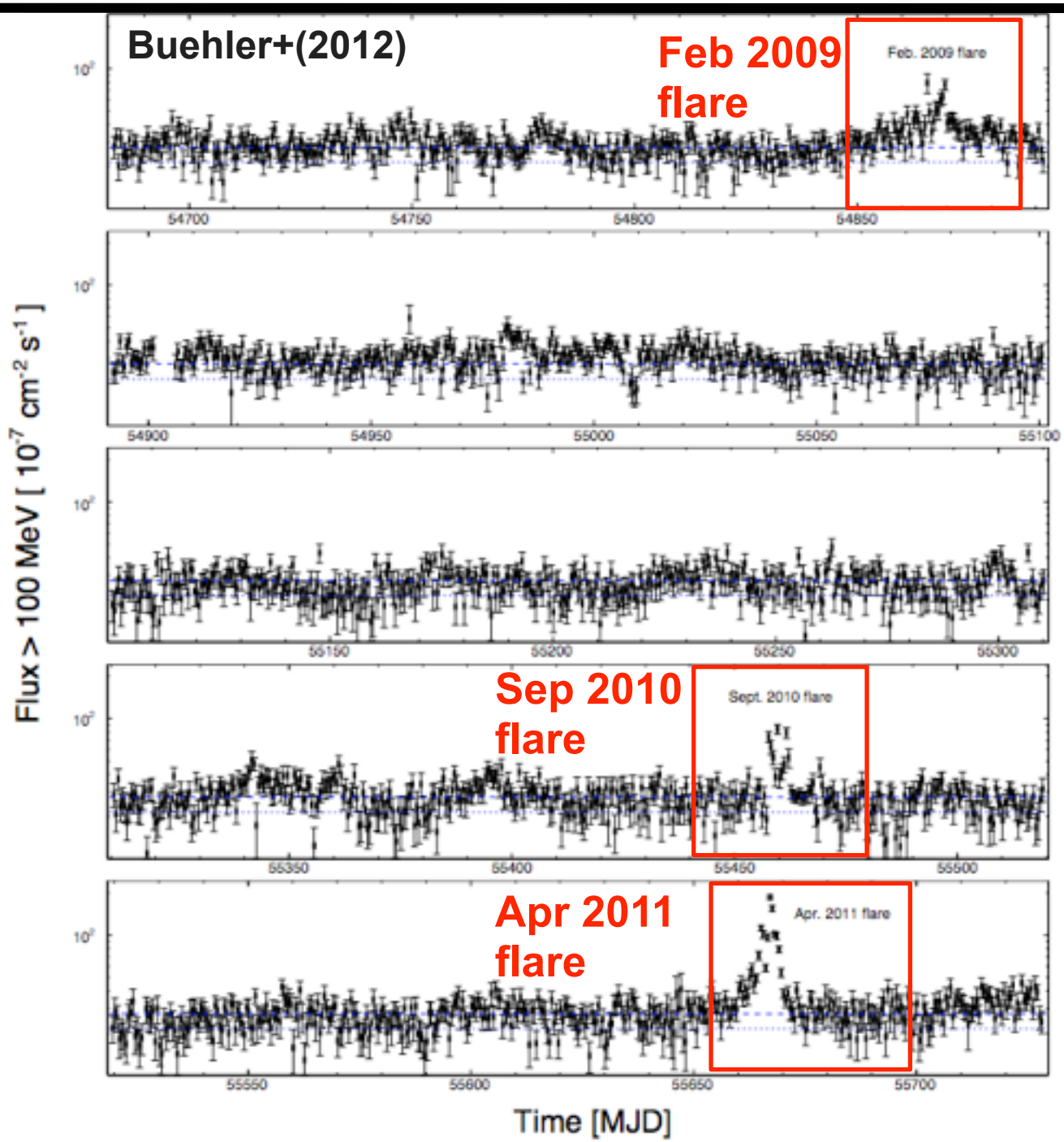


The Crab Seen by Fermi-LAT

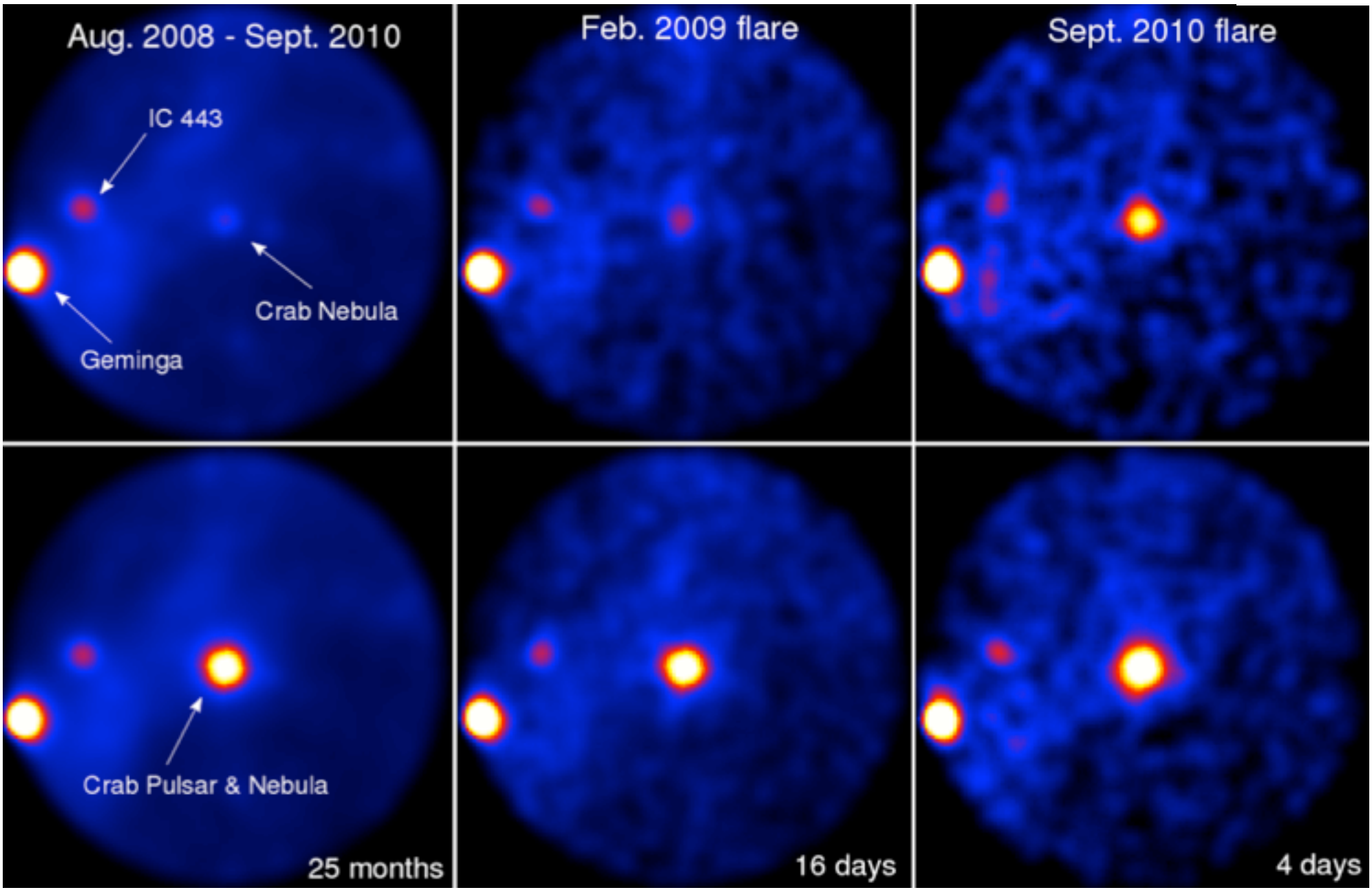
Average gamma-ray spectra



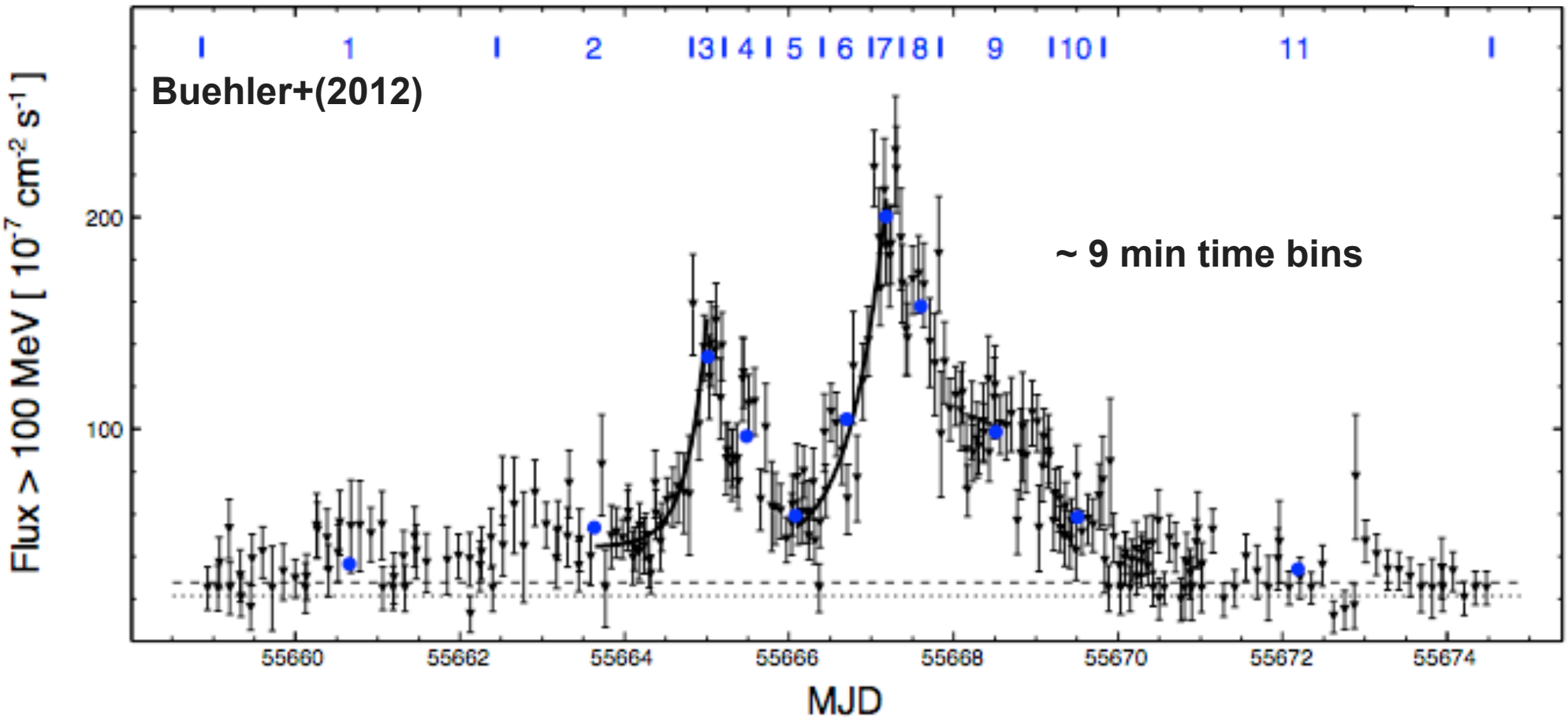
Long Term Lightcurve



The Crab Flares: LAT Images

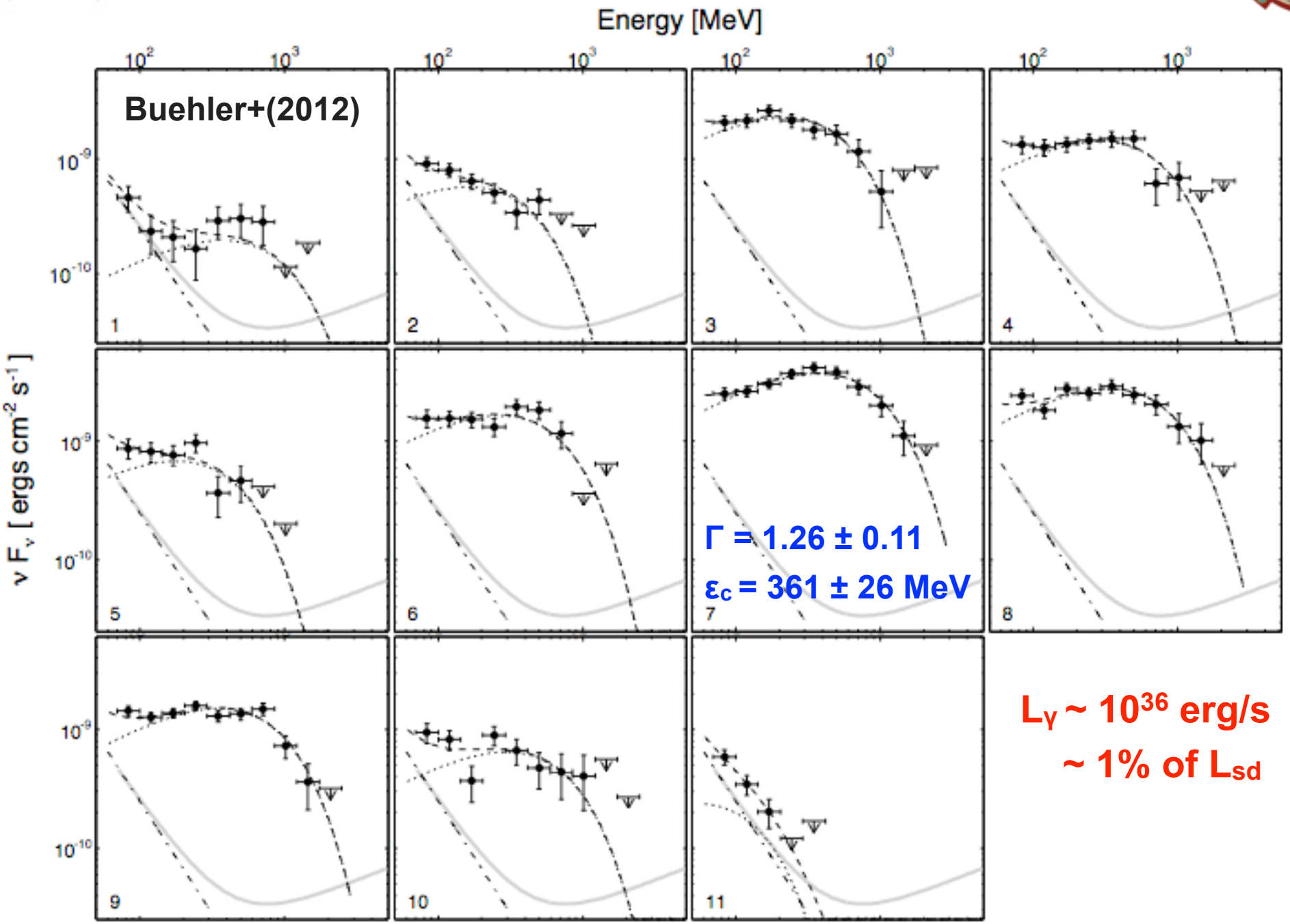


The April 2011 Flare



- Synchrotron nebula brightened by a factor of ~30
- Flux doubling time : 4-8 hours
- No change in pulsar flux and phase

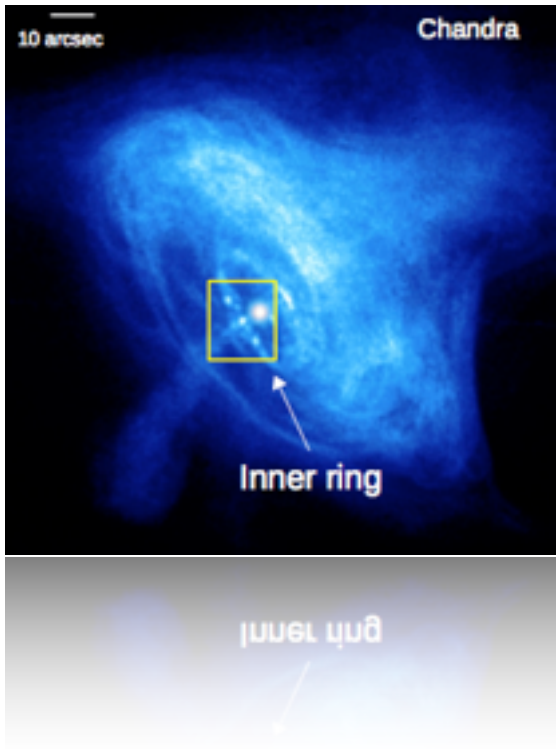
The April 2011 Flare: Spectral Evolution



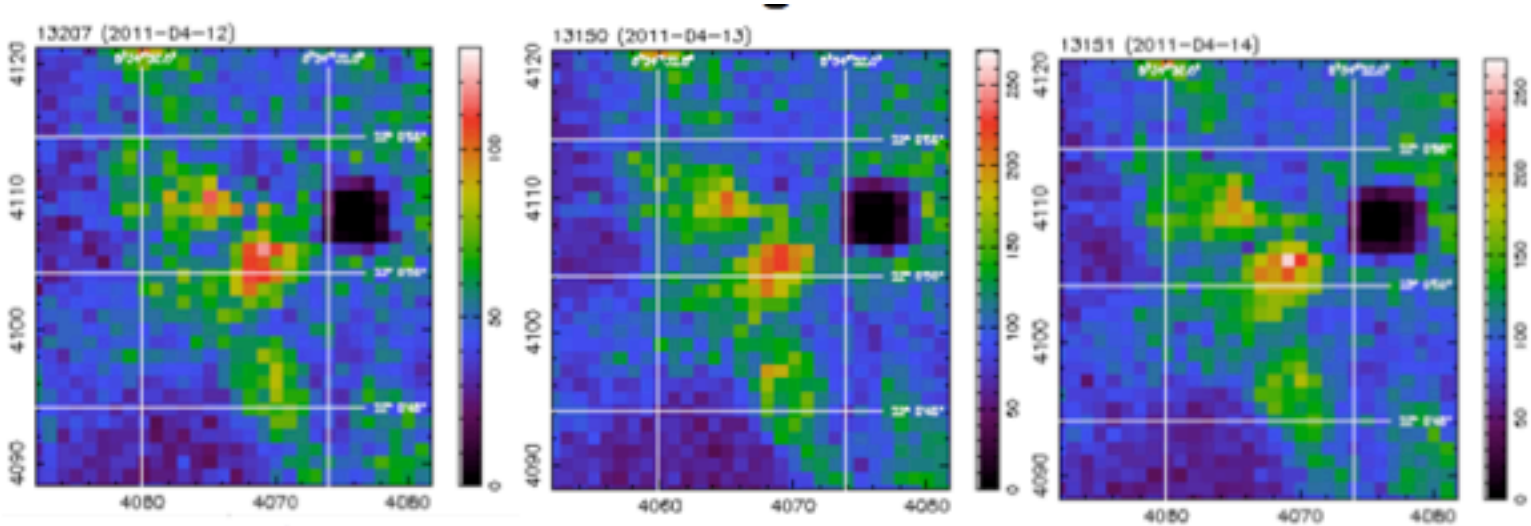
$L_\gamma \sim 10^{36}$ erg/s

$\sim 1\%$ of L_{sd}

X-ray Images During the Flare



- Chandra observations during the April 2011 flare
- No correlated activities in the inner ring region



From Allyn Tennant (Chandra observations led by Martin Weisskopf)

Why Puzzling?

✚ **Compactness**

Doubling time t ~ 4-8 hours ➜ Emission region < ct ~ 3×10^{-4} pc

(Inner ring ~ 0.1 pc)

Large luminosity (~ 1% of spindown power) from a compact region

✚ **Spectrum**

$\Gamma = 1.26 \pm 0.11$: Flare energy is carried by the highest energy electrons

$\varepsilon_c = 361 \pm 26$ MeV: Appears to violate the radiation reaction limit

Balance between acceleration (E<B) and synchrotron cooling

➜ Cutoff of synchrotron spectrum must be:

$\varepsilon_c < (9/4\alpha_F) m_e c^2 = 160$ MeV

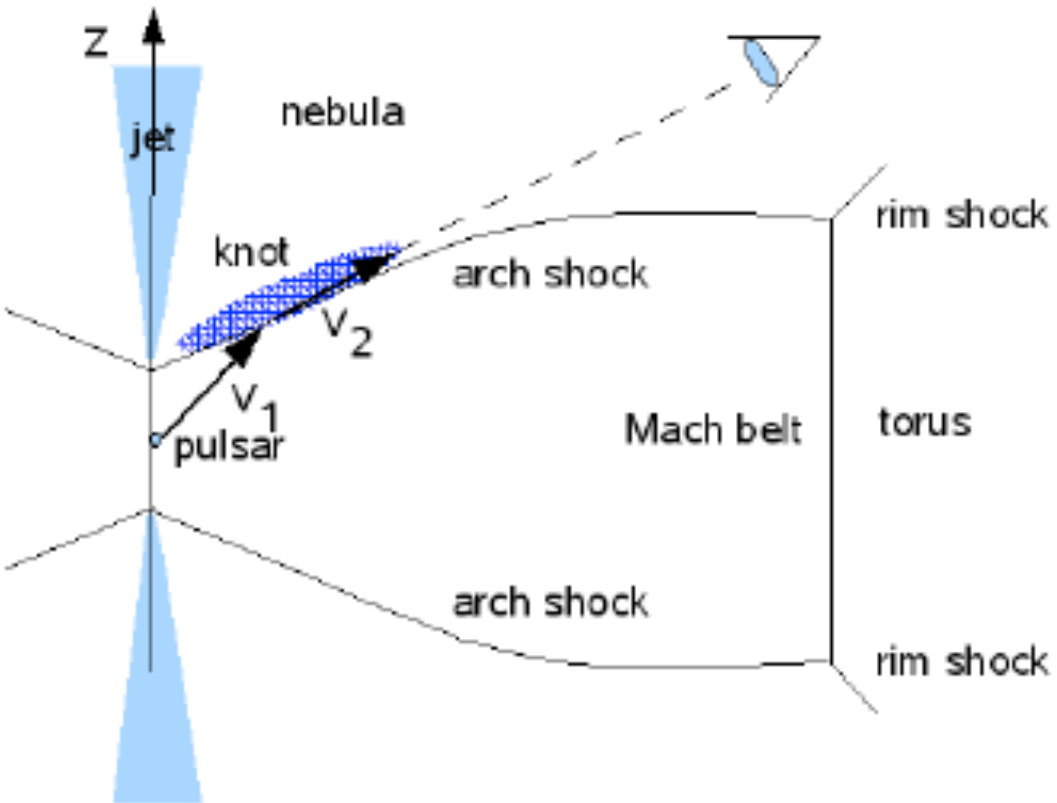
At least, relativistic beaming is necessary (δ ~ a few)

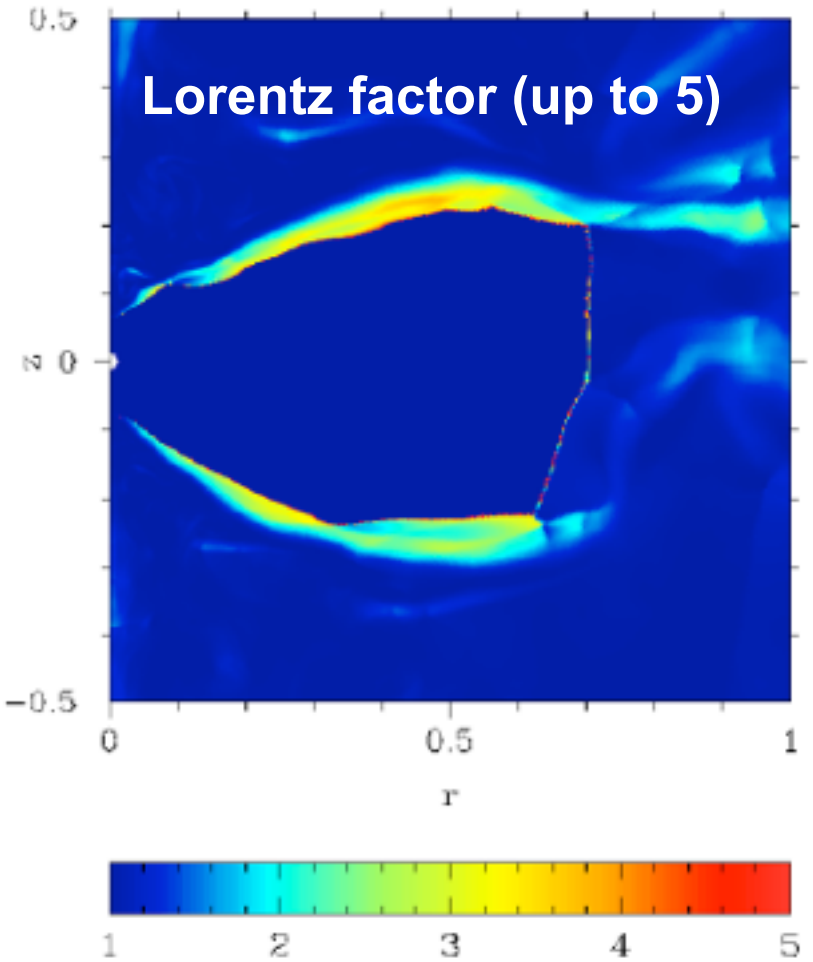
(But HST/Chandra images show only a mildly relativistic flow of ~0.5c)

Highly Relativistic Post-shock Flow?

✚ Komissarov & Lyutikov (2012)

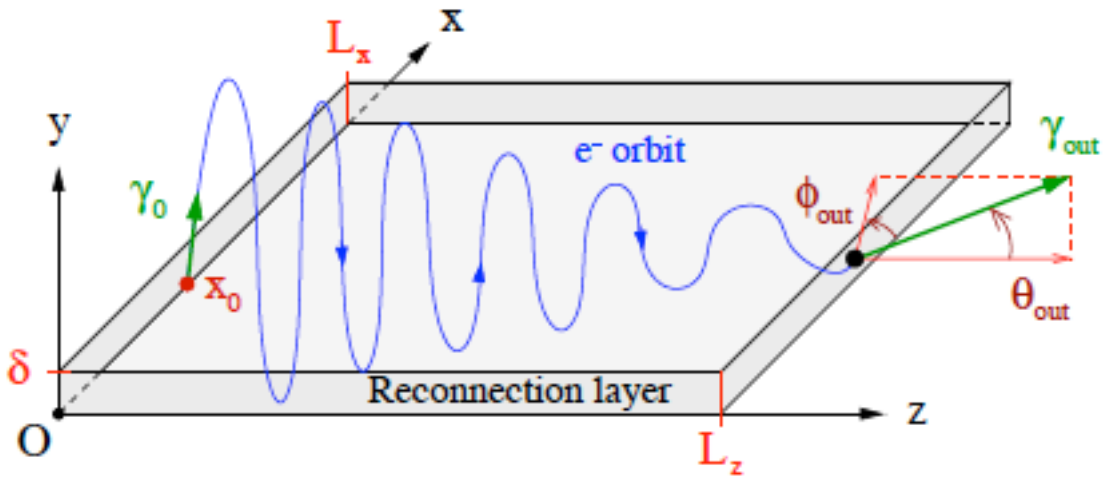
- RMHD simulations suggest highly relativistic flows near termination shock (Komissarov & Lyubarsky 04).
- High resolution simulations suggest variability of termination shock (Camus+09).





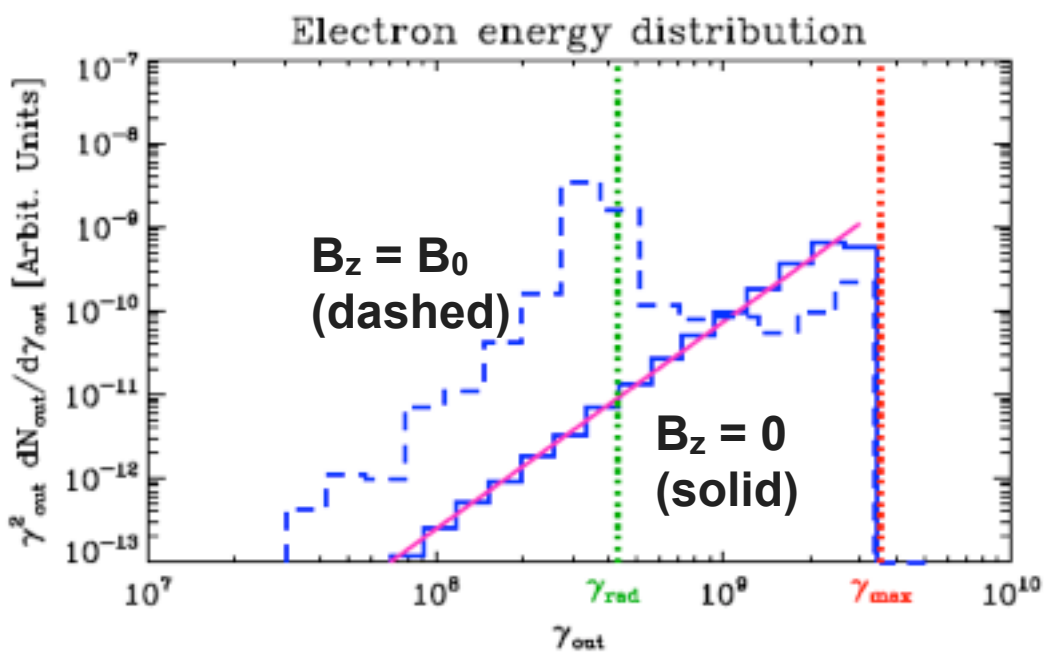
Magnetic Reconnection?

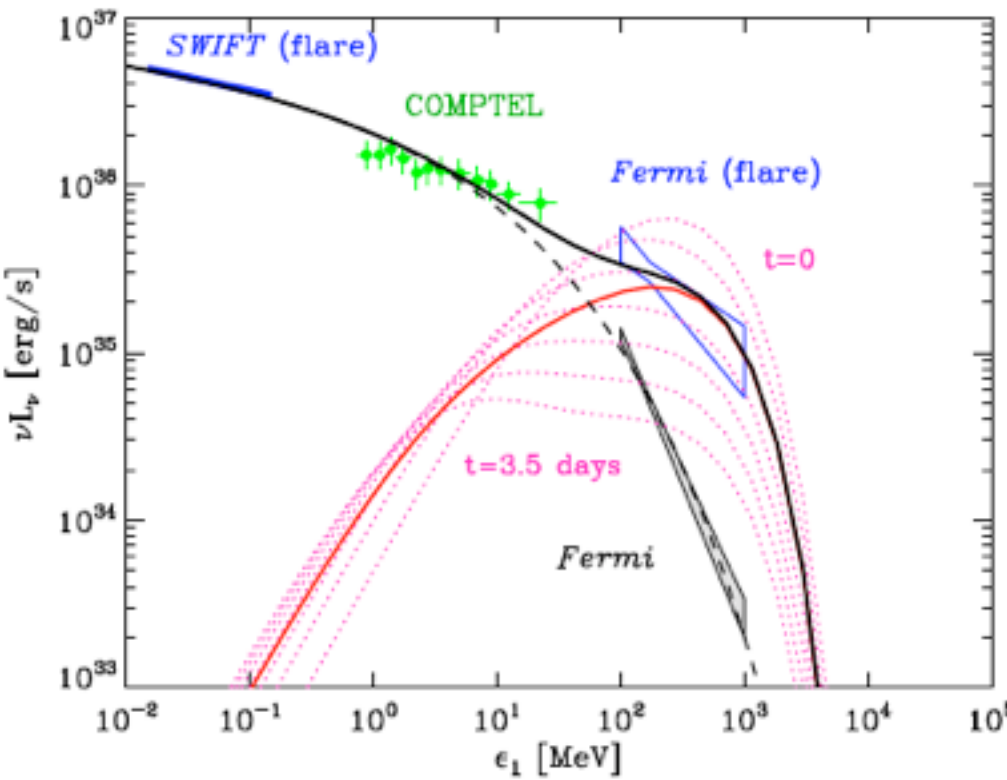
✚ Cerutti, Uzdensky, & Begelman (2012)



Magnetic reconnection:

- electrons accelerated by reconnection electric field
- focused inside the current layer where B field is small (E>B)
- a beam of PeV electrons





Summary

- **Fermi-LAT observations of the Crab pulsar:**
  - Extra TeV emission challenges pulsar models
  - LAT observations will aid in understanding the TeV emission

- **Fermi-LAT observations of the Crab Nebula:**
  - Flares of synchrotron radiation challenge PWN models
  - Very efficient e-e+ acceleration (close to theoretical limit)
  - Change of a beaming factor seems to play a key role
  - Stimulating theoretical work