



Fermi
Gamma-ray Space Telescope

37th International Cosmic Ray Conference

Study of the gamma-ray state changes of PSR J2021+4026 with *Fermi*-LAT

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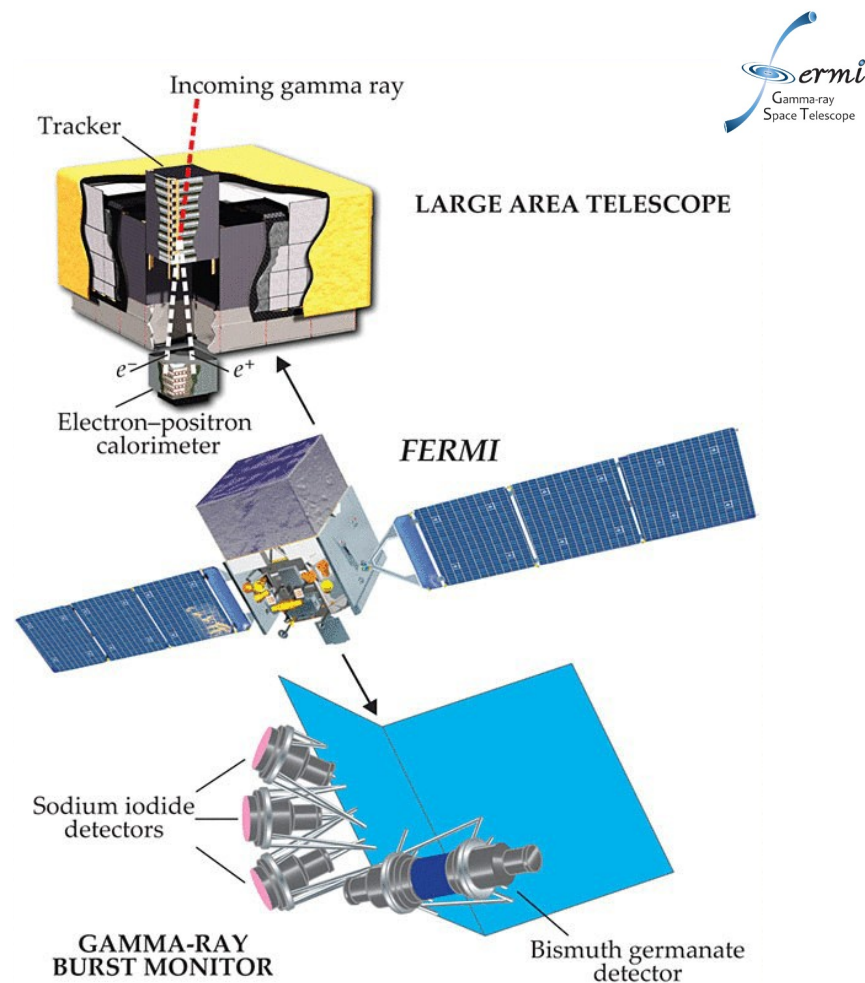
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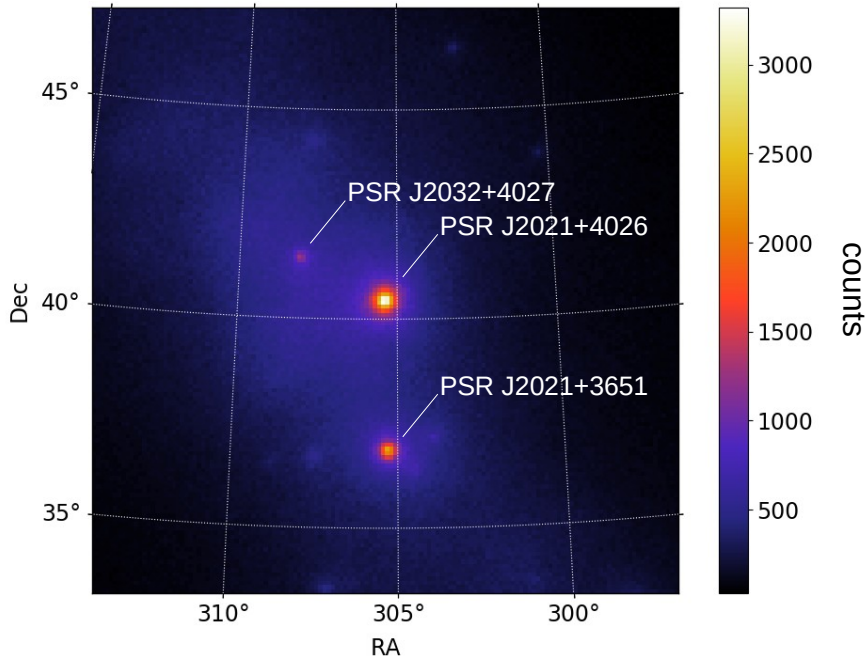
The *Fermi* Large Area Telescope

- Main instrument of the *Fermi* Gamma-ray Space Telescope
- NASA mission, operative since June 2008
- **Pair-conversion** telescope (Atwood et al., 2009)
- Sensitive to gamma rays **above 20 MeV**
- **>5000 gamma-ray sources** detected (4FGL-DR2; Abdollahi et al., 2020)
- **>250 gamma-ray pulsars** *

* <https://confluence.slac.stanford.edu/display/GLAMCOG/Public+List+of+LAT-Detected+Gamma-Ray+Pulsars/pulsars>



PSR J2021+4026, the first variable gamma-ray pulsar



- **Isolated, radio-quiet** gamma-ray pulsar in the Gamma Cygni SNR
- First discovered with *Fermi* LAT with period \sim **265 ms** (Abdo et al. 2009)
- X-ray counterpart (Weisskopf et al. 2011) and pulsations (Lin et al. 2013)
- Abrupt **flux** and **spin-down variations** (Allafort et al. 2013)
- **Periodical** switch between states (\sim 6 years)

So far:

- **Flux** and **timing** widely studied (Allafort et al. 2013; Ng et al. 2016; Takata et al. 2020)
- Changes in the gamma-ray **pulse profile**
- Weak indications of **spectral variability**



This work:

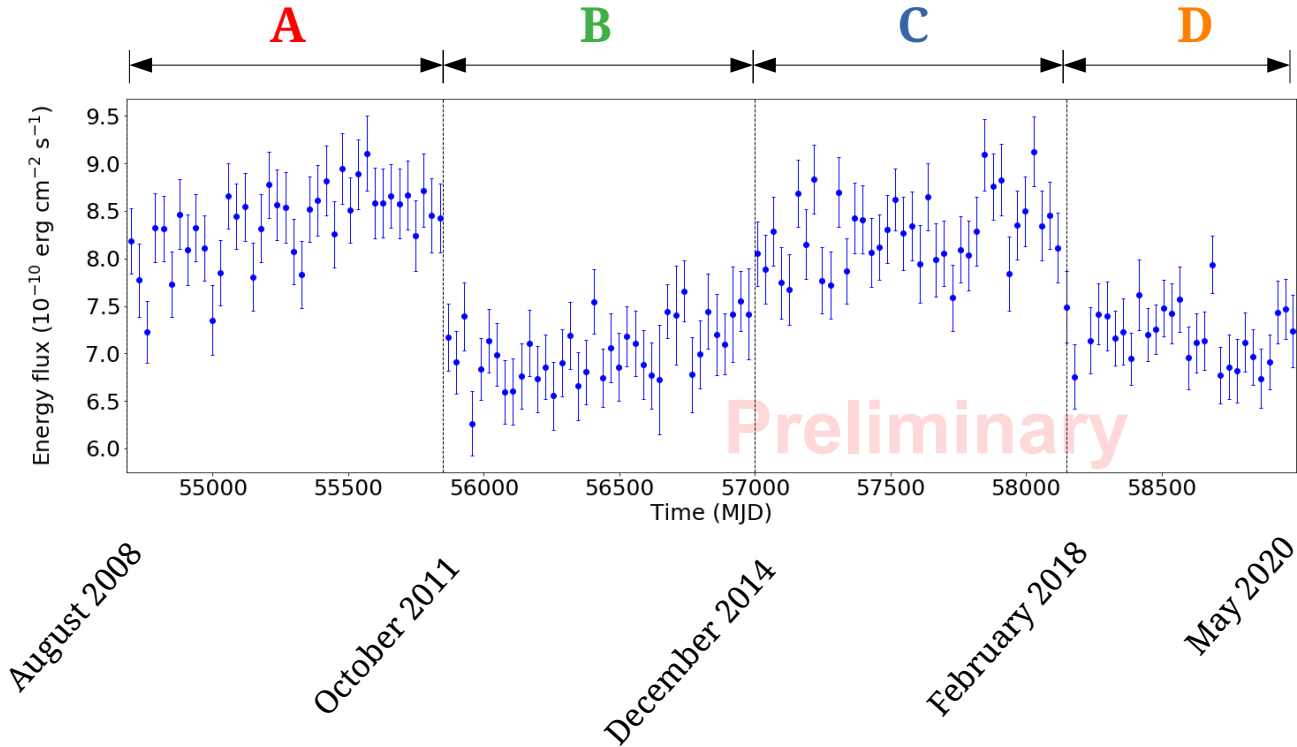
- Updated analysis software (*Fermitools* 1.2.23)
- Improved model of the gamma-ray sky (**4FGL-DR2**)
- High-quality *Fermi*-LAT data (**Pass8 Release 3**)



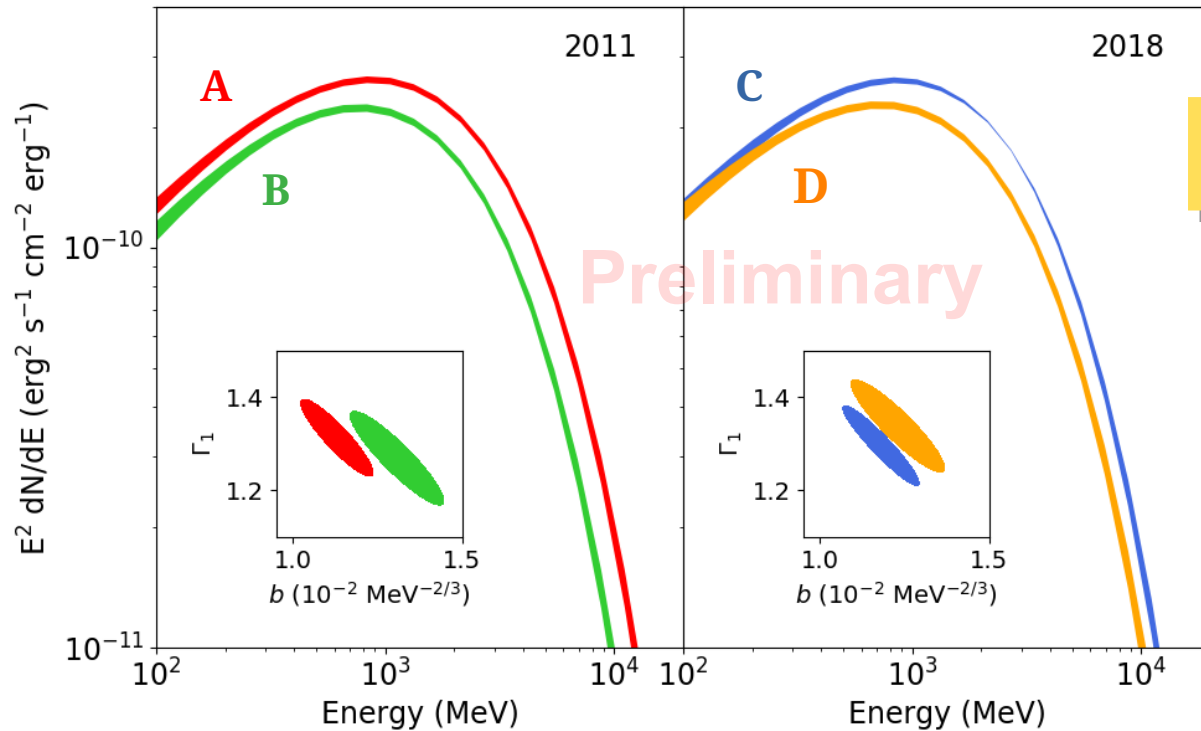
**Improved
accuracy**

The binned likelihood analysis

- Maximum likelihood fit with summed PSF components
- **12 years** of *Fermi*-LAT data
- **Region:** 10° radius, 0.1 pixels
- **Energy:** 100 MeV – 300 GeV, 35 log bins
- **Model:**
 - sources within 20°
 - extended sources
 - diffuse emission
 - free variable sources



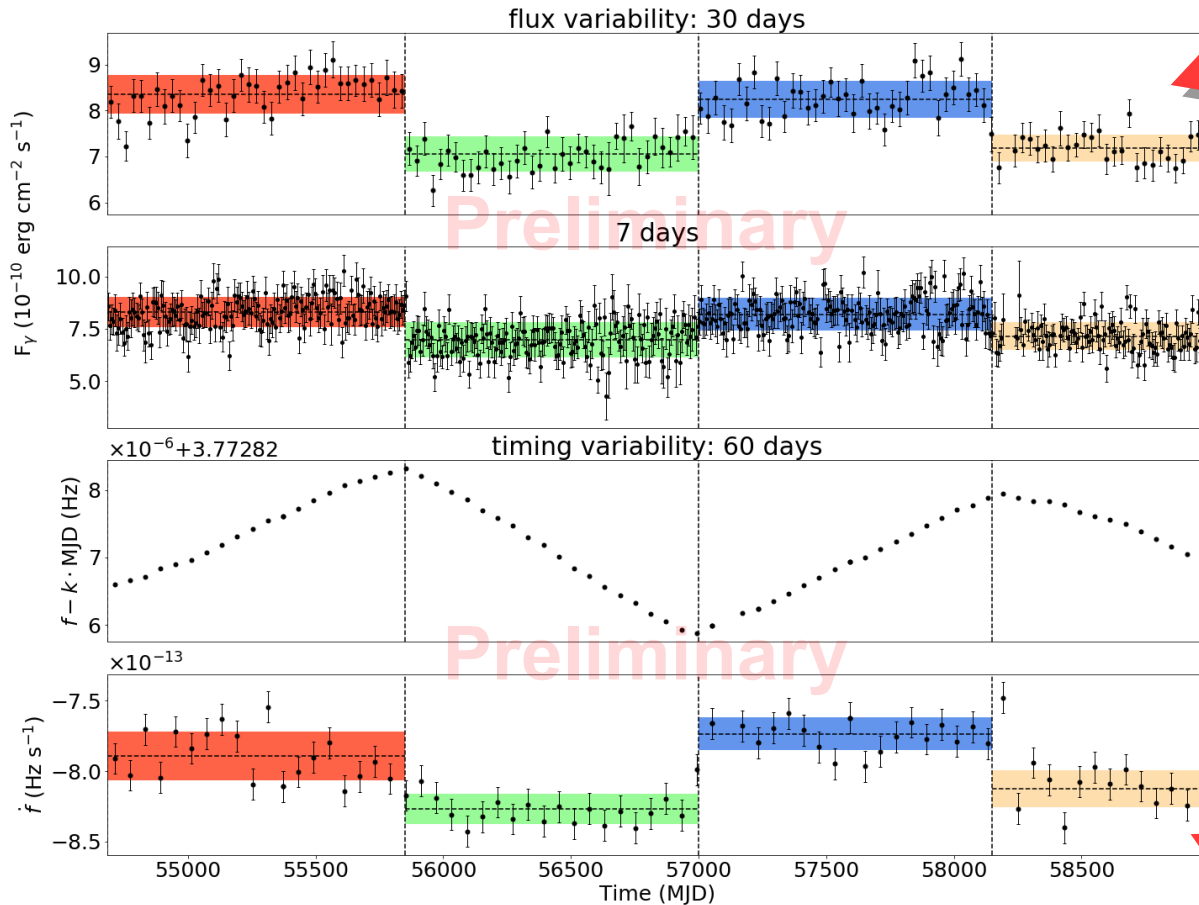
Results: spectral energy distribution



$$dN/dE \propto E^{-\Gamma_1} \exp[-b E^{2/3}]$$

- Free spectral parameters
- Flux drop accompanied by **spectral softening**
- $\sim 3\sigma$ variations across state changes

Results: flux and timing evolution



$\Delta F_\gamma / F_\gamma \sim 15\%$

- **Energy flux:** 30 days and 7 days
- **Timing:** 60 days
- **H-test** (de Jager and Busching, 2010)

$\Delta \dot{f} / \dot{f} \sim 5\%$

- Abrupt state changes in October 2011 and February 2018
- 15% drop in **gamma-ray flux**
- 5% increase in **spin-down rate**
- No sudden variations in rotational frequency
- 3σ indications of **spectral softening**

**How can we
interpret the
results?**

Investigating the nature of PSR J2021+4026

- **Simple model:** glitch produced by starquake (Ng et al. 2016)

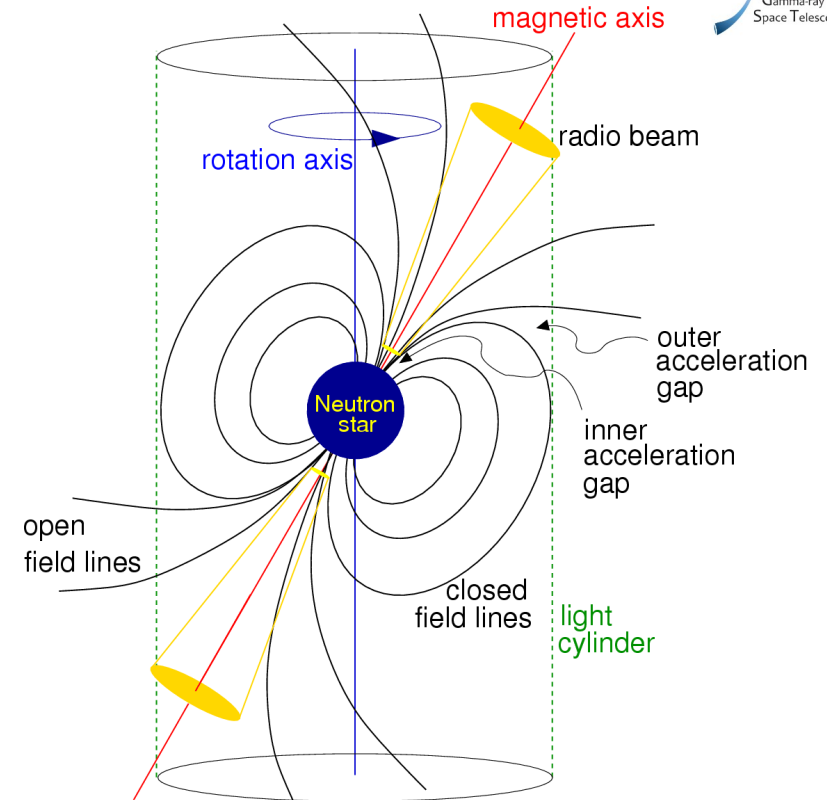
- Gamma-ray spin-down luminosity (Spitkovsky, 2006):

$$L_{sd} \propto f^4 (1 + \sin^2 \alpha), \quad \Delta \dot{f} / \dot{f} = \frac{\sin 2\alpha \Delta \alpha}{1 + \sin^2 \alpha}$$

- Change in the **magnetic inclination angle:**

$$\Delta \alpha \sim 6^\circ, \quad \Delta L_{sd} / L_{sd} \sim 5\%$$

- More sophisticated models required



Lorimer and Kramer, 2005

- Confirmed **periodicity of flux changes** with improved accuracy
- **Enhanced significance** of spectral variations
- Detailed investigation of gamma-ray emission properties across state changes
- Still no indications of variability in the X-rays
- **Gamma-ray variability**: key instrument to study the dynamics of magnetospheres



Thank you for listening!

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References

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