

VHE Observations of Pulsars

Andrew McCann

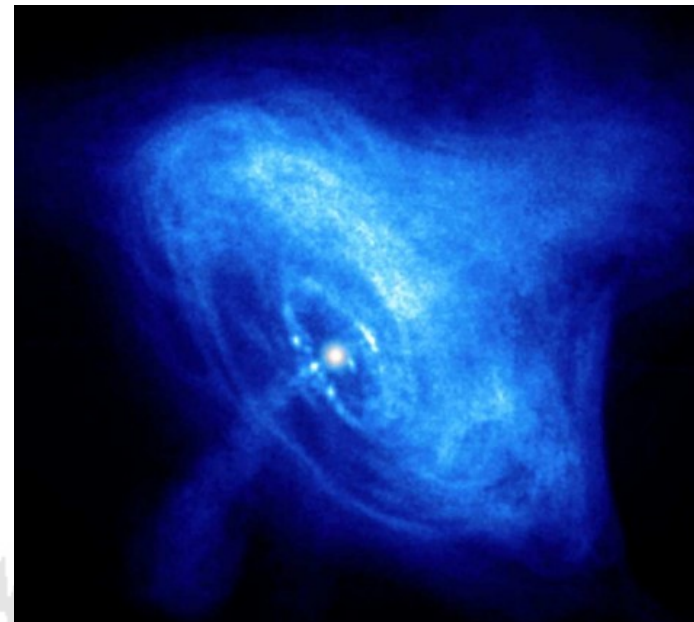
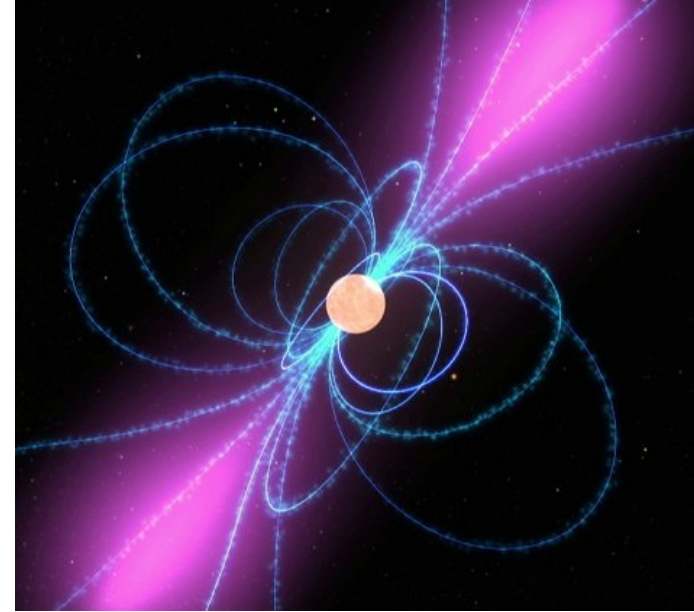


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AT THE UNIVERSITY OF CHICAGO

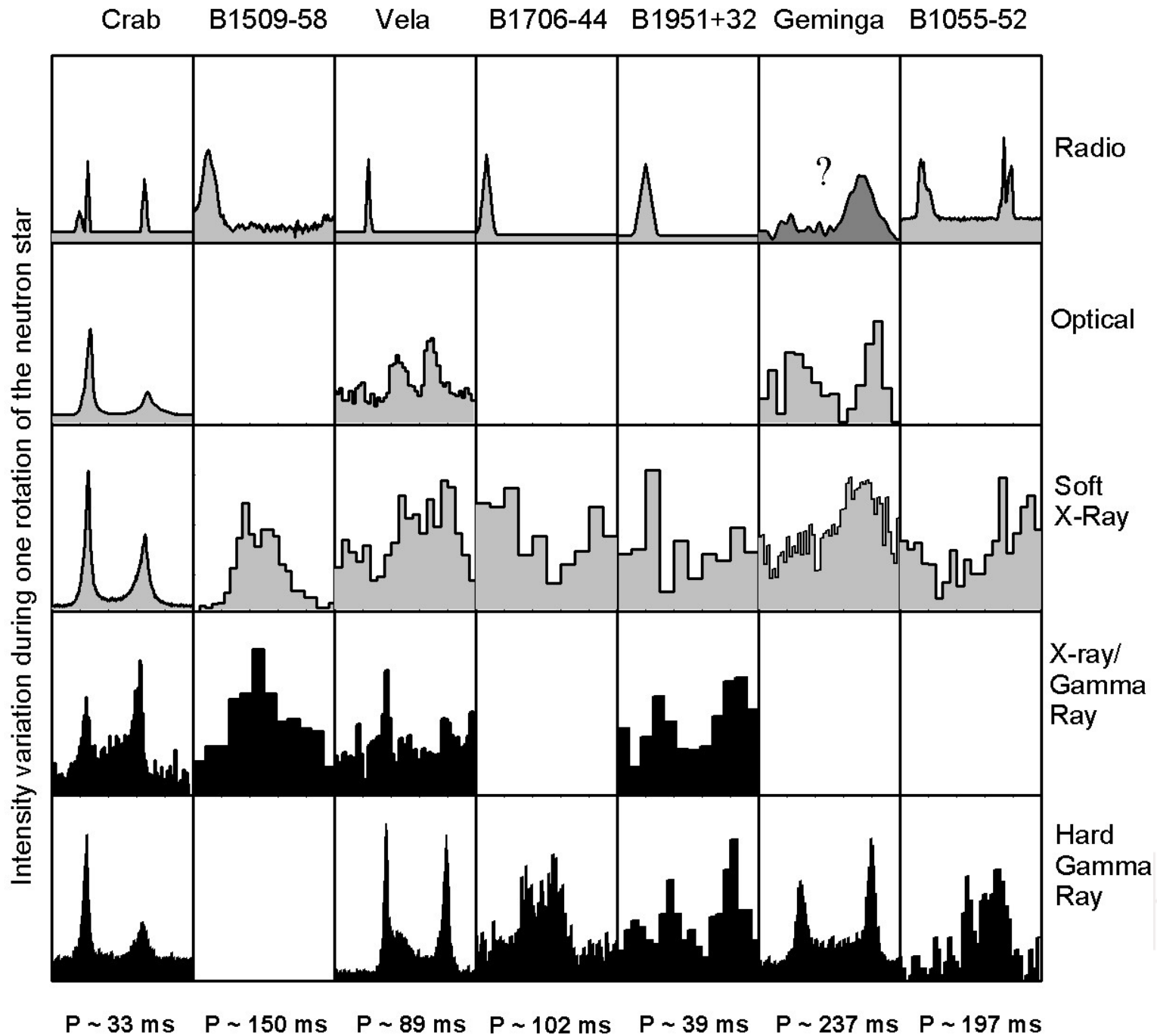


Overview

- Quick Gamma-ray pulsar history
- What we know from Fermi
- VHE pulsations from the Crab
- VHE/GRP Crab correlation Search
- LIV with pulsars (and why it's cool)
- Summary



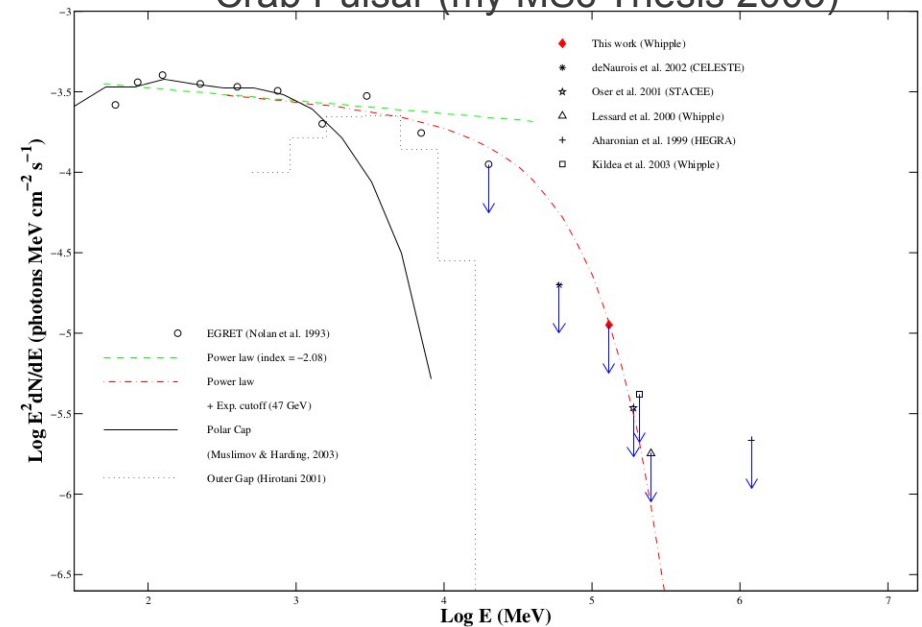
Gamma-ray pulsars prior to June 2008



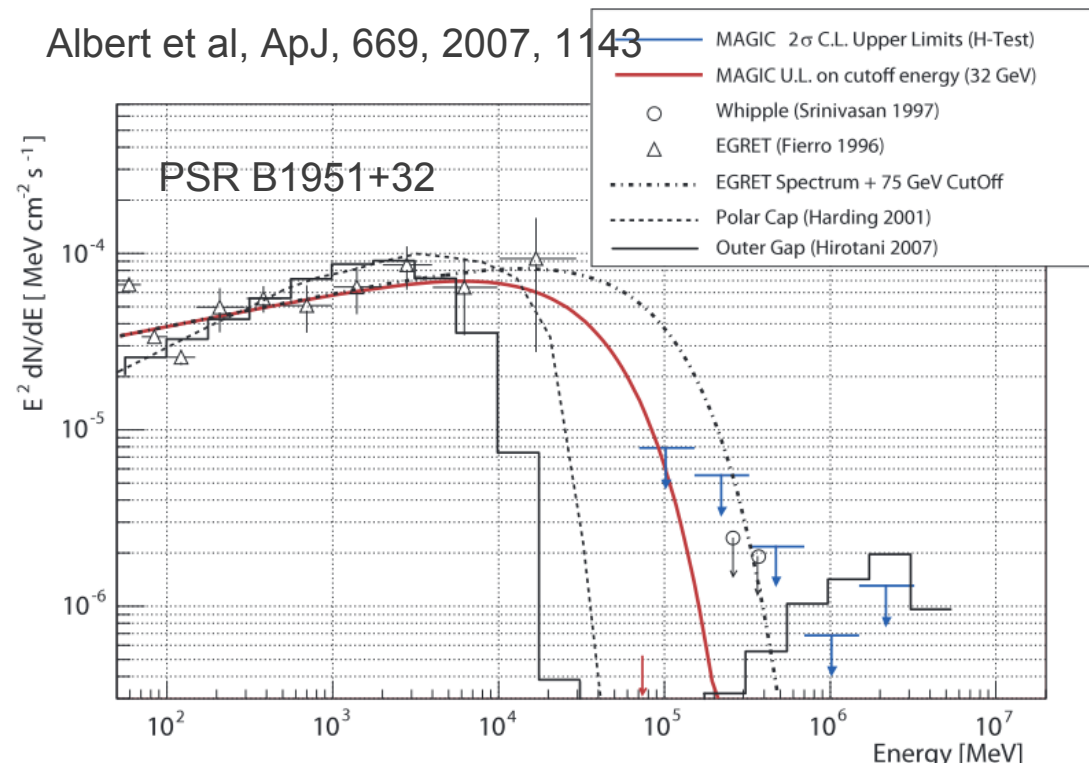
Gamma-ray pulsars prior to June 2008

- EGRET/COMPTEL detected 7 gamma-ray pulsars
- Emission spectrum is a power-law with evidence for a spectral break around a few GeV
- Geminga (1 of the 7) is a one-of-a-kind “radio quiet” pulsar
- In 2007 MAGIC detected the Crab pulsar at 25 GeV and interpret an exponential cut-off in the SED
- **Question:** What is the shape of the emission spectrum above the spectra break.

Crab Pulsar (my MSc Thesis 2005)

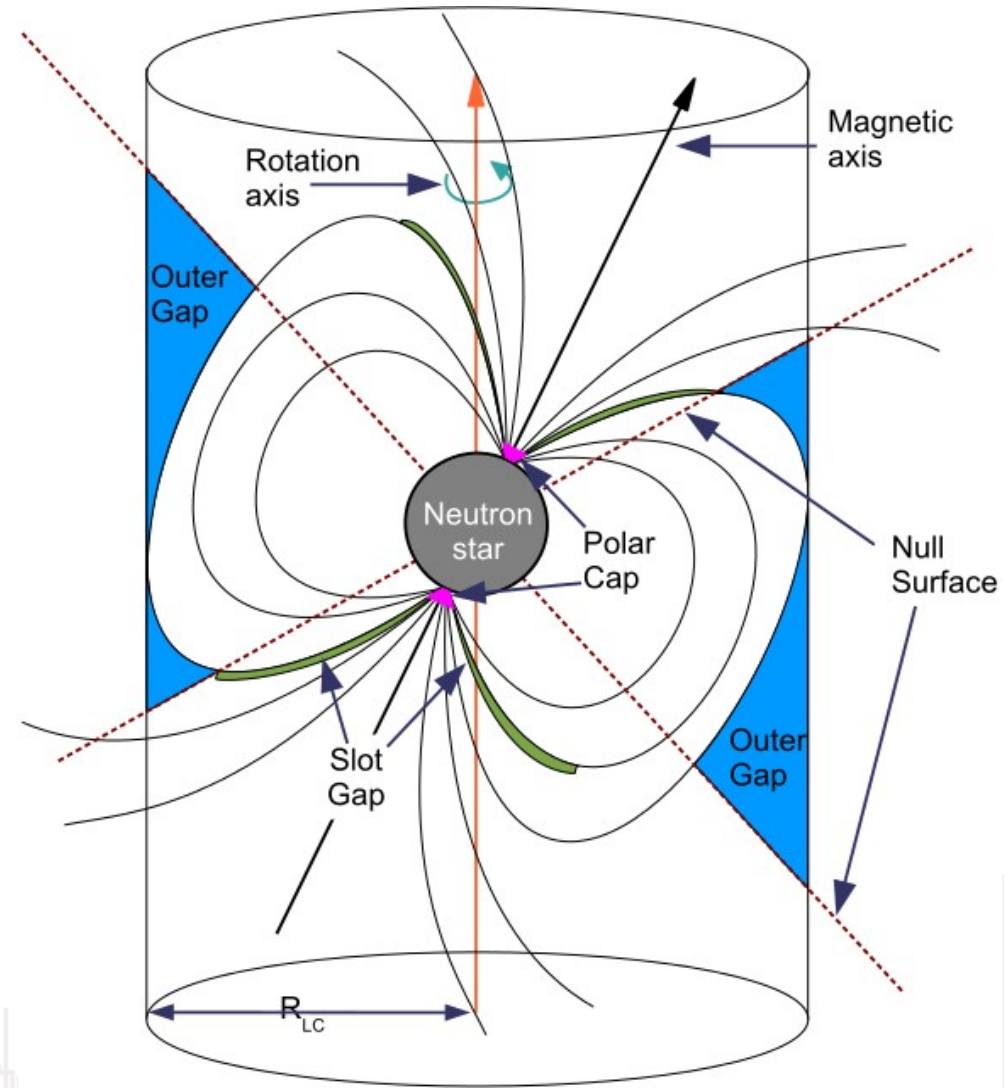


Albert et al, ApJ, 669, 2007, 1143



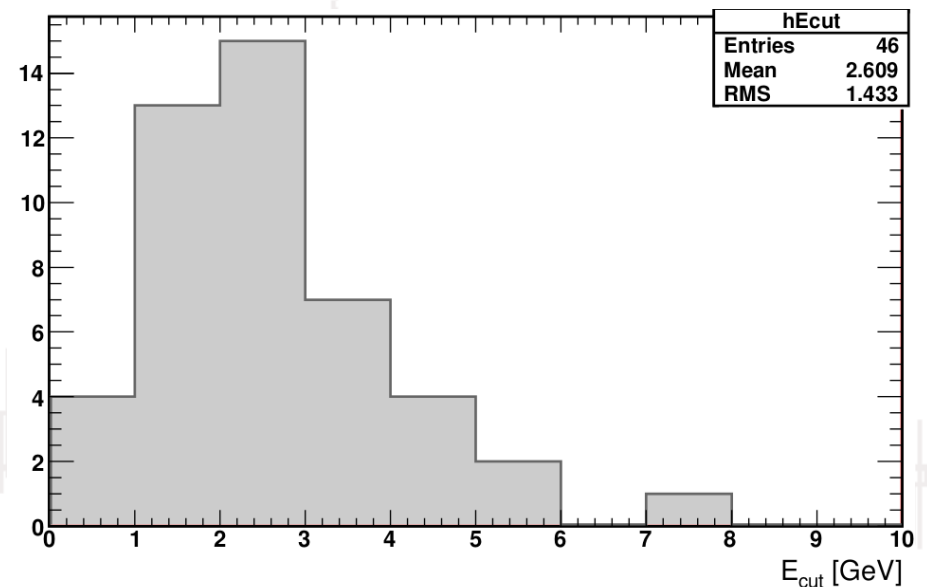
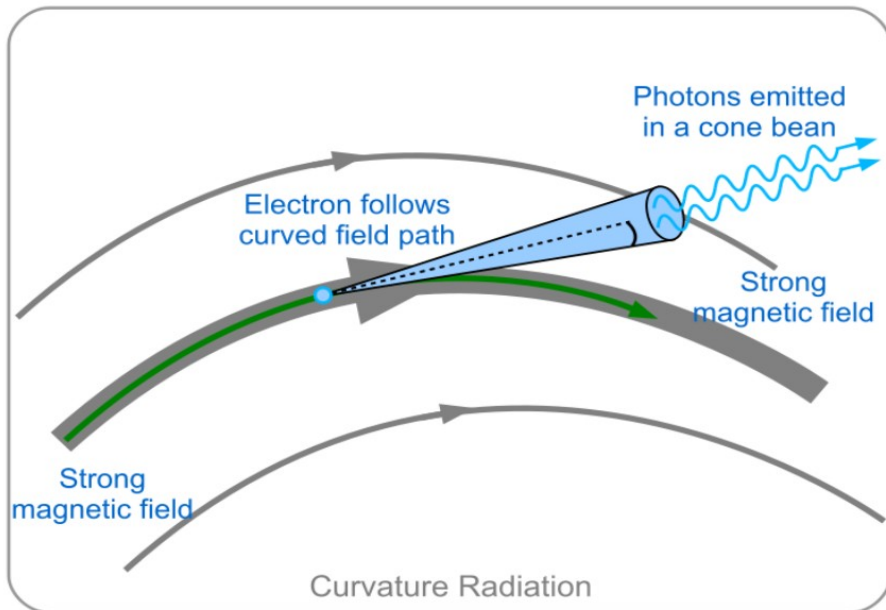
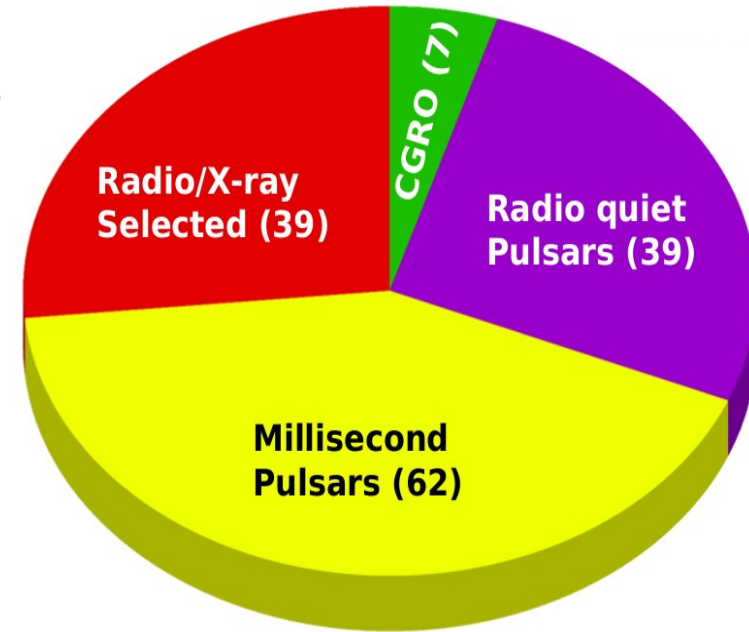
Decades-old puzzle: Origin of Emission

- Pulsar is surrounded by a co-rotating electron/positron plasma
- This extends out to the light-cylinder, where the co-rotation velocity reaches the speed of light
- Vacuum gaps are believed to form in the plasma which can support large accelerating electric fields
- Particles are energized in these gaps and radiate gamma-rays
- **Question:** Which region in around the pulsars does the emission come from?
- **Question:** Which emission processes make the gamma-rays (synchrotron, inverse-Compton, curvature radiation)
- **Some clues:** The shape of the pulsar emission light curves and the shape of the spectral energy distribution

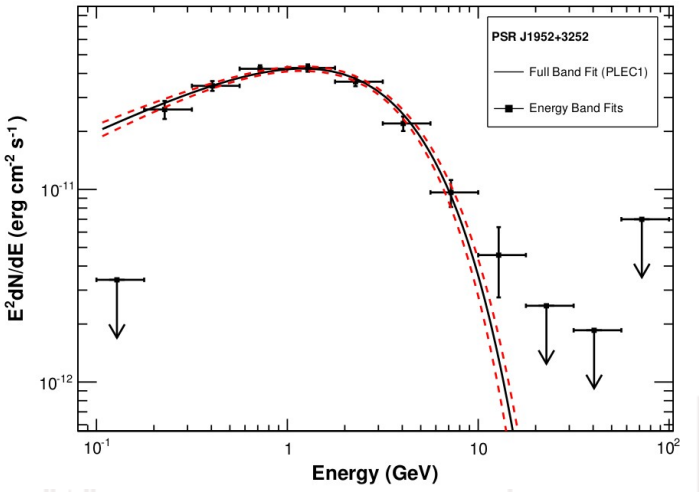
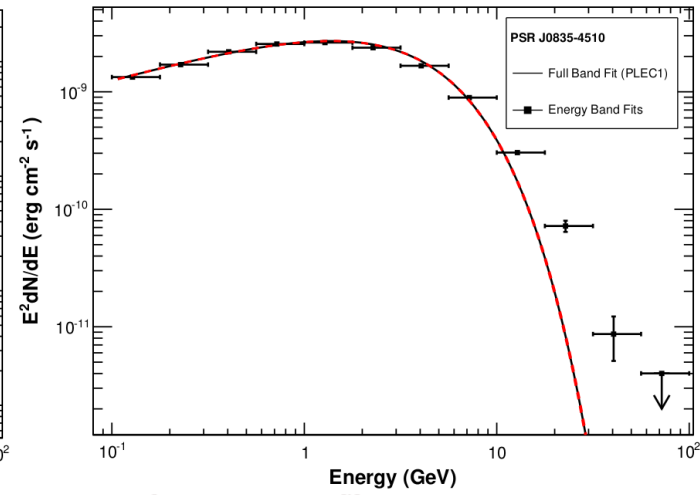
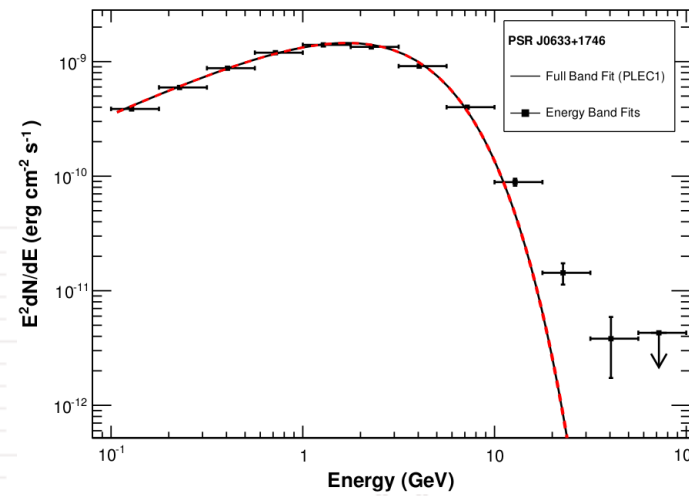
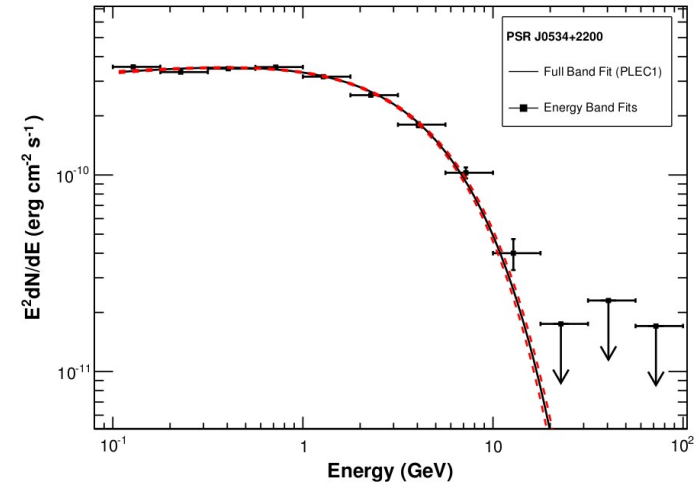
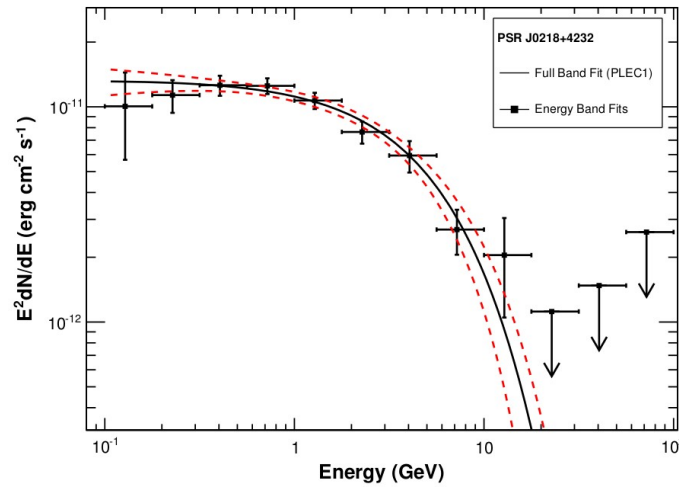
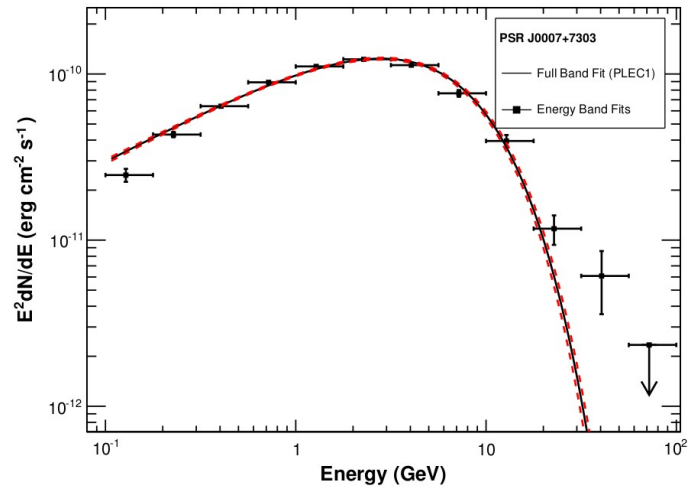


The Fermi Era

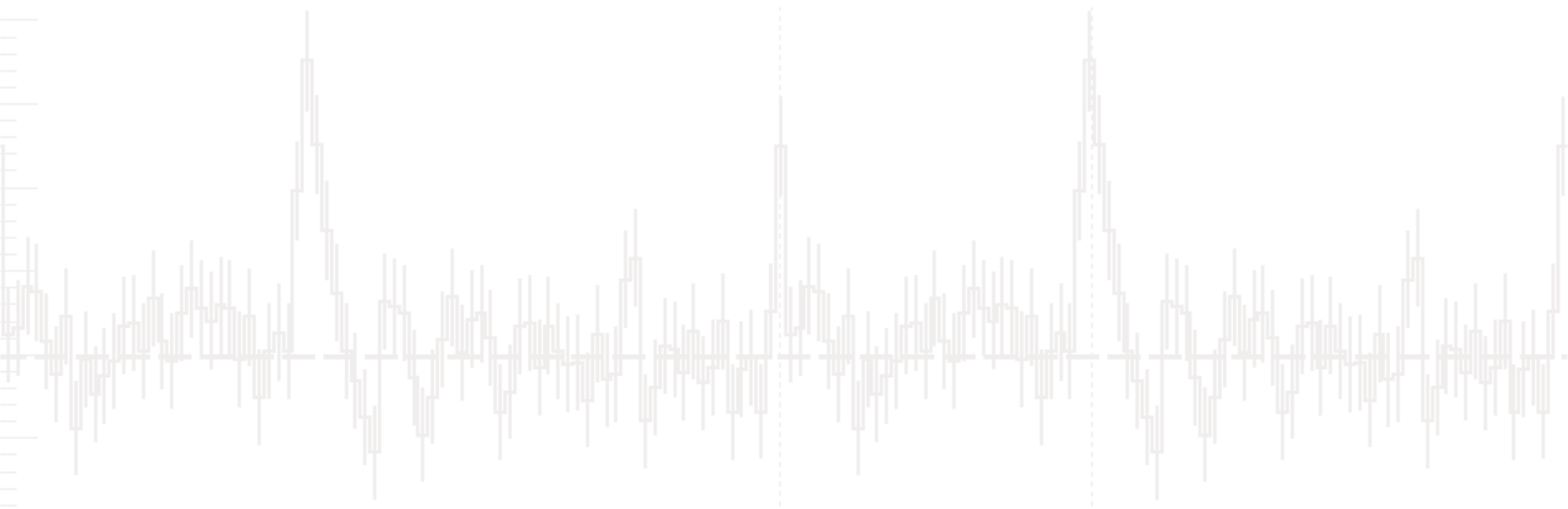
- Fermi has detected over new 140 pulsars in the last 6 years
- Their SEDs are described as power-laws with a spectral break at 1-6 GeV
- Above the break the SED falls like an exponential cut-off (maybe)
- Canonical picture of emission is Curvature radiation at the radiation-reaction limit



The Fermi Era

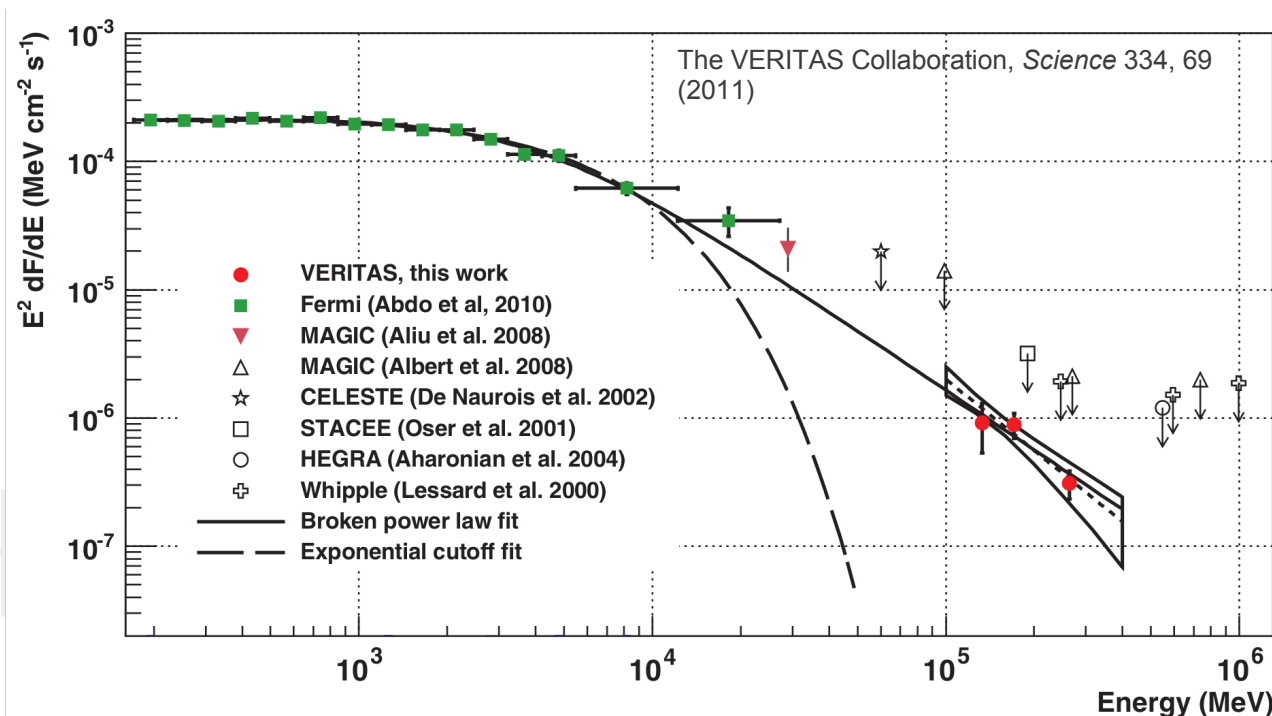
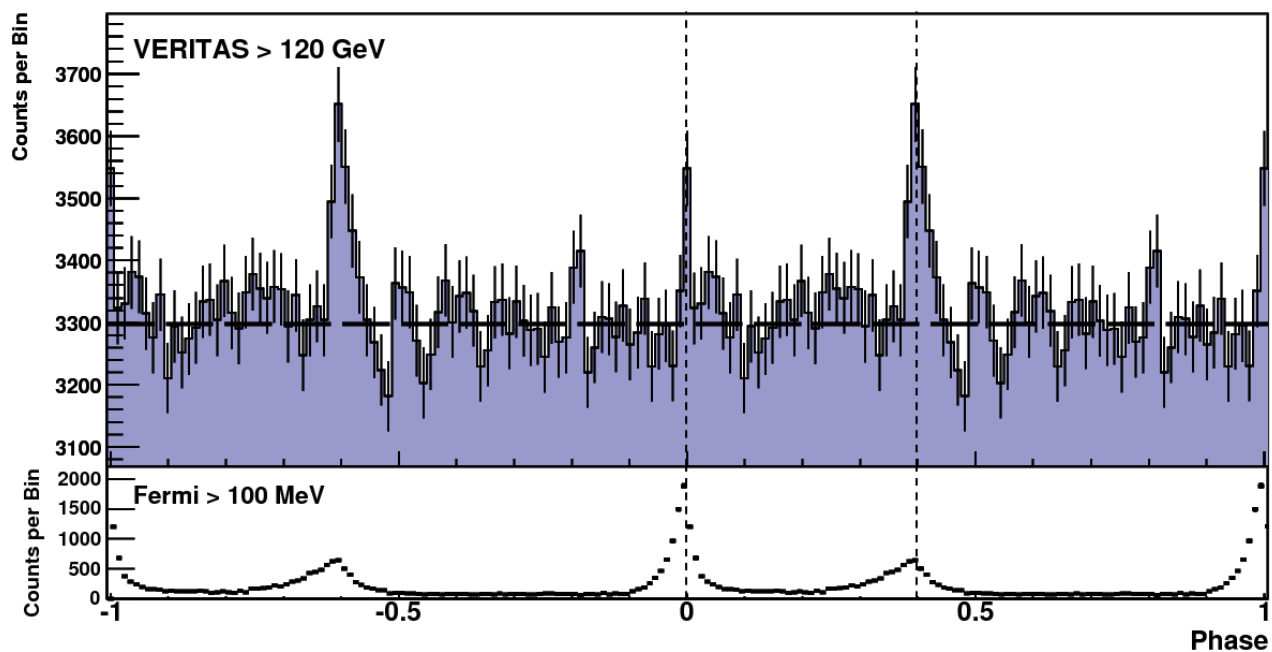


Pulsed VHE emission from the Crab



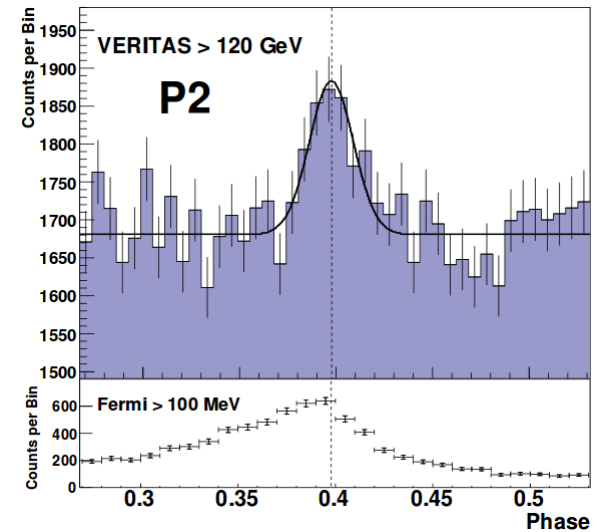
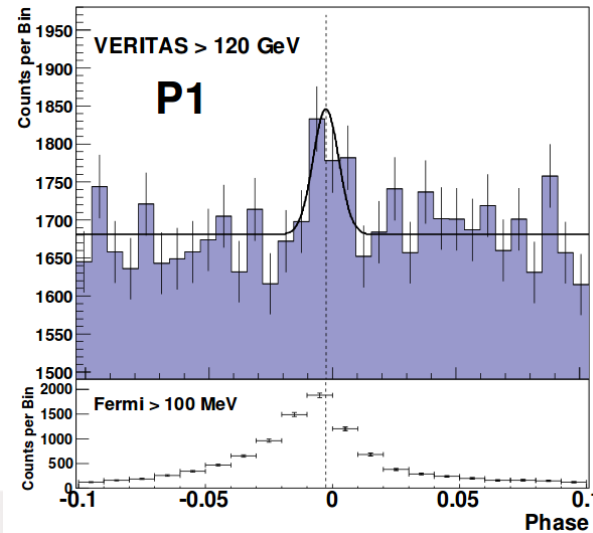
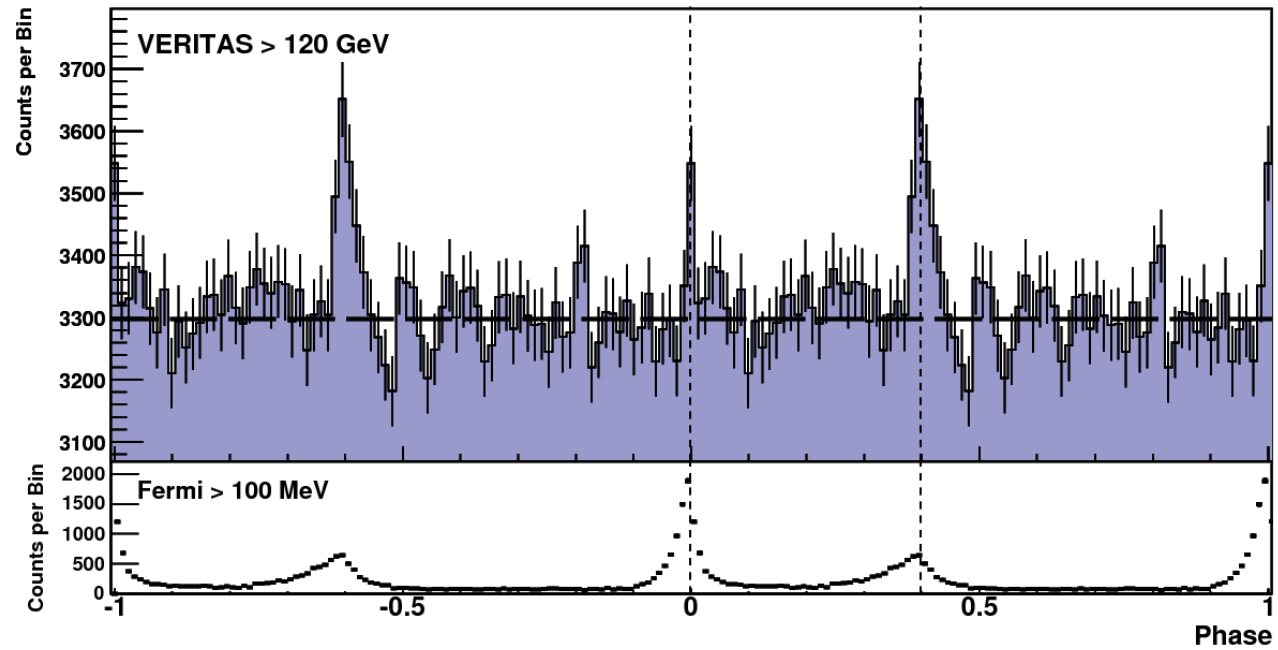
Pulsed VHE emission from the Crab

- **First detection** of any pulsar above 100 GeV
- **Power-law-type SED** above the spectral break
- **Strong limits** on the altitude of emission above the NS surface (>10 stellar radii)
- **P2 dominates** over P1
- **Emission pulses** are 50-65% narrower than the Fermi emission pulses



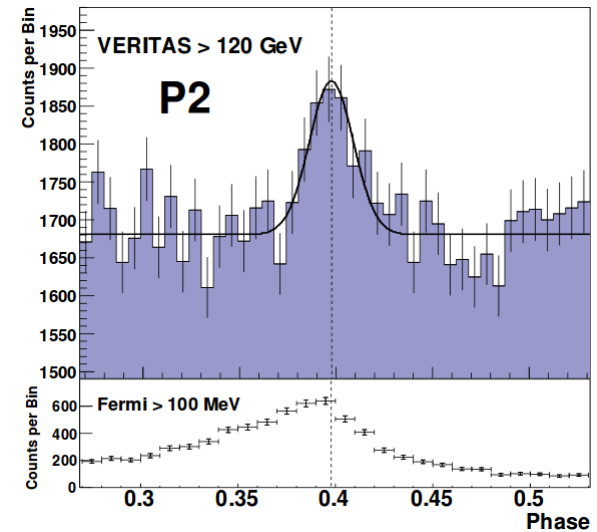
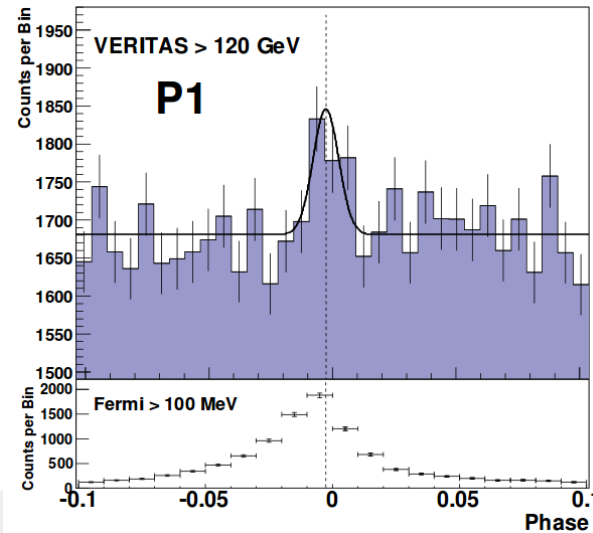
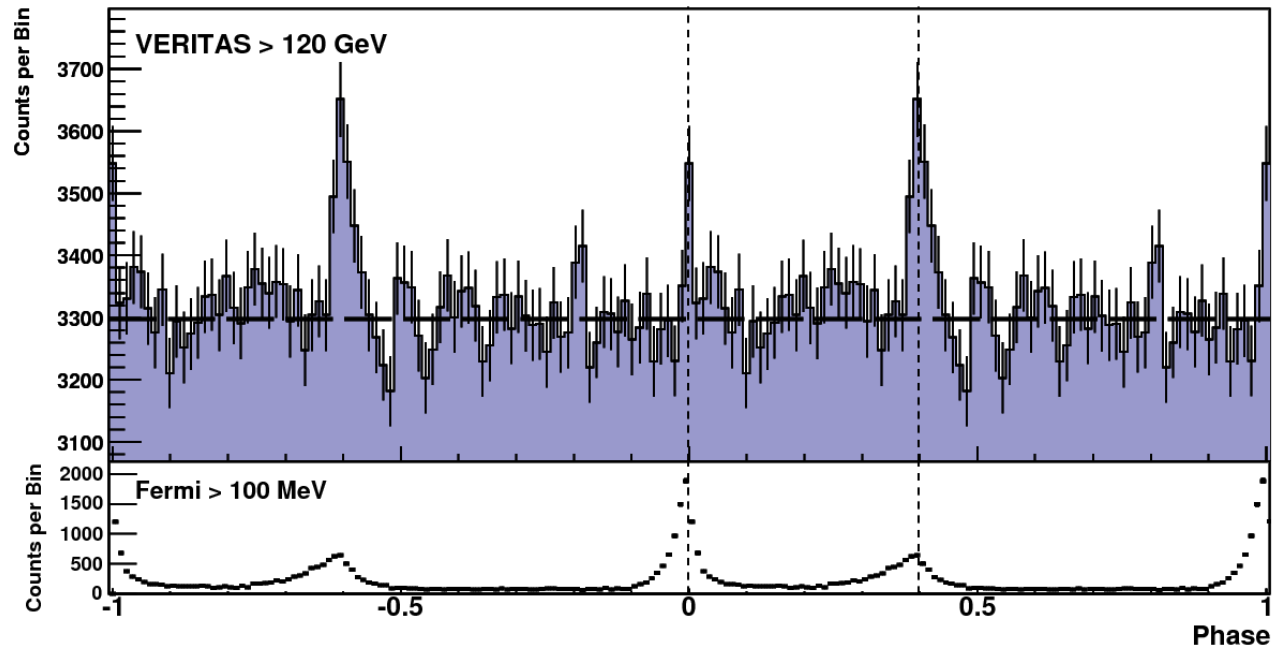
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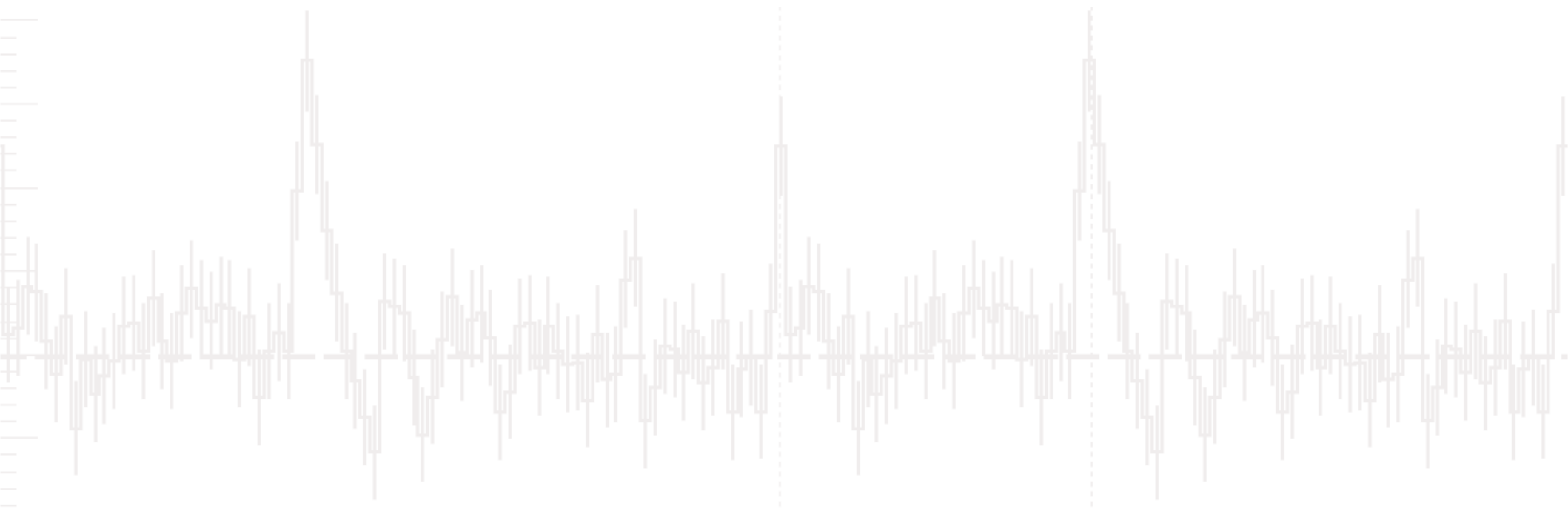


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- **Not Expected**
 - Stresses curvature-radiation picture
 - Inverse-Compton or Wind-zone emission?
- **Is the Crab unique** or is ~100 GeV emission seen in other pulsars?

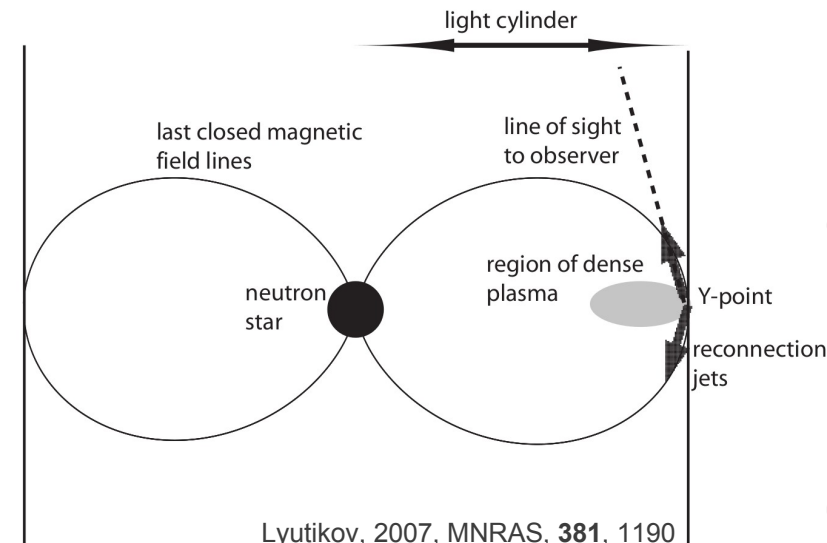
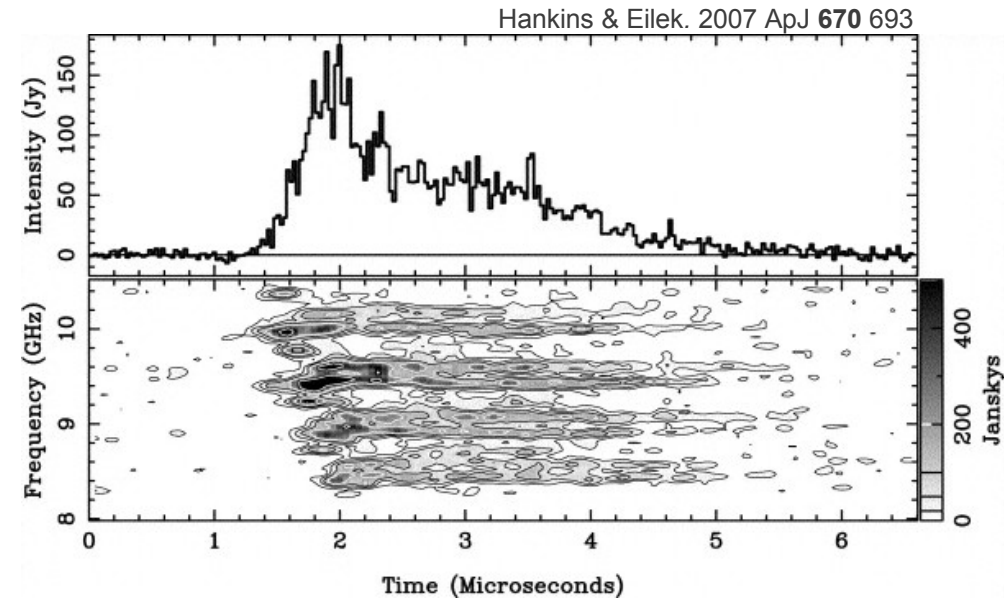


Pulsed VHE emission and Crab GRPs



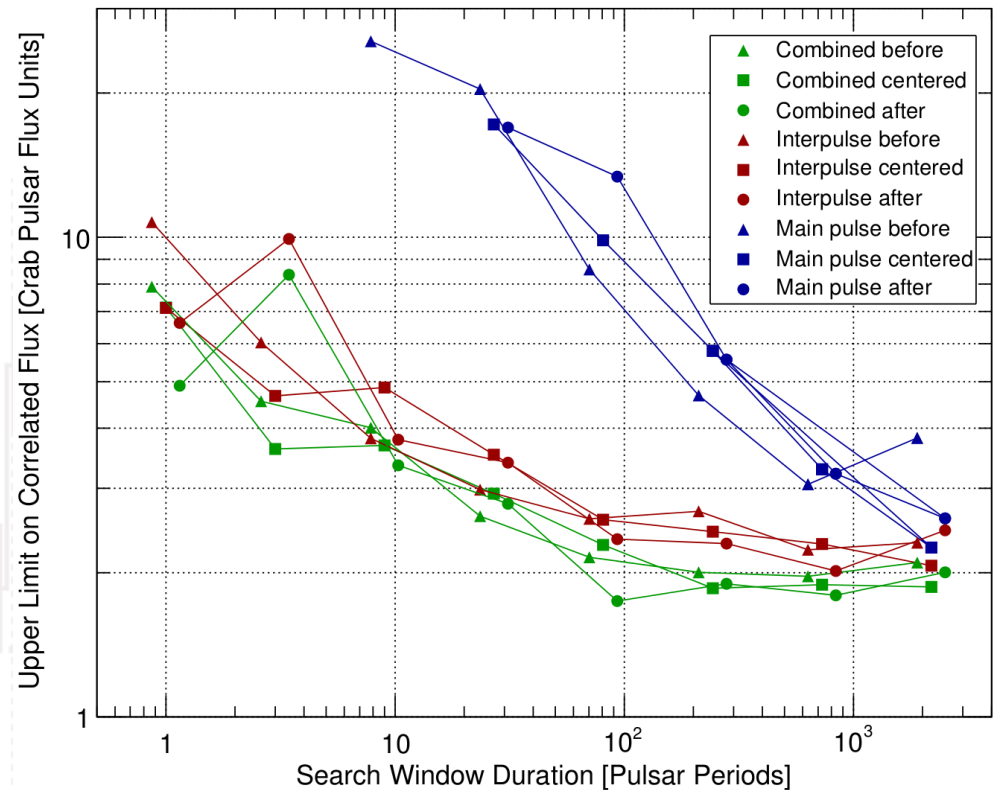
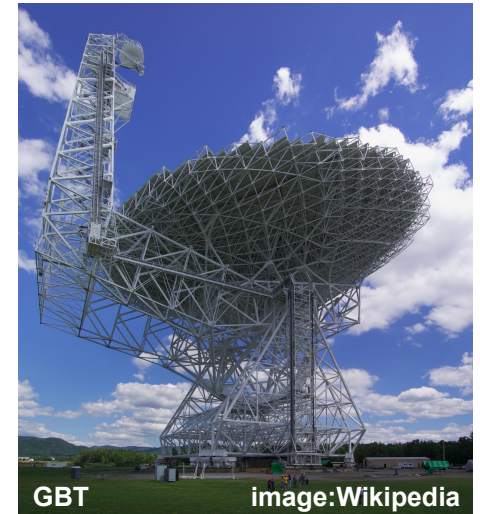
Pulsed VHE emission and Crab GRPs

- Crab Pulsar one of several known to emit Giant Radio Pulses
- No wide consensus on the mechanisms behind their emission
- Evidence for a GRP-Optical connections seen by Shearer *et al* (2003)
- Above 5 GHz the characteristics of main-pulse and interpulse GRP are seen to diverge
- A model for interpulse GRPs was put forward by Lyutikov (2007)
- This model predicts the existence of very energetic particles in the outer gap with Lorentz factors $\sim 10^8$
- These particles may generate gamma rays with energies of 1-100 GeV

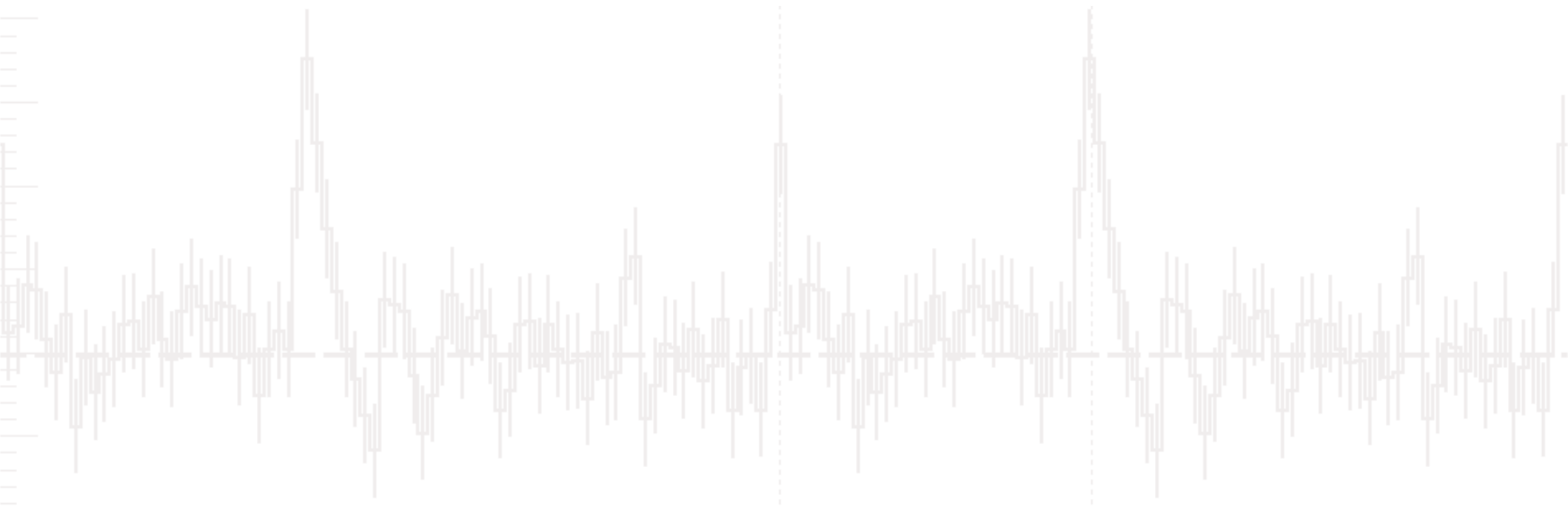


Pulsed VHE emission and Crab GRPs

- First ever limit on 100 GeV enhancement during GRPs
- 95% C.L. on correlated flux is 5-10 times Crab Pulsar flux for inter-pulse GRPs
- Similar limits for found for 0.1-5 GeV gamma rays (Bilous *et al*, 2011)
- **Published in ApJ 2012**

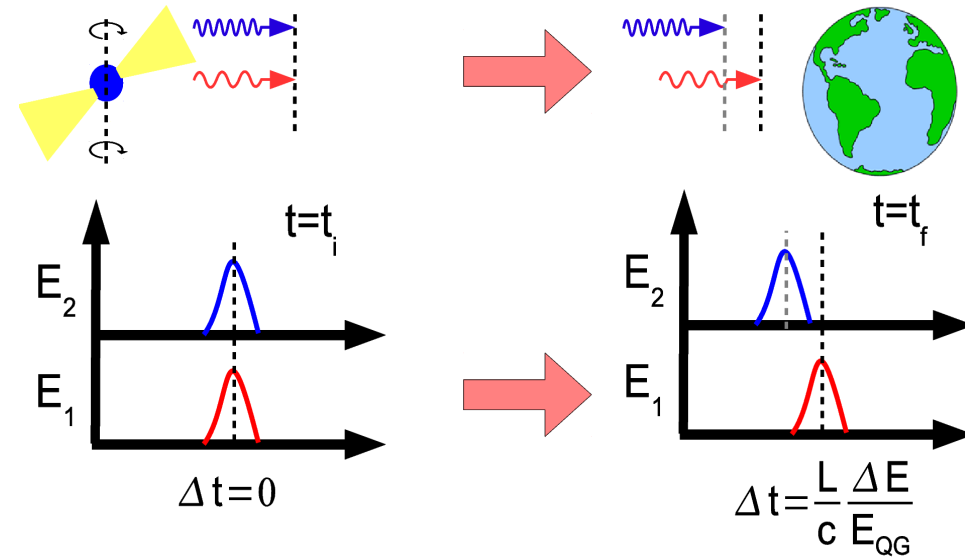


Lorentz Invariance Tests with Pulsars



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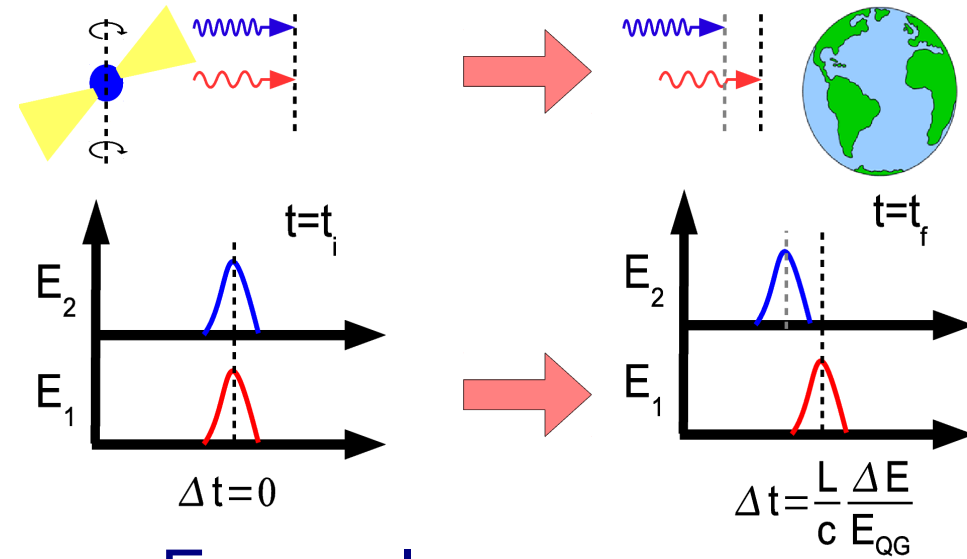
- Return to an **old idea** (Kaaret 1999, A&A, **345**, L32-L34)
- Search of effects of **Lorentz Invariance Violation** on the arrival time of pulses
- Place a lower limit on the energy scale of **Quantum Gravity**



$$E_{QG} = \frac{L}{c} \frac{E_2 - E_1}{\Delta t_1}$$

Lorentz Invariance Tests with Pulsars

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Propagation distance.
Larger => Stronger limits

Energy lever arm.
Larger => Stronger limits

$$E_{QG} = \frac{L}{c} \frac{E_2 - E_1}{\Delta t_1}$$

Temporal time scale.
Shorter => Stronger limits

Lorentz Invariance Tests with Pulsars

32ND INTERNATIONAL COSMIC RAY CONFERENCE, BEIJING 2011



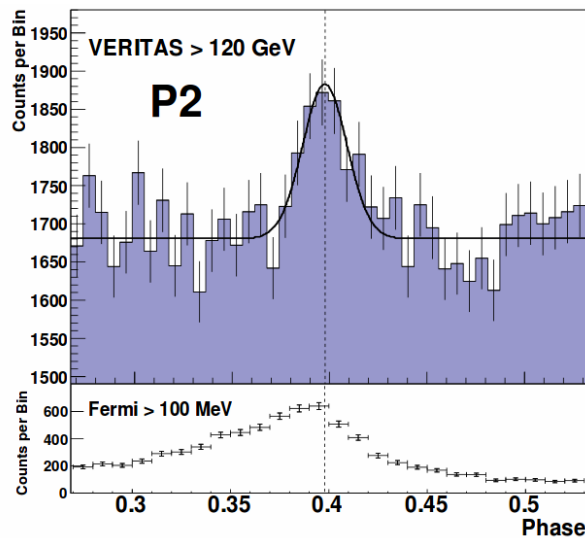
33ND INTERNATIONAL COSMIC RAY CONFERENCE, RIO DE JANEIRO 2013
THE ASTROPARTICLE PHYSICS CONFERENCE

ICRC
2013

Prospects of performing Lorentz invariance tests with VHE emission from pulsars

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¹SCIPP, University of California, 1156 High Street, Santa Cruz, CA 95060, U.S.A.
nepomuk.otte@gmail.com

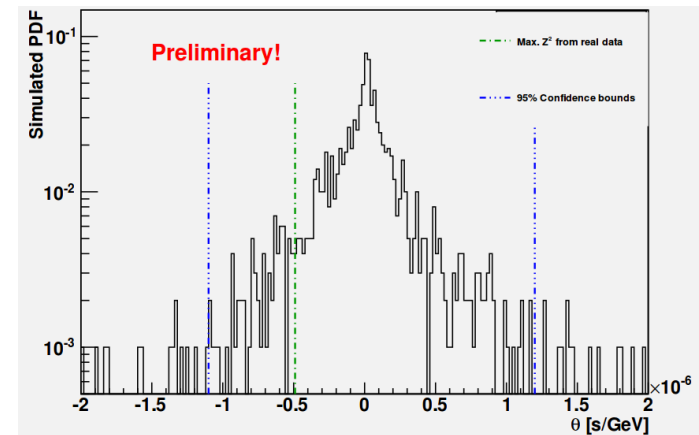


- Using 2007-2011 photon list
- Simple peak separation method
- Linear limit = $\sim 3 \times 10^{17}$ GeV
- Quadratic limit = $\sim 7 \times 10^9$ GeV

Lorentz Invariance Violation Limits from the Crab Pulsar using VERITAS

BENJAMIN ZITZER¹, FOR THE VERITAS COLLABORATION.

¹ Argonne National Laboratory, 9700 S. Cass Ave. Lemont, IL, USA
bzitzer@anl.gov



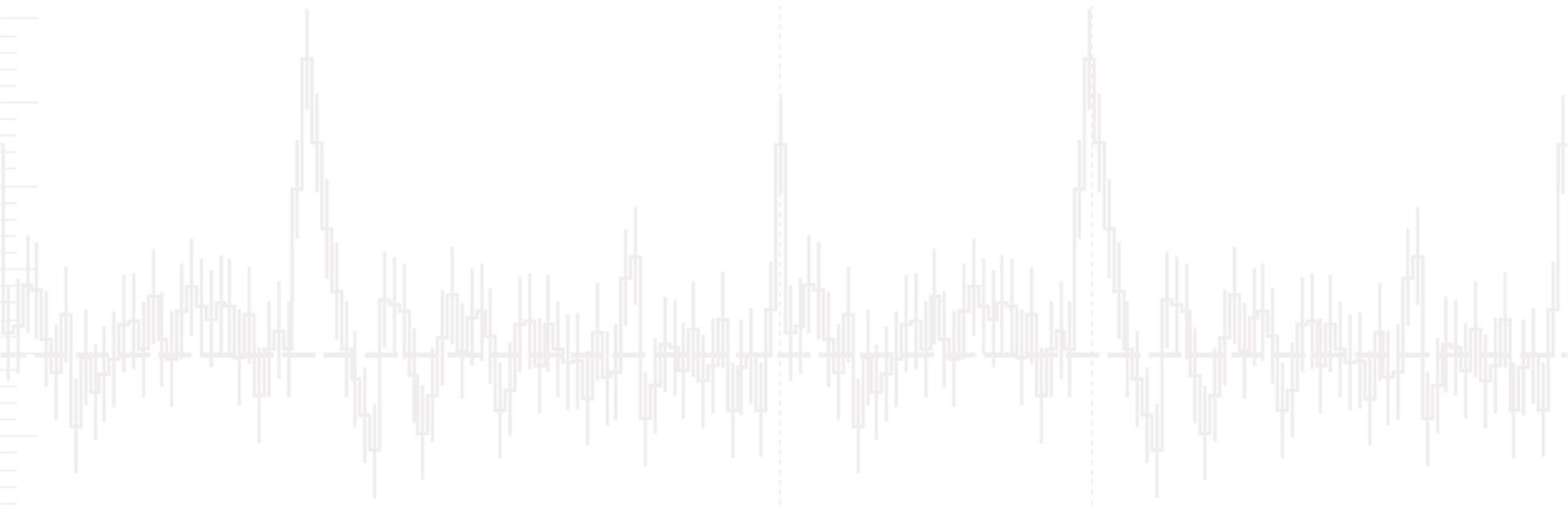
- Using 2007-2011 photon list
- Dispersion Cancellation with Z^2 cost function
- Linear limit = $\sim 2 \times 10^{17}$ GeV

Why do LIV with Pulsars?

- Tests **do not rely on** random transient events and observational **luck**.
- **Limits improve** with longer exposures.
- Limits are based on **highly significant measures of peak** positions and **not** a handful of **single photons**.
- Intrinsic **source delays can be distinguished** from LIV effects:
 - **Source Effect:** The delay separation is **constant in phase** as the pulsar period lengthens, **not constant in time**
 - **LIV Effect:** The delay effect **is constant in time**. As the pulsar period lengthens should **shift in phase** by: $\Delta\Phi(t) = \Delta t / (P + t\dot{P})$
- Likely avoid the “**messy astrophysics**” involved in GRBs and AGN

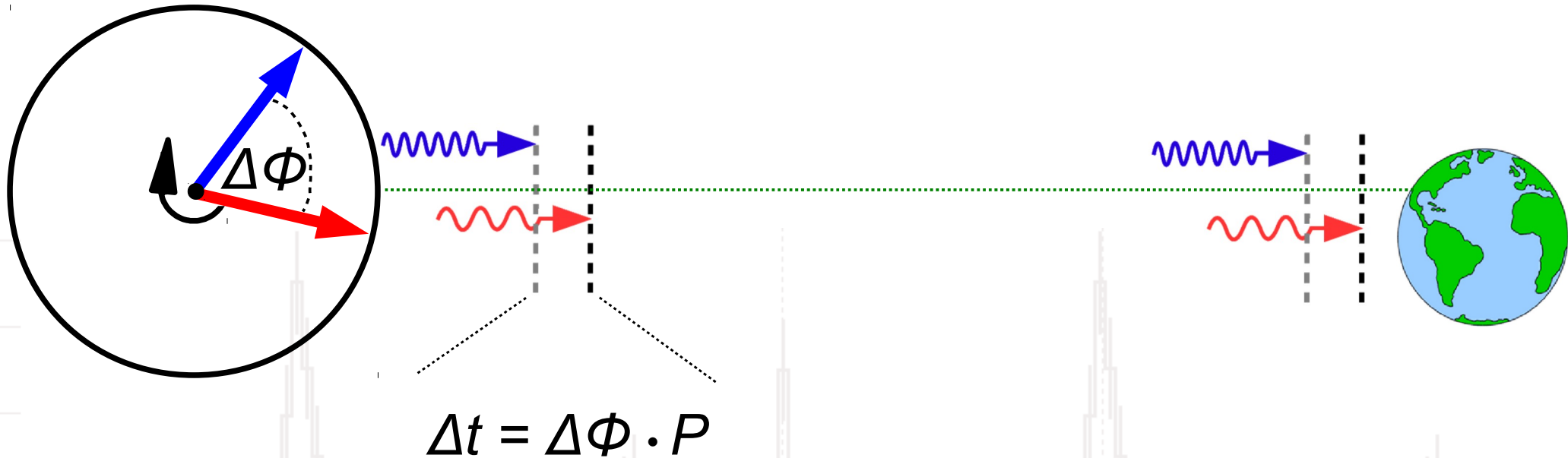
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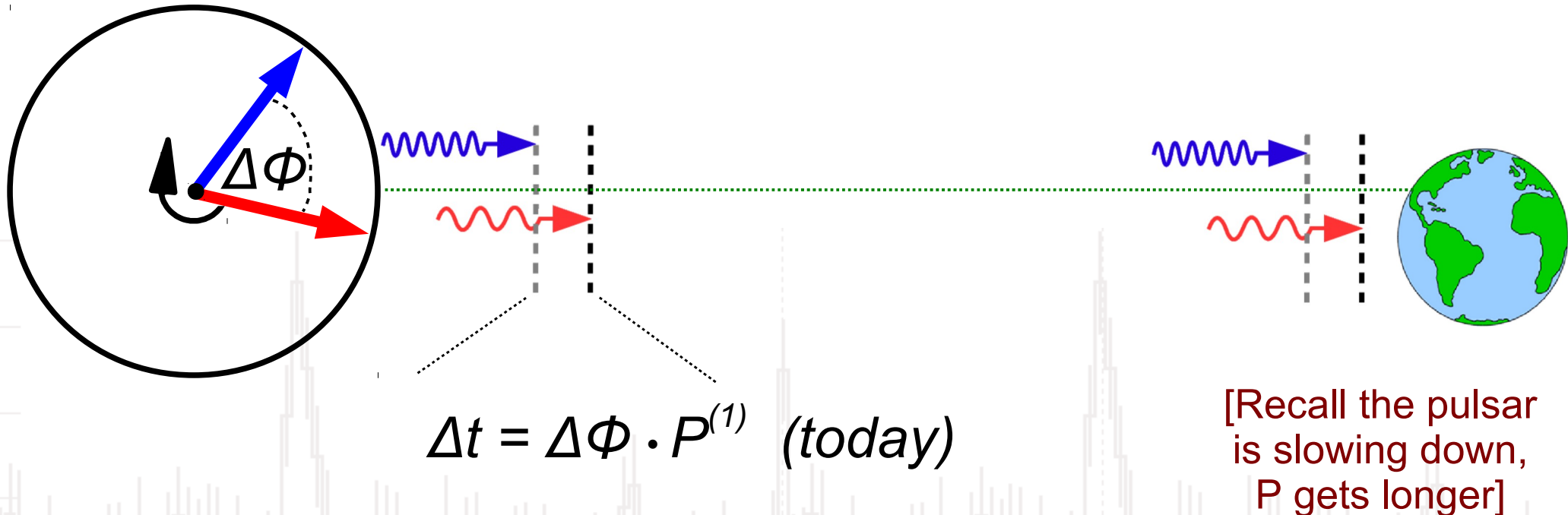
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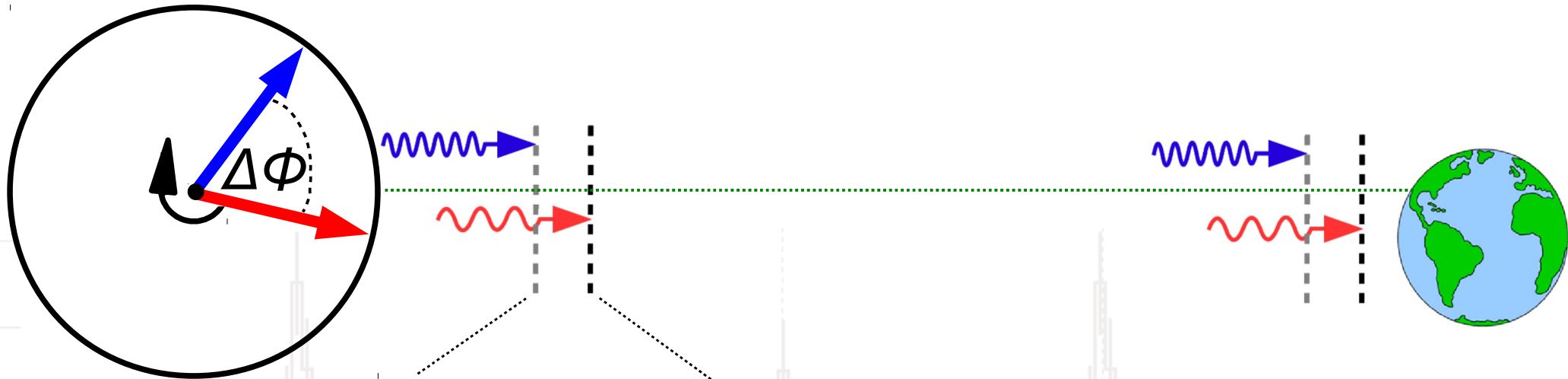
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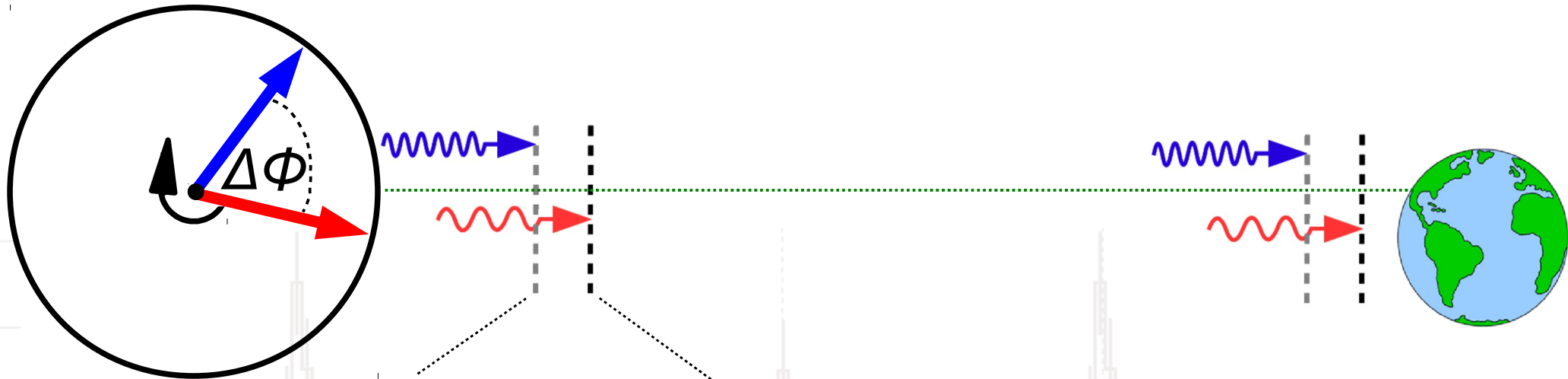
$$\Delta t = \Delta\Phi \cdot P^{(1)} \quad (\text{today})$$

$$\Delta t = \Delta\Phi \cdot P^{(2)} \quad (\text{some future time})$$

[Recall the pulsar is slowing down, P gets longer]

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⇒ separation is **not constant in time** if it's source effect

[Recall the pulsar is slowing down, P gets longer]

Summary

- VERITAS has detected power-law-type emission from the Crab pulsar above 100 GeV (confirmed by MAGIC)
- P2 is dominant over P1 and the peaks are 50% narrower
- Canonical emission picture in trouble (or maybe the Crab is just a freak [which it is])
- VERITAS has placed a limit on the pulsed VHE enhancement in the Crab correlated with GRPs measured at 8.9 GHz
- Lorentz Invariance Test with pulsars are cool (limits improving)
- Is the Crab unique or do other pulsars make VHE radiation (HESS II?)
 - 1 New VHE pulsar → New Pulsar Astrophysics (emission sites/mechanisms)
 - 1 New VHE pulsar → LIV limits (Especially an MSP)
 - 1 New VHE pulsar → New galactic DM backgrounds at ~100 GeV
- Fermi has given us 140+ new pulsar targets. Lets go hunting!