Pulsars at very high energy

JRJC - October 2018

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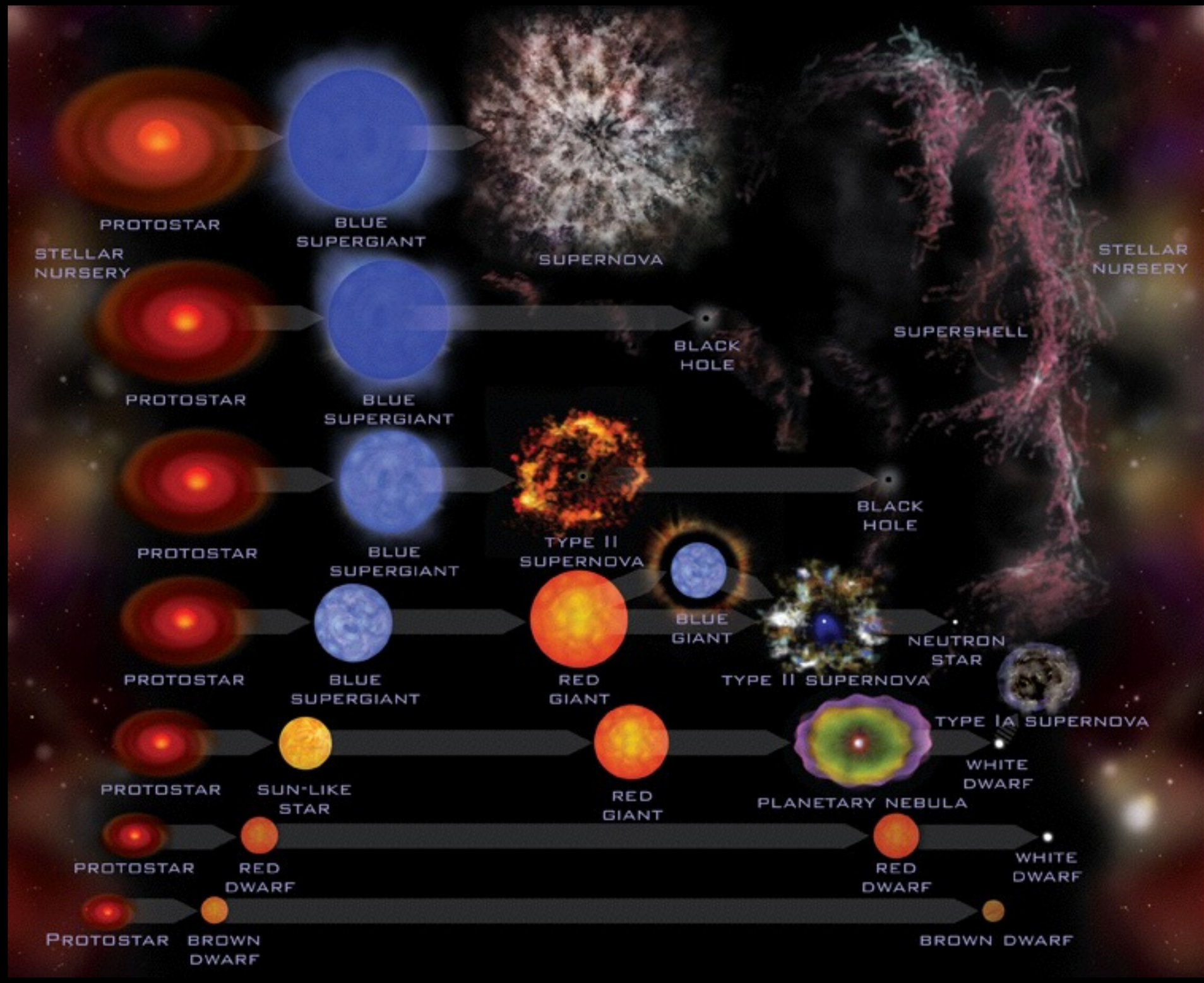
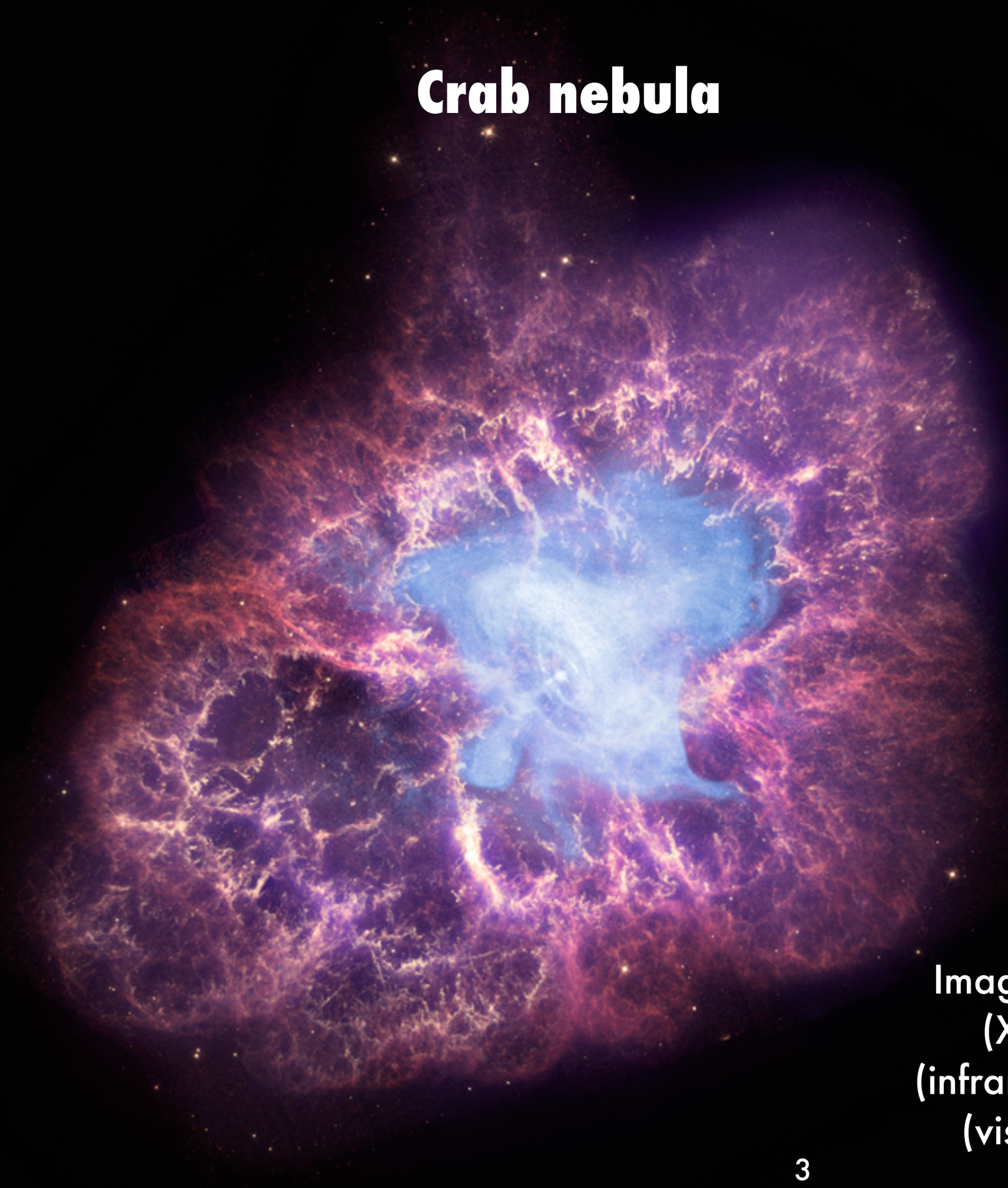
Stellar evolution



Crab nebula



A massive star explodes in a **supernova** at the end of its life : external layers are ejected (remnants of the supernova), **internal layers collapse** and give birth to a pulsar

Image obtained with Chandra (X-rays, in blue), Spitzer (infrared, in purple) and Hubble (visible, in yellow and red)

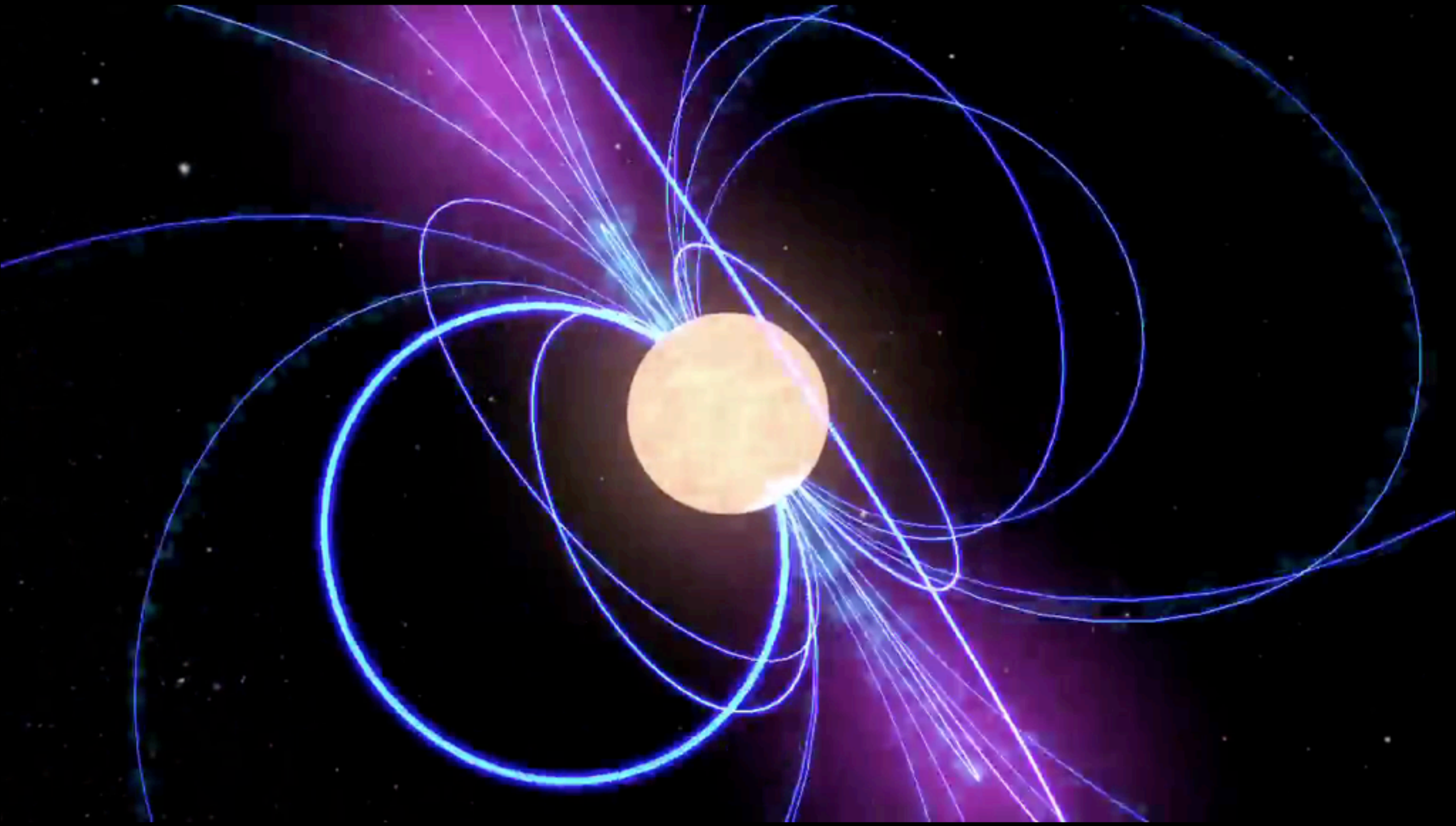
Pulsars: highly magnetized, fast-spinning neutron stars

- Solar mass in a ~10 km radius
- Density is like the mass of the English Channel (la Manche) contained in the volume of an oyster

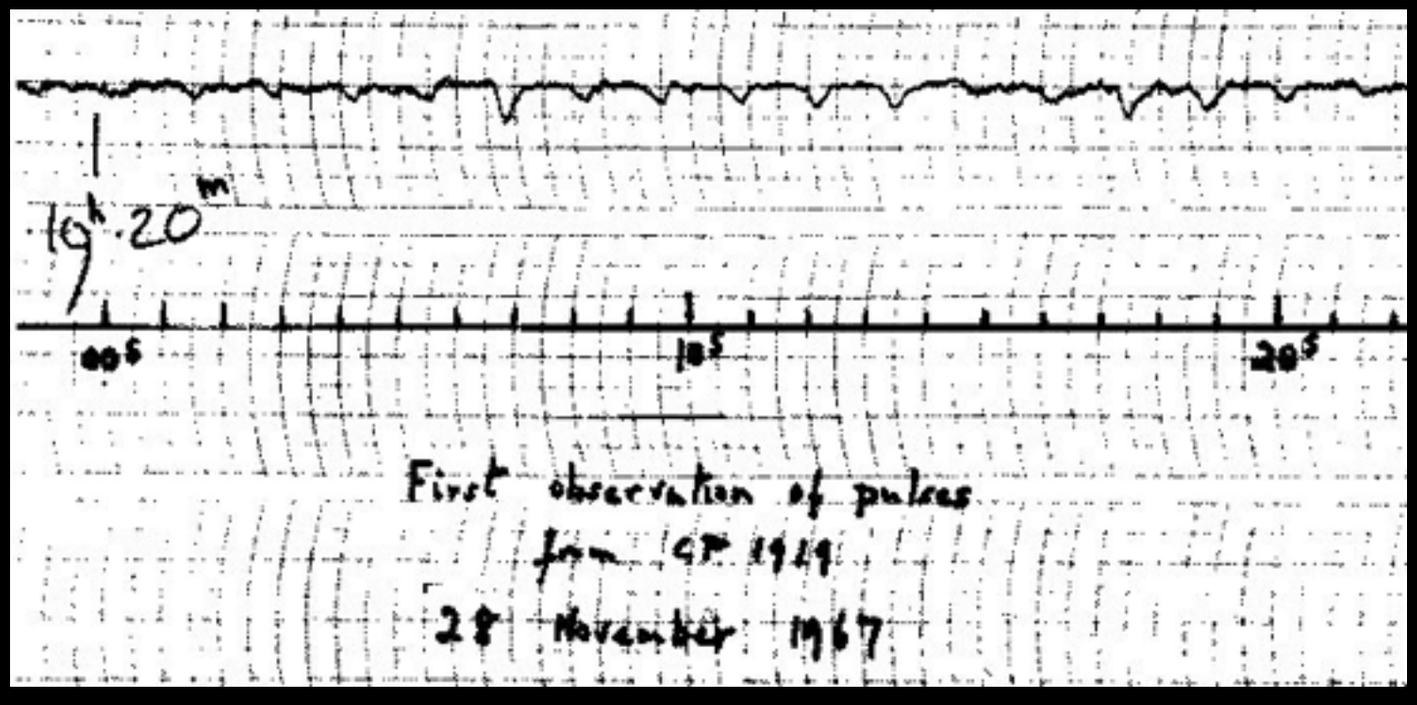
- Neutron stars $\begin{cases} n \rightarrow p^+ + e^- + \bar{\nu}_e \\ p^+ + e^- \rightarrow n + \nu_e \end{cases}$

Equilibrium between the gravity and the strong force

- Radius diminishes drastically so the intensity of the magnetic field, as well as the speed of rotation, increases a lot



1967: first detection of pulsars (« pulsating stars »)



First named « LGM » for « Little Green Men »

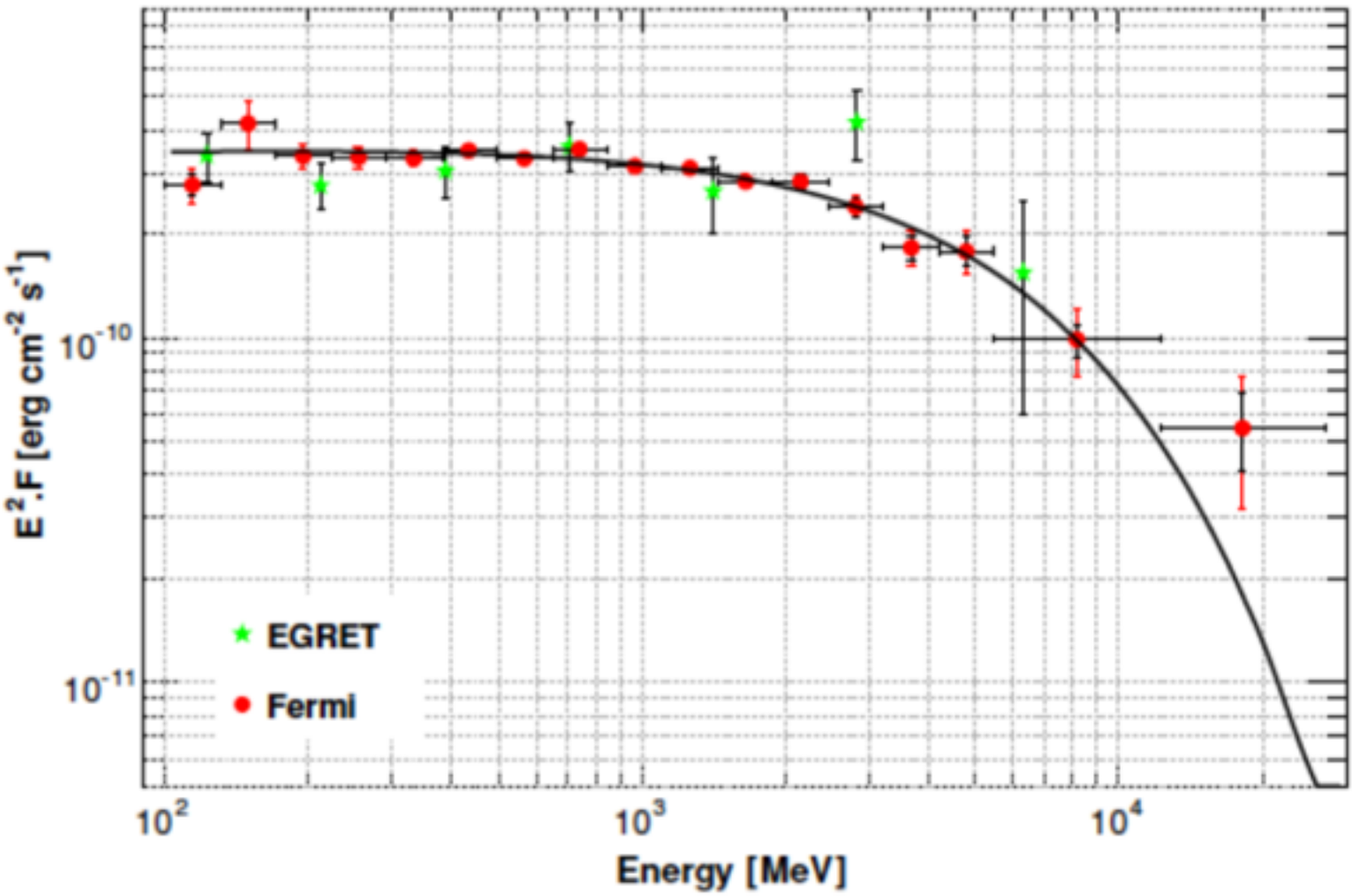
In astronomy, periodicity explained by:

- **Rotation**
- Orbital motion
- Modulation

- Since 1967 : more than 2000 pulsars detected in radio
- **More than 200 in gamma**

Fermi-LAT era since 2008

Fermi detected more than **200 gamma pulsars** (7 before : a revolution in the world of gamma pulsars!) and it seemed to **exclude very high energy pulsed emission:**

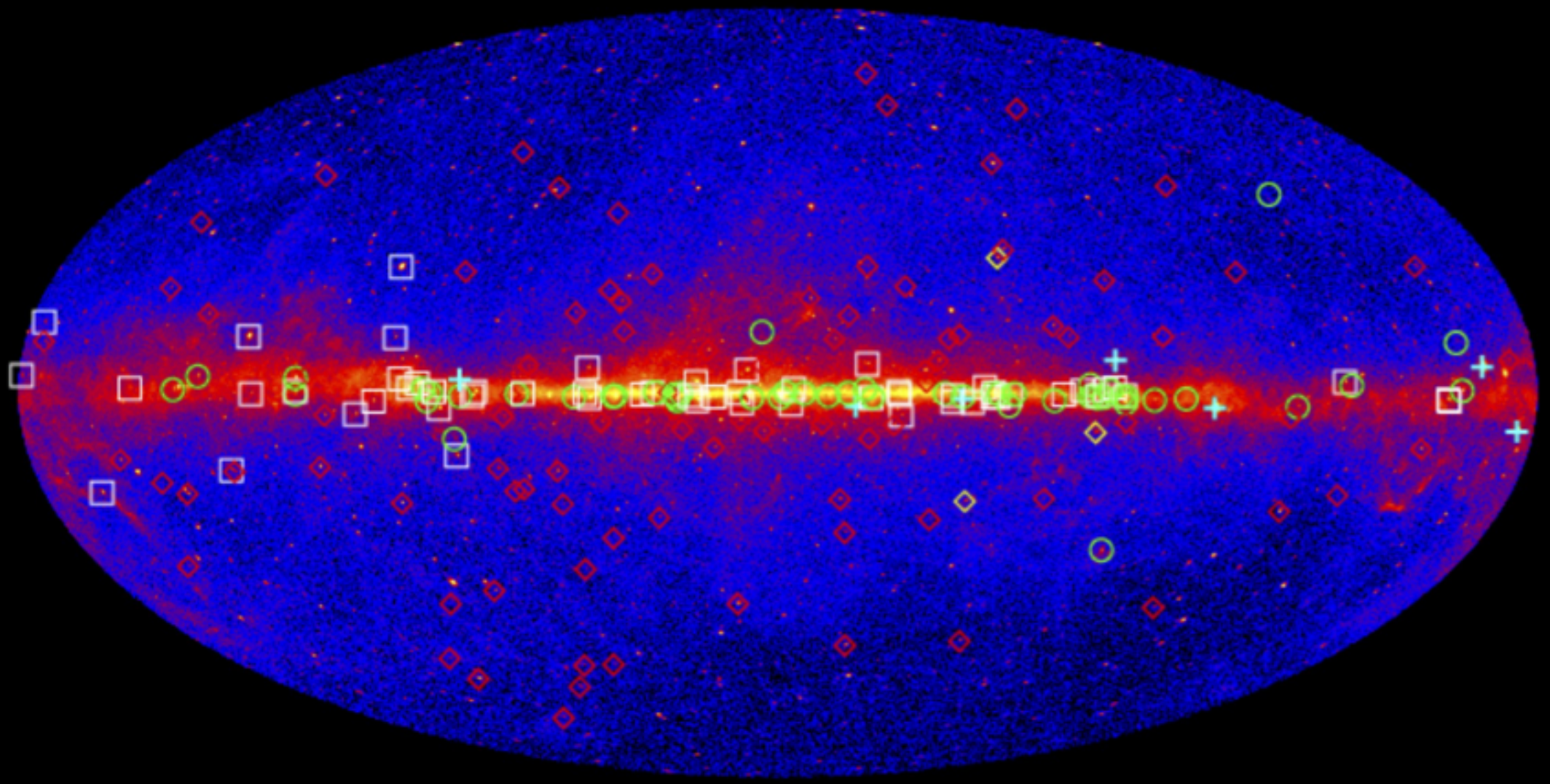


A (sub-)exponential **cut-off around the GeV** is established for pulsars

LAT pulsars

Courtesy
Lucas Guillemot

Public list of LAT-detected pulsars available at: https://confluence.slac.stanford.edu/x/5JI6Bg



58 young radio- and X-ray-selected (green circles, cyan crosses: EGRET pulsars)

57 young gamma-ray-selected (white squares)

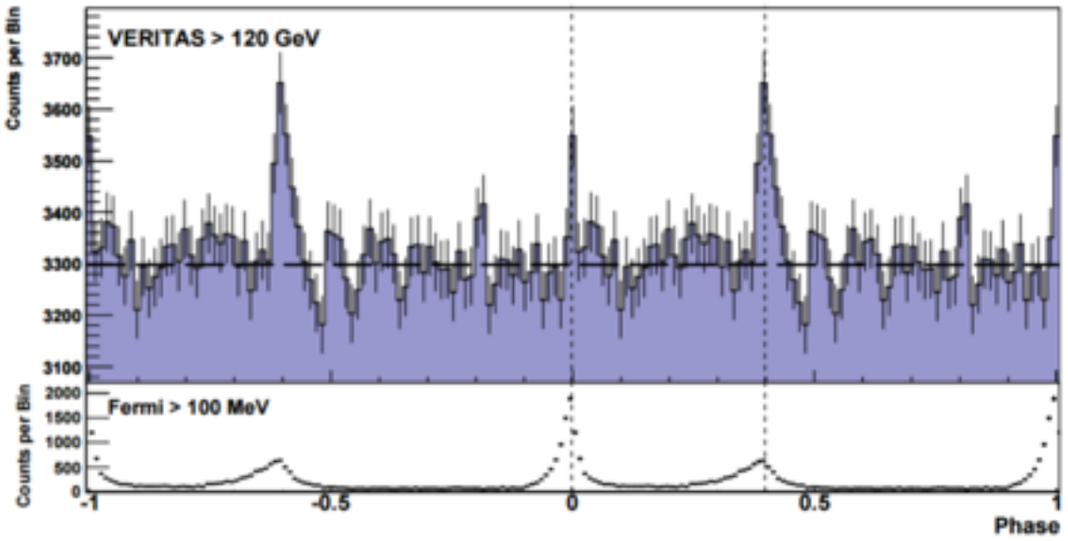
92 radio-selected MSPs (red diamonds), 3 gamma-ray-selected MSP (yellow diamonds)

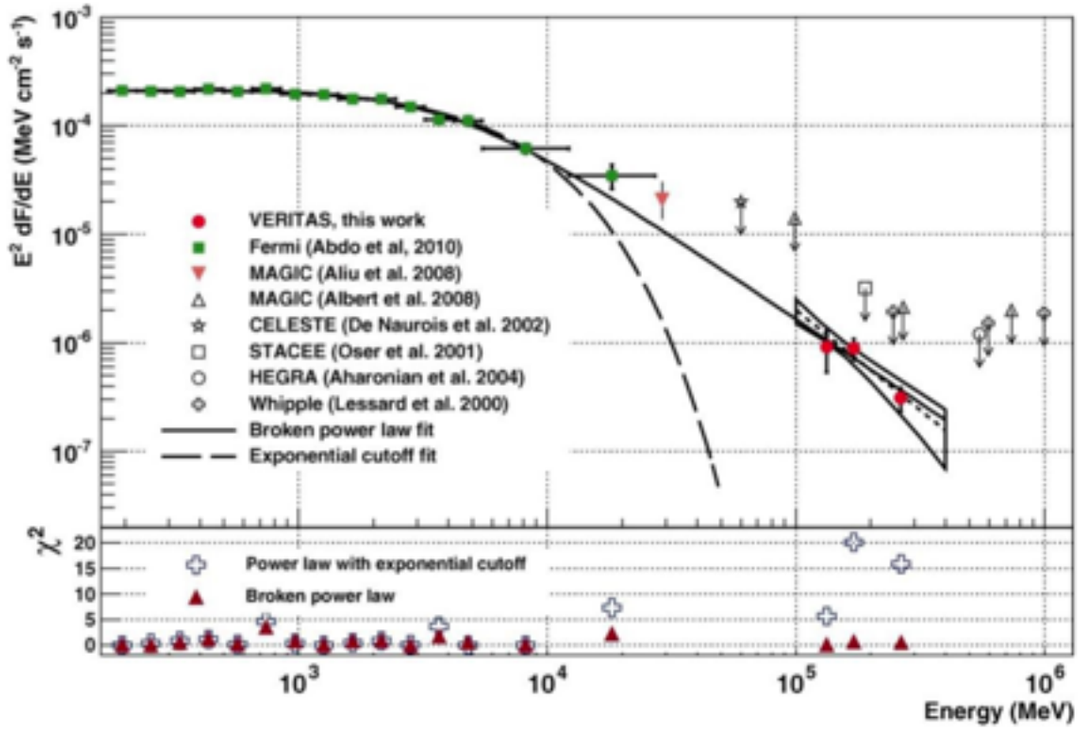
210 in total!

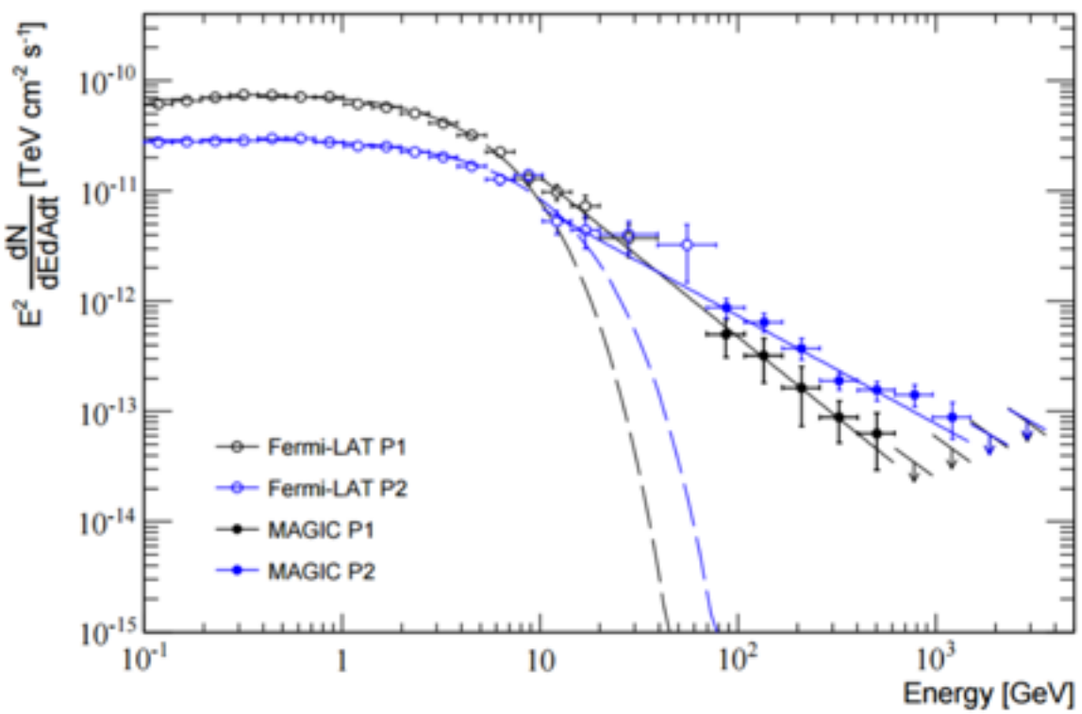
L. Guillemot, 16/10/17

VHE detections from the Crab pulsar

2011: VERITAS detects a pulsed signal from the Crab at 100-400 GeV Confirmed by MAGIC



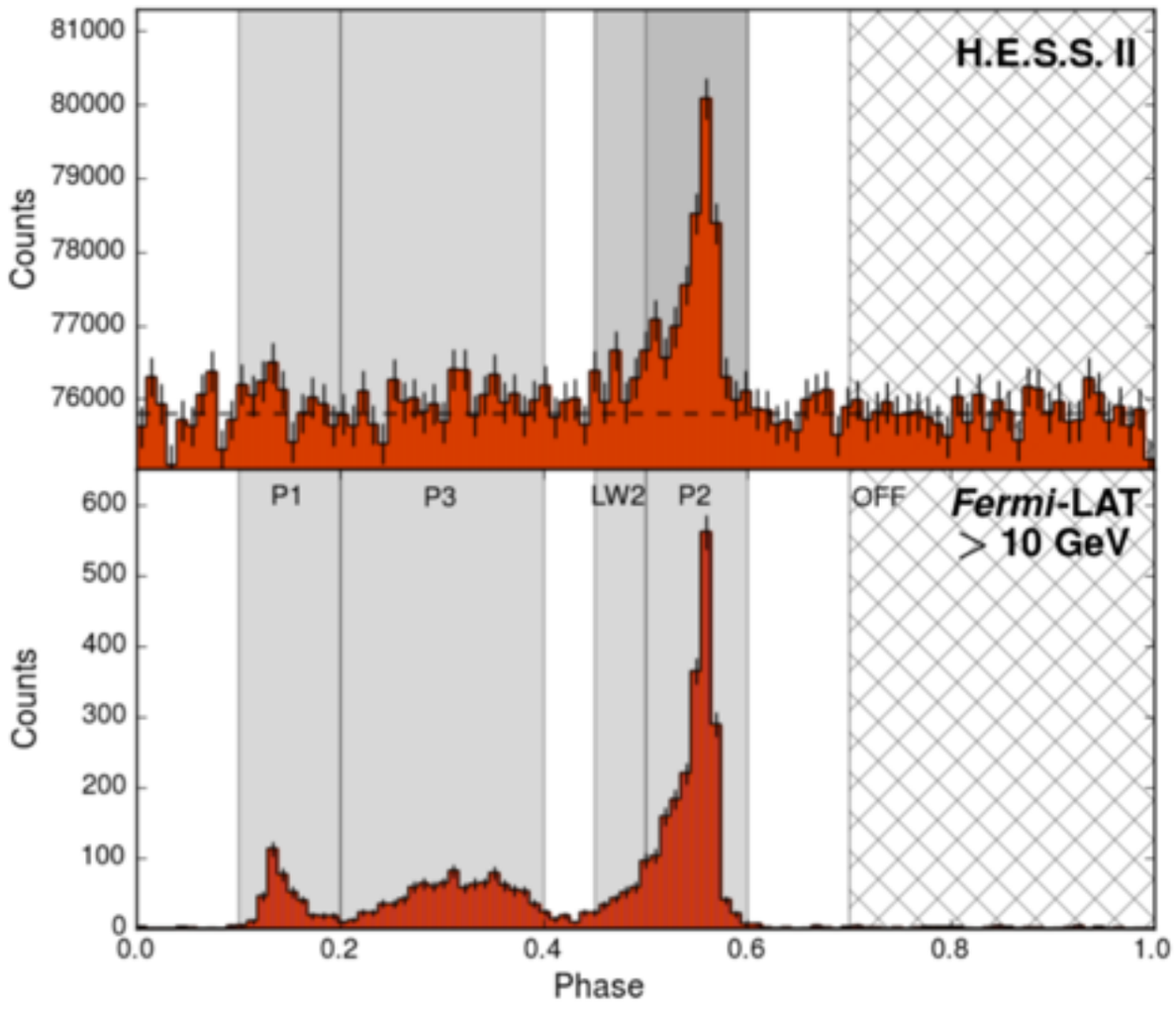


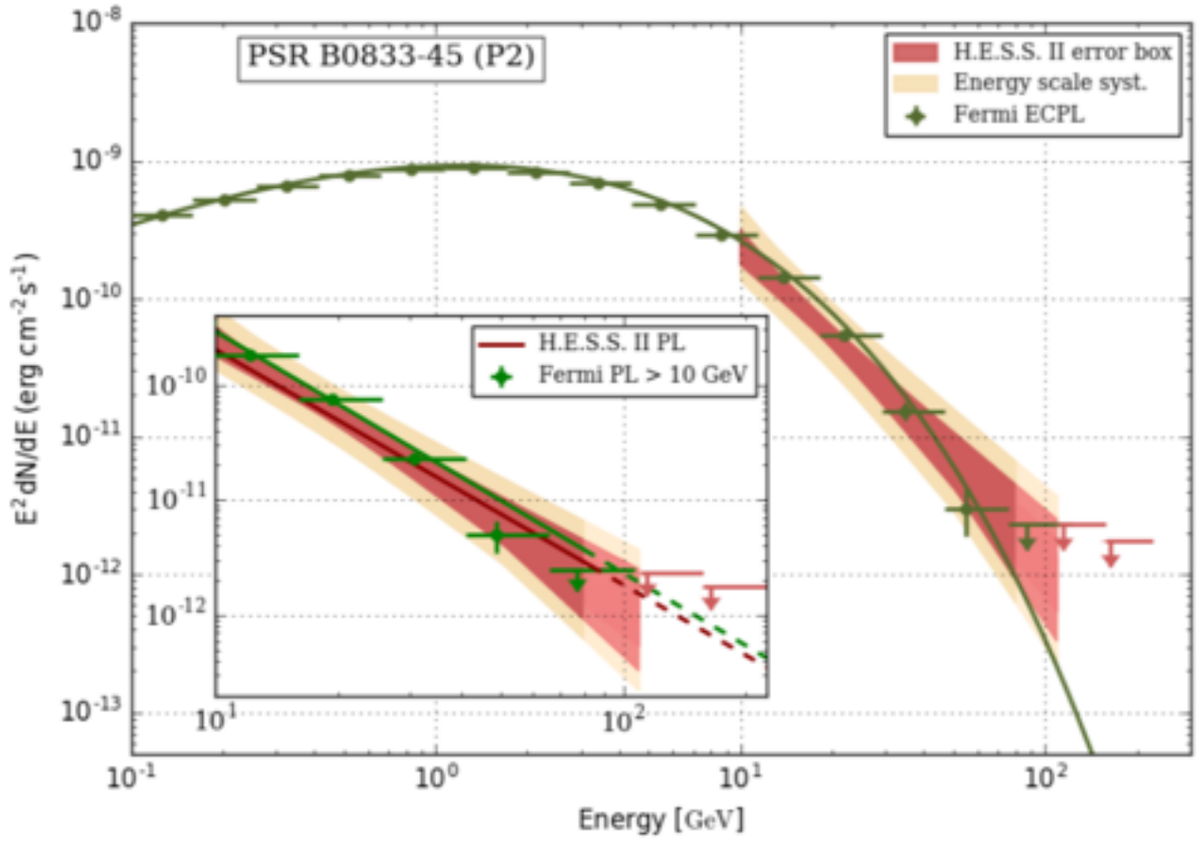


2016: MAGIC detects up to 1 TeV

No exponential cut-off but a power law!

H.E.S.S. observations of the Vela pulsar < 120 GeV

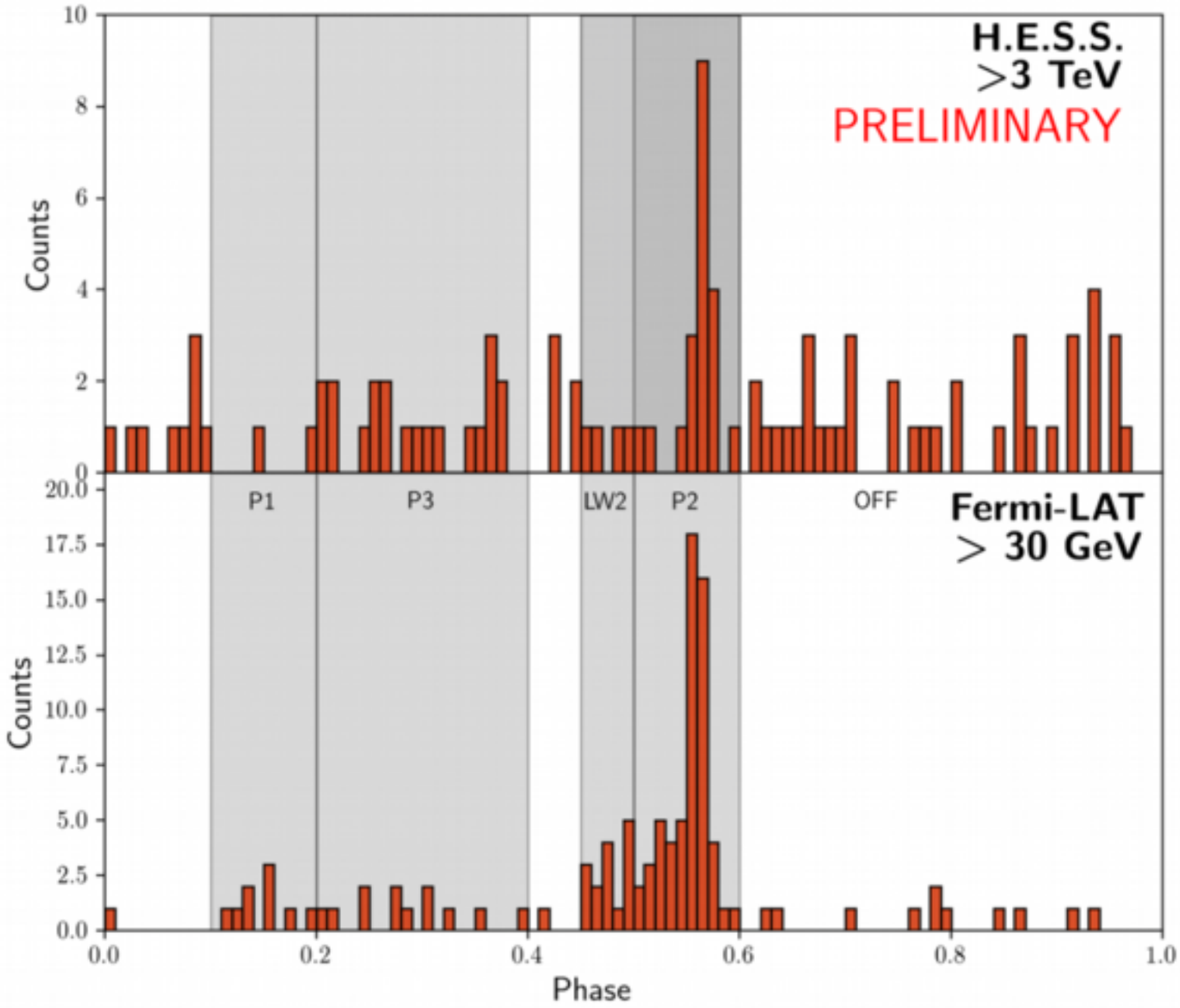




The GeV component turns off around 100 GeV...

H.E.S.S. observations of the Vela pulsar > 3 TeV

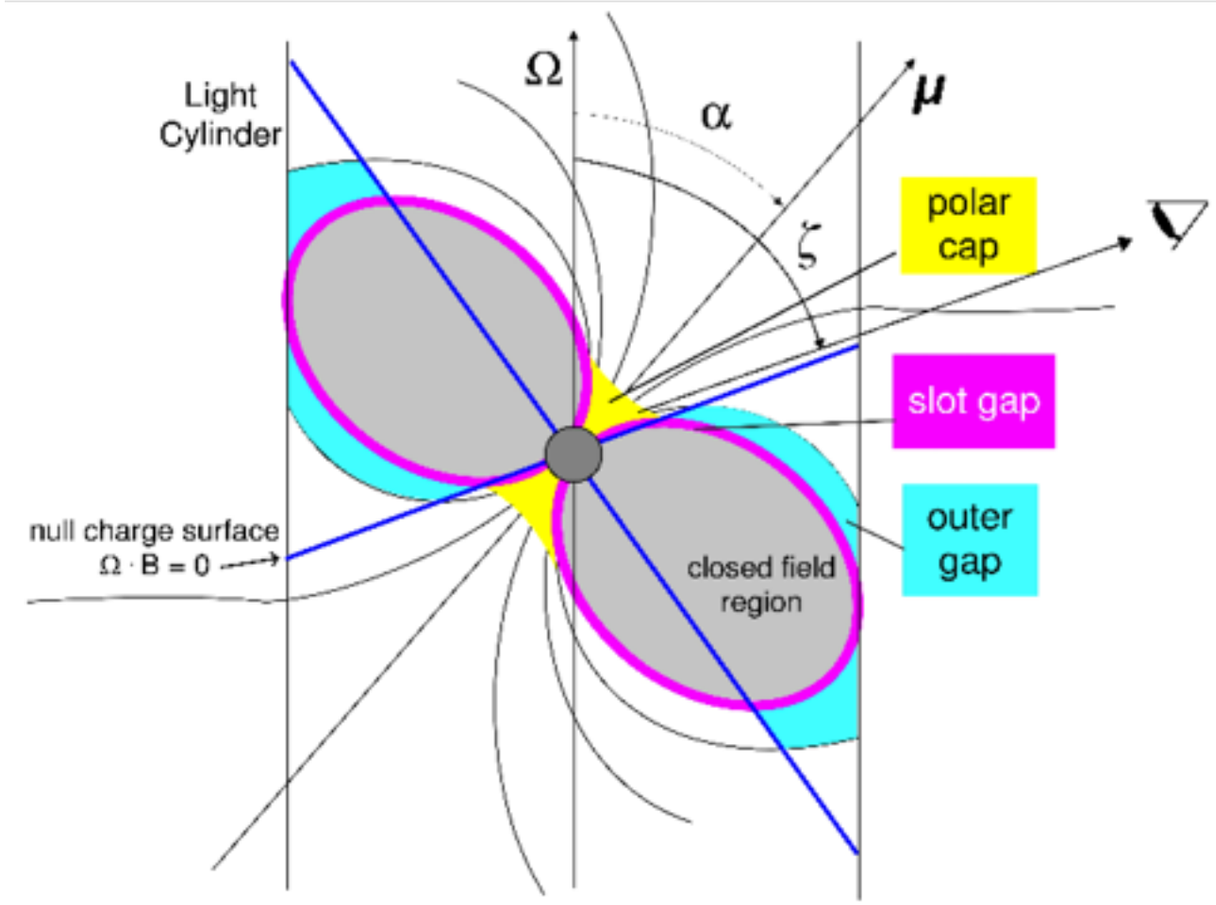
But we do see a pulsed component way above!



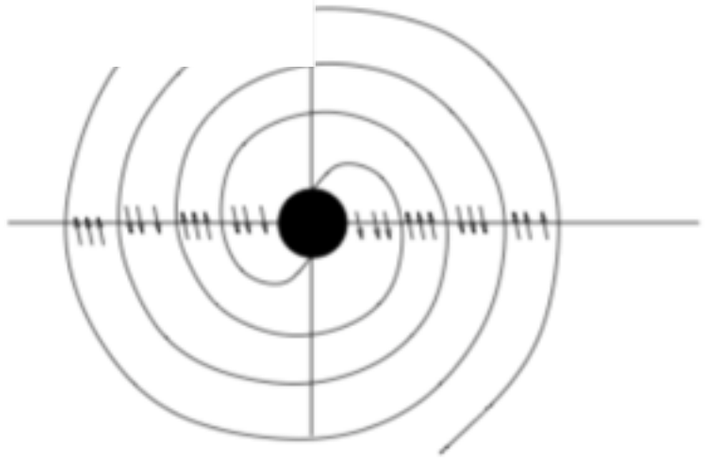
> 3 TeV: 5.3σ
> 7 TeV: 5.6σ

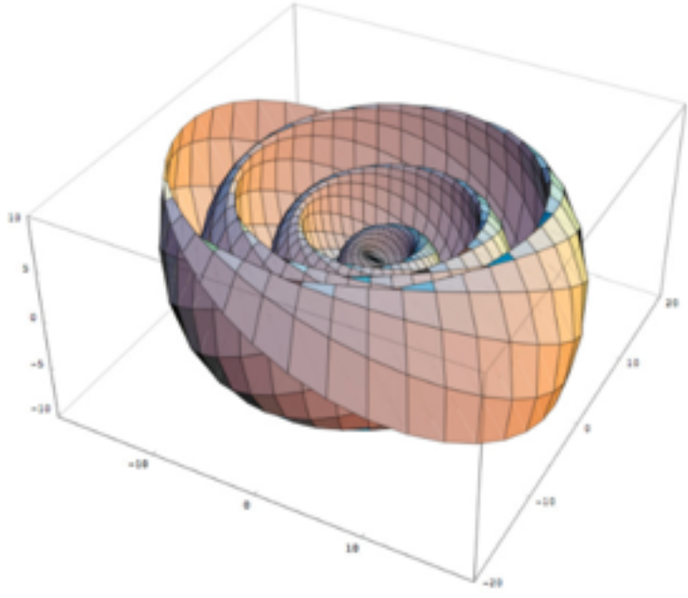
Very unexpected component at the TeV !

Different models for the pulsed emission



- Different models to explain **acceleration and emission** of these particles
- Different regions **inside and outside of the light cylinder**
- Different **processes** implicated

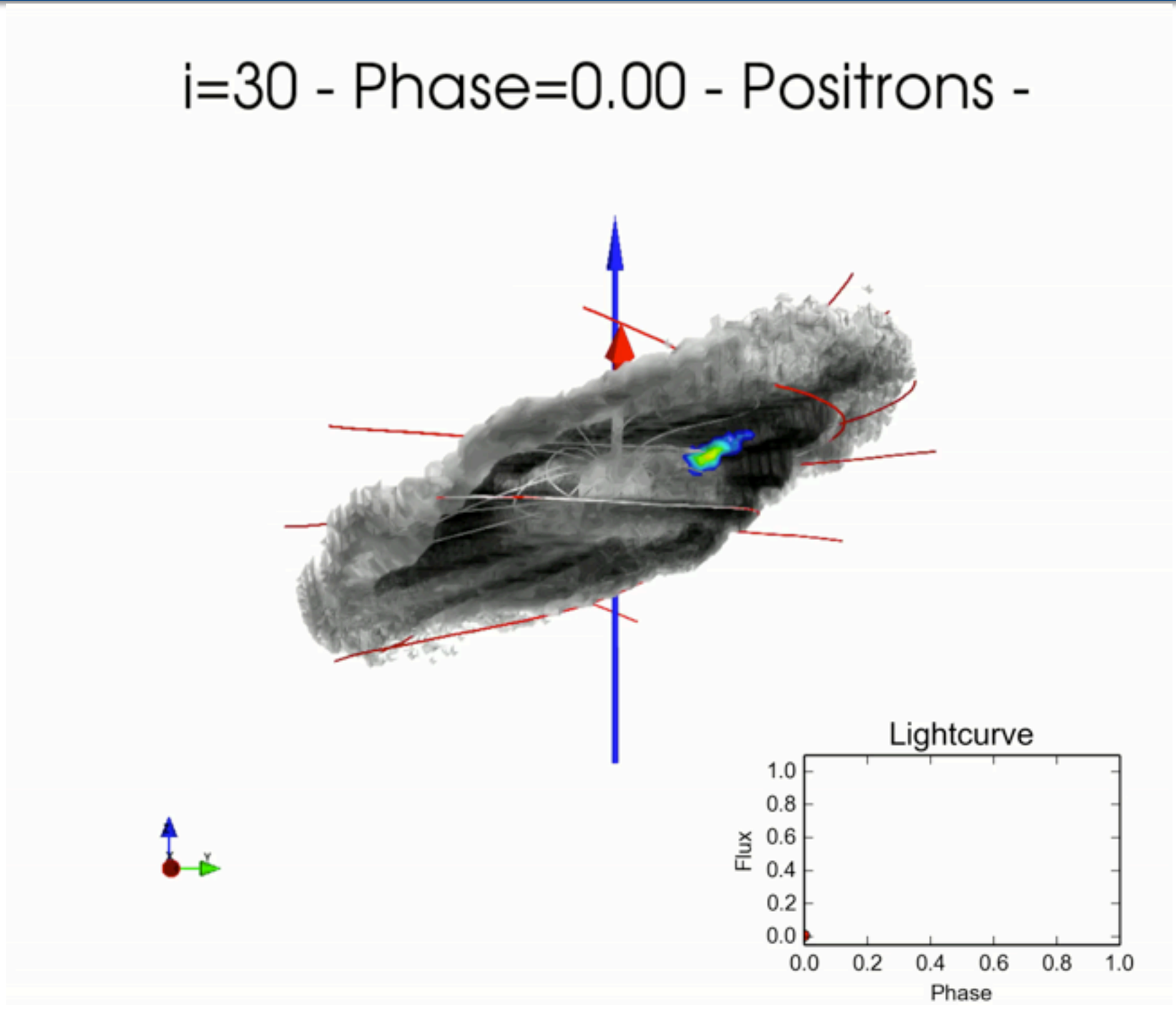




Model of the relativistic striped wind

Particle-in-cell, Benoît Cerutti

- Alleviate difficulties of pulsar modeling through **simulations**
- Starting from **physical principles**
- Solving equations for each cell step by step



My PhD

- **TeV component of Vela pulsar** discovered with an incredibly low number of photons: a **Monte Carlo study** to understand better the behavior of statistical tests at low statistics was needed, also a study on the biases on a spectrum reconstructed with so few events
- **Phenomenology** : can we extend the **striped wind model** to explain this component ?
- Do **other pulsars** have a similar component ?

Thank you !