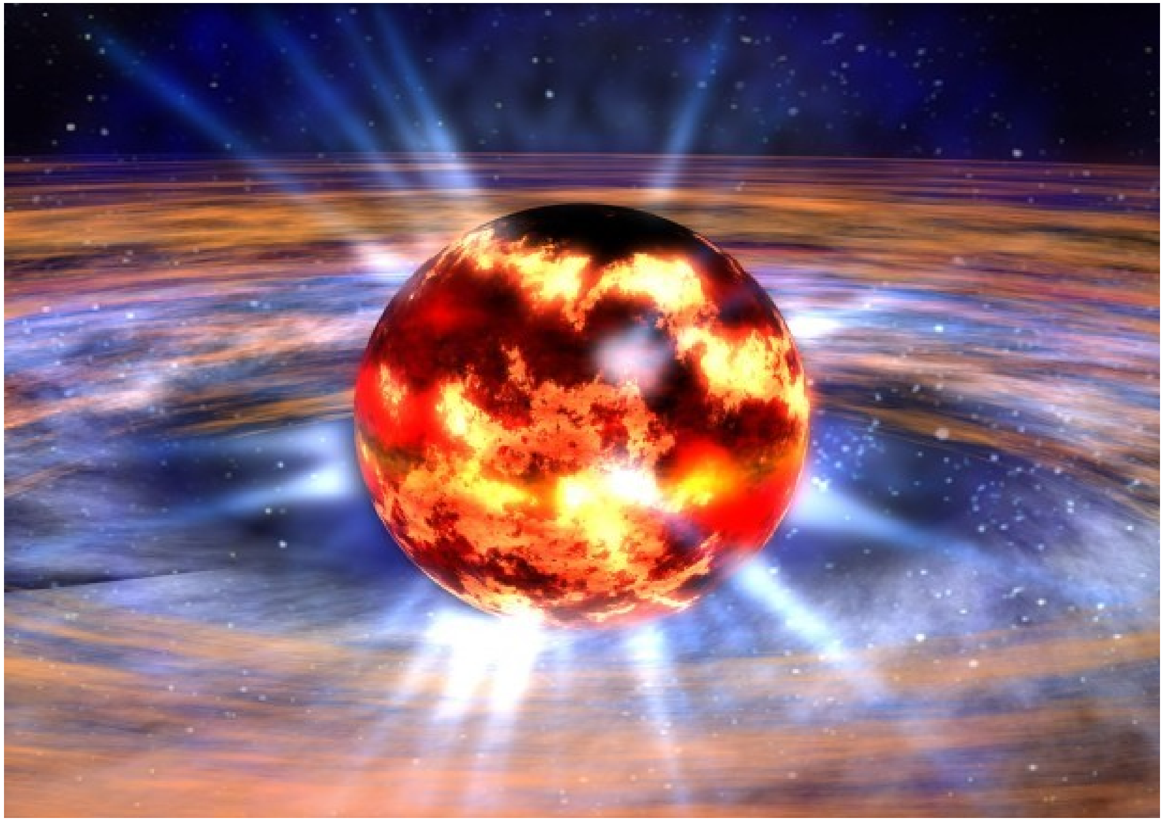
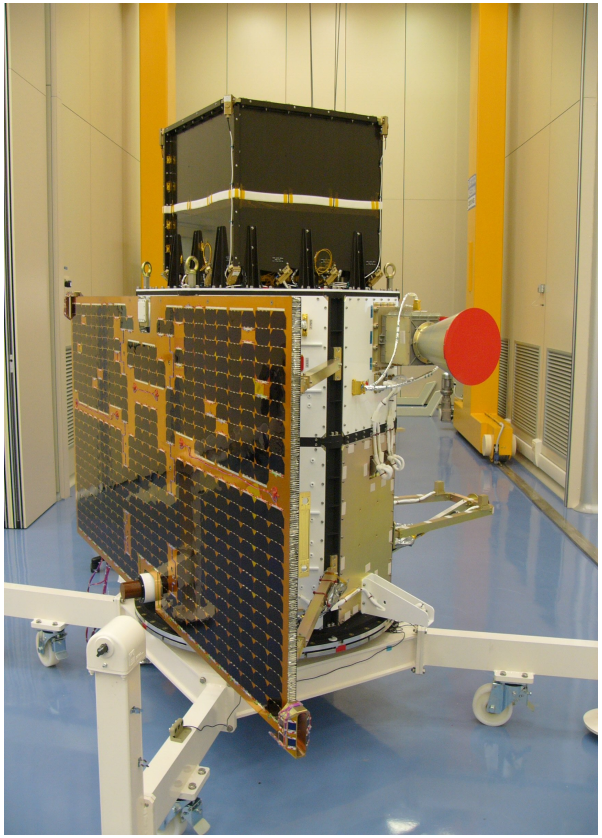
Observations of "Soft" Gamma-Ray Pulsars with AGILE

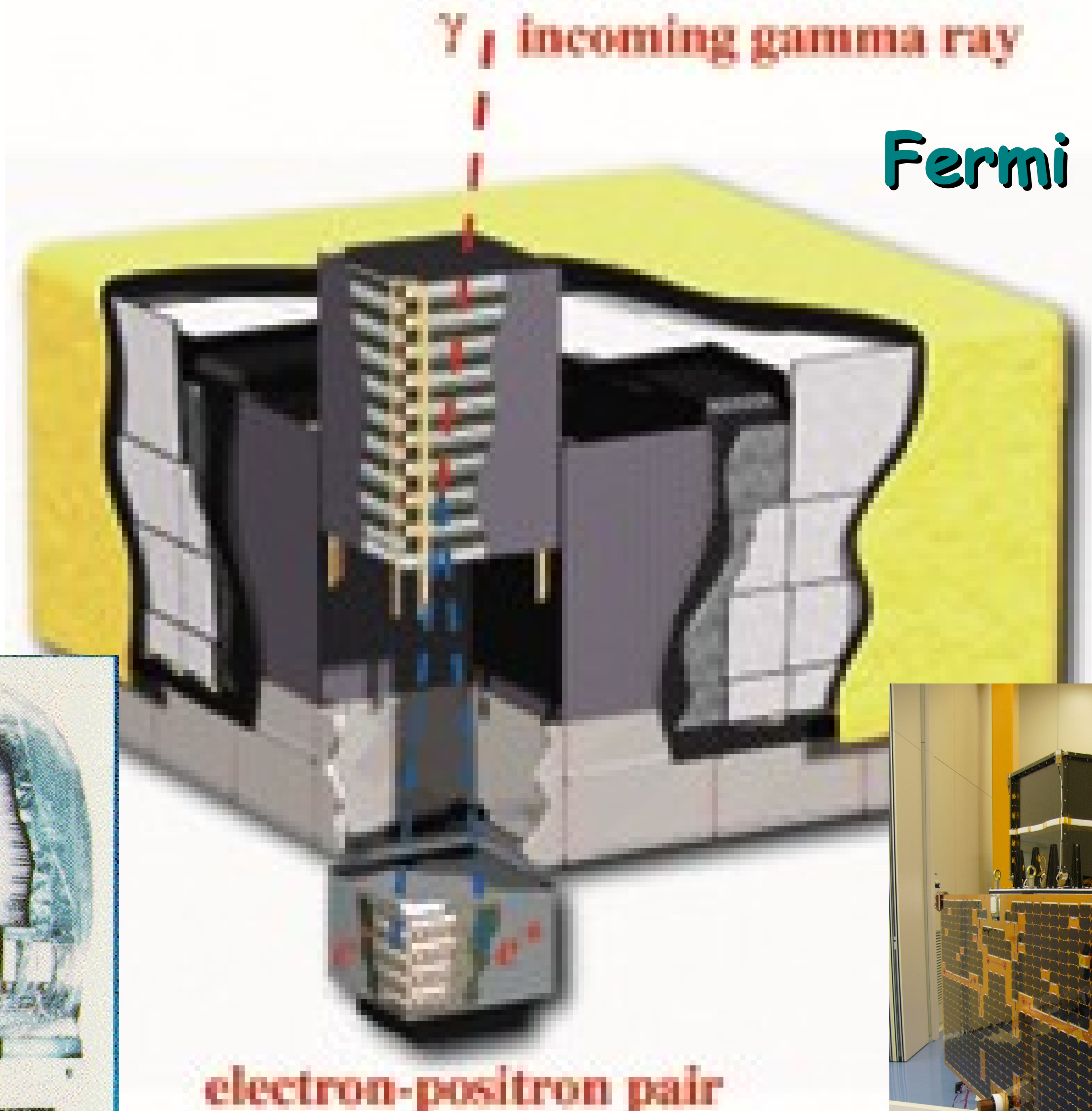




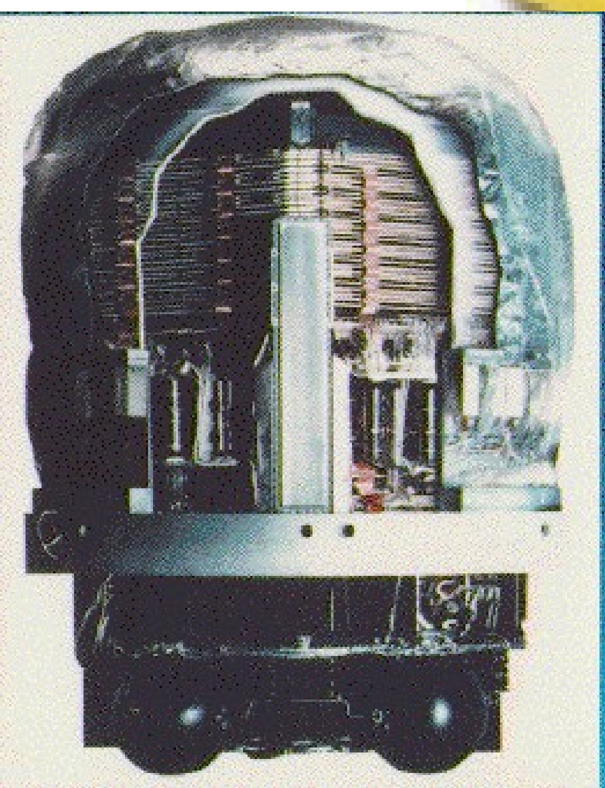
Maura Pilia
on behalf of the AGILE Pulsar WG

AGILE 9th Workshop - Roma, 16th April 2012

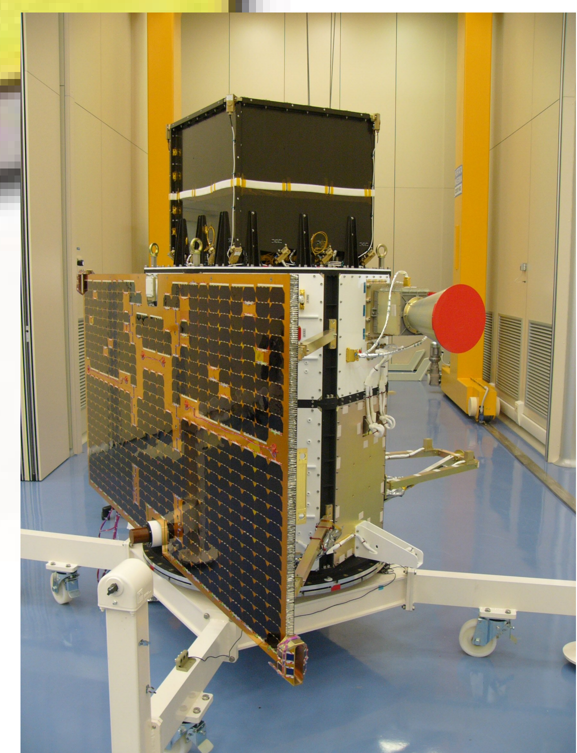
Fermi



EGRET



AGILE

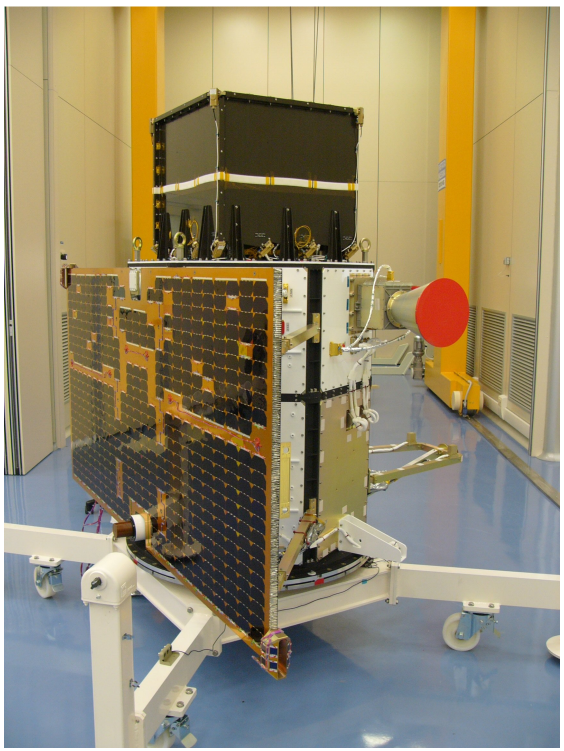


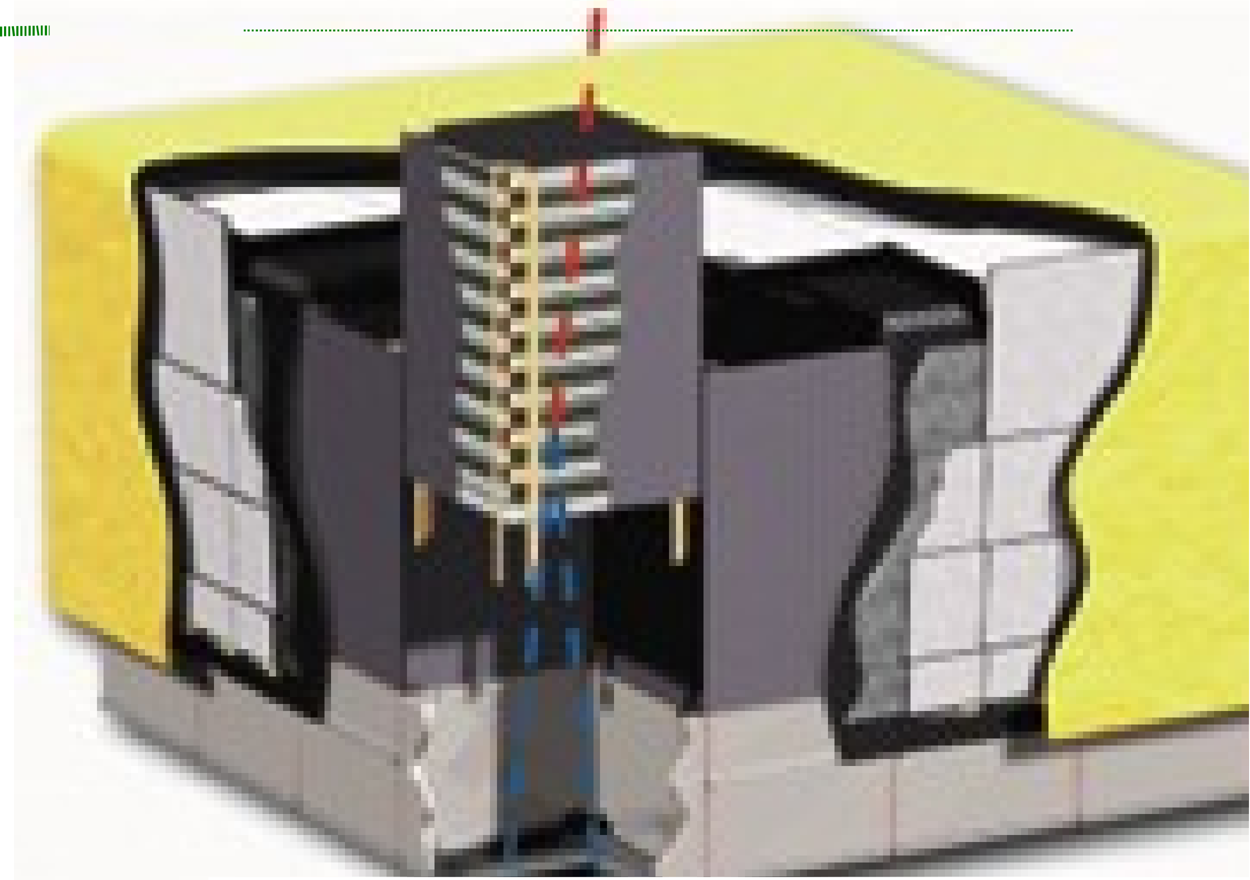
AGILE

Fermi

20 MeV – 50 GeV

20 MeV – **300 GeV**





In the 30-100 MeV AGILE sensitivity is competitive (500 cm^2 eff. Area for timing).

The 1 GeV Fermi sensitivity is much better than the AGILE one.

New Gamma-Ray Pulsars

Pellizzoni et al., 2009b

J2229+6114, J2021+3651, …: Vela-like

B1509-58 : High B pulsar

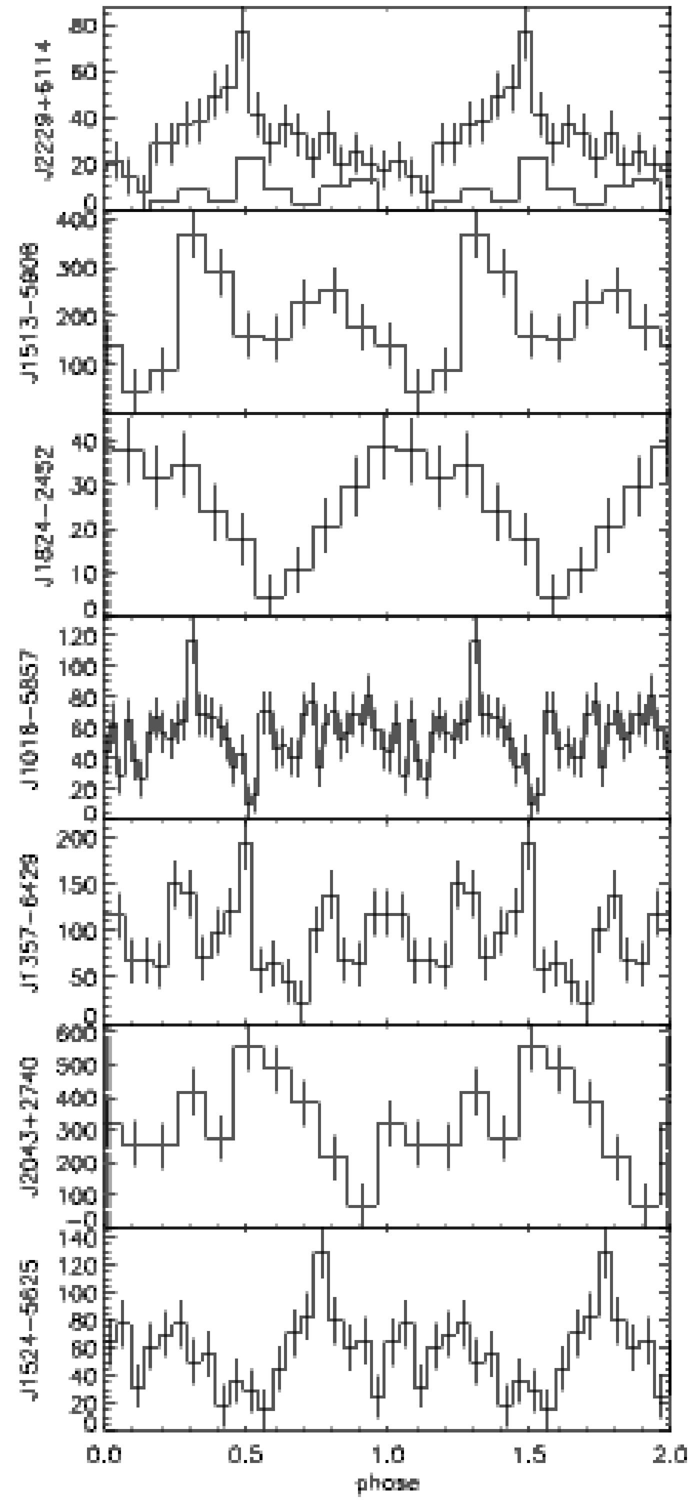
B1821-24: ms PSR in Globular Cluster

J1016-5857: possibly 3EG source

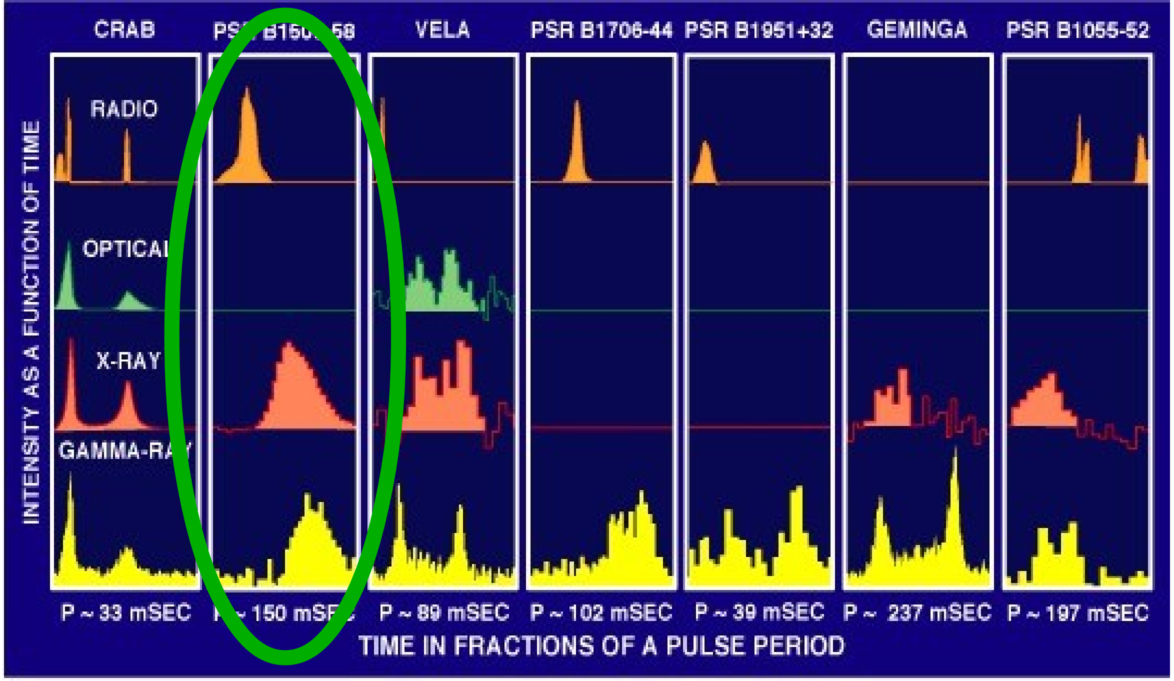
J1357-6429

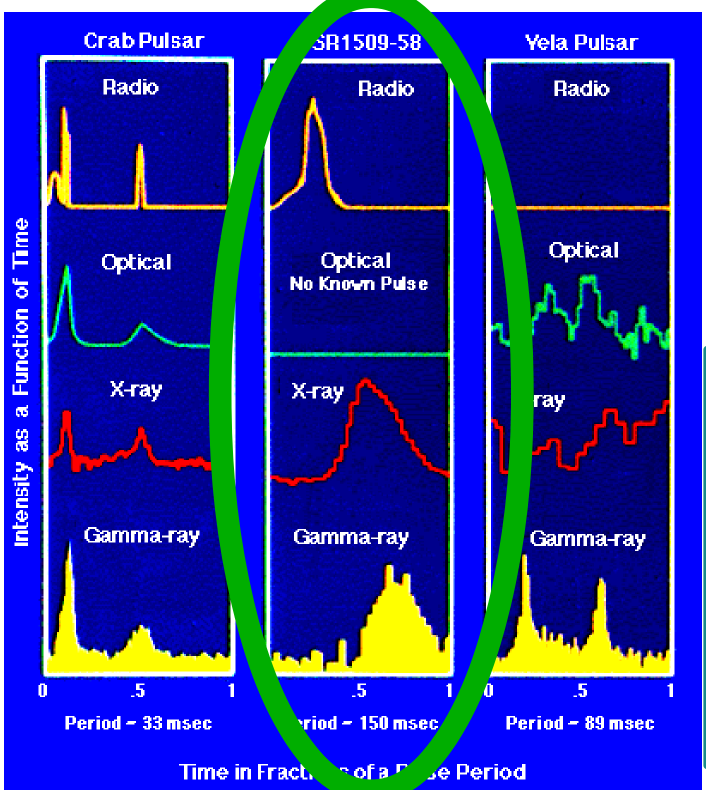
J2043+2740: oldest gamma-ray pulsar

J1524-5625



PSR B1509-58





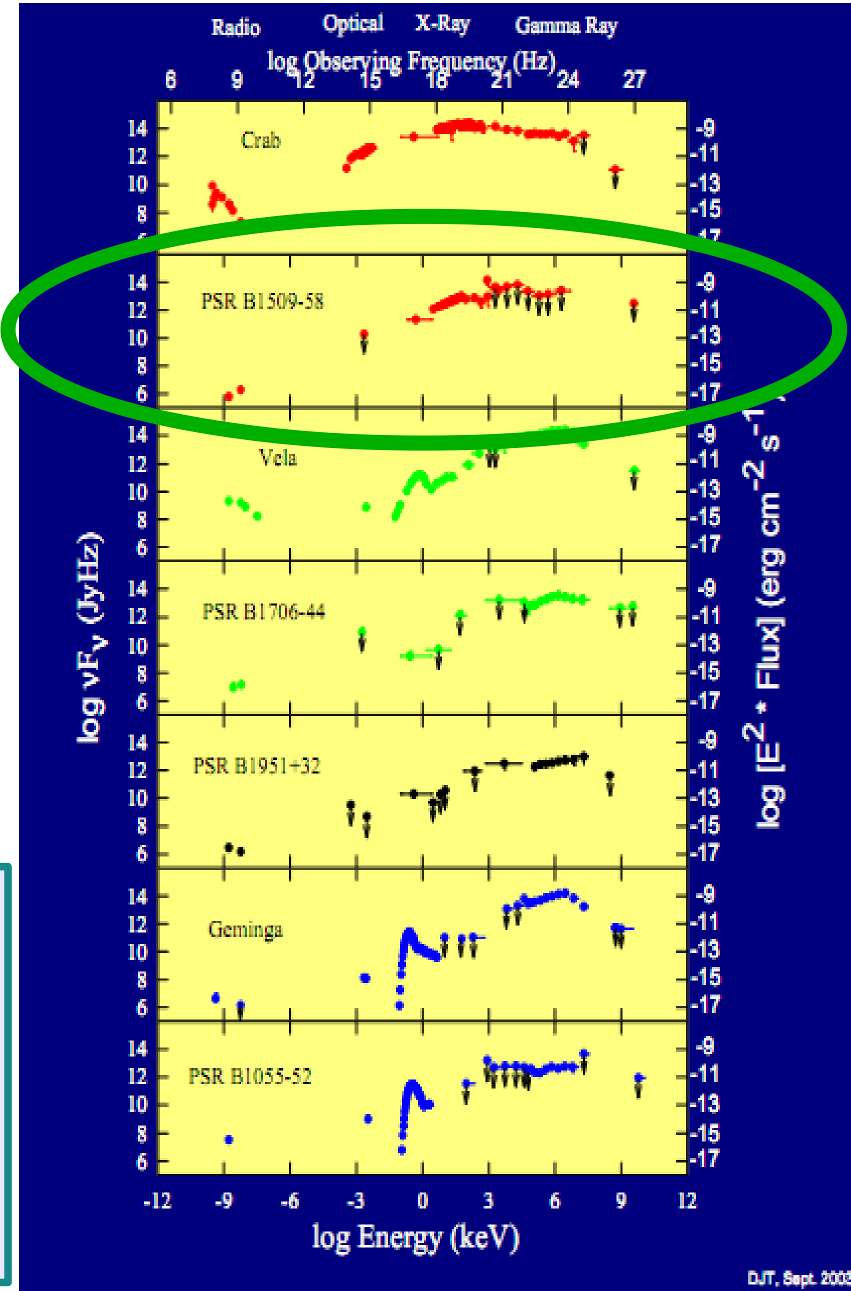
$$P \simeq 150\, ms$$

$$\dot{P} \simeq 1.53 \times 10^{-12}\, s\, s^{-1}$$

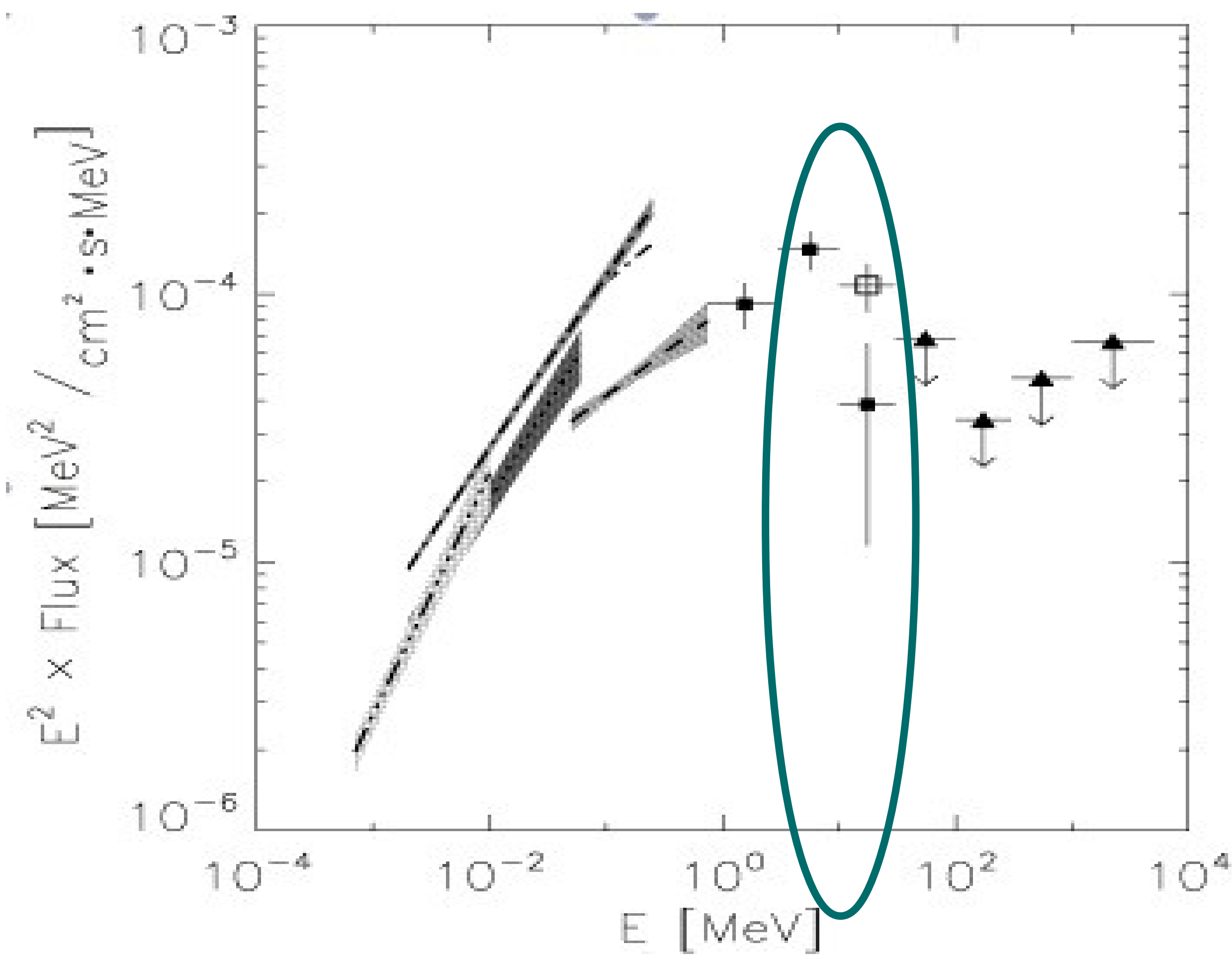
$$\tau_{sd} \approx 1570\, yrs$$

$$\dot{E} \approx 1.8 \times 10^{37}\, erg\, s^{-1}$$

$$B \approx 3.1 \times 10^{13}\, G$$

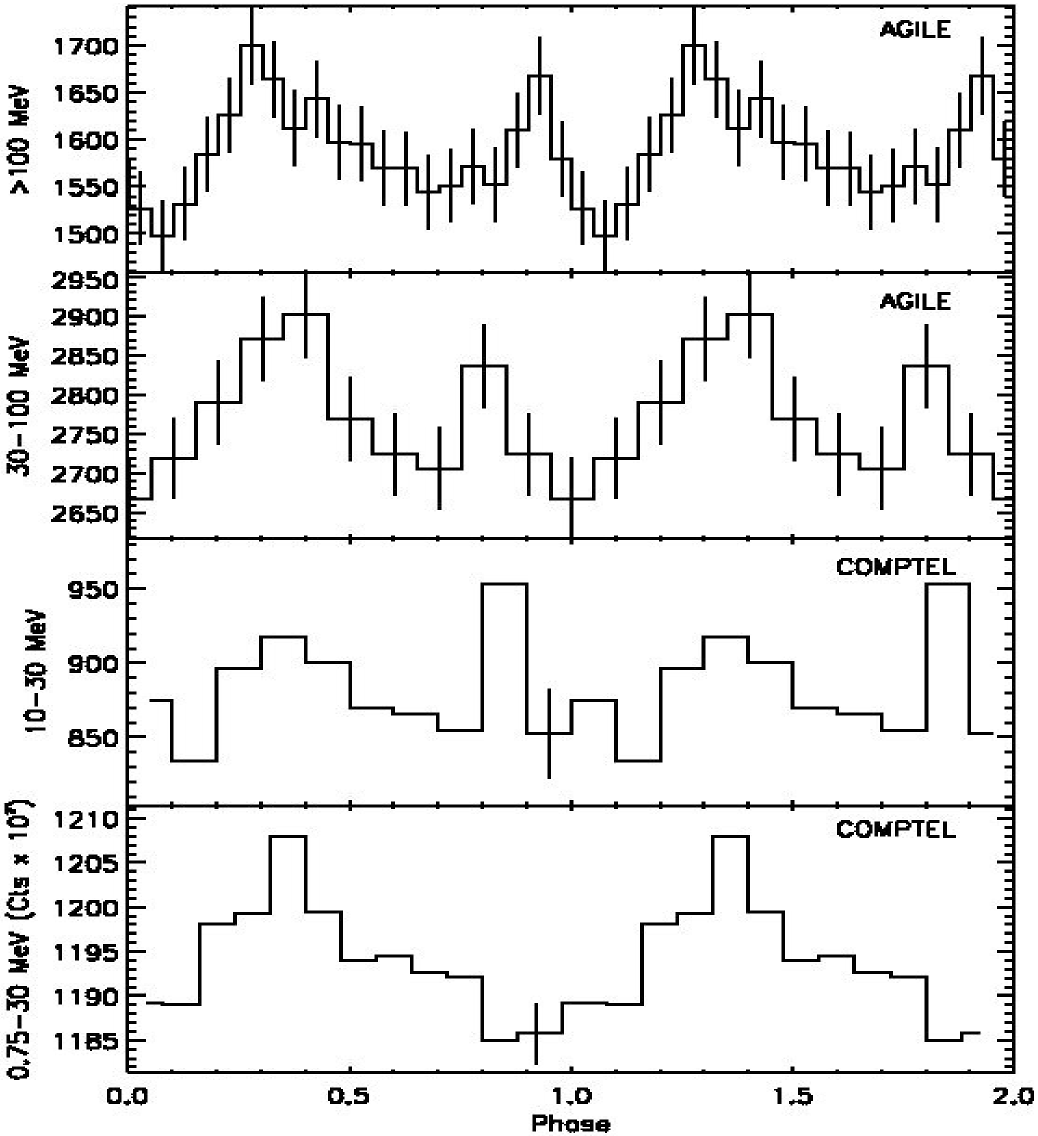


PSR B1509-58 with Comptel



Kuiper et al. 1999

PSR B1509-58 with AGILE (1)



Pellizzoni et al. ApJ, 695, L115, 2009

Pilia et al. ApJ, 723, 707, 2010

Detection of PSR B1509−58 and its pulsar wind nebula in MSH 15−52 using *Fermi* - LAT 5

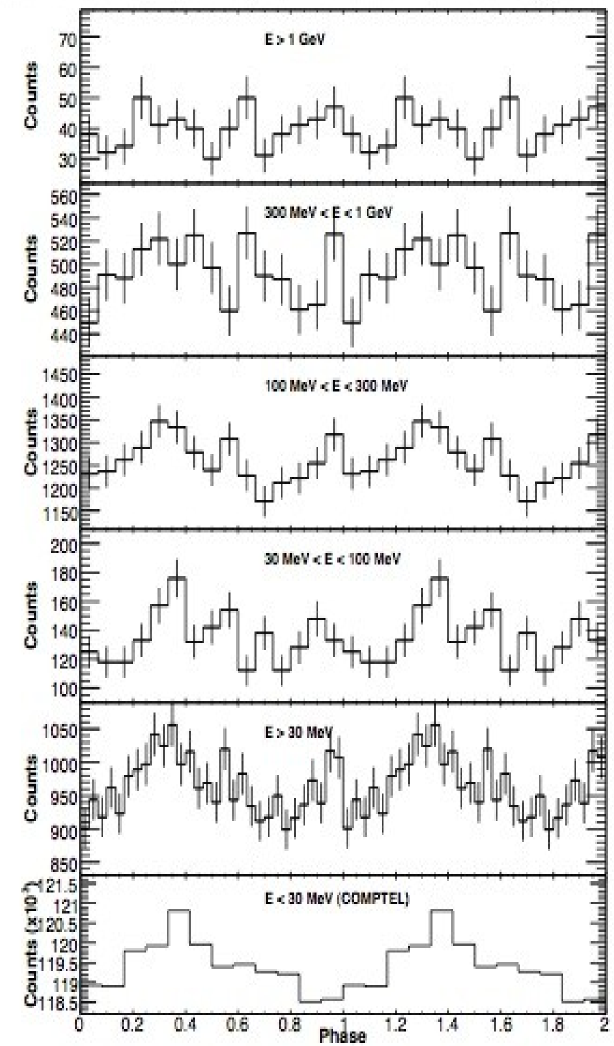
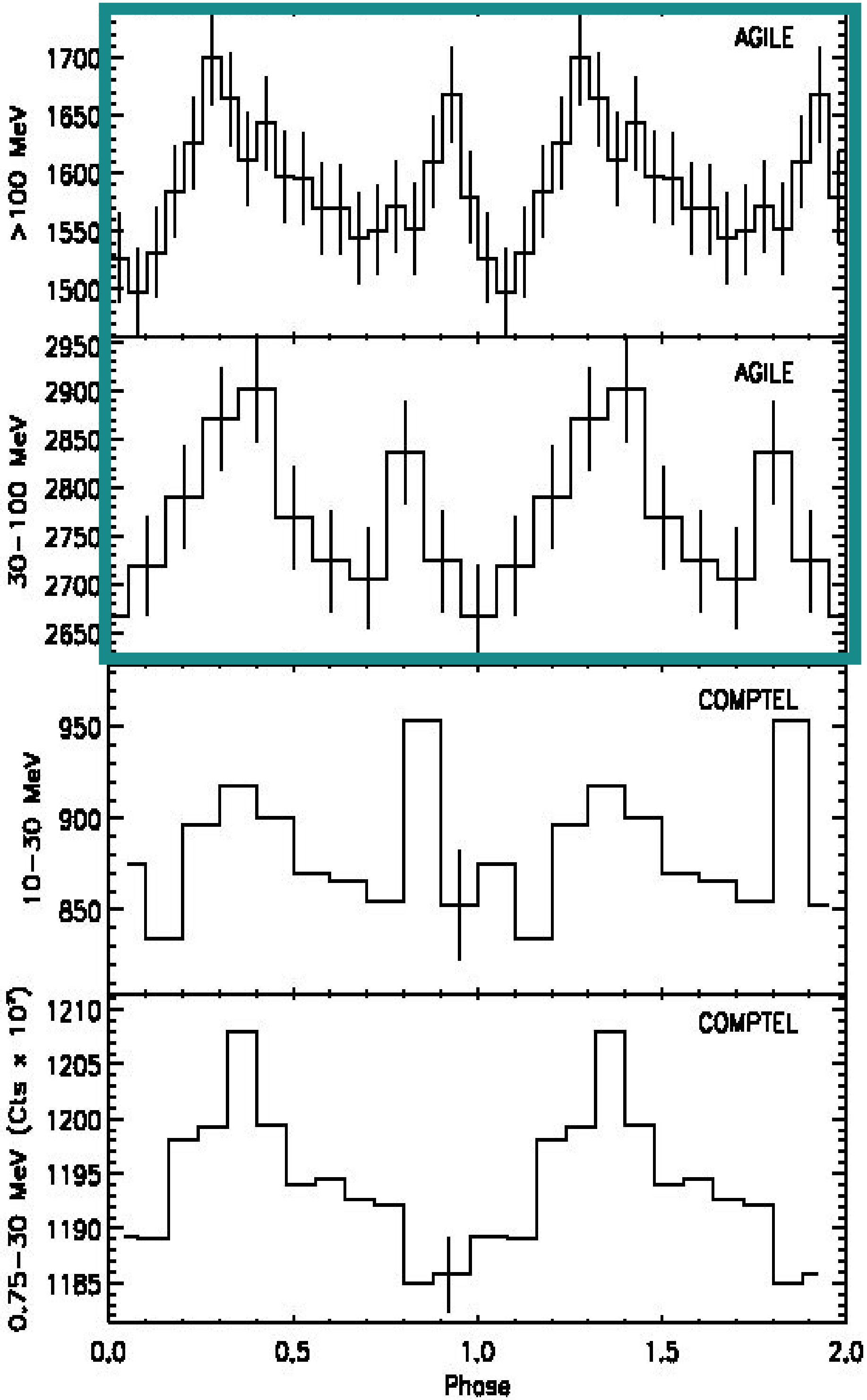


FIG. 2.— Light curves of the pulsar PSR B1509−58 in different energy bands within a circular region of energy-dependent radius. From bottom to the top: COMPTEL (0.75 – 30 MeV; Kuiper et al. 1999) and LAT profiles in 30 MeV–300 GeV, 30 MeV–100 MeV, 100 MeV–300 MeV, 300 MeV–1 GeV, 1 GeV–300 GeV energy bands are presented. Two cycles are shown.

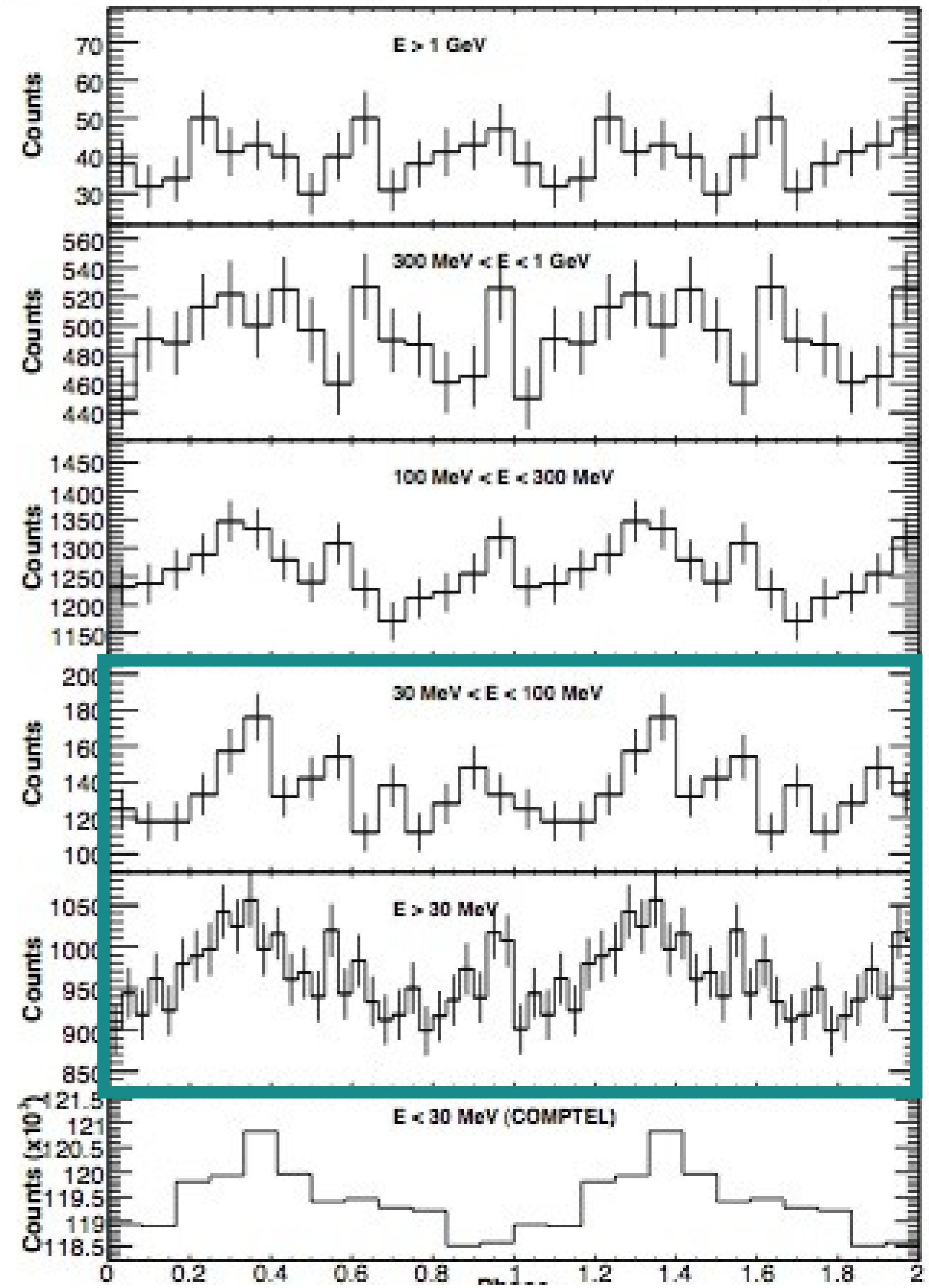
Abdo et al. ApJ, 714, 927, 2010

The "soft" ᵞ-pulsar B1509-58



AGILE (Pilia et al. 2010)

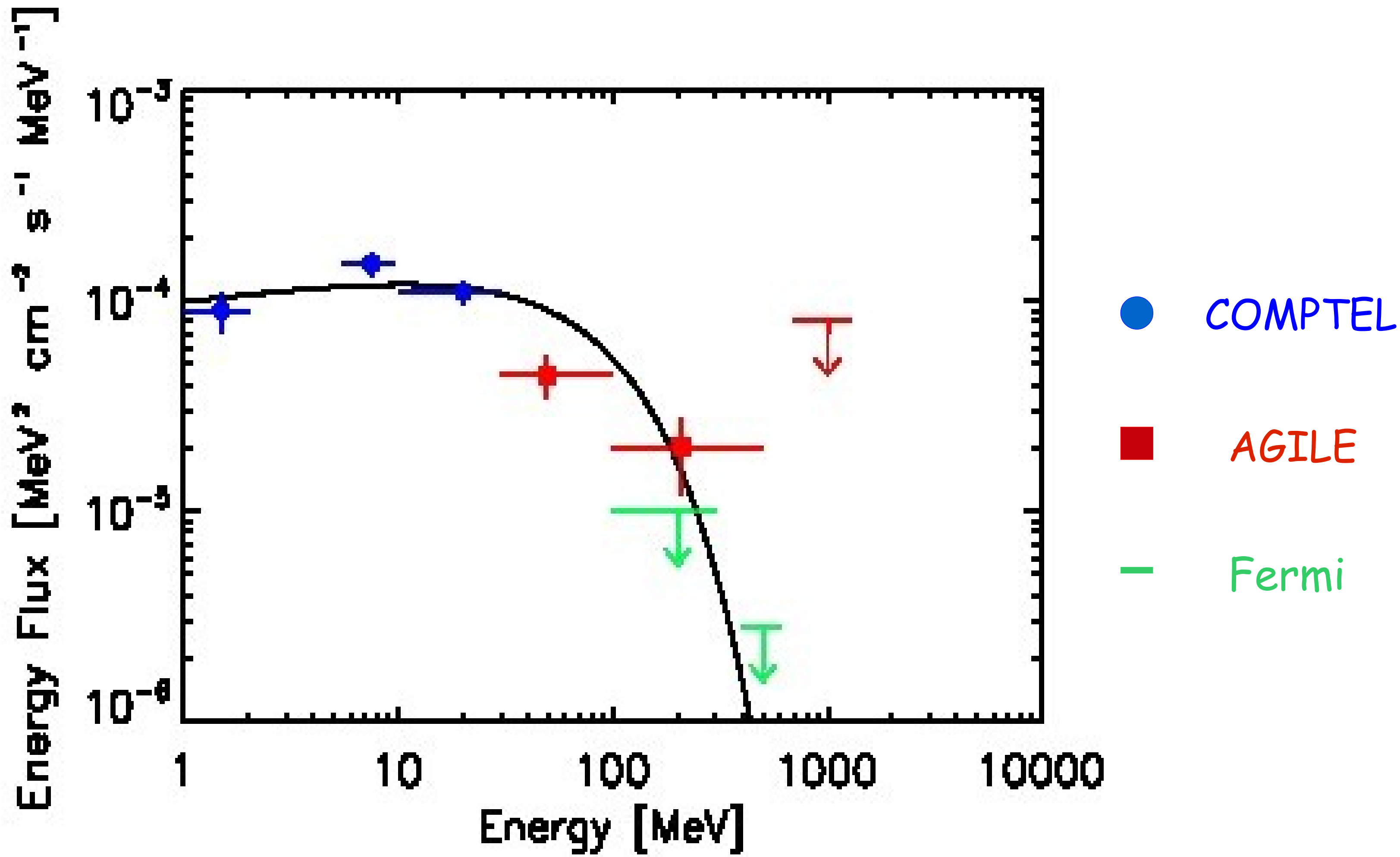
Detection of PSR B1509−58 and its pulsar wind nebula in MSH 15−52 using *Fermi* - LAT



Fermi (Abdo et al. 2010)

ight curves of the pulsar PSR B1509−58 in different energy bands within a circular region of energy-dependent radii

PSR B1509-58 with AGILE (2)



Pilia et al. 2010

Polar Cap - Photon Splitting

Harding, Baring & Gonthier 1997

- Third order QED process

- Forbidden in vacuum

- For $B \leqslant B_{cr}$ ($B_{B1509} = 3.1 \times 10^{13}\, G$) it takes place BEFORE the threshold for pair production

- $\gamma \rightarrow \gamma\,\gamma$ so that high energy emission (> some GeVs) is inhibited

Photon Splitting - Pair Production

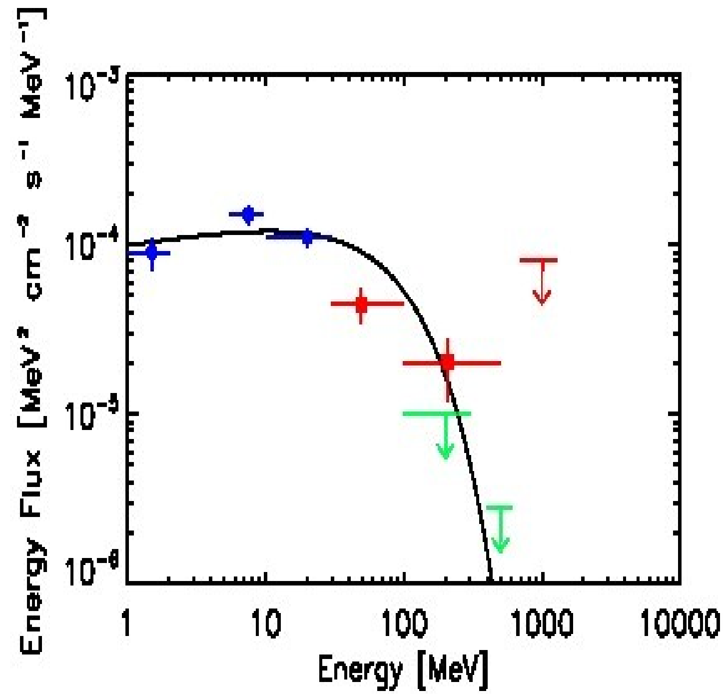
$$F(E) \propto E^{-\alpha} \exp[-(E/E_C)]$$

$$\alpha = 1.87 \pm 0.09$$

$$\epsilon_{esc}^{sat} \simeq 0.077 \left(B' \sin\theta_{kB}, 0\right)^{-6/5}$$

$$B' = B/B_{cr}$$

$_{kB}$ = angle between the photon momentum and the magnetic field vectors

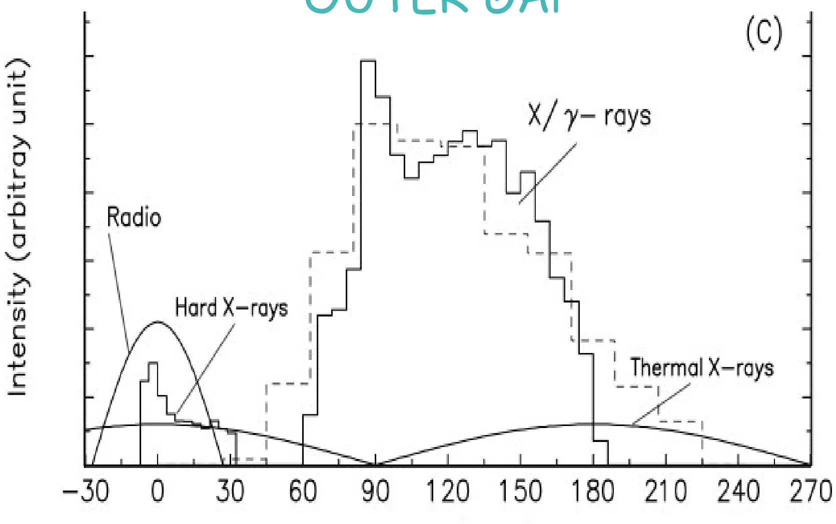


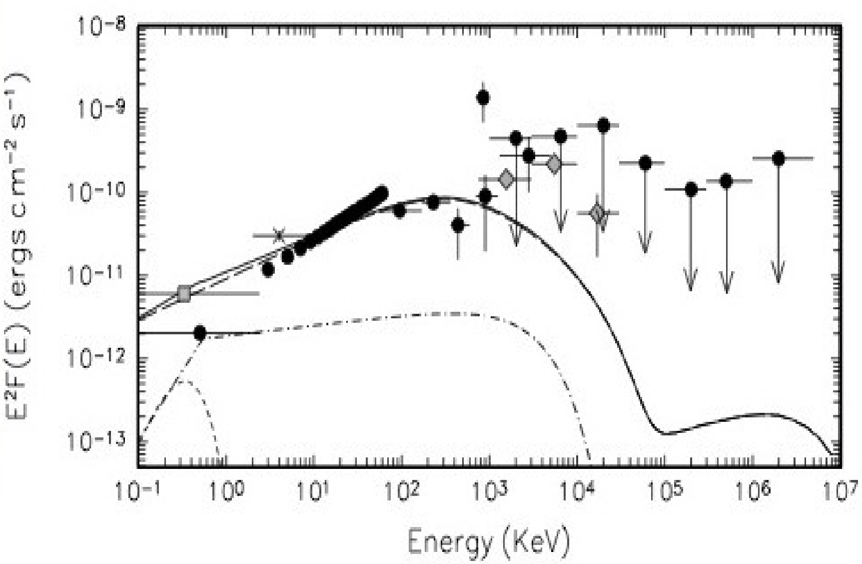
Pilia et al. 2010

- Given the observed cutoff energy ($E_C = 81 \pm 20\ MeV$), the corresponding magnetic field is $B' = 0.3$. This implies emission at height $h \simeq 1.3\, R_{NS}$ above the PC, where the pair production ensues.

Alternative scenarios

OUTER GAP





Zhang & Cheng 2000

$\alpha \approx 60°$ $\zeta \approx 75°$

TWO POLE CAUSTIC GAP

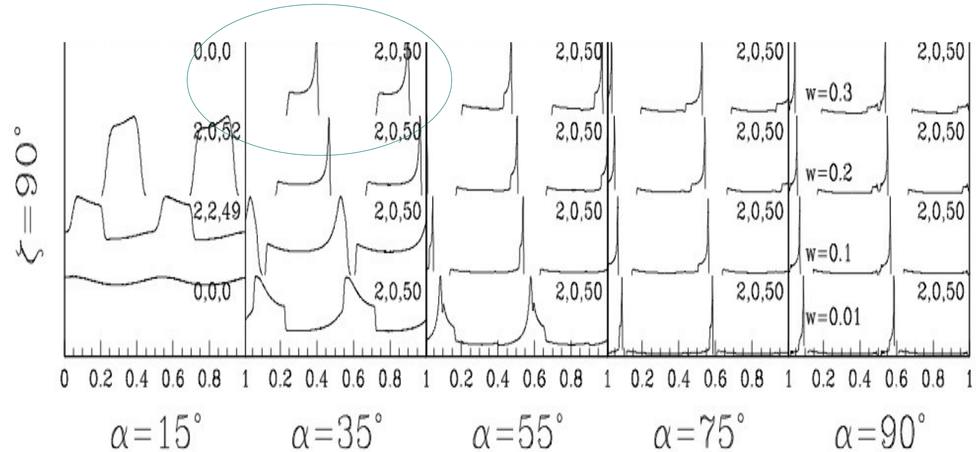


FIG. 9.— Collection of sample light curves for the TPC model. Four select w (values in bottom right panel) are shown for each panel; the radio pole has closest approach at phase=0. The values for the number of all peaks, the number of broad peaks and the maximum peak separation (in %) are indicated by each curve. Intensities are normalized to pulse maximum.

Watters et al. 2009

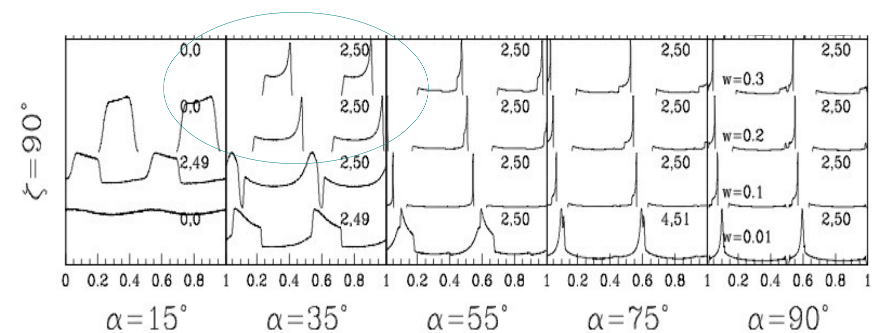


FIG. 14.— Light curves for the Two Pole Caustic (TPC) model. Each panel shows curves for four values of the gap width w. The curves are labeled with the number of major peaks and the peak separation, in percent.

Romani & Watters 2010

$\alpha \approx 35°$ $\zeta \approx 90°$

Geometry Constraints

OUTER GAP		TWO POLE CAUSTIC GAP	
$\alpha \approx 60°$	$\zeta \approx 75°$	$\alpha \approx 35°$	$\zeta \approx 90°$

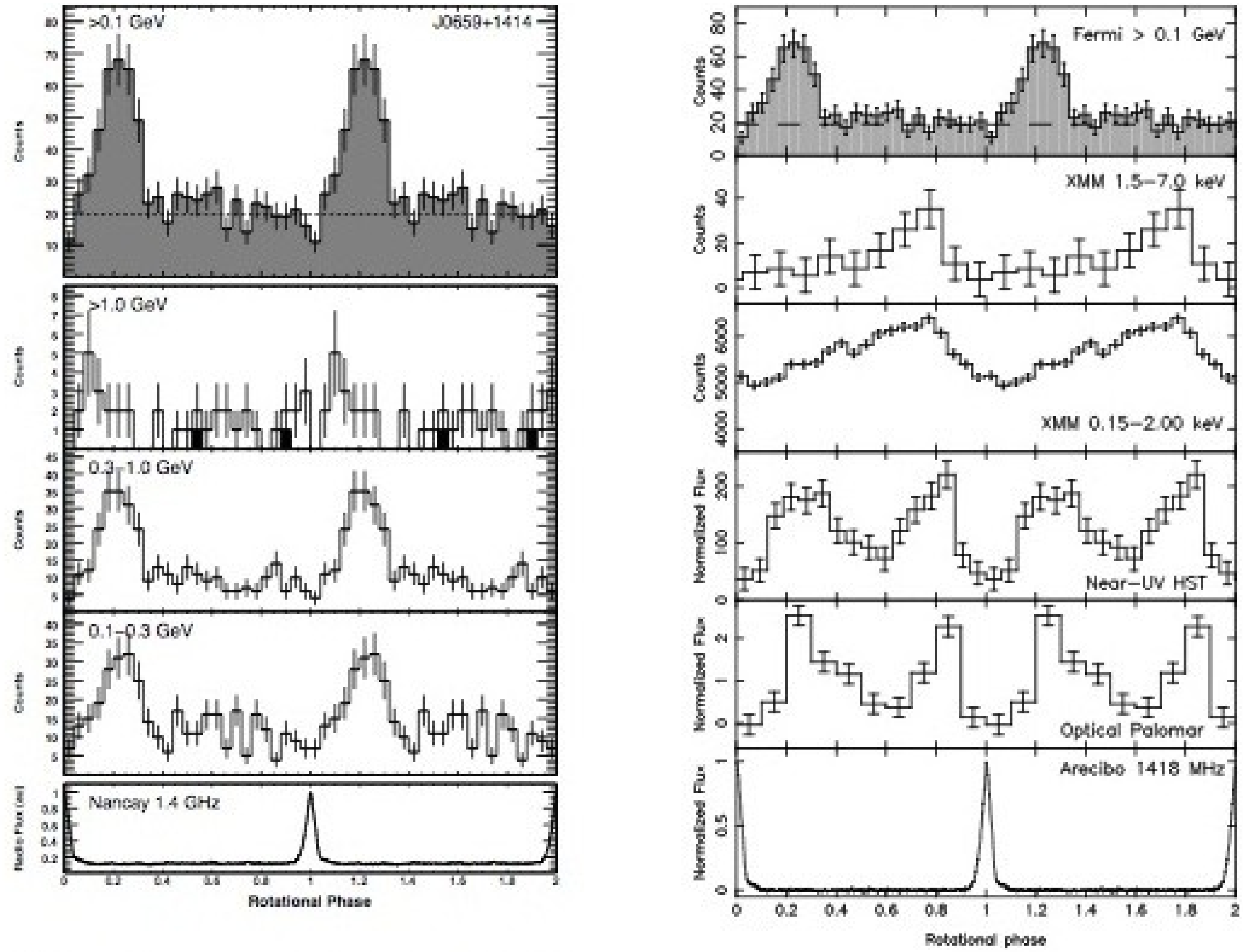
α = magnetic inclination
ζ = viewing angle

- $\alpha < 60°$ at the 3σ confidence level (Crawford et al. 2001)

- If $\zeta > 70°$ (Melatos 1997) then $\alpha > 30°$ at the 3σ level

- For these values, however, the Melatos model for the spin down of an oblique rotator predicts a braking index $n > 2.86$ slightly inconsistent with the observed value $n = 2.839(3)$ (Livingstone et al. 2005)

A Similar Case: PSR B0656+14



$$E_C = 700\, MeV$$

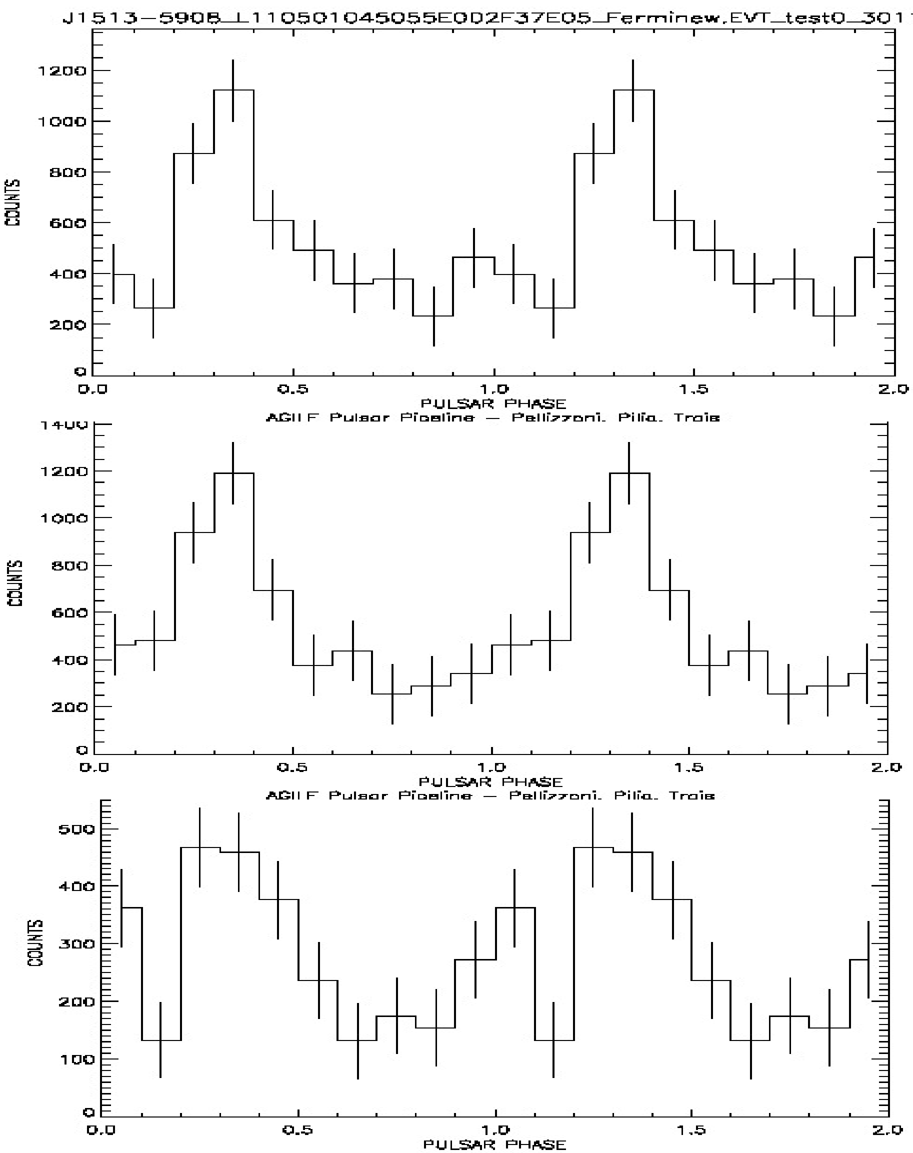
Weltevrede et al. 2010

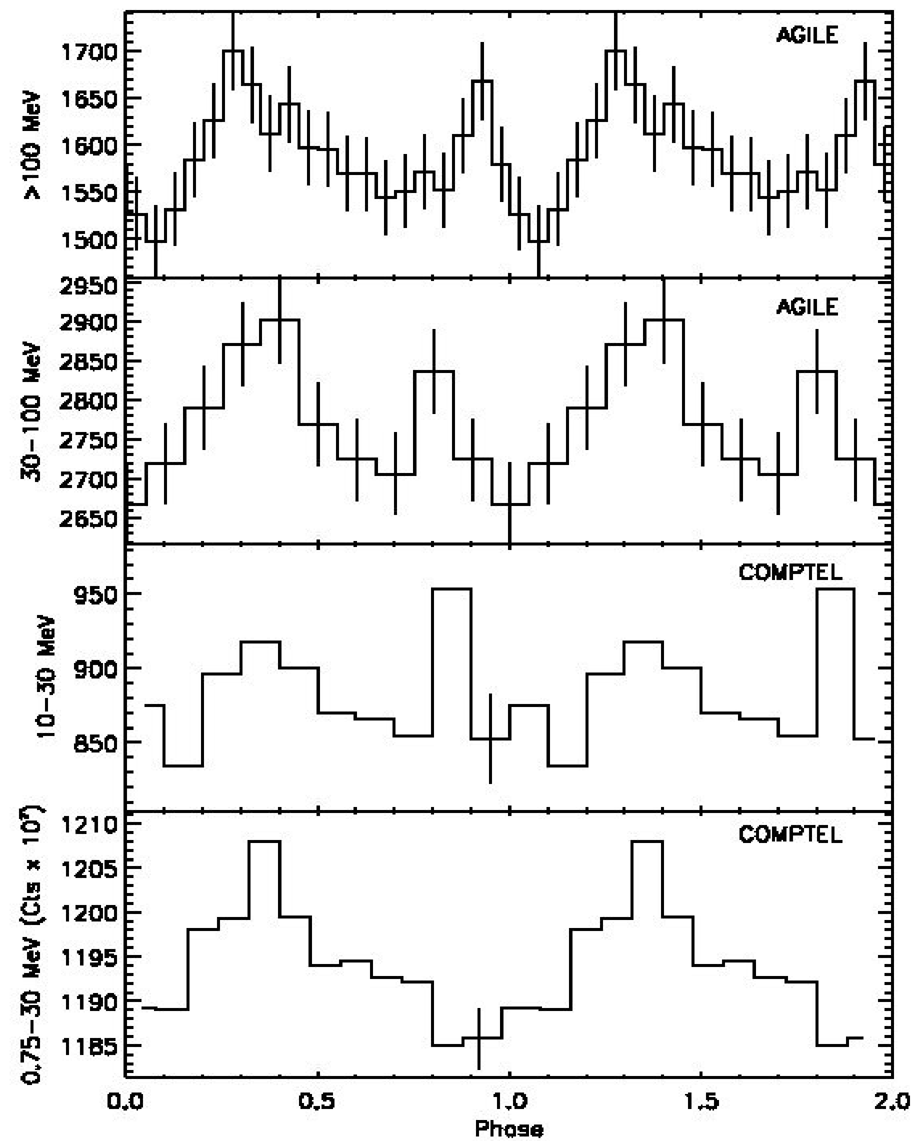
New Results from Fermi

E < 500 MeV

E < 300 MeV

E < 150 MeV





Interpretation

Our observations are compatible with emission from the polar cap regions powered by photon splitting cascades.

This likely inerpretation could represent the first physical measurement ever made related to the QED photon splitting process.

The fact that PC emission at HE appears rare might be explained by the requirement that a number of conditions concur to have low magnetospere emission, e.g. an aligned geometry and high magnetic fields.

New class of "soft" gamma-ray pulsars?

PSR J1846-0258 in SNR Kes 75

$P \simeq 324\,ms$

$\dot{P} \simeq 7 \times 10^{-12}\, s\, s^{-1}$

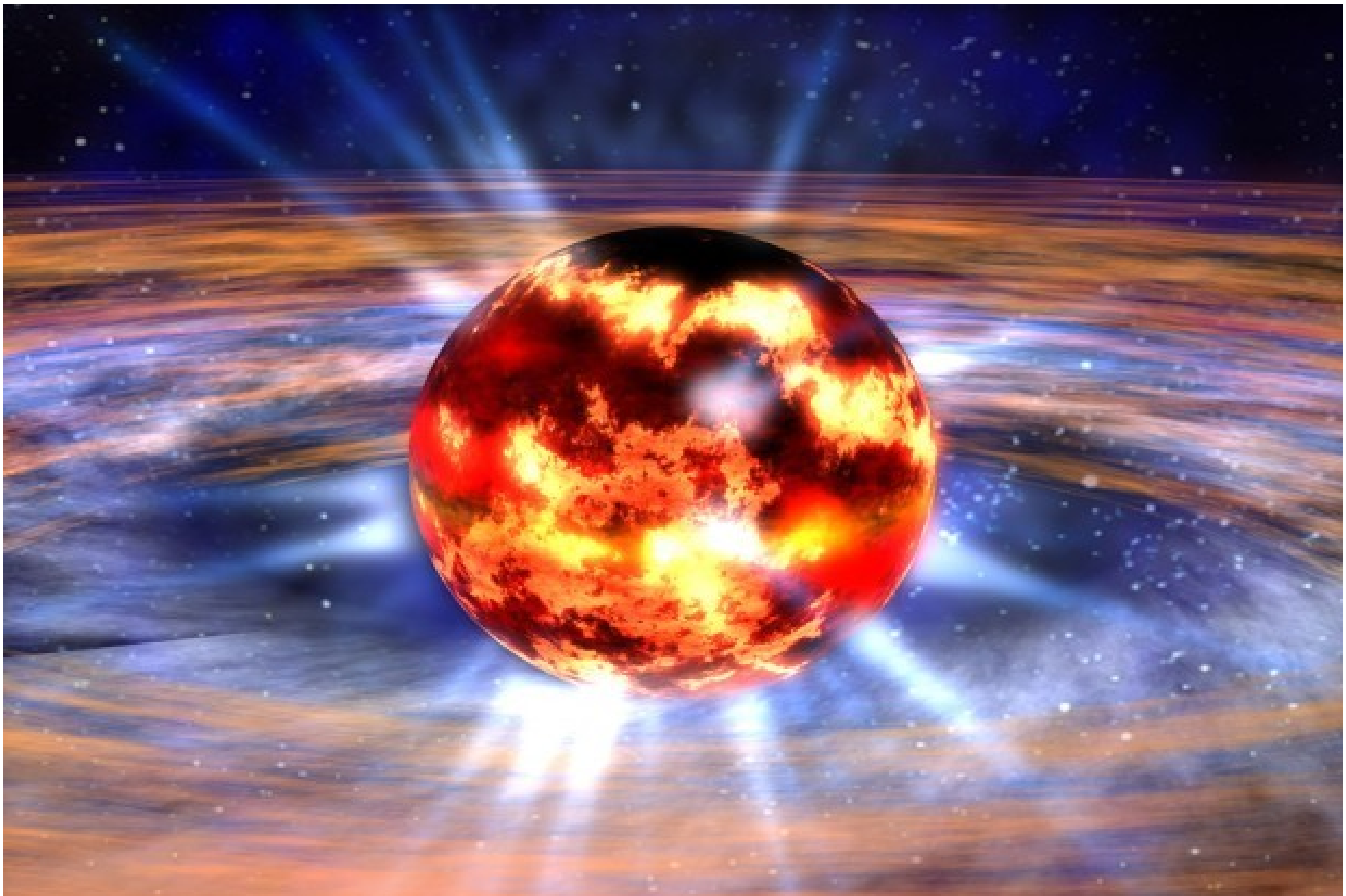
$\tau_{sd} \approx 723\, yrs$

$\dot{E} \approx 8 \times 10^{36}\, erg\, s^{-1}$

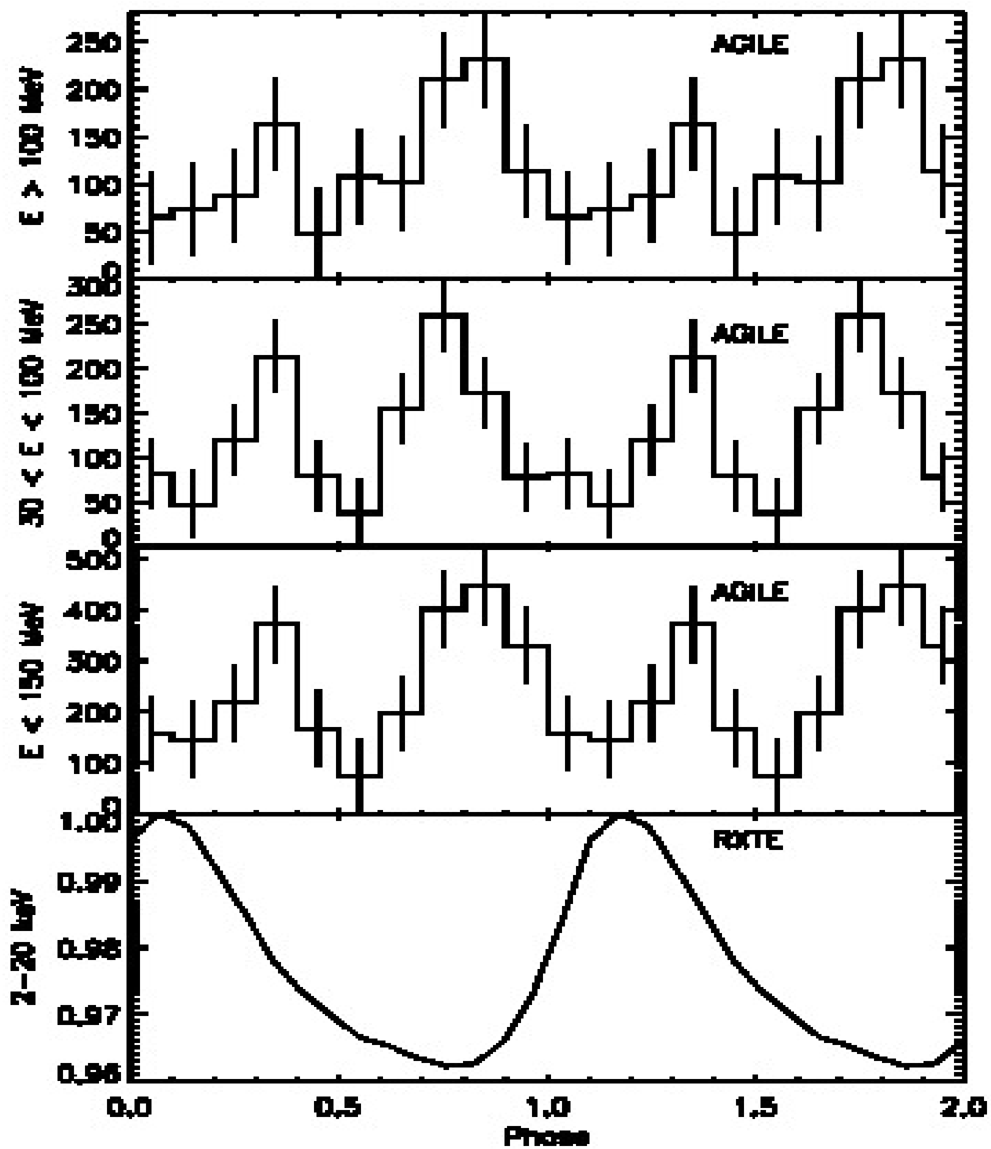
$B \approx 4.9 \times 10^{13}\, G$

B > Bcritical

Pulsar vs Magnetar

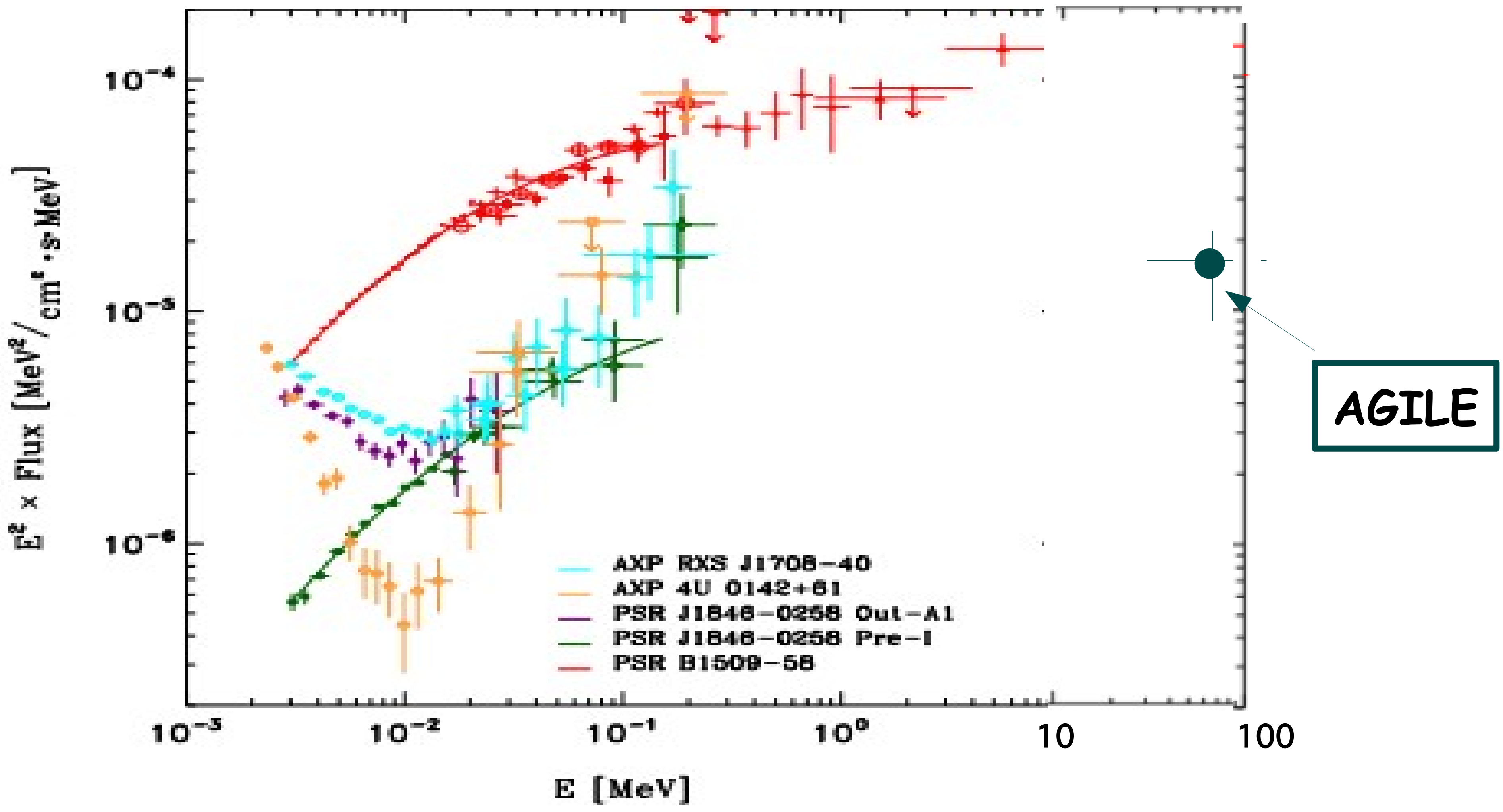


AGILE Observations of PSR J1846-0258



Pilia et al., submitted to ApJ

Spectrum of PSR J1846-0258



Kuiper & Hermsen 2009

Pilia et al., submitted

J1846-0258 vs J1119-6127

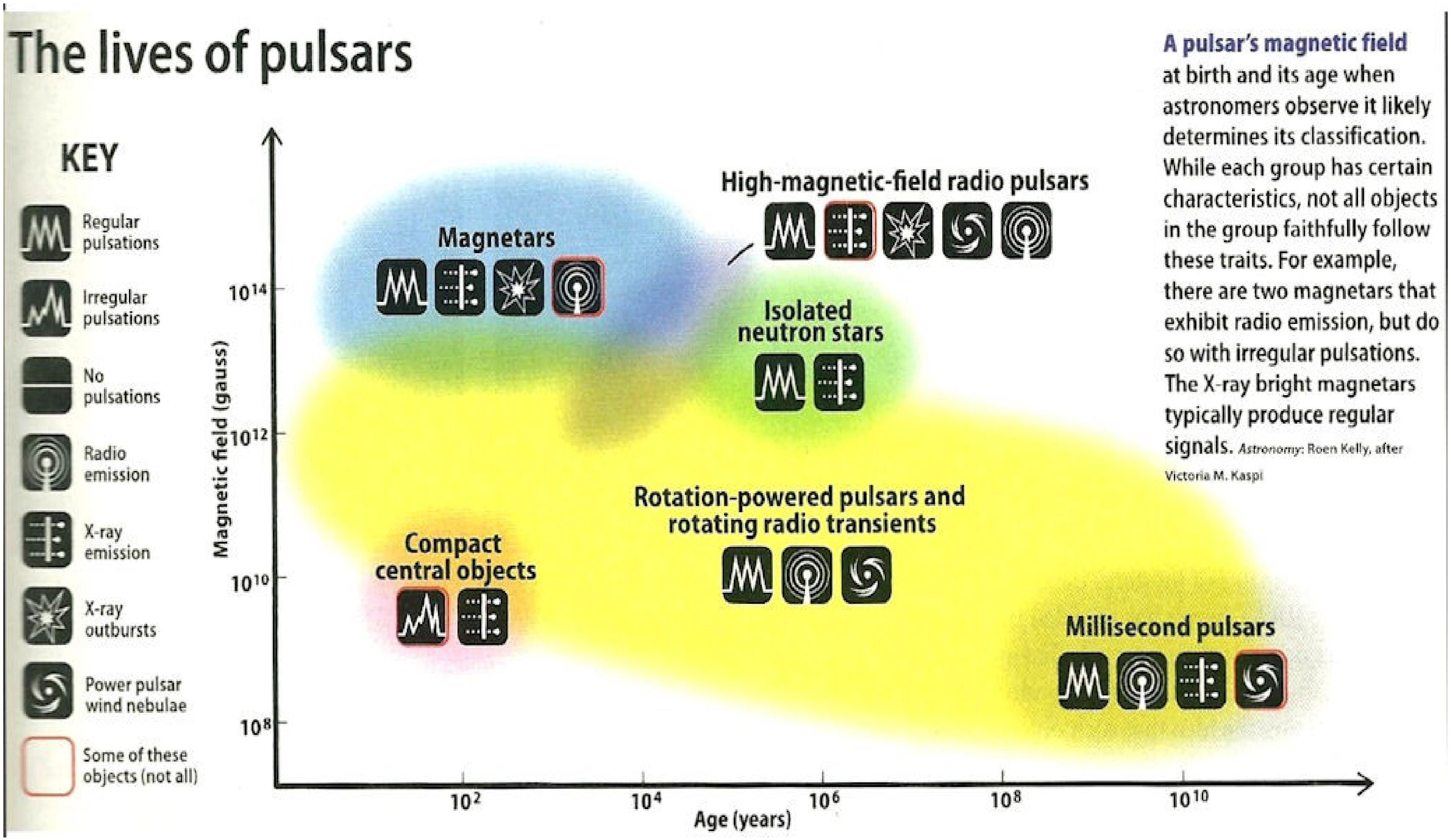
- High B (4.9×10^{13}) G
- E_{cutoff} = 18(6) MeV
- No evidence for geometry
- Best explained by polar cap + photon splitting

Pilia et al. submitted

- High B (7×10^{13}) G
- E_{cutoff} ~ 1 GeV
- Close to orthogonal geometry
- Best explained by outer gap emission

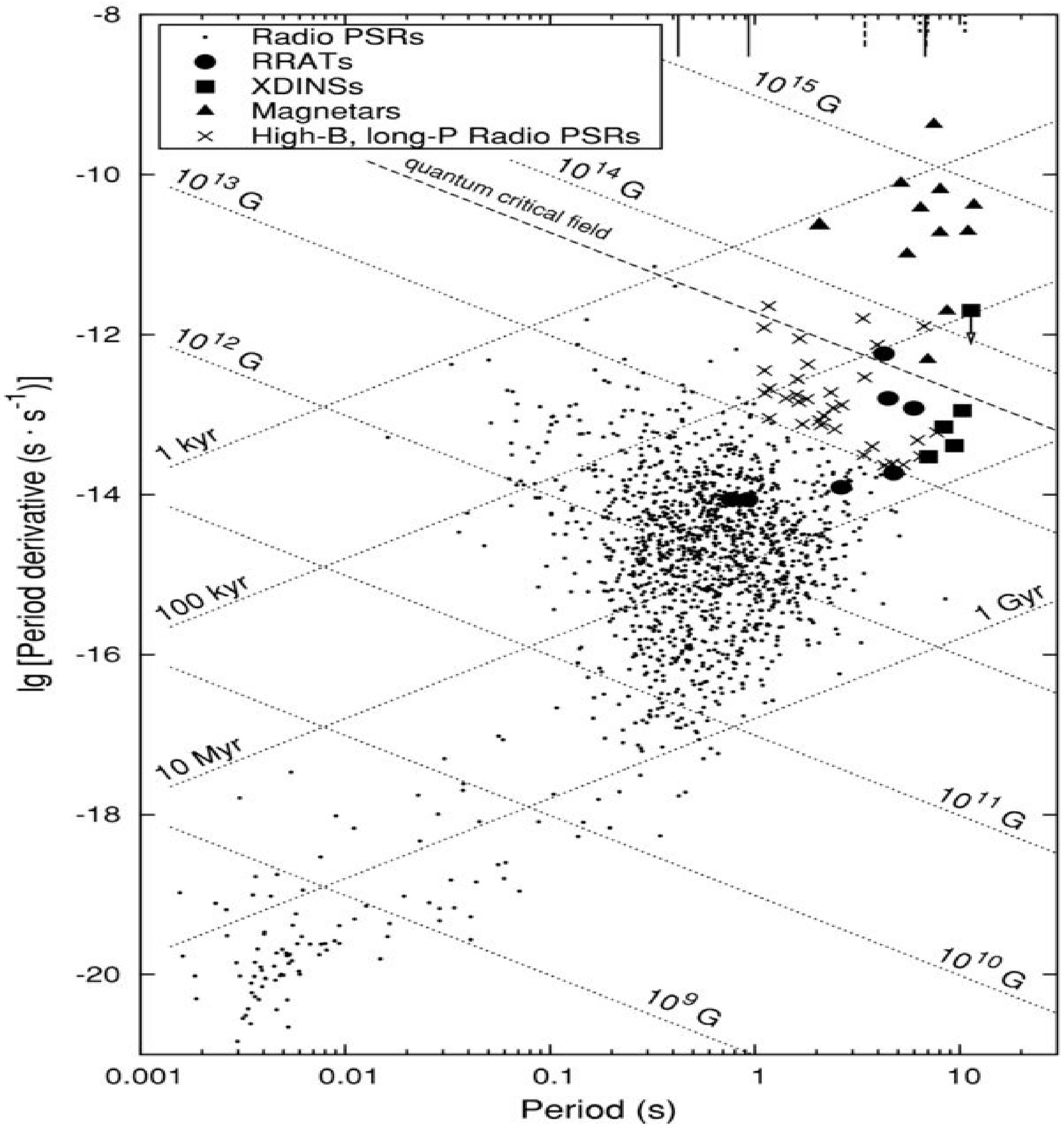
Parent et al. 2011

Diversity & Evolution



Kaspi et al. 2010

P-Pdot Diagram for High B Pulsars



Kondratiev et al. 2010

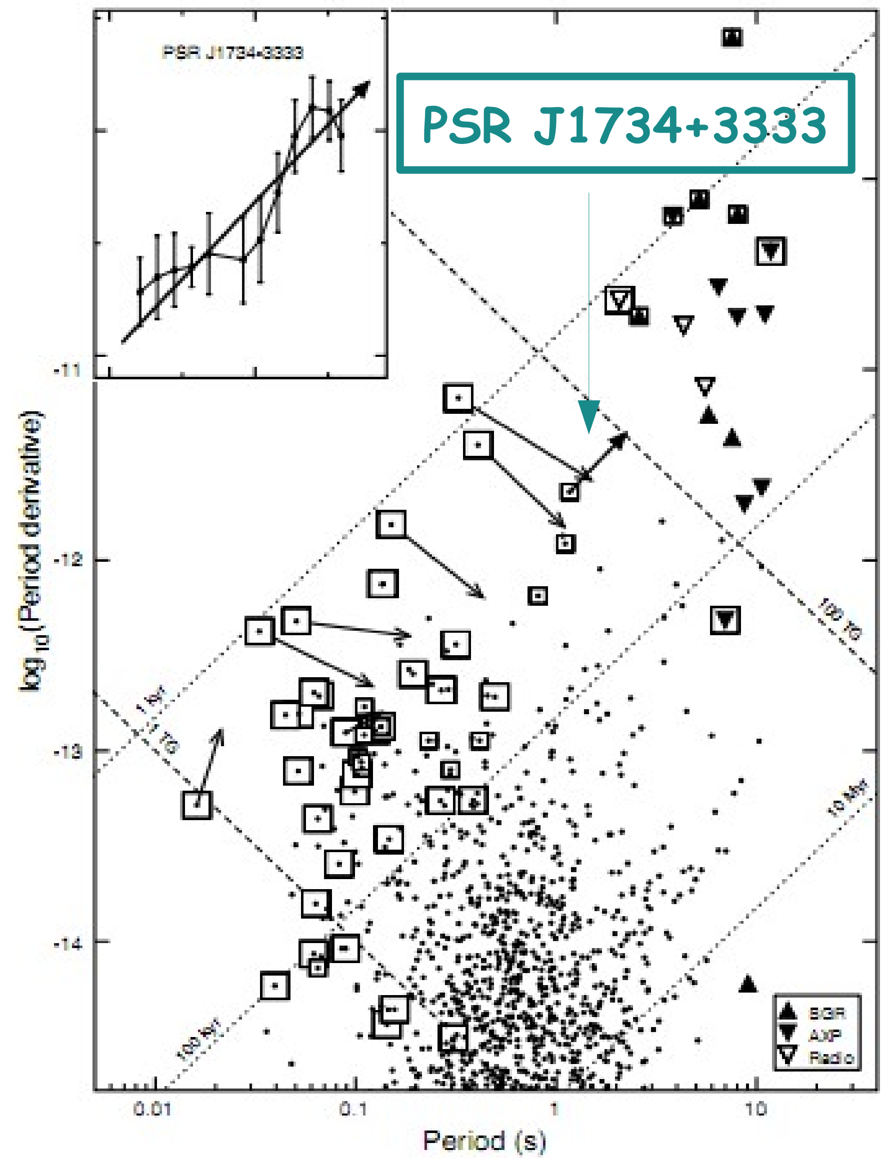
Evolutive Path?

Braking Index: $n = \frac{\Omega \ddot{\Omega}}{\dot{\Omega}^2} \ll 3$

Frequent Glitch Activity

$$B = 3.2 \times 10^{19} \sqrt{P \dot{P}} \uparrow$$

$$\tau = \frac{1}{n-1} \frac{P}{\dot{P}} \downarrow$$



Espinoza et al. 2011

Evolutive Path?

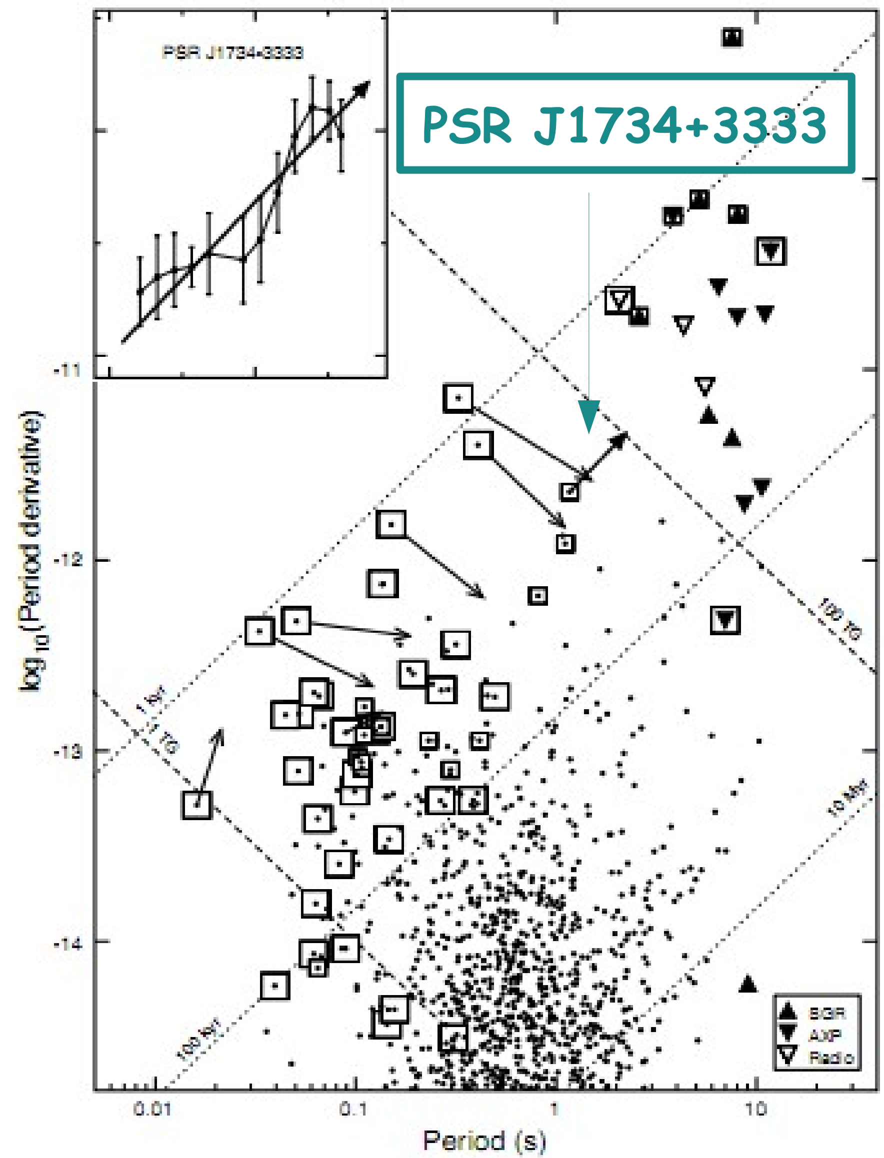
Braking Index: $n = \frac{\Omega \ddot{\Omega}}{\dot{\Omega}^2} \ll 3$

Frequent Glitch Activity

$$B = 3.2 \times 10^{19} \sqrt{P \dot{P}}$$

$$\tau = \frac{1}{n-1} \frac{P}{\dot{P}}$$

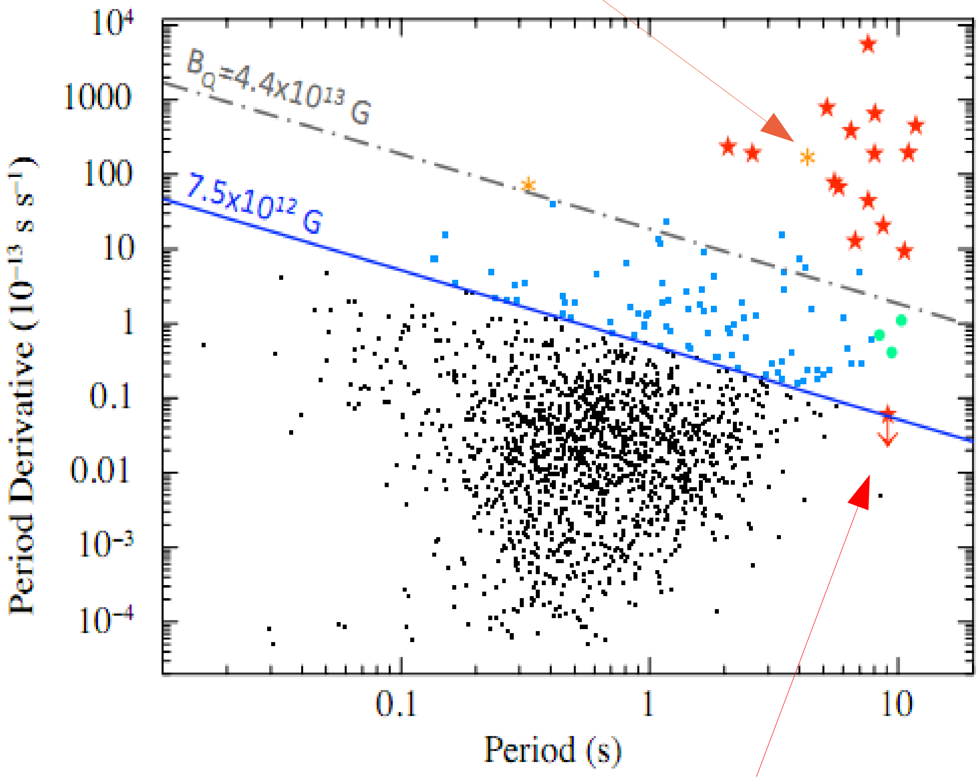
High B, small age → <u>MAGNETARS</u>

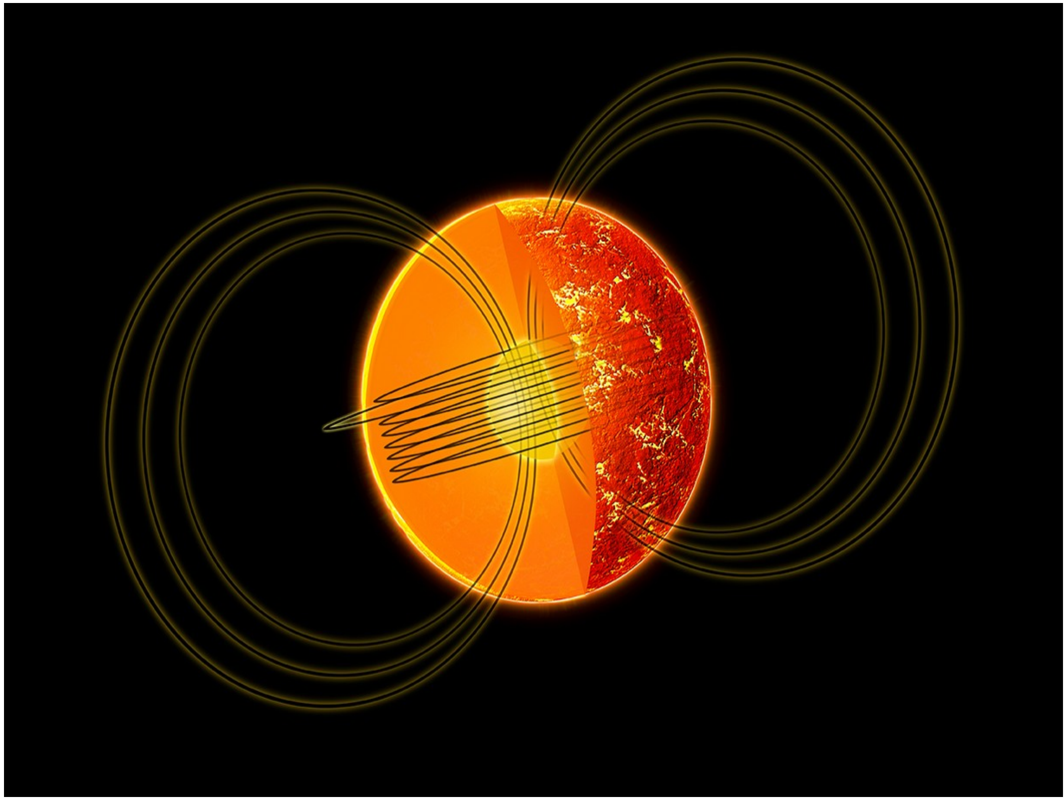


Espinoza et al. 2011

Importance of the Toroidal Field

PSR J1846-0258





SGR 0418+5729

Rea et al. 2010

Interpretation

A progressive alignment of the spin and magnetic axes (w&j07) could trigger changes in the toroidal field structure which would explain the magnetic activity and consequent observed decrease in n (lkg11).

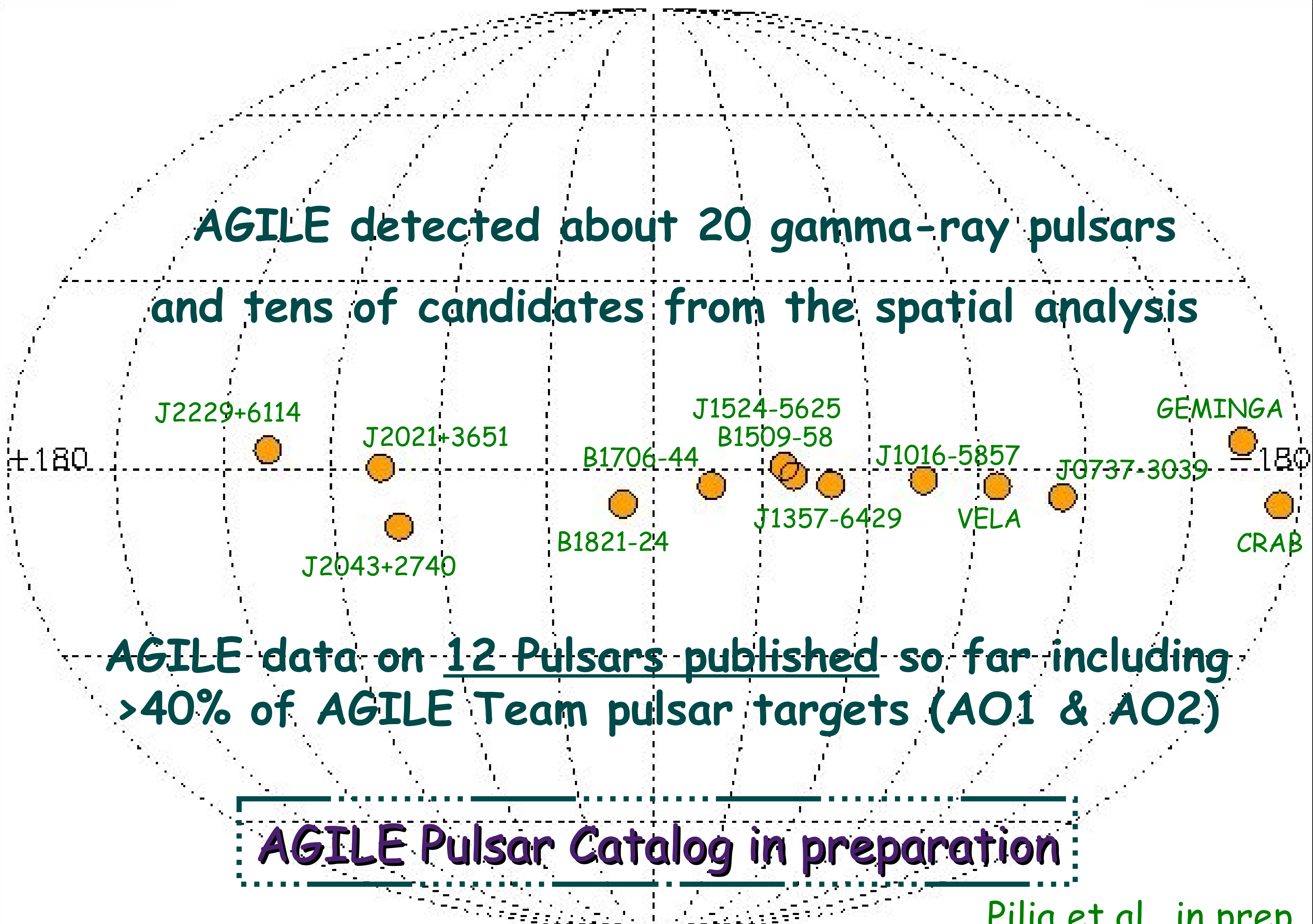
A magnetic field above the quantum critical value is observed and an aligned geometry is proposed.

Our observations are compatible with emission from the polar cap regions powered by photon splitting cascades also responsible for the absence of radio emission (high B).

<u>Are we witnessing a conversion?</u>

Future Work

AGILE detected about 20 gamma-ray pulsars and tens of candidates from the spatial analysis



AGILE data on <u>12 Pulsars published</u> so far including >40% of AGILE Team pulsar targets (AO1 & AO2)

AGILE Pulsar Catalog in preparation

Pilia et al., in prep.

Thank you!