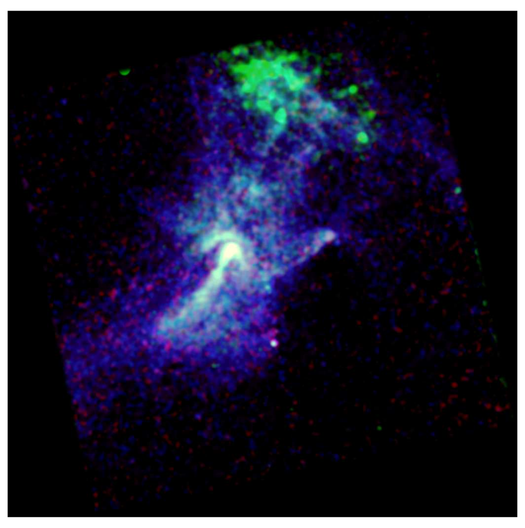

Linking the soft γ-ray pulsar population with the FERMI LAT pulsar population: completing the high-energy picture

SRON Netherlands Institute for Space Research

L. Kuiper (SRON) and W. Hermsen (SRON, UvA)

University of Amsterdam

Abstract While at high-energy γ-rays (>100 MeV) the FERMI LAT already detected more than 60 pulsars, the number of pulsars seen at soft γ-rays (20 keV - 30 MeV) is still very small, though steadily growing. Namely, in recent years targeted deep radio and/or X-ray observations of young Supernova remnants, TeV sources and newly discovered INTEGRAL sources revealed the presence of young and energetic pulsars, surrounded by bright pulsar wind nebulae. Currently, the total number of detected soft γ-ray pulsars counts 13 secure members. The average characteristics of these soft γ-ray pulsars differ from those of the LAT detected pulsars, e.g. the FERMI LAT pulsar population typically reaches its peak luminosity at GeV energies, the soft γ-ray pulsar population does so at MeV energies. In this presentation I will discuss the characteristics of this soft γ-ray pulsar population in comparison with the FERMI LAT findings in order to obtain a complete high-energy picture of the pulsar population.

Introduction

Rotation-powered pulsars (RPP) form a well-established galactic γ-ray source population known to emit steadily from radio frequencies up to high-energy γ-rays. Despite decades of theoretical modeling the origin and nature of the high-energy ($\gtrsim 0.1$ keV) emission is still not yet clear. The most developed models assume as production site of the high-energy emission in the pulsar magnetosphere either a location near (or starting near) the magnetic pole (polar cap, slot gap models) or in vacuum gaps in the outer magnetosphere (outer gap models). The predictions with respect to phase-resolved spectra, pulse morphology and polarization at high-energies by these models are very different (see e.g. overview by Harding et al., 2007).

After more than two years of operations FERMI LAT (20 MeV - 300 GeV) discovered the pulsed fingerprints (see e.g. Abdo et al., 2010; Ray et al., 2011) of more than 60 pulsars, a significant fraction of these is γ-ray only i.e. Geminga-like with no obvious counterparts at other (less energetic) wavelengths regimes. The γ-ray pulse profiles fall into one of three catagories: two peaks with separations in the range 0.4-0.5, overlapping peaks separated by ~ 0.2, and single peaked profiles. The pulsed spectra can be described adequately by cutoff power-law models and reach maximum luminosities at GeV energies. The distribution of the photon indices peaks in the range 1–2, while that of cutoff energies peaks in the range 1–3 GeV. These early findings already exclude an high-energy γ-ray origin from sites near the polar cap, and favour strongly an outer-magnetospheric origin.

Soft γ-pulsars

At hard X-rays/soft γ-rays ($\gtrsim 20$ keV) the pulsed signals from only a handful of pulsars had been detected, hampered mainly by the large underlying background and intrinsic source weakness. A significant fraction of the soft γ-ray pulsars were found after the CGRO era using high-resolution imaging (Chandra) and large sensitive area X-ray observatories (RXTE, XMM Newton, Suzaku) enabling the detections at soft X-rays (0.1-10 keV) of energetic point-sources in young supernova remnants, unidentified CGRO EGRET (>100 MeV), INTEGRAL (20-300 keV) or HESS/VERITAS/Magic (>300 GeV) error boxes.

Currently, from nine of these (post-CGRO) sources the pulsed signals have been detected up to $\sim 50-150$ keV using the soft γ-ray/hard X-ray instruments aboard RXTE, PCA and HEXTE, and INTEGRAL, namely: PSR J1846-0258 (in Kes 75), PSR J1930+1852 (in G54.1+0.3), PSR J1617-5055 (isolated), PSR J1811-1925 (in G11.2-0.3), PSR J0205+6449 (in 3C58), and recently AX J1838.0-0655, PSR J2229+6114 (G106.6+2.9), IGR J14003-6326 and IGR J18490-0000 (see Table 1 for an overview).

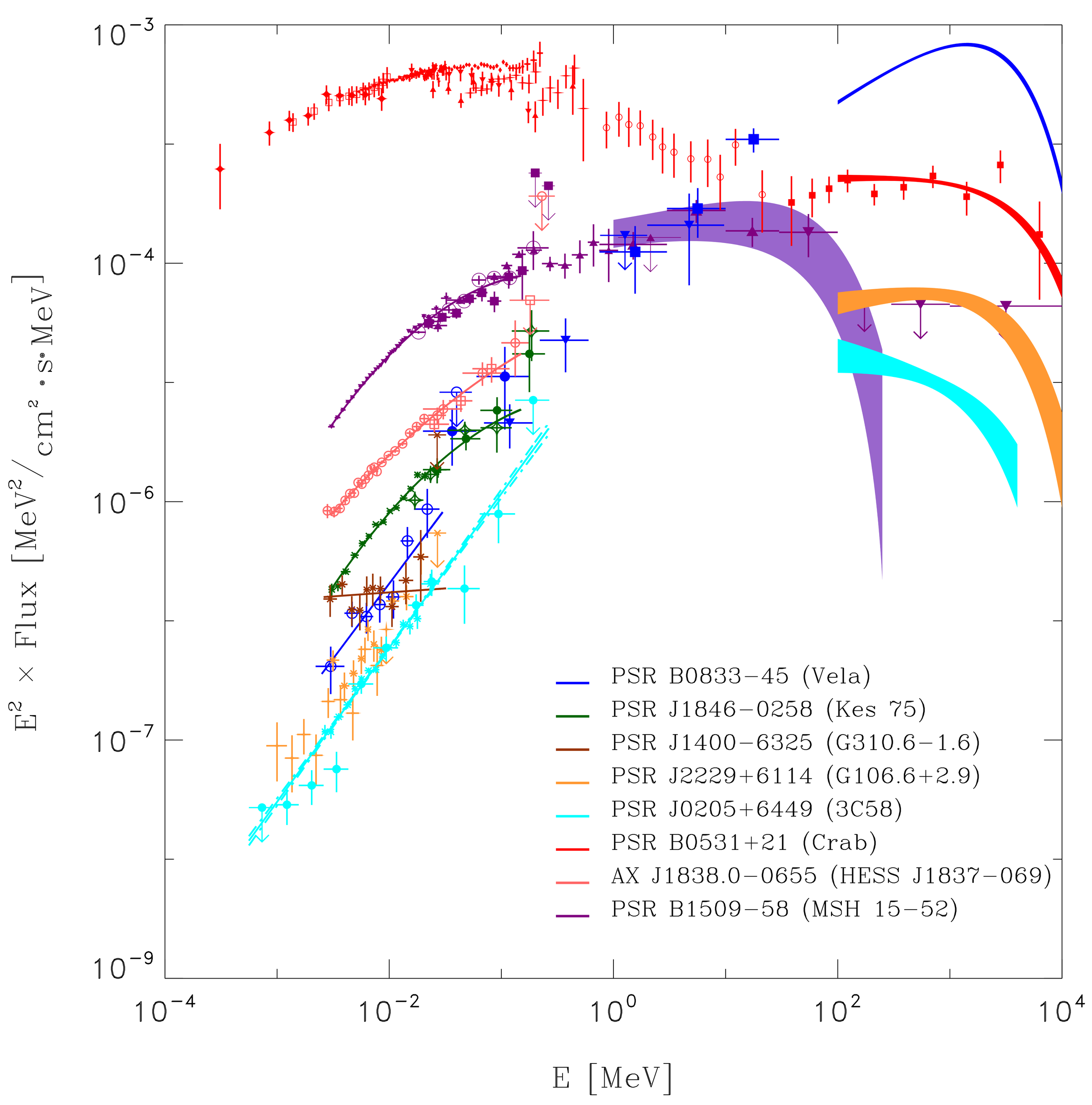

Figure 1: High-energy pulsed emission spectra of a subset of young RPPs with secure detections at hard X-rays over a eight decades wide energy interval. Their maximum luminosity is reached at MeV energies ("prototype" PSR B1509-58; purple data points/lines) in contrast to the middle-aged pulsars, peaking at GeV energies, of which Vela is the "prototype" (see dark blue points/lines). Note, also the variety of spectral shapes within this small sample of hard X-ray pulsars from almost flat at hard X-rays (Crab, IGR J14003-6326 [and 0540-69]) to very hard (all the rest)

These nine new soft γ-ray pulsars all, except IGR J14003-6326, have hard pulsed X-ray spectra with photon power-law indices in the range $\sim 1.1-1.5$ across the 2-150 keV band, with a similar spectral shape as PSR B1509-58 – the "proto-type" soft γ-ray pulsar detected by CGRO BATSE, OSSE and COMPTEL, and recently by AGILE and FERMI – which peaks in the MeV band (νF_ν). A compilation of the pulsed high-energy spectra of a subset of the soft γ-ray pulsars listed in Table 1 is shown in Fig. 1.

name	period (ms)	age (kyr)	radio	pulse shape	photon index	FERMI LAT	TeV PWN
PSR B0531+21 (Crab)	33.5	1.23	bright	two pulses	curved	yes	yes
PSR B0540-69 (N158A in LMC)	50.5	1.7	very dim	structured broad	curved	...	...
PSR B0833-45 (Vela)	89	11	bright	multiple sharp	1.1	yes	yes
PSR B1509-58 (MSH 15-52)	150	1.6	bright	single broad	curved	yes	yes
PSR J1846-0258 (Kes 75)	324	0.72	quiet	single, broad	1.20(1)	no	yes
PSR J1811-1925 (G11.2-0.3)	65.0	24.0	quiet	single, broad	1.11(1)	no	...
PSR J1930+1852 (G54.1+0.3)	136	2.9	very dim	single, broad	1.21(1)	no	yes
PSR J1617-5055	69.0	8.0	very dim	single, broad	1.30(1)	no	yes
PSR J0205+6449 (3C58)	65.7	5.4	very dim	two sharp pulses	1.1(1)	yes	...
PSR J2229+6114 (G106.6+2.9)	51.6	10.5	weak	two pulses	1.11(3)	yes	yes
AX J1838.0-0655	70.5	23.0	quiet	structured broad	1.12(1)	no	yes
IGR J14003-6326	31.2	12.7	dim	broad	1.95(4)	...	no
IGR J18490-0000	38.5	42.9	...	broad	1.50(2)	...	yes

Table 1: Rotation powered pulsars with (securely detected) pulsed emission in the hard X-ray band ($\gtrsim 20$ keV). Pulse shape and photon index are for the 2–150 keV band.

Moreover, their pulse shapes (see e.g. Fig. 2) mimic that of PSR B1509-58, a single broad asymmetric pulse with a faster rise and shallower fall, except AX J1838.0-0655 (broad structured peak), PSR J0205+6449 (two very narrow peaks at ~ 0.5 phase separation, Kuiper et al., 2010) and PSR J2229+6114 (two broad pulses at ~ 0.5 phase separation). For PSR J0205+6449 also sharp pulses are detected by FERMI LAT at high-energy γ-rays (Abdo et al., 2009a), however, the relative contributions of the pulses are inverted compared to the hard X-ray profile. Furthermore, contrary to the hard X-ray profile PSR J2229+6114 has one single asymmetric pulse at >100 MeV (Abdo et al., 2009a).

Soft γ-ray pulsar- versus FERMI pulsar population

If we compare the characteristic age ($\tau = p/2\dot{p}$) and spin-down luminosity ($L_{sd} = 4\pi^2 \cdot I \cdot \dot{p}/p^3$) distributions of both the soft γ-ray pulsar population (see Table 1) and the 46 members of the FERMI pulsar population given in Abdo et al. (2010), then we observe that the soft γ-ray pulsars are on average **younger** and **more energetic** than the FERMI detected pulsars (see Fig. 3). Note, that currently both populations have 5 members in common. More importantly, the large majority of the FERMI LAT pulsars, luminous at GeV energies, is **not** detected at soft γ-ray energies, in spite of huge amounts of INTEGRAL exposure time on their celestial positions.

Our sample at soft γ-rays is apparently a different pulsar selection, younger and more luminous, reaching maximum luminosity at MeV energies given the hard spectrum and non-detection above 100 MeV, than that uncovered by FERMI LAT, that has peak luminosities at GeV energies. Also, contrary to (most of) the FERMI pulsars the soft γ-ray pulsars are (almost) all embedded in a pulsar wind nebula (PWN), that shines brightly at soft X-rays and TeV energies. In these nebulae most of the spin-down energy is dissipated by interaction of the relativistic pulsar wind particles and matter/ambient magnetic field in the direct environment of the pulsar.

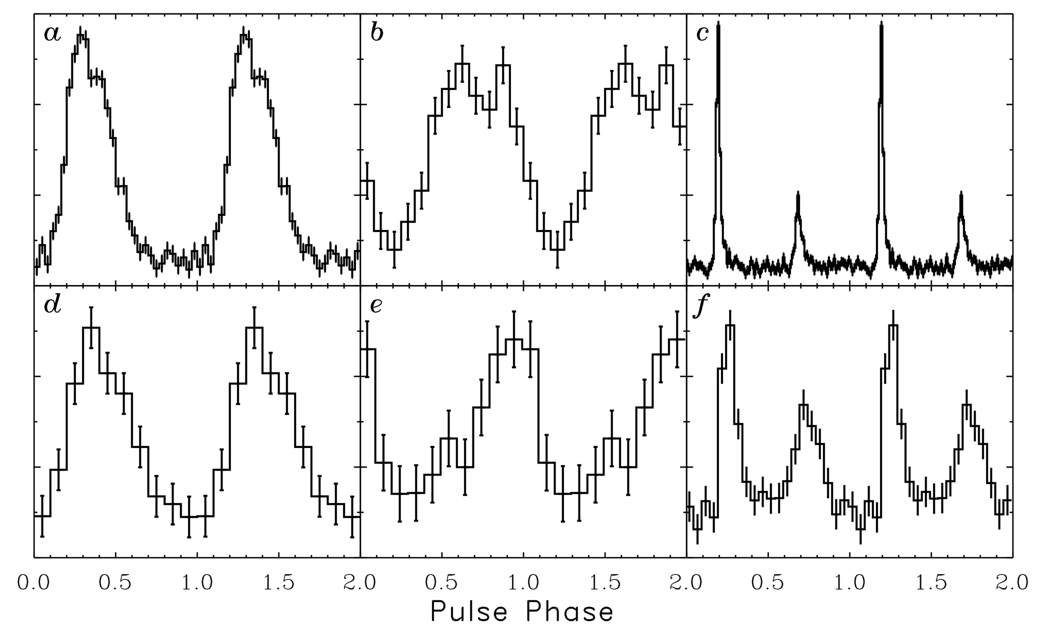

Figure 2: Pulse shapes for a subset of the soft γ-ray pulsars listed in Table 1: *a)* PSR B1509-58 (20-300 keV), *b)* AX J1838.0-0655 (20-150 keV), *c)* PSR J0205+6449 (2-20 keV), *d)* PSR J1846-0258 (20-150 keV),*e)* IGR J18490-0000 (15-150 keV) and *f)* PSR J2229+6114 (2-20 keV).

References

Abdo A. A., et al., 2009a, ApJ 699, L102

Abdo A. A., et al., 2009b, ApJ 706, 1331

Abdo A. A., et al., 2010, Ap&SS 187, 460

Harding A. K., et al., 2007, Ap&SS 309, 221

Kuiper L., et al., 2010, A&A 515, 34

Ray P. S., et al., 2011, Astrophysics and Space Science Proc., 37

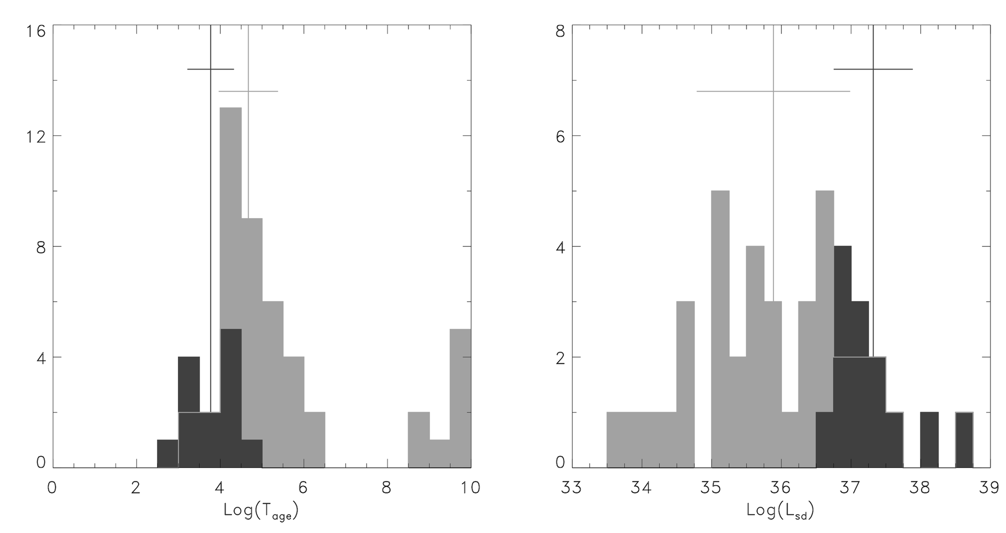

Figure 3: Characteristic age τ (left) and spin-down luminosity distributions of the FERMI (>100 MeV) pulsar population (light grey) and the soft γ-ray pulsar population (drak grey). The vertical lines represent the average values of the $^{10}\log(\tau)$ and $^{10}\log(L_{sd})$ distributions, excluding the millisecond pulsars, and the horizontal lines the 1σ width.

Conclusions

We compared the soft γ-ray pulsar population with the FERMI LAT pulsar population and found that:

- The soft γ-ray pulsar population is younger and more energetic than the FERMI LAT one.
- The hard pulsed spectra at soft γ-ray energies up to ~ 150 keV and non-detections above 100 MeV of most of the soft γ-ray pulsars imply that the soft γ-ray pulsars reach their maximum luminosities in the MeV range – like PSR B1509-58. The FERMI LAT pulsars do so in the GeV range.
- Most of the soft γ-ray pulsars are not detected in the high-energy γ-ray band, while most of the FERMI LAT pulsars are not detected in the soft γ-ray band.
- The large majority of the soft γ-ray pulsars has broad and asymmetric single pulses contrary to the FERMI LAT population, which shows predominantly double pulses.
- Soft γ-ray pulsars are in general associated with bright X-ray/TeV PWNe.