Analysing the X-ray behaviour of Fermi/LAT pulsars

Martino Marelli, Andrea De Luca and Patrizia Caraveo (IASF-INAF Milano)

By re-analysing all the available X-ray data, we assess the X-ray behaviour of the Fermi/LAT pulsars.
After revisiting the relationships between the pulsars' rotational energy losses and their X and γ-ray luminosities, we focus on the distance-independent to X-ray flux ratios. When plotting our Fγ/Fx values as a function of the pulsars' rotational energy losses, one immediately sees that pulsars with similar energetics have Fγ/Fx spanning 3 decades. Such spread, most probably stemming from vastly different geometrical configurations of the X and γ-ray emitting regions, defies any straightforward interpretation of the plot. Dividing our pulsar sample into radio-loud (RL) and radio-quiet (RQ) subsamples, we find that, on average, radio-quiet pulsars do have higher values of Fγ/Fx, implying an intrinsic faintness of their X-ray emission and/or a different geometrical configuration.

γ-ray and x-ray luminosities

To study the relationships between Ė and the luminosities in the X-ray and γ-ray bands, we set the beam factor "f" (dependent from the magnetic e visual angles) to 1 (Watters et al. 2009).
Our results in the X-ray band are in agreement with Possenti et al. (2002) and Kargaltsev&Pavlov (2008). The **double-linear fit found for the γ-ray band** has been posited from the theoretical side for different pulsar emission models (see e.g. Zhang et al. 2004 and Muslimov&Harding 2003). The χ^2 values of both relations are an indication of a superimposed scatter of the luminosities values around the best fit functions. Such scatter is less pronounced in the γ-ray band. Different geometrical configurations, that translates into different beam factor for each pulsar, as well as wrong distance estimates can be responsible for the scattered appearance of Figs. 1 and 2

Figure 1

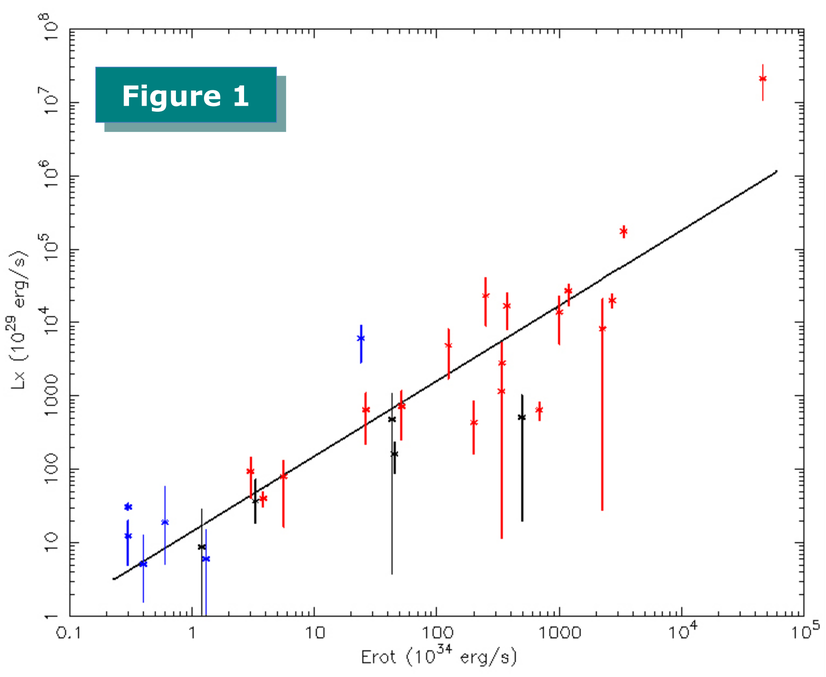
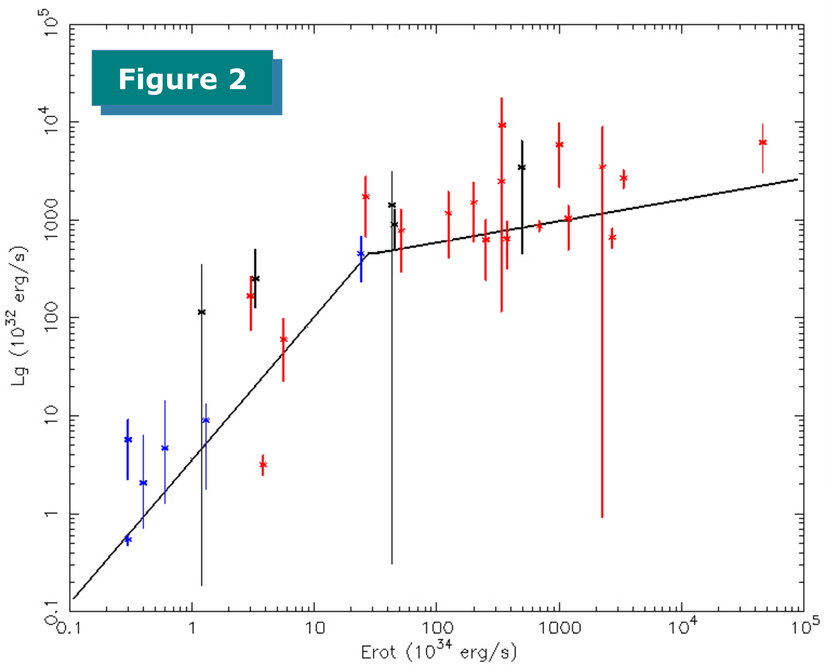


Figure 2



Figures 1,2,4 : Green: IBIS pulsars; black: radio-quiet pulsars; red: radio-loud pulsars; blue: millisecond pulsars. Triangles: upper and lower limits; squares: low-quality pulsars; stars: high-quality pulsars.
Figure 3 : Grey: radio-quiet high-quality pulsars; Orange: radio-loud high-quality pulsars.

γ-to-x flux ratios

At variance with the X-ray and gamma-ray luminosities, the ratio between the X-ray and gamma-ray luminosities is independent from pulsars' distances. Figure 4 shows Fγ/Fx as a function of Ė for all the published Fermi pulsars. The scatter of the Fγ/Fx values for a given value of Ė is evident. **Such a spread is obviously unrelated to distance uncertainties (as it is for the luminosities' relations) but it's probably due to geometrical effects**: different beam factors for different pulsars and for the two energy bands for each pulsar. The dashed line in Figure 4 is the combination of the best fits of Lγ-Ė and Lx- Ė relationships, considering fγ=1 and fx=1 so that it represents the hypothetical value of Fγ/Fx that each pulsar would have if fγ=fx: all the pulsars with a value of Fγ/Fx below the line have fx < fγ.
Figure 3 reports the histogram of the Fγ/Fx values for high-quality pulsars. RL pulsars have <Fγ/Fx> ~ 800 while the RQ population has <Fγ/Fx> ~ 4800. Applying the Kolmogorov-Smirnov test on high-quality pulsars' Fγ/Fx values, we obtain that the chance for the two datasets belong to the same population is 0.0016. We can conclude, at a 3σ confidence level, that the RQ and RL datasets we used are somewhat different. While it would be hard to believe that RL and RQ pulsars belong to two different neutron star populations, the KS test probably points to **different geometrical configurations (possibly coupled with viewing angles) that characterize radio-loud and radio-quiet pulsars.**

Conclusions

First, we reproduced the well-known relationship between the NS luminosities and their rotational energy losses. The spread seen in such relationships can be due both to geometrical effects or to a poor characterization of pulsars' distances. The distance independent Fγ/Fx values computed for pulsars of similar age and energetic show a spread by up to 3 orders of magnitude, pointing to important (yet poorly understood) **differences both in position and height of the regions emitting at X and γ-ray wavelengths within the pulsars' magnetospheres**. Selection effects cannot account for the spread in the Fγ/Fx relationship. In spite of the highly scattered values, a decreasing trend is seen when considering young and energetic pulsars. Moreover, radio quiet pulsars are characterized by higher values of Fγ/Fx probably **pointing to different geometrical configurations that characterize the two populations.**

Figure 3

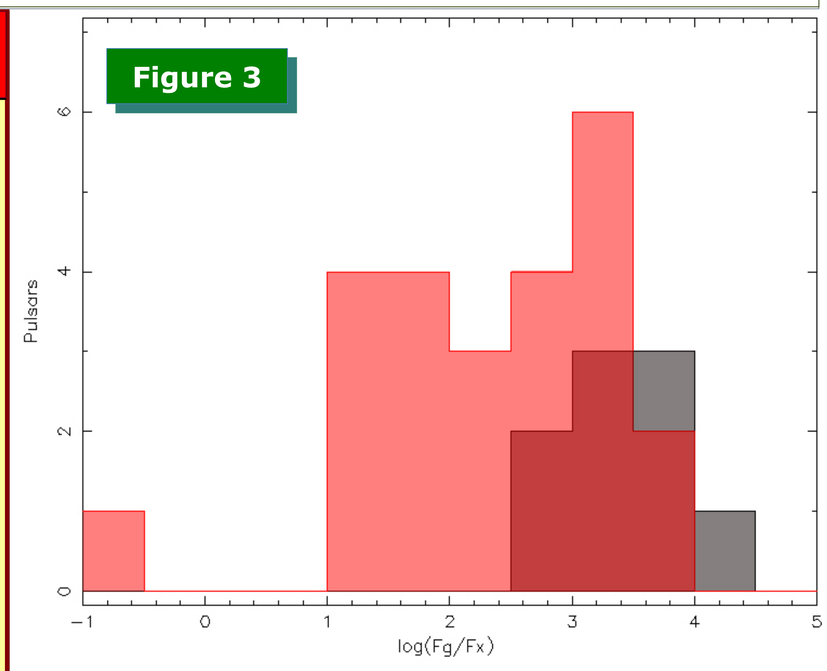
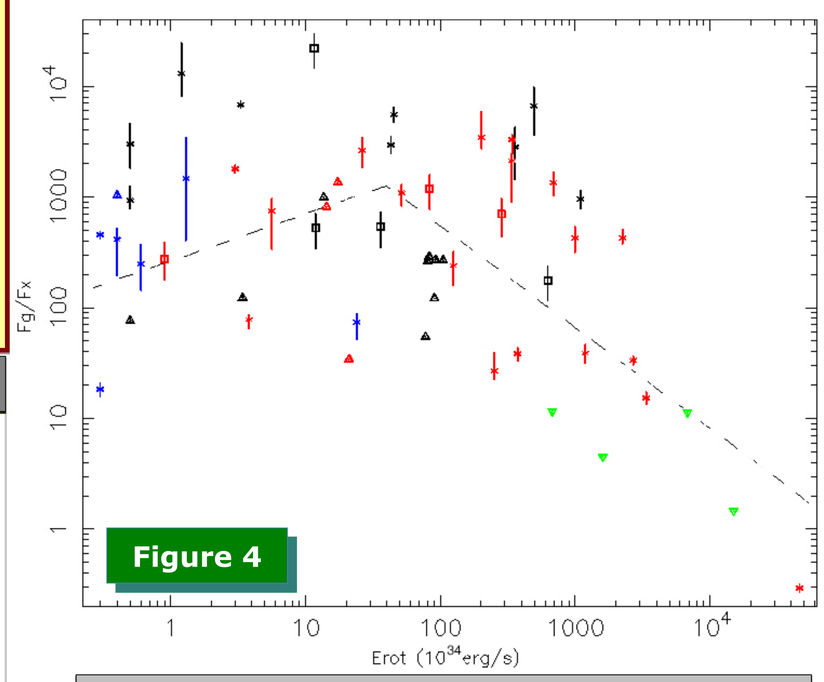


Figure 4



Selection effects

- The two populations of RQ and RL pulsars are unveiled with different techniques: using the same dataset, pulsars with known rotational ephemerides have a detection threshold lower than pulsars found through blind period searches (Abdo et al. 2008). Such an effect does not affect our main results (Marelli et al. 2011, Abdo et al. 2008).
- We chose only pulsars with a good X-ray coverage. Such a coverage depends on many factors that cannot be modelled. A rough evaluation of such an effect can be done using the method developed by Schmidt (1968) to compare the spatial distributions of the two samples. The results show that the two populations are equally affected by the selection criteria.

Notes

We considered all the Fermi pulsars published as of 2011, January. Our sample encompasses 54 pulsars: 32 radio-loud and 22 radio-quiet. All the timing and γ-ray data are taken from the Fermi pulsar catalog. We also considered 4 pulsars listed in the 4th IBIS catalog and not (yet?) detected by Fermi. Pulsars are divided into three categories on the basis of the goodness of X-ray spectrum: upper limits (no X-ray detection), low quality (X-ray counterpart of unknown spectral shape) and high quality pulsars. All the analysis are done by considering only high-quality pulsars. For the analysis the γ and X-ray luminosities we used only pulsars with clear distance estimates.

References

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