Mem. S.A.It. Vol. 84, 572

Memorie della

Completing the census of Fermi pulsars with X-ray observations

D. Salvetti[1,2,3], A. De Luca[1,2], P. A. Caraveo[1,2], and M. Marelli[1]

[1] INAF – Istituto di Astrofisica Spaziale e Fisica Cosmica - Milano, Via E. Bassini 15, I-20133 Milano, Italy, e-mail: salvetti@lambrate.inaf.it
[2] INFN – Istituto Nazionale di Fisica Nucleare, Sezione di Pavia, Via Bassi 6, I-27100 Pavia, Italy
[3] Università degli Studi di Pavia, Dipartimento di Fisica Nucleare e Teorica, via Bassi 6, I-27100 Pavia, Italy

Abstract. The Large Area Telescope (LAT) onboard Fermi shed new light on the Galactic population of rotation-powered pulsars (PSRs), unveiling a large number of young radio-quiet (Geminga-like) γ-ray PSRs, of young radio-loud γ-ray PSRs and of γ-ray-emitting millisecond PSRs. Moreover, among the $\sim$1800 γ-ray sources in the Fermi-LAT Second Source Catalog (2FGL), approximately 30% remain unidentified. γ-ray PSRs could account for an important fraction of these sources. To complete the census of PSRs, we implemented a statistical method (Logistic Regression) to quantify the probability for each unidentified source to be a PSR, based solely on the observed γ-ray properties of the source. We are performing X-ray follow-up observations of the most promising sources, which include good radio-quiet γ-ray millisecond PSR candidates. Their discovery would have very important implications for our understanding of PSRs.

Key words. catalogs – methods: statistical – pulsars: general – galaxies: active – gamma rays: general – X-rays: general

1. Introduction

The Fermi-LAT (Atwood et al. 2012) Second Source Catalog (2FGL) lists 1873 sources detected during the first 24 months of operation by the LAT in the 100 MeV to 300 GeV energy band (Nolan et al. 2012).

For each LAT object, the proposed associations with sources in other astronomical catalogues is based primarily on positional coincidence. The 95% uncertainty radii for 2FGL sources are typically 10′. Thus, these position measurements are often inadequate to make identifications based solely on location. With this caveat, 1096 sources were associated with AGNs, 6 with galaxies, 108 with pulsars, 87 with SNRs, PWNe, globular clusters, novae and binaries, while 576 2FGL sources ($\sim$30%) remain unidentified.

Among the identified pulsars, approximately a third are young radio-loud pulsars, a third are young radio-quiet pulsars and a third are radio-loud millisecond pulsars (MSPs). Because of the large number of unidentified sources in 2FGL, γ-ray pulsars could account for an important fraction of these objects. To

Send offprint requests to: D. Salvetti

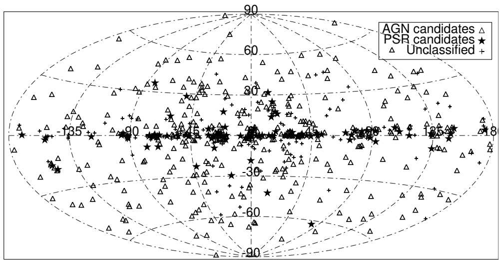

Fig. 1. Spatial distribution, in Galactic coordinates, for 2FGL unidentified sources classified as AGN candidates (triangles) and pulsar candidates (filled stars) by the Logistic Regression analysis. Those sources left unclassified are shown as crosses.

complete the census of Fermi pulsars, we implemented a statistical method to quantify the probability for each unidentified source to be a pulsar, based solely on the observed γ-ray properties of the source.

2. Logistic Regression analysis

We used a Logistic Regression (LR) analysis method (Hosmer & Lemeshow 2000) to quantify the probability of an unidentified source to be a γ-ray pulsar based on its γ-ray properties, in order to plan X-ray follow-up observations. LR is part of a class of generalized linear models and it allows us to define a multivariate relation between a dependent variable and several independent ones.

LR must be trained on known objects in order to predict the membership of a new object to a given class on the basis of its observables. We decided to train the predictor using the pulsars and AGNs identified in the 2FGL catalog because they are abundant and have different phenomenologies (Nolan et al. 2012). As discussed in Ackermann et al. (2012), we chose the predictor variables and the two classification thresholds which distinguish more efficiently a pulsar from an AGN. Chosen predictor variables are related to temporal and spectral properties of the γ-ray sources. The validation of this method was described in Ackermann et al. (2012)

Applying the LR model to the 2FGL unidentified sources we found that 108 sources are classified as pulsar candidates, 325 as AGN candidates while 143 remain unclassified after the analysis. Their spatial distribution, in Galactic coordinates, is shown in Fig. 1.

3. X-ray follow-up observations

While for radio-loud pulsars an accurate, contemporaneous radio ephemeris eases the γ-ray pulsation search, for a radio-quiet pulsar the periodicity has to be searched directly in γ-ray data, using a "blind search" algorithm (Atwood et al. 2006). These algorithms are very sensitive to positional offsets. To increase the efficiency of the algorithm we are performing X-ray follow-up observations of the most promising sources, i.e. 2FGL unidentified sources classified as pulsar candidates by the LR analysis, to detect the X-ray counterpart of the putative pulsar. In this way the blind search will be run on the (much smaller) sky area covered by the error regions of the detected X-ray sources.

4. Conclusions

Using a Logistic Regression analysis method we expect $\sim$100 new γ-ray pulsars to be discovered. Among our best pulsar candidates, a few could likely be radio-quiet MSPs, as argued by their off-plane position and by the lack of any radio PSR in spite of deep searches. Their discovery would have very important implications for our understanding of pulsars. Moreover, enlarging the sample of γ-ray pulsars we will be able to understand the physics of pulsar magnetospheres (the "pulsar engine") and the evolution of the pulsar population with age.

References

Ackermann, M., et al. 2012, ApJS, 753, 83

Atwood, W. B., et al. 2006, ApJL, 652, L49

Atwood, W. B., et al. 2009, ApJ, 697, 1071

Hosmer, D. & Lemeshow, S. 2000, Applied Logistic Regression, 2nd edn. (John Wiley & Sons, Inc., New York)

Nolan, P. L., et al. 2012, ApJS, 199, 31