Tracking millisecond pulsars responsible for the Fermi GeV excess

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Abstract. More than 10 years ago, an excess of γ-ray photons coming from the Galactic center was discovered in the Fermi-LAT data. First attributed to dark matter, it has since been shown that it should have at least a partial stellar origin. One hypothesis is the presence of a population of millisecond pulsars (MSPs) confined in the Galactic bulge. We here present our recent progress in the selection of MSP candidates.

1 The Fermi GeV excess and the millisecond pulsar hypothesis

Millisecond pulsars (MSPs) are neutron stars with periods up to 30 ms. They have a magnetic field strength from 10^7 to 10^{11} G, which produces a beamed emission responsible for the pulsar lighthouse effect. MSPs are known to emit in radio, X- and γ-rays. They were proposed as an explanation for the Fermi GeV excess, a signal of γ-ray photons coming from the Galactic center region not reproduced by astrophysical models of diffuse γ-ray emission [1]. In particular, the spatial distribution of the photons making up this excess emission was found to correlate with old stars in the Galactic bulge [2, 3], and recent evidence for point sources below the telescope detection threshold supported this hypothesis [4].

In [5], we have developed a phenomenological model for X-ray MSPs in the Galactic bulge, whose γ-ray emission can fully explain the excess. We predict about 3×10^4 MSPs in the Galactic bulge. The X-ray flux for each MSP is computed from a gamma-to-X correlation we built from the sample of known MSPs. For more details we refer to [5]. Our conclusion was that a hundred MSPs could have been detected in past observations in our region of interest, $6^\circ \times 6^\circ$ around the Galactic center. We found more than 3000 non extended, non variable Chandra sources with a power-law-compatible spectrum in this same region. This demonstrated that the MSP explanation to the GeV excess was not excluded by X-ray data.

The Monte Carlo simulation used in [5] is now publicy available here. Our simulation includes MSP position (see figure 1 left), γ-ray luminosity, γ-to-X flux ratio and X-ray spectral index, which allowed us to compute their X-ray flux. The probability density functions we used were either found in the literature or computed them from published data.

2 Promising candidate selection and radio follow-up

Among the 3000 Chandra sources mentioned in section 1, we selected those with neither ultraviolet nor optical possible counterparts as promising MSP candidates [6]. We then defined two categories: 1) **compact objects** *i.e.* about 40 candidates with only a faint infrared

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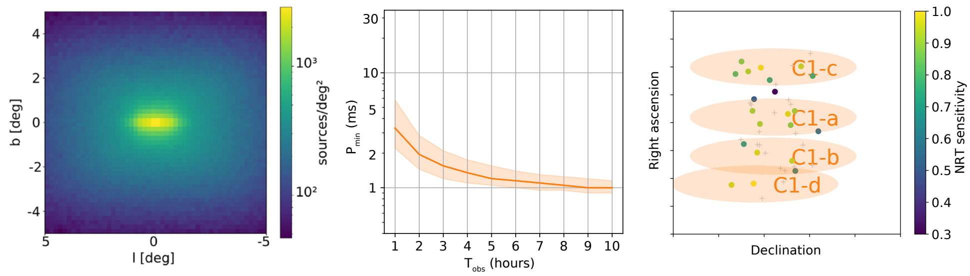

Figure 1. *Left:* Positions of MSPs in our simulation. *Middle:* Minimal detectable MSP period as a function of GBT observing time for one promising candidate. The line assumes a radio spectral index $\alpha = -1.9$ and the shaded area considers $-2.43 < \alpha < -1.37$. *Right:* NRT observation strategy. The orange ellipses show the NRT beam. Colored dots indicate the positions of the most interesting MSP candidates and the sensitivity of the telescope at this position. Gray crosses represent other candidates.

counterpart verifying $\log_{10}(F_X/F_{IR}) > 0.5$ [7] and 2) **radio sources** *i.e.* about 10 promising candidates with only a radio counterpart detected in unpublished VLA 1.4 GHz images. These promising targets motivated dedicated radio follow-up studies which are essential to detect pulsations.

We predicted the optimal radio observation time to undoubtedly confirm the MSP nature of some of our radio sources with Parkes and the GBT (see figure 1 middle) and were granted more than 55 hours of observations. We also obtained about 18 hours of radio observation with the NRT to observe two clusters of MSP candidates. The observation strategy was optimized to cover the maximum number of candidates in a minimal amount of time with a maximal sensitivity (see figure 1 right). Data reduction and analysis are currently on-going and our preliminary results are encouraging.

3 Conclusion and perspectives

By modeling the multi-wavelength MSP emission in X and gamma rays, we have defined a list of most promising X-ray bulge MSP candidates. Radio observations will conclusively adjudicate on their pulsar nature. Finding MSPs will be a huge step forward in understanding the GeV excess, but finding no pulsars will also be interesting. If our candidates are not pulsars, then what could they be? Finally, Einstein Telescope and CTA will help solve the excess mystery in the future, from a multi-messenger point of view [8, 9].

References

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