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Blind Search Methods for Binary Gamma-ray Pulsars

Lars Nieder[1,2], **Colin J. Clark**[1,2,3] **and Holger J. Pletsch**[1,2]
on behalf of the *Fermi*-LAT Collaboration †

[1] Albert-Einstein-Institut, Max-Planck-Institut für Gravitationsphysik,
D-30167 Hannover, Germany,
email: `lars.nieder@aei.mpg.de`

[2] Leibniz Universität Hannover, D-30167 Hannover, Germany

[3] Jodrell Bank Centre for Astrophysics, School of Physics and Astronomy,
The University of Manchester, Manchester M13 9PL, UK

Abstract. Gamma-ray observations by the *Fermi* Large Area Telescope (LAT) have been used very successfully in the last 9 years to detect more than 200 gamma-ray pulsars. Sixty of these have been found by directly searching for pulsations in the gamma-ray data, but only one binary MSP has been found this way. Pulsars in binaries are often difficult to detect in radio data because of large eclipses, and some binary MSPs may even be radio quiet. For those, a gamma-ray blind search might be the only possibility for detection. While searches for isolated pulsars up to kilohertz frequencies are already computationally very challenging, blind searches for binary gamma-ray pulsars are simply infeasible without further knowledge of their orbital parameters. Here we present methods with which we can conduct searches for candidate binary gamma-ray pulsars for which orbital constraints are known from optical observations of a likely companion star. We also highlight some example sources where these methods have been used.

Keywords. gamma-rays: stars – pulsars: general – methods: data analysis – methods: statistical

1. Search Methods

Blind searches for unknown gamma-ray pulsars are computationally limited. Searches for millisecond pulsars (MSPs) in binary systems are entirely infeasible without prior constraints. Here we present results from a paper in preparation that describes our efforts to make searches for binary gamma-ray pulsars in circular and slightly eccentric orbits feasible and more efficient. These extend the search methods for isolated pulsars from Pletsch & Clark (2014) by efficient tools needed in searches for binary pulsars.

Sensitive searches for binary pulsars require scans over large, curved and highly dimensional parameter spaces using dense search grids. In order to build efficient stochastic search grids [Fehrmann & Pletsch (2014)] we compute a distance *metric* (i.e. an analytical approximation to the *mismatch*, the expected loss in the signal-to-noise ratio, as function of the distance to the nearest grid point) on the parameter space.

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Furthermore, we exploit constraints on the orbital parameters, extracted from the optical lightcurve of the pulsar's likely companion star, to greatly reduce the number of needed binary grid points. This method was crucial for the detection of the binary MSP, PSR J1311−3430 [Pletsch *et al.* (2012)].

2. Search Design

A grid of search locations is produced to cover the orbital parameter space with an optimal density guided by the metric. At each point, a semicoherent search, combining photons coherently within a window of length $T_{\rm coh}$, is performed over spin frequency and spin-down rate. More sensitive but more expensive stages are used to follow up the most promising candidates. The metric also provides a tool to estimate the number of search grid points, N, needed for the first stage by integrating over the search volume, Λ:

$$N \propto m_{\rm max}^{-7/2} \int_{\Lambda} \sqrt{\det\, g(\vec{\lambda})}\, {\rm d}\vec{\lambda} \tag{2.1}$$

$$\vec{\lambda} = \left\{ f, \dot{f}, \Omega_{\rm orb}, x, T_{\rm asc}, e, \omega \right\} \quad \text{and} \quad \sqrt{\det\, g(\vec{\lambda})} = T_{\rm obs}^2\, T_{\rm coh}^2\, f^5\, \Omega_{\rm orb}\, x^4 \tag{2.2}$$

Search parameters:
- $T_{\rm obs} \equiv$ Observation time
- $T_{\rm coh} \equiv$ Coherence time
- $m_{\rm max} \equiv$ Maximum mismatch in grid

Pulsar parameters:
- $f \equiv$ Spin frequency
- $\dot{f} \equiv$ Spin-down parameter

Orbital parameters:
- $\Omega_{\rm orb} \equiv$ Orbital frequency
- $x \equiv$ Projected semi-major axis
- $T_{\rm asc} \equiv$ Epoch of ascending node
- $e \equiv$ Eccentricity of orbit
- $\omega \equiv$ Longitude of periastron

The recovered signal-to-noise ratio depends on the search parameters,

$$S/N \propto (1 - m)\sqrt{T_{\rm coh} T_{\rm obs}}\,. \tag{2.3}$$

Decreasing the search volume with orbital constraints allows us to increase the coherence time, or decrease the mismatch, resulting in a more sensitive search!

3. Applications

The likely counterparts of several pulsar candidates, e.g. 3FGL J0523.3−2528 [Strader *et al.* (2014)] and 3FGL J1653.6−0158 [Romani *et al.* (2014)], have been detected. Using the extracted orbital constraints we launched blind searches within those sources on the distributed volunteer computing system *Einstein@Home*.

The new methods can also be used to search for binary pulsars which have been detected in radio but for which the timing solution is not yet precise enough to find gamma-ray pulsations via folding. Additionally, eclipsing binary MSPs can be more easily timed in gamma rays (which are not absorbed by the intrabinary material) than with radio observations.

References

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