# A Search for Very Short Orbital Period Binaries (and Very Long Period Pulsars)

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A number of gamma-ray binaries have previously been found from a search for periodic modulation of LAT light curves, these include three high-mass systems (1FGL J1018.6-5856, LMC P3 and 4FGL J1405.1-6119) and a candidate redback (4FGL J1702.7-5655). We are now expanding this search to shorter periods to investigate a previously unexplored area. This has the potential to find "exotic" binaries, or perhaps long-period pulsars. We have so-far searched down to periods of 0.005 days (432 s) and plan to go to even shorter periods. This is computationally demanding and we are using NASA Goddard's large "Discover" cluster.

## Searching All Sources

From a systematic search for periodic modulation in all cataloged LAT sources, we previously identified three as high-mass gamma-ray binaries - systems that contain an O or Be star primary, including one in the LMC. We also found periodic emission from a candidate redback, the first system where the period was initially found in gamma rays for such a system, and the first spider to show gamma-ray eclipses. These searches were made down to periods of 0.05 days. Now, to explore new parameter space, we are going to shorter and shorter periods. Initially 0.005 days (432 s) with the goal of going to shorter periods still. This fills a gap between earlier orbital period searches, and traditional pulsar searches.

What will be found is very uncertain, but there are several classes of objects that are possibilities. The discovery of a novel type of sources in this unexplored parameter regime would be particularly exciting! We therefore search for modulation in all sources.

## *Weighting, Weighting*

We make aperture photometry light curves with a radius of 3 degrees. To optimize signal-to-noise, we weight each photon by the probability that it came from the source of interest. Probabilities are obtained from `gtsrcprob` and the latest version of the LAT catalog.

We search for periodic modulation by calculating discrete Fourier transforms. The exposure of each time bin can vary enormously, and so we weight each data point's contribution by the relative exposure.

## Need for High-End Computing

As we search to shorter periods, the computational demands increase rapidly. The number of frequency steps is ~proportional to the highest frequency searched. In addition, for a binned light curve, shorter time bins must be used to provide at least ~10 bins per period. Together this results in the number of calculations $\propto f_{max}^2$ Previous searches ran on modest scale workstations, but took a long time. This is now impractical and a large cluster is needed. Fortunately, the searches easily scale as the analysis for each source is independent. In addition, sections of the Fourier Transform can be calculated separately then joined together.

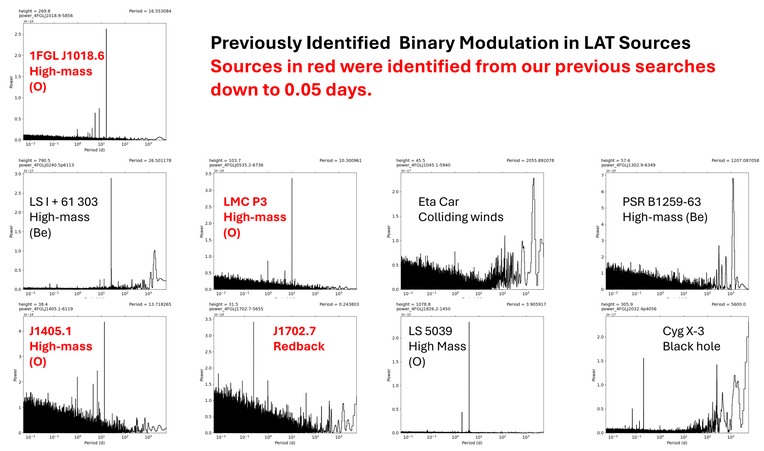
## Need for Multi-wavelength Data

Our expanded search generates many more independent trials compared to our previous searches. The detection of a candidate modulation at a different wavelength can lead to the confirmation of even a modest significance gamma-ray detection. In addition, multi-wavelength data are required to identify the nature of a source. Observations include radio, X-ray and optical.

## NASA Center for Climate Simulation

One of the Scalable Compute Units of NASA's Discover Supercomputer

*"The centerpiece of the NCCS is the over 127,232-core "Discover" supercomputing cluster, an assembly of multiple Linux scalable units built upon commodity components capable of nearly 8.1 petaflops, or 8,100 trillion floating-point operations per second."*



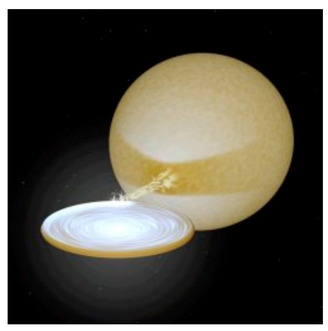

**Previously Identified Binary Modulation in LAT Sources**
**Sources in red were identified from our previous searches down to 0.05 days.**

## The Short Orbital-Period Zoo

The search for binaries in this period range is highly speculative. However, we already know of a variety of short-period binaries that contain compact objects. Within this period range, mysterious long-period pulsars are also now being discovered.

### Ultra-Compact X-ray Binaries

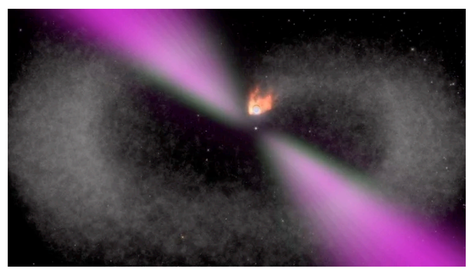
The prototype of this system is 4U 1820-30 (Stella+ 1987) which consists of a neutron star that exhibits X-ray bursts in a 685 s (0.008 day) orbit with a degenerate dwarf companion with a mass of about ~0.07M⊙. It also exhibits a long-term period of ~176 days.



(van der Slyus/Hynes)

### Short Orbital-Period Spiders

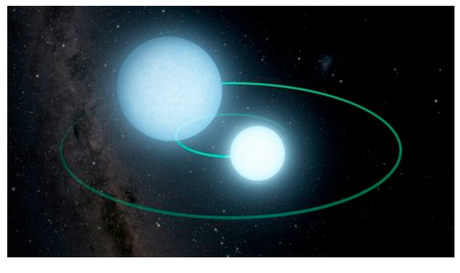
The candidate black widow system ZTF J1406+1222 is part of a hierarchical triple, and has a 62 min (0.043 day) orbital period (Burdge+ 2022) - the shortest known period for such a system, and challenges formation models.



(NASA's Goddard Space Flight Center/Cruz deWilde)

### Double Compact-Object Systems

ZTF J1539+5027 is a double white dwarf binary that is undergoing rapid orbital decay and currently has an orbital period of only 414 s (Burdge+ 2019). Systems that contain two neutron stars or a neutron star and a black hole, are precursors to gravitational wave emitters. The discovery of such a system in the Galaxy would be of immense importance.

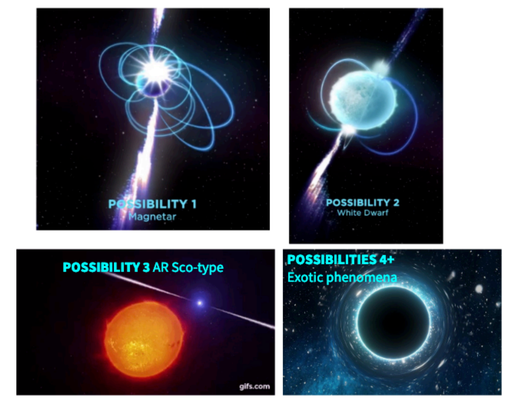


(Caltech/IPAC/R. Hurt)

## And Also Slow Pulsars

Pulsars with exceptionally long periods are now known to exist. These include:
GPM J1839-10 P = 1091 s
GLEAM-X J1627 P = 1080 s
GCRT J1745 P = 4620 s
ASKAP J1935 P = 3228 s

The emission mechanism is unclear, but they are suspected to be highly magnetized neutron stars, and could even be related to FRBs (e.g. Cooper & Wadiasingh 2024). It has been suggested that there could be ≳ 13,000 of these objects in the Galaxy (Beniamini+ 2023).



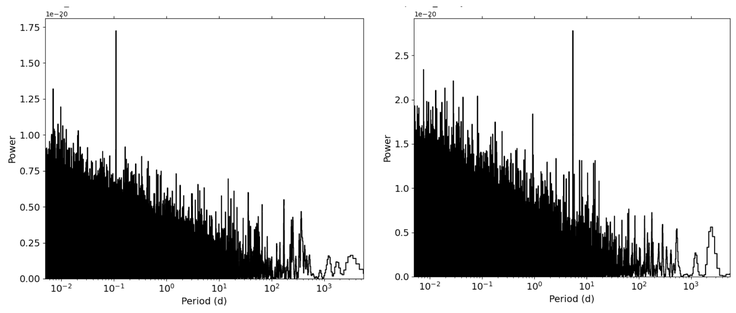

(Hurley-Walker 2024)

## Search Status

We have completed our initial search down to a period of 0.005 days for all sources in the 4FGL DR4 catalog.

Several possible candidates have been identified, although none has yet been confirmed. We continue to monitor the strength of the peaks in the power spectra as additional LAT data continues to be obtained. For a persistent periodic modulation, the relative height of a peak in the power spectrum compared to the noise level scales directly as the length of the light curve.

We are also conducting a variety of multi-wavelength followups to find counterparts and determine if they are modulated on the candidate periods. This would provide definite confirmation that a periodicity is real.




**Examples of candidate periods**

## Shorter and Shorter

Now that we have explored down to 0.005 days (432) seconds, 10x shorter than used previously, we plan to search to shorter periods still. Initially twice as short, with the goal of another factor of 10 shorter (0.0005 days, 43.2 s). For each source this will result in a 100 fold increase in compute demands.

### References

Beniamini+ 2023, MNRAS, 520, 1872
Burdge+ 2019, Nature, 571, 528
Burdge+ 2022, Nature, 605, 41
Cooper & Wadiasingh 2024, MNRAS, 533, 2133
Stella+ 1987, ApJ, 312, L17

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