Discovery of PSR J2339–0533, a redback millisecond pulsar powering the Fermi LAT bright source 0FGL J2339.8–0530

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Fermi Gamma-ray Space Telescope

Large Area Telescope (LAT)
20 MeV - >300 GeV

Gamma-ray Burst Monitor (GBM)
NaI and BGO Detectors
8 keV - 40 MeV

Recently completed 7 years of operations

- Large area: 8000 cm² area (at 1 GeV)
- Broad band: 20 MeV to >300 GeV
- Good localization: 0.6–0.8 deg radius PSF (1 GeV)
- Continuous sky survey mode of operation with wide FOV

Five years of LAT survey data
Using LAT to Find Radio Pulsars

Out of 1873 sources, 575 unassociated with plausible counterparts at other wavelengths

Best targets are sources with low variability and “pulsar-like” spectra

Used multiple techniques for ranking sources

Success! 68 MSPs found!

Fermi Pulsar Search Consortium (PSC) searches with GBT, Parkes, Nançay, Effelsberg, GMRT, and Arecibo.
Digging Deeper: X-ray and Optical Studies

At time of 2FGL, 6 remaining UNIDs out of 250 bright sources, all pulsar-like

- Bright unassociated sources subjected to deep X-ray, optical and radio imaging observations to look for likely counterparts
- Could any be radio-quiet MSPs?
- 5/6 now identified
  - J2339-0533, this talk
  - J1311-3430 optical, blind search, radio MSP
  - J1227-4853 transitional MSP
  - J1653.6-0158 optical orbit MSP
  - J1906.5+0720 blind search PSR
  - J1702.5-5654 still UNID
Kong et al. discovered variable X-ray and optical source

Romani & Shaw added optical spectroscopy and solved the orbit

$T_{\text{eff}}$ varies from 3000 to 6000 K

Clearly a binary MSP in a 4.6 hour orbit. Modeling suggested a black widow type system with low mass (< 0.1 Msun) companion

Precise optical position + orbital period and phase led to a major search for gamma-ray pulsations from a radio quiet MSP

No gamma-ray pulsations found...

(Romani & Shaw 2011)
After several unsuccessful tries, 2.88 ms pulsations discovered in 1.6 hr GBT observation at 820 MHz

DM 8.72 gives D=450 pc

Measured semimajor axis 0.611 lt-s, larger than expected

$M_C > 0.26 M_☉$

Redback, not black widow

Often not visible, highly variable 'weather' in the system

(Ray et al. 2015, in prep)
Limited search around radio orbital parameters quickly found LAT pulsations in this bright source

Missed previously because optical data suggested much lighter companion (thus a smaller orbit)

Holger Pletch et al. (2015) timed it with LAT data, determining F1, proper motion, and orbital period variability (req. 6 derivatives)
Summary

Optical and X-ray studies of LAT unassociated sources is a very promising avenue to continue to explore

New Pass8 sources lists in development

So far, no radio quiet MSP has been discovered, but some of them are very hard to see in radio because of material in the system

J2339-0533 is a nearby `redback' binary MSP system that can be well studied in radio, gamma-ray, X-ray and optical
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![Graph showing orbital period versus minimum companion mass for different types of binaries. The graph includes data points for globular cluster binaries, field binaries, and Fermi PSC.]