Discovery of an Ultra-Compact Gamma-ray Millisecond Pulsar Binary Candidate

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Millisecond Pulsars (MSPs)

- Very rapid rotating neutron star
- Majority are in binaries
- Some are isolated systems
- MSPs are detected in the radio, X-ray, gamma-ray, and OIR
- MSP begins its life as a normal pulsar and is spun up via accretion from its companion
Black Widow MSPs

- Some MSP binaries have an orbital period of < 1 day
- Pulsar radiation can ablate the companion, leaving an isolated MSP at the end
Black Widow MSPs

- Companion can either be a less massive (< 0.05 $M_\odot$) degenerate object (black-widow) or a late-type star (redback)
- BW/RB MSPs are the missing link between LMXBs and isolated MSPs
- Because of the pulsar’s heating on the companion, the optical emission from the companion can be changed by more than 2 magnitudes in an orbital cycle
How can we search for BW/RB MSPs?

• Traditionally, MSPs are discovered via radio timing
• Radio timing at the Fermi’s gamma-ray positions
• Blind search of gamma-ray pulsation is now possible with Fermi; it is however very hard for MSPs (Pletsch+ 2012, Science) and optical data are required
• MSPs can be “radio-quiet” that have not been seen yet
• No radio => Need X-ray/gamma-ray data
• Too many X-ray sources and many different classes of sources
• Gamma-ray data are more “simple”
What has Fermi found: The LAT two-year catalog

- Blazars: 57%
- Unknown: 31%
- Non-blazar active galaxies: 1%
- Pulsars: 6%
- Supernova remnants: 4%
- Globular clusters, high-mass binaries, normal galaxies and more: 1%

Credit: NASA/Goddard Space Flight Center
Selecting MSP candidates in the Fermi catalog

- Steady (variability index)
- Non power-law source (curvature index)
- High Galactic latitude
- No reported radio emission
- Archival X-ray imaging data (compare gamma-ray and X-ray, and hopefully multi-wavelength follow-up)
Multi-wavelength campaign for searching “radio-quiet” MSPs

- Select suitable unidentified Fermi objects (UFOs) for follow-up X-ray and optical observations
- Swift/Chandra/XMM observations can identify possible counterparts; no radio counterparts
- Identify the optical counterpart and look for optical variability due to the orbital modulation
UFO as a "radio-quiet" gamma-ray emitting MSP in a binary? 1FGL J2339.7-0531

Optical/X-ray @4.6hr

Kong+ 2012

Fermi
JVLA Continuum Observation of the RB MSP 1FGL J2339.7-0531

63 μJy
IFGL J1653.6-0158: a “radio-quiet” ultra-compact MSP?

- Steady gamma-ray source
- Exponential cutoff power-law spectrum
- X-ray/gamma-ray flux ratio: ~0.5% (typical of MSPs)
- No pulsation from GBT (Ransom+ 2011) and Effelsberg (Barr+ 2013)
- The brightest X-ray source within the Fermi error circle has an optical counterpart (R~20)
IFGL J1653.6-0158: a “radio-quiet” ultra-compact MSP?

- Preliminary study was performed with the 1m telescope at Lulin Observatory in Taiwan.
- Variability on timescale of 1 hour is seen.
- We performed a time-series observation with the 2.5m INT at La Palma in 2014 June.
IFGL J1653.6-0158: a “radio-quiet” ultra-compact MSP?
IFGL J1653.6-0158: a “radio-quiet” ultra-compact MSP?

Chandra

Kong+ 2014
Accreting millisecond X-ray pulsars (AMXPs) have been found with ultra-compact (< 80 min) binary periods

An ultra-compact binary consists of a compact object and a degenerate or partially degenerate companion

Ultra-compact binaries are important sources for gravitational waves

It should be natural to have an ultra-compact rotation-powered MSP when the accretion of an ultra-compact AMXP stops

1FGL J1653.6-0158 could be the first example of an ultra-compact MSP
Optical spectroscopy shows that 1FGL J1653.6-0158 is hydrogen poor (Romani+ 2014) => more likely a black widow instead of a redback

Pulsation search (radio, gamma-ray, and X-ray) will be the ultimate test

An accurate optical orbital period will be crucial

JVLA proposal was proposed to confirm if it is truly “radio-quiet”

XMM and NuSTAR observations to obtain a better X-ray lightcurve and phase-resolved spectroscopy were proposed

We are looking forward to the 3FGL catalog (>300 new UFOs)