



Multi-wavelength Observations of “radio-faint” Black Widow/Redback Millisecond Pulsars

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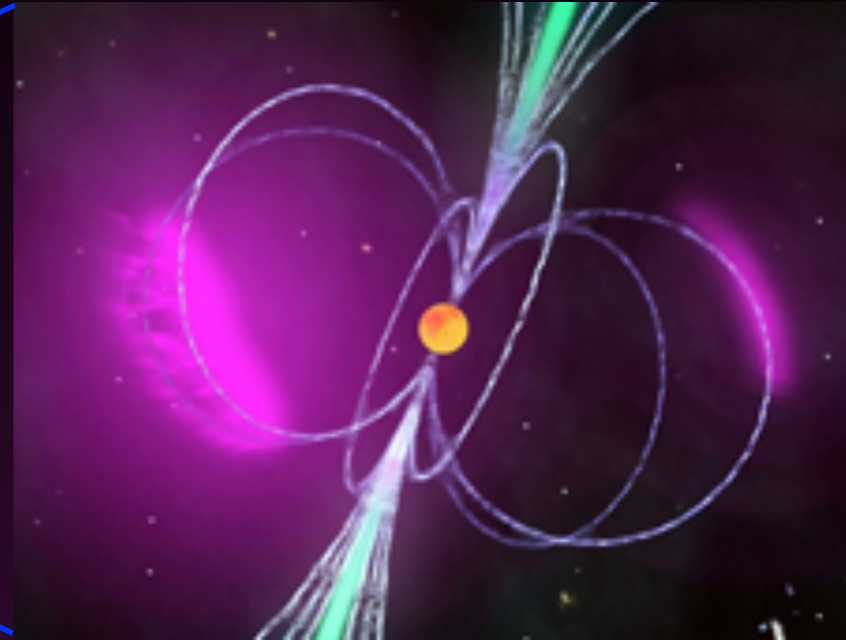
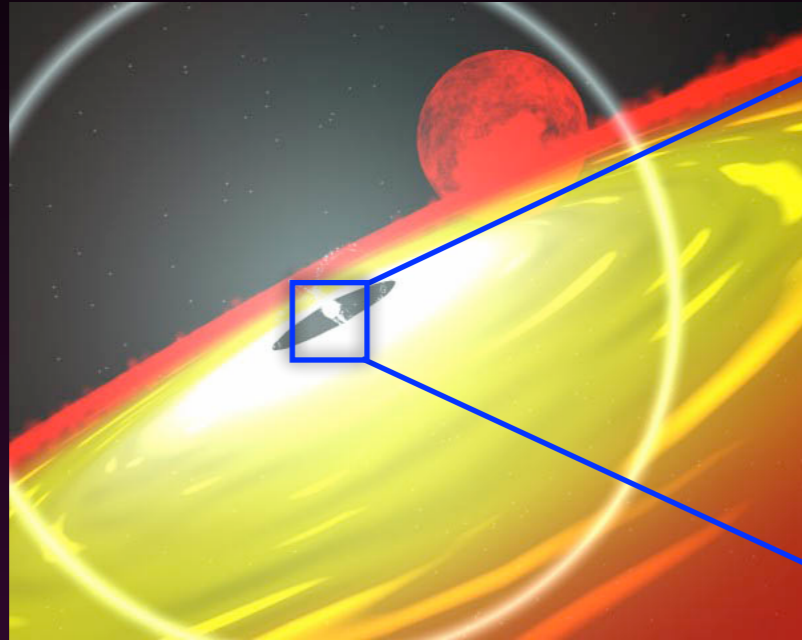
On behalf of the Fermi Asian Network (FAN)

Black Widow/Redback MSPs

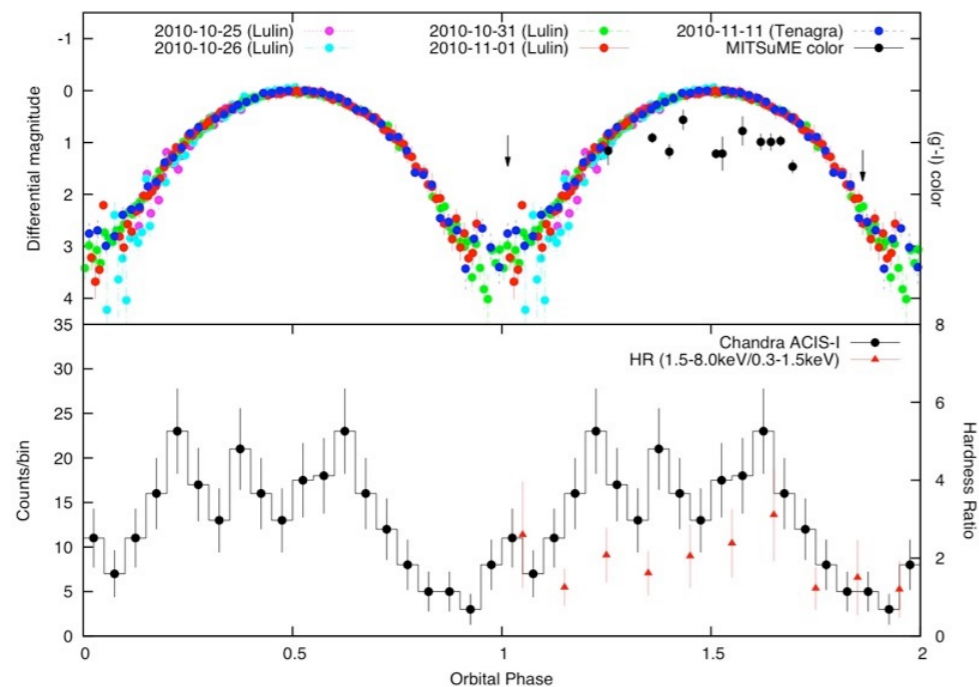
- MSP begins its life as a normal pulsar and is spun up via accretion from its companion
- Some MSP binaries have an orbital period of < 1 day
- Companion can either be a less massive ($< 0.05 M_{\odot}$) degenerate object (black-widow) or a late-type-like star (redback)
- Pulsar radiation can ablate the companion, leaving an isolated MSP at the end
- BW/RB are the missing link between LMXBs and isolated MSPs. All 3 tMSPs are RBs.



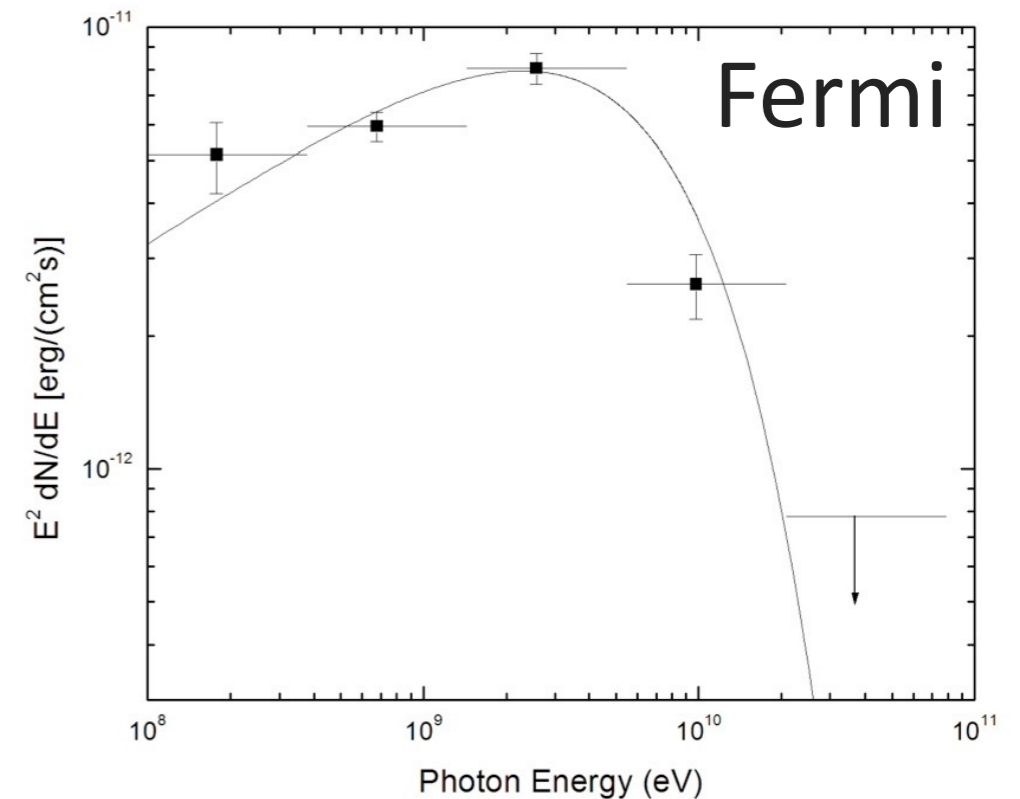
Multi-wavelength Emissions of BW/RB



Optical/X-ray @4.6hr



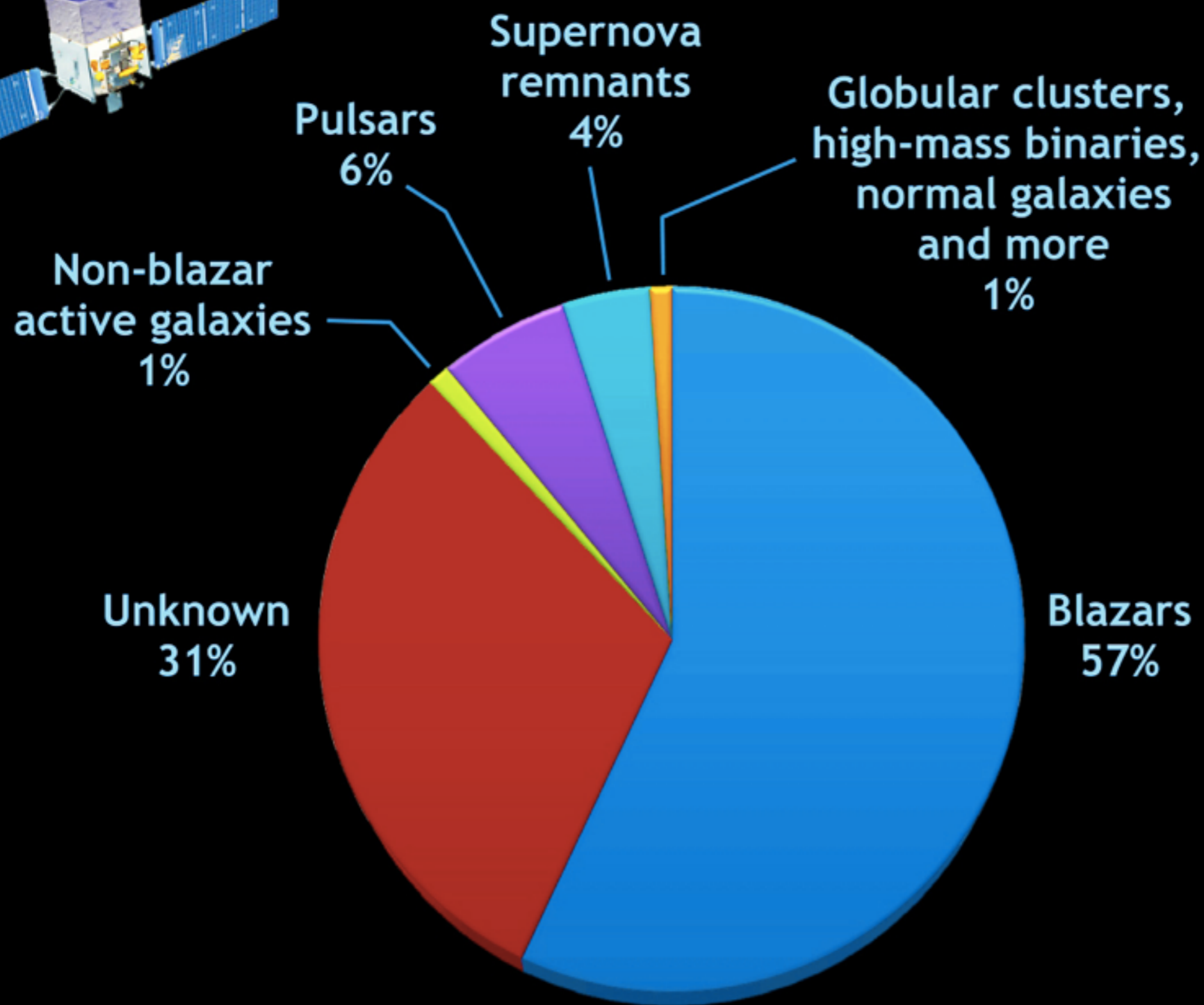
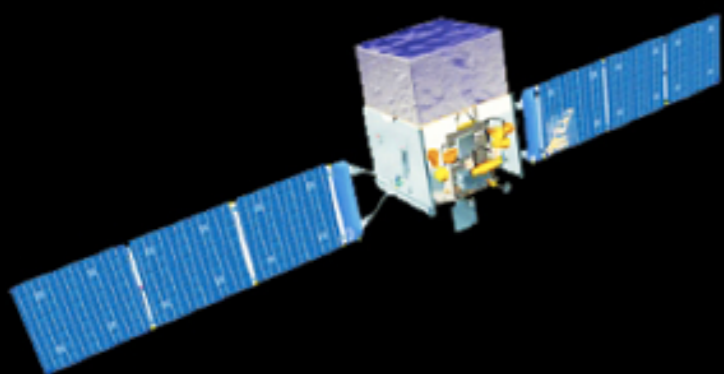
Kong+ 2012



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-faint" 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

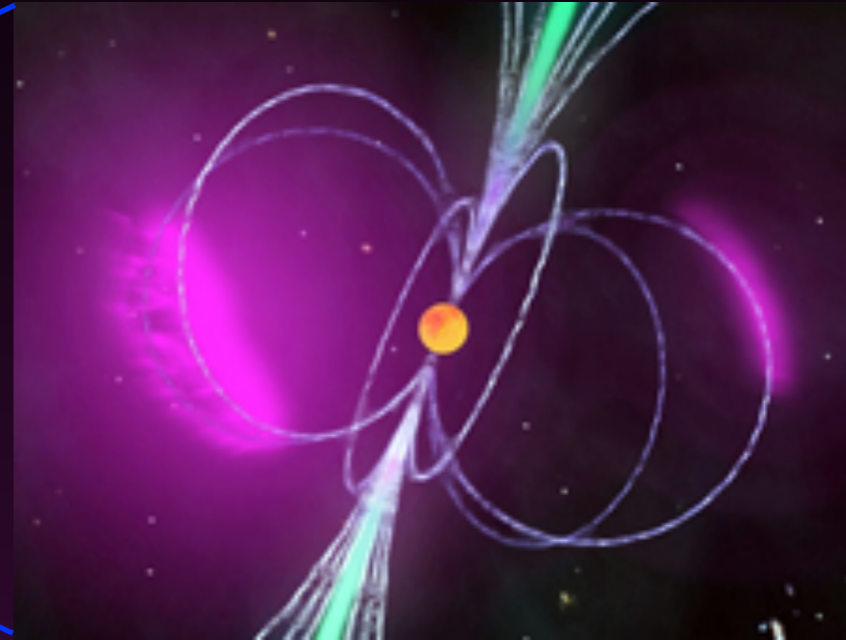
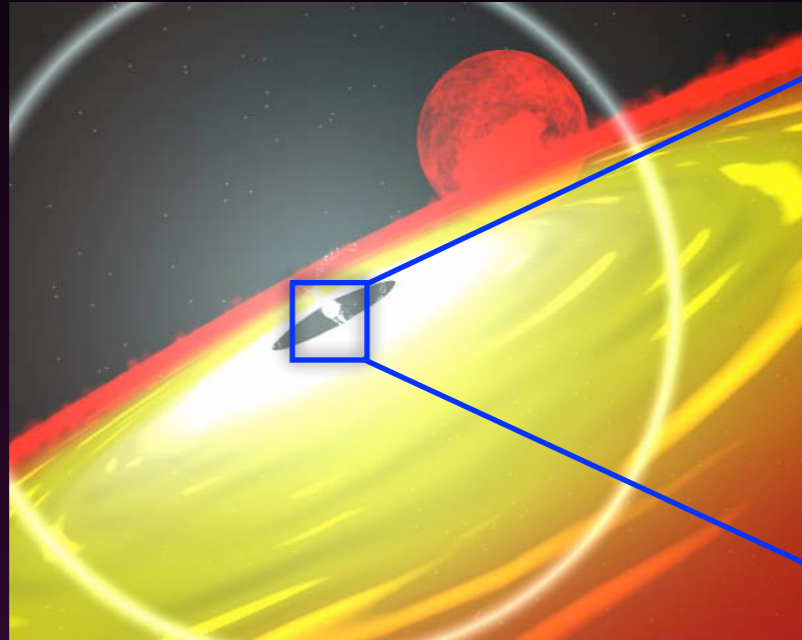


Multi-wavelength campaign for searching “radio-faint” MSPs

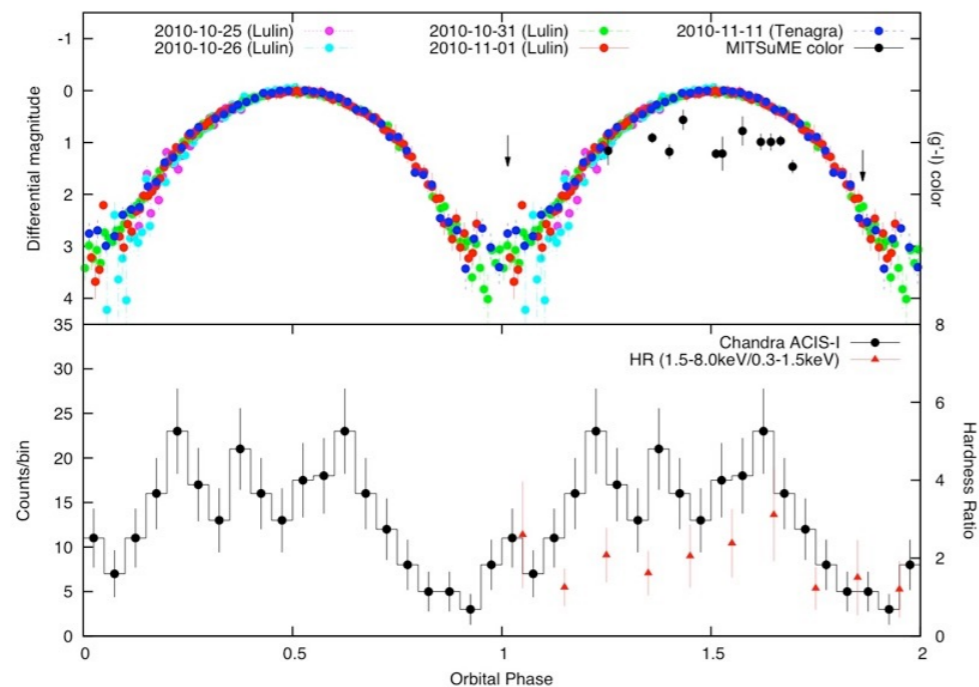
- Select suitable unidentified Fermi objects (UFOs) for follow-up X-ray and optical observations
- Swift/Chandra/XMM observations can identify possible counterparts; no radio counterparts
- Identify the optical counterpart and look for optical variability due to the orbital modulation
- In principle, a blind search in optical data is also possible (but will be very time consuming); we are trying with the Palomar Transient Factory (iPTF).

1FGL J2339.7-0531 = PSR J2339-0533

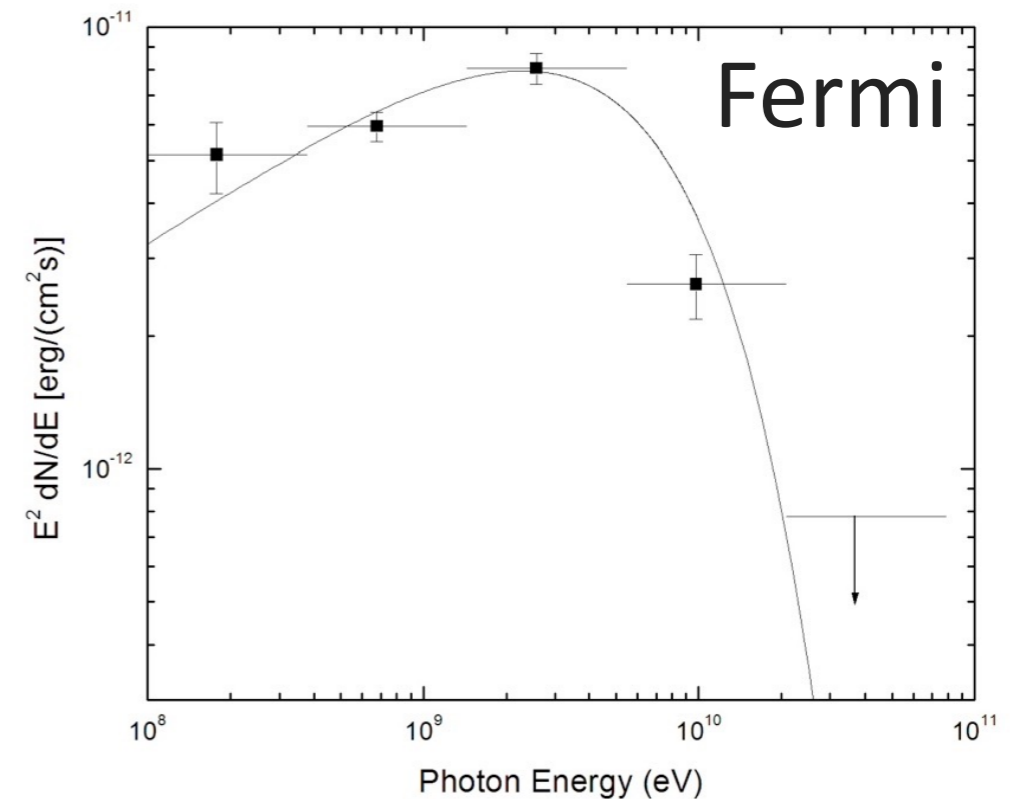
(Kong+ 2011,2012; Romani+ 2011)



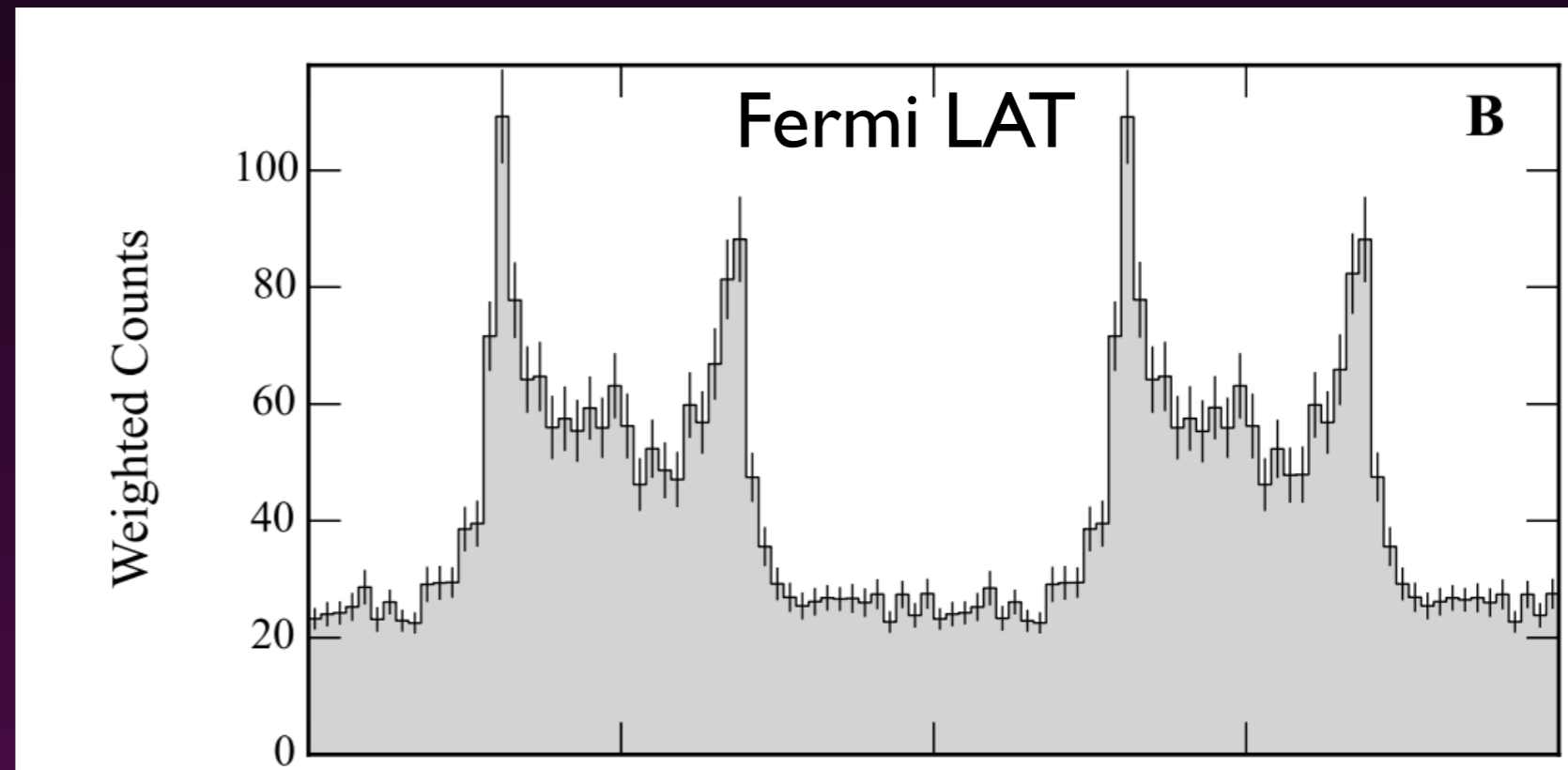
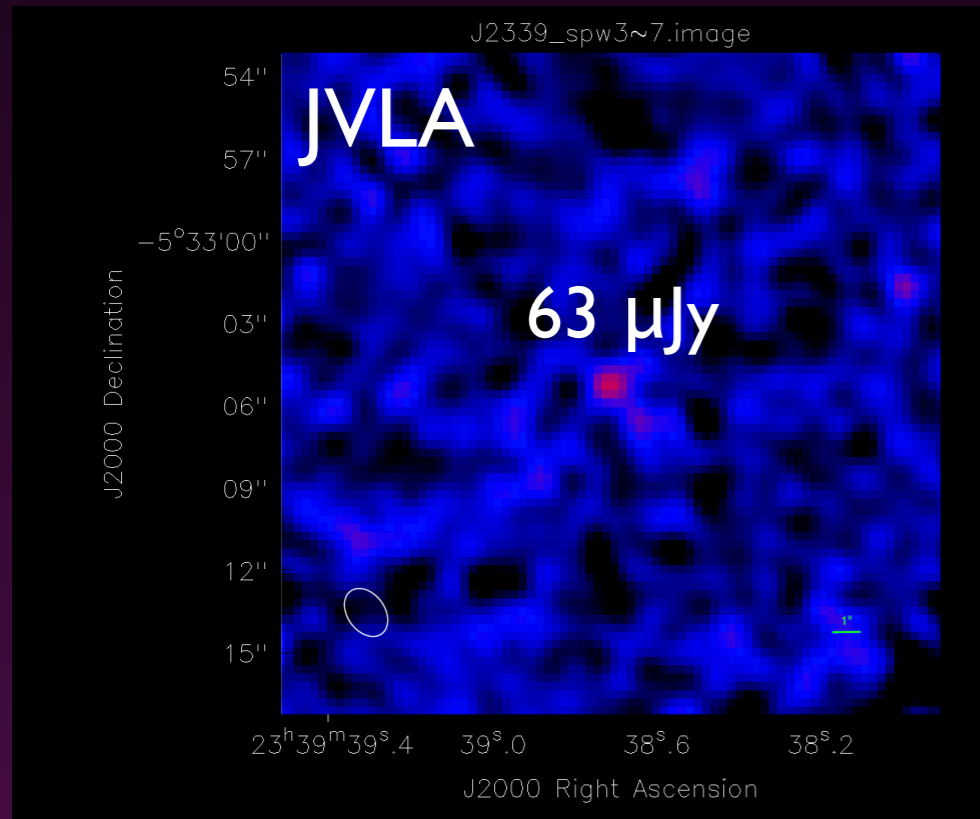
Optical/X-ray @4.6hr



Kong+ 2012



JVLA Continuum Observation and gamma-ray pulsation of the RB MSP 1FGL J2339.7-0531



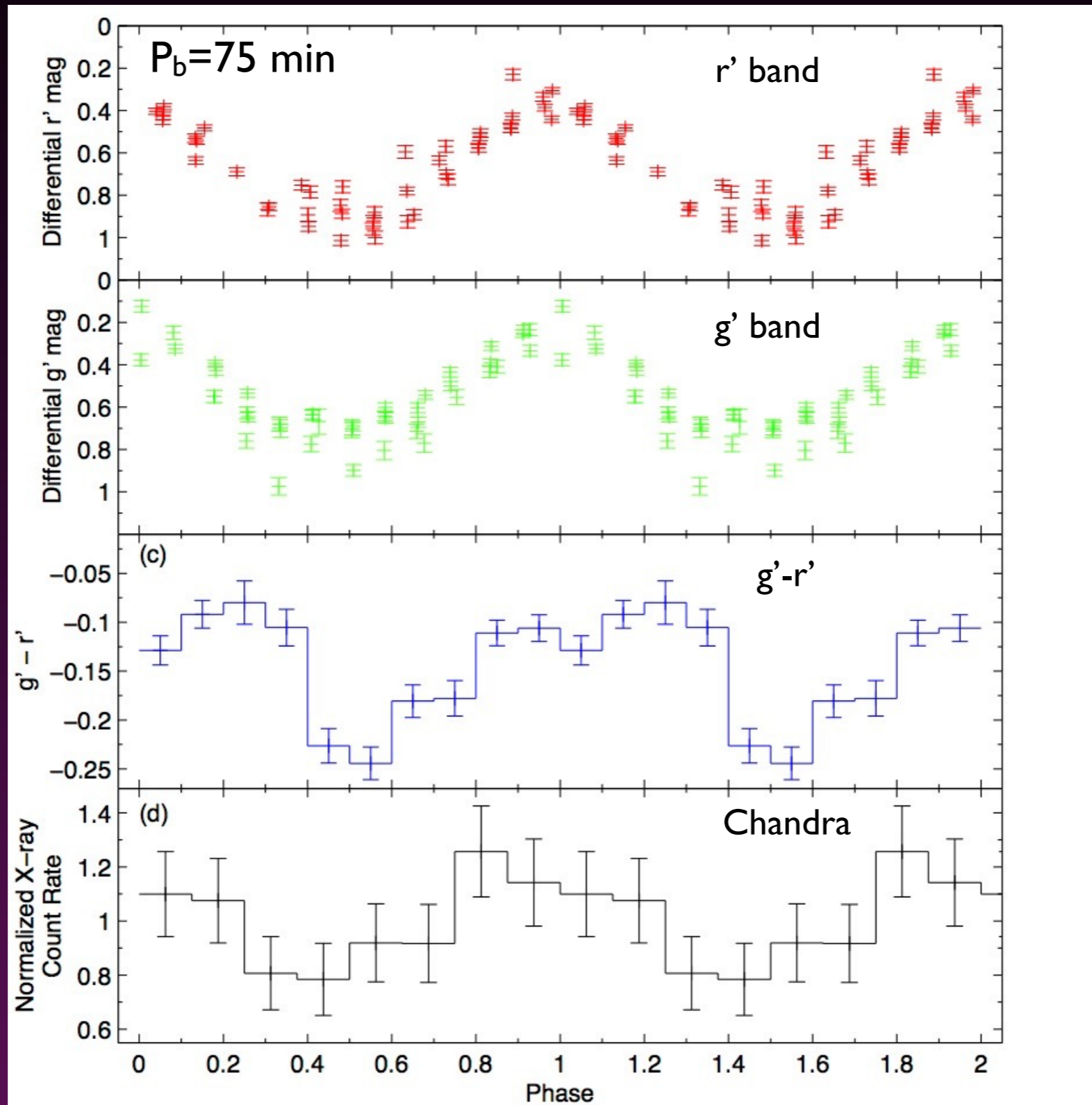
See also P. Ray for the
radio pulsation

Pletsch+ 2015

New BWs/RBs from UFOs

- 2FGL J1311.7-3429 = PSR J1311-3430 (Romani 2012)
- 1FGL J1653.6-0158 (Kong+ 2014; Romani+ 2014)
 - $P_{\text{orb}}=75$ min; ultra-compact system
 - Hydrogen poor (Romani+ 2014)
 - No radio pulsation; New JVLA observations will be carried out in coming months
- 1FGL J0523.5-2529 (Strader+ 2014)
- 3FGL J1544-1125 (Bogdanov & Halpern 2015; tMSP candidate)

1FGL J1653.6-0158: a “radio-quiet” ultra-compact MSP?



Ultra-compact MSP: A Missing Black Widow

- 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
- I FGL J1653.6-0158 could be the first example of an ultra-compact MSP

Isolated MSPs from UFOs?

- 2FGL J1744.1-7620, 2FGL J1625.2-0020: Faint X-ray counterparts (possibly thermal origin) were identified. $F_x/F_{\text{gamma}} < 0.1\%$, much smaller than typical BW/RB (Hui+ 2015, submitted)
- No optical counterpart associated with the X-ray source (may need bigger telescopes)

Multi-wavelength Synergy

- Radio and gamma-ray timing are still the most efficient way to search for new BW/RB MSPs
- Gamma-ray data with X-ray/optical identification will play a key role when radio pulsation search fails
- Orbital modulation from optical data are critical for searching radio/gamma-ray pulsation (Pletsch+ 2012)
- All-sky optical survey (e.g., iPTF and LSST in the future) may find new candidates
- LSST + SKA (+ PANGU ?) will create a huge BW/RB MSP database for a population study