Multiwavelength Observations of PSR J1048+2339 (3FGL J1048.6+2338)

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Arecibo Radio Pulsations Search

- 34 Fermi sources (2013): Cromartie et al. (2015)
    - Non-variable, unassociated.
    - Fermi error ellipse < 15' across (diameter of Arecibo 327 MHz beam)
    - |b| > 4 deg
    - Pulsar-like gamma-ray spectra.
- First 6 MSP discoveries:
    - P = 1.99 – 4.66 ms
    - DM = 17 – 65 pc/cc
    - All are binary: Pb = 2.6 – 1980.0 hours.
    - 3 Black Widows, 2 Redbacks, 1 NS-WD system

- 19 of 25 known BWs and 9 of 13 known RBs in the Galactic field were discovered in radio searches of Fermi unassociated sources.

PSR J1048+2339

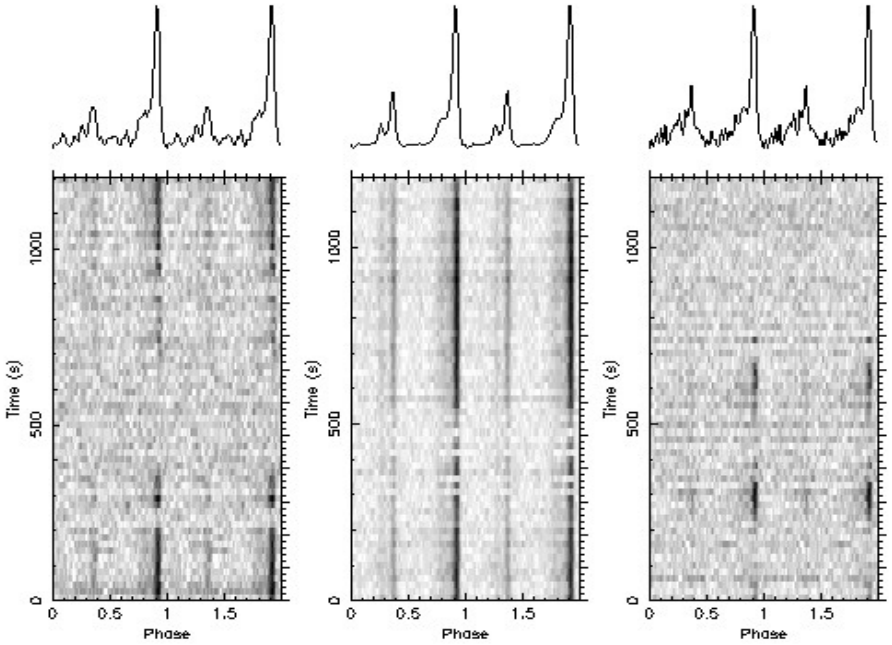


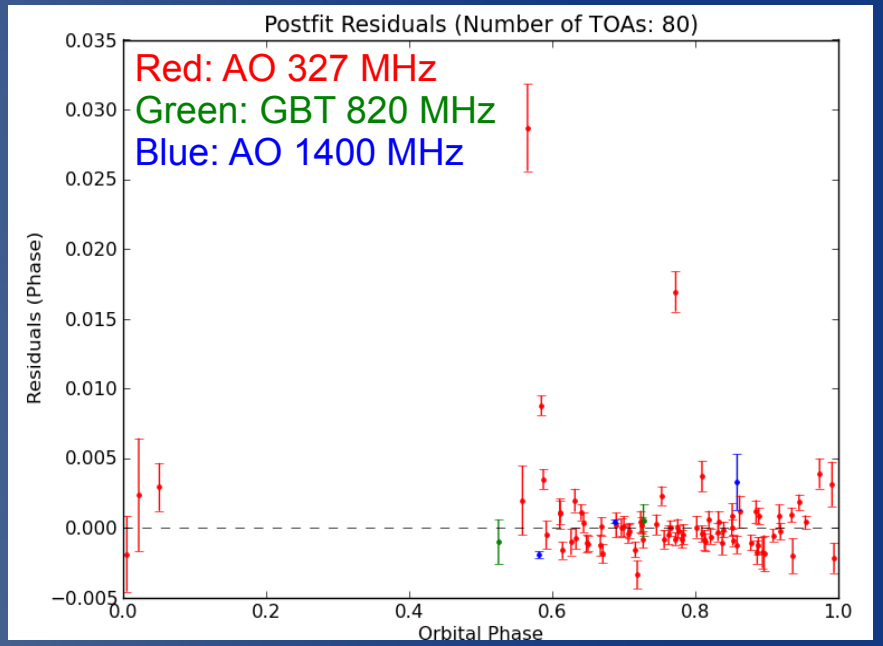
Fig. 1.— Folded pulse profiles and subintegration vs. pulse phase for three epochs when observations were made at different orbital phases approaching eclipse ingress. Left: MJD 57084, $\phi_{\rm orb} = 0.70 - 0.76$. Middle: MJD 57075, $\phi_{\rm orb} = 0.84 - 0.89$. Right: MJD 57064, $\phi_{\rm orb} = 0.94 - 0.99$. Two full rotations are shown in each panel.

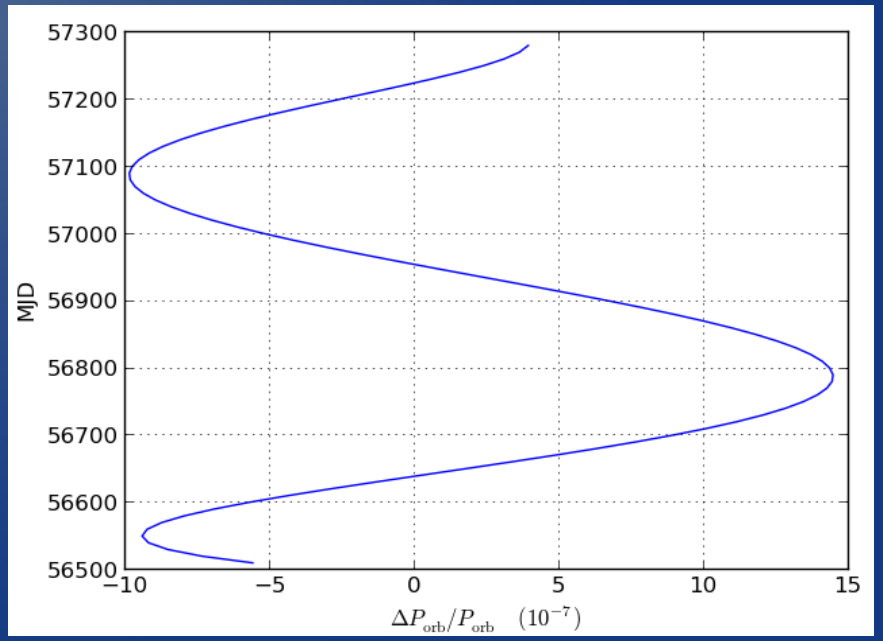
Arecibo 327 MHz

- Pulsar: P = 4.67 ms, DM = 16.65 pc/cc
- DM-based distance (NE2001) = 0.7 kpc
- Eclipsing redback system: Porb = 6 h
- Mc,min ~ 0.3 Msun
- Eclipses over ~50% of the orbit.

Radio Timing Solution

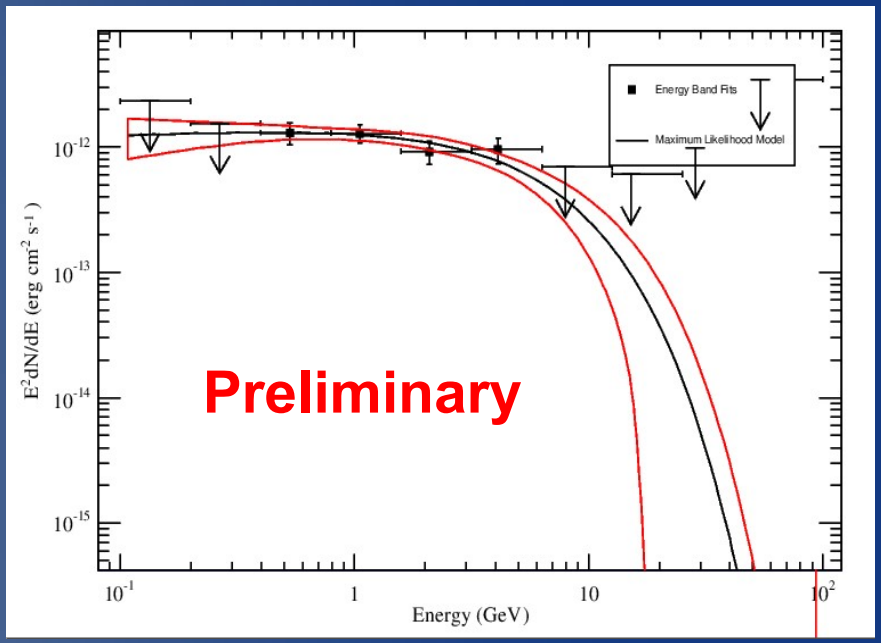
- Time span ~ 2 years.
- Fitted 5 orbital period derivatives → short time scale orbital variations.
- Property in common with other redbacks (J1023+0038, J2339-0533).
- Possible cause: quasi-periodic changes in gravitational quadrupole moment of the companion.
- Variable mag. field of companion → torque between radiative and convective layers → oblateness and ang. momentum change → orbital period change (Applegate 1992).
- Other possible causes of large PBDOT would result in monotonic change in PB (grav. wave emission, mass loss, Doppler shifts due to Galactic rotation or Shklovskii effect).





Gamma-ray Analysis

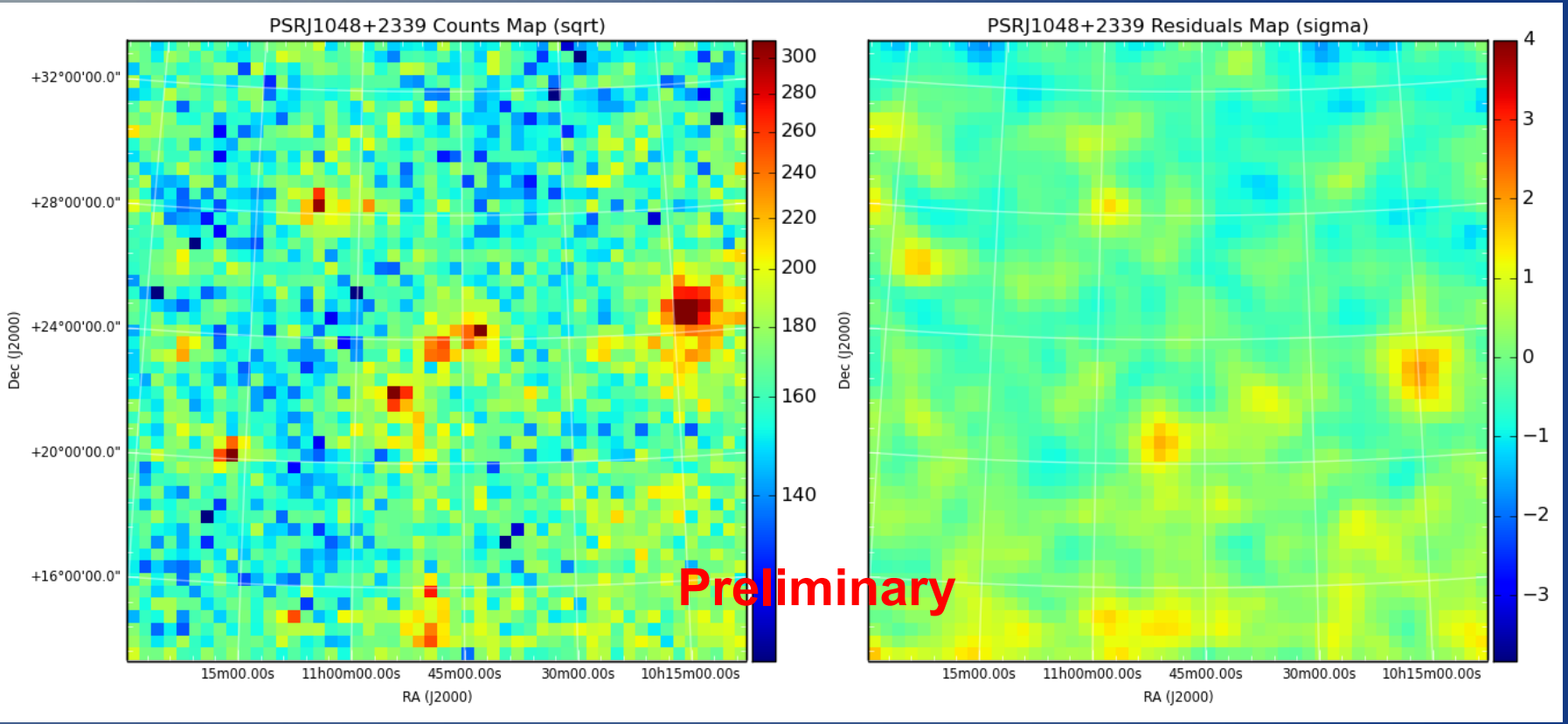
- Pass 8 data from 4 Aug. 2008 – 15 July 2015.
- SOURCE class events (evclass=128 and evtype=3) from intervals of good science data (DATA_QUAL=1 and LAT_CONFIG=1) within a 15 deg radius around the source.
- Zenith angle cut at 90 deg.
- Binned likelihood analysis over 20 deg x 20 deg region using 0.1 deg pixels.
- Gamma-ray spectrum fitted with an exponentially cutoff power law: cutoff energy = 5.0(23) GeV, spectral index = 1.9(2).



Spectral model for the pulsar:

$$\frac{dN}{dE} = N_0 \frac{E^{-\Gamma}}{E_0} \exp\left(\frac{-E}{E_c}\right)$$

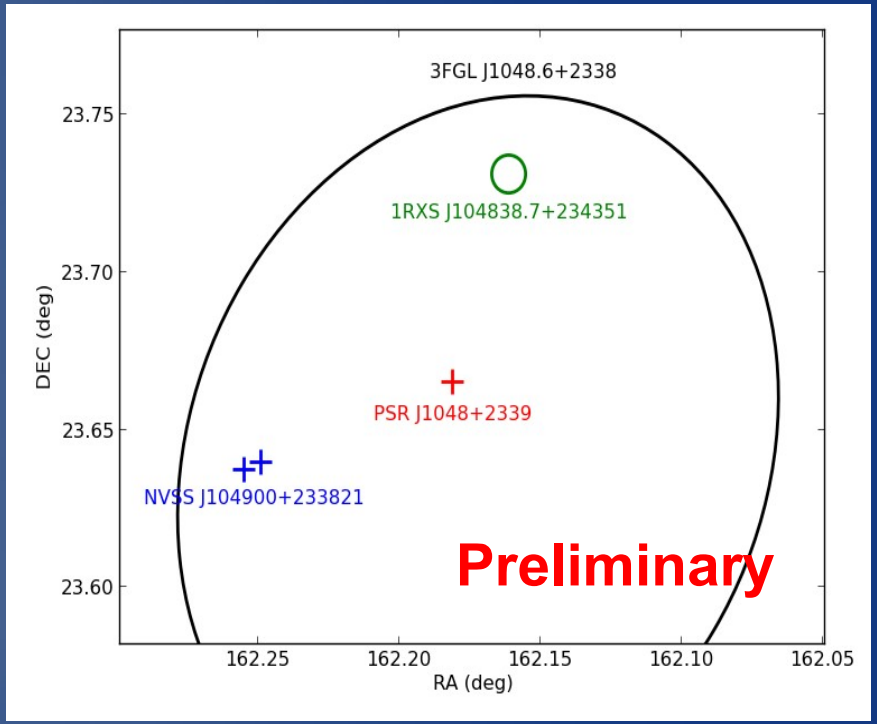
Gamma-ray Analysis (cont.)



Counts and residuals map from binned likelihood analysis of 20 deg x 20 deg field around PSR J1048+2339

Gamma-ray Counterpart

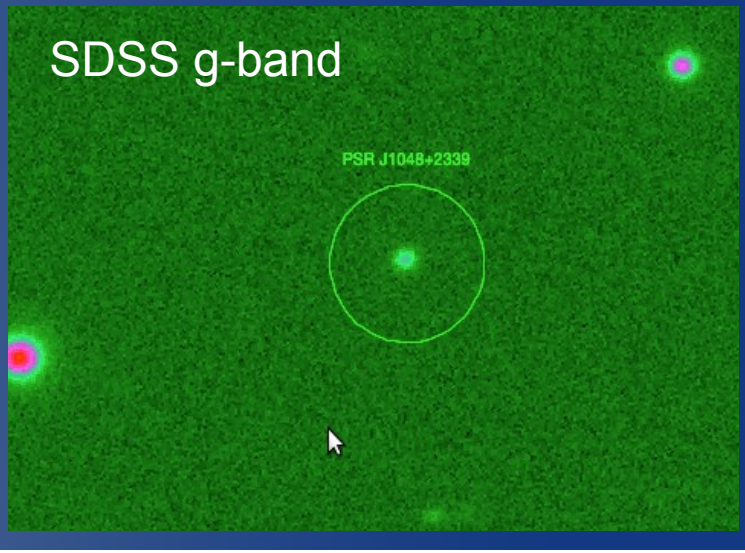
- Fermi-LAT source 3FGL J1048.6+2338 was selected for radio search from preliminary version of 3FGL.
- Published 3FGL: association with a BL Lac AGN → likely spurious.
- Pulsations search used events within 2 deg radius of pulsar position, weights based on spectral fit.
- Weighted H-test = 18.8; 3.45-sigma significance.
- No definite pulsation detection, but H-test improves as we extend the radio ephemeris time span.



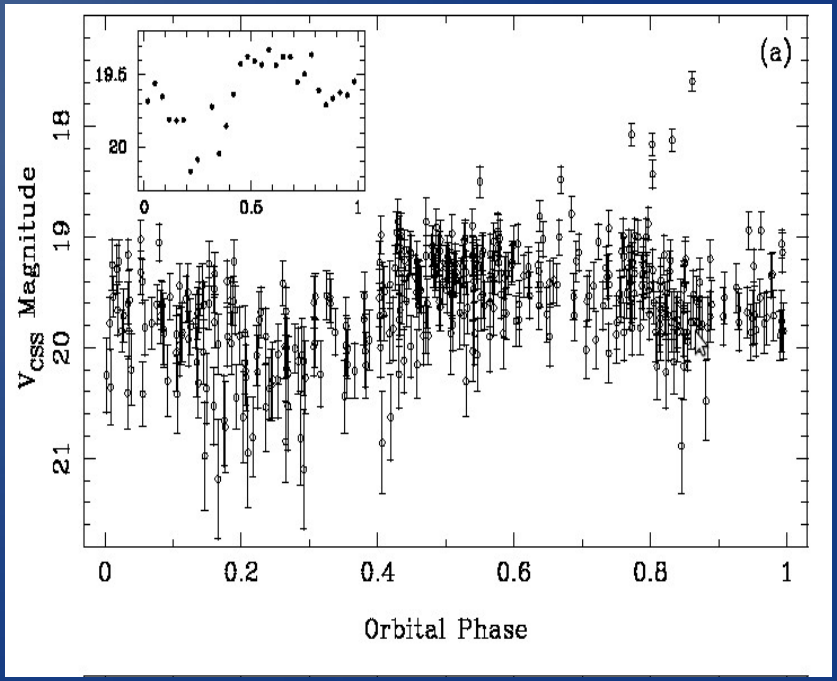
- Cannot yet extend timing solution to Fermi data before radio ephemeris start time due to orbital period variations and unmodeled proper motion.

Optical Counterpart

- 20-th magnitude source in SDSS, Palomar Transient Factory, Catalina Real-Time Transient Survey
- 1.0-magnitude modulation at the 6-hour orbital period; occasional flares.
- Companion luminosity suggests spectral type M4 V, with underfilled Roche lobe.

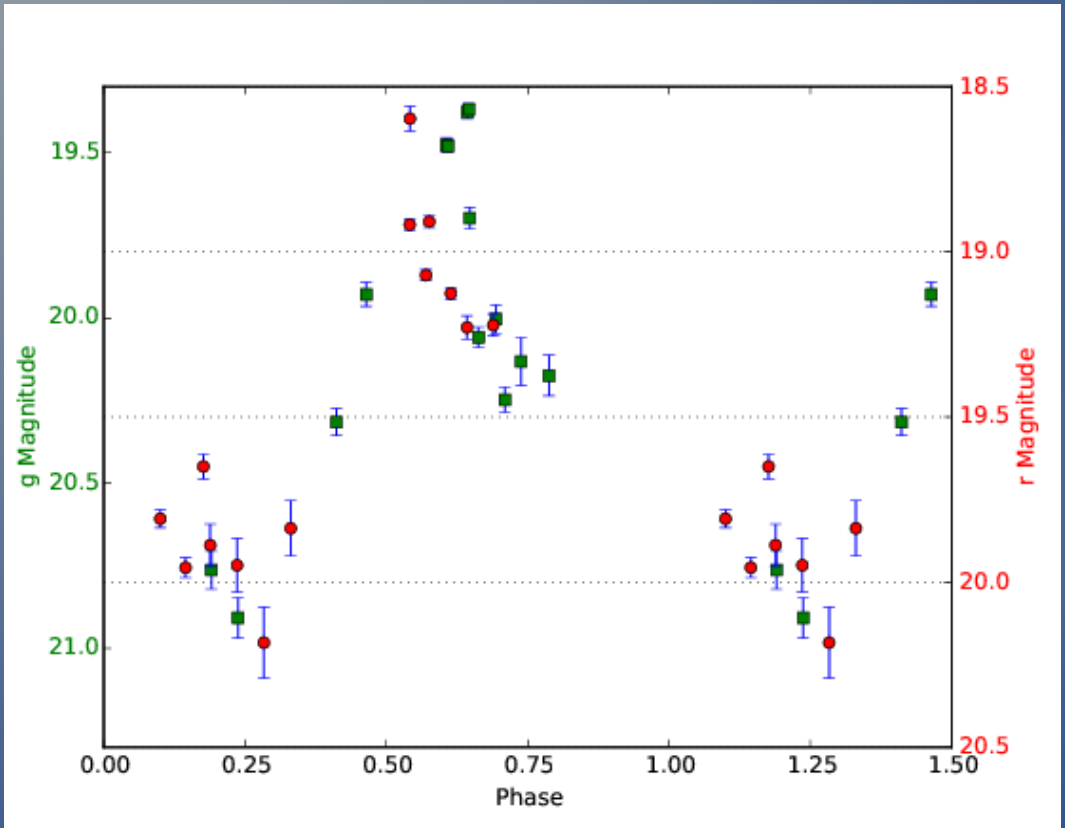


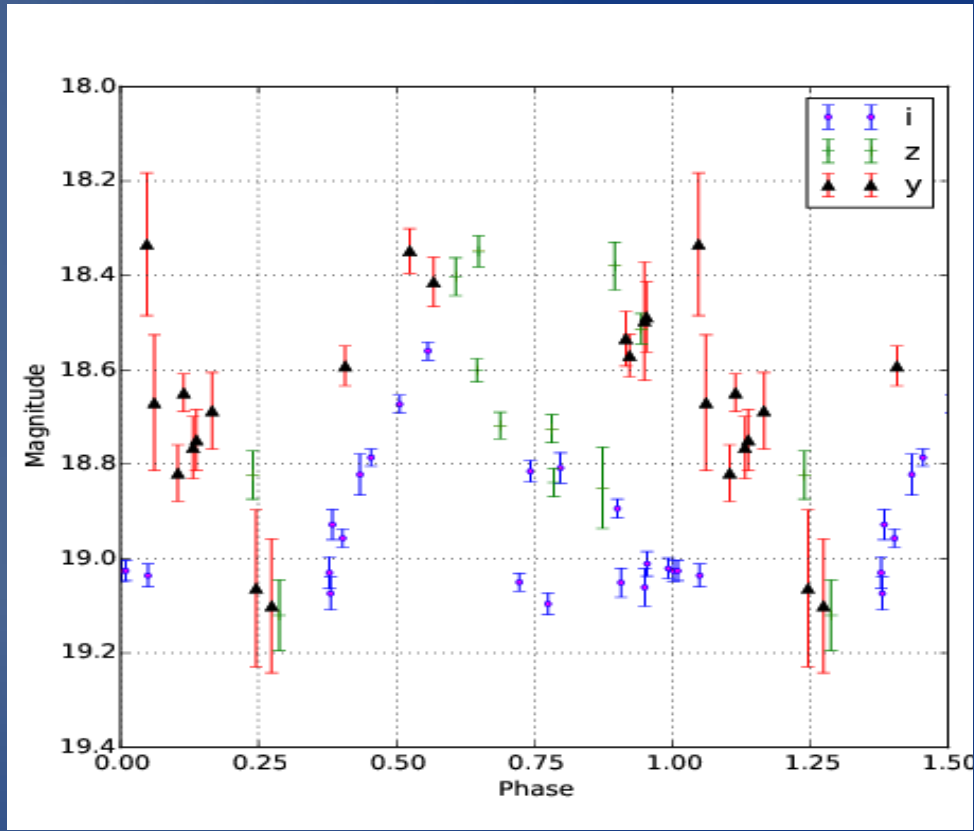
- Pulsar heats companion; orb. light curve mininum near phase ~ 0.25 → viewing cold side of companion.
- No max. at ~0.75 → Heating by asymmetric shock, or companion mag. field may channel pulsar wind to specific surface regions.



Catalina orbital light curve

Optical Counterpart (cont.)





- Pan-STARRS photometric light curves in g & r filters (left); i, z, and y filters (right).
- Intensity modulation more pronounced in g & r.
- Full interpretation of the optical variability is still in progress.

Summary

- J1048+2339 is one of few pulsars with optical and gamma-ray counterparts.
- Also one of few pulsars with an oscillating orbit → likely due to changes in the gravitational quadrupole moment of the companion.
- Companion shows asymmetric heating.
- A rare combination of paths to study a redback system.
- Paper in preparation and near submission.

- Fermi continues to facilitate many interesting pulsar discoveries → Especially true for BW and RB binary systems.