

Discovery of the Galactic High-Mass Gamma-ray Binary 4FGL J1405.1-6119

(arXiv:1908.10764)

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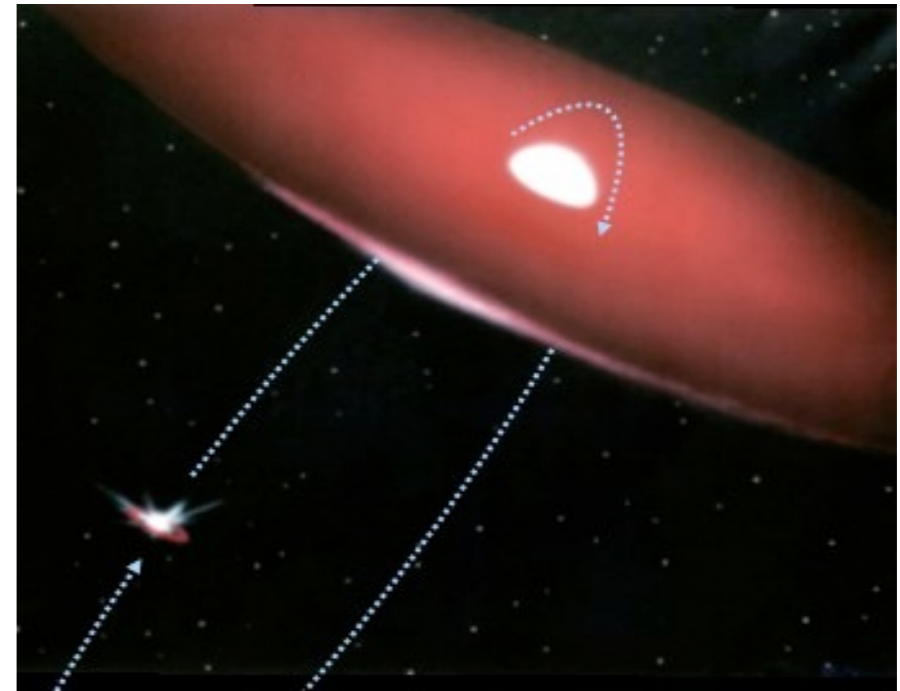
6: CSIRO Astronomy and Space Science

7: IRAP

8: University of Cape Town

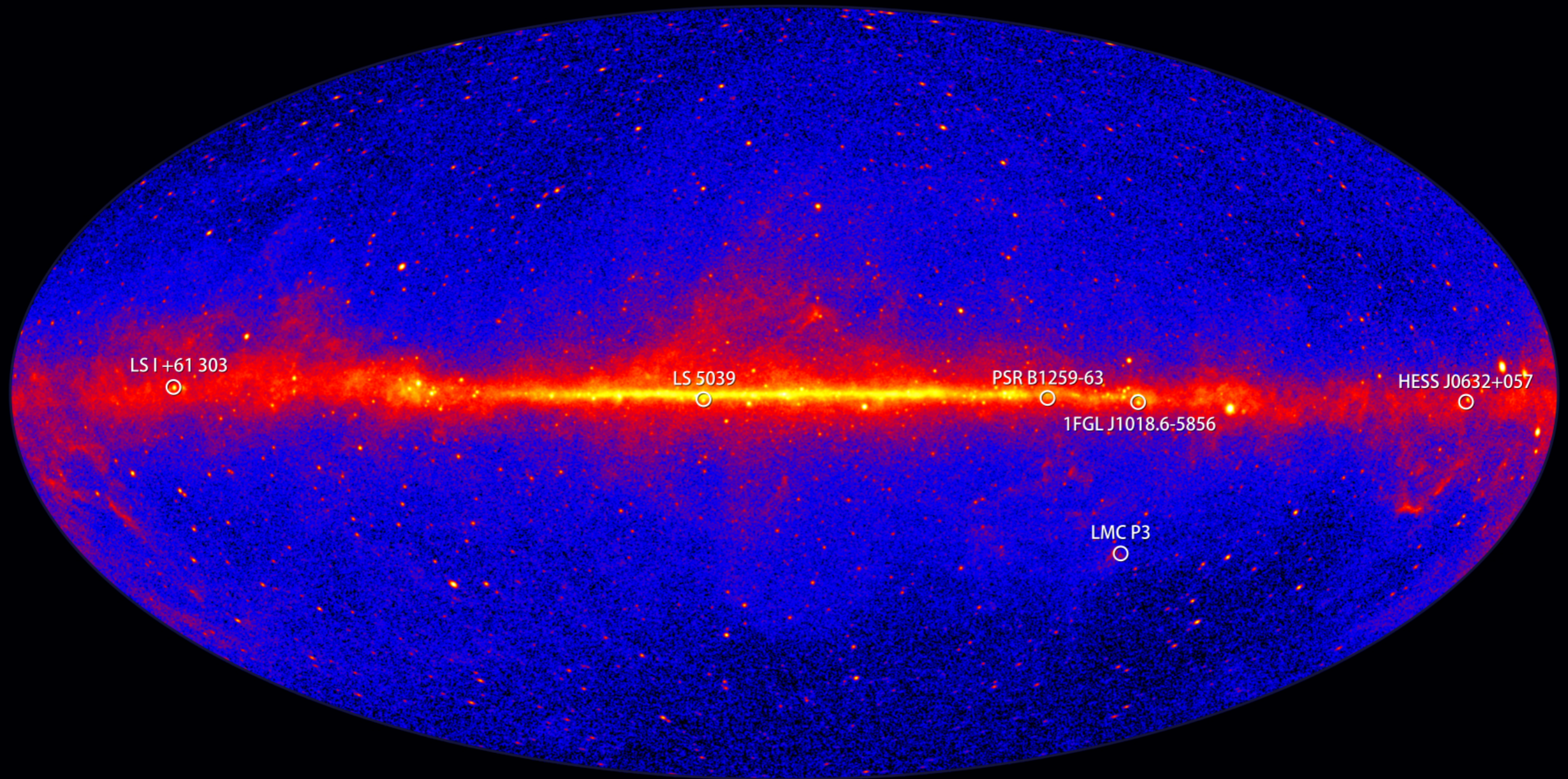
What is a Gamma-ray Binary?

- Binary with SED peak > 1 MeV, contains compact object.
- Emission driven by interaction between binary components.



- Pulsar orbiting a hot (O or B type) companion.
- Pulsar and stellar winds (or Be disk) collide and form shocks
- Fermi acceleration at shock + inverse Compton scattering of seed photons from OB star.

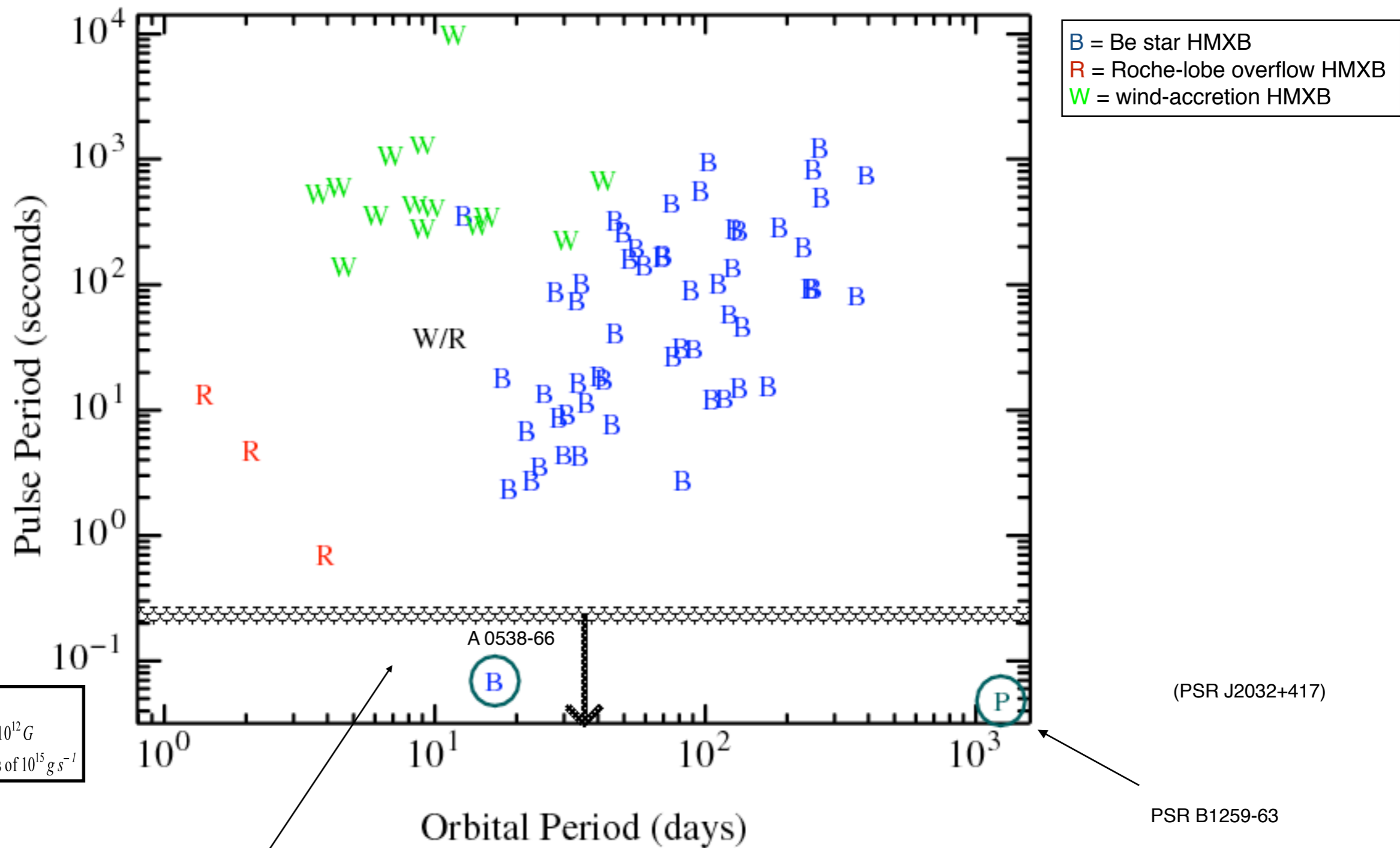
Very Few Gamma-ray Binaries are Known



J1018.6-5856 and LMC P3 were found from our search.

(PSR J2032+4127 not plotted here.)

X-ray Binaries Born as Gamma-ray Binaries



HMXBs containing neutron stars can begin as gamma-ray binaries with rapidly rotating neutron stars before spinning down.
 (And eventually become double neutron star binaries...)

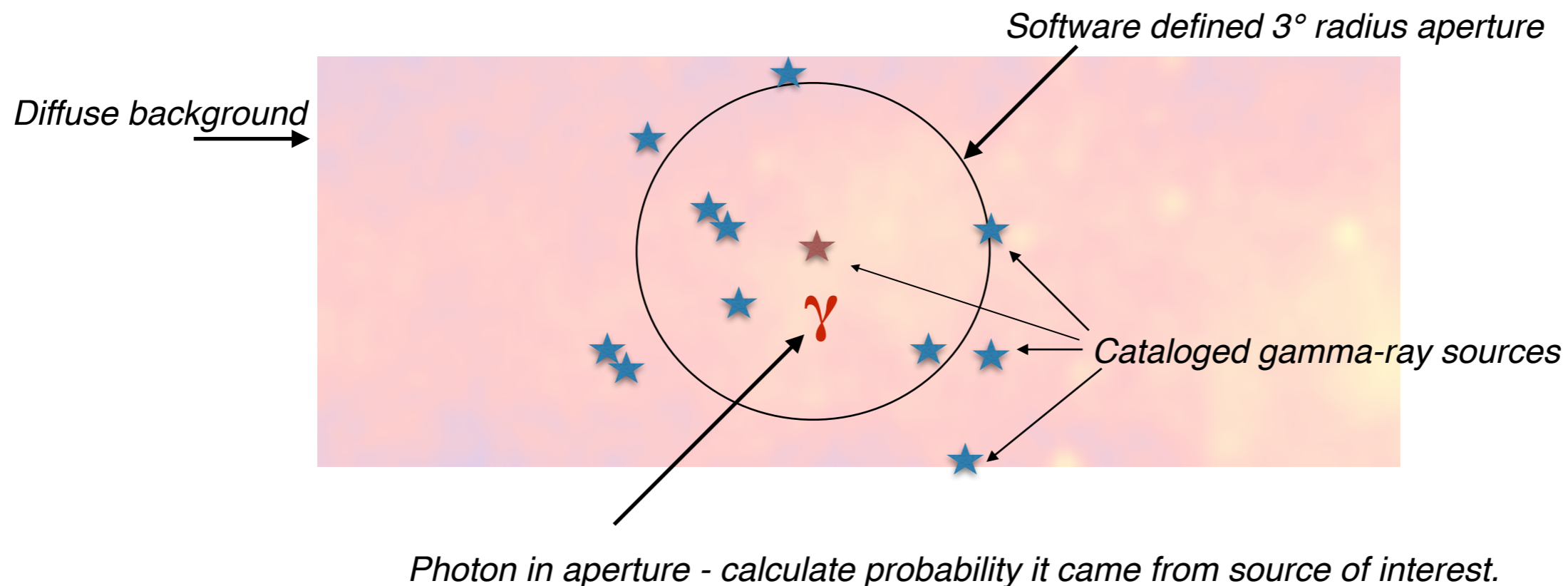
The Hunt for New Gamma-ray Binaries



- ~30 gamma-ray binaries were predicted in the Milky Way as early phase of HMXB evolution.
- Dubus+ (2017) estimate 10^{+89}_{-52}
- We search for gamma-ray binaries from detection of periodic variability with the LAT.
- We create light curves, and power spectra of these, for all sources in Fermi catalogs.

Optimizing Signal/Noise

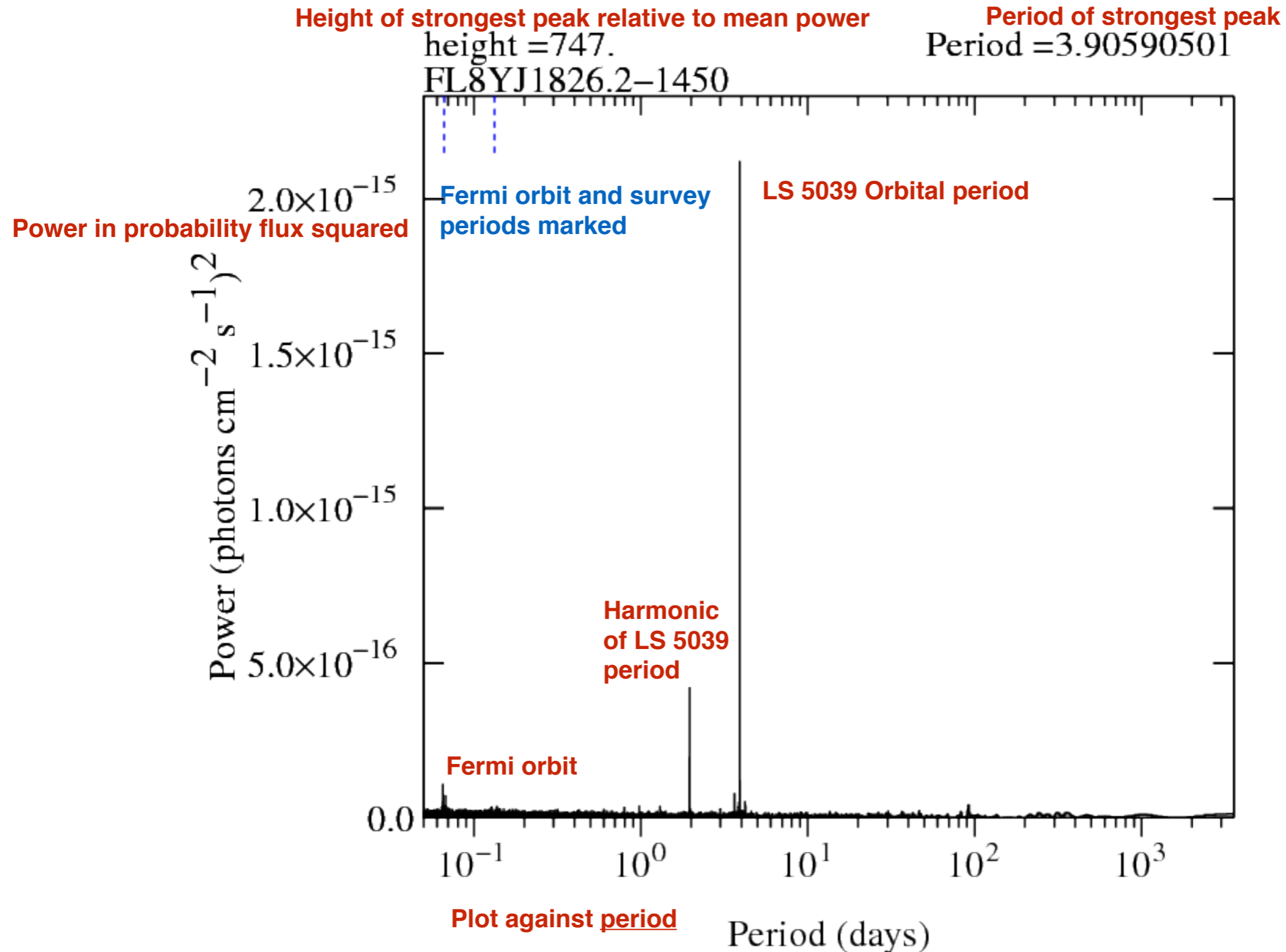
- Aperture photometry with 3° radius.
- Don't sum *photons* in aperture, instead sum their **probability** of coming from source of interest.
- Construct model for 10° region using LAT catalog, including diffuse background.



- In addition, for power spectrum weight each data point by exposure.

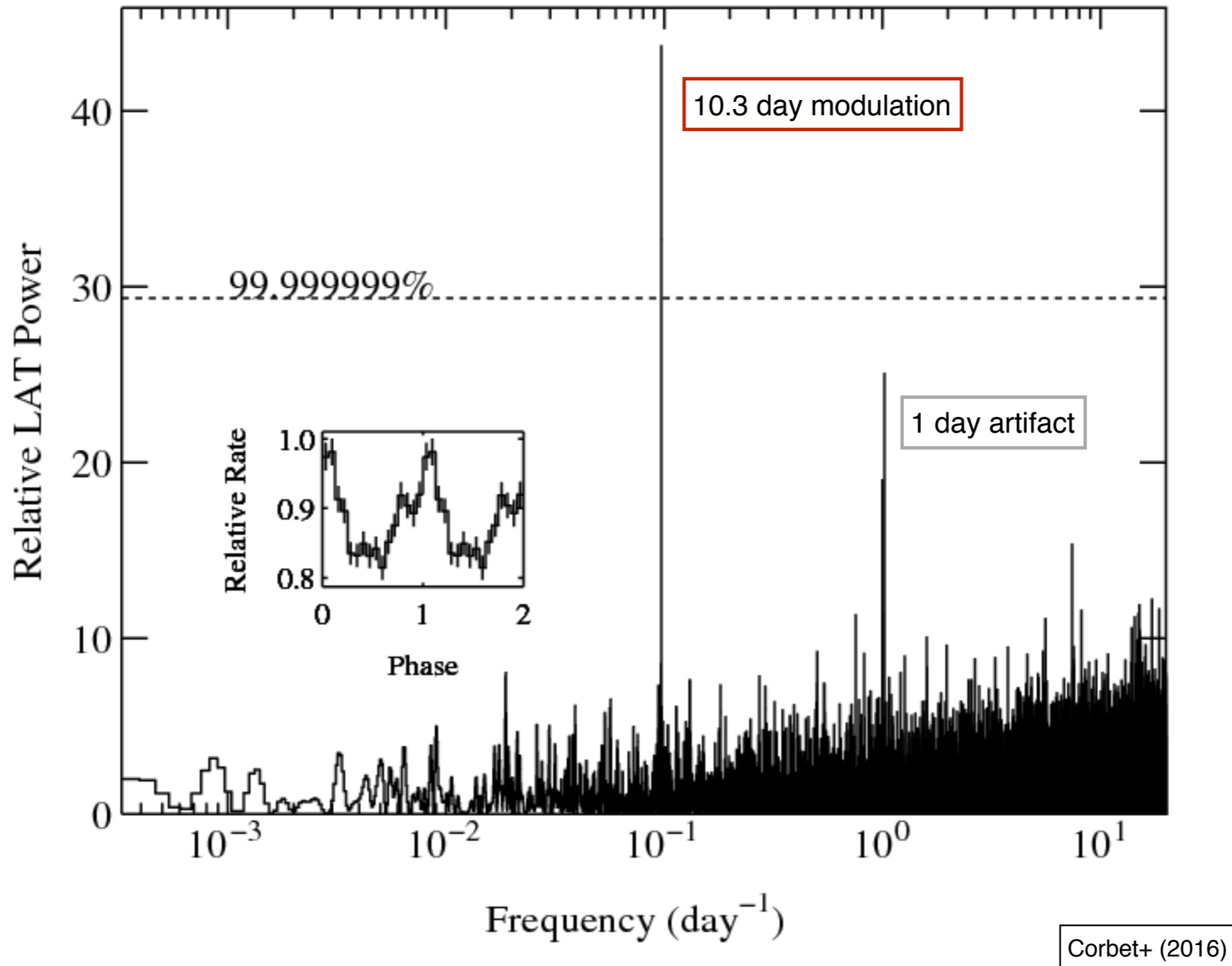
Example Output: LS 5039

- For every source we produce a plot of the power spectrum.
- This is LS 5039, strongest orbital peak of all sources.
 - Primary is *O5V star*.



Discovery of First γ -ray Binary Beyond Milky Way

“LMC P3” was an unassociated source in the LAT LMC survey. (i.e., no definite counterpart)



Counterpart: HMXB Candidate in an SNR

Chandra

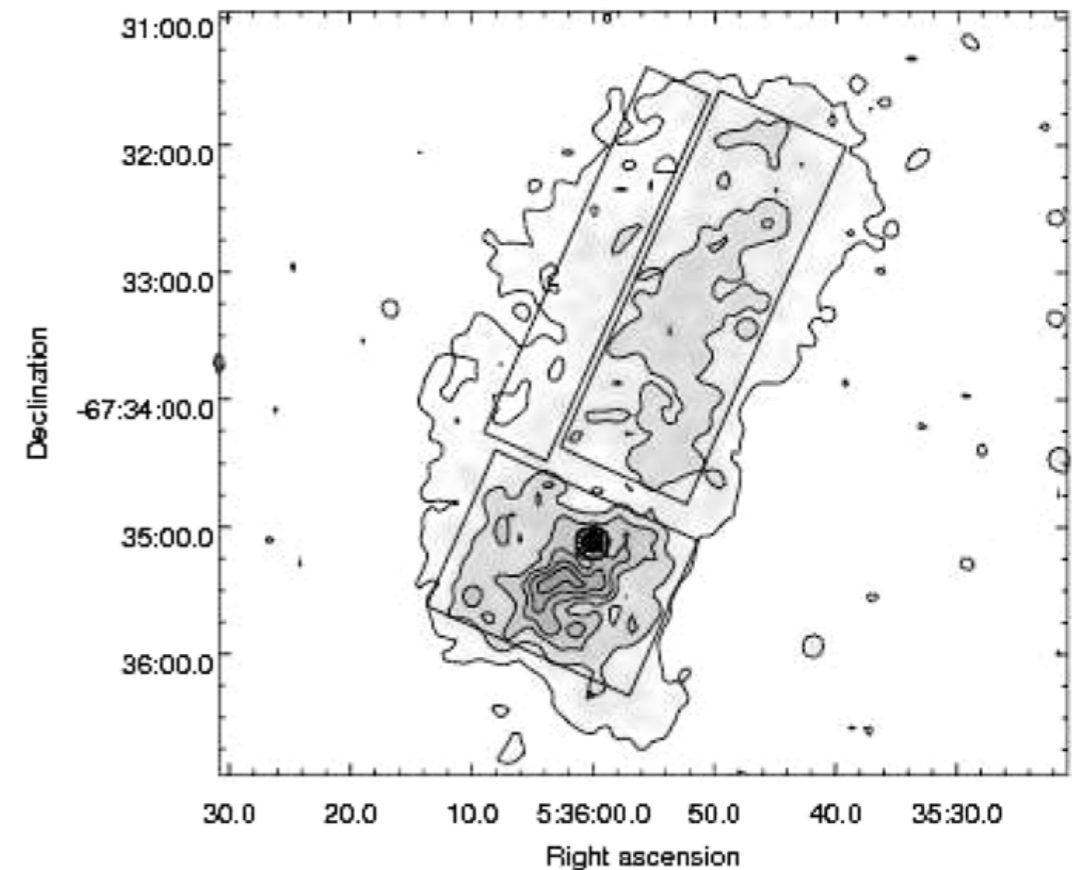
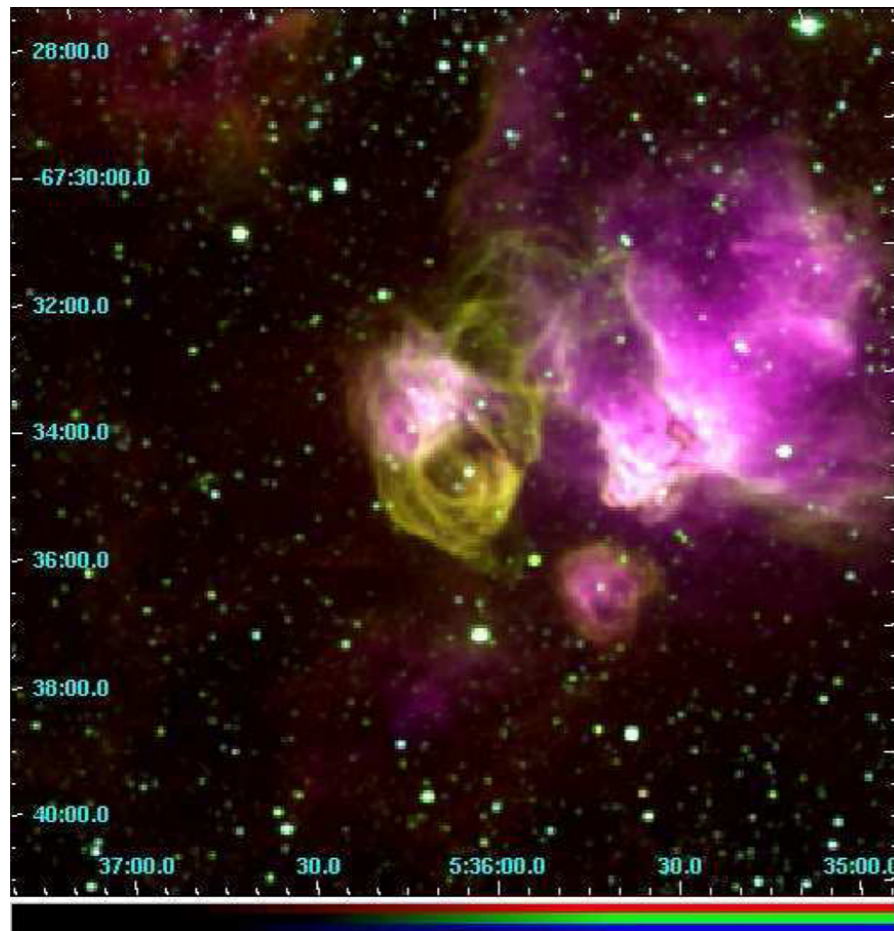


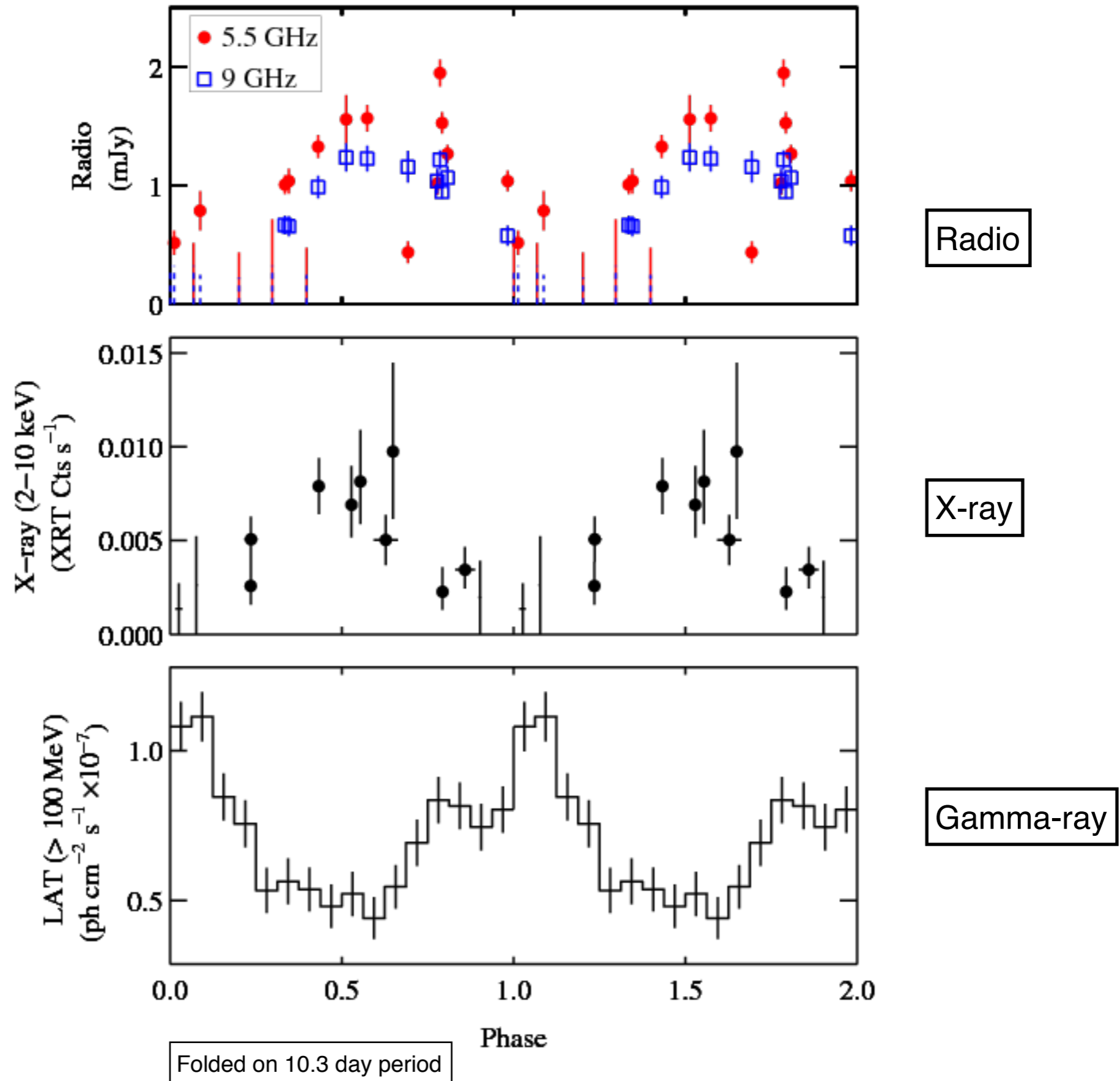
Figure 1. H II region DEM L241 showing H emission in red and [S II] emission in yellow. The [S II] emission defines the supernova remnant and correlates well with the X-rays. Figure from R. C. Smith & the MCELS Team (1999).

Seward+ (2012) had previously identified a candidate HMXB in the SNR DEM L241. ($L_x \sim 2 \times 10^{35} \text{ ergs s}^{-1}$).
Optical counterpart is O5III star.

LAT team previously noted DEM L241 as a candidate for the counterpart of P3 (along with AGN, HII region etc.), although it was just outside LAT error ellipse.

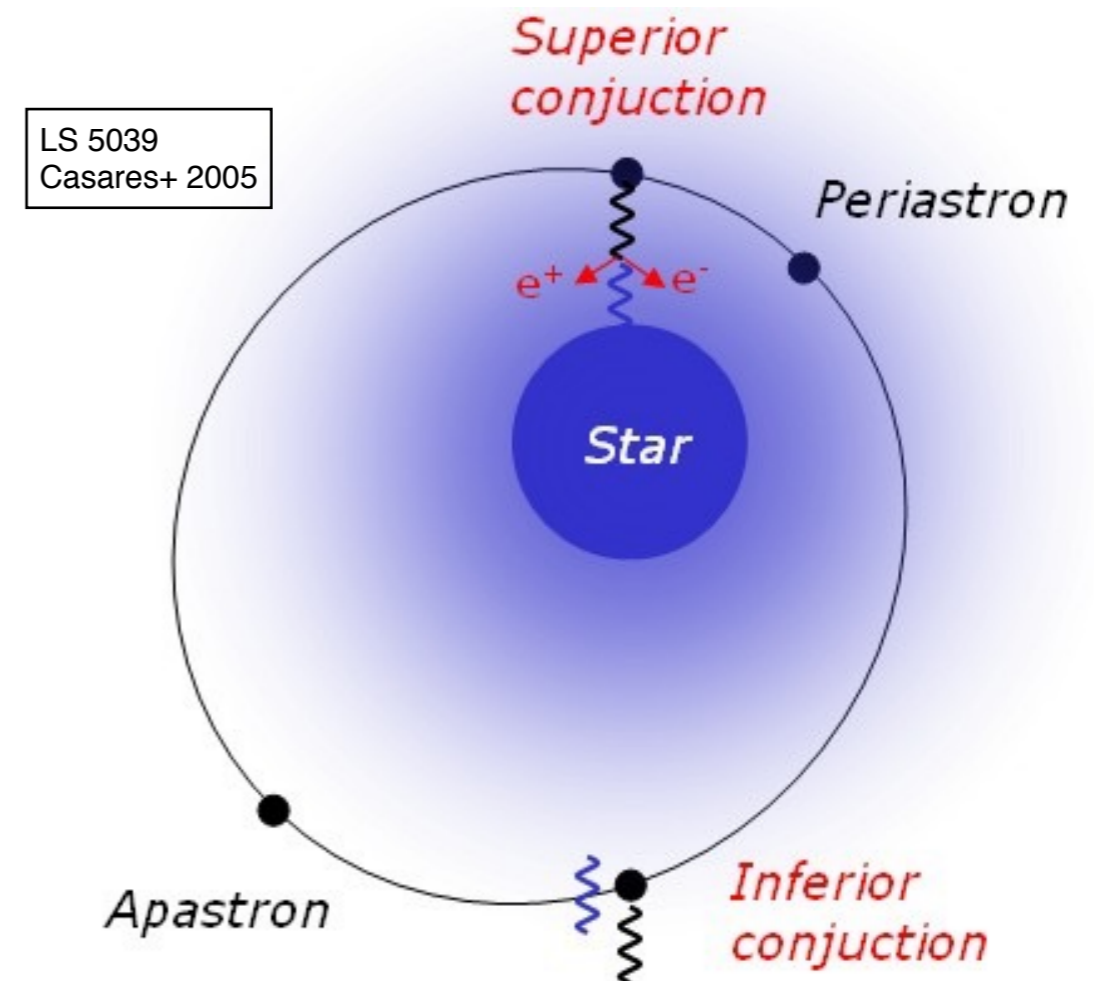
We investigated this candidate HMXB with Swift XRT and ATCA...

Multiwavelength Properties of LMC P3



Origin of Orbital Modulation

- Two main effects that could modulate gamma-rays.
- Eccentric orbit with increased interactions near periastron.
- System geometry.
 - Compton scattering at intra-binary shock gives strongest gamma-ray emission observed at superior conjunction.



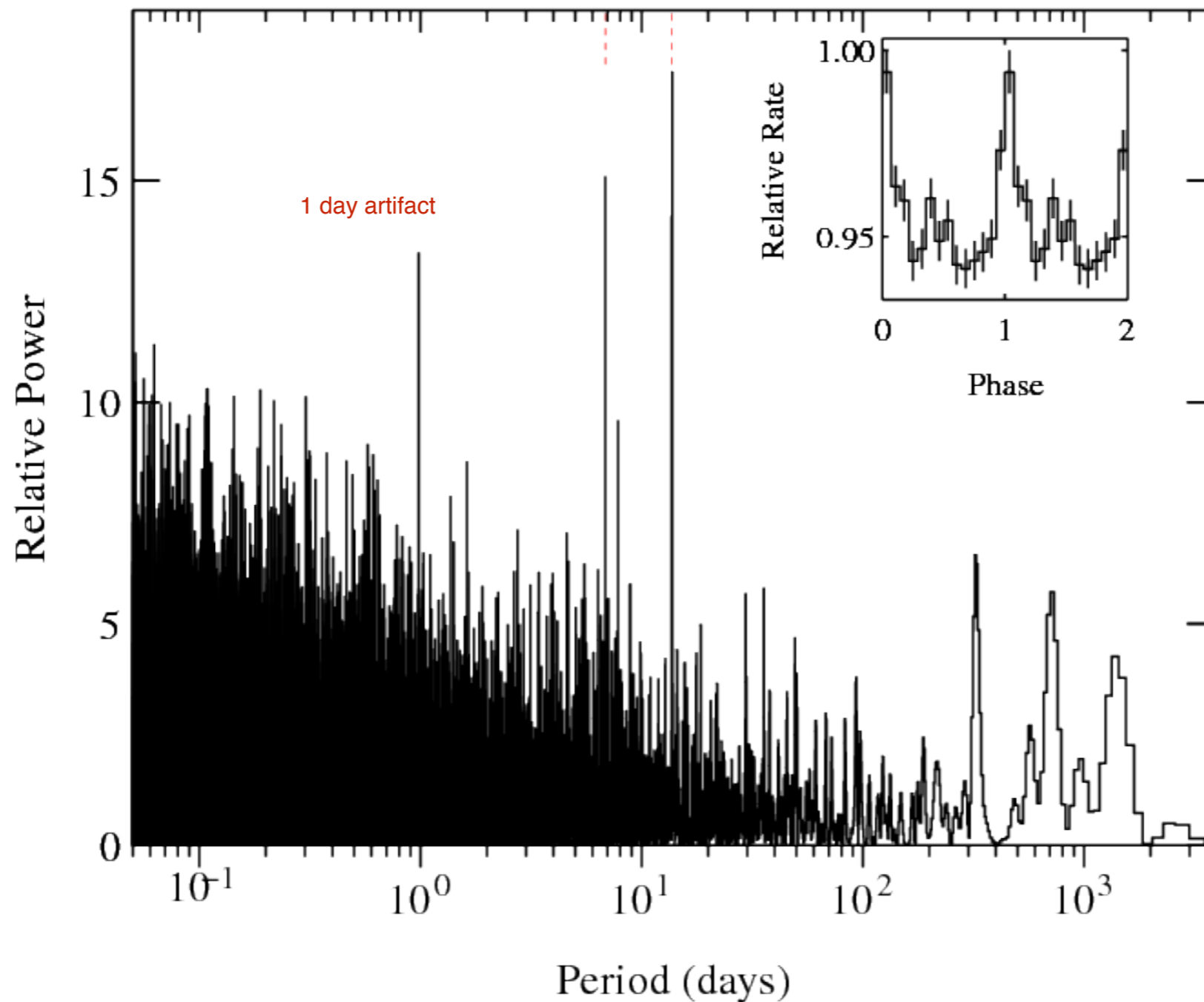
Searching the FL8Y Source List

- FL8Y source list contains 5524 sources, compared to 3033 in 3FGL catalog.
- Examined all sources, but concentrated on:
 - (i) sources close to the Galactic plane
 - (ii) candidate periods > 1 day. (high-mass systems, reduced search frequencies)
- One source (also in 3FGL etc., now in 4FGL) in particular had an interesting power spectrum...

4FGL J1405.1-6119

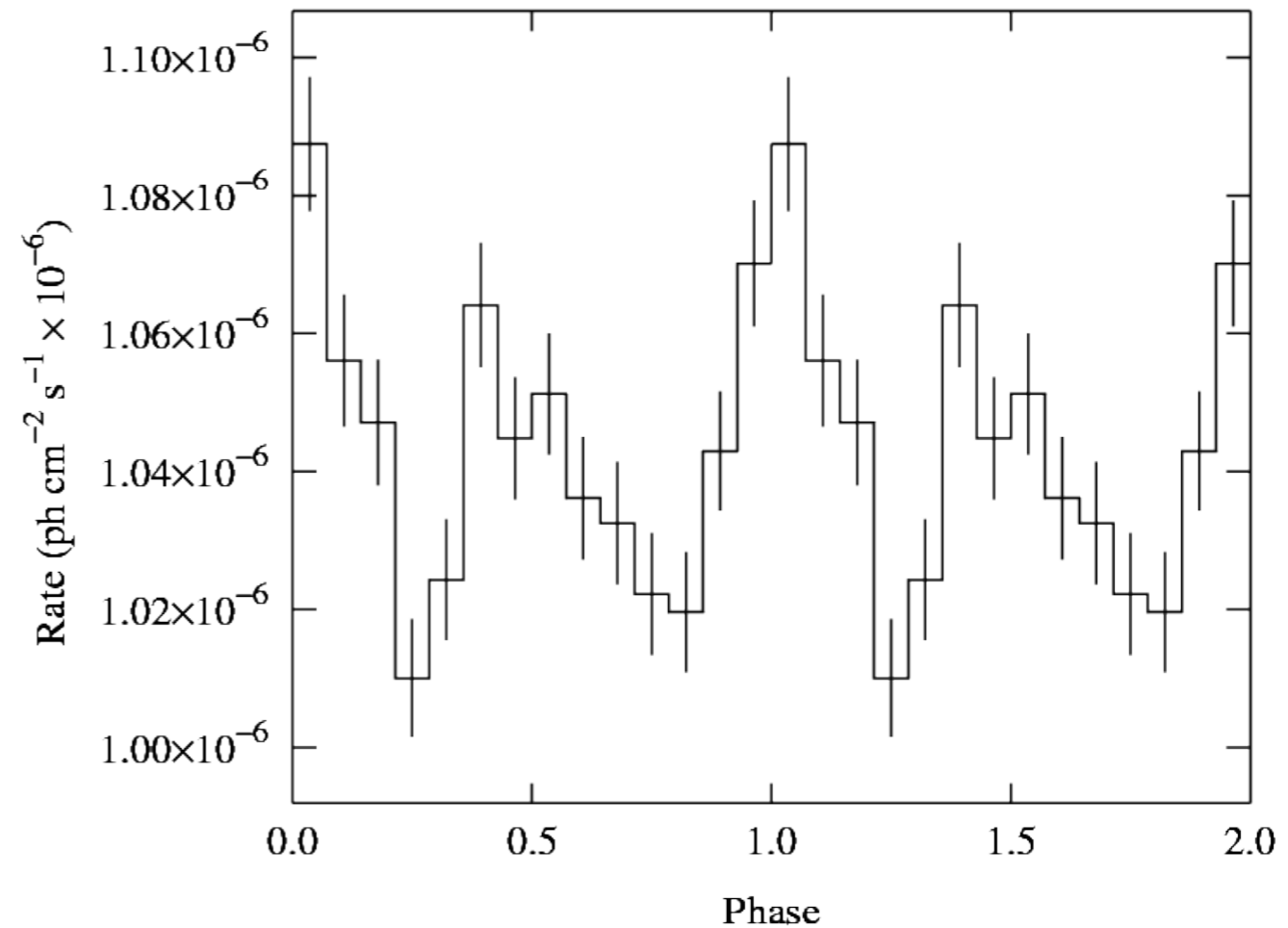
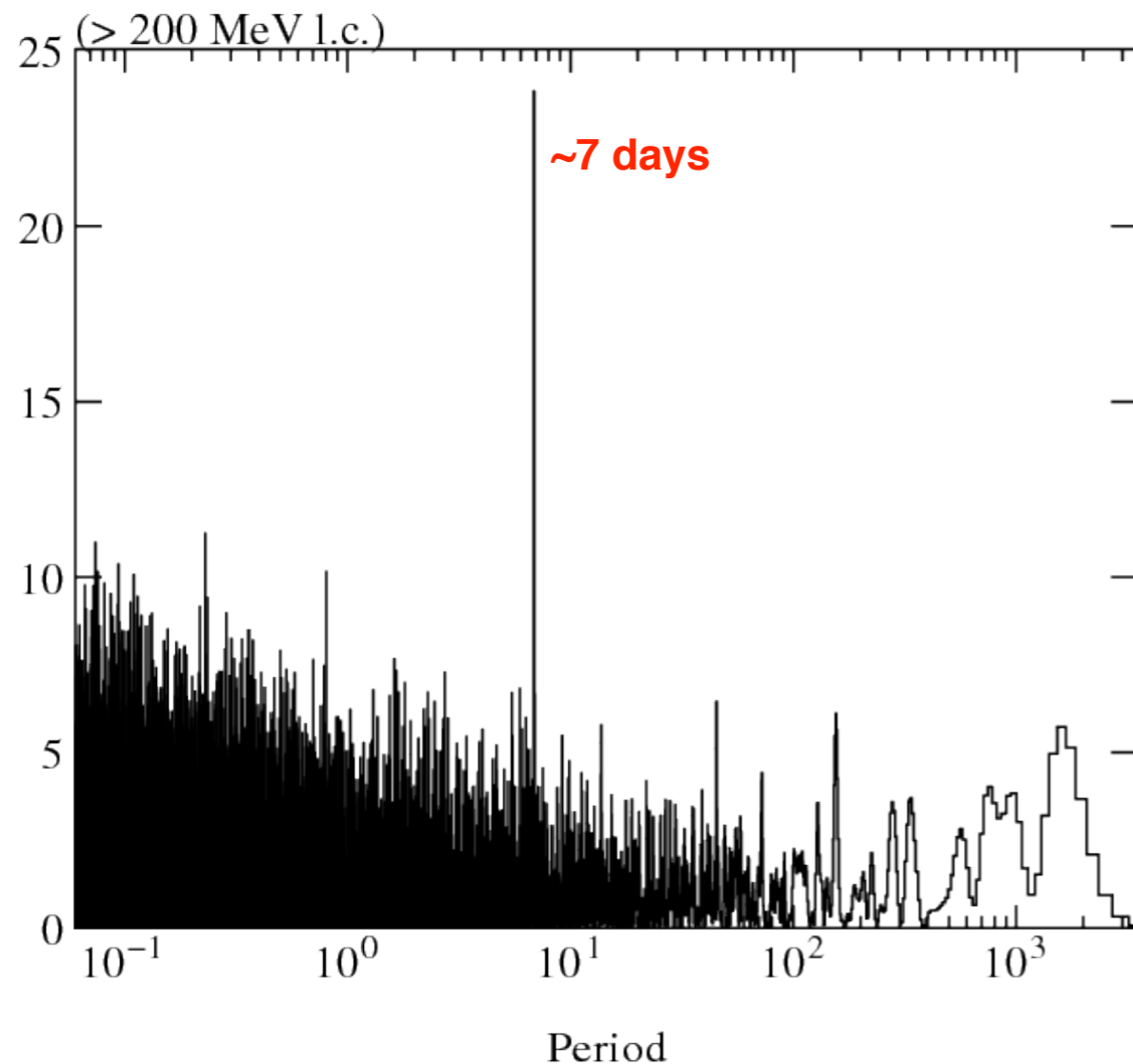
- J1405.1 has been present in all previous LAT catalogs.
- Based on its gamma-ray spectrum, it had been suggested to be a pulsar (Lee+ 2012, Saz Parkinson+ 2016, Wu+ 2018)
- Saz Parkinson+ (2016) had noted XRT and Chandra source in Fermi error box.
- Landi+ (2017) had proposed apparently variable INTEGRAL source (IGR J14059-6116) to be the X-ray counterpart (= XRT source).
- Landi+ also noted near-IR 2MASS/WISE source coincident with XRT position, and reported the near-IR colors made it unlikely to be an AGN.

Power Spectrum of J1405.1-6119



- Two harmonically related peaks at ~ 7 days and ~ 14 days.
- Each *individual* peak modest significance (0.005, 0.08)
- But probability of seeing *harmonic* of stronger peak by chance is 2×10^{-6}
- Probability flux shows single sharp peak - but, photon weighting may affect shape...

Power Spectrum of Unweighted Photons



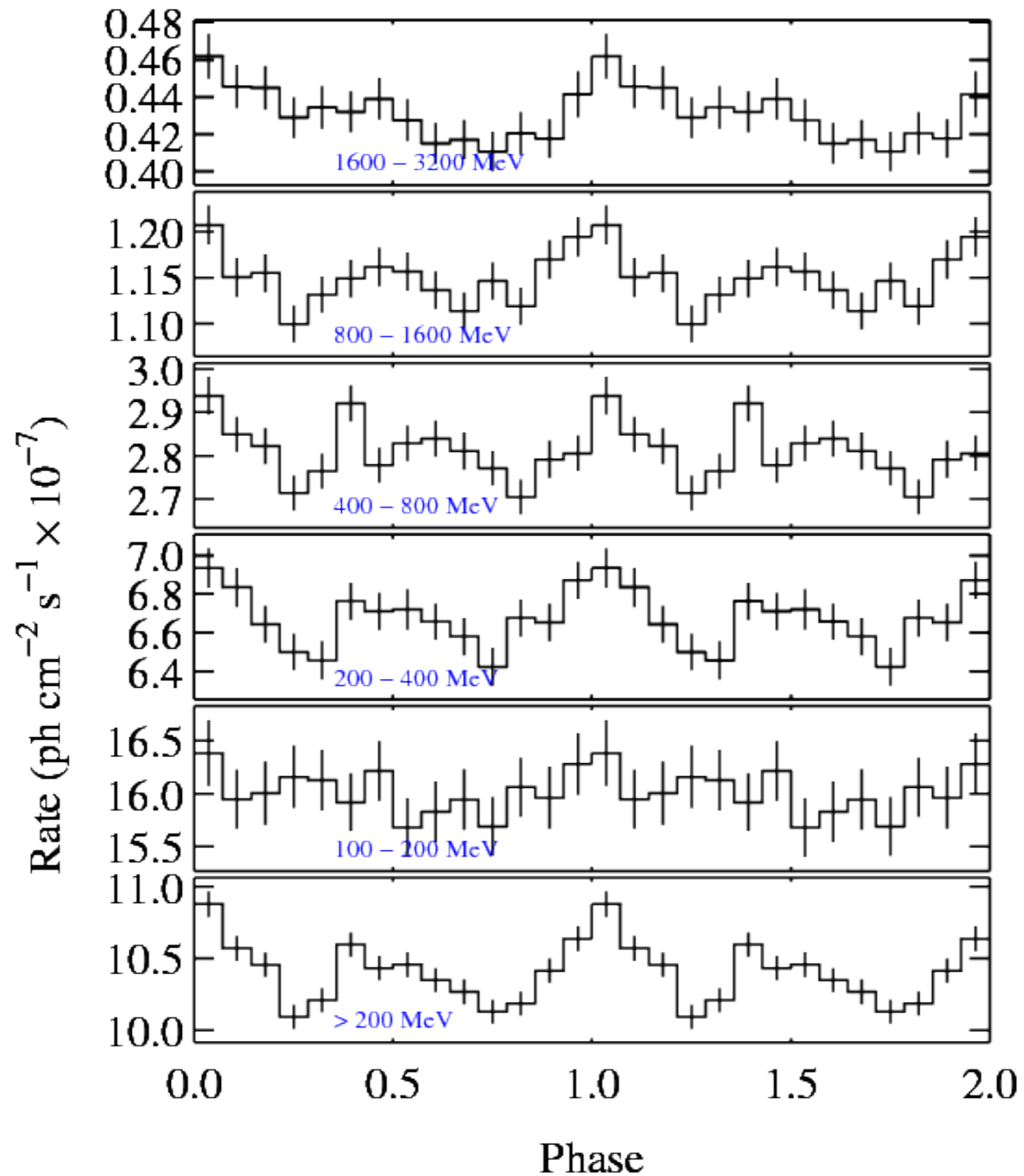
Folded on **14 day** period

Without probability weighting

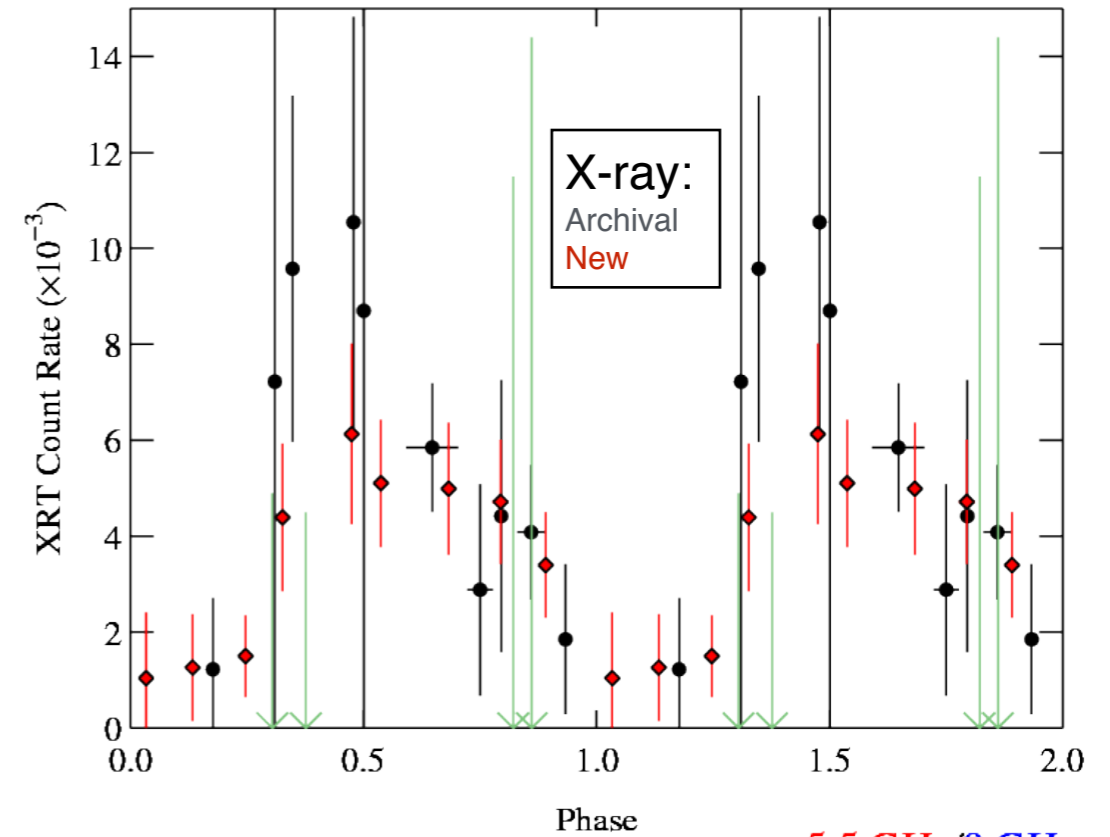
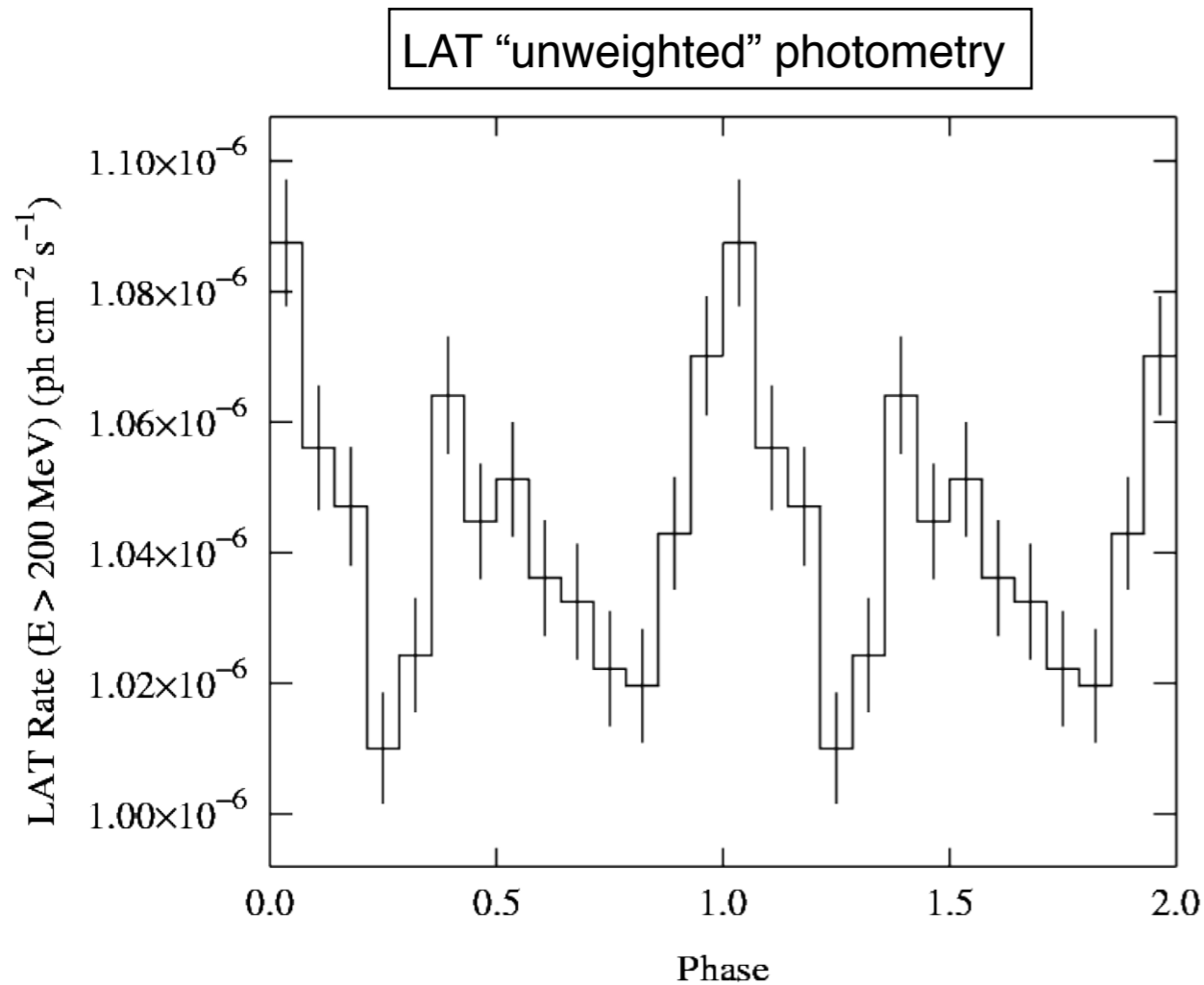
- Only strong *harmonic* at ~ 7 days is seen.
- Profile is double-peaked.

(For weighted analysis, higher-energy photons with smaller PSF are more heavily weighted.)

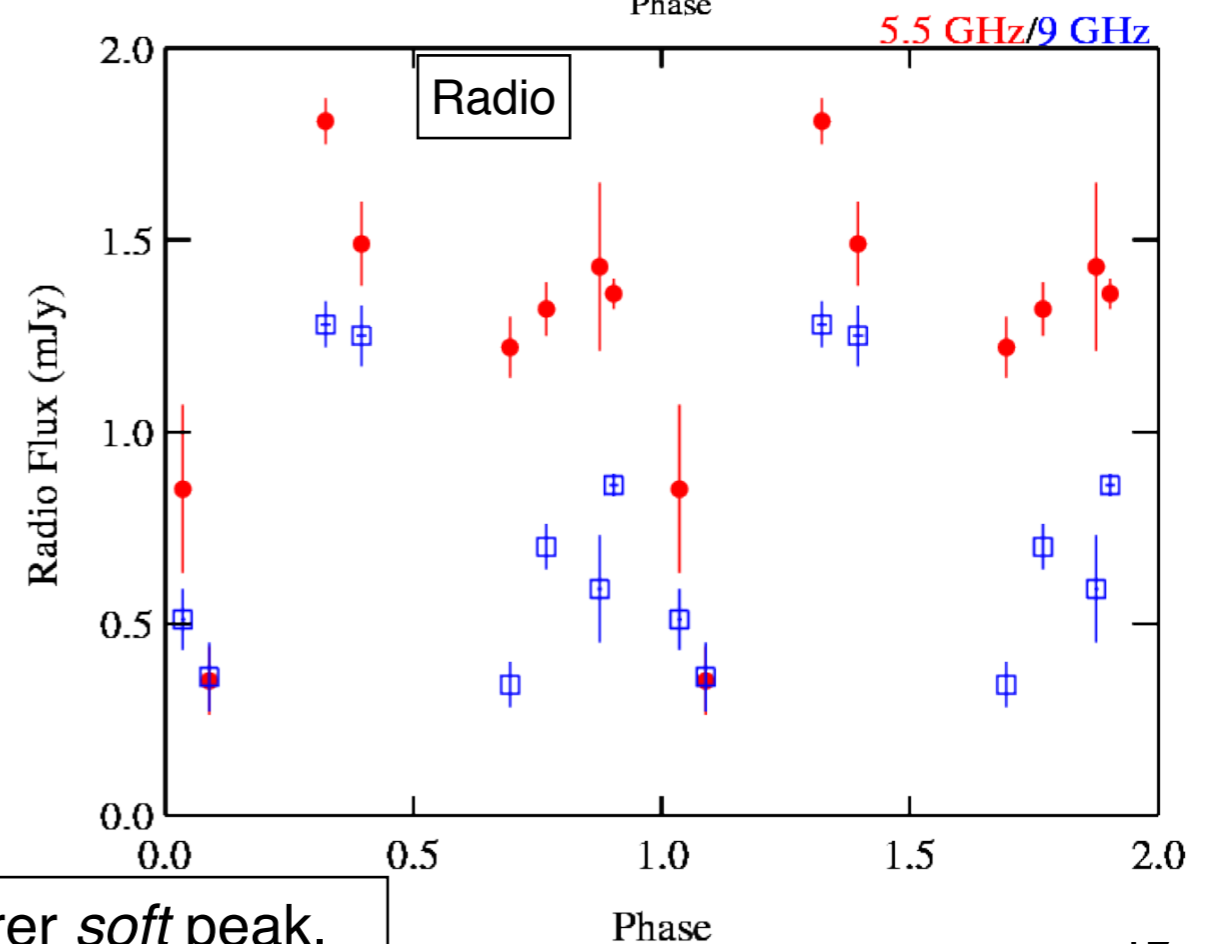
Gamma-ray **Unweighted** Modulation Appears Energy-Dependent



X-ray and Radio Support for J1405.1



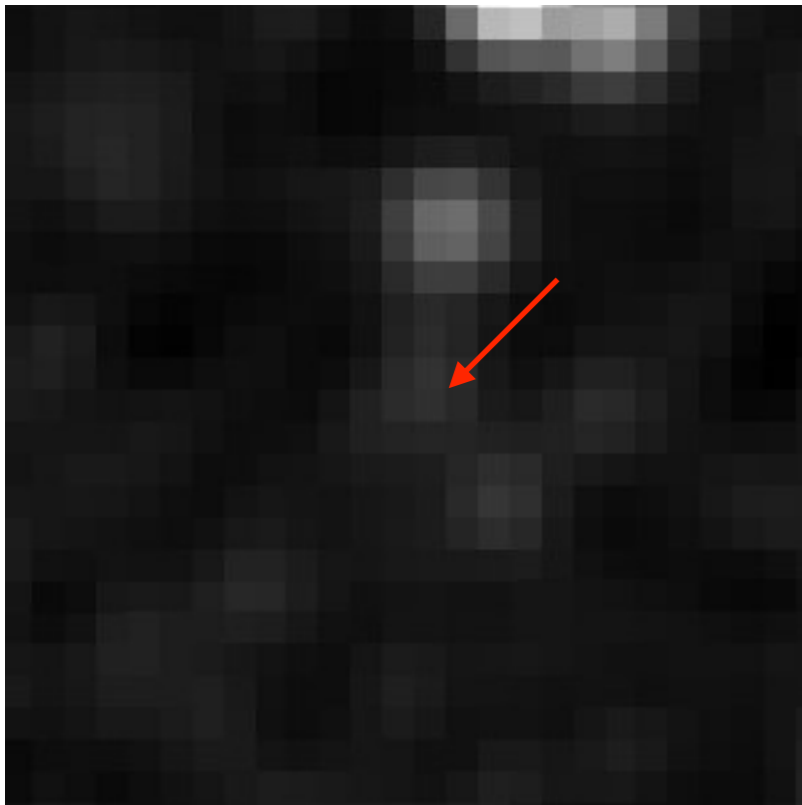
- “Conventional” LAT aperture photometry shows double-peaked profile on $\sim 14 \text{ d}$ period.
- *Secondary* γ -ray peak is *softer*.



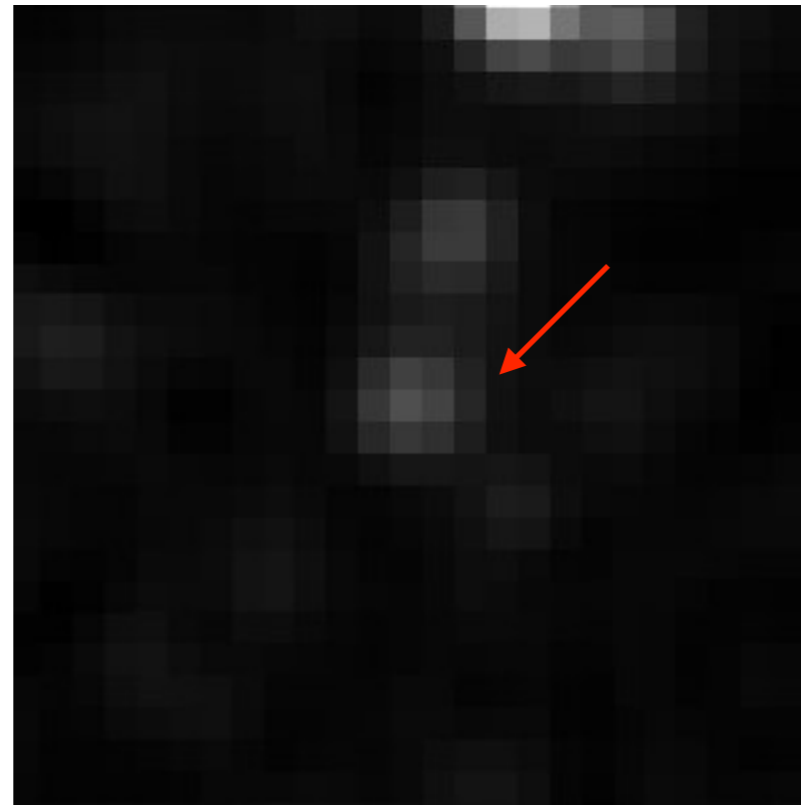
- X-ray and radio modulated nearer *soft* peak.

Near-Infrared (2MASS) Counterpart of J1405.4

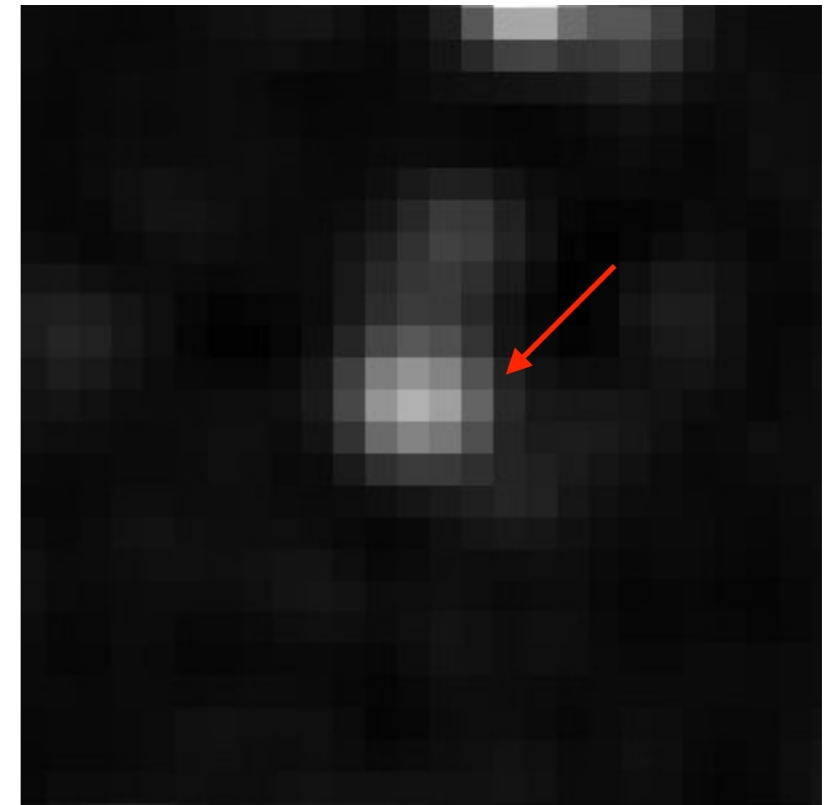
Extremely heavily reddened. $E(B-V) \sim 11$



J-Band
(1.2 μm)

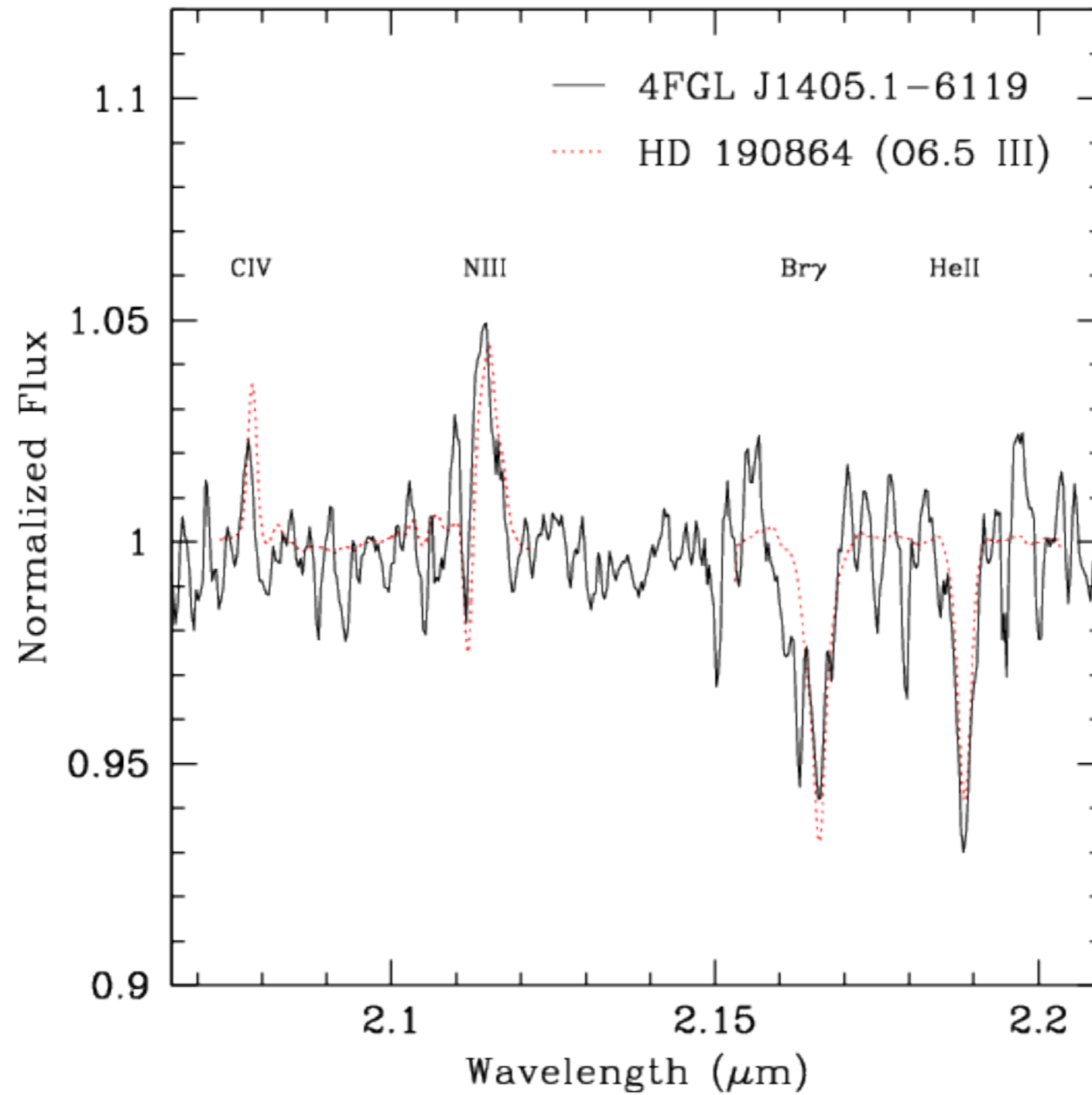


H-Band
(1.7 μm)



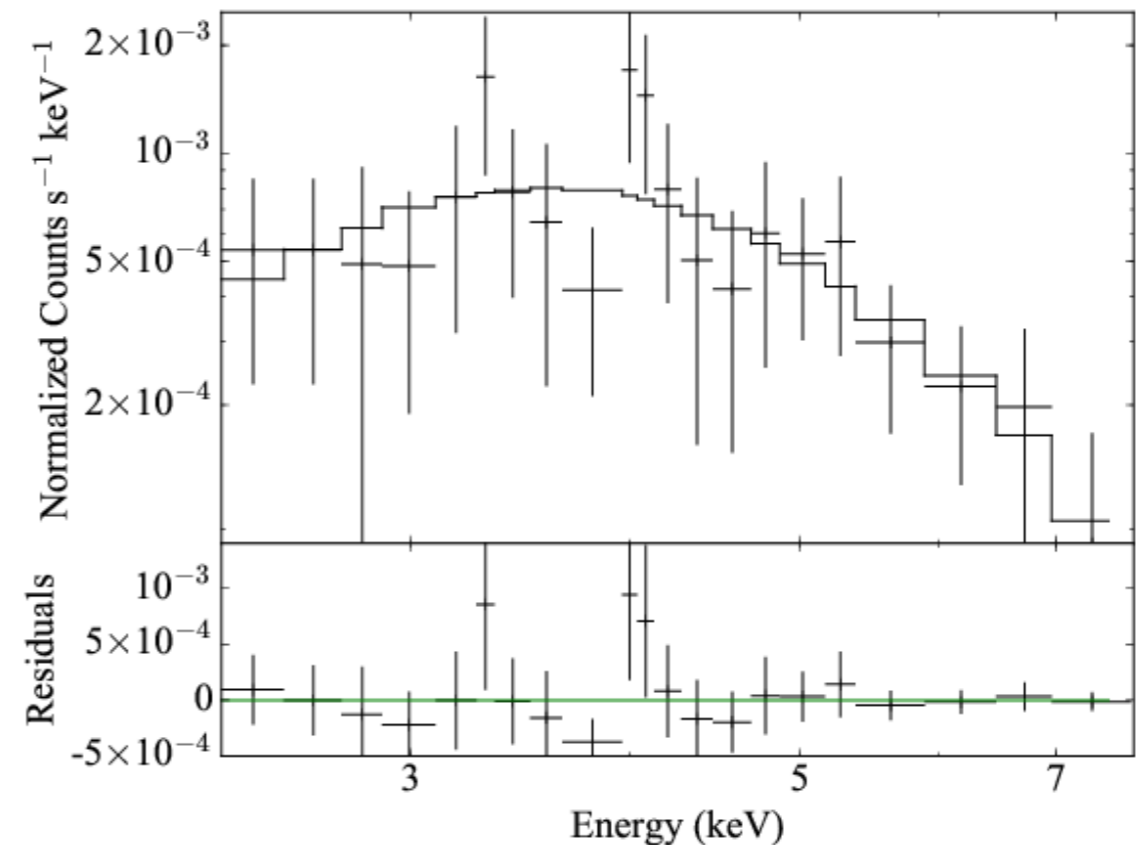
K-Band
(2.2 μm)

Gemini/Flamingos near-IR spectrum shows counterpart is **O6.5 III** Confirms it's a binary (distance ~ 7.7 kpc)



Further X-ray Observations

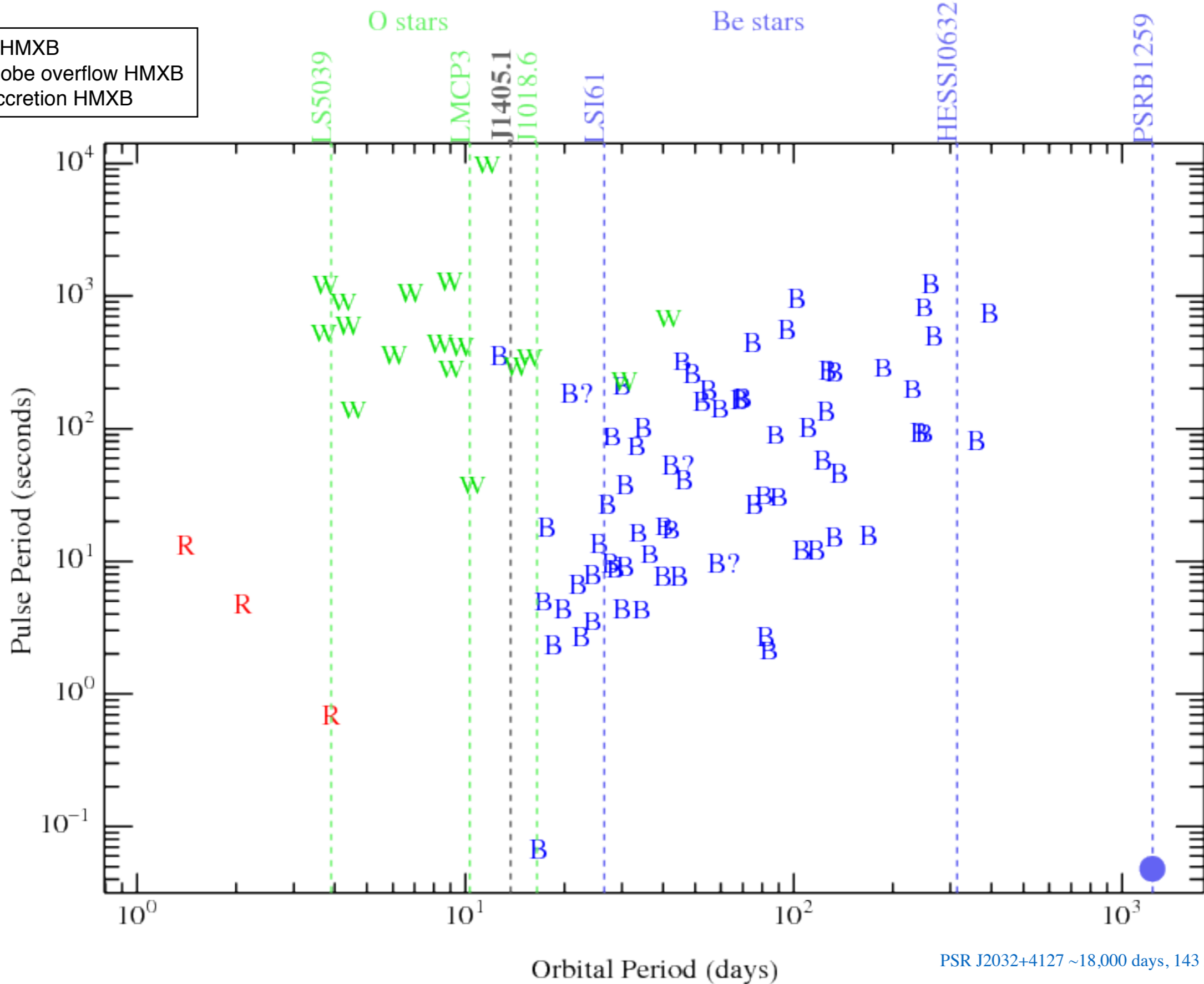
- The count rate in the XRT is very low – the spectrum could only be poorly measured.



- Limits how well the spectral properties, and so emission mechanism(s), can be constrained. Also limits pulsation searches.
- We have had a NuSTAR and XMM proposal accepted.
- These observations have just now been carried out – and we're looking forward to the results!

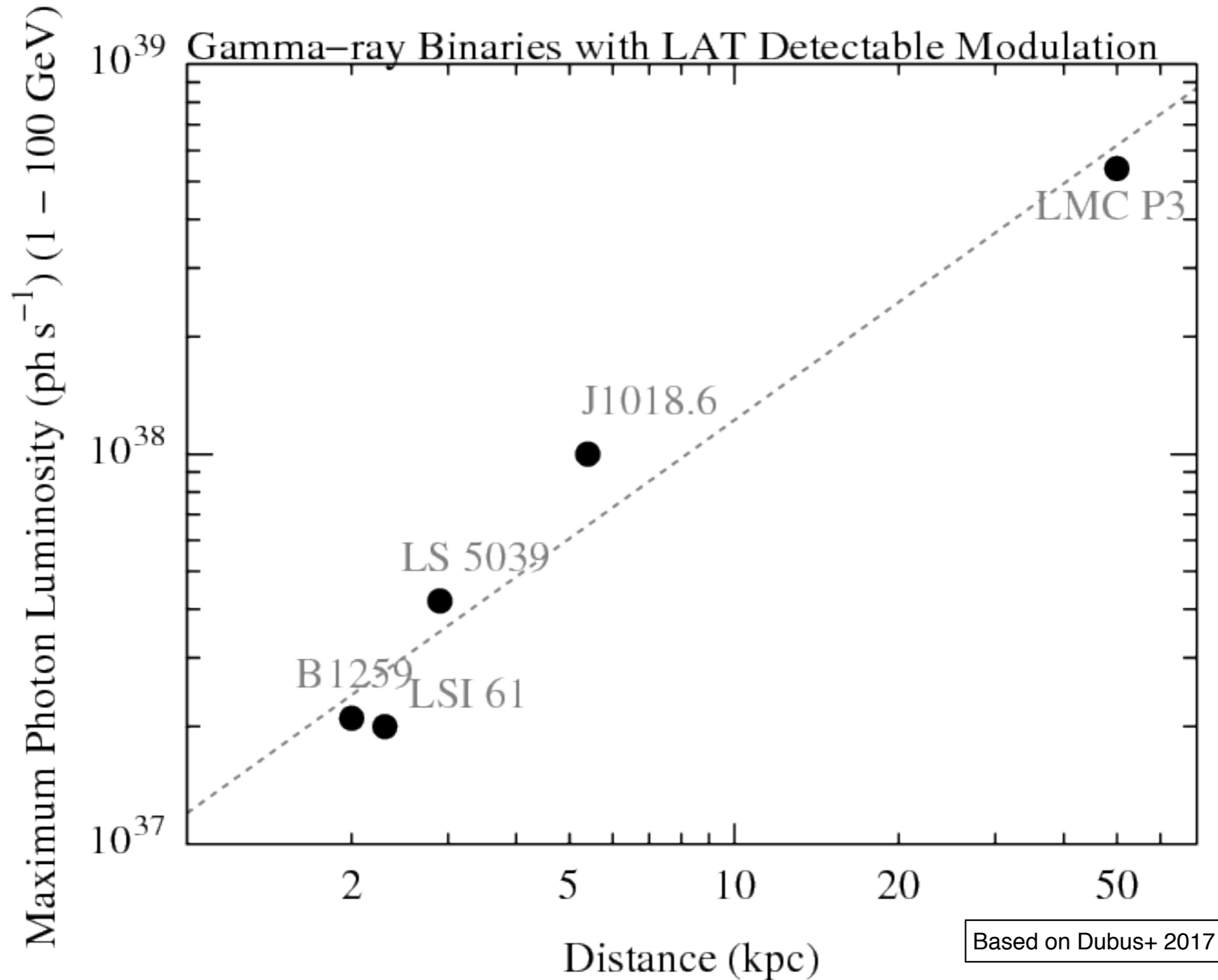
Orbital Periods: Gamma-ray & X-ray Binaries

B = Be star HMXB
R = Roche-lobe overflow HMXB
W = wind-accretion HMXB

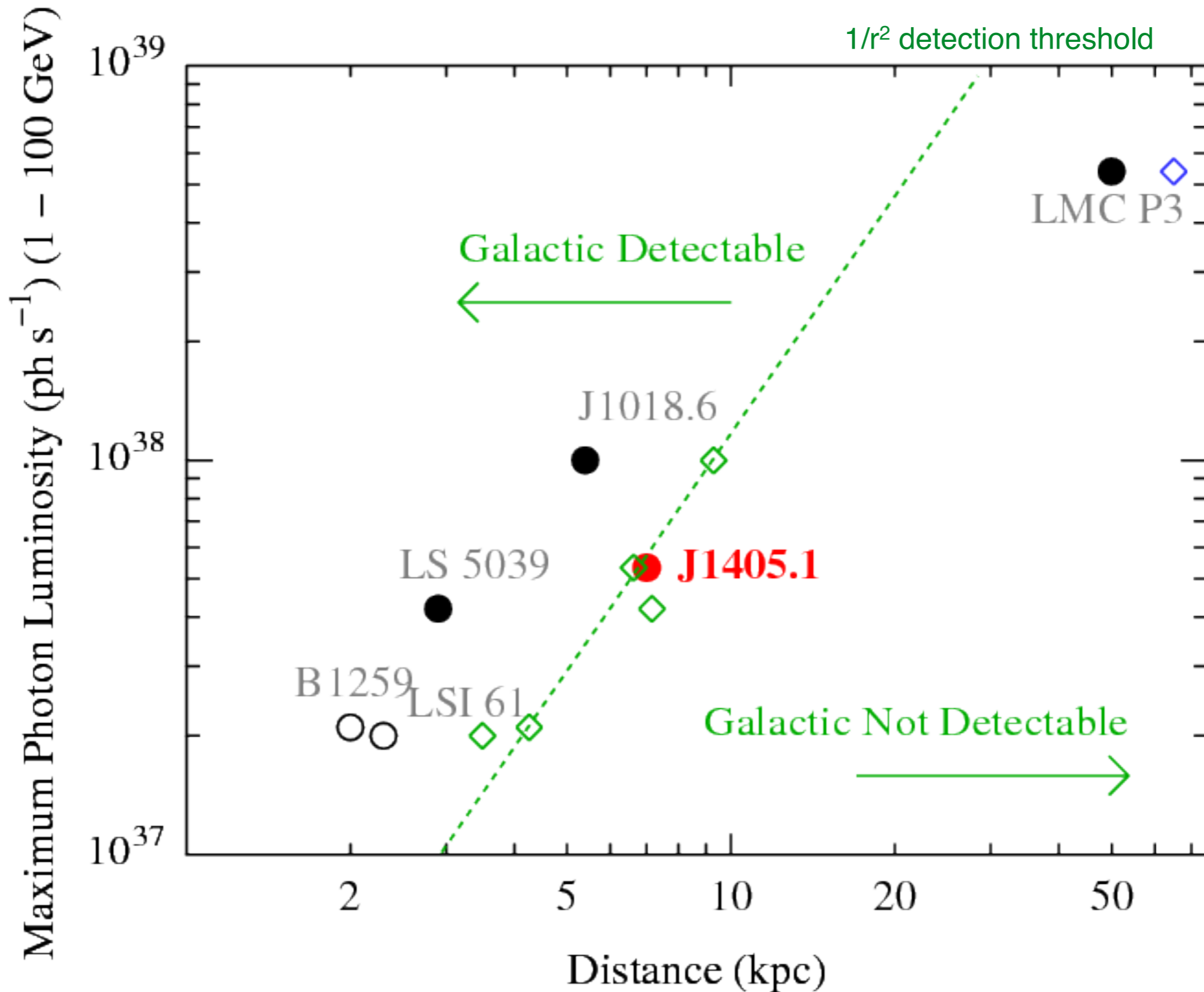


PSR J2032+4127 ~18,000 days, 143 ms

How Far Are We Detecting Gamma-ray Binaries?



Maximum Binary Modulation Detection Distances



Galactic Binary Population & Future Prospects

- Orbital modulation of gamma-rays can reveal binaries.
- We now have one more binary with an O star primary!
- XMM/NuSTAR observations just now obtained.
 - Radial velocity curve from near-IR would also be important.
- This is the third O star binary we have found from LAT variability.
- The Galactic population of γ -ray binaries is still unclear.
- We are probably only scratching the top of the luminosity distribution. (Particularly Be star systems.)
- We continue our search as Fermi acquires more data, and are now investigating the new 4FGL catalog...