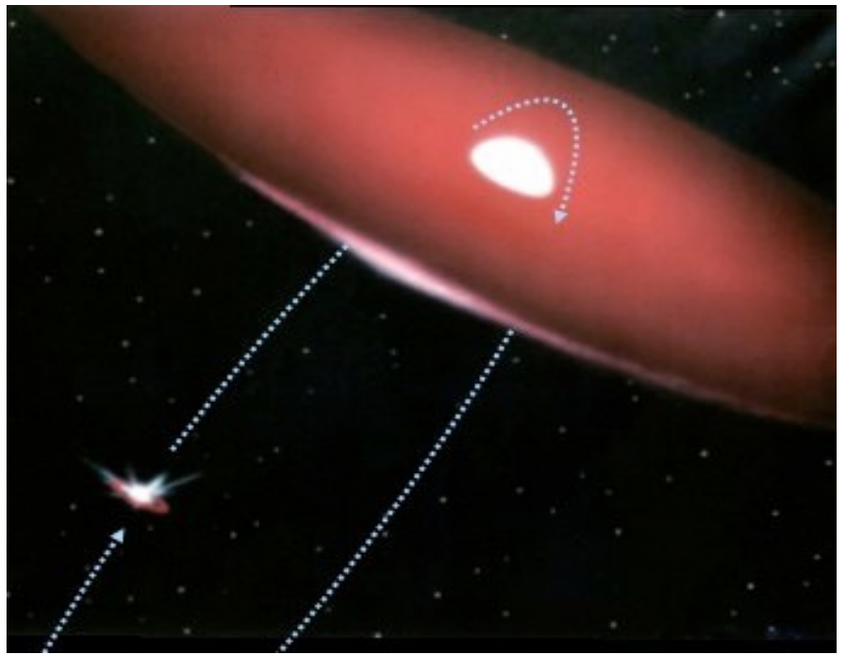
Discovery of a New Galactic Gamma-ray Binary

Robin Corbet[1], L. Chomiuk[2], M.J. Coe[3], J.B. Coley[4],
G. Dubus[5], P. Edwards[6], P. Martin[7], V.A. McBride[8],
J. Stevens[6], J. Strader[2], L.J. Townsend[8]

1: University of Maryland, Baltimore County
NASA Goddard Space Flight Center
Maryland Institute College of Art
2: Michigan State University
3: Southampton University
4: Howard University, NASA GSFC/NPP
5: IPAG Grenoble
6: CSIRO Astronomy and Space Science
7: IRAP
8: University of Cape Town

What is a Gamma-ray Binary?

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

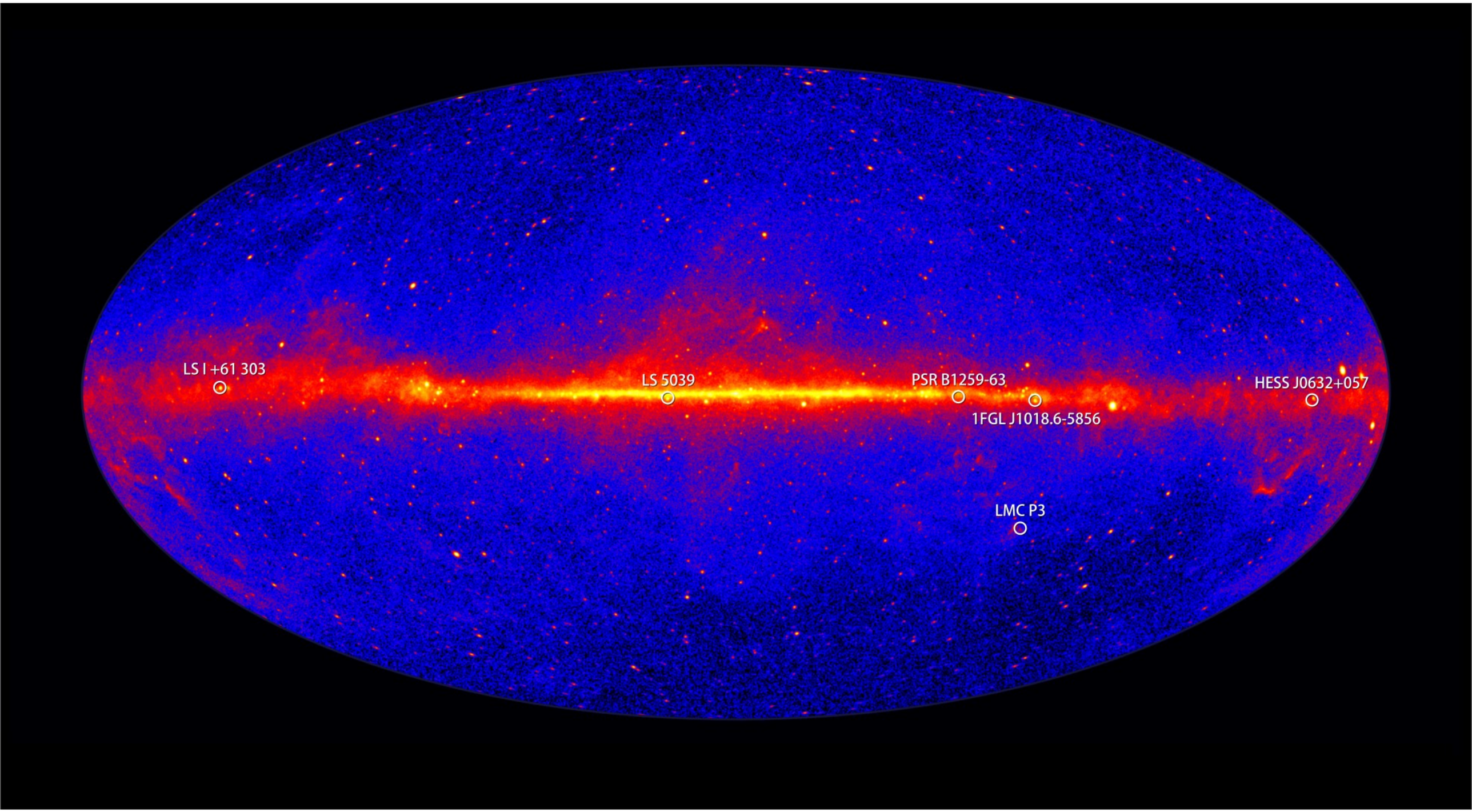


• Pulsar orbiting a hot (O or B type) companion.

• Pulsar and stellar winds (or Be disk) collide and form shocks

• Fermi acceleration at shock + inverse Compton scattering of seed photons from OB star.

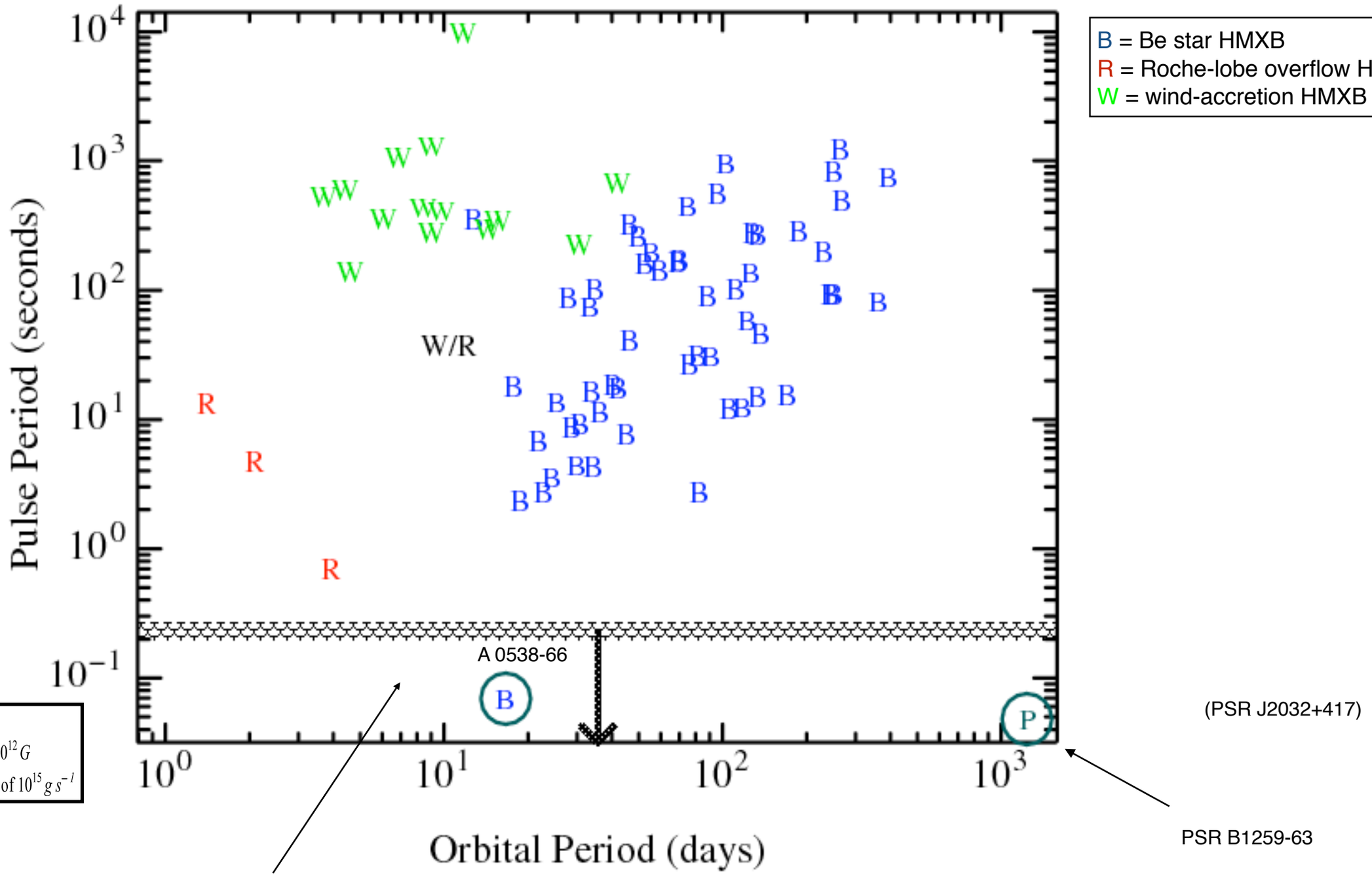
Very Few Gamma-ray Binaries are Known



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



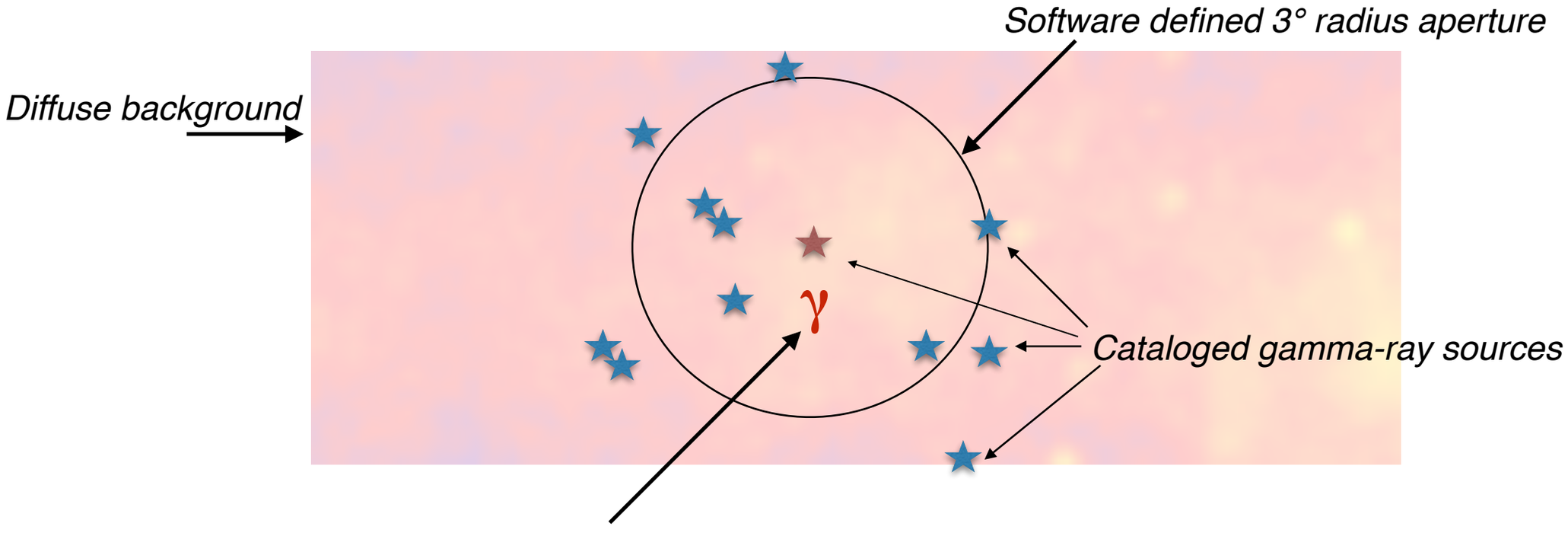
HMXBs containing neutron stars can begin as gamma-ray binaries with rapidly rotating neutron stars before spinning down.

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 101^{+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.

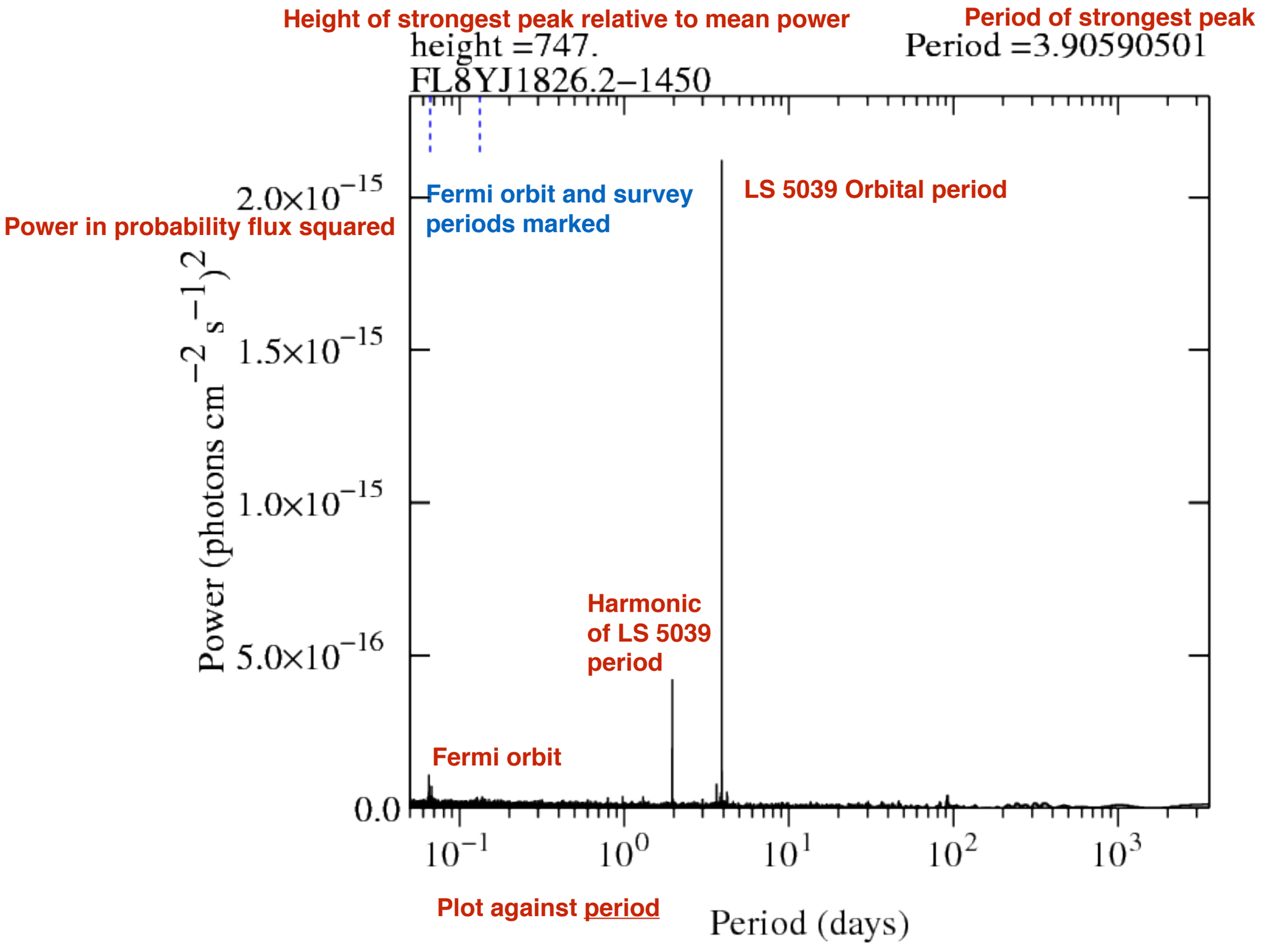


Photon in aperture - calculate probability it came from source of interest.

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

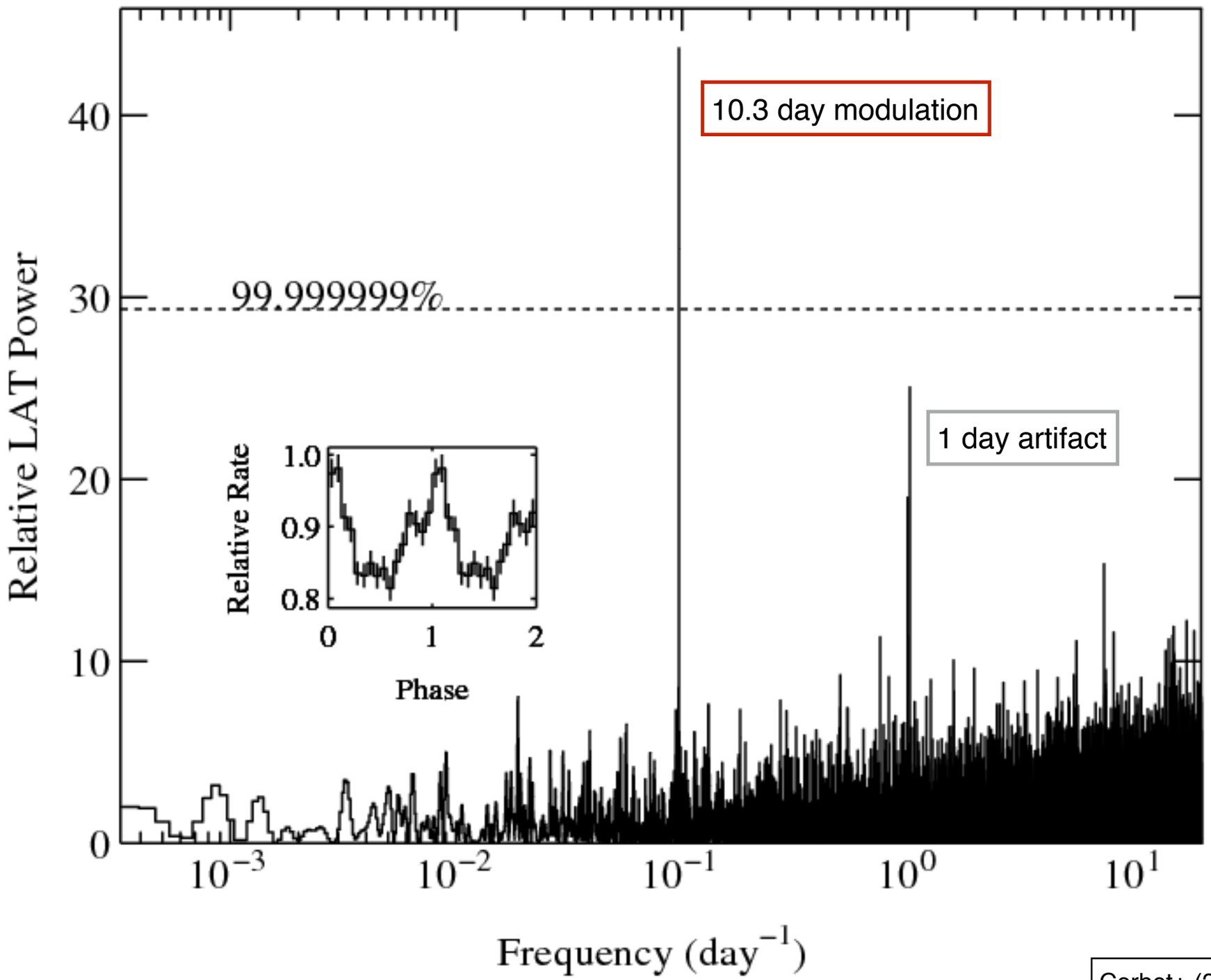
Example Output: LS 5039

- 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

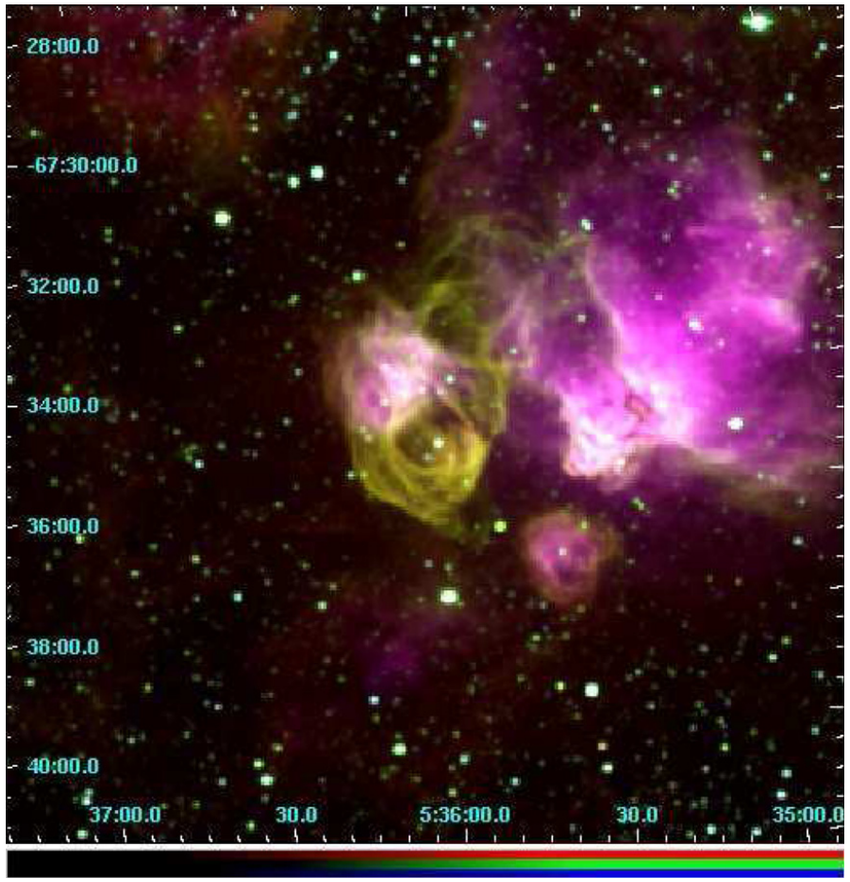
"LMC P3" was an unassociated source in the LAT LMC survey. (i.e., no definite counterpart)



Corbet+ (2016)

Counterpart: HMXB Candidate in an SNR

Chandra



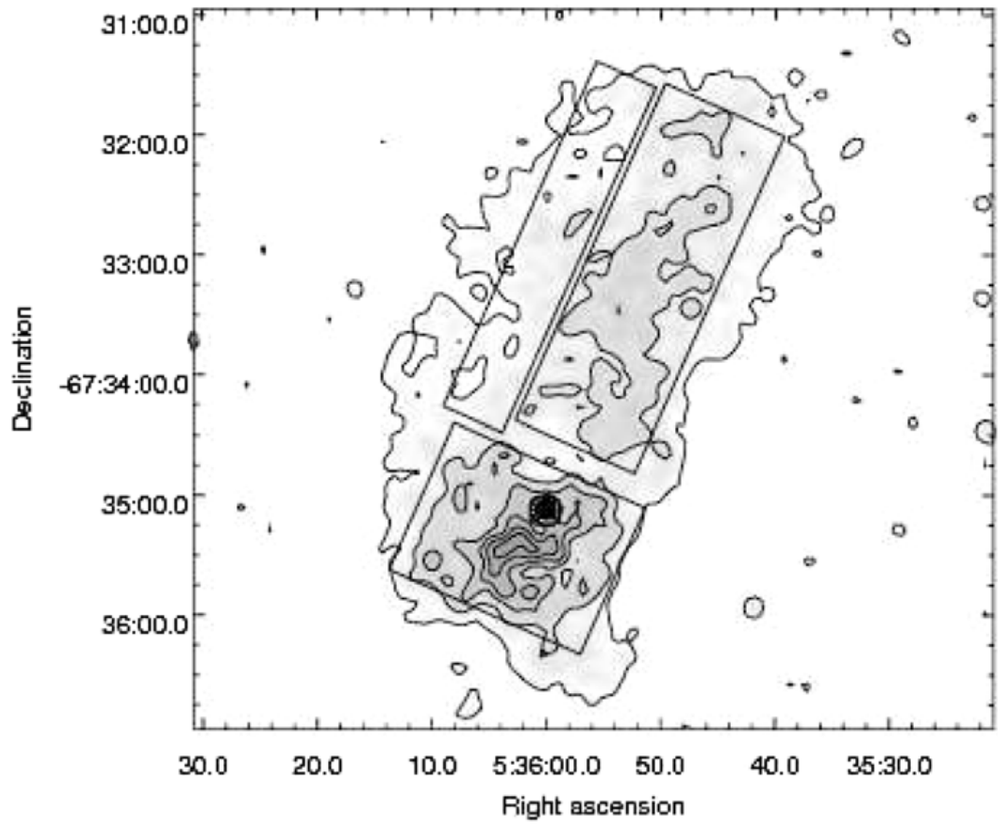


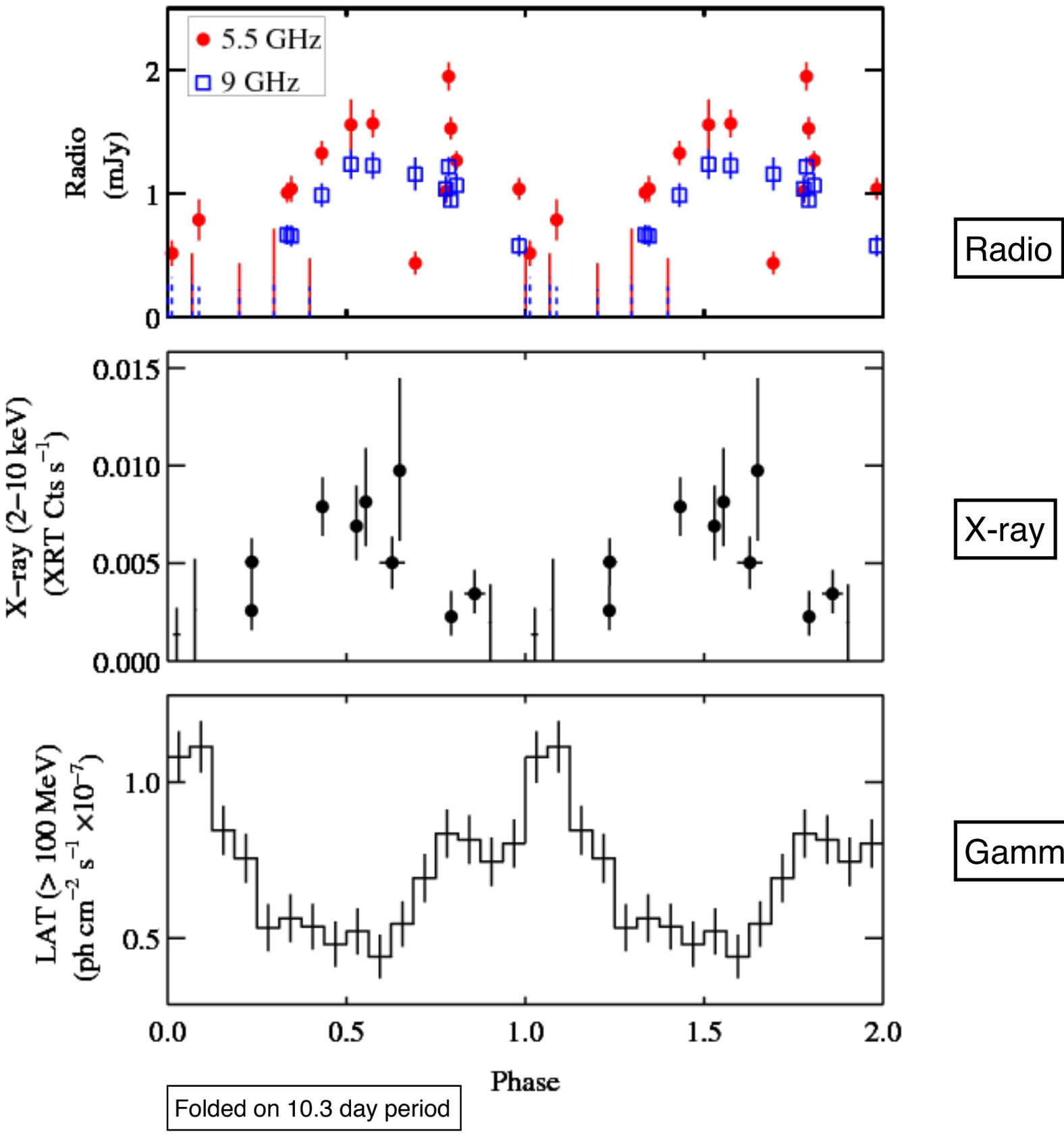
Figure 1. H II region DEM L241 showing H emission in red and [S II] emission in yellow. The [S II] emission defines the supernova remnant and correlates well with the X-rays. Figure from R. C. Smith & the MCELS Team (1999).

Seward+ (2012) had previously identified a candidate HMXB in the SNR DEM L241.
(L_x ~2x10^{35} 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



Radio

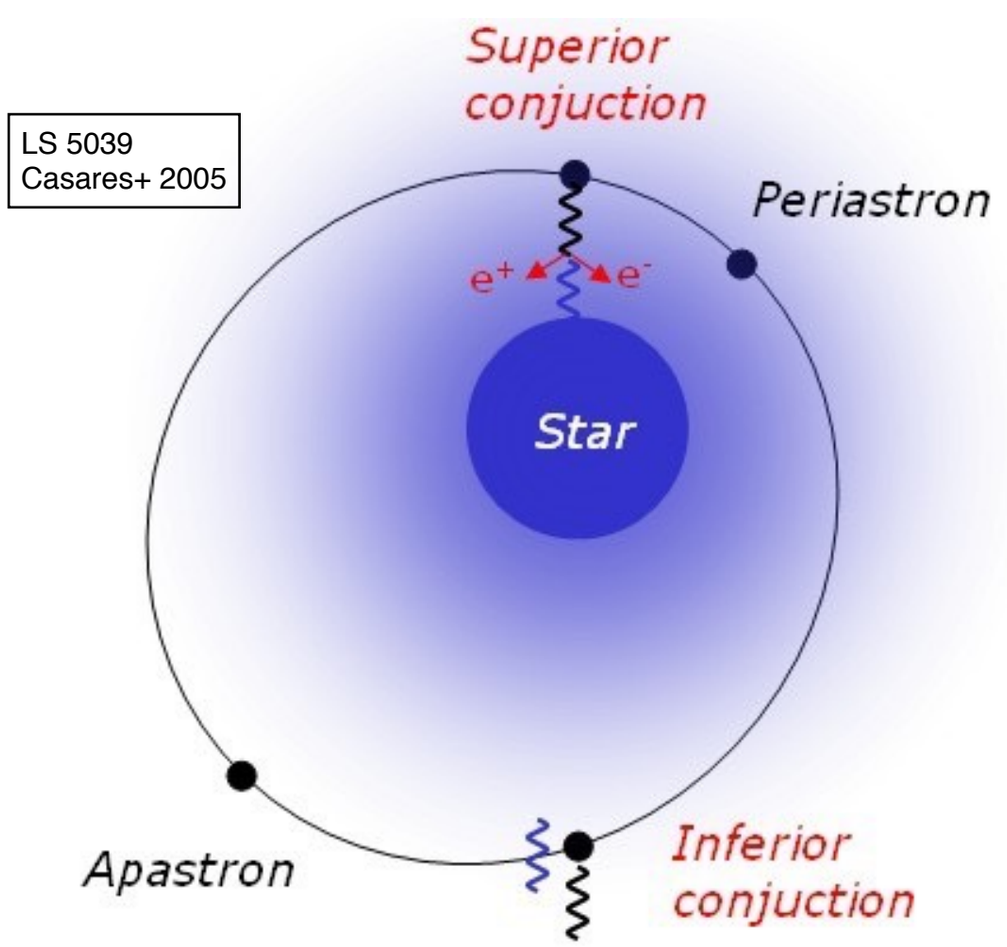
X-ray

Gamma-ray

Folded on 10.3 day period

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.

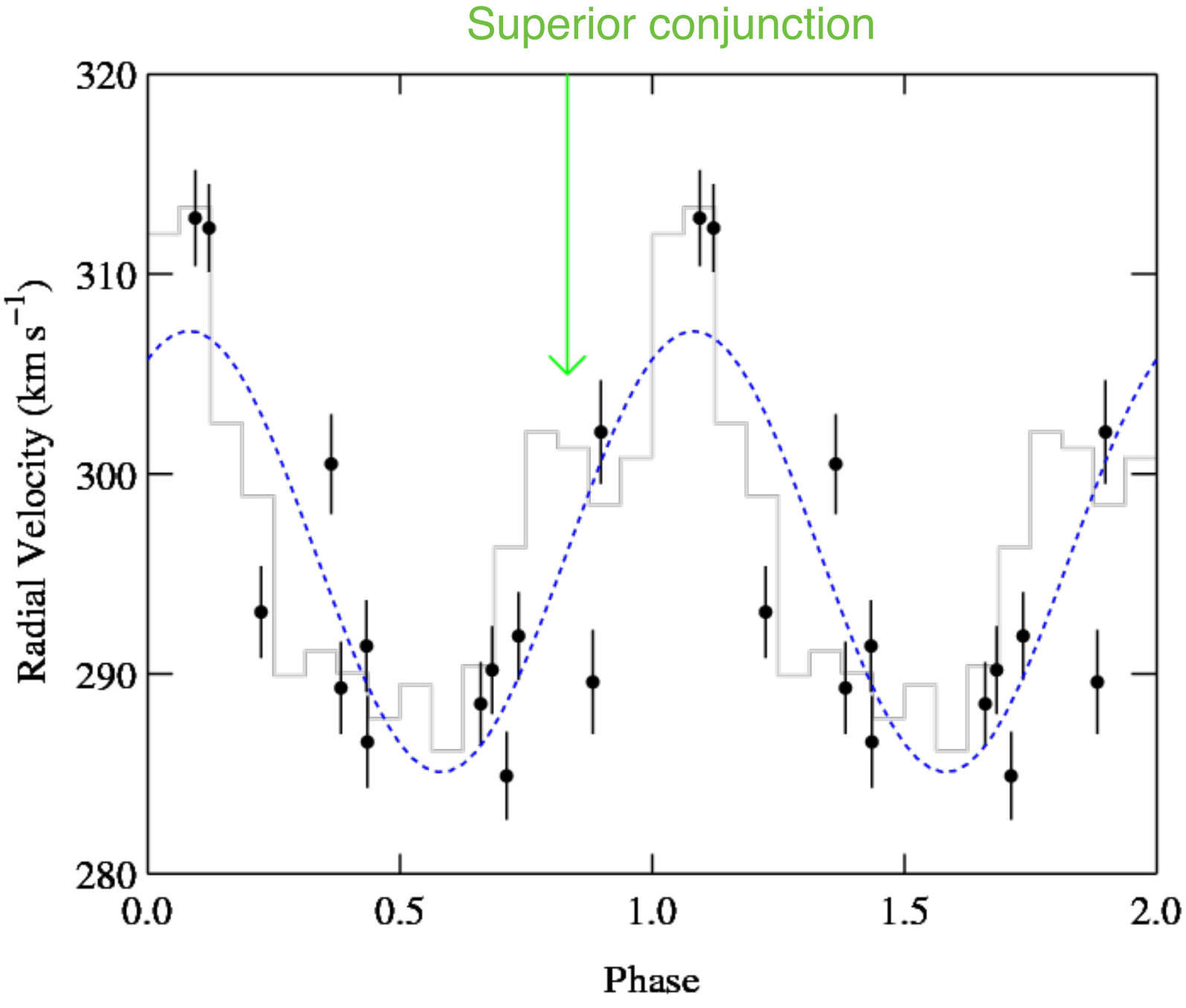


LMC P3: Optical Radial Velocity Measurements Favor Neutron Star

f(M) = (1.3 +1.1, -0.6) x $10^{-3} M_\odot$
For $1.4 M_\odot$ neutron star, i ~ 34-63°; for $10 M_\odot$ black hole, i =8±2°

Gamma-ray maximum after superior conjunction.

⇒ some eccentricity?

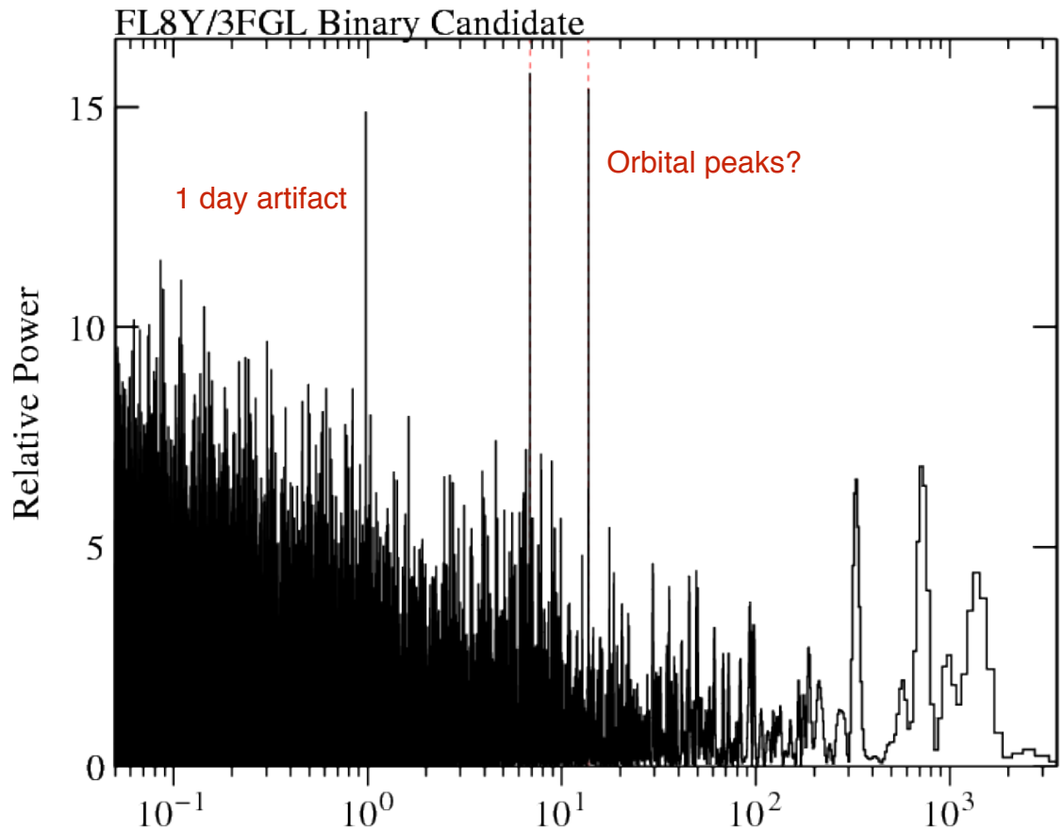


Searching the FL8Y Source List

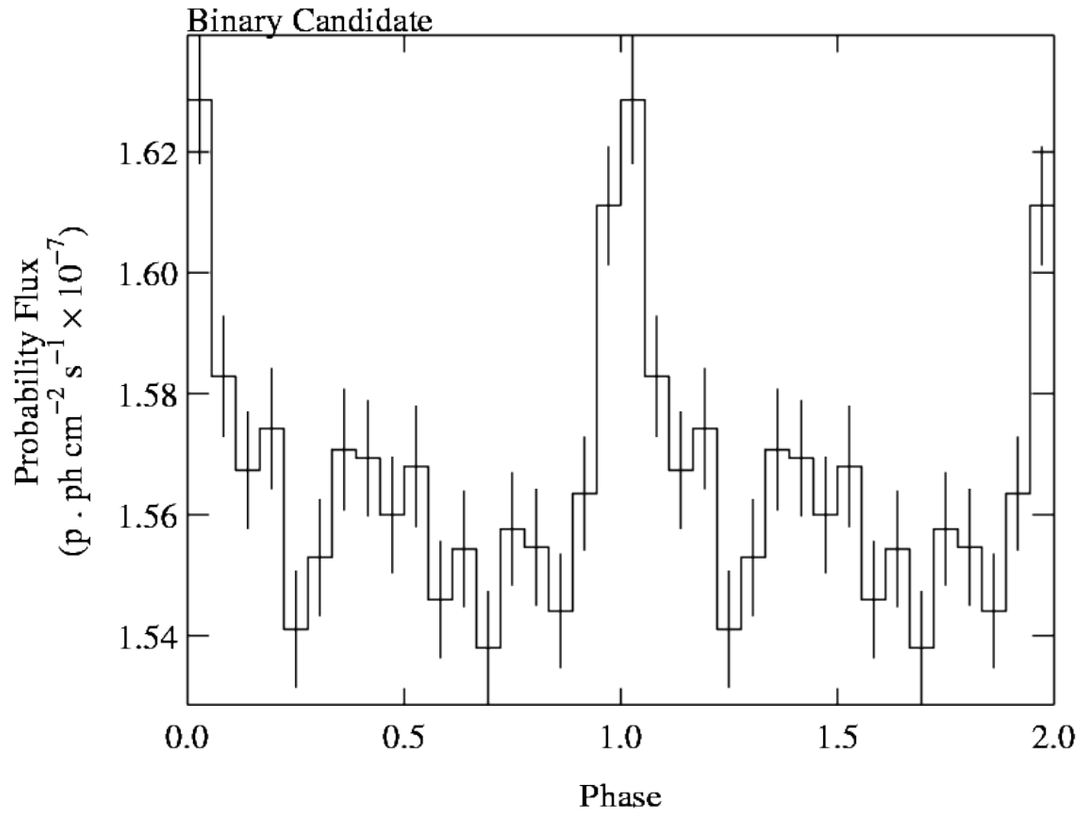
- FL8Y source list contains 5524 sources, compared to 3033 in 3FGL catalog.
- Examine all sources, but concentrate on:
  - (i) sources close to the Galactic plane
  - (ii) candidate periods > 1 day. (high-mass systems, reduced search frequencies)
- One source (also in 3FGL etc.) in particular had an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

Power Spectrum of J1405.4-6119

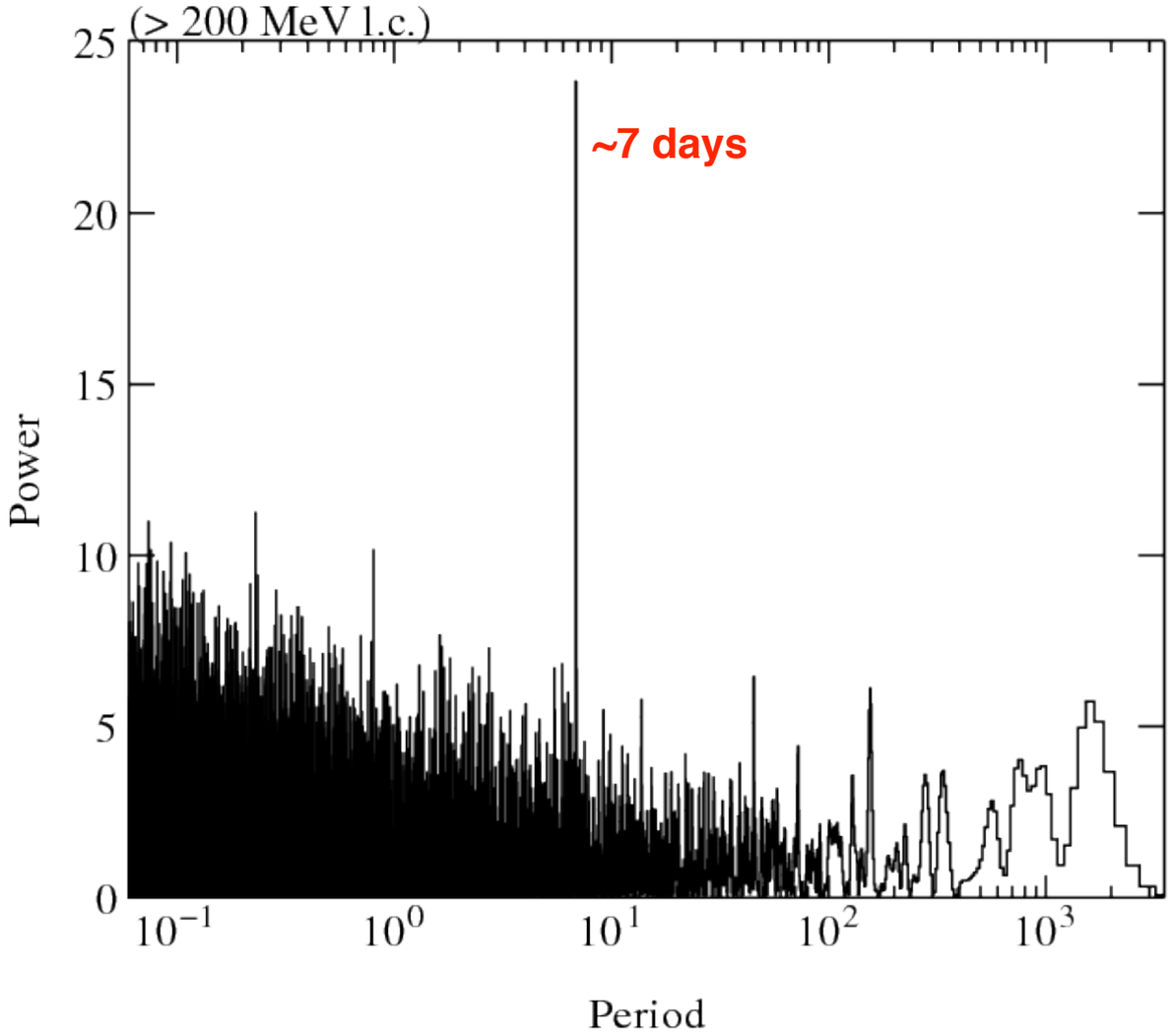
- Two harmonically related peaks at ~7 days and ~14 days.
- Each *individual* peak modest significance (0.005, 0.08)
- But probability of seeing *harmonic* of stronger peak by chance is 2×10^{-6}
- Source 0.3° from Galactic plane.

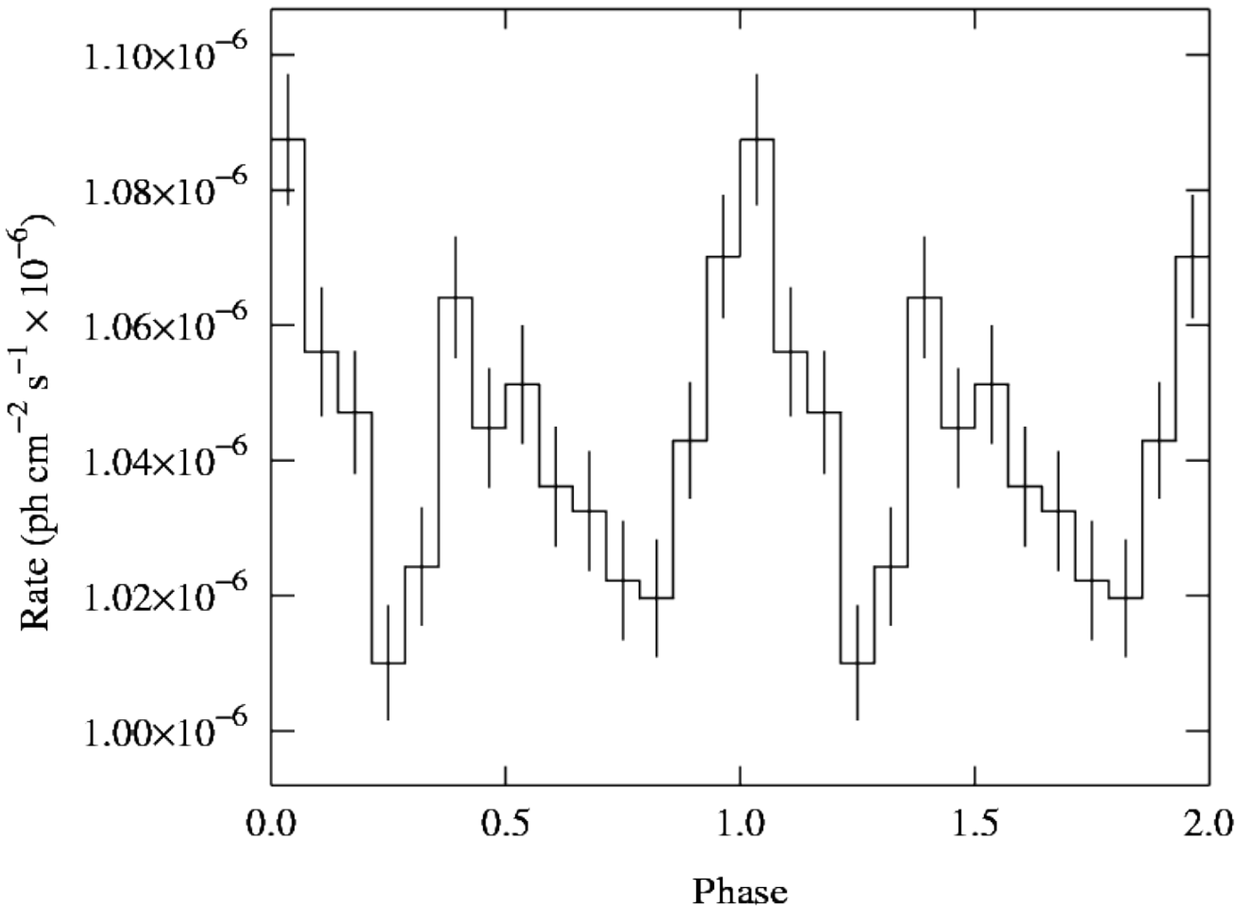


- Probability flux shows single sharp peak.
- But, photon weighting may affect photometric properties…



Power Spectrum of **Unweighted** Photons





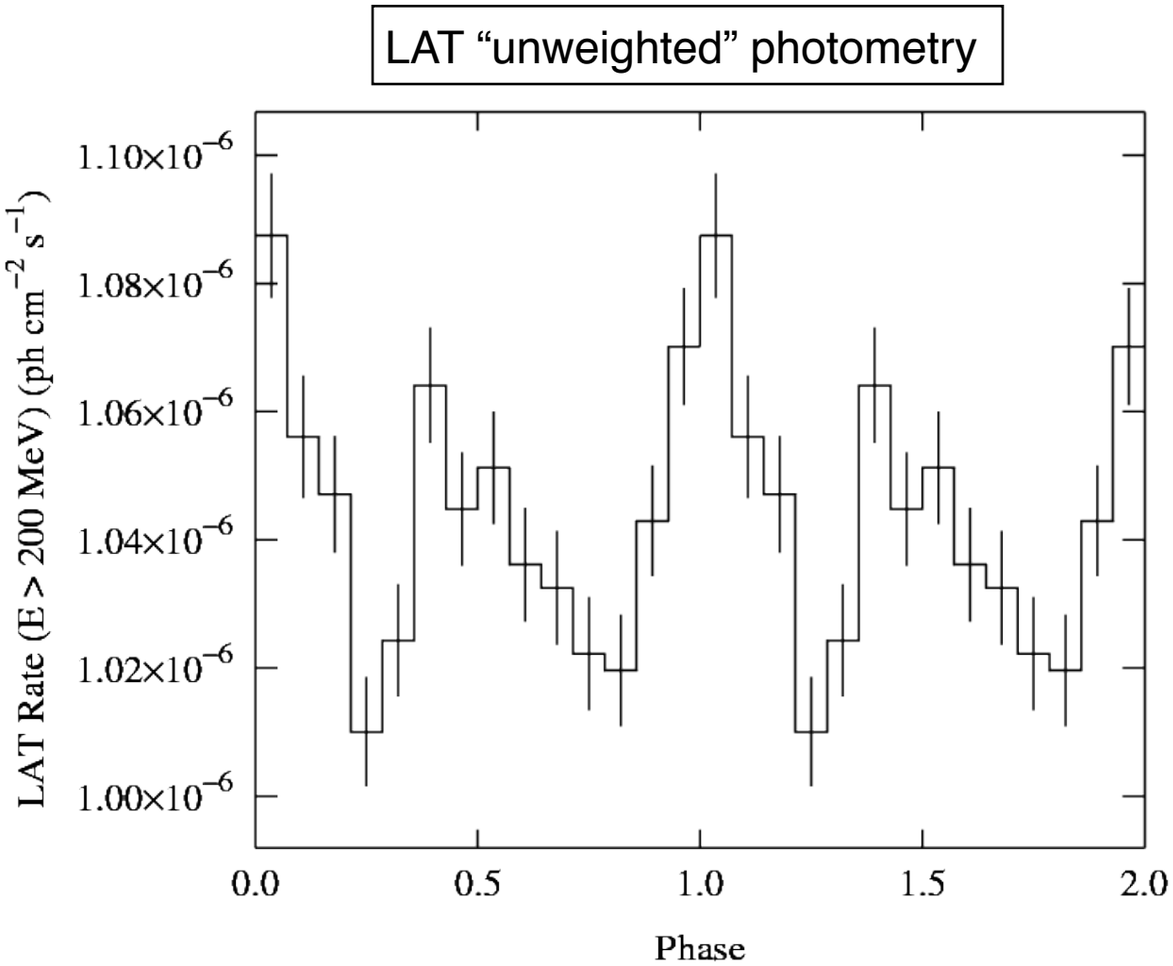
Folded on **14 day** period

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.)

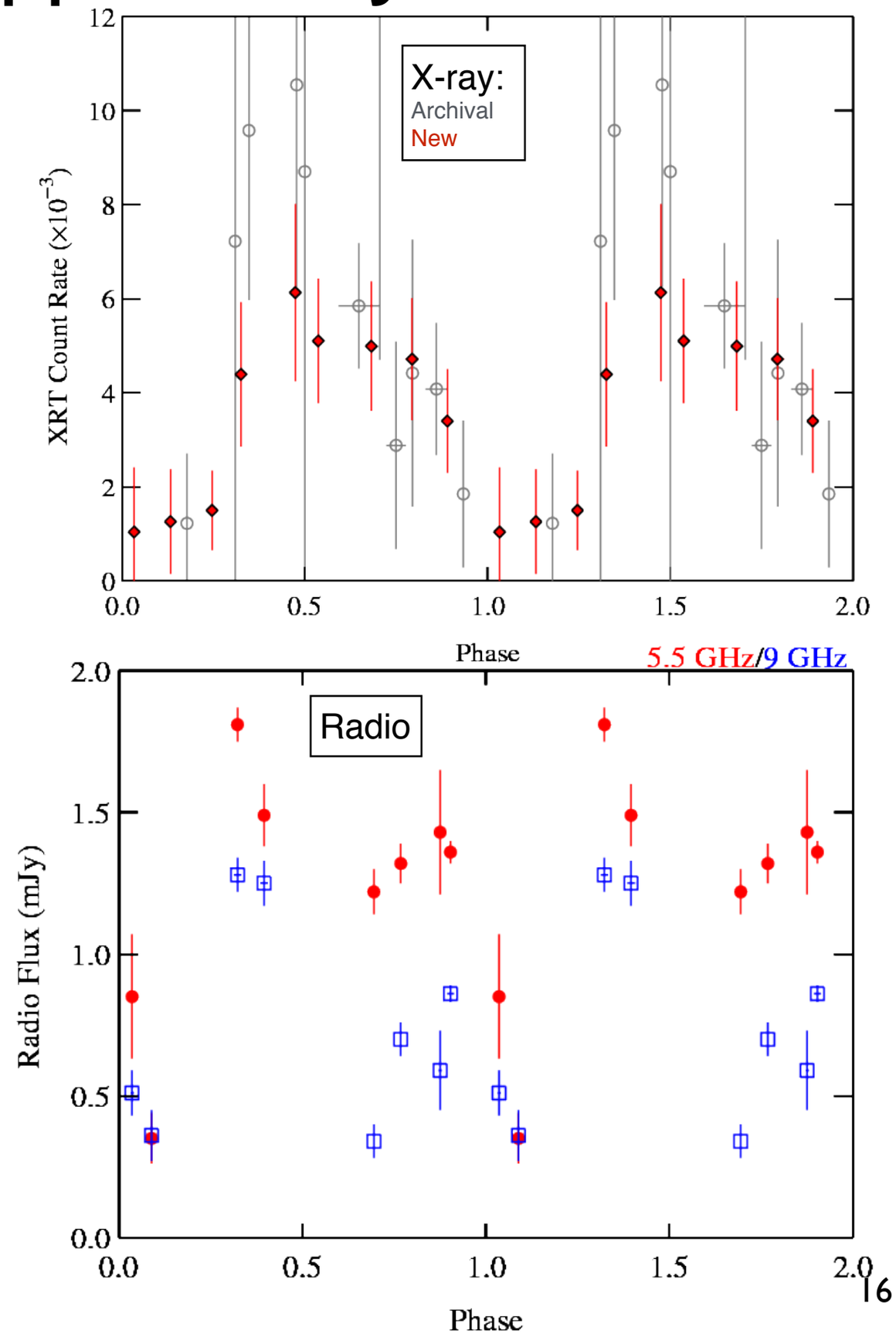
X-ray and Radio Support for J1405.4



- “Conventional” LAT aperture photometry shows double-peaked profile on ~14 d period.

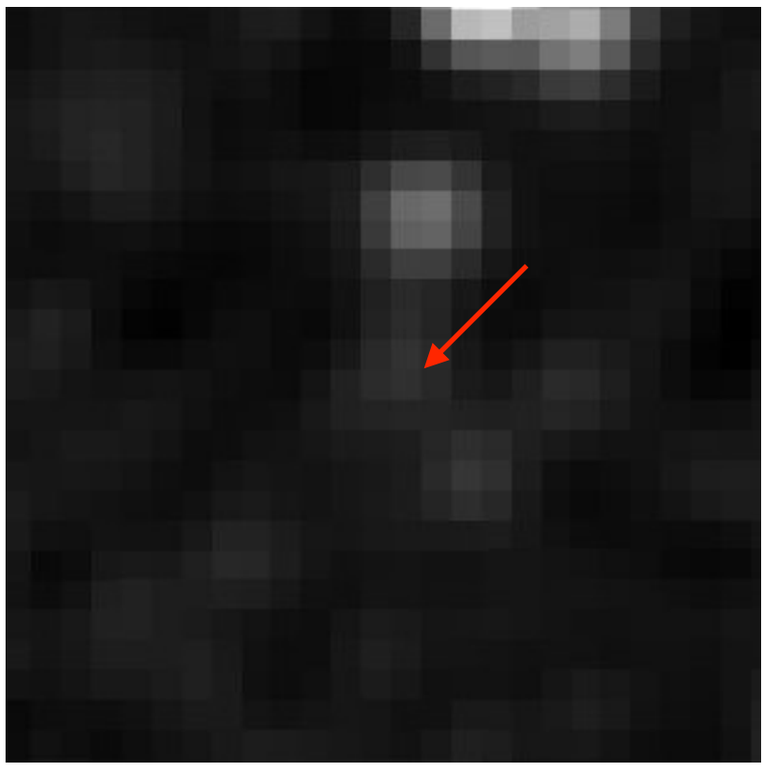
- *Secondary* γ-ray peak is *softer*.

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

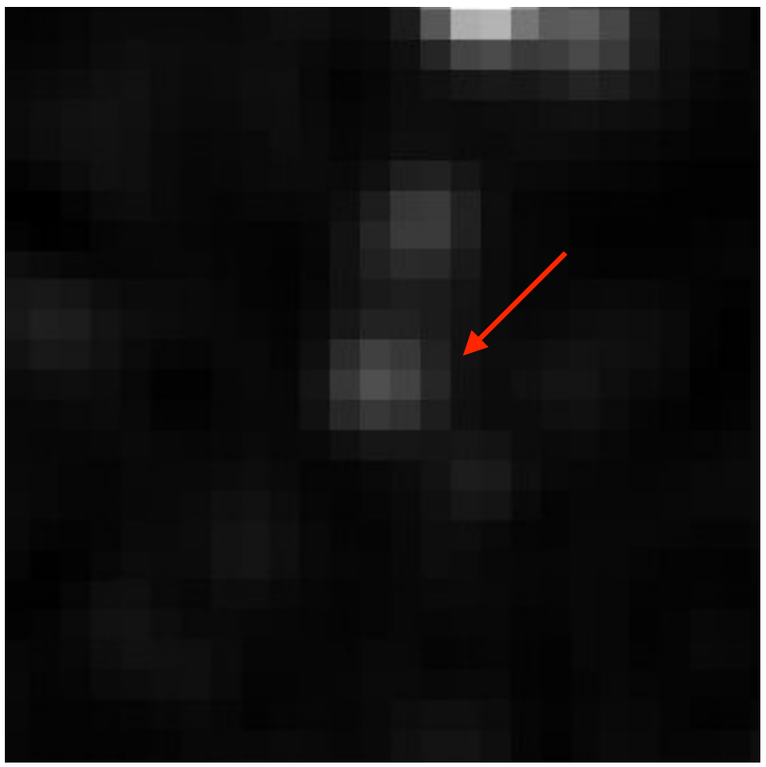


Near-Infrared (2MASS) Counterpart of J1405.4

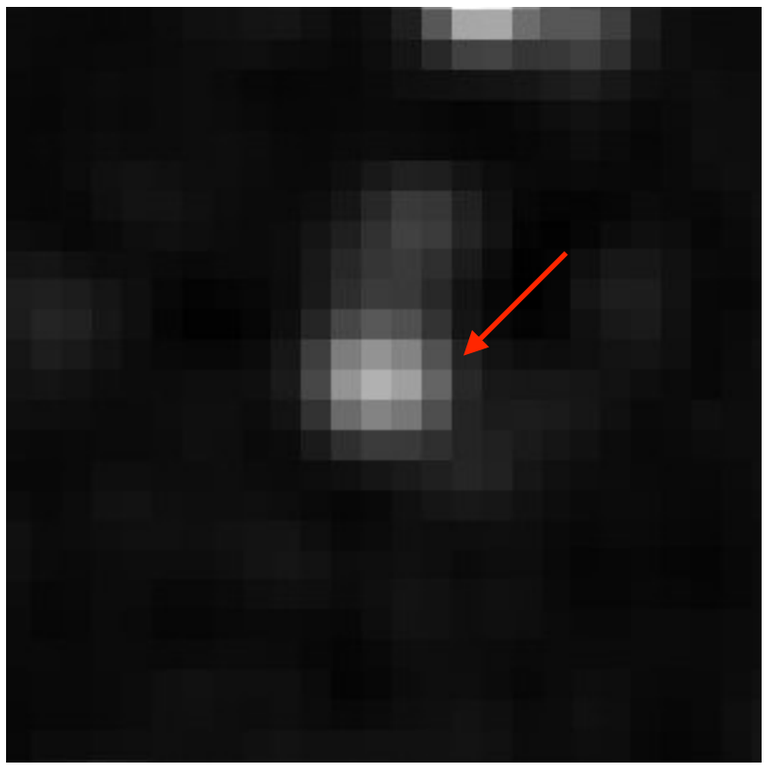
Extremely heavily reddened. E(B-V) ~11



J-Band
(1.2 μm)



H-Band
(1.7 μm)

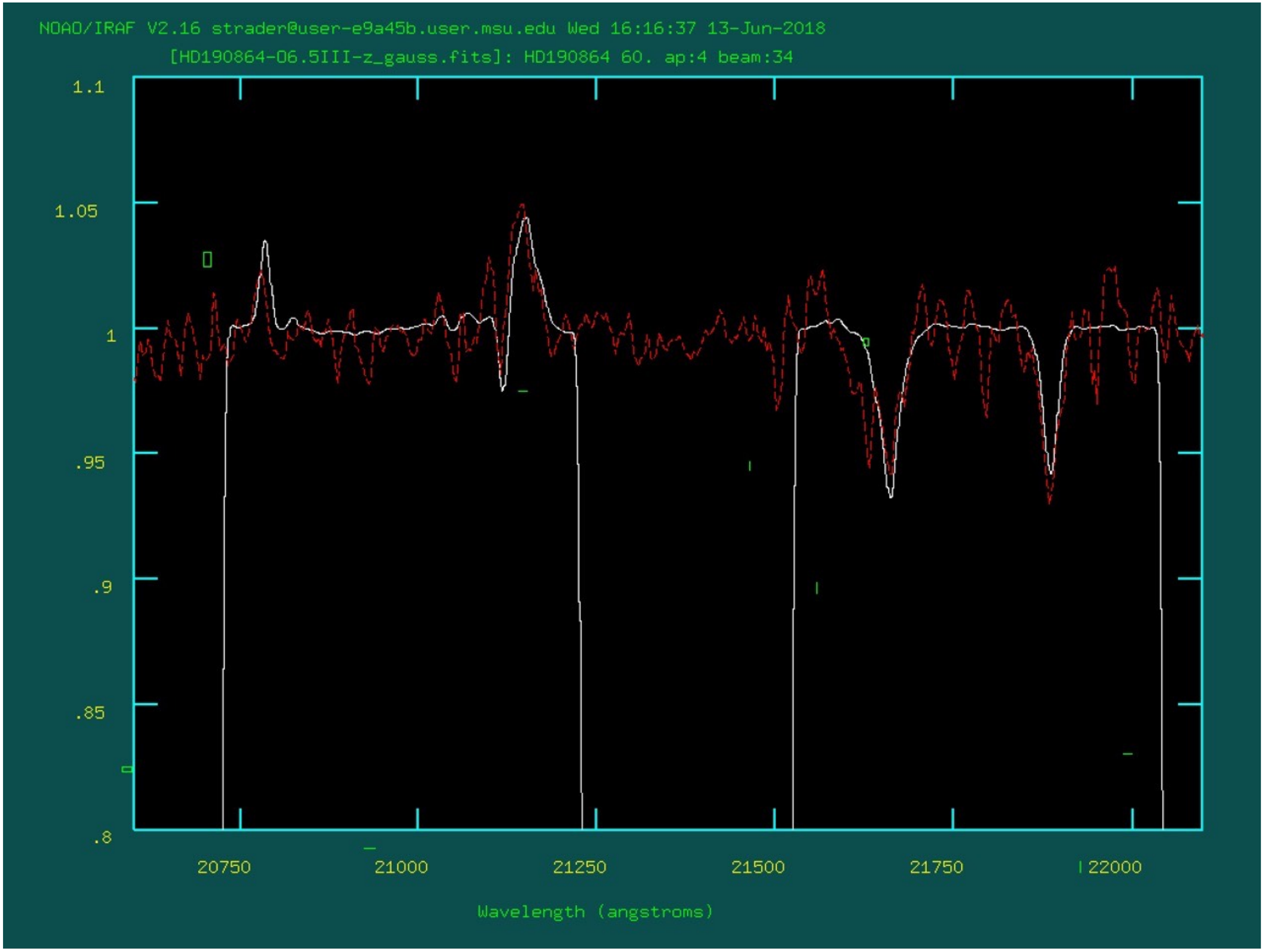


K-Band
(2.2 μm)

Gemini/Flamingos near-IR spectrum shows counterpart is O6.5 III

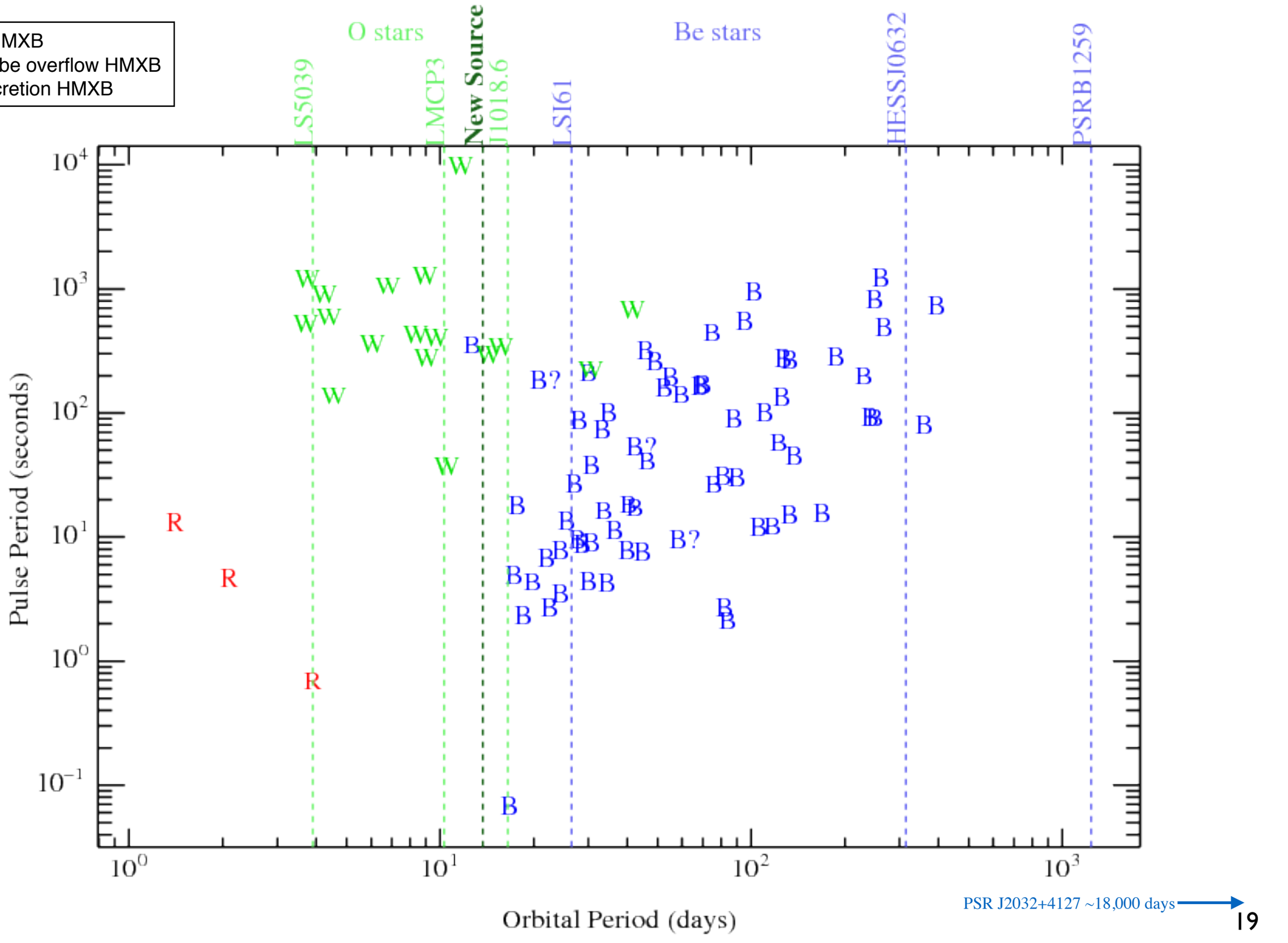
Confirms it's a binary!

(distance ~6 kpc)



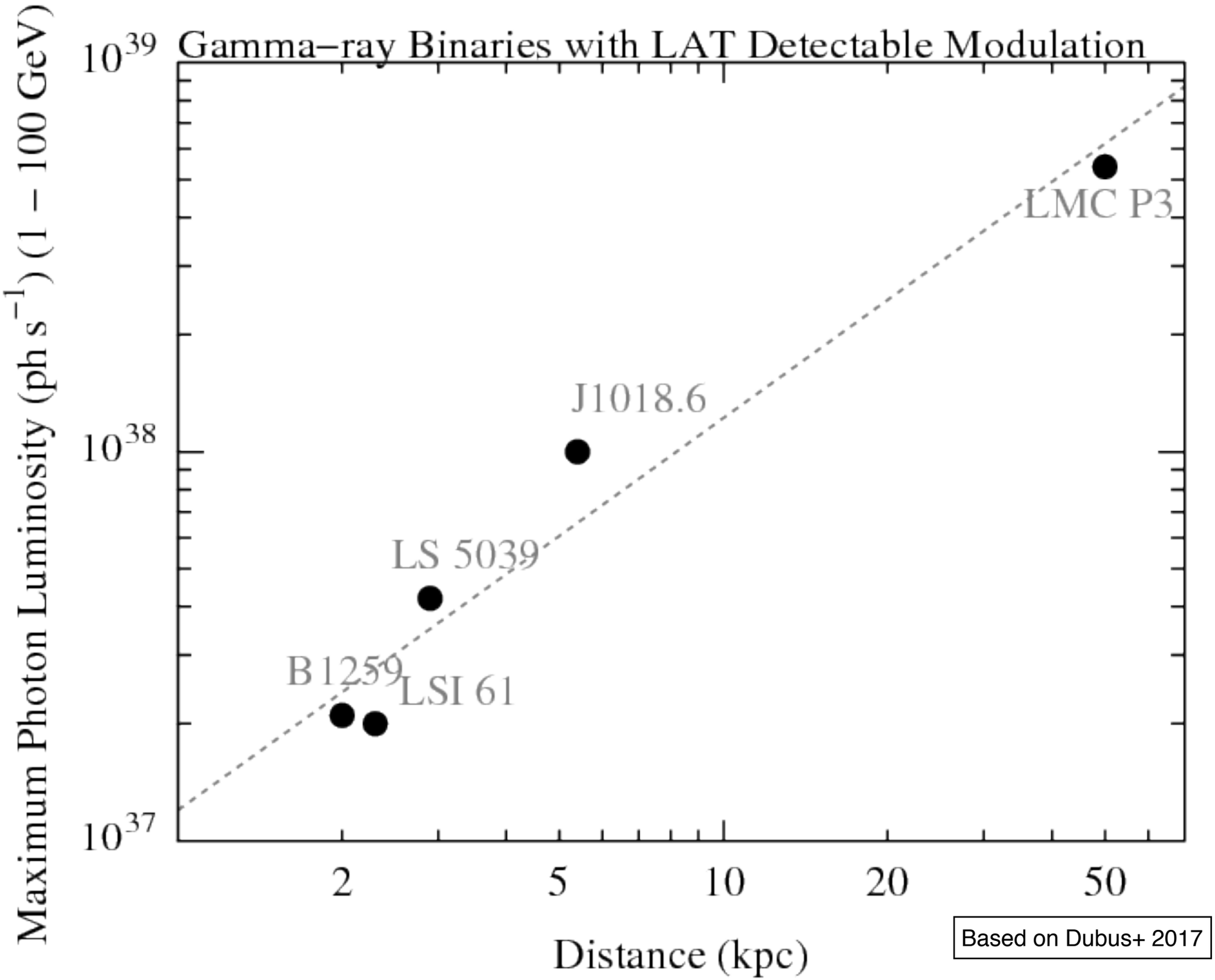
Orbital Periods: Gamma-ray & X-ray Binaries

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



PSR J2032+4127 ~18,000 days →

How Far Are We Detecting Gamma-ray Binaries?



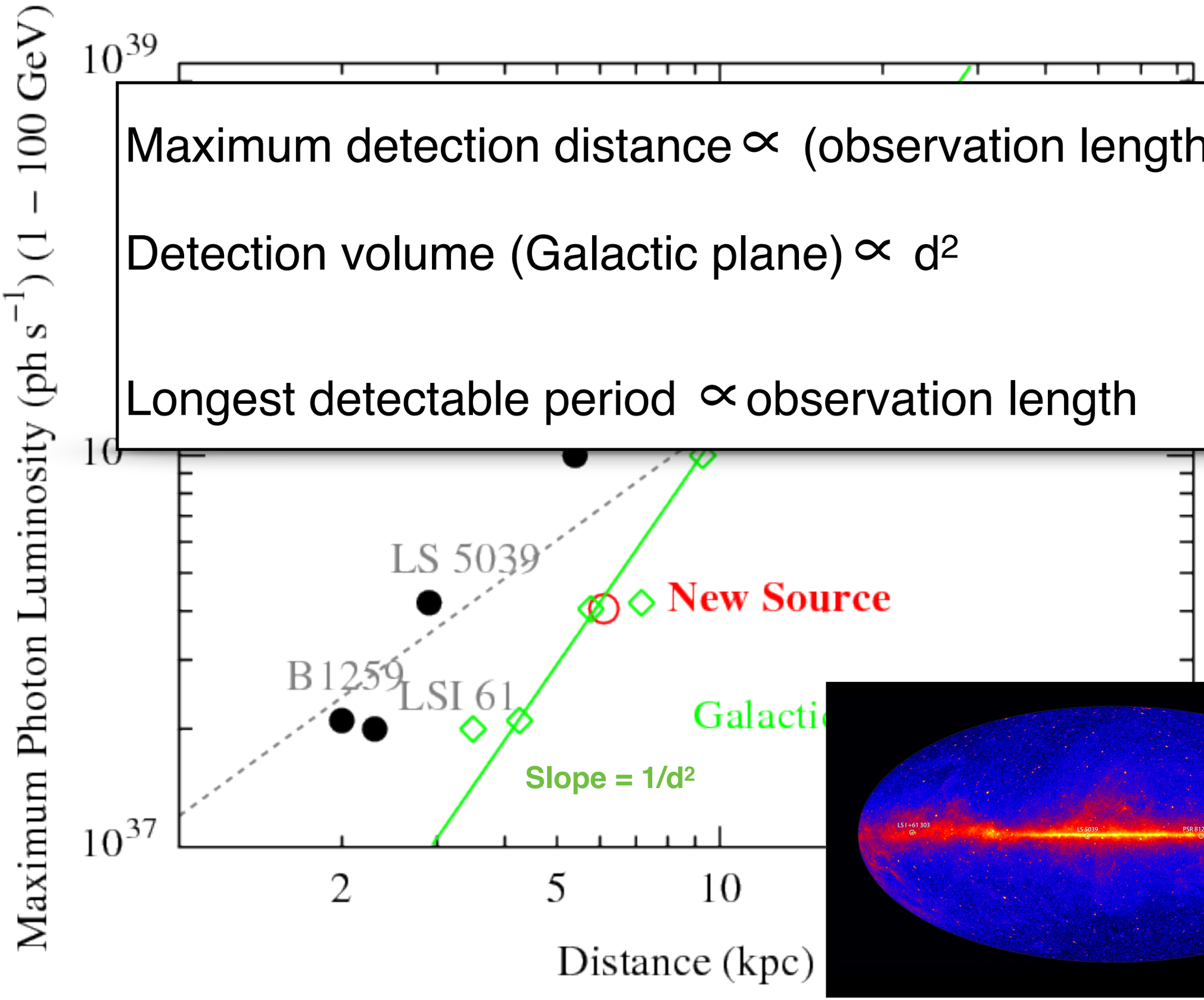
Based on Dubus+ 2017

How Far Could We Find Gamma-ray Binaries?

Maximum detection distance ∝ (observation length)$^{1/4}$

Detection volume (Galactic plane) ∝ d^2

Longest detectable period ∝ observation length



Galactic Binary Population & Future Prospects

- Power spectra are a powerful way to find binaries.
- Multiwavelength observations crucial to confirm binaries, and understand astrophysics.
- We have one more binary with O star primary!
  - The third O star binary we found from LAT variability.
- Galactic population of γ-ray binaries is still unclear.
  - Probably only scratching the top of the luminosity distribution. (Particularly Be star systems.)
- We continue to search for binaries as Fermi acquires more data, and eagerly await the 4FGL catalog…