Discovery of a New Gamma-Ray Binary: 1FGL J1018.6-5856

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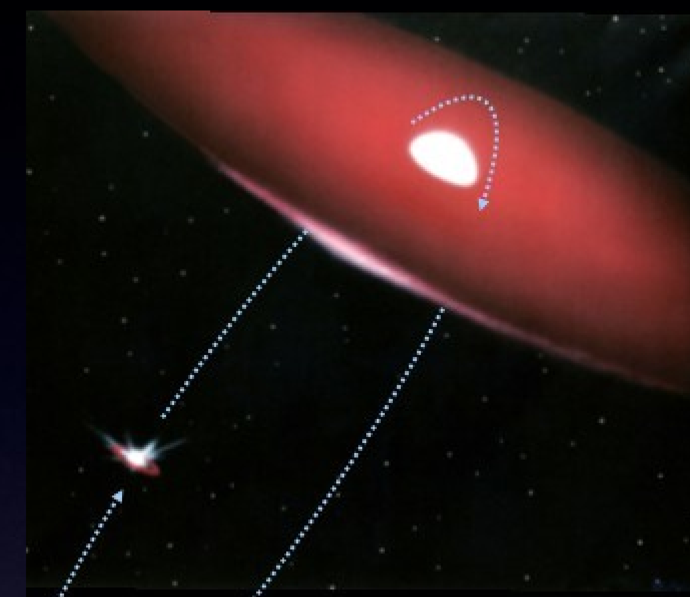
Definition of a Gamma-ray Binary

- A binary star system containing a neutron star or black hole.
- Detectable gamma-ray flux.
- The gamma-ray emission is caused by an <u>interaction</u> between the two binary components.
  - Excludes pulsars in binaries where there is no interaction.
- (Optional!) Distinguish between:
  - Gamma-ray binaries: gamma-ray luminosity dominates spectrum
  - Gamma-ray emitting X-ray binaries: X-ray flux >> gamma-ray flux

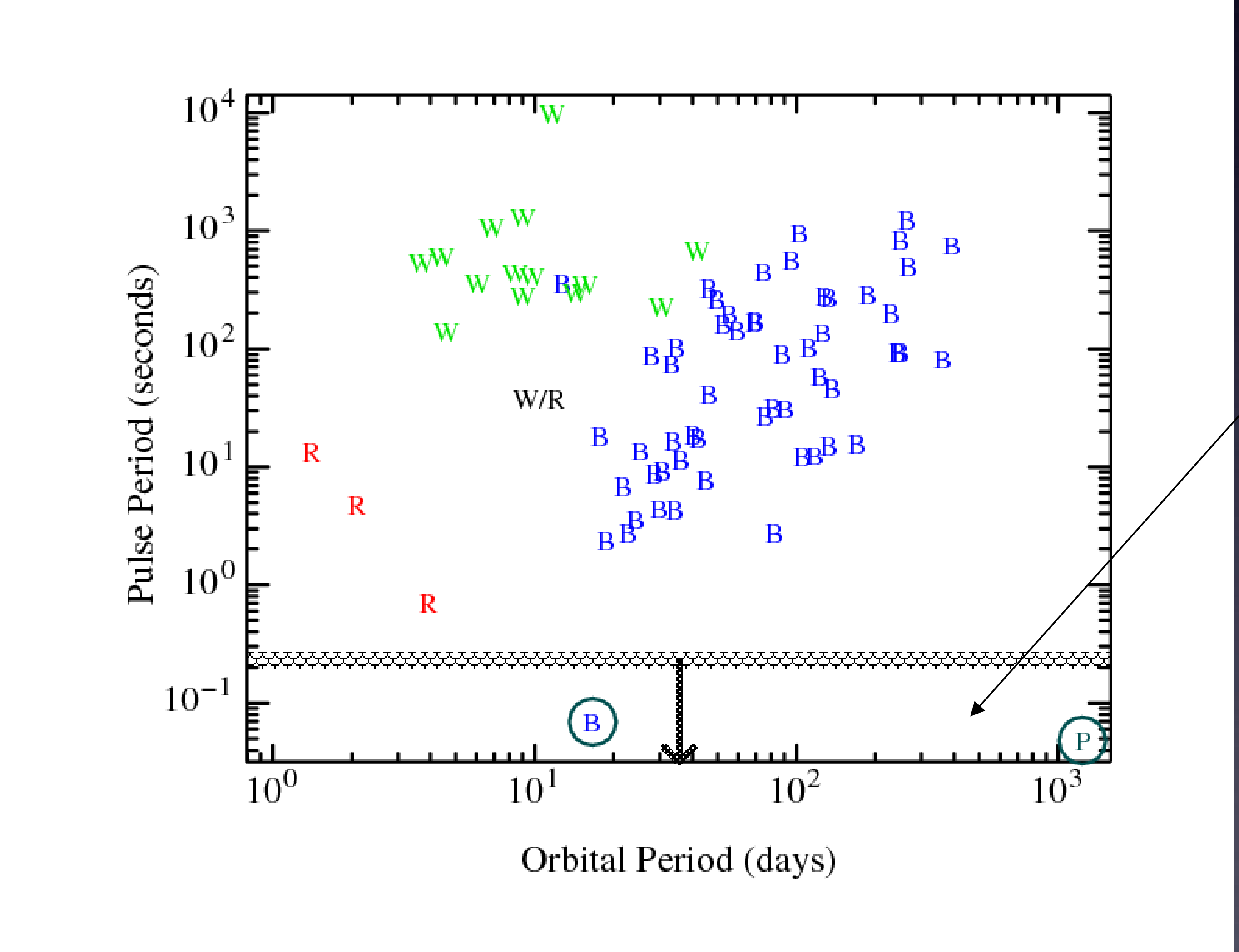
What Makes a Gamma-ray Binary?



- To make a gamma-ray binary you need:
  - Power source
  - Non-thermal mechanism. e.g. Fermi acceleration at shocks + inverse Compton scattering.
- The "conventional" models are:
  - Accreting microquasar with relativistic jets
  - Pulsar interacting with the wind of an O or B type companion. (Pulsar and stellar winds collide and form shocks.)

High-Mass X-ray Binary/Gamma-ray Binary Connection?

Do neutron star high-mass X-ray binaries go through a gamma-ray binary phase early in their lives? (e.g. Meurs & van den Heuvel 1989)



A newly born neutron star is rapidly rotating. Pulsar wind interacts with companion's wind and produces gamma-rays until it has spun down.

Gamma-ray Binaries are Rare

The Fermi LAT had previously detected only:

Cygnus X-3: transient *microquasar*, Wolf-Rayet (+ black hole?). 4.8 hr orbital period.

- LS I +61 303: Be star, *suspected pulsar companion*. 26.5 day period.
- PSR B1259-63: Be star, *definite 48ms pulsar companion*. 3.4 year period.
- LS 5039: O6.5V((f)) star, *suspected pulsar companion*. 3.9 days.
  - These were all previously known, or at least suspected, gamma-ray binaries - even before Fermi.
  - (Cyg X-1 & HESS J0632+057 not detected with LAT)

Either the mechanisms that make gamma-ray binaries occur infrequently, or else more systems remain to be discovered!

Fermi and the LAT

Fermi was launched on June 11, 2008

The primary instrument is the LAT: 100 MeV (or lower) to 300 GeV (and higher).

The LAT has several advantages over previous detectors:

- Instrument performance: Improved effective area, field of view, angular resolution.
- Observation mode: the LAT operates in sky survey mode almost all the time. The ***entire sky is observed every ~3 hours***. Can study binaries on wide range of timescales.

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The Hunt for New Binaries

- Known gamma-ray binaries all show gamma-ray modulation on their orbital periods.
- New binaries are expected to be found from the detection of periodic variability with the LAT.
- However, even with the improved sensitivity of the LAT, gamma-ray count rates are still low.
  - Even a “bright” source may only give ~20 photons/day in the LAT.

Need to obtain the highest possible signal-to-noise light curves and make sensitive period searches.

Optimizing Light Curves

- There are two basic ways to make LAT light curves:
  - Maximum likelihood fitting.
  - Aperture photometry.
- Likelihood fitting is slow, and is difficult/impossible if not many photons are present in a time bin.
- Aperture photometry is non-optimal. Ignores source photons outside the aperture, includes background inside the aperture.
  - Problem compounded by strong LAT PSF energy dependence.
- Instead, use a "weighted photon/infinite aperture" technique. Sum the probabilities that each photon came from source of interest.
  - Can give a significant increase of Signal/Noise

Optimizing Power Spectra

- To search for periodic modulation, use power spectra.
- We want ability to search for short orbital periods, like Cyg X-3's 4.8 hour period.
  - Short time bins are needed (e.g. < 1ks). Shorter than the LAT sky survey period of ~3 hours.
  - This gives big variations in exposure.
  - Use "exposure weighting" of each data point's contribution to the power spectrum.

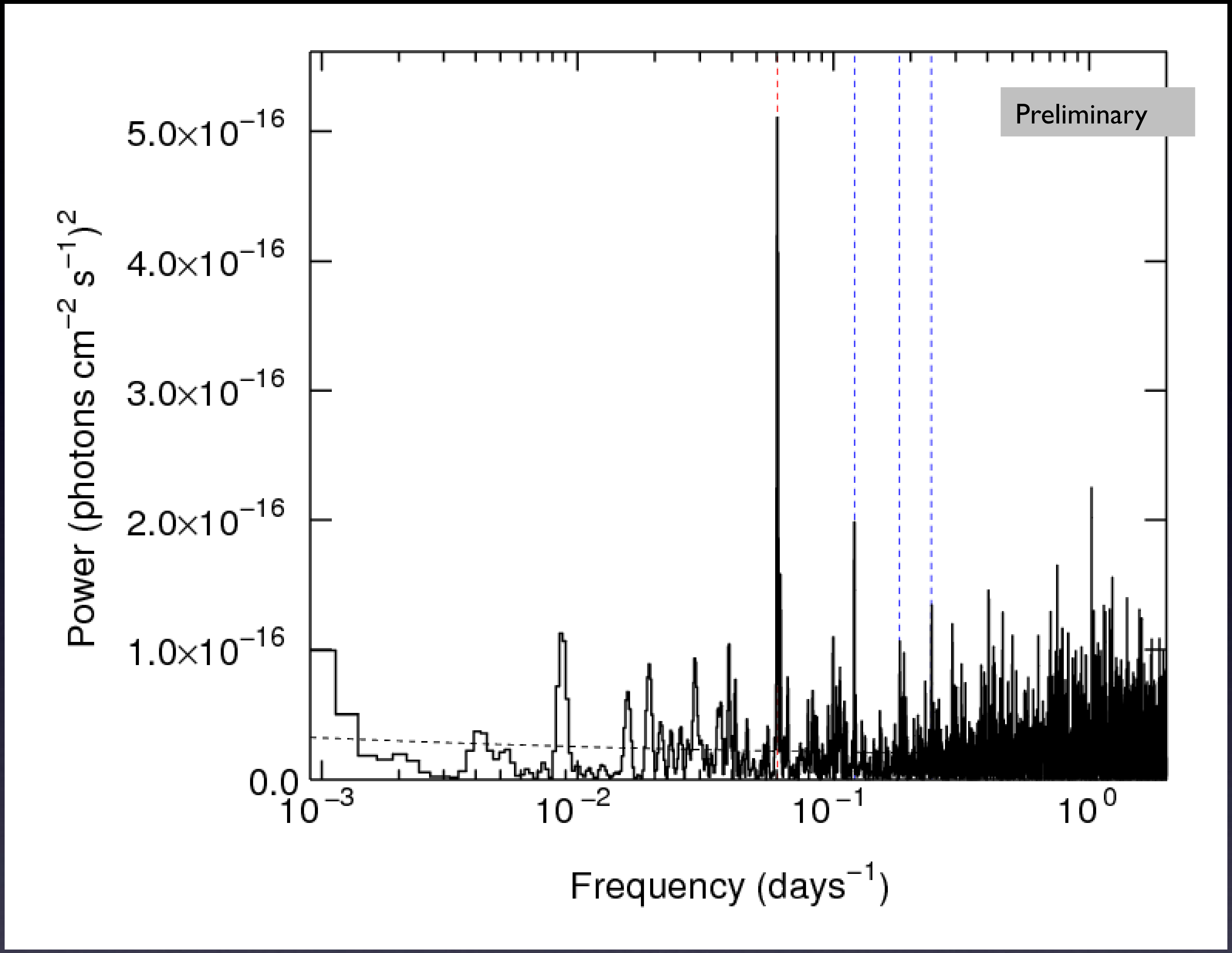
The Search

- Made weighted-photon light curves for all 1,451 1FGL (1st Fermi catalog) sources:
    - 3 degree radius aperture.
    - 600 s time bins (barycenter corrected).
    - 100 MeV to 200 GeV.
    - 752 days long (2.06 years) for <u>initial</u> search.
- Calculated exposure-weighted power spectra for all sources: 0.05 to 752 days.
- Easily detected LS I +61 303 and LS 5039, but not Cyg X-3. (To detect Cyg X-3 must only use data from active states.)
- And a candidate for a new binary...

Part 2: *Finding* a Gamma-ray Binary: Multiwavelength Observations of 1FGL J1018.6-5856

- 1FGL J1018.6-5856 is one of the brighter Fermi sources.
- LAT spectrum similar to a pulsar - but <u>no</u> pulsations seen.

A 16.6 Day Period in 1FGL J1018.6-5856



Probability of peak at 16.6 days arising by chance is < 10^{-7}.
Second (and possibly higher) harmonics of this period are also seen.
Modulation at 16.6 days is not seen in any other Fermi source.

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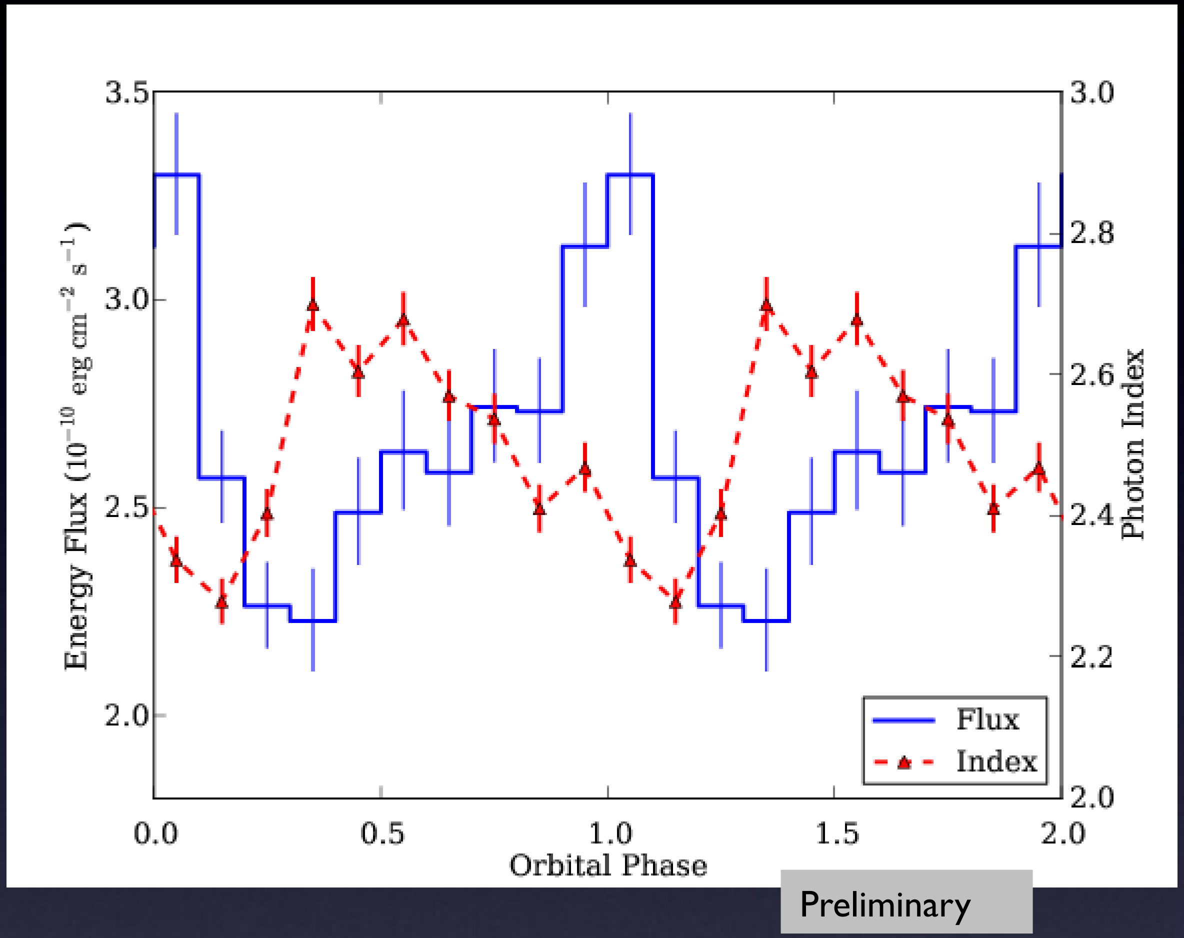
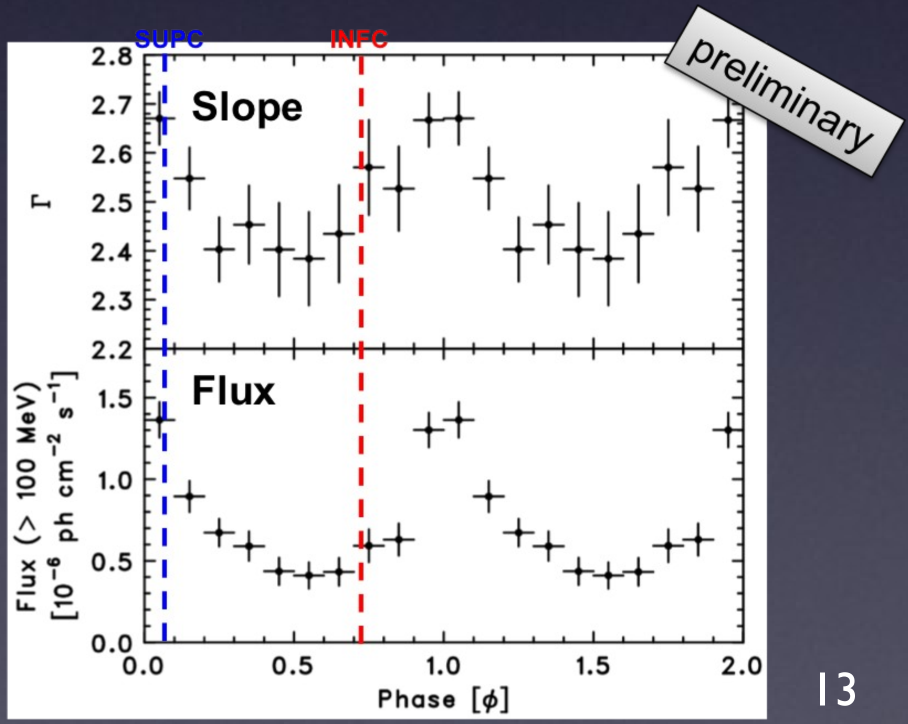
Flux/Spectral variability on 16.6 day period

- Gamma-ray spectrum is also modulated on the 16.6 day period. (Harder when bright.)
- *Qualitatively* similar to LS 5039 (3.9 day period), but <u>not</u> LS I +61 303.
- Except... LS 5039 is softer when bright.



LS 5039
(Hadasch et al)



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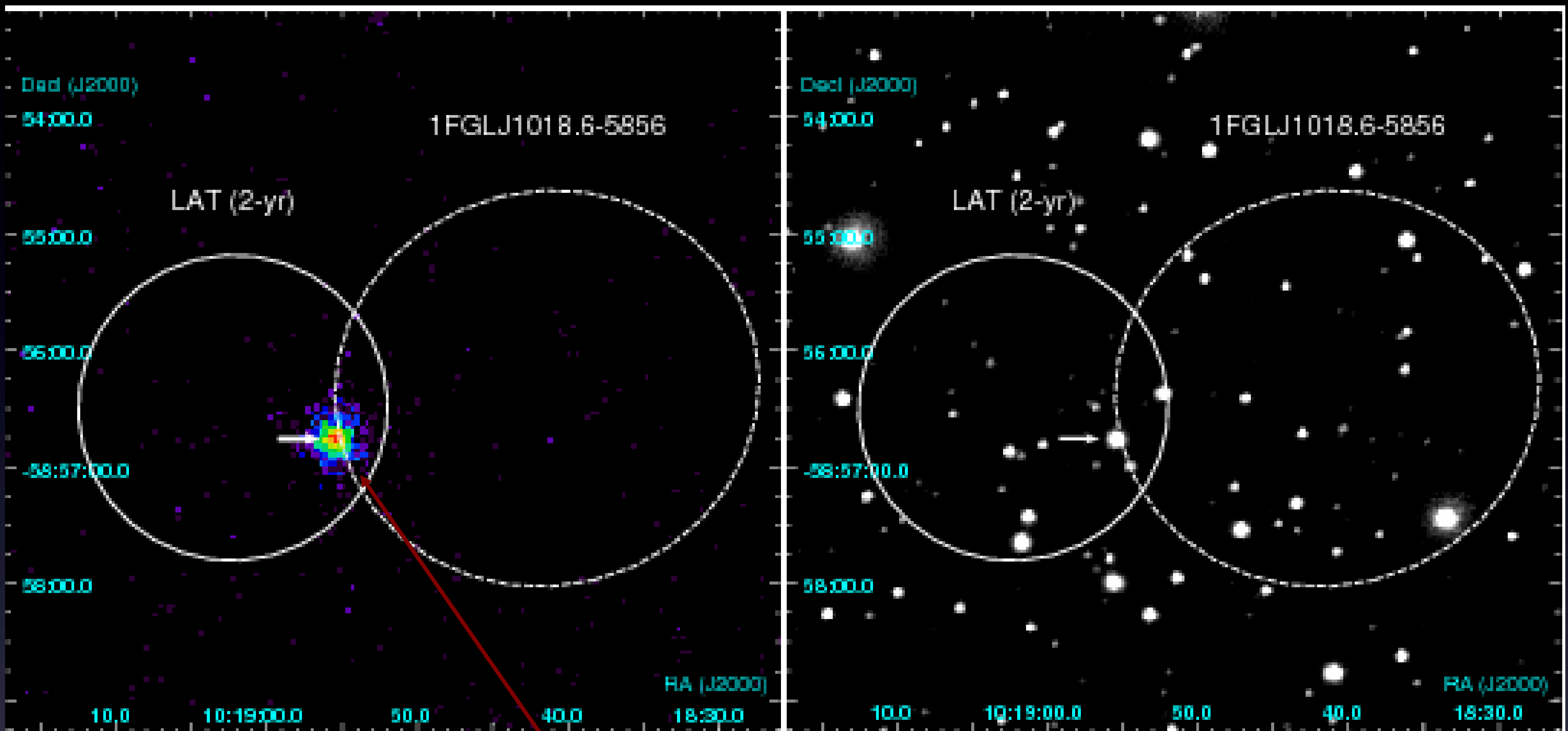
X-ray/Optical Counterpart (i)



Swift XRT
(X-ray)

Swift UVOT
(UV/optial)

Preliminary

A prominent X-ray source is present at the edge of the LAT error circle.

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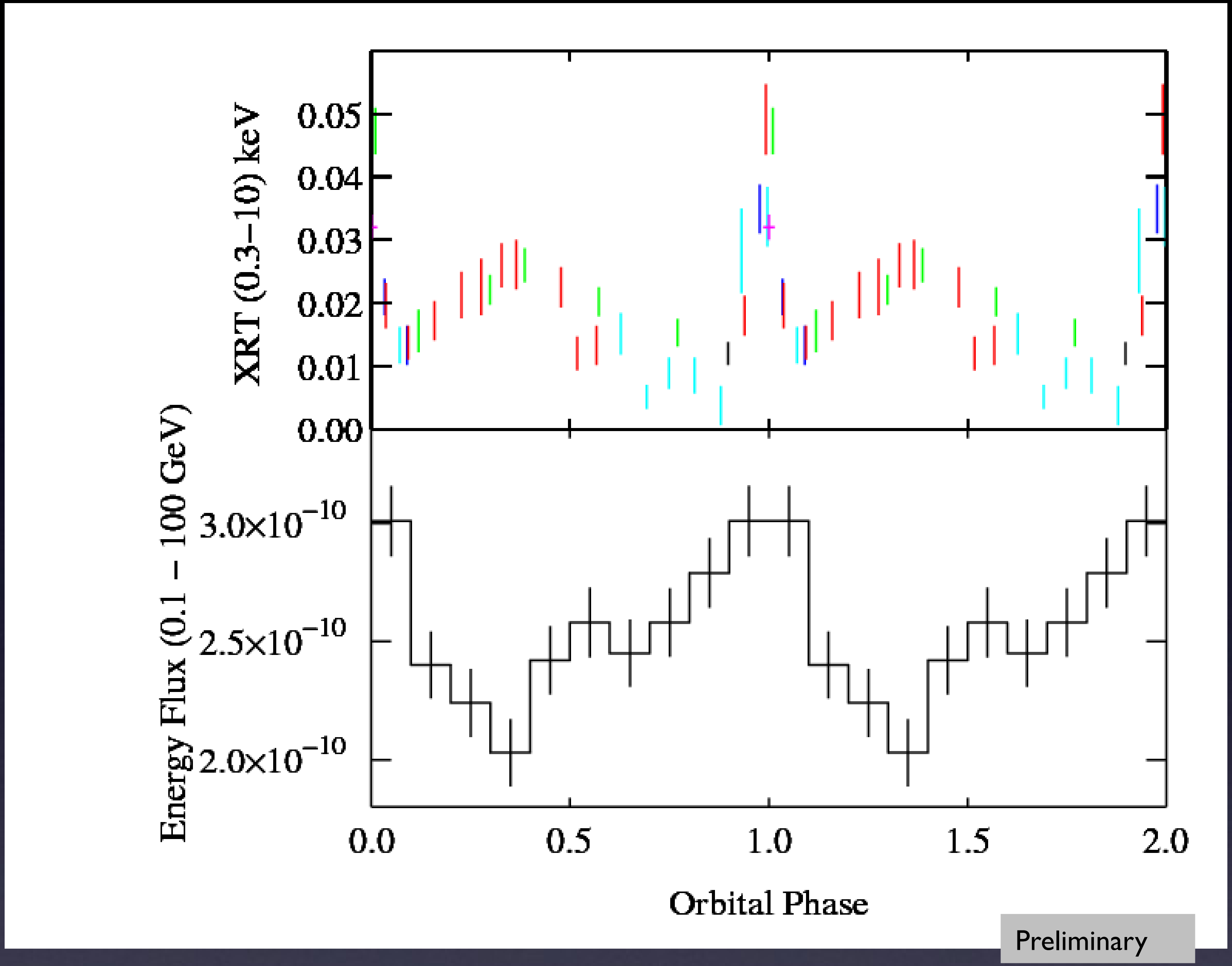
Large X-ray variability (Swift XRT)



- Different colors (top panel) show X-ray data from different 16.6 day cycles.
- Flare-like behavior near phase 0, coinciding with gamma-ray maximum.
- X-ray modulation also has a quasi-sinusoidal component with peak at phase ~0.4

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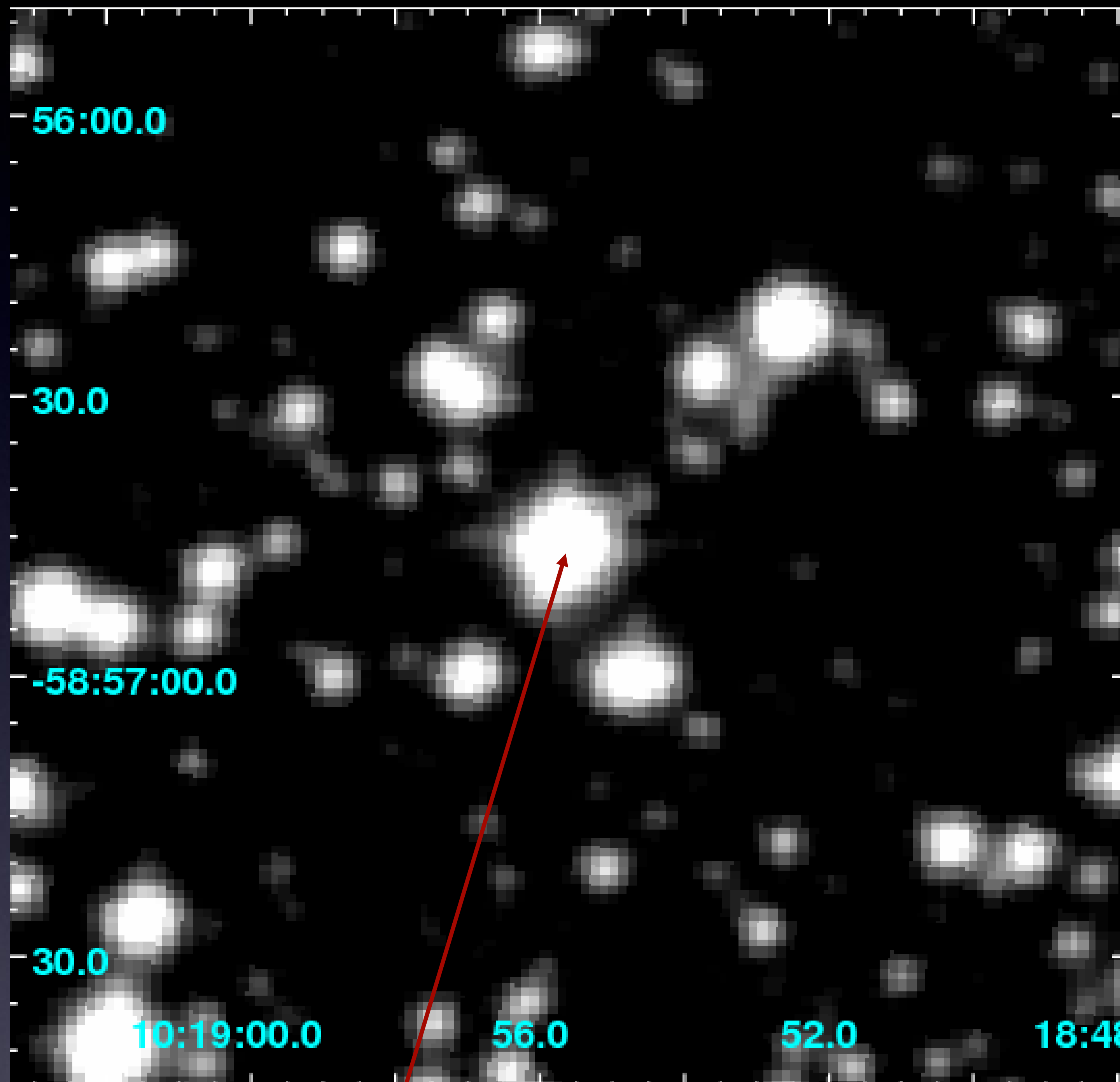
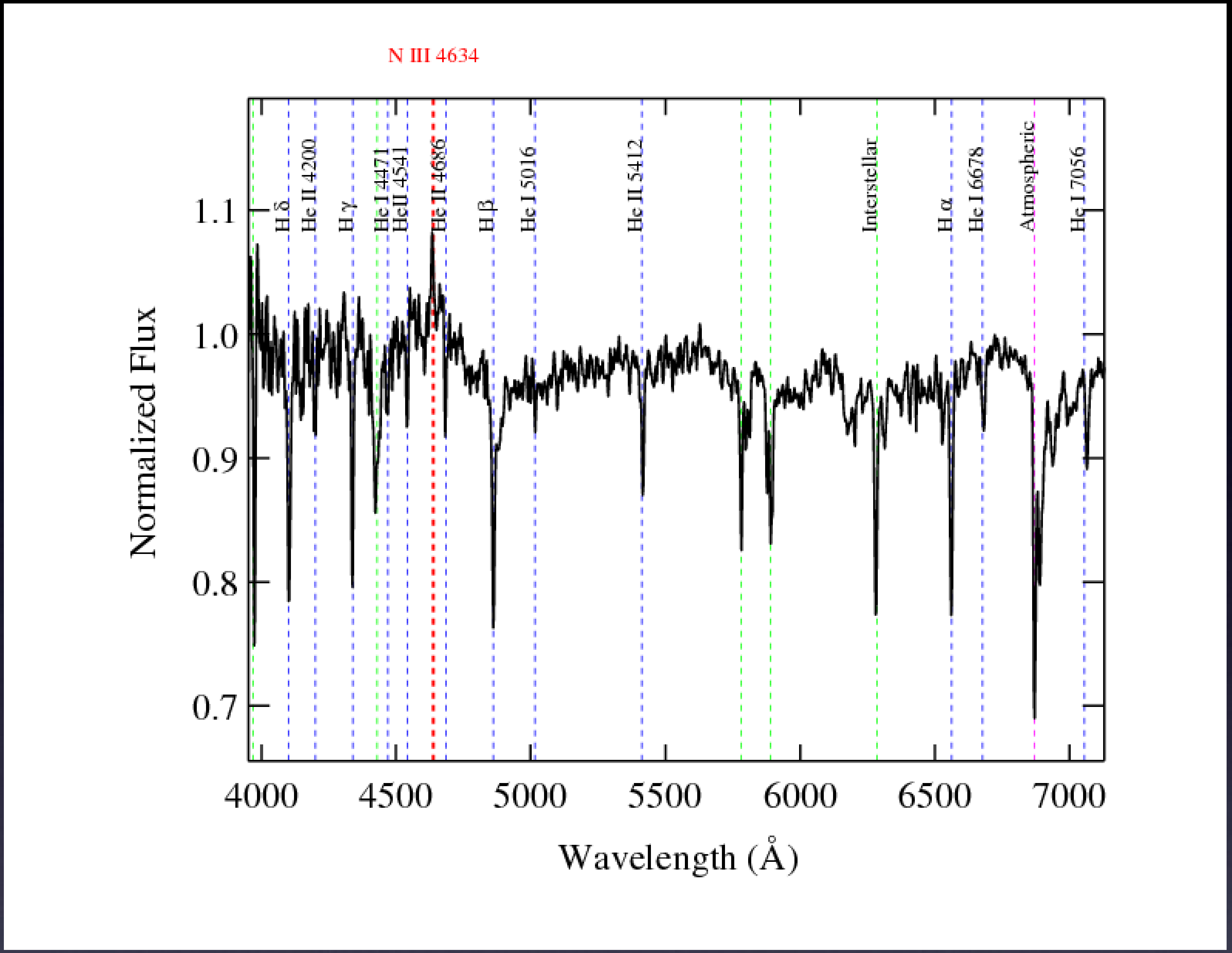
Optical/X-ray Counterpart (ii)



DSS red image: Swift position coincides with bright (B ~13, R ~12) star.

Optical Spectrum

- H, He I/II lines indicate early spectral type.
- He II 4686Å absorption ⇒ main sequence.
- He II/I ratio ⇒ ~O6
- NIII emission ⇒ O6V((f)).
- Spectral type is <u>almost identical</u> to LS 5039.



SAAO 1.9m telescope

Interstellar absorption lines ⇒ E(B-V) ~1.25.
V ~12.6 (ASAS Catalogue)
Distance ~5 kpc (±~2kpc)

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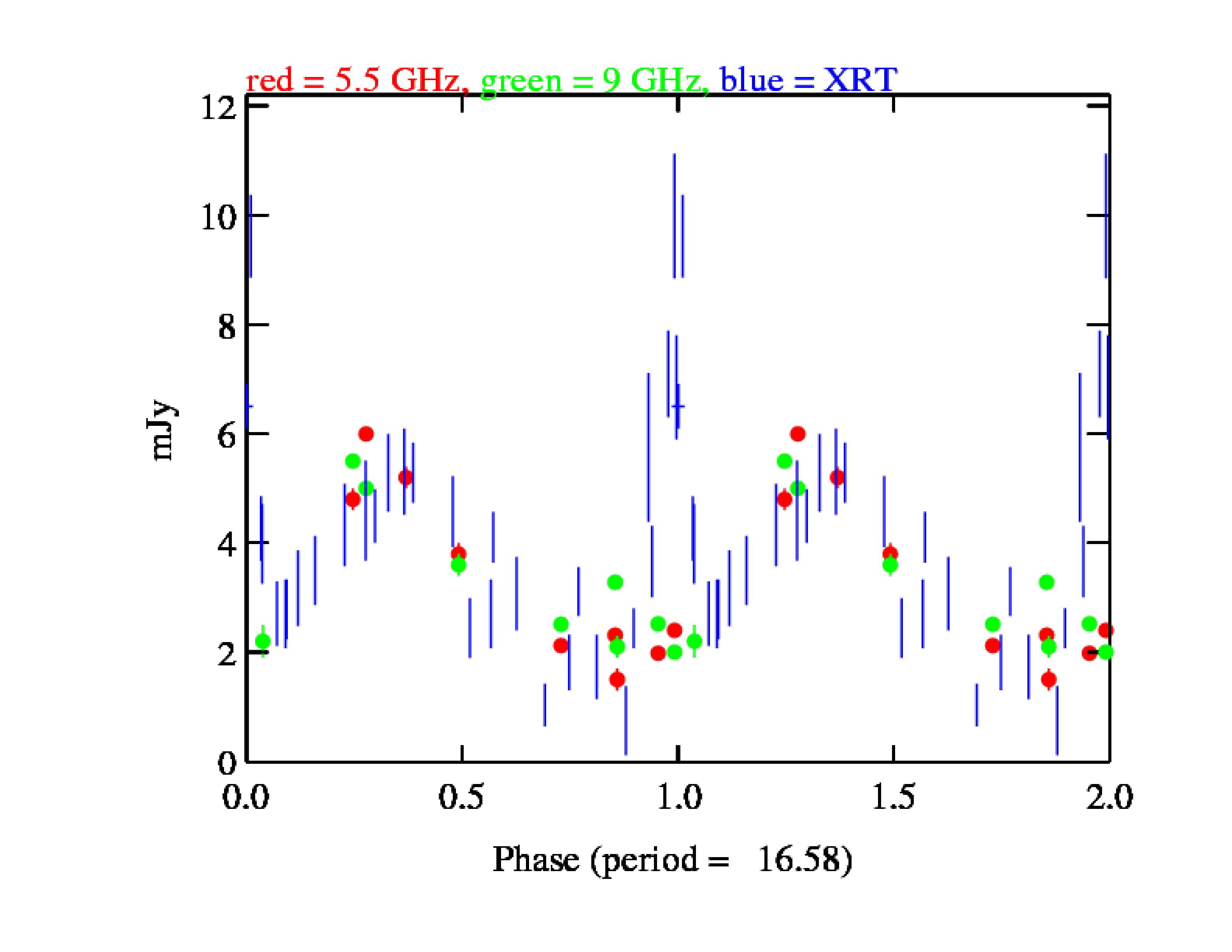
And a spatially coincident, variable radio source!



(ATCA Radio data)

The radio flux appears to be modulated on the orbital period.
But, no increase at phase 0.
Radio flux may be following sine wave component of X-ray flux.

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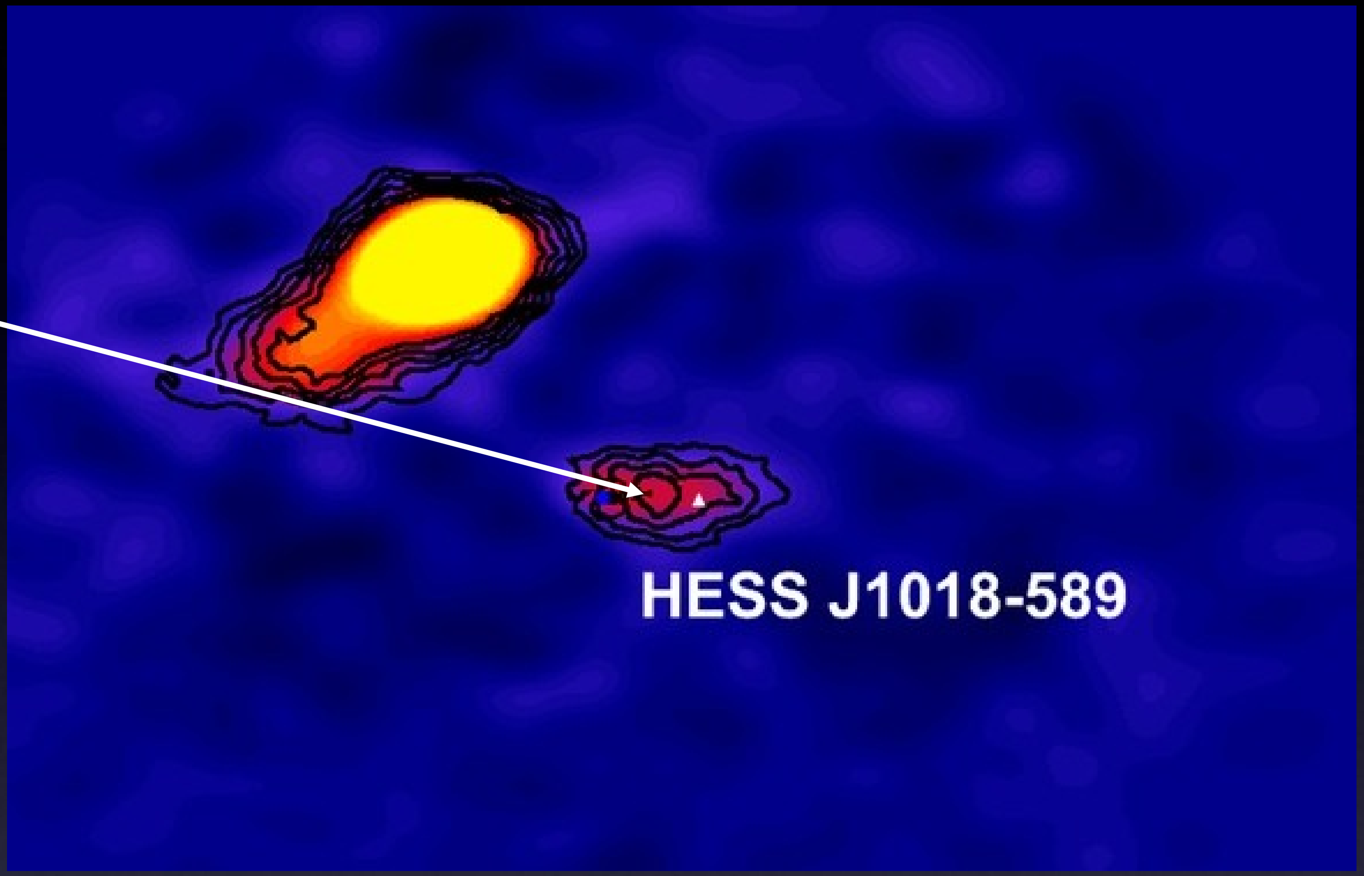
TeV Emission from the Vicinity of 1FGL J1018.6-5856

- H.E.S.S. (de Ona Wilhelmi et al., 2010 & poster B06) reported a TeV source in this region.

- The positions are consistent, but it's not certain the HESS source is associated with 1FGL J1018.6-5856.

- TeV emission is seen (at least sometimes) from LS 5039 and LS I +61 303,

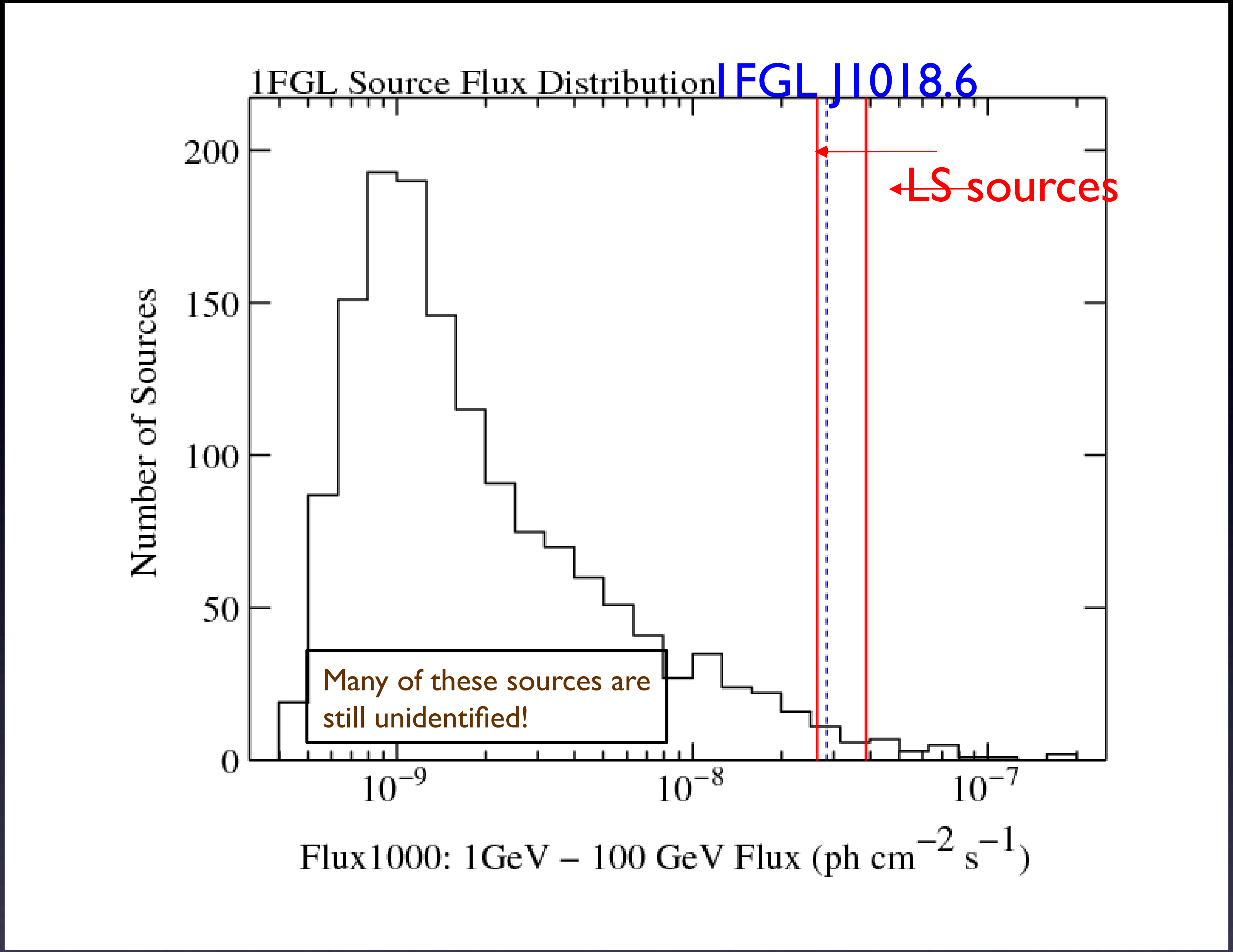
- Is this the TeV counterpart of 1FGL J1018.6??



Summary (Part 1/2)

- 1FGL J1018.6-5856 is a gamma-ray binary, similar to LS 5039:
  - LAT light curve shows very significant modulation at 16.6 days.
  - LAT spectrum is cut-off power law, hardness varies on 16.6 day period, similar to LS 5039.
  - There are X-ray, optical, and radio counterparts:
    - Optical counterpart ~O6V((f)), just like LS 5039.
    - X-ray counterpart is highly variable (like LS sources). Orbital phase dependent. (Weird light curve!)
    - The radio counterpart is variable (more like LS I +61 303?).
- 1FGL J1018.6-5856 <u>may</u> contain a rapidly rotating pulsar interacting with the wind of an O star.
- A determination of orbital parameters from optical radial velocity study would greatly help in modeling the system – proposal accepted for 2012

Summary (Part 2/2): Prospects for Future Discoveries...



- So far, we've only found binary periods in the very brightest sources.
- With additional data, we can investigate more of the main body of the 1FGL source catalog "iceberg".
- We hope that there are more binaries waiting to be discovered!