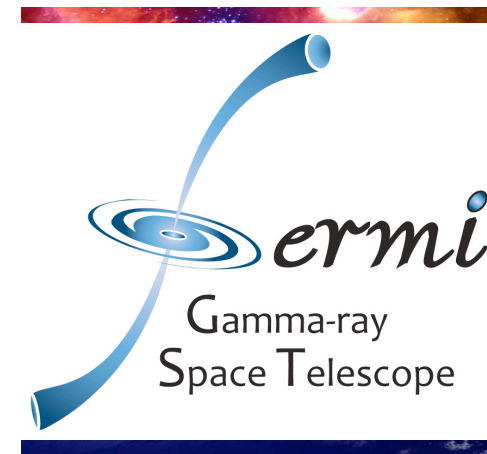




Workshop on Variable Galactic Sources

Gamma-ray binaries: GeV spectra and variability

Diego F. Torres, on behalf of the Fermi collaboration



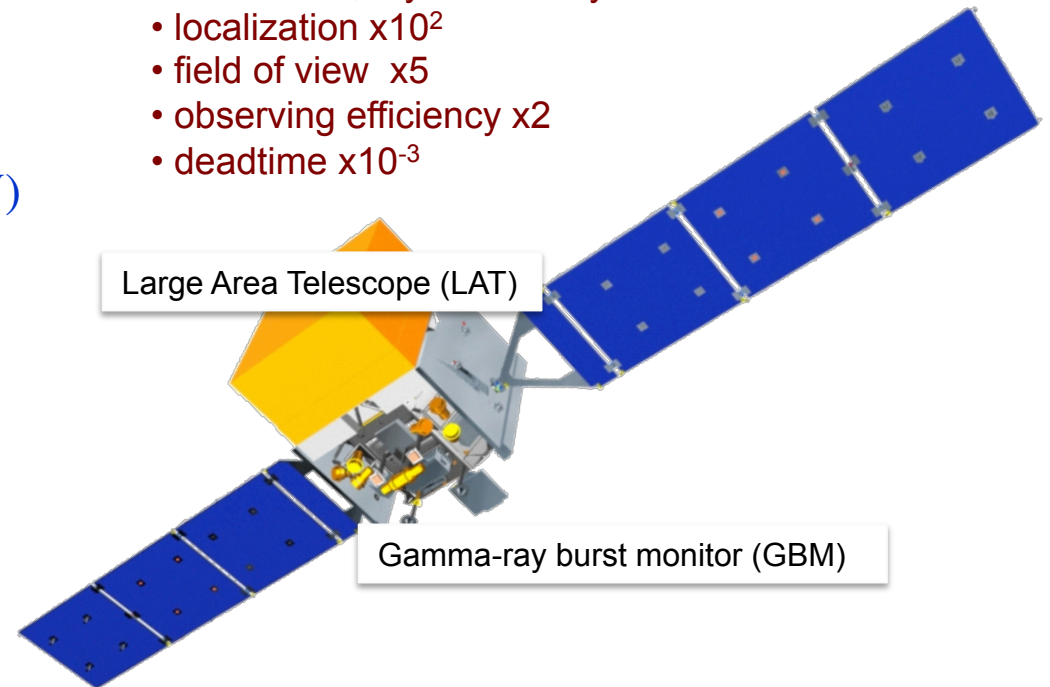
Heidelberg, December, 2010

The Fermi satellite

- Two Fermi instruments:
 - LAT:
 - high energy (20 MeV – >300 GeV)
 - GBM:
 - low energy (8 keV – 30 MeV)

Compared to EGRET:

- > 100 MeV, 1 yr sensitivity x25
- localization x10²
- field of view x5
- observing efficiency x2
- downtime x10⁻³



- Huge field of view
 - LAT: 20% of the sky at any instant; in sky survey mode, expose all parts of sky for ~30 minutes every 3 hours. GBM: whole unocculted sky at any time.
- Huge energy range, including largely unexplored band 10 GeV - 100 GeV

PI: Peter Michelson (Stanford & SLAC)
 ~270 Members (including ~90 Affiliated Scientists, plus 37 Postdocs, and ~50 Graduate Students)
 Managed at Stanford Linear Accelerator Center (SLAC).

XRB/MQ/binaries study group:

G. A. Caliandro

S. Chaty

T. Cheung

S. Corbel

R. Corbet,

R. Dubois,

G. Dubus,

D. Hadasch,

A. Hill,

M. Kerr,

E. Koerding

T. Tanaka,

D. F. Torres

et al.

ApJ 2009, 701, L123

ApJ 2009, 706, L56

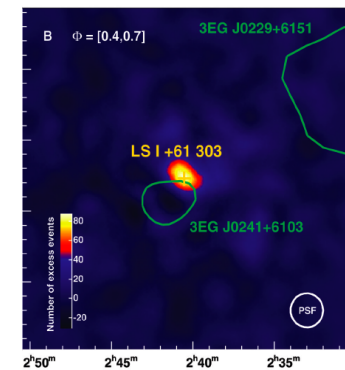
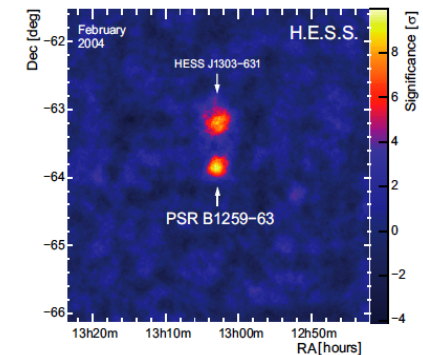
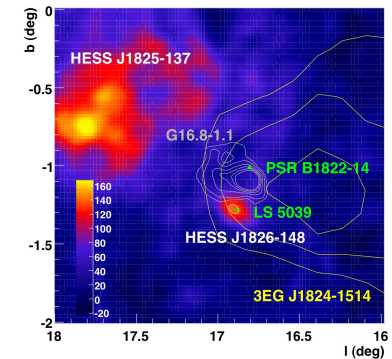
Science 2009, 326, 1512

Science 2010, 329, 817

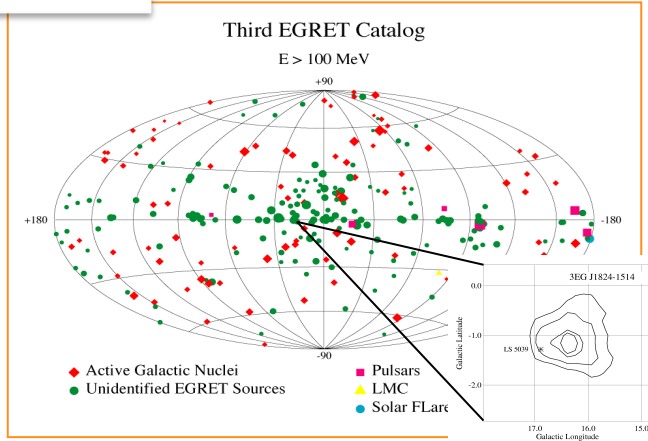
Several other works in preparation.

Covered in detail in other talks

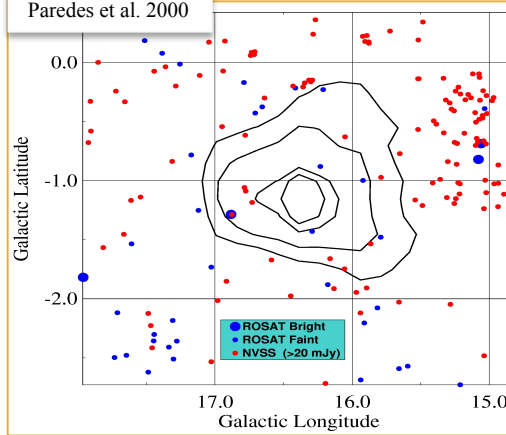
- LS I +61° 303 (MAGIC / VERITAS): Pulsar/binary or microquasar?
- LS 5039 (HESS) Pulsar/binary or microquasar?
- PSR B1259-53 (H.E.S.S.) Pulsar/binary system.
- HESS J0632+057 is one of the very few point-like TeV sources, with a similar SED, for which gamma-ray binary origin is being considered (e.g. Hinton et al. 2009).
- In addition, MAGIC has reported on a possible flare from Cyg X-1; which clearly represents a different phenomenology (and SED) to the three previous cases.
- Other binaries had been proposed and/or searched for, but no evidence for them to shine at TeV is found., e.g., [Cyg X-3, Cen X-3, Her X-1, SS 433, etc.]



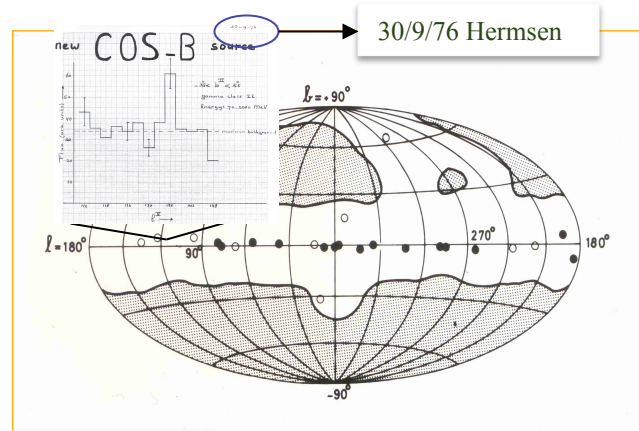
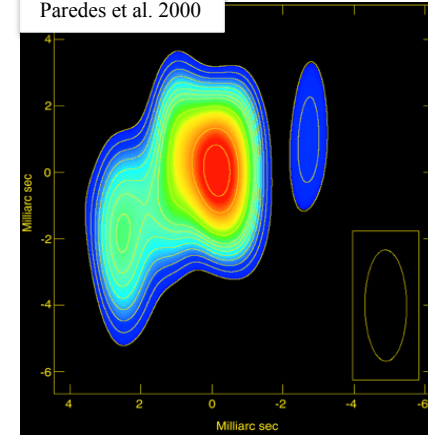
LS 5039



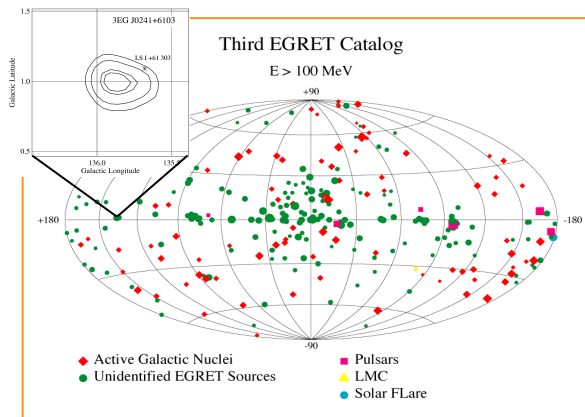
Paredes et al. 2000



Paredes et al. 2000



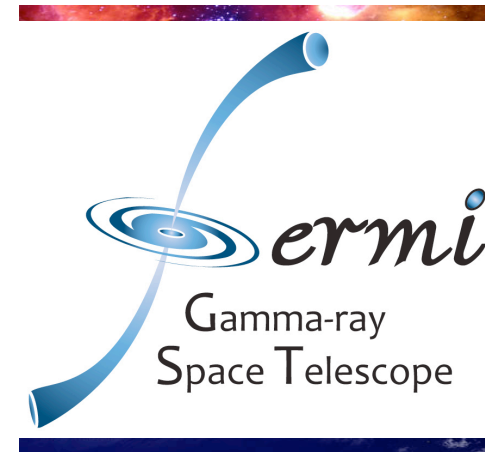
LS I+61 303



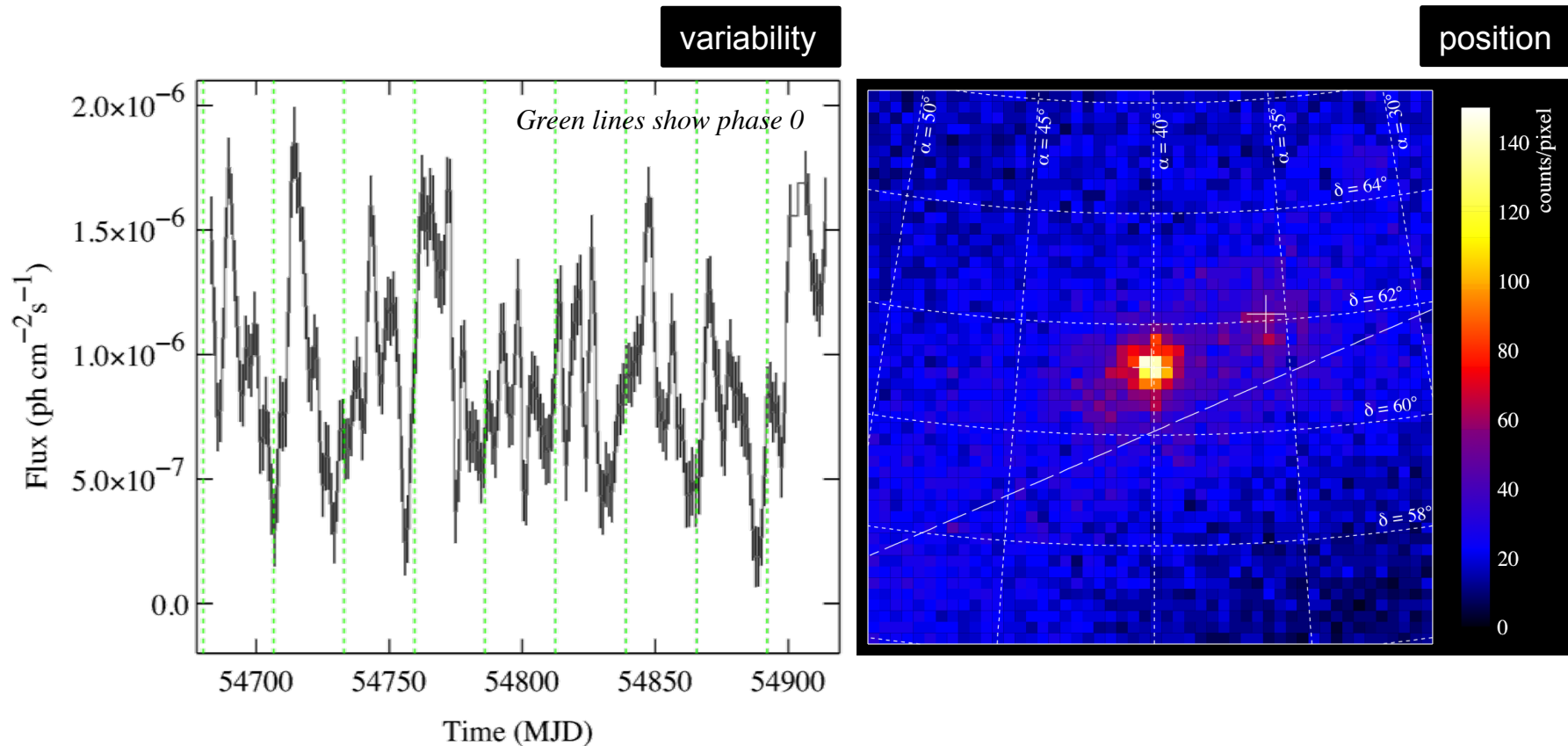
No confirmed variability (orbital) // Bad positioning // many candidates in the field led these sources to remain unidentified.



Sources we have seen: LS I +61 303

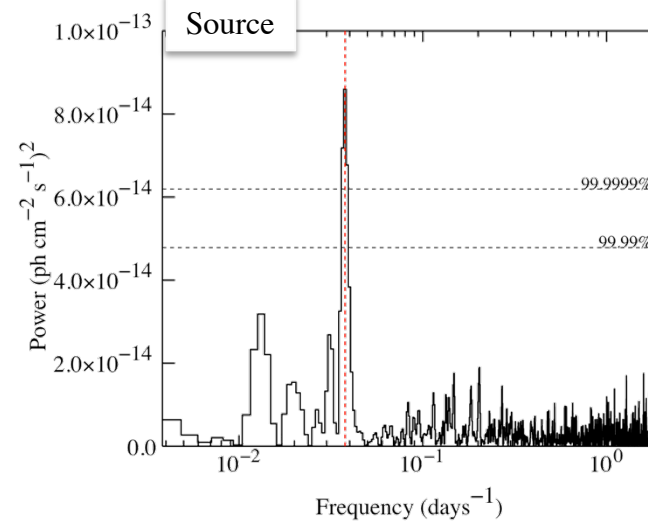


- LS I +61°303 HE γ emission has been fitted to R.A.=40.076, Dec.=61.233 with 95% error radius of 1.8’.
- This location is consistent with the known position of the optical counterpart.
- Flux variability is also clearly evident

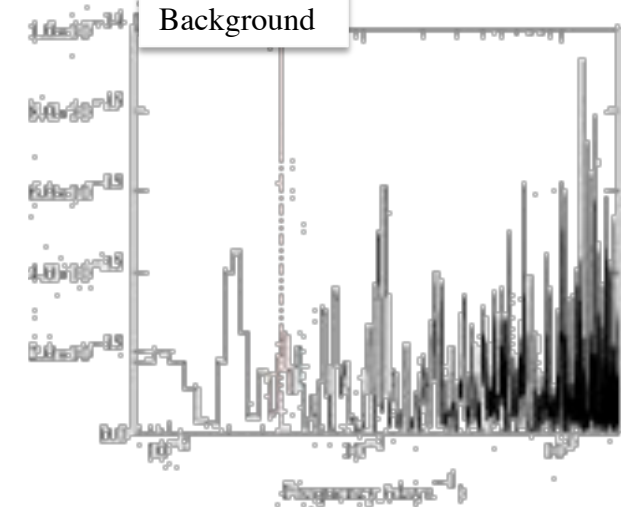


- We detect a periodicity in the LS I +61°303 light curve at 26.6 ± 0.5 days.
- Folded light curve indicates peaks of emission around periastron.
- Anti-correlation with TeV emission detected by MAGIC.
- We see no statistically significant dependence of the spectrum with phase.

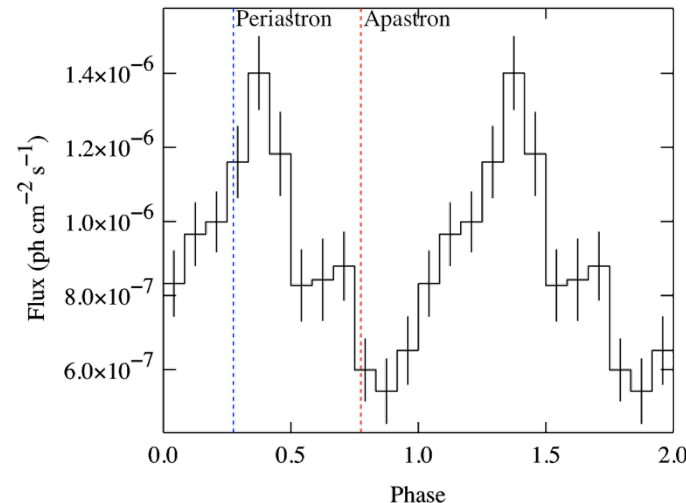
Red line shows known 26.5 day orbital period



Power spectrum



Folded lightcurve



Exponential cutoff form clearly favored over power law: chance prob for PL $\sim 10^{-9}$

Unbinned likelihood fitting of the phase averaged flux yields

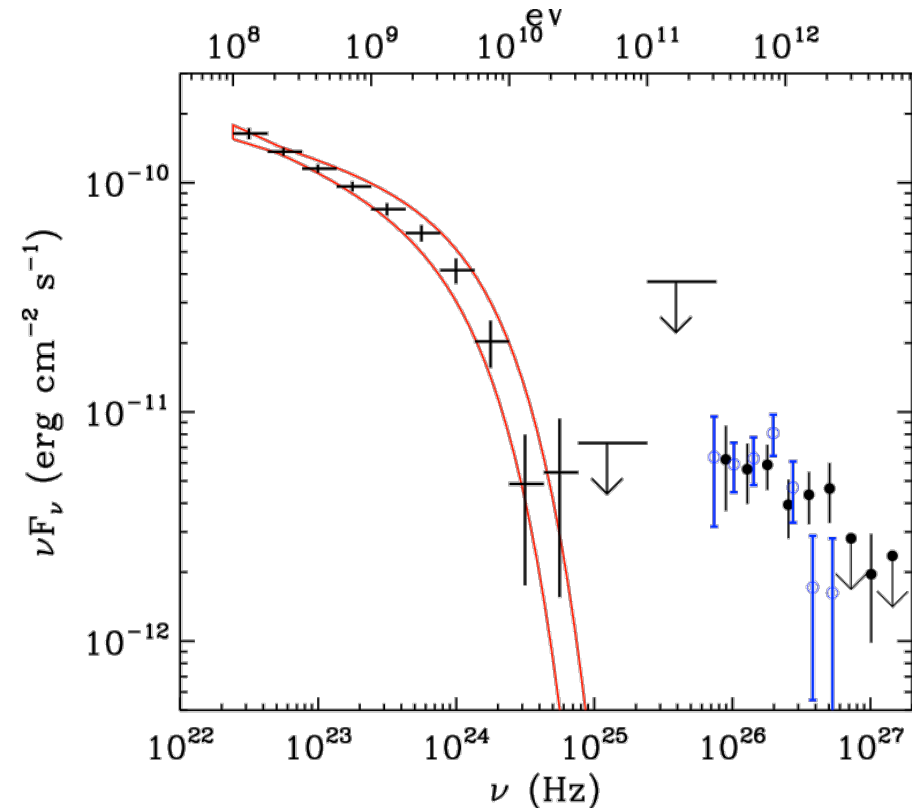
$$F = A E^{-\Gamma} \exp(-E/E_c)$$

Flux ($E > 100$ MeV)

$$= 0.82 \pm 0.03 \text{ (stat)} \pm 0.07 \text{ (syst)} 10^{-6} \text{ ph/cm}^2/\text{s}$$

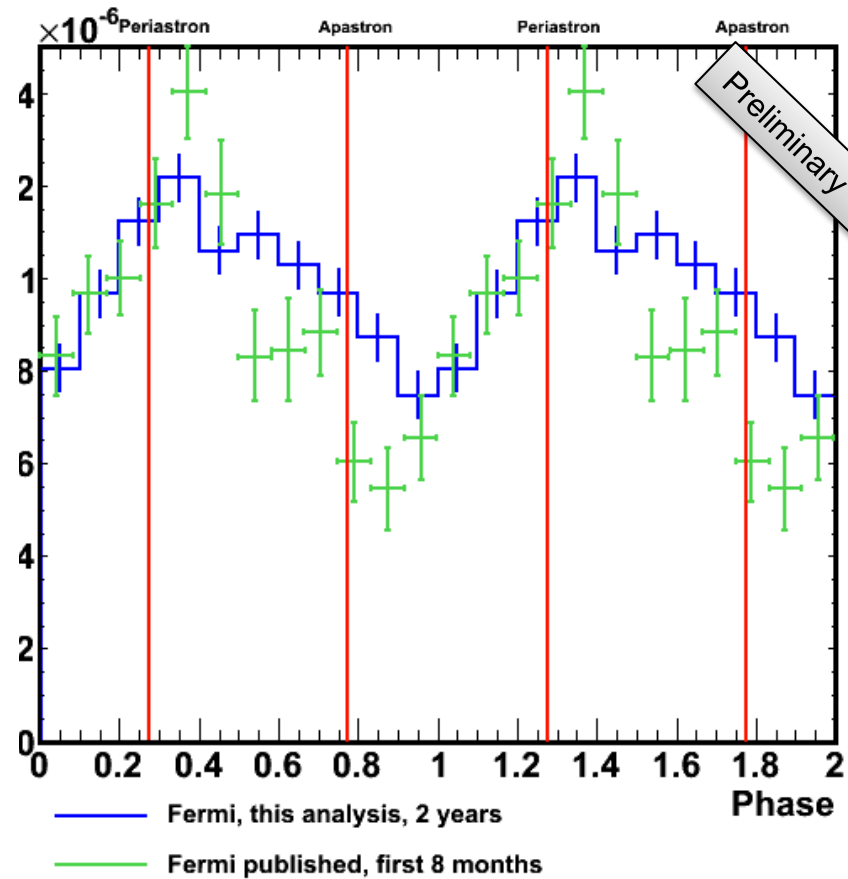
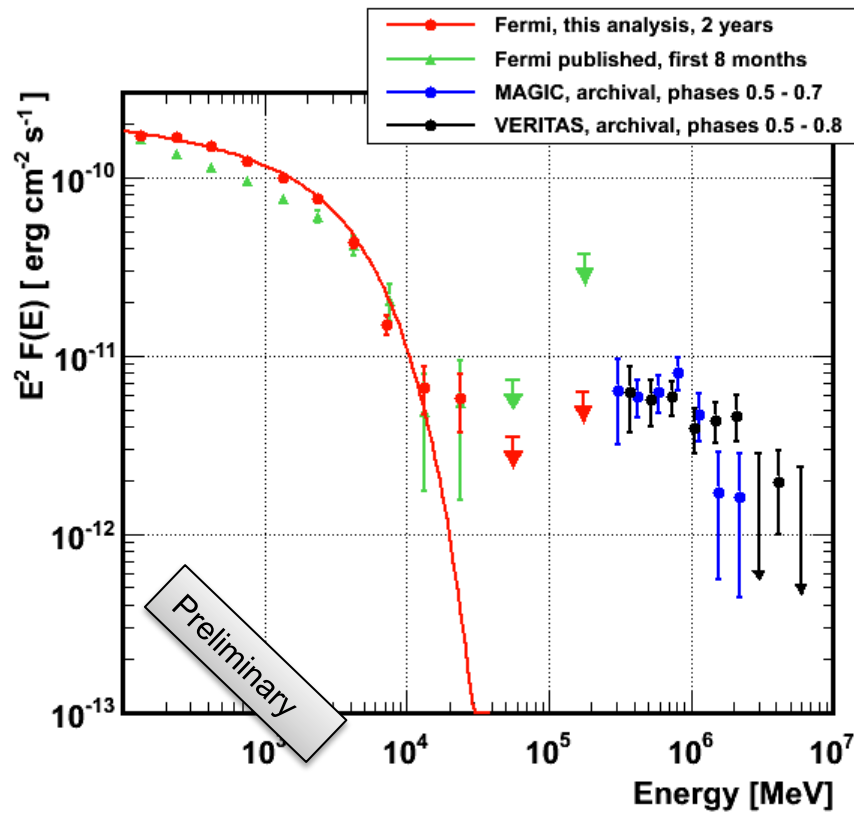
$$\Gamma = 2.21 \pm 0.04 \text{ (stat)} \pm 0.06 \text{ (syst)}$$

$$E_c = 6.3 \pm 1.1 \text{ (stat)} \pm 0.4 \text{ (syst)} \text{ GeV}$$

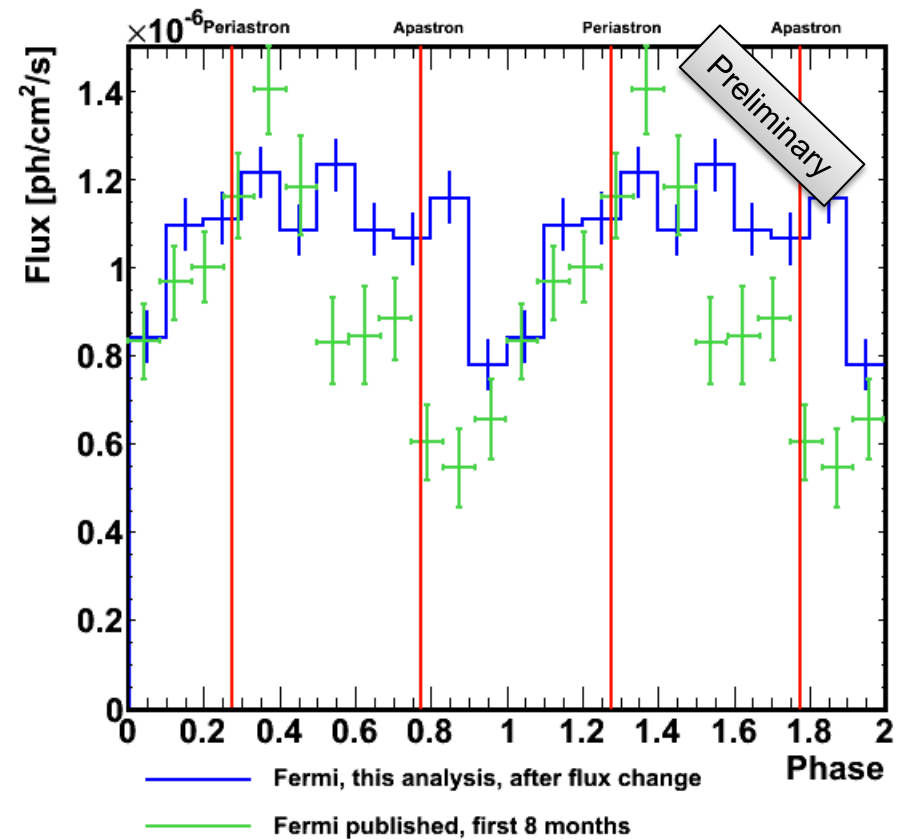
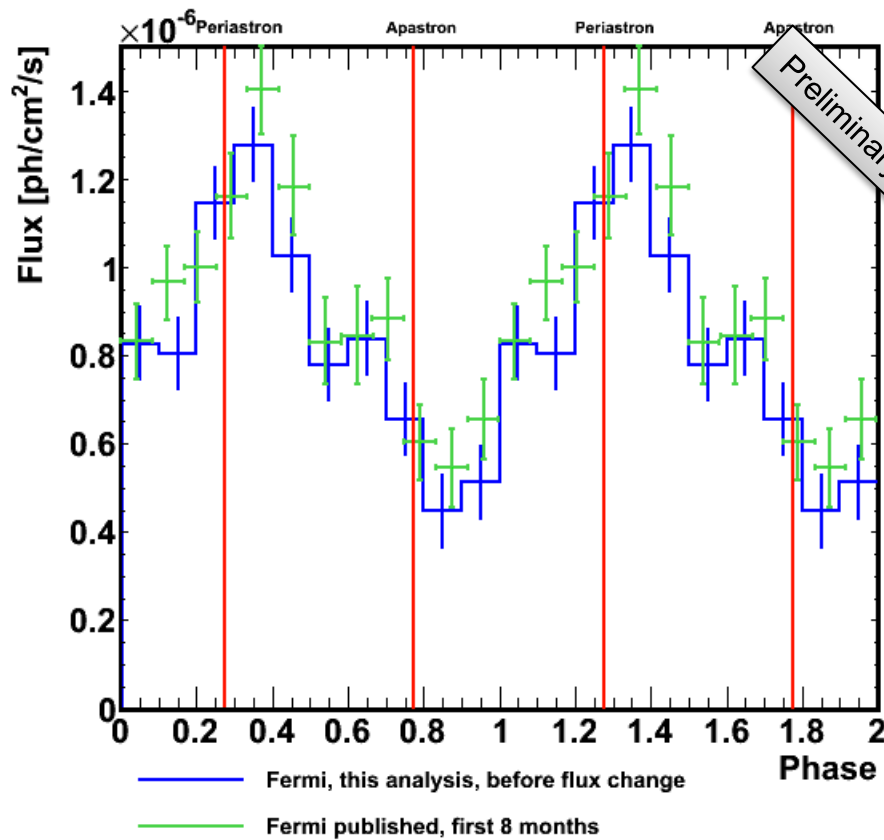


VHE Blue: MAGIC
VHE Black: Veritas } phases 0.6-0.75

New spectra and lightcurve (2 years) compared with earlier publication (8 months)



New lightcurve presents a flux change around March 2009.

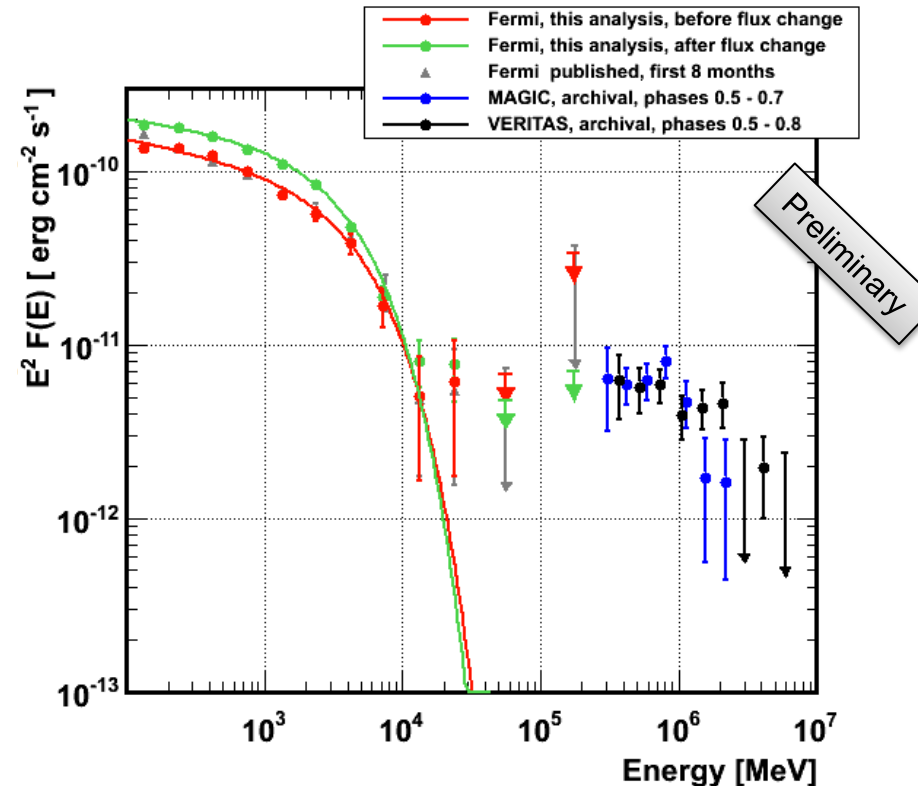


Flux increase of ~33% after March 2009

The modulation gets fainter after the change in flux

LSI spectra – before/after flux change

- Flux increase of ~33% after March 2009: a change of state?
- more flux in apastron region wrt periastron
- any relation to the super orbital period?

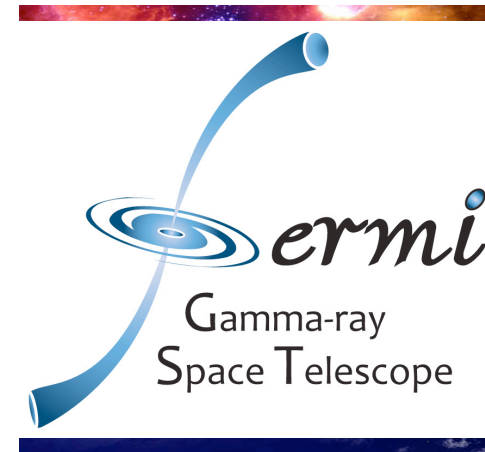


- Spectra of LSI before March 2009 and after March 2009 (compared with earlier publication).

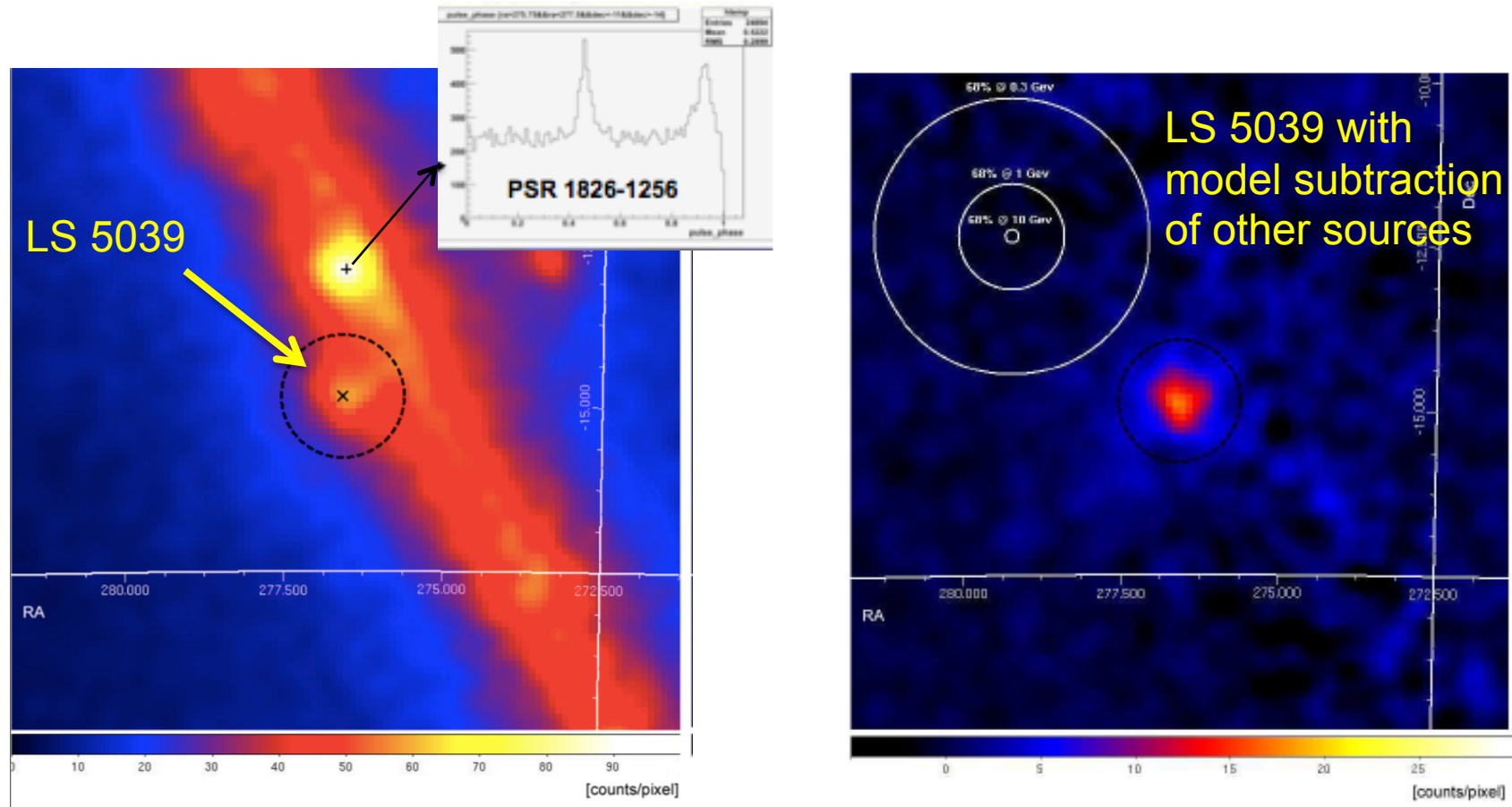
New data allows for distinctions of spectra around the orbit; which will be reported in the forthcoming publication.



Sources we have seen: LS 5039



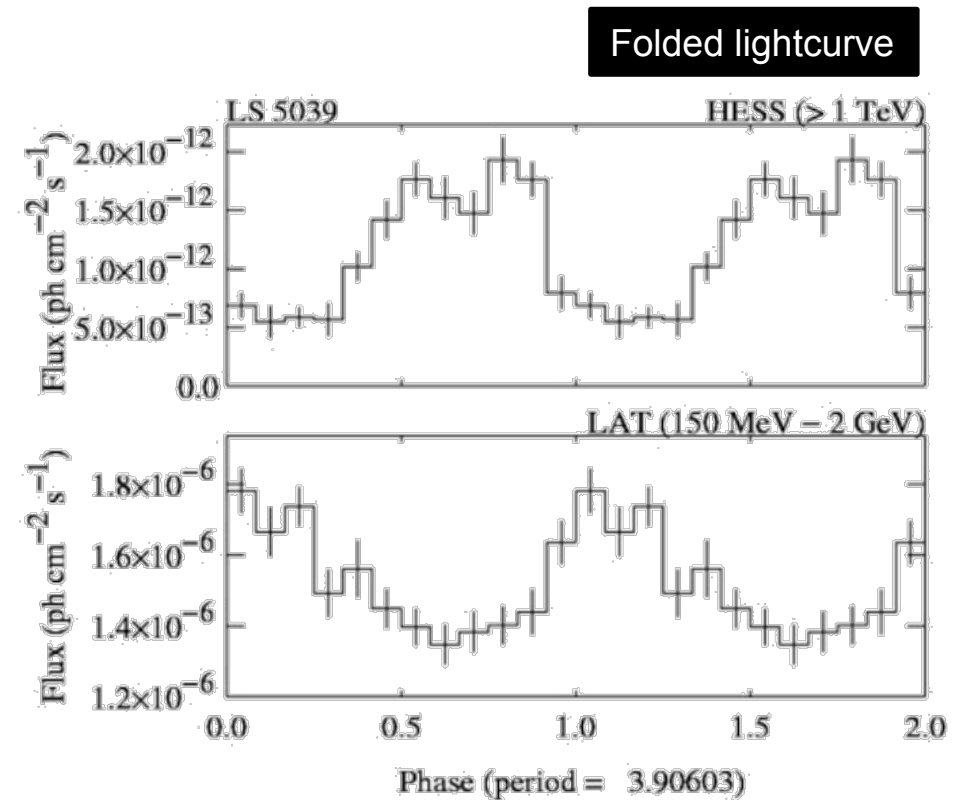
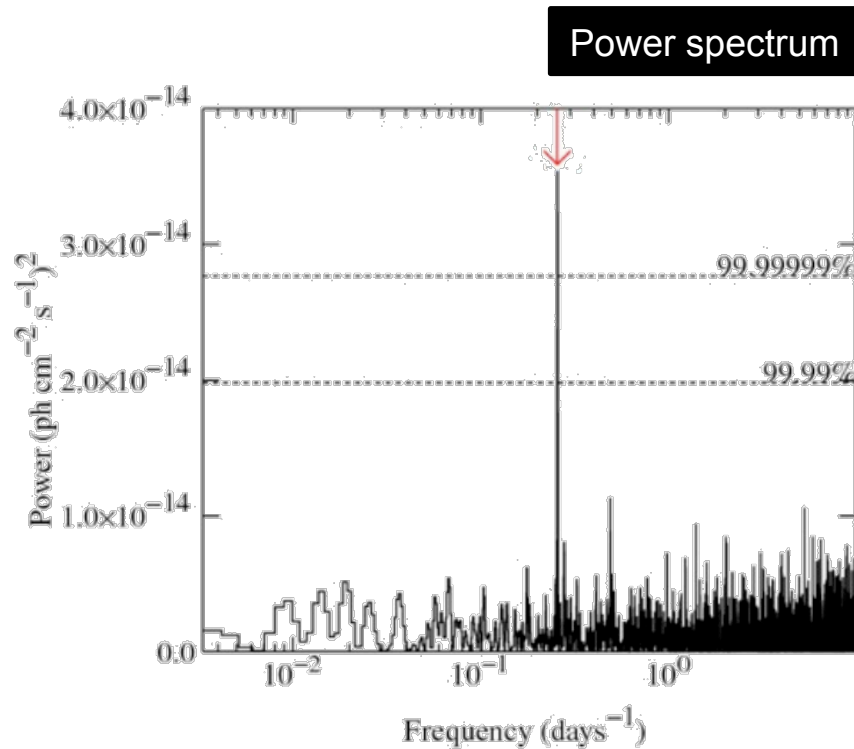
LS 5039: the Fermi view, first months of data (I)

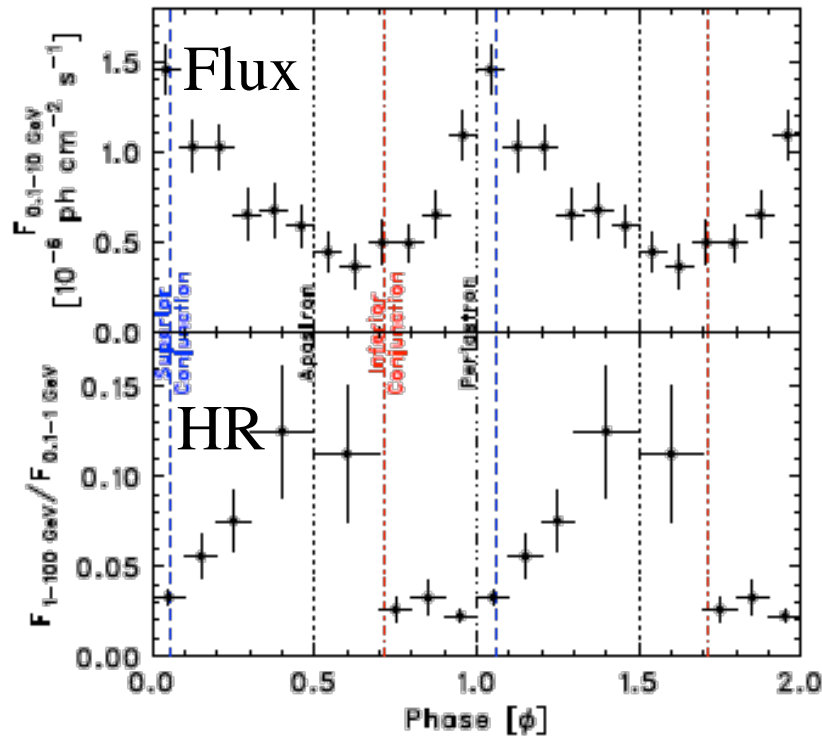


**LS 5039 sits in a bath of galactic diffuse emission
Detected at $\sim 25 \sigma$**

Faint compared to the Galactic plane and there is also emission from the nearby pulsar PSR 1826-1256, that is removed in the plot to the right (off pulse) together with the diffuse model

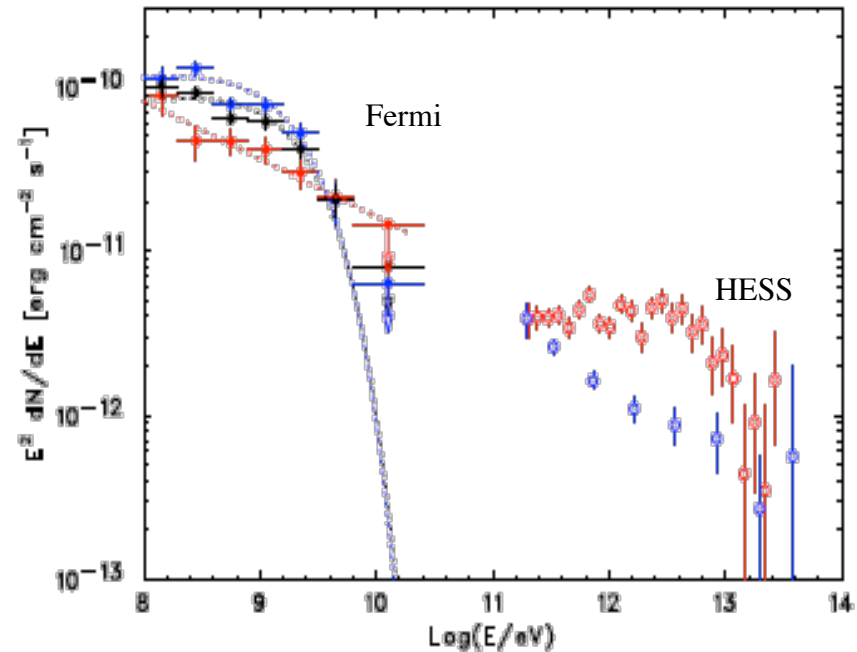
- We detect a periodicity in the LS 5039 light curve at 3.91 ± 0.05 days
- Folded light curve indicates peaks of emission around periastron
- again anti-correlated with VHE.





Top: Flux > 100 MeV
 Bottom: Hardness ratio – (1-100) GeV/ (0.1-1) GeV

Indications of spectral variability, most pronounced between inferior and superior conjunction

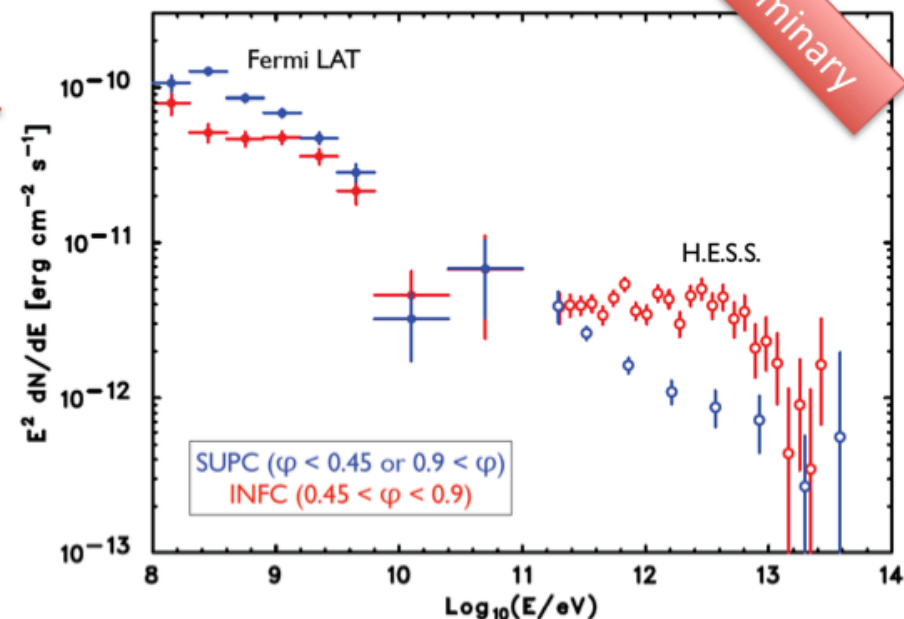
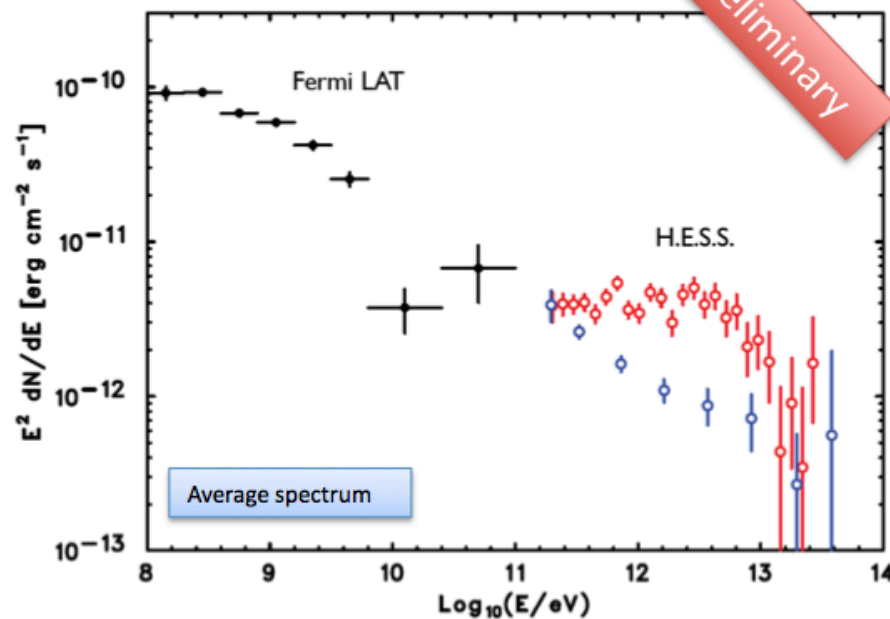
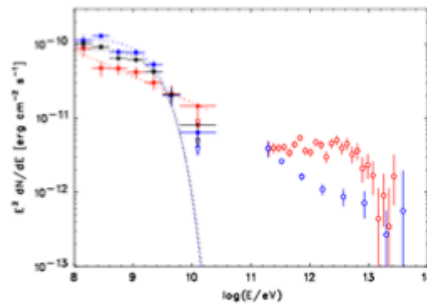


Blue – superior conjunction
 Red – inferior conjunction

We see an exponential cutoff at SUPC (Bulk of data is at SUPC)

Insufficient statistics at INFC to confirm exponential cutoff there.

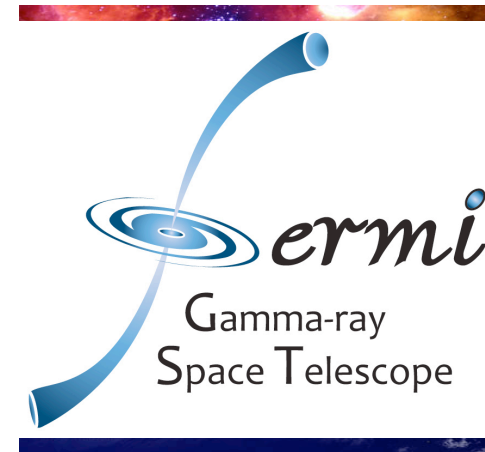
LS5039 - spectra



- New spectra of LS 5039 (2 years of data; August 2008/August 2010) separated in INFC and SUPC. Note the additional data points at higher energies compared to the earlier publication.



Sources we have seen: Cyg X-3



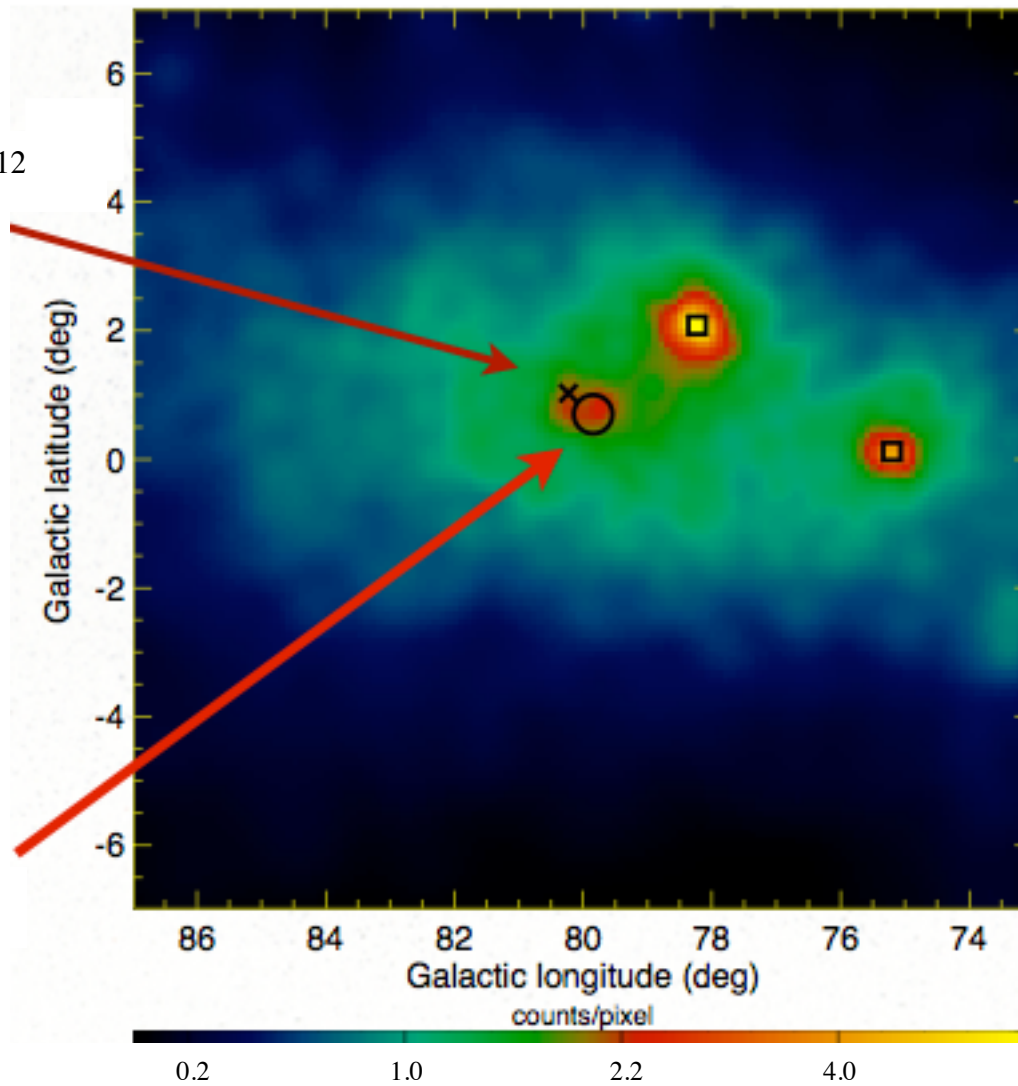
Cyg X-3: The Fermi view (I)

- Cyg X-3 is a high-mass X-ray binary with a Wolf-Rayet star primary.
- Orbital period is exceptionally short for an HMXB at only 4.8 hours.
- The compact object is (usually) thought to be a black hole
- Radio outbursts are common and relativistic jets are produced.

- Lamb et al. '77 reported detection with SAS-2 of source with orbital modulation.
- Not seen with Cos B (Hermsen et al. '87).
- EGRET (Mori et al. '97) saw a source consistent with the position of Cyg X-3, but didn't see any orbital modulation.
- Similar results at TeV energies. Early reports of detection, followed by non-detections with the current generation of instruments.

- AGILE (Tavani et al. '09) recently reported a detection of a source consistent with the location of Cyg X-3.
- AGILE didn't see orbital modulation and so the identification of the AGILE source with Cyg X-3 was not 100% secure.

PSR B J2032+412

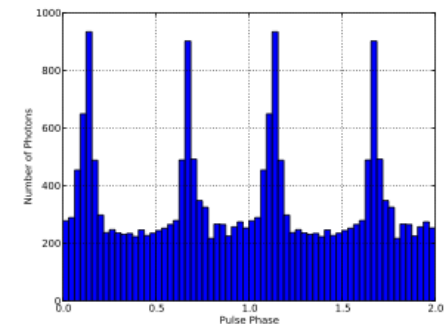


Cyg X-3

- The Cygnus region is crowded and complex.

- In addition to diffuse emission, there are 3 pulsars including PSR J2032+4127 only 30' from the location of Cyg X-3.

- The PSR emission can be removed



After phase selection:

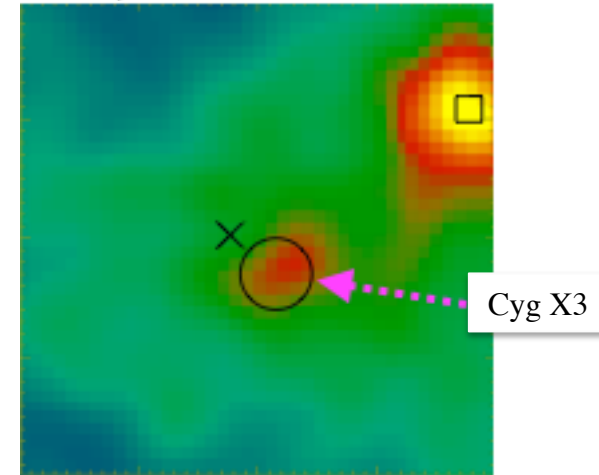
- No detection of PSRJ2032+4127
- Bright source at the location of Cyg X-3 ($\sim 29\sigma$)

Average flux (>100 MeV):

1.19 ± 0.06 (sta) ± 0.37 (sys) 10^{-6} ph s $^{-1}$ cm $^{-2}$

Soft spectrum:

PL index: 2.70 ± 0.05 (stat) + 0.20 (syst)



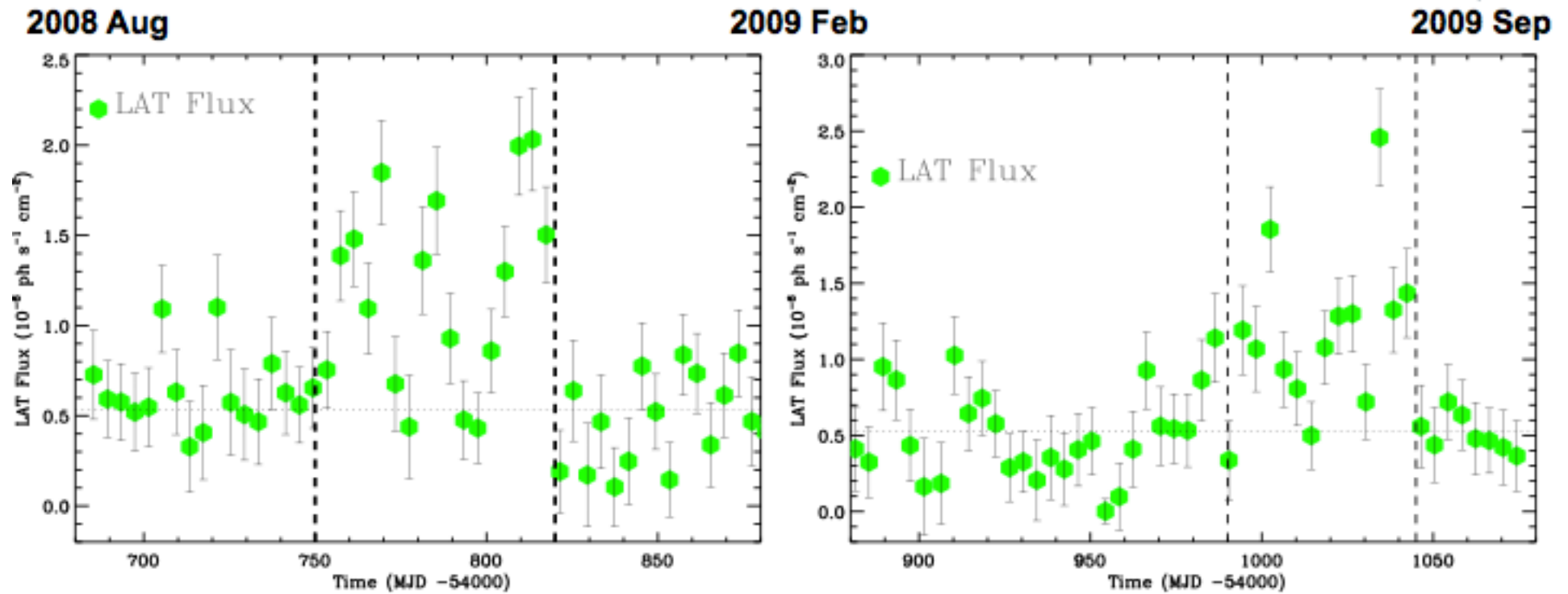
Two main active periods are seen.

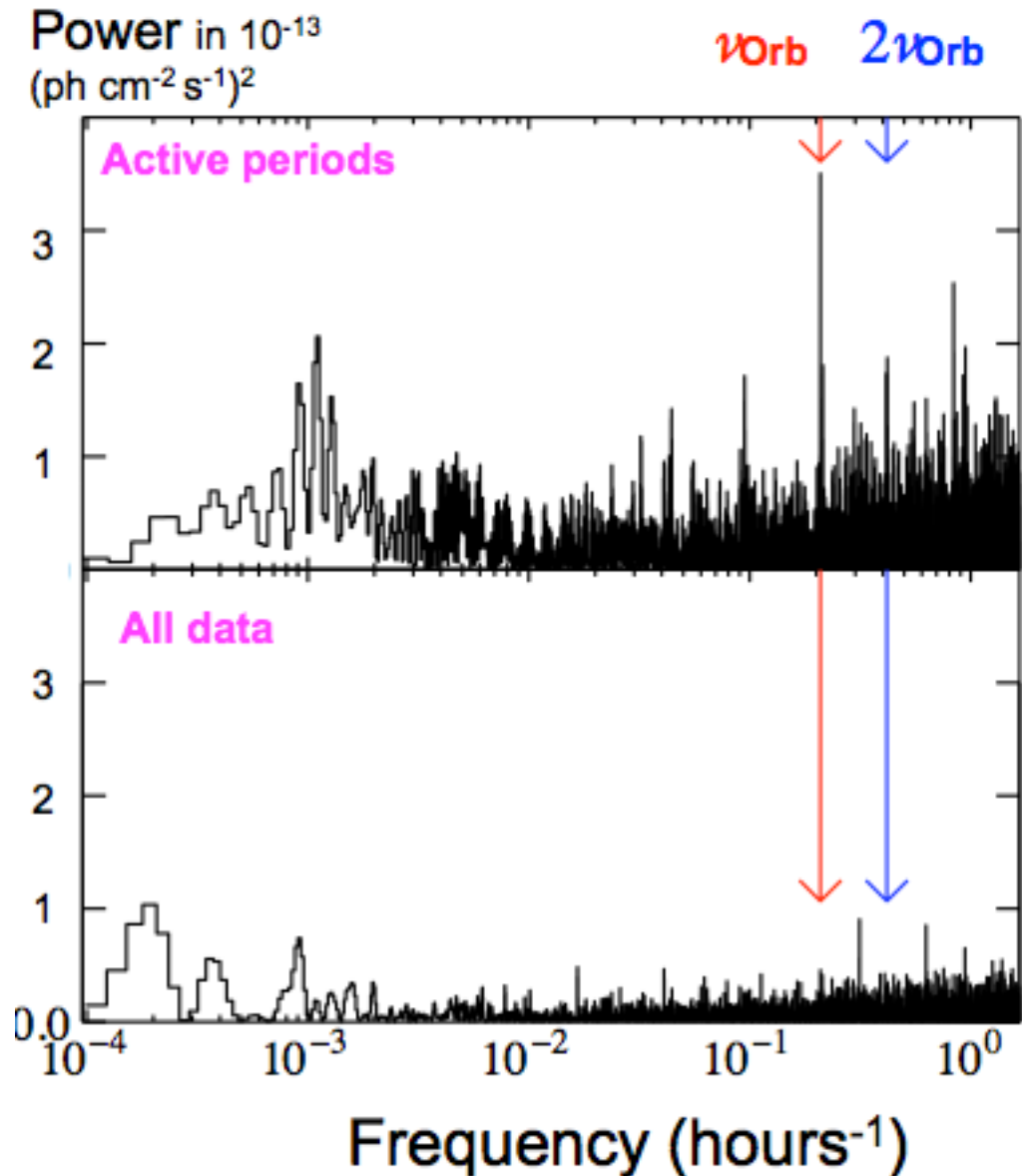
- October to December 2008
- June to August 2009.

There may be one or several flares occurring during each active state.

Peak flux corresponds to $\sim 5 \times 10^{36}$ (d/7 kpc) 2 erg s $^{-1}$

Lightcurves across the active periods.





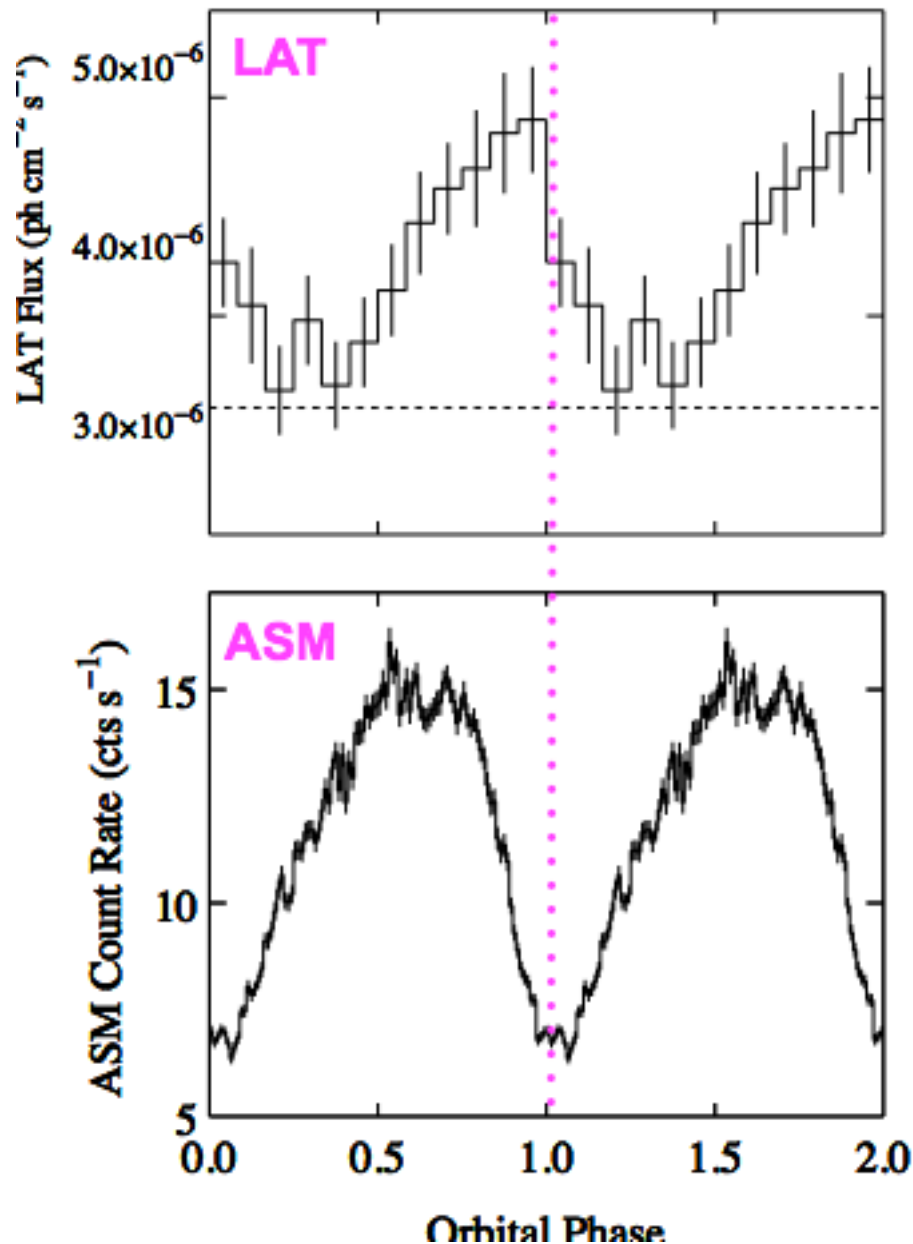
Cyg X-3 orbital period = 4.8 hours (red arrows)

No significant orbital modulation in the entire dataset

Significant detection of Cyg X3 orbital period in the two active periods (probability of a false detection $\sim 10^{-9}$)

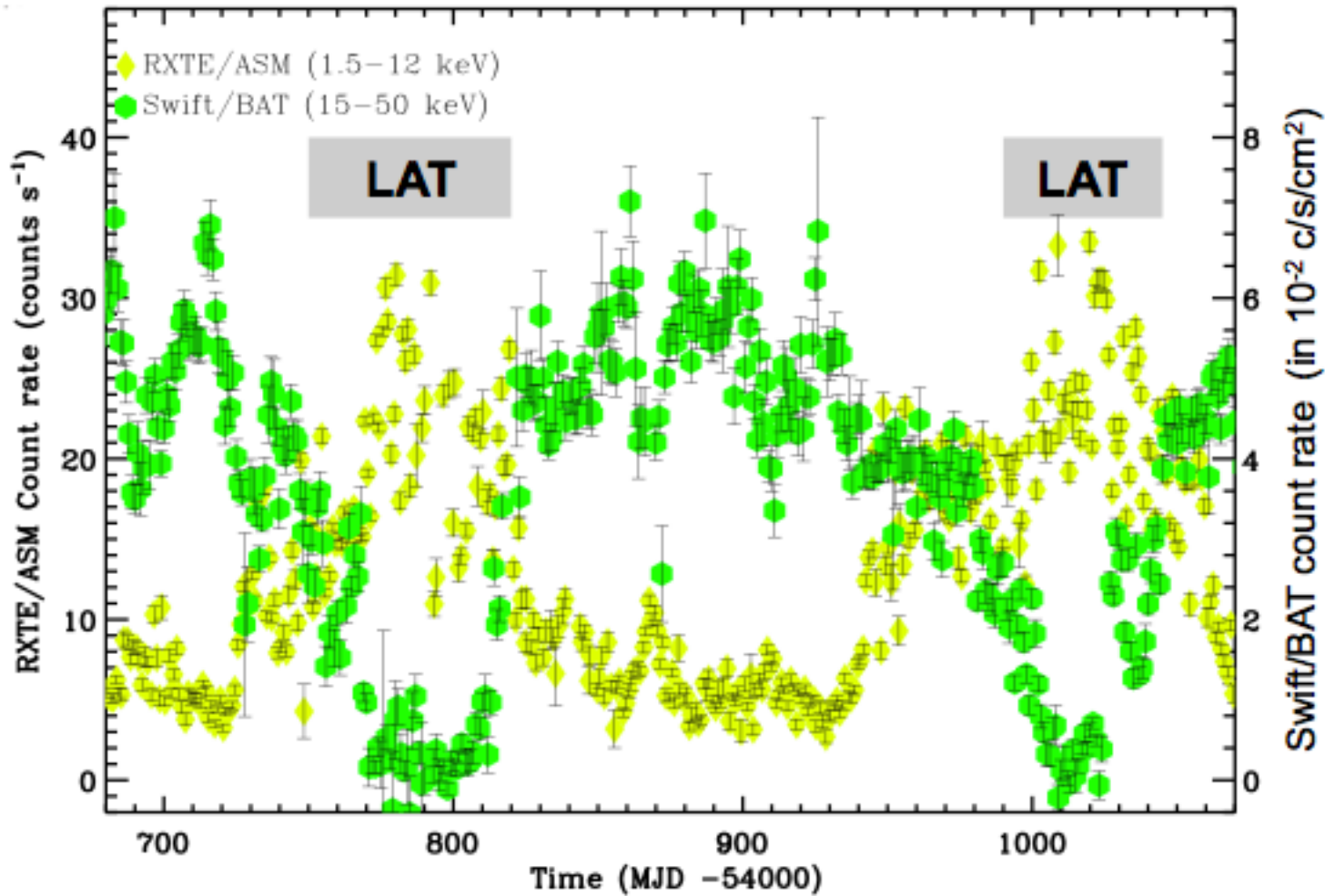
Identification of the LAT source with Cyg X3

When do the active phases happen?

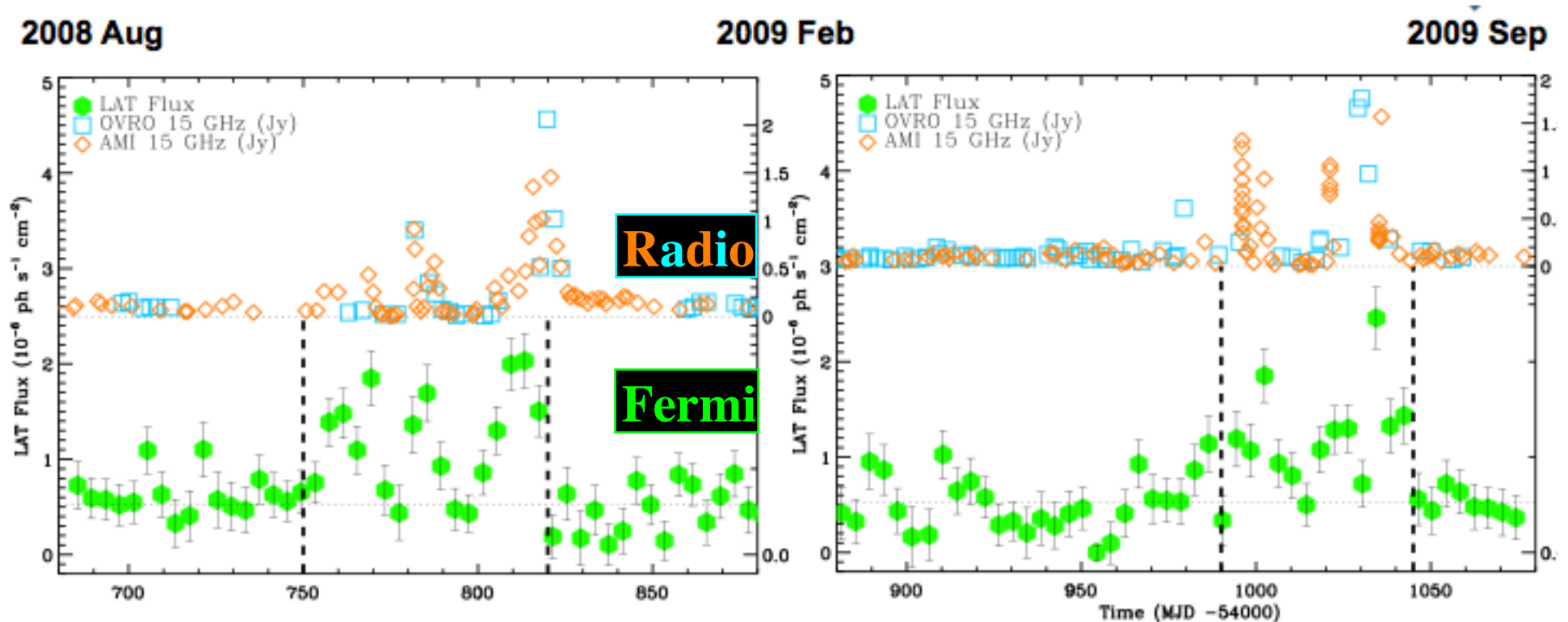


- RXTE/ASM and LAT: same asymmetric shape, slow rise followed by a fast decay
- The LAT maximum is shifted by 0.3 to 0.4 in phase from X-ray maximum

Cyg X-3: Active gamma periods in the soft X-ray states



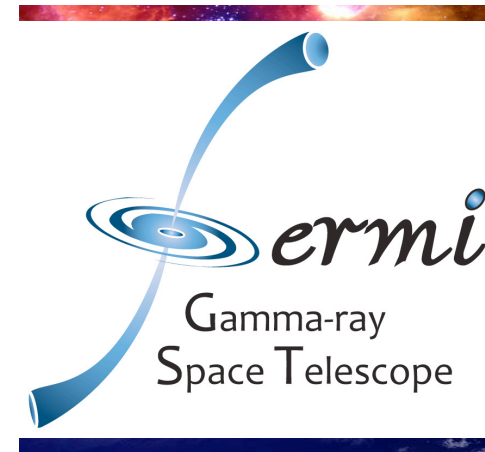
•The two active periods of Cyg X3 as seen by **LAT** correspond to the **soft X-ray state** of Cyg X-3



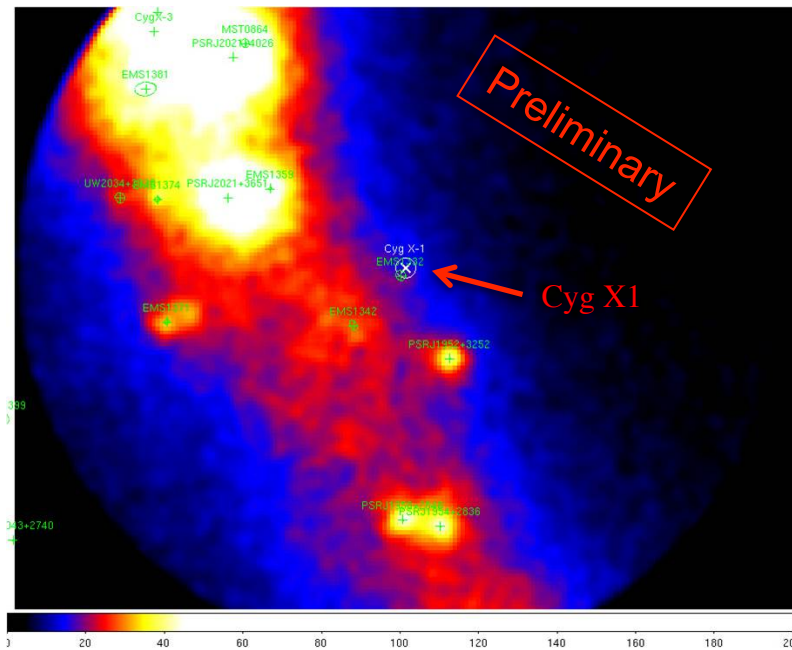
- The LAT active periods of Cyg X-3 occur close to radio (AMI + OVRO) flares
- Hint that the gamma-ray emission precedes the radio emission but..
- Lag of the radio light-curve not well constrained: 5 +/- 7 days



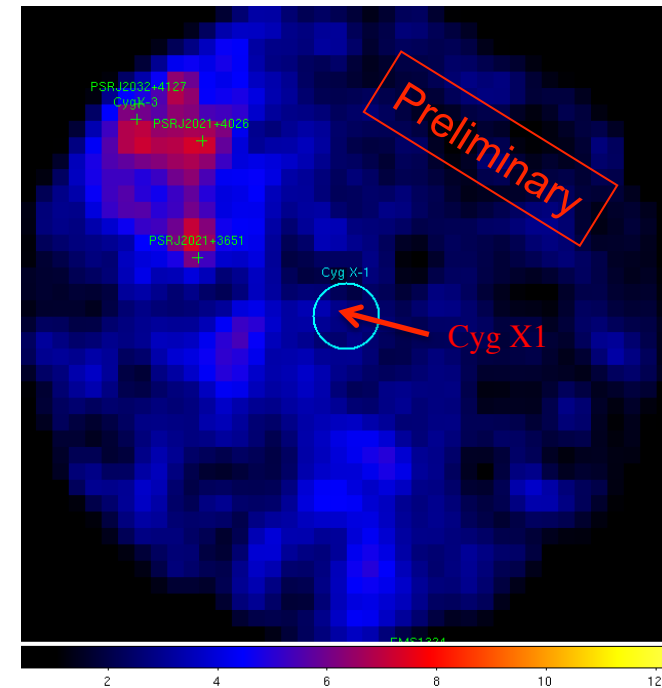
Sources we have not seen (yet)



- Two flares reported by AGILE: **2009-10-15 & 2010-03-24**
 - so far, no confirmation with Fermi...

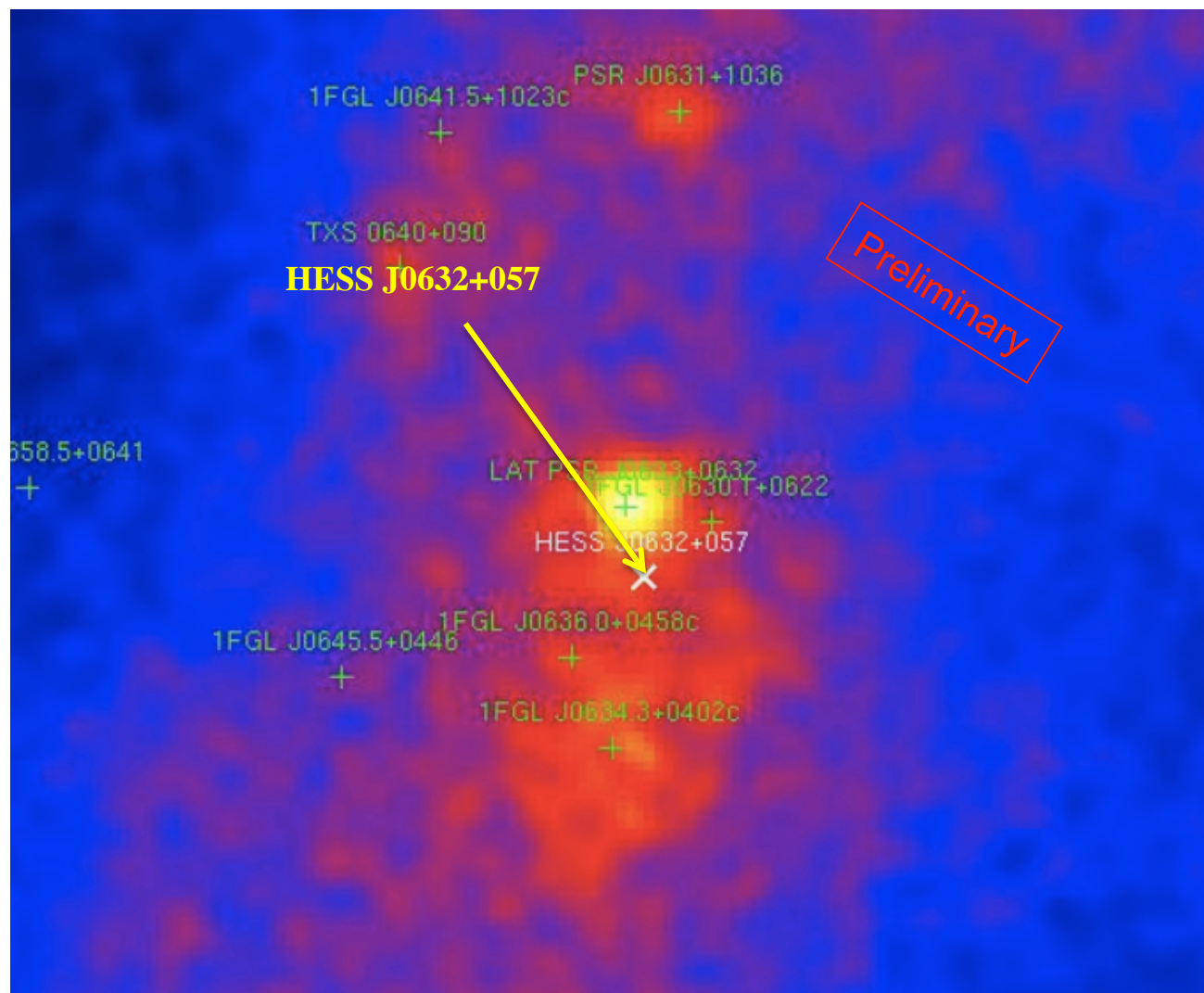


17 months



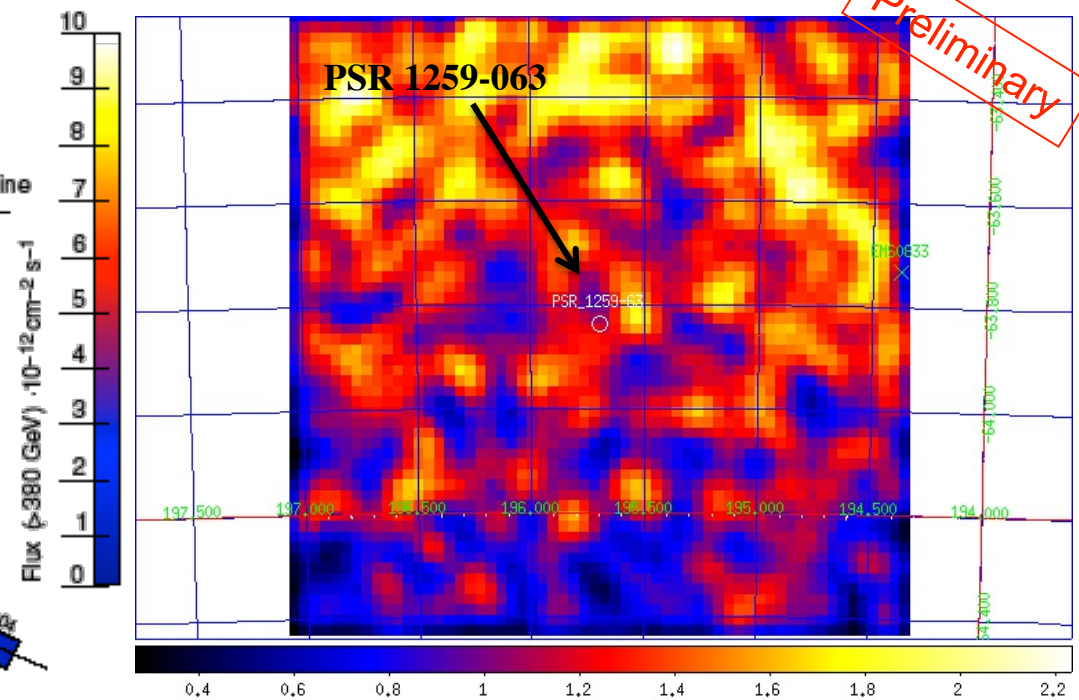
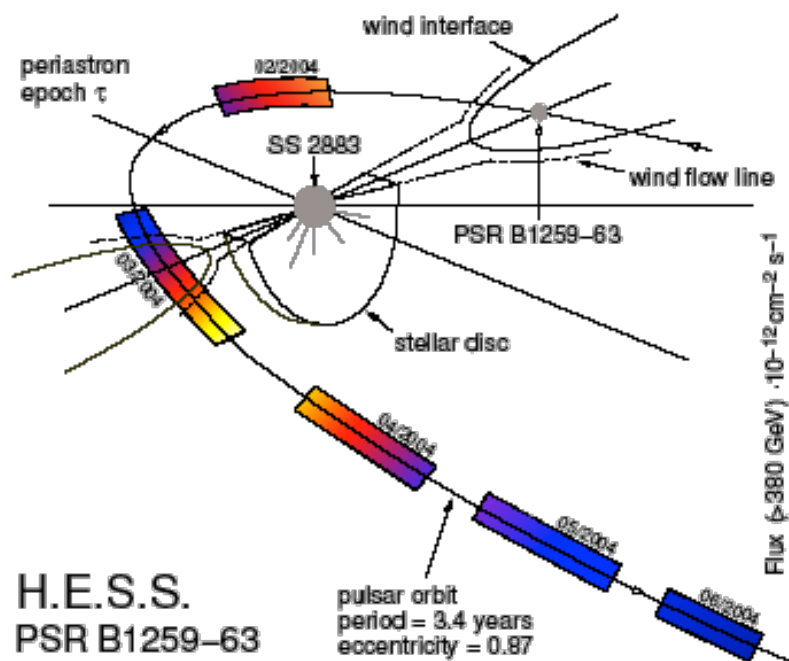
e.g., During AGILE 2009 flare

<http://fermisky.blogspot.com/2010/03/lat-limit-on-cyg-x-1-during-reported.html>



(PL index fixed to -2.2)
UL: 5.2×10^{-8} ph/cm²/s

PSR B1259-63 – upper limits only yet



UL: 6.7×10^{-8} ph/cm²/s
(PL index fixed to -2.2)

Fermi/LAT and Swift/XRT detection of increased activity from the binary system PSR B1259-63/SS 2883

ATel #3046; *P.H.T. Tam, A.K.H. Kong, R.H.H. Huang (NTHU, Taiwan), C.Y. Hui (Chungnam, Korea)*

on 21 Nov 2010; 7:15 UT

Distributed as an Instant Email Notice (Request for Observations)

Password Certification: Albert Kong (akong@phys.nthu.edu.tw)

Subjects: X-ray, Gamma Ray, Request for Observations, Binaries, Pulsars
Referred to by ATel #: [3054](#)

We report on the gamma-ray detection by the Large Area Telescope aboard the Fermi Gamma-ray Space Telescope from the sky position of the binary system PSR B1259-63/SS2883. A preliminary analysis of the region around the system has resulted in a detection significance of about 4 standard deviations using data taken between 2010-11-18 00:00:00 (UT) to 2010-11-21 00:04:42 (UT).

Based on the same data set and using a single power law model for the source, the averaged gamma-ray flux is around 4×10^{-8} photons/s/cm² over the energy range 300 MeV to 100 GeV and the photon index is about 1.7. We note that the gamma-ray flux from the binary system has increased over the last few days and we expect the flux to increase further in the coming days. Note that an earlier LAT observations this year did not reveal any emission from the source (ATel #[2780](#)).

Swift/XRT observed the region around PSR B1259-63 starting on 2010 Nov 20 05:02 (UT) for about 3.8 ks. The source spectrum of PSR B1259-63 is best described by an absorbed power-law with $N_H = 6.9(+5.5, -4.2) \times 10^{21}$ cm⁻² (90% confidence) and a photon index of 1.3 ± 0.4 (reduced $\chi^2/\text{dof} = 0.51/14$). The absorbed 1-10 keV flux is around 6.5×10^{-12} erg/s/cm². The Swift observation hence suggests an increasing X-ray flux compared to previous observation taken on 2010 Aug 8 (ATel #[2782](#)), and similar hardening behavior has been seen during the first, pre-periastron passage of the disk (Chernyakova et al. 2006, 2009).

PSR B1259-63 will pass through the periastron of its companion star SS 2883 in 2010 mid-Dec. The increase of X-ray and gamma-ray flux therefore occurs around the time when the pulsar enters the equatorial disk of the Be stars.

Multiwavelength observations of the source are strongly encouraged.



PSR B1259-63 – upper limits only yet

Fermi LAT Continuous Observations of the PSR B1259-63 Region

ATel #3054; *A. A. Abdo (NRC Research Associate, resident at NRL), J. E. Grove (NRL), Richard Dubois (SLAC), G. A. Caliandro (IEEC-CSIC) on behalf of the Fermi Large Area Telescope*

Collaboration

on 24 Nov 2010; 1:41 UT

Password Certification: J. Eric Grove (eric.grove@nrl.navy.mil)

Subjects: Gamma Ray, >GeV, Binaries, Pulsars, Transients

We provide further information on searches for GeV activity from the system PSR B1259-63 as it approaches periastron passage. Periodic routine estimates of the significance of any detection are being made as part of a multi-wavelength campaign, and they show no significant detections prior to or subsequent to the time reported by Tam et al. in ATEL #3046 (2010-11-18 00:00:00 to 2010-11-21 00:04:42 UTC). For the indicated three-day interval, an excess of gamma-ray emission positionally consistent with PSR B1259-63 has a likelihood test statistic (TS) of 14. For the two free parameters of the spectral model this corresponds to a single-trial chance probability of $\sim 0.1\%$. Furthermore, we judge that the detection significance should be diluted by a factor of ~ 10 trials, given that any positive excess within at least the preceding month would have been considered of equal interest. The chance probability of such an event is thus of order 1%, which we consider to be too high to establish a secure detection. To avoid false positives, we adopt the conservative position that a secure detection in LAT data requires a substantially higher confidence level or continued detection over a longer interval. We note that there is no significant detection ($TS < 1$) of PSR B1259-63 in the subsequent interval (2010-11-21 00:04:42 to 2010-11-22 23:56:38 UTC), so that the continued rise in flux predicted in ATEL #3046 has not been detected. For completeness we report that we performed this likelihood analysis in a 15-deg radius region surrounding the system, modeling the Galactic diffuse background and all point sources from the Fermi Large Area Telescope First Source Catalog (Abdo et al. 2010, ApJS, 188, 405). Fermi operates in an all-sky scanning mode, and the LAT team will continue its planned close monitoring of this source through the coming months. For this source, the Fermi LAT contact person is Aous Abdo (aous.abdo@nrl.navy.mil). The Fermi LAT is a pair conversion telescope designed to cover the energy band from 20 MeV to greater than 300 GeV. It is the product of an international collaboration between NASA and DOE in the U.S. and many scientific institutions across France, Italy, Japan and Sweden.

Concluding remarks

- First positive identifications of orbitally-variable emission from LS I +61 303 & LS 5039 at GeV energies
 - Observation of exponential cutoff spectrum in both cases
 - An ongoing effort: variability is present
 - Spectral changes along orbit measured in both sources
- Detection of a LAT source positionally consistent with Cyg X-3 & identified by its orbital period. First detection of a microquasar at high energy
- Variability in gamma-rays: associated with the soft X-ray state and also with periods of relativistic ejection events
- We are actively looking for other gamma-emitting XRBs in the galaxy, among known XRBs and blindly in the unidentified gamma-ray sources.