Observing TeV Binaries with VERITAS, *Fermi*-LAT and *Swift*-XRT

Payel Kar

for the VERITAS Collaboration

THE UNIVERSITY OF UTAH

Fermi Gamma-ray Space Telescope

VERITAS

INTERNATIONAL FERMI SYMPOSIUM

NOVEMBER 9-13, 2015

WASHINGTON D.C.

The VERITAS Observatory

- Array of 4 IACT, 12m Davies-Cotton Reflector, 345 hexagonal facets
- Located at Fred Lawrence Whipple Observatory, AZ
- Energy Range 85 GeV to > 30 TeV,
- PMT Camera (~40% QE), FoV 3.5°
- 3 Level Trigger
- Upgraded twice:
  - telescope relocation
  - PMT upgrade and trigger upgrade
- High duty cycle

Member Institutions

U.S.
Adler Planetarium
Argonne Nat. Lab
Barnard College
Columbia Univ
DePauw Univ.
Georgia Tech.
Grinnell College
Iowa St. Univ.
Purdue
SAO, UCLA
UCSC
Univ. of Chicago
Univ. of Delaware
Univ. of Iowa
Univ. of Minnesota
Univ. of Utah
Washington Univ.

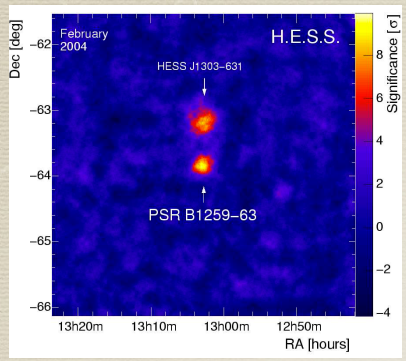
Canada
McGill Univ.

Germany
DESY- Zeuthen
Potsdam U.

Ireland
Cork Inst. Tech.
Galway-Mayo Inst.
N.U.I. Galway
UCD

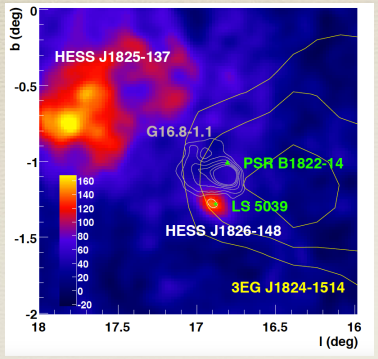
Smithsonian

Gamma-Ray Binaries



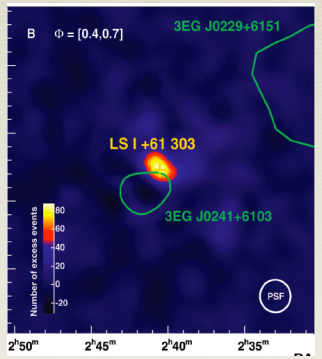
PSR B1259-63

F. Aharonian et al 2005



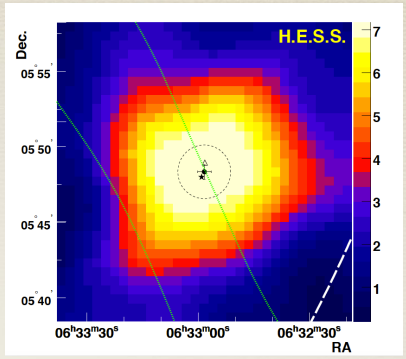
LS 5039

F. Aharonian et al 2005



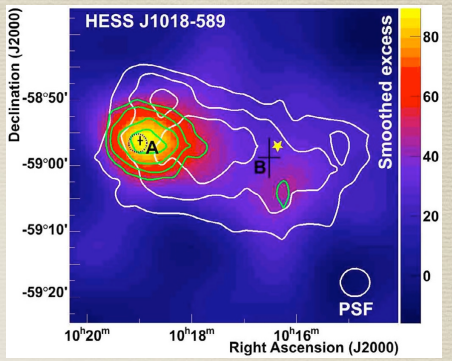
LS I +61 303

J. Albert, et al 2006



HESS J0632+057

F. Aharonian et al 2007

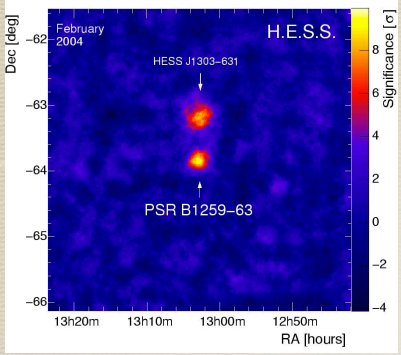


1FGL J1018.6+5856

Abdo et al. 2012

- Massive star (O/Be) in eccentric orbit around compact objects (Black Holes or Neutron Stars)
- TeV, GeV & X-ray variability mostly modulated by orbital periods
- Similar spectral energy distributions peaking above 1 GeV

Gamma-Ray Binaries



PSR B1259-63

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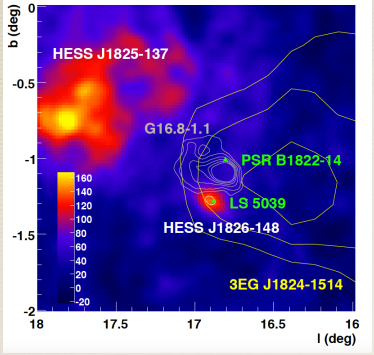
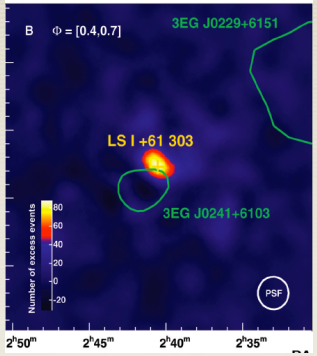
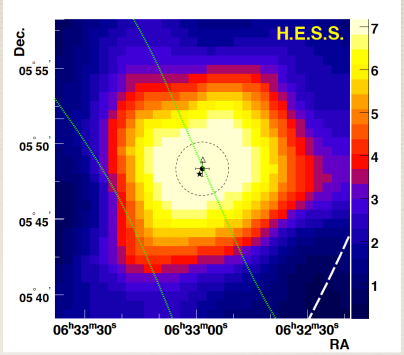


LS 5039

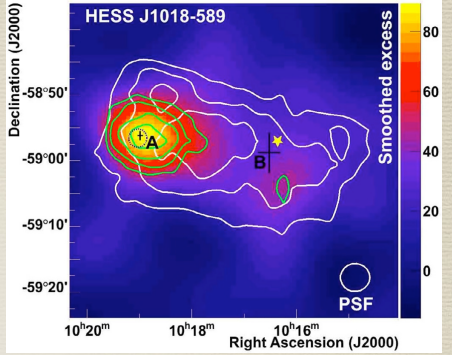
F. Aharonian



LS I +61 303



HESS J0632+057

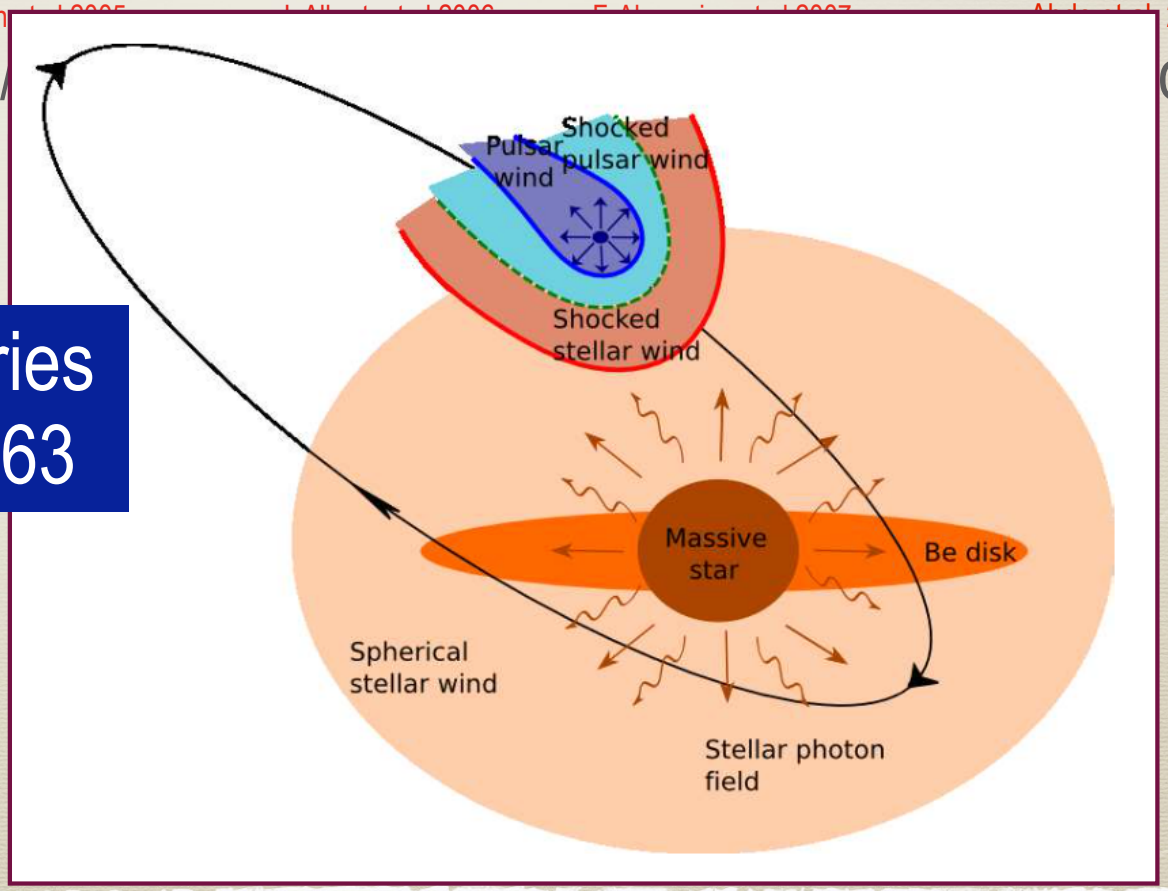


1FGL J1018.6+5856

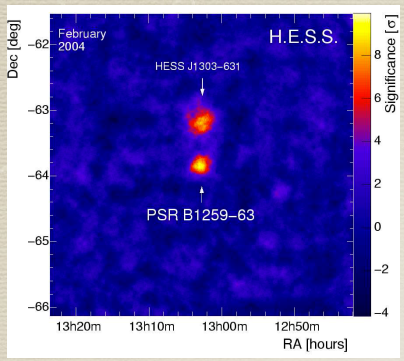
2012

- Massive star (O/ cts
  (Black Holes or

Pulsar Wind Binaries like PSR B1259-63



Gamma-Ray Binaries



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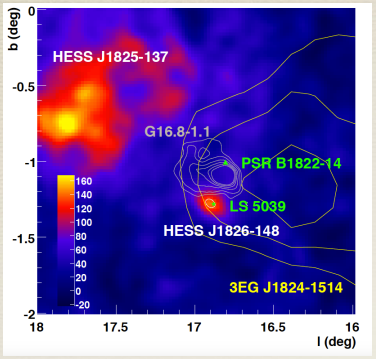

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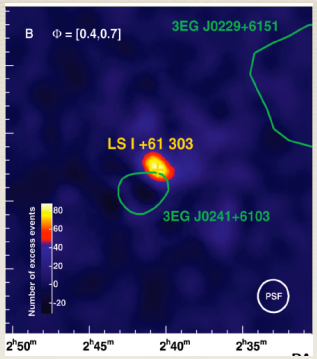

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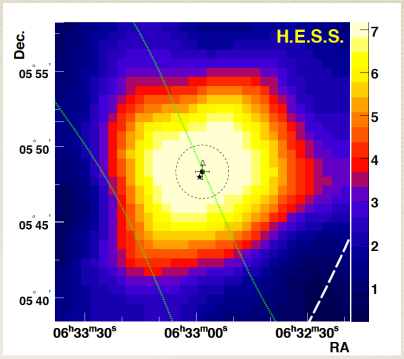
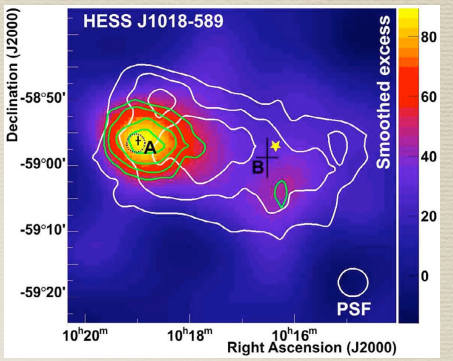
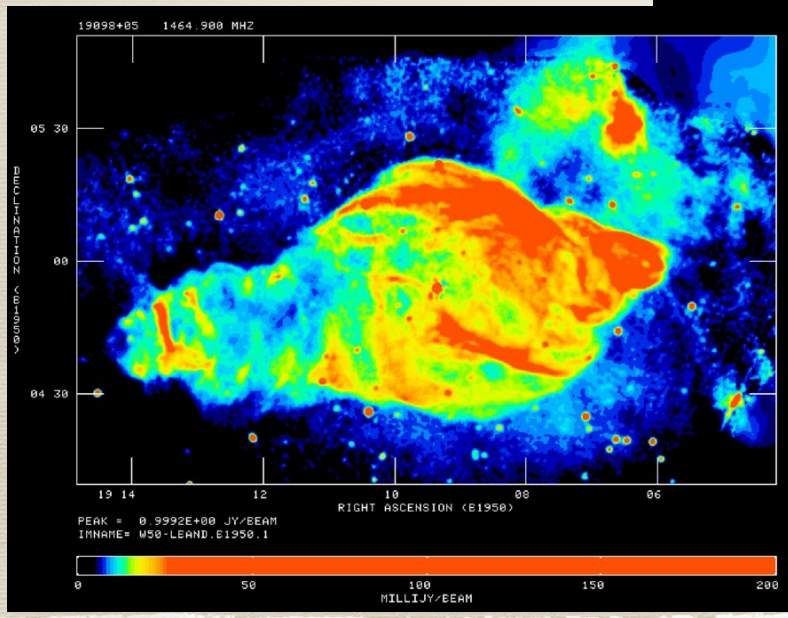


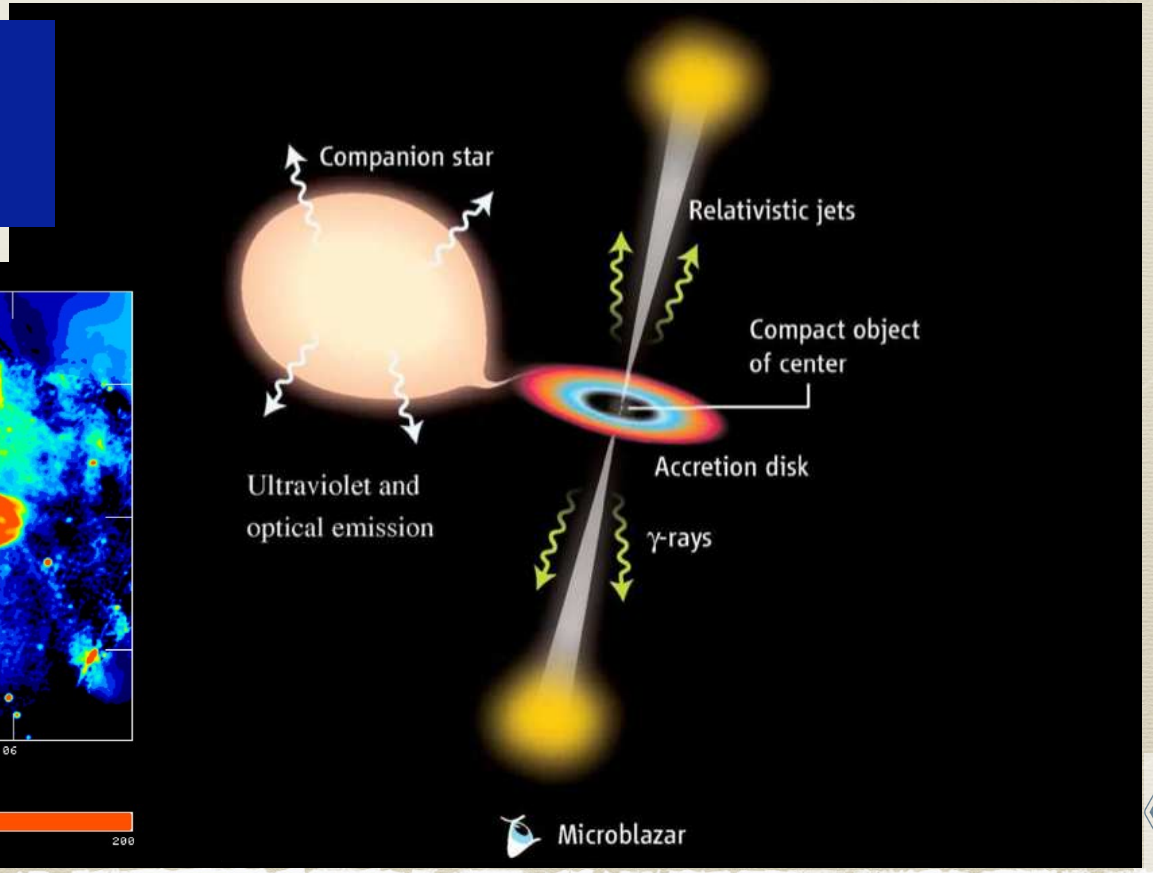
HESS J0632+057



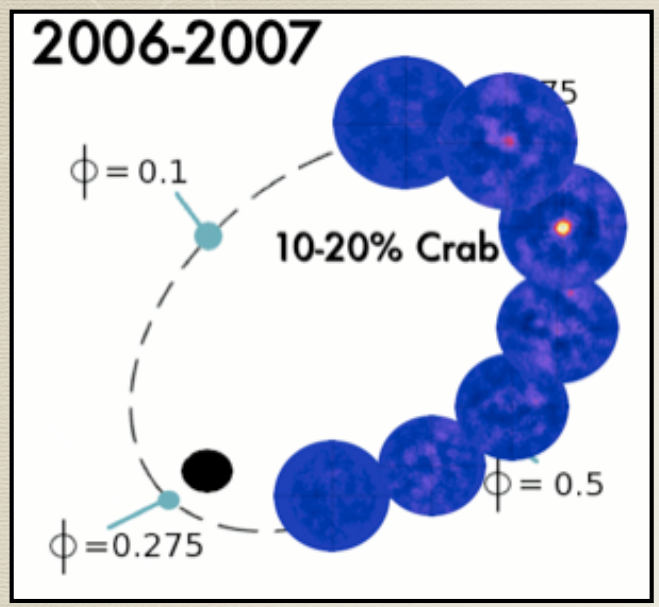
1FGL J1018.6+5856

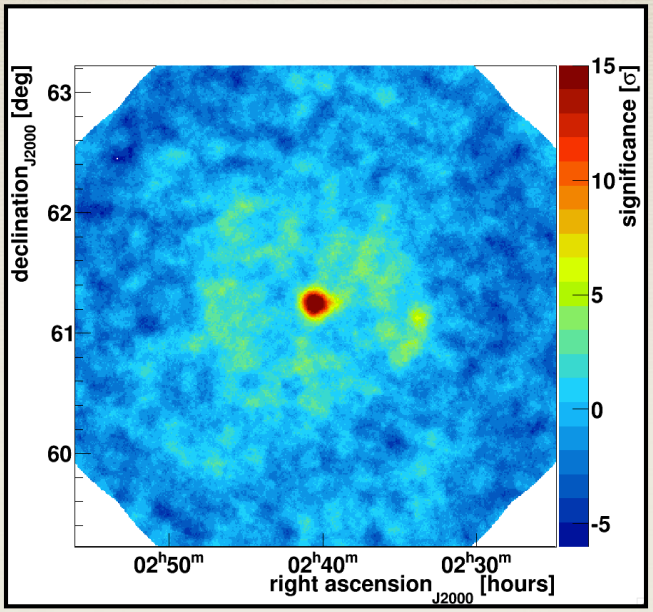
Microquasars like SS433

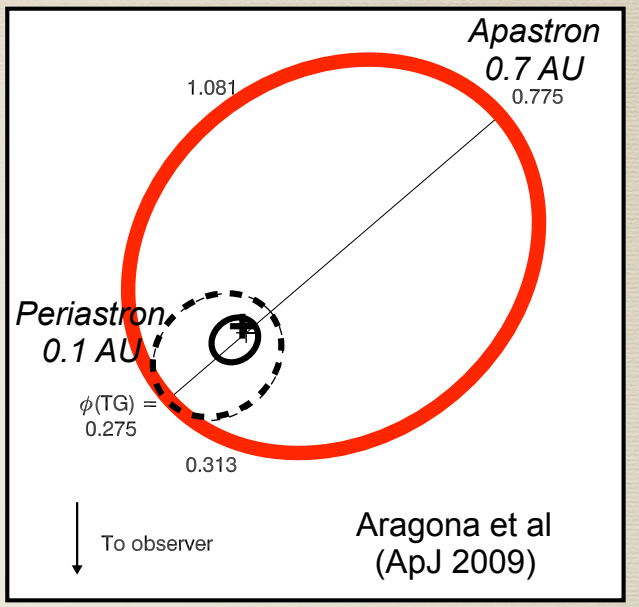




LS I +61303

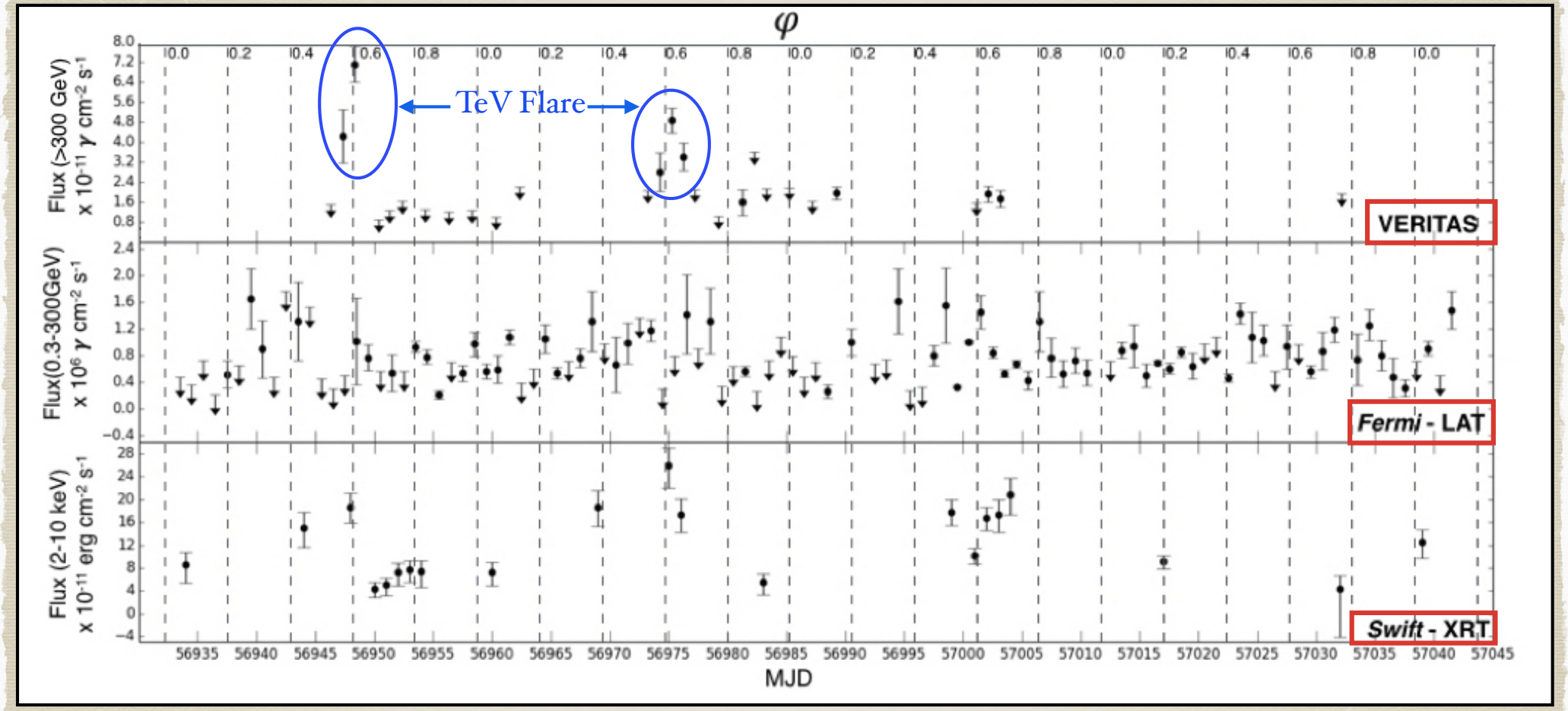






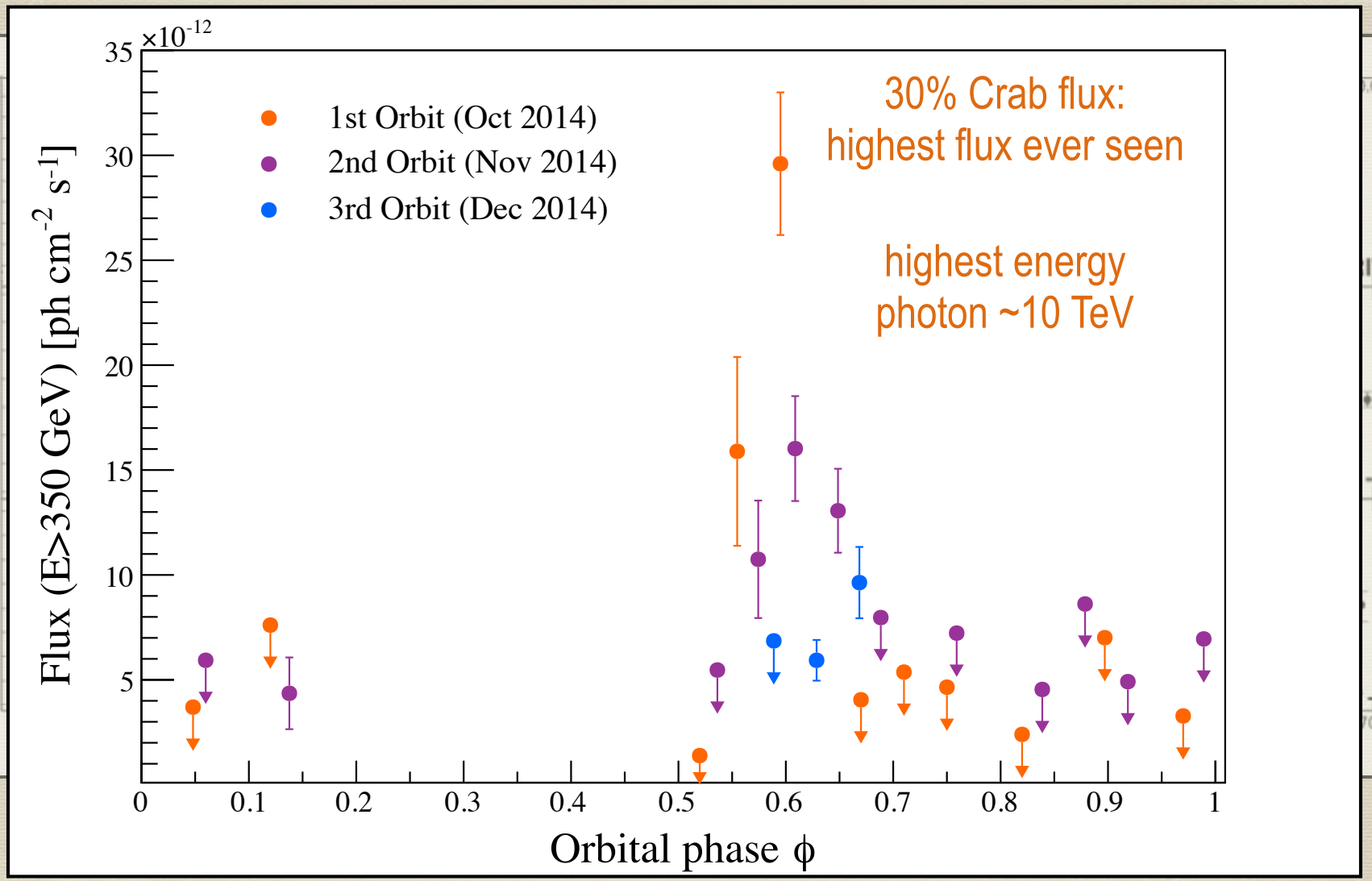
- Be star + compact object at ~2 kpc
- 26.5 day orbit; unknown inclination
- 1667 day super-orbital modulation
- high X-ray activity
  orbital, super-orbital variability & magnetar-like flares (e.g. Smith et al 2009)
- extended radio emission throughout orbit (Dhwawan 2006)
- GeV flux modulated by orbital and super-orbital period (LAT 2013)

Light Curve of LS I +61 303 (2014-2015)



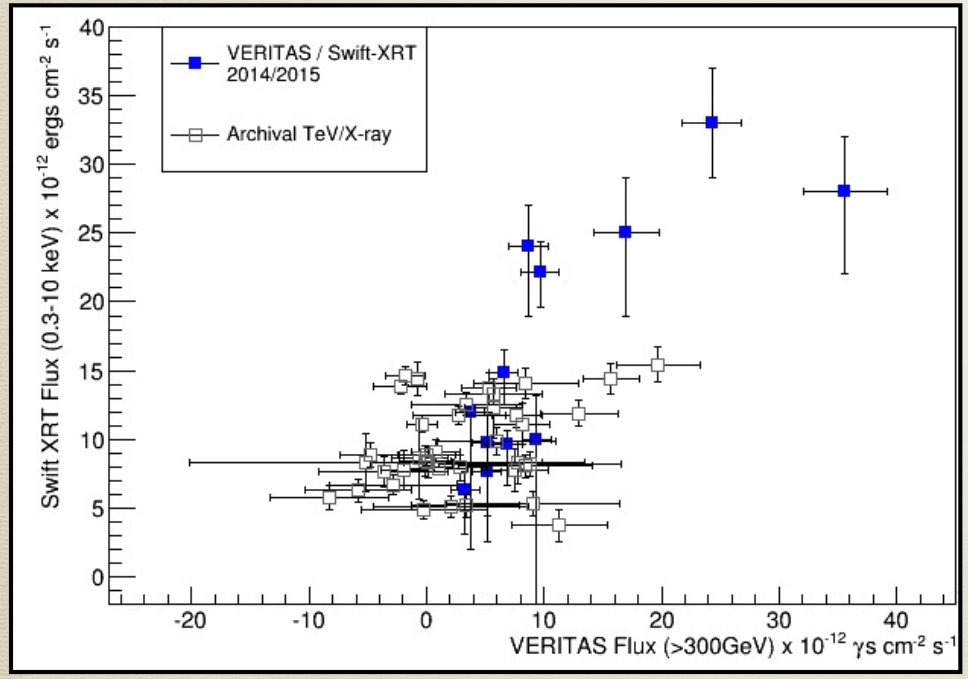
- Flux upper limit at 99% confidence level for data points < 3σ
- X-Ray flare between $\varphi \simeq 0.35$ to $\varphi \simeq 0.75$ modulated by super-orbital period
- TeV flare between $\varphi \simeq 0.55$ to $\varphi \simeq 0.65$

Light Curve of LS I +61 303



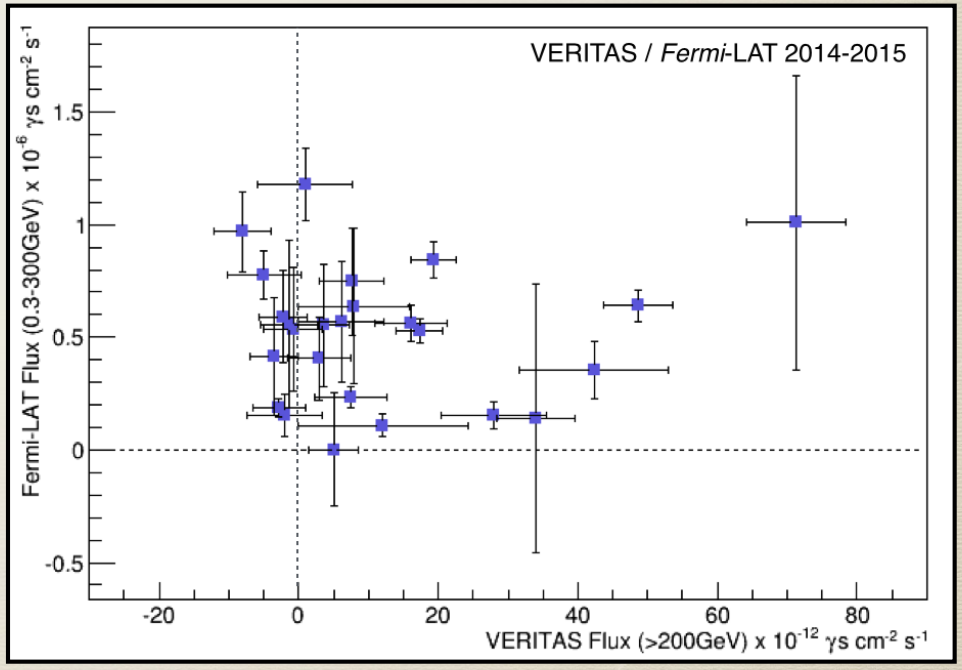
Correlation Studies

- Archival data had no correlation
- Previously correlation seen by MAGIC in 2007
- Pearson correlation coefficient for X-Ray and TeV fluxes $0.80^{+0.14}_{-0.38}$



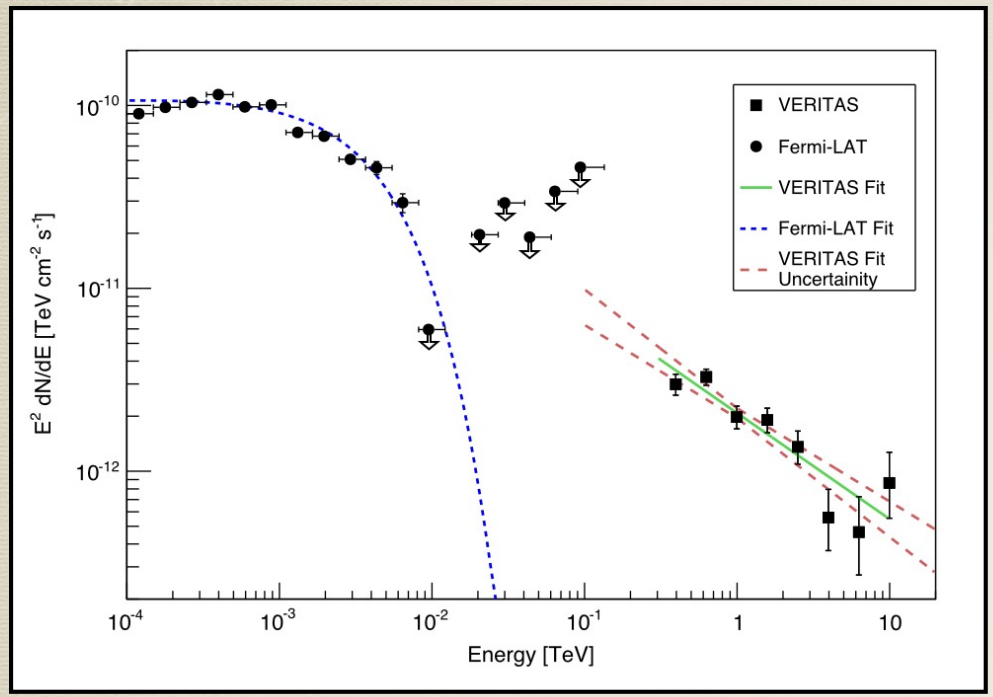
X-Ray Flux vs TeV Flux

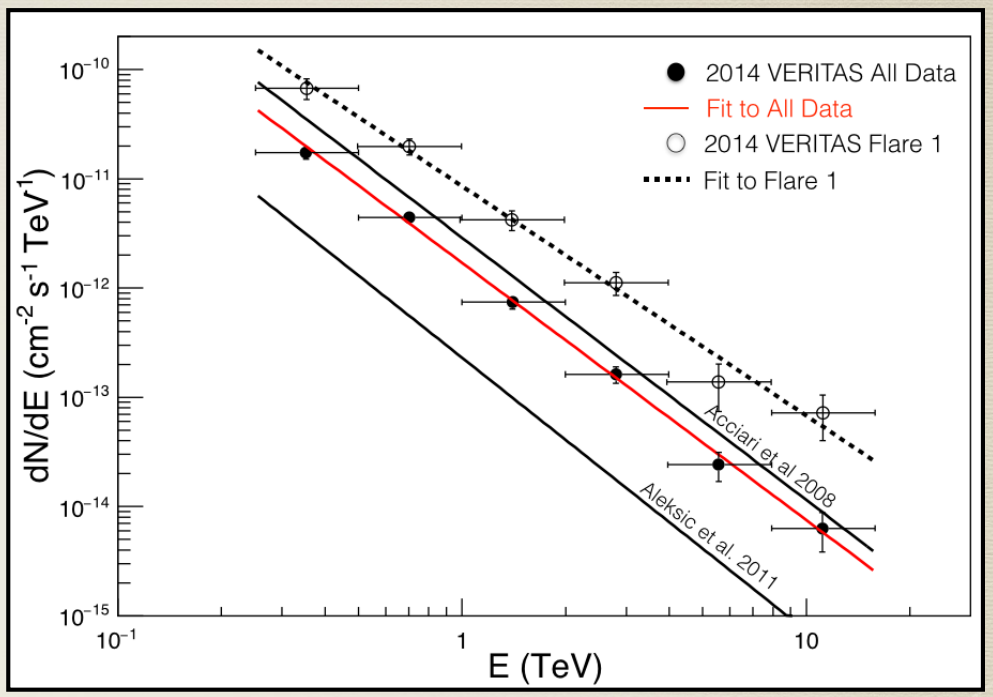
- Lack of any correlation
- Pearson correlation coefficient for GeV and TeV fluxes $0.071^{+0.36}_{-0.39}$



GeV Flux vs TeV Flux

VERITAS & *Fermi*-LAT SEDs



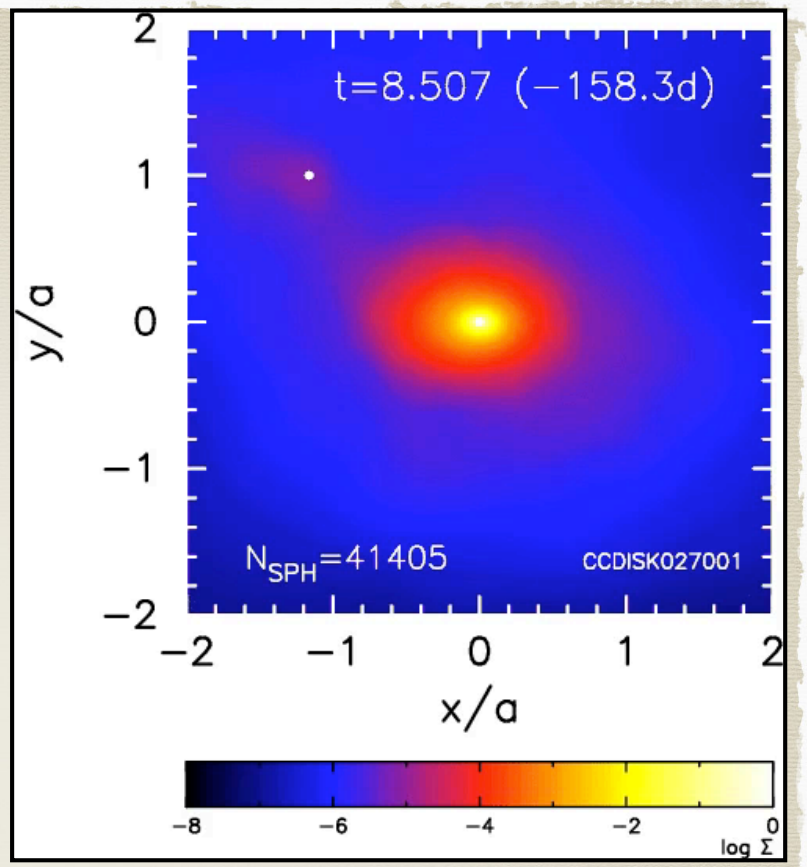


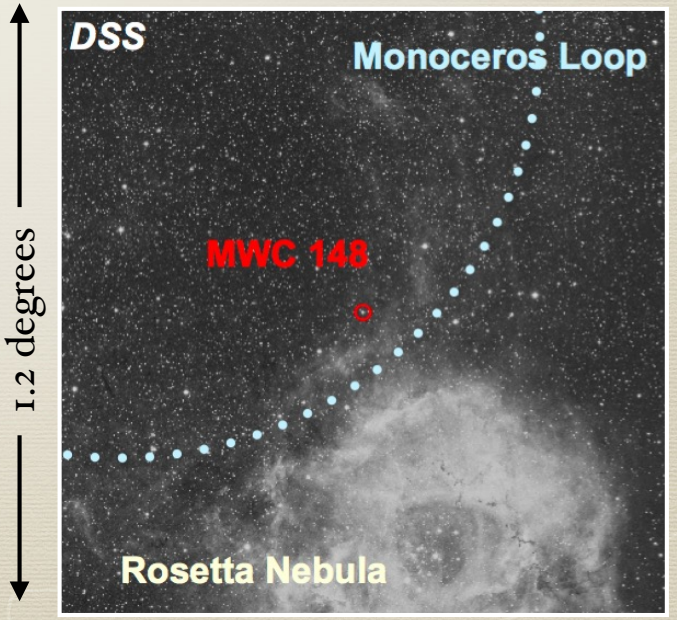
O'Faoláin de Bhróithe A. for VERITAS, ICRC 2015 - The Hague

- GeV is fitted with Power Law with exponential cutoff. at ~5 GeV
- Missing emission in 10GeV-300 GeV
- TeV spectra fits well with Power Law

HESS J0632+057

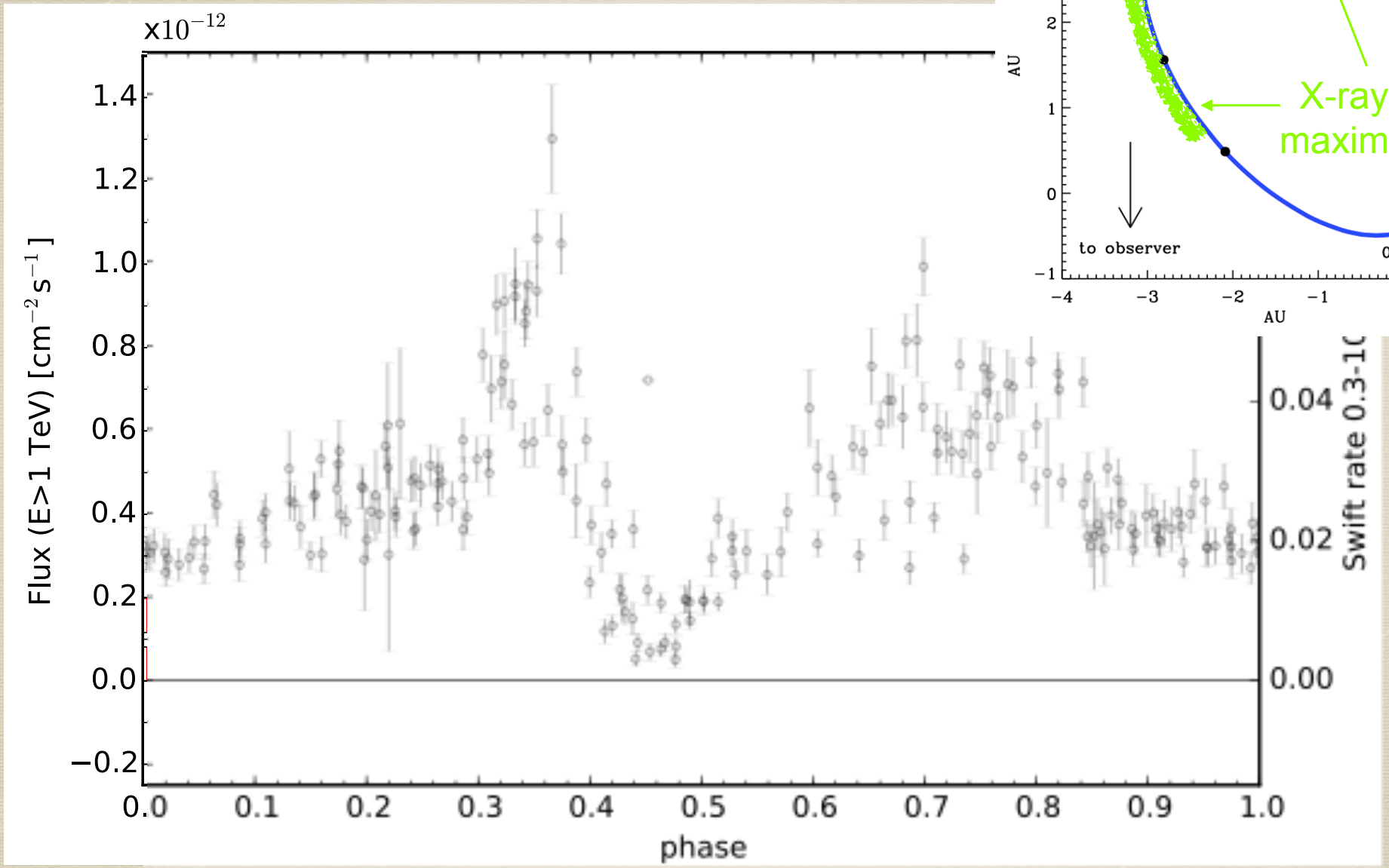
- Be star (MWC 148; 16 M⊙) + compact object at ~1.6 kpc
- Period ~315 days
- Discovered in Gamma-rays
  - serendipitous discovery by HESS (~3% Crab Nebula flux)
  - identified as variable source by VERITAS
  - observations by HESS, MAGIC and VERITAS (2004-2015)
- binary nature shown with Swift-XRT observations
- orbital parameters determined by X-ray and optical observations

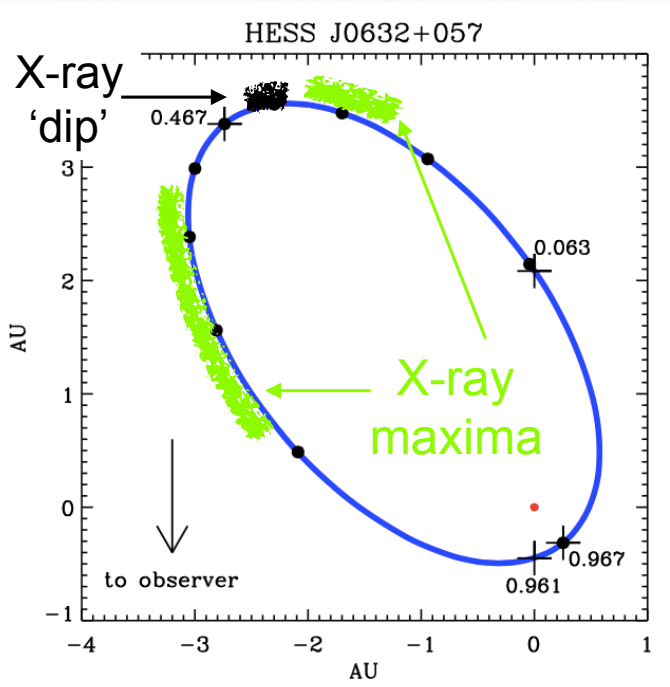




HESS J0632+057 Simulation from Okazaki A.T. et al.
Variable Galactic Gamma Ray Sources, Heidelberg, May 2015

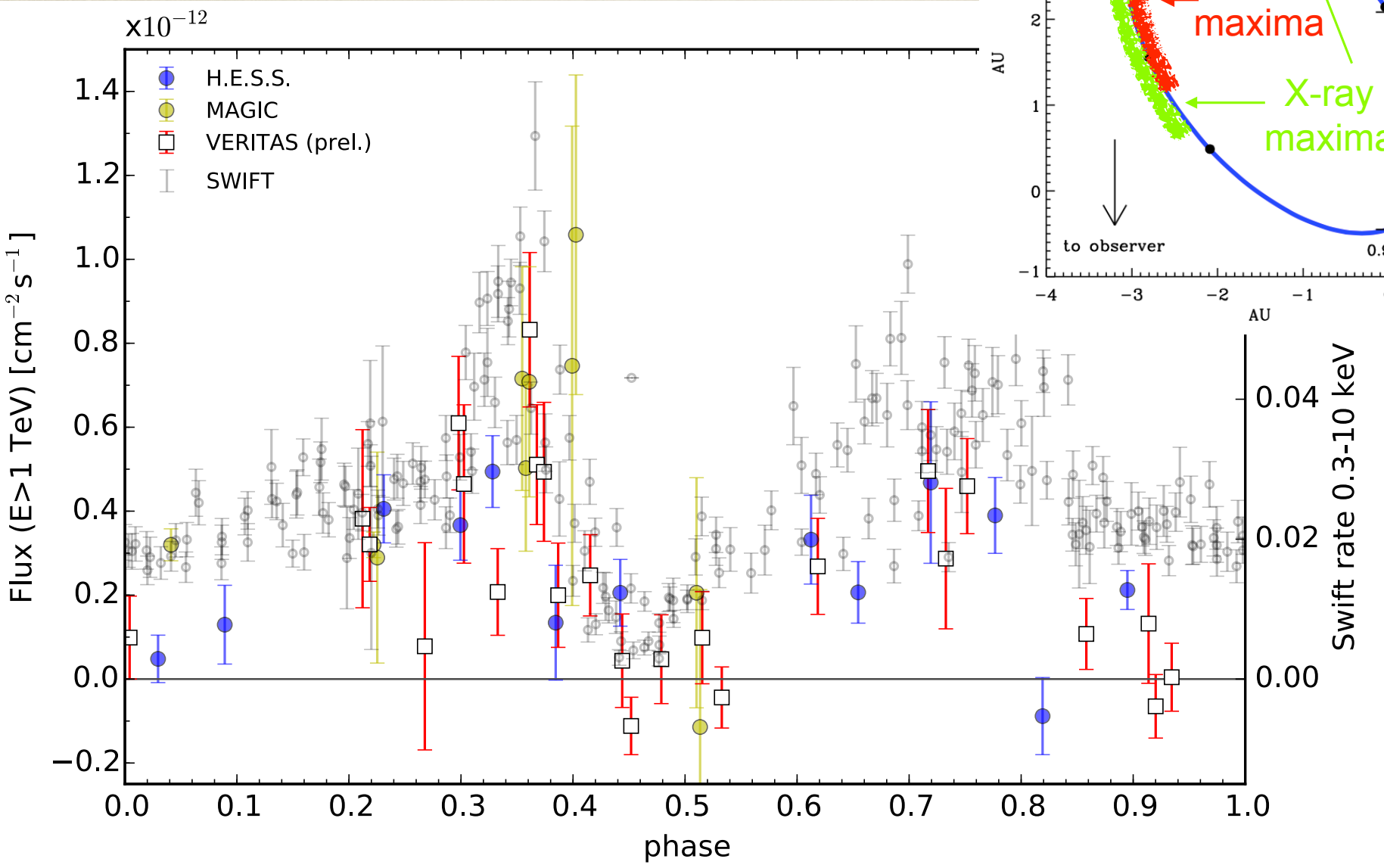
HESS J0632+057: X-ray Light Curve

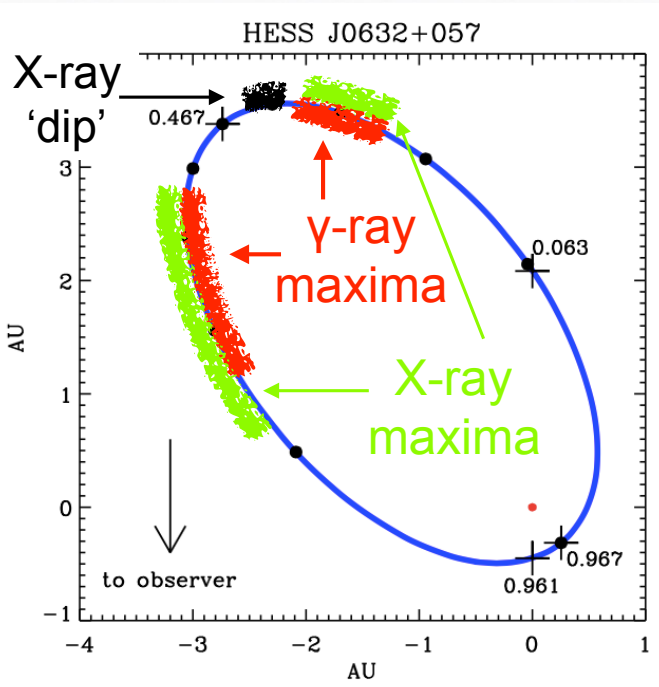




Orbital parameters from Bongiorno et al (2011),
Casares et al 2012 (Fig from Dubus 2013), Aliu et al 2014

HESS J0632+057: TeV Light Curve





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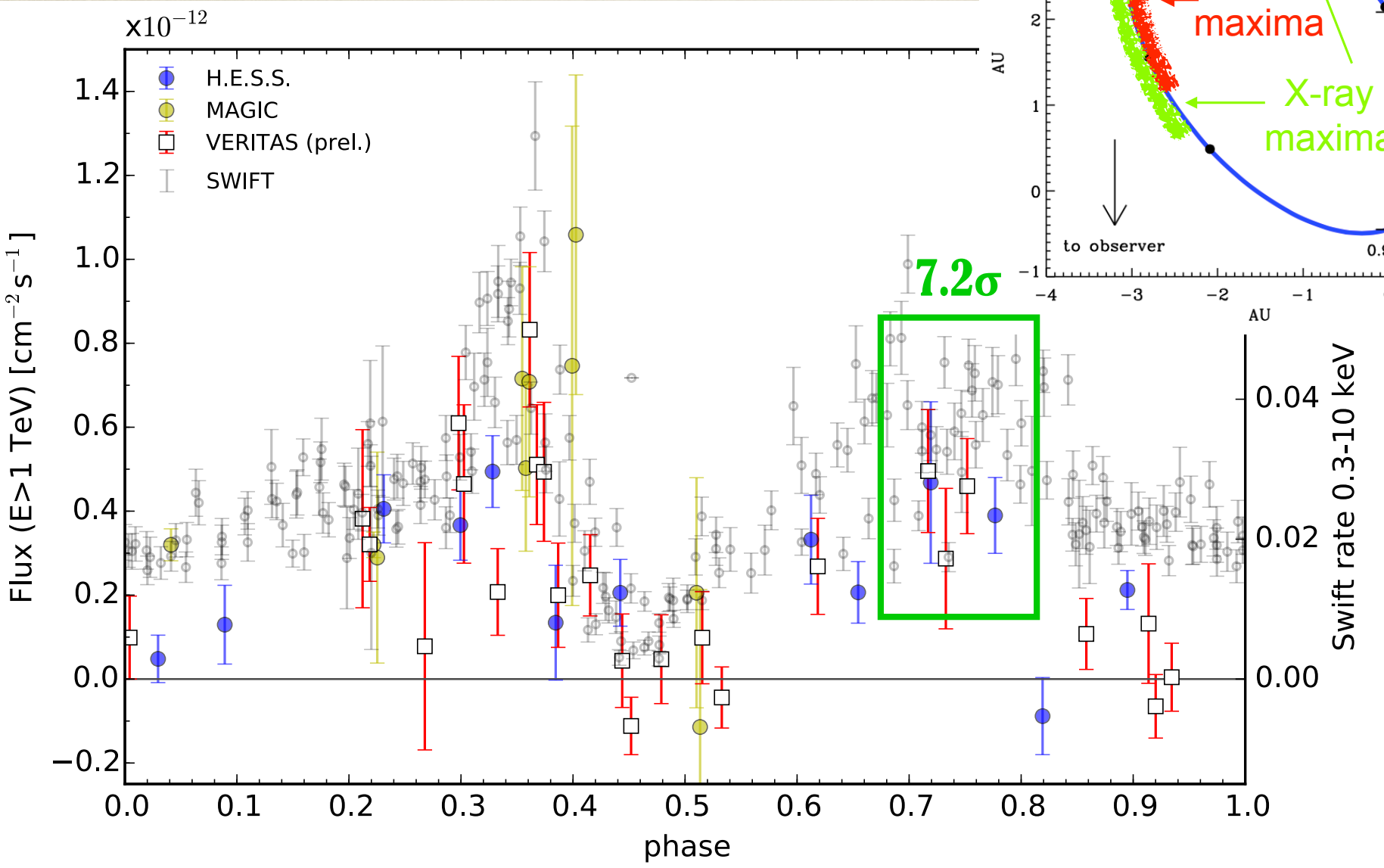
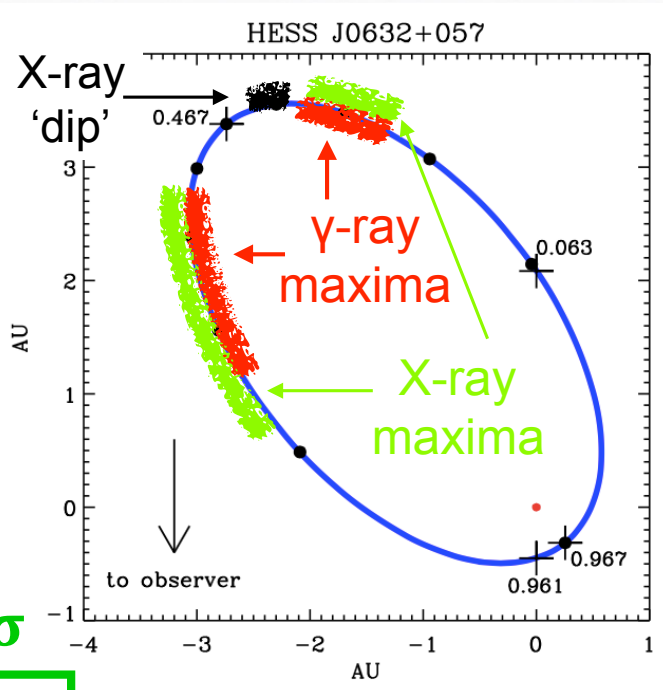
HESS J0632+057: TeV Light Curve





Orbital parameters from Bongiorno et al (2011),
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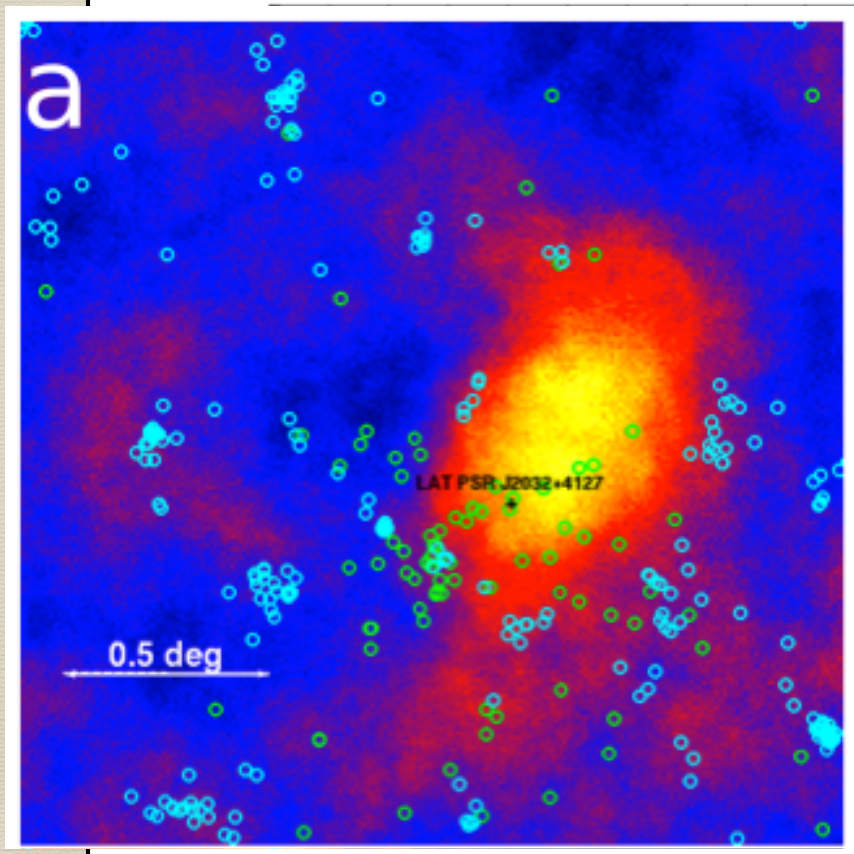
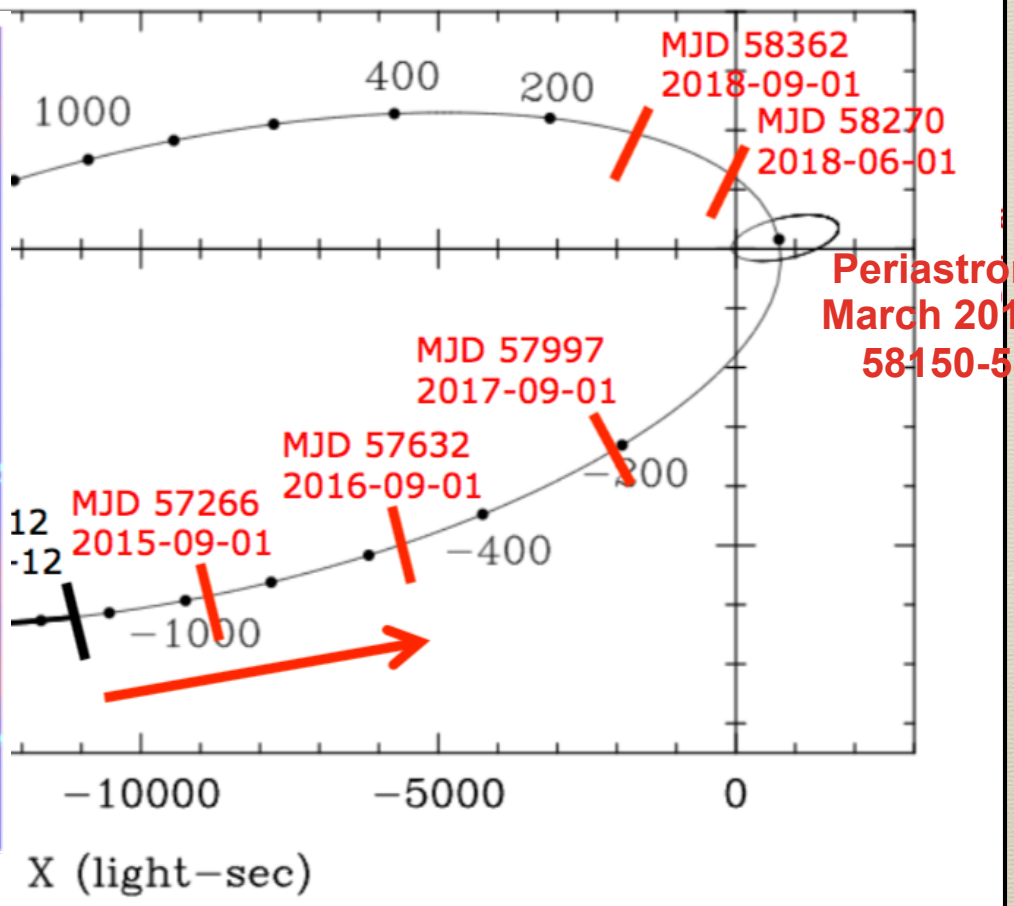
VERITAS Binary Observation Program

	type	D (kpc)	orbital period [d]	GeV/ TeV detecti	type of observation	reference (VERITAS)
LS I +61 303	Be+neutron star? BH?	1.6	26.5	✔/✔	regular since 2006 (10-30 h/season)	ApJ 2008, 2009, 2011, 2013
HESS J0632+057	B0pe + ??	1.5	315	✘/✔	regular since 2006 (10-30 h/season)	ApJ 2009, 2014
LS 5039	06.5V +neutron	2.5	3.9	✔/✔	(~10 h/season)	-
Cygnus X-1	O9.7Iab + BH	2.2	5.6	(✘/✔)	ToO (X-rays/LAT)	-
Cygnus X-3	Wolf Rayet + BH?	7	0.2	(✔)/✘	ToO (X-rays/LAT)	ApJ 2013
V407 Cygni	Nova in a symbiotic binary	2.7		✔/✘	ToO (triggered by Fermi)	ApJ 754, 77 (2012)
Be/X-ray Binary discover program	Be-XRB	-	-	-	filler program	-
Millisecond pulsar binaries	MSPB	-	-	-	regular (10-15 h/season)	-
TeV 2032+4130	UID source	-	20/30 years	✘/✔	TBD	ApJ 2014

VERITAS Binary Observation Program

	type	D (kpc)	orbital period	GeV/ TeV detecti	type of observation	reference (VERITAS)
TeV 2032+4130	UID source	-	20/30 years	✘/✔	TBD	ApJ 2014





Summary

- Long-term monitoring of HESS J0632+057
  - clear detection of second peak (phases 0.7-0.8) with 7.2 σ
- Complex variability in LS I +61 303
  - bright flare of LS I +61 303 in Autumn 2014 with day-scale variability
  - X-Ray and TeV emission appears correlated but not with GeV
- VERITAS binary discovery program
  - systematic search for gamma-ray emission from O/Be-X-ray binary systems
  - filler observing program
  - TeV J2032 may be observed during 2017/2018