Observations of gamma-ray binaries with VERITAS

PSR J1023+0038, HESS J0632+057 & LS I +61 303

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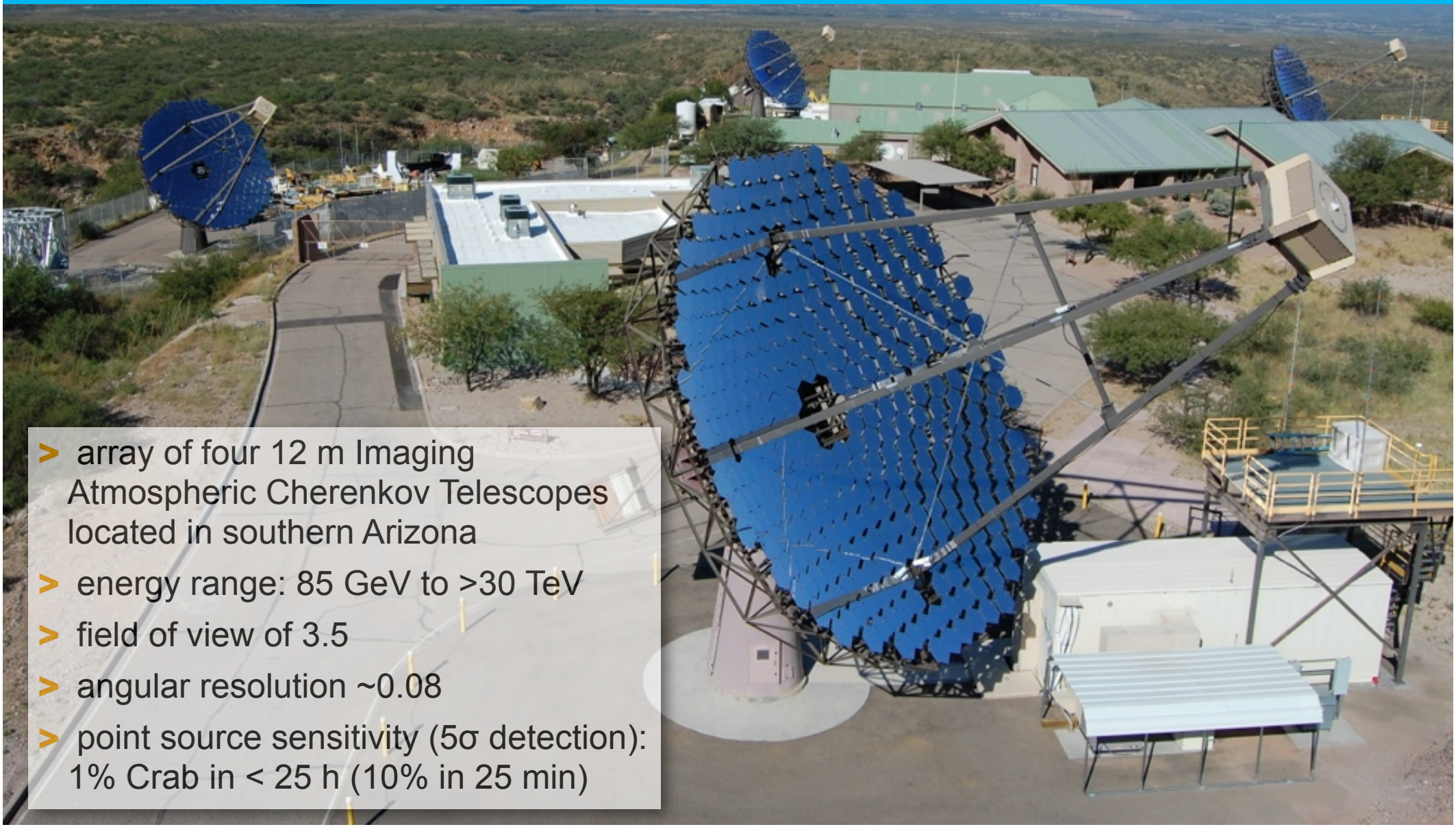
for the VERITAS Collaboration

DESY

HELMHOLTZ ASSOCIATION

Alliance for Astroparticle Physics

VERITAS



- array of four 12 m Imaging Atmospheric Cherenkov Telescopes located in southern Arizona
- energy range: 85 GeV to >30 TeV
- field of view of 3.5
- angular resolution ~0.08
- point source sensitivity (5σ detection): 1% Crab in < 25 h (10% in 25 min)

The VERITAS Binary Program

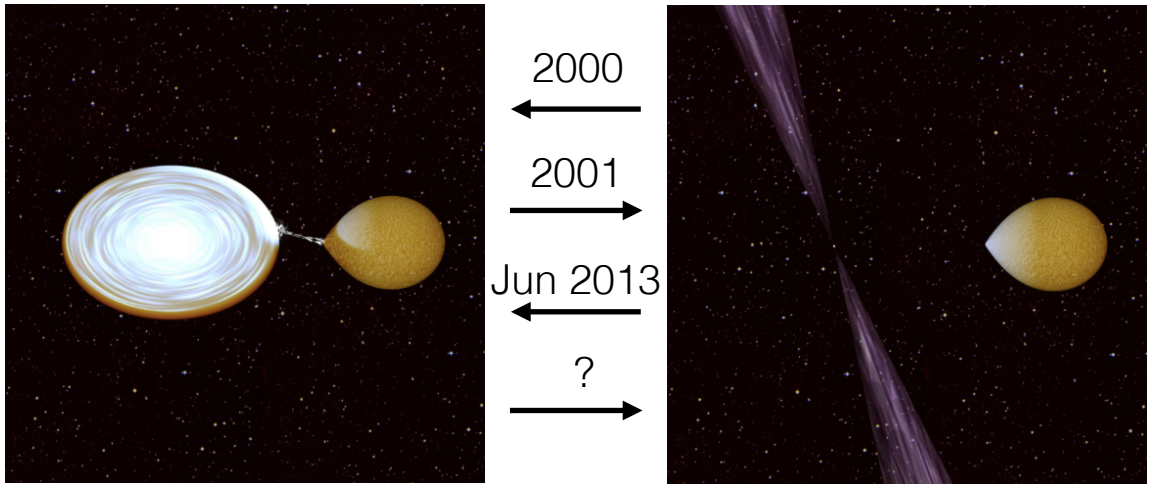
	type	D (kpc)	orbital period [d]	GeV/TeV detection	type of observation	reference (VERITAS)
LS I +61 303	Be+neutron star? BH?	1.6	26.5	✔/✔	regular since 2006 (10-30 h/season)	ApJ 2008, 2009, 2011, 2013
HESS J0632+057	B0pe + ??	1.5	315	✘/✔	regular since 2006 (10-30 h/season)	ApJ 2009, 2014
LS 5039	06.5V+neutron star? BH?	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
1A0535+262	Be/pulsar binary	2	111	✘/✘	ToO (triggered by Swift XRT)	ApJ 733, 96 (2011)
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	-
BAT flaring hard X-ray objects	SGRs+XRBs	-	-	-	ToO	-
Millisecond pulsar binaries	MSPB	-	-	-	regular (10-15 h/season)	-
Magnetars	SGRs+AXPs	-	-	-	ToO (GRB pipeline)	Proc of ICRC 2009

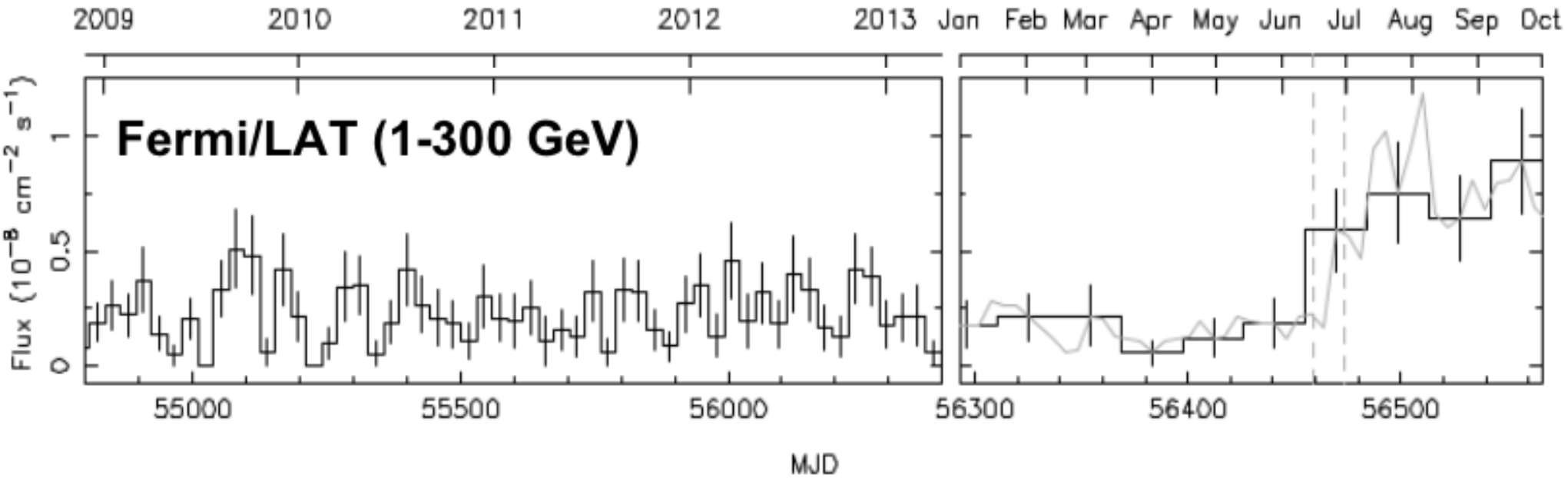
PSR J1023+0038: A new type of gamma-ray binary?

PSR J1023+0038: 1.69 ms spin period, 4.8 hr orbital period at 1.3 kpc

The June 2013 state change:

- Radio pulsations disappear
- an accretion disk appears in optical
- GeV gamma-rays flux increases by a factor >5





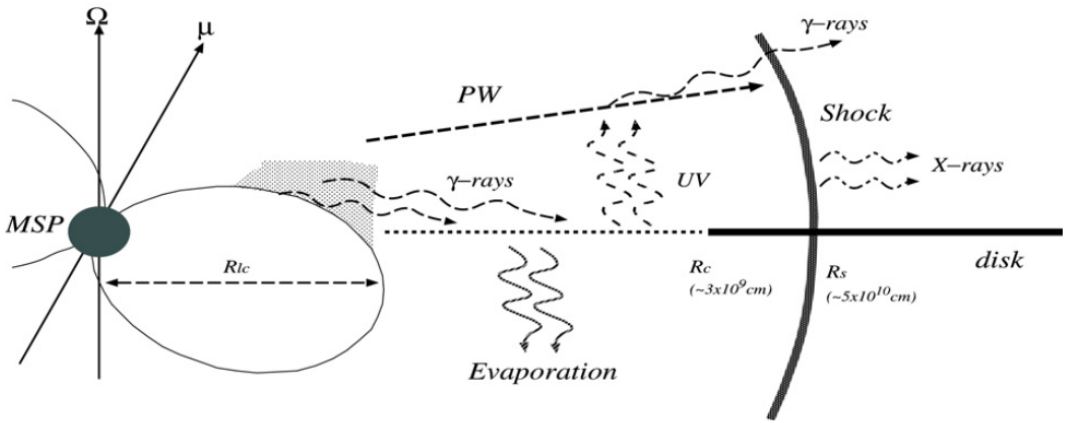
PSR J1023+0038: A new type of gamma-ray binary?

VERITAS observations in the Radio msPulsar phase

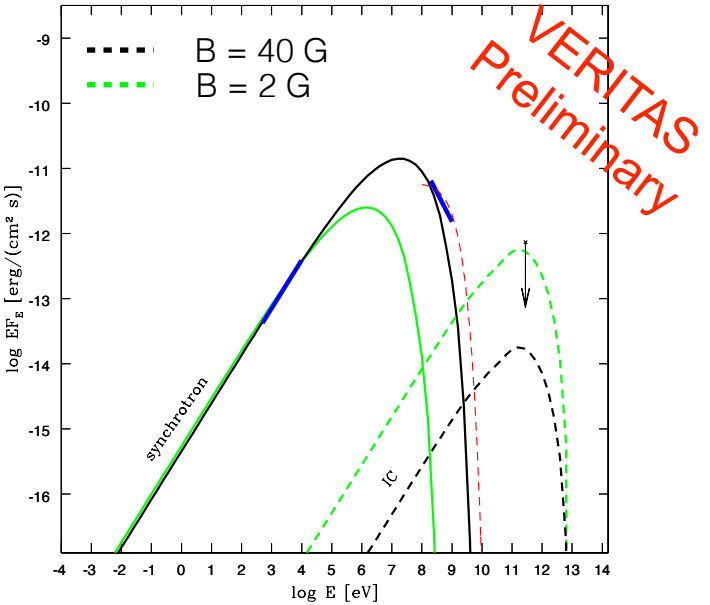
- 20 h of observations between Dec 2010 - Feb 2011
- UL (95% , E > 280 GeV): F < 1.1x10^{-8} cm^{-2}s^{-1}

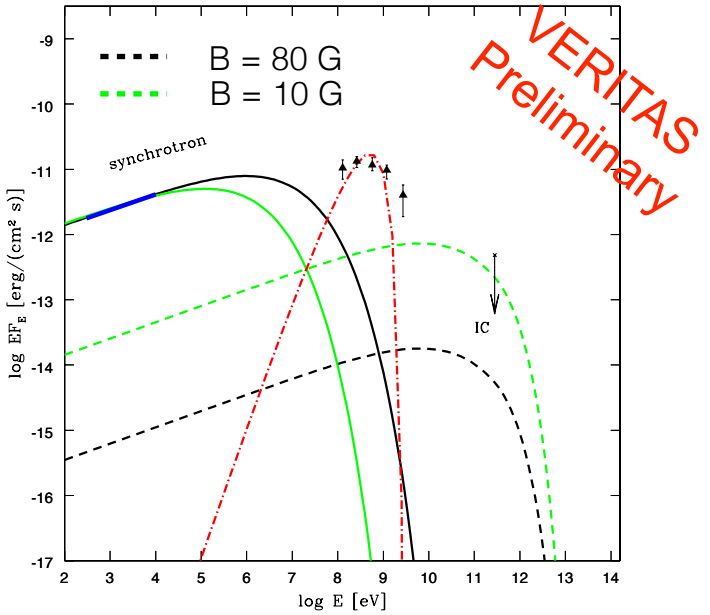
VERITAS observations in the LMXB phase

- 10 h of observations during Dec 2013
- UL (95% , E =): F < erg cm-2s-1



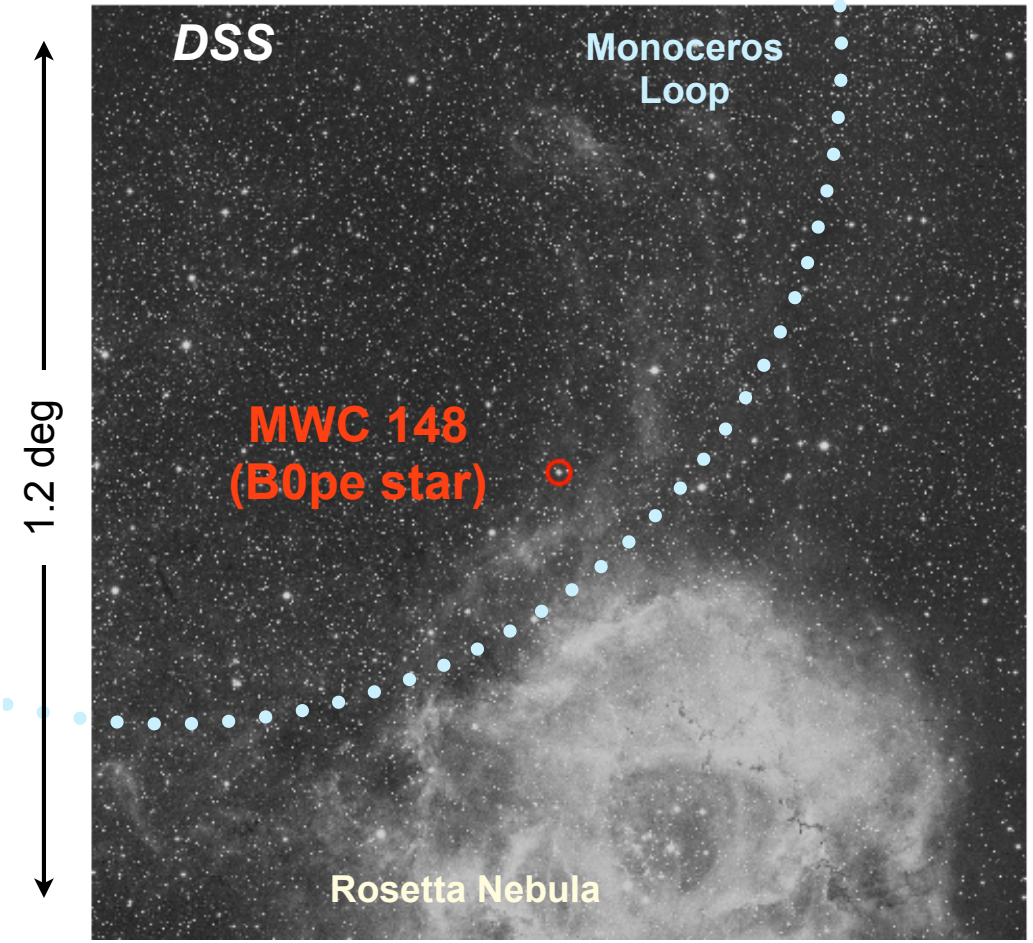
Takata et al 2014



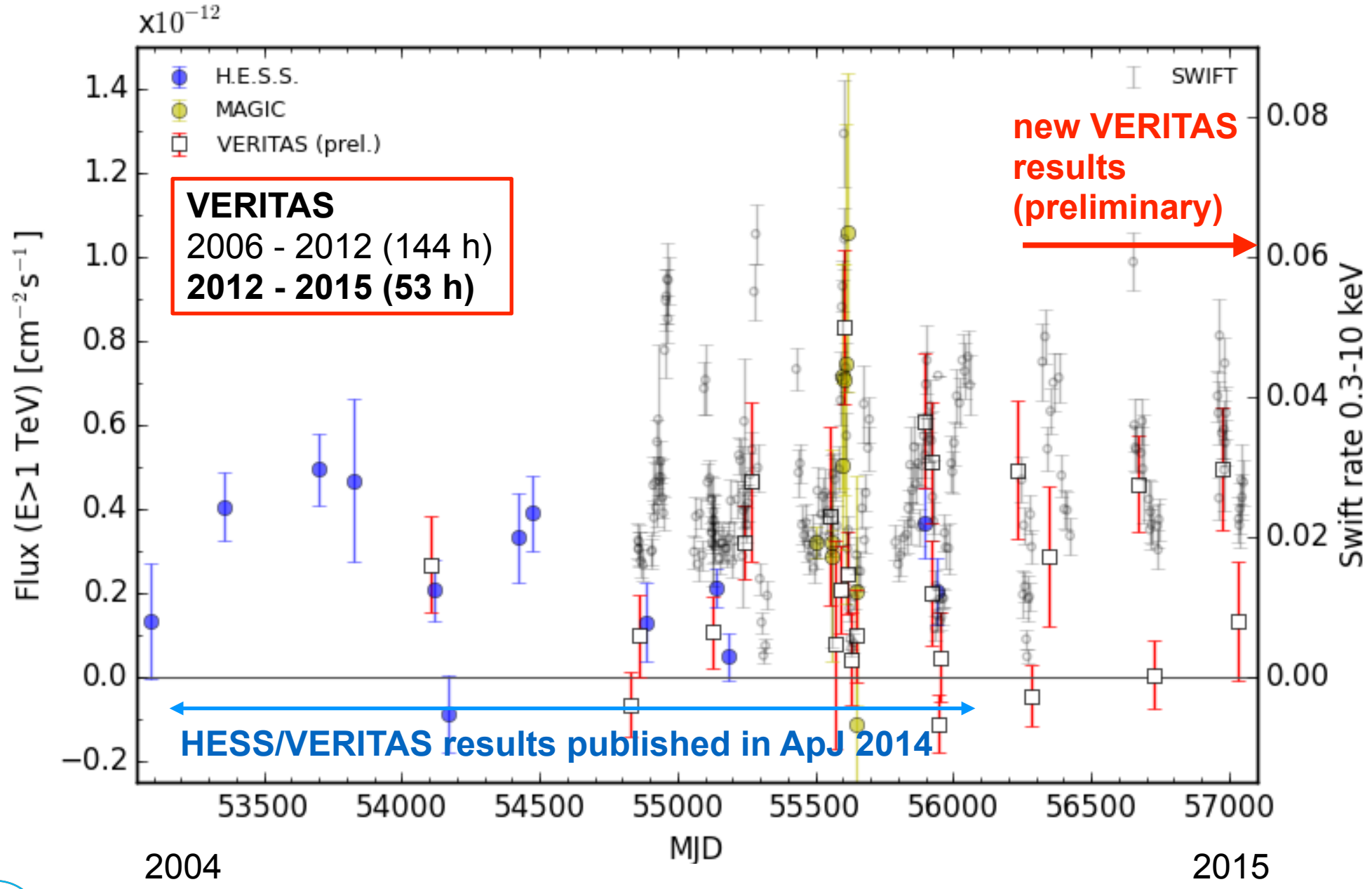


HESS J0632+057

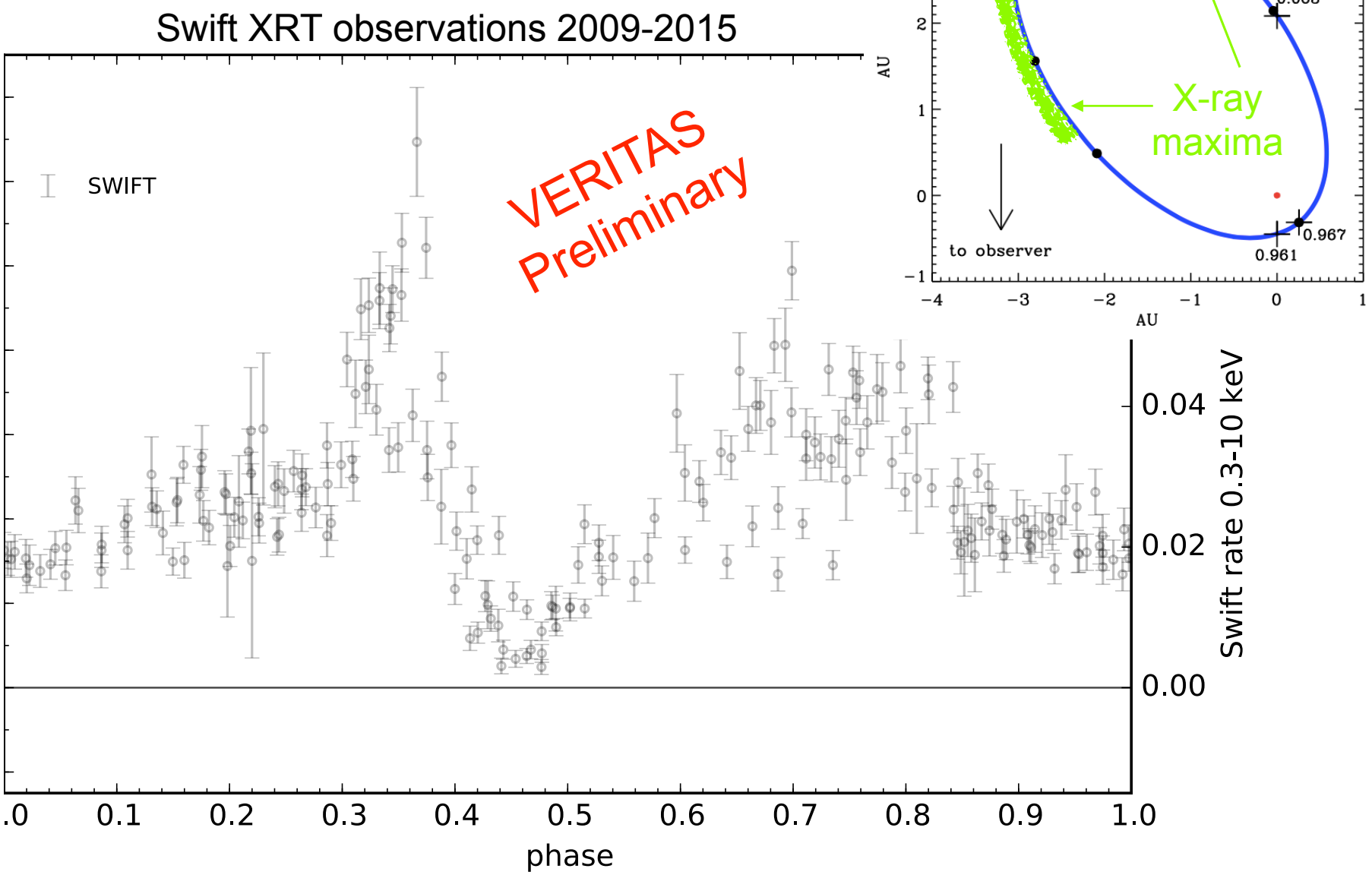
- Be star (MWC 148; 16 $M_\odot$) + compact object at 1.6 kpc
- Period ~315 days
- Discovered in Gamma-rays
  - serendipitous discovery by HESS (~3% Crab Nebula flux)
  - variability detected by VERITAS
  - observations by HESS, MAGIC and VERITAS (2004-2015)
- binary nature shown with Swift XRT observations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



HESS J0632+057/VER J0633+057: X-ray and TeV



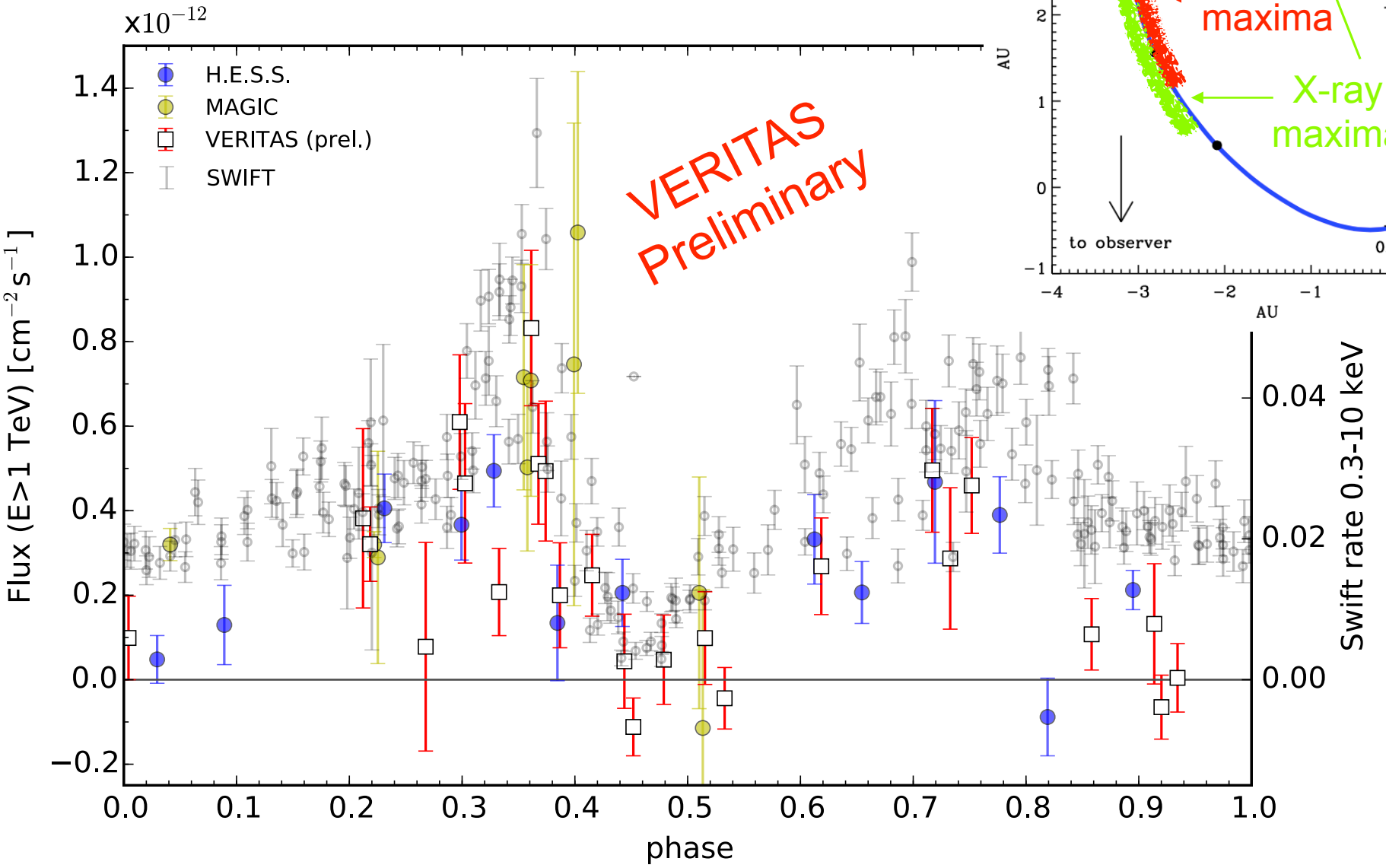
HESS J0632+057: X-ray light curve



(315 d orbital phase)

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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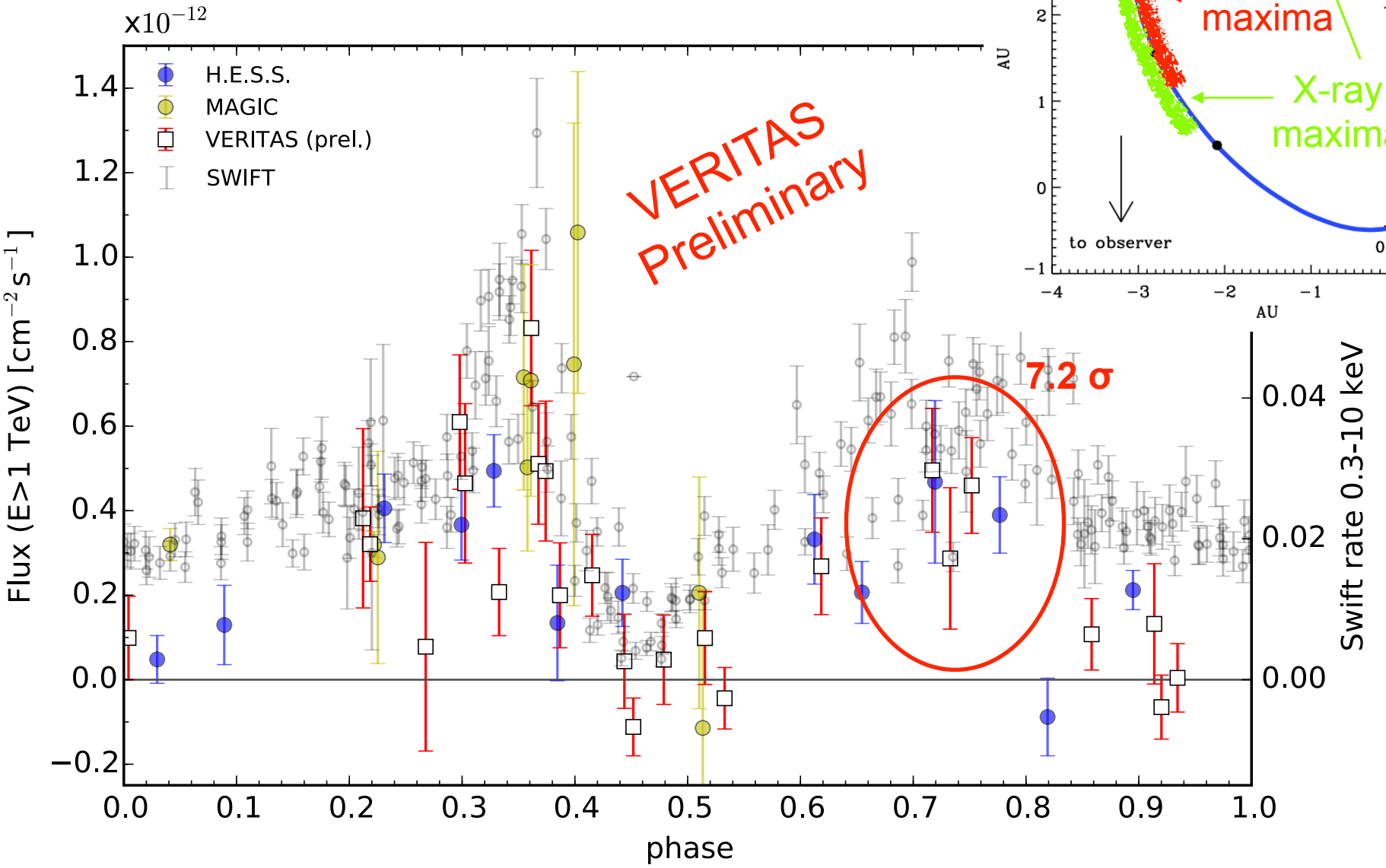

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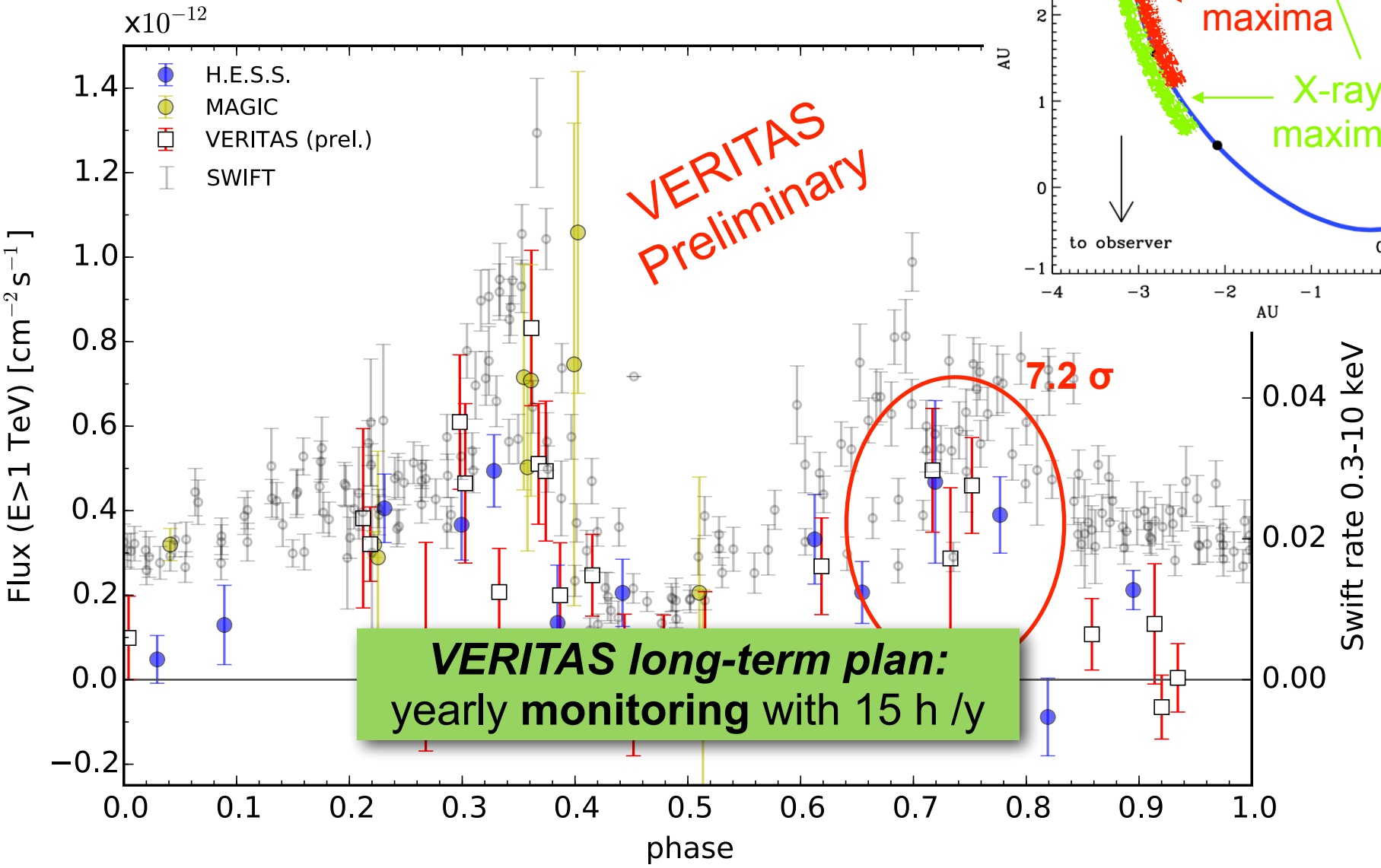


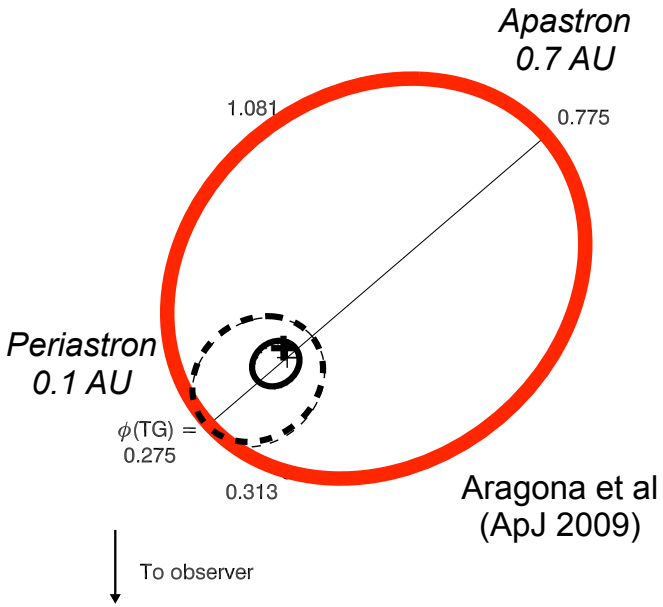
VERITAS long-term plan:
yearly **monitoring** with 15 h /y

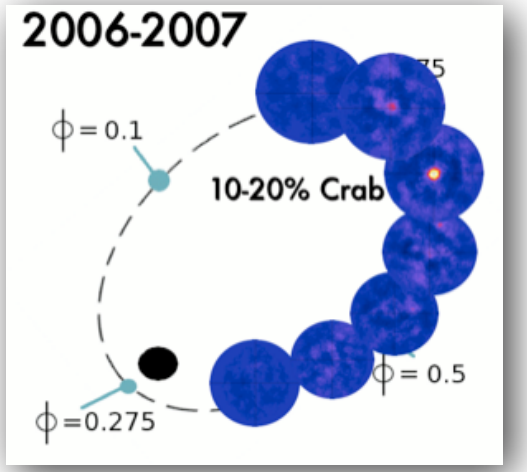
(315 d orbital phase)

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

LS I +61 303

- Be star + compact object at 1.6 kpc
- 26.5 day orbit; unknown inclination
- 1667 day super-orbital modulation



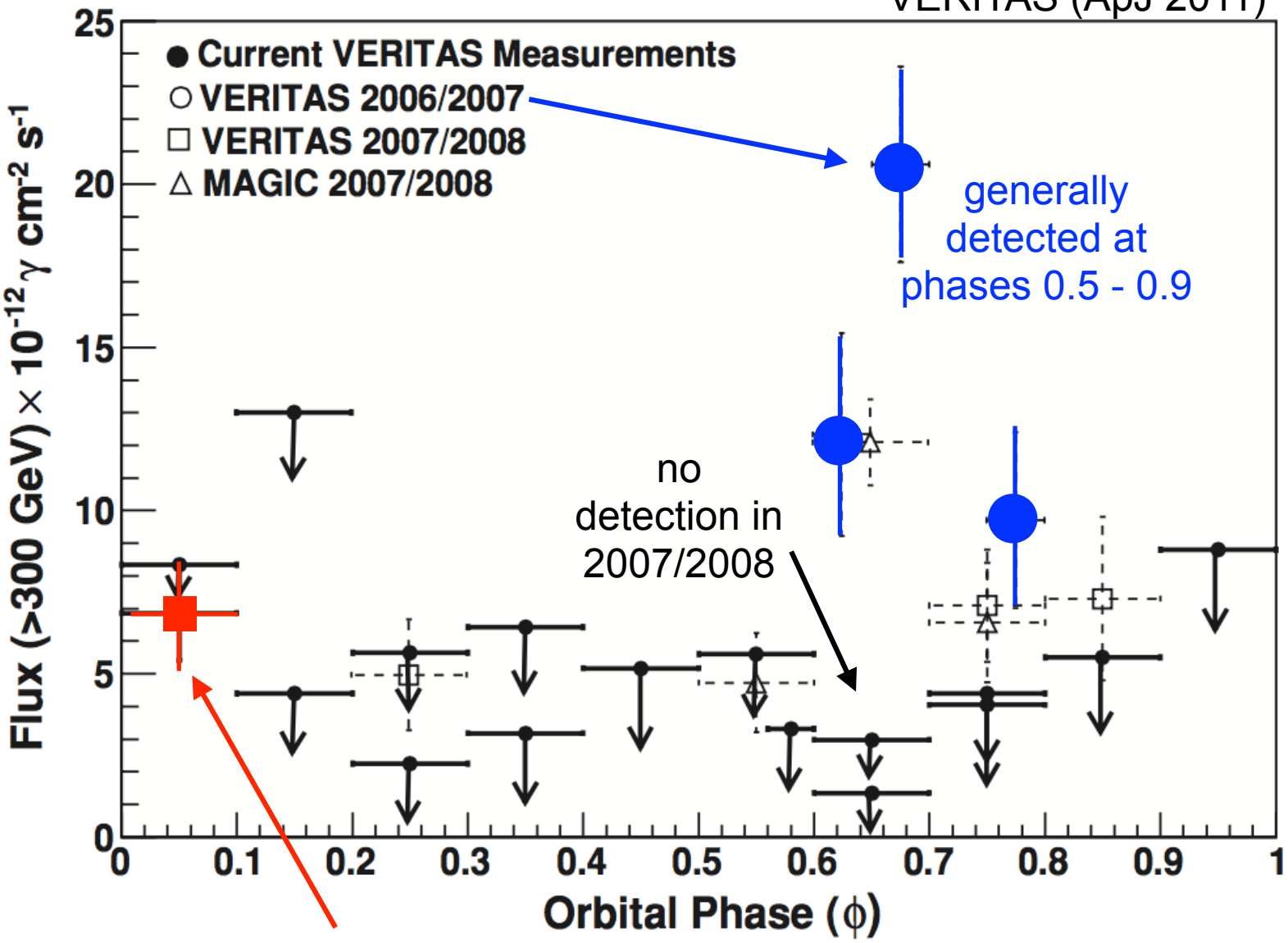


- high X-ray activity
  orbital, super-orbital variability & magnetar-like flares (e.g. Smith et al 2009)
- extended radio emission throughout orbit (Dhwawan 2006)
- GeV flux modulated by orbital and super-orbital period (LAT 2013)
- indications for X-ray / VHE correlation during one orbit (MAGIC 2009), not confirmed by using multiple orbits (VERITAS 2011)

>180 h of VERITAS observations (2006-2015)

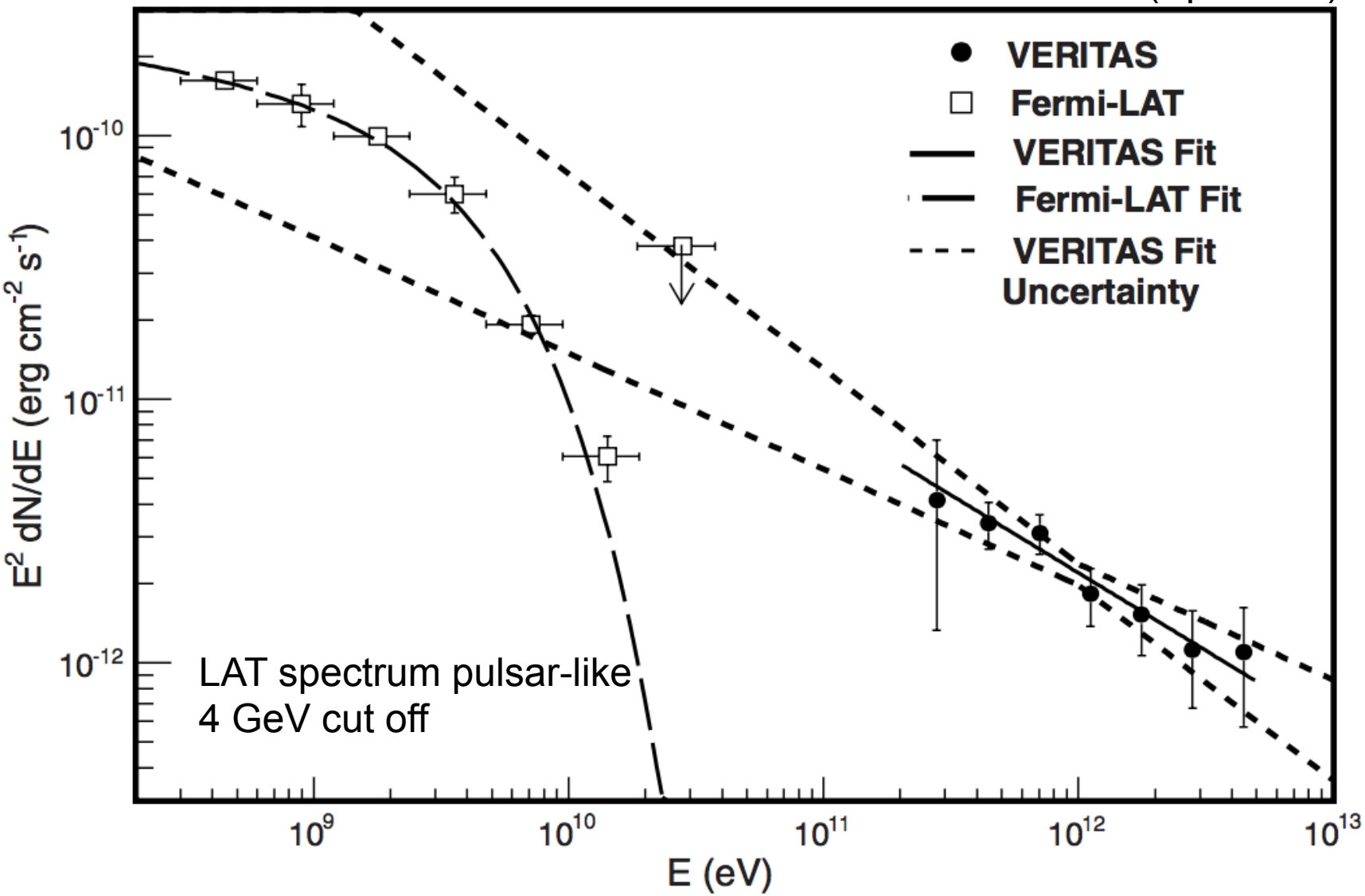
LS I +61 303 in gamma rays

VERITAS (ApJ 2011)

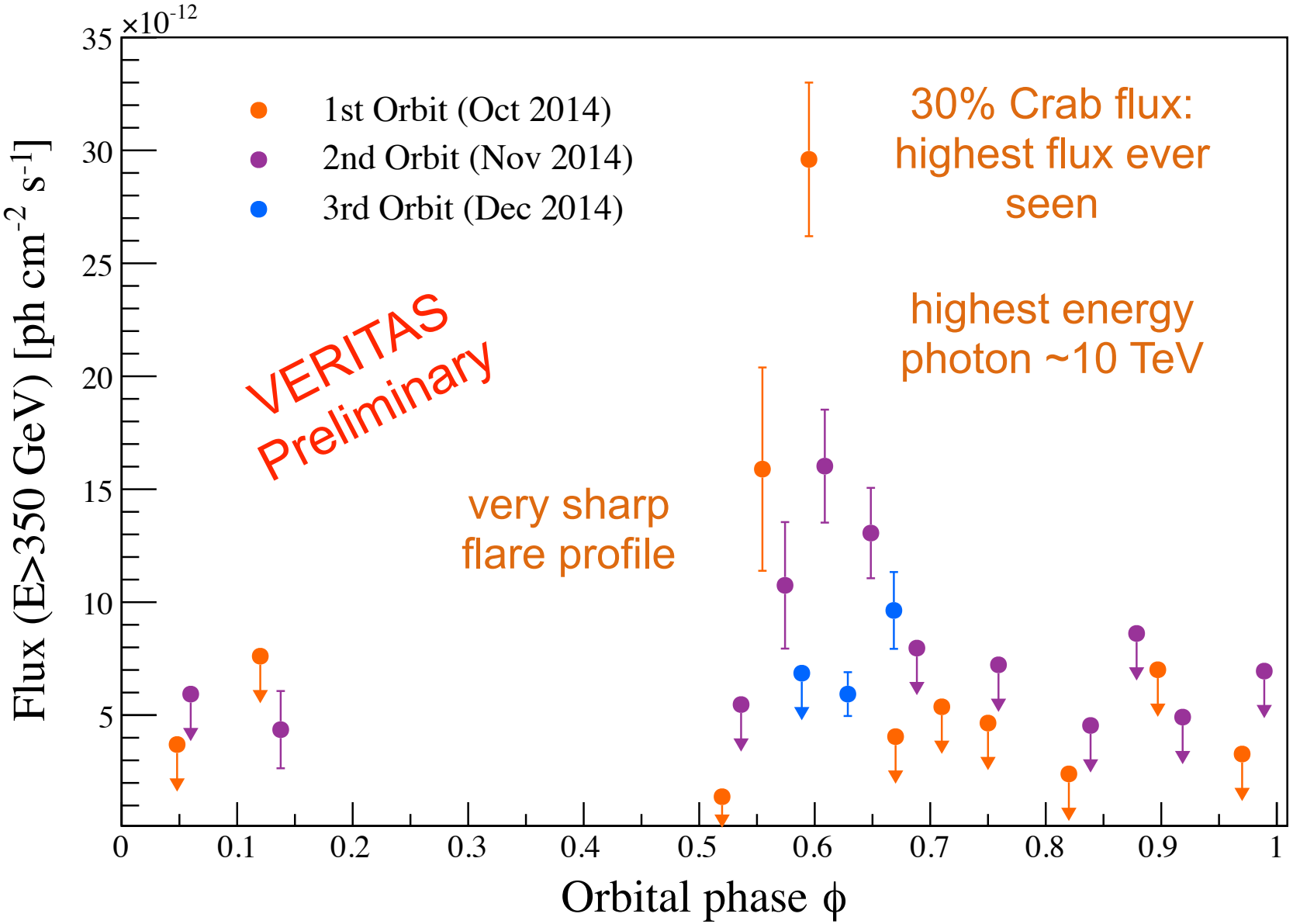


LS I +61 303 in gamma rays

VERITAS (ApJ 2013)



Historically bright flares of LS I +61 303 in 2014



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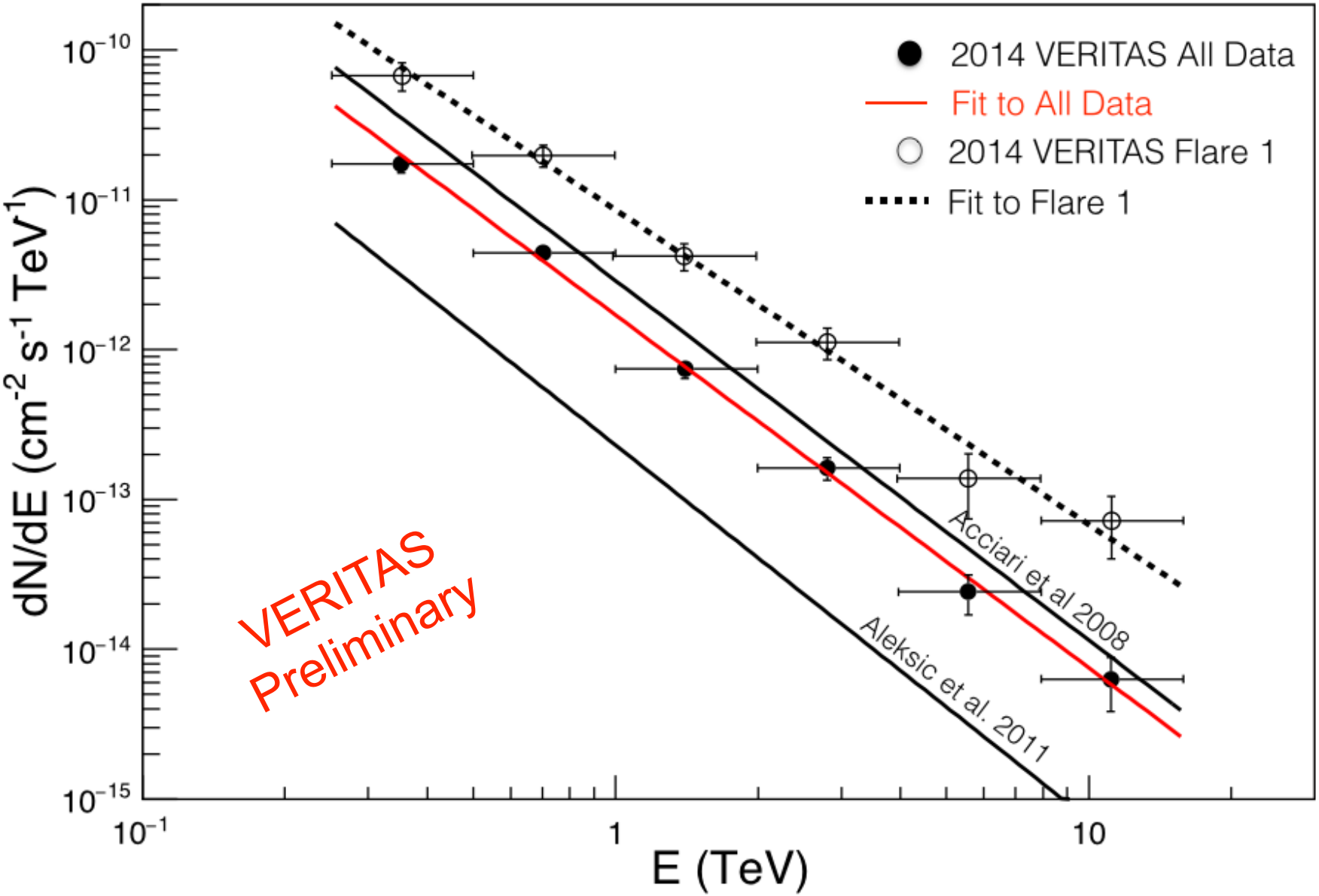
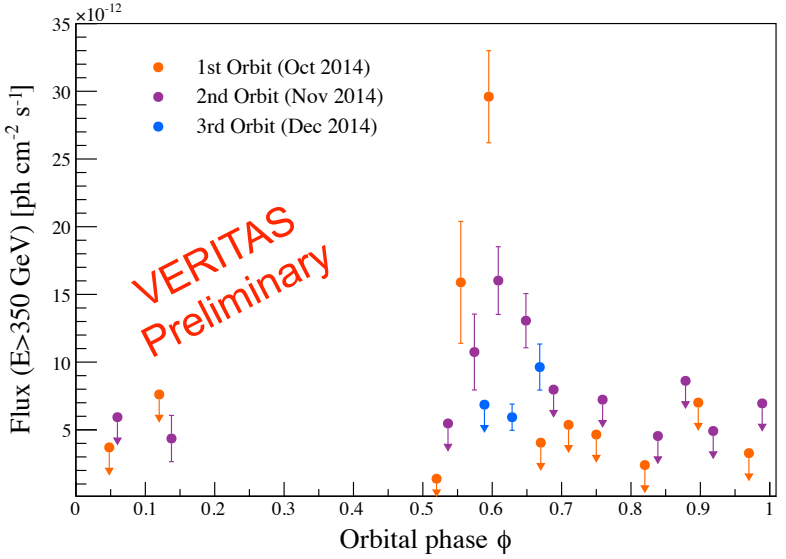
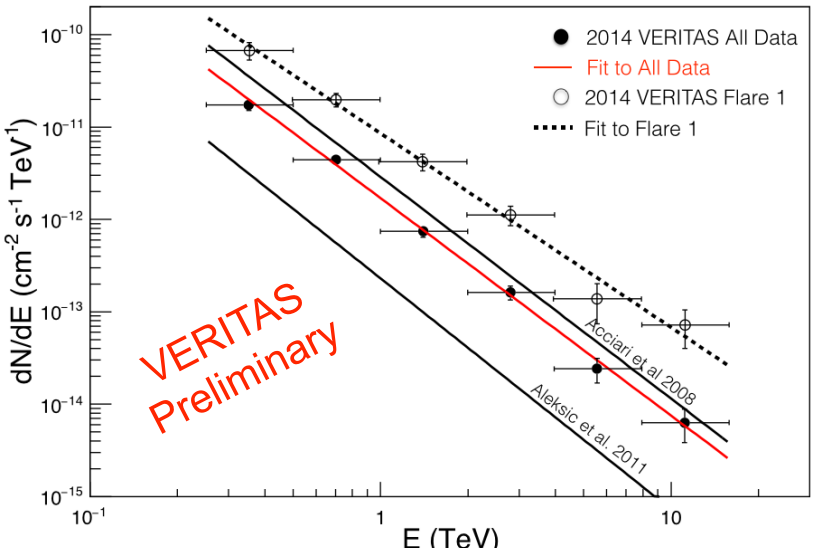


LS I +61 303 in 2014 and future plans

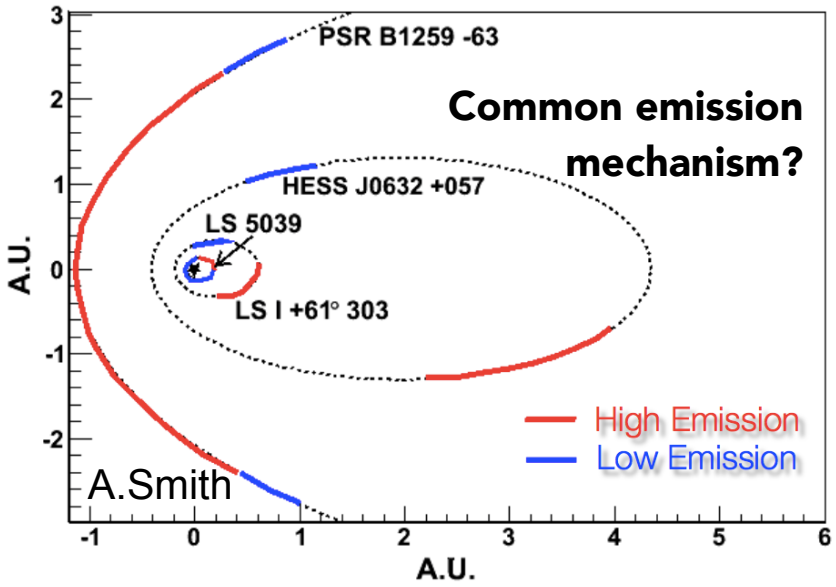
- Atel #6785, publication in preparation
- time-scale for variability <2 days
- multi-wavelength analysis (LAT, Swift XRT, Radio (AMI & RATAN), Ritter Observatory)
- preliminary results of XRT and LAT analysis show no evidence for similar high emission
- plans for future observations
  - yearly monitoring (12 h/y) is part of the VERITAS long-term observing plan
  - coordinated observations with MAGIC (started in Nov 2014)

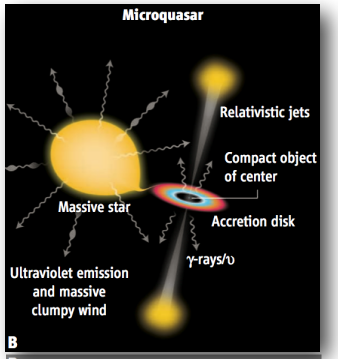


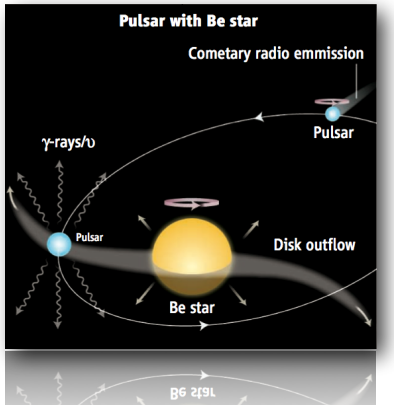


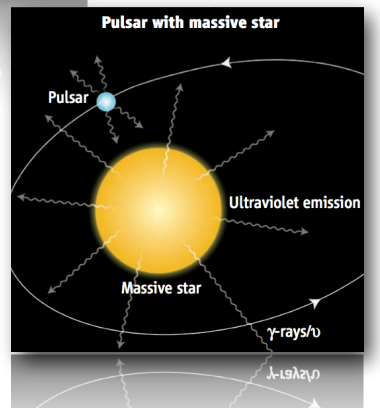
Summary of VERITAS Binary observations

- observations of PSR J1023+0038 in LMXB and MSP phase
- 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
- VERITAS binary discovery program
  - systematic search for gamma-ray emission from O/Be-X-ray binary systems
  - filler observing program









Mirabel (Science 2012)