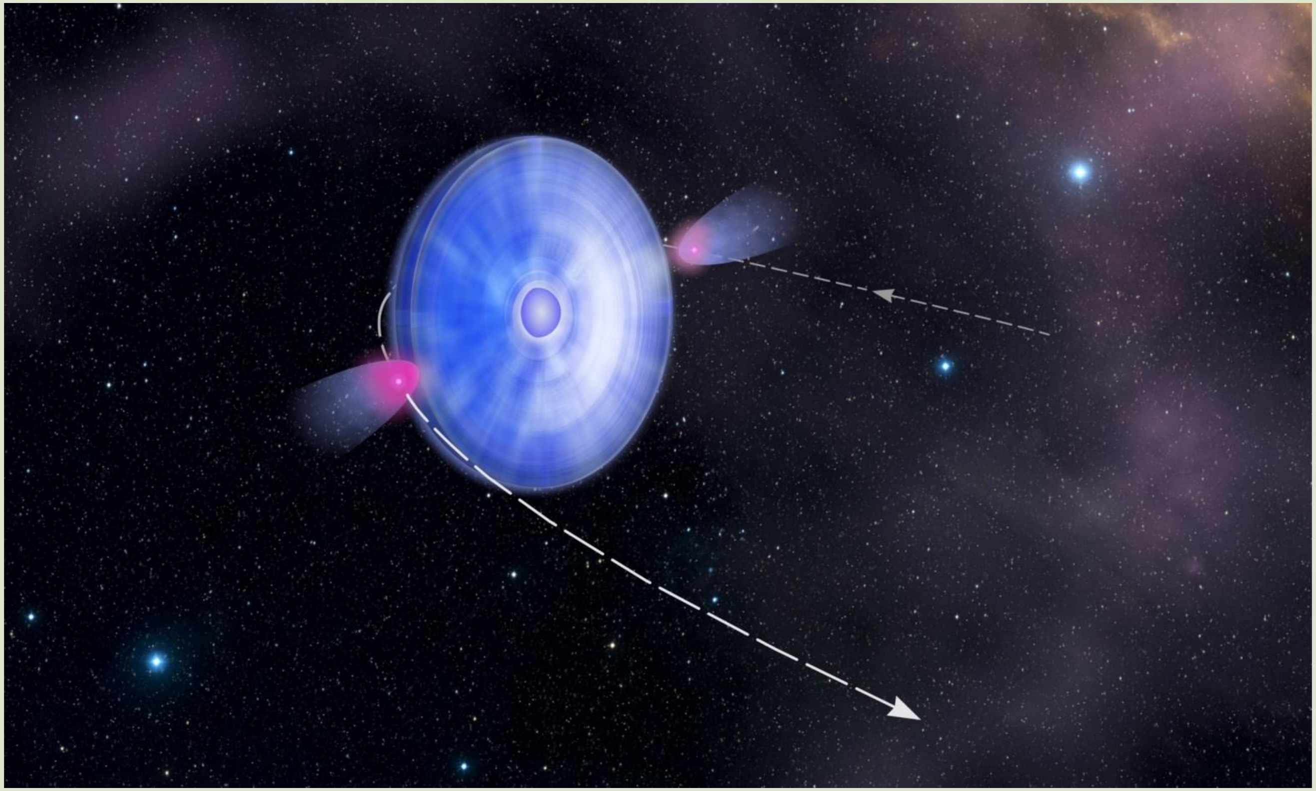

Probing orbital parameters of gamma-ray binaries with TeV light curves

Iurii Sushch
Brian van Soelen
Martin Pohl

Here was supposed to be the slide introducing gamma-ray binaries

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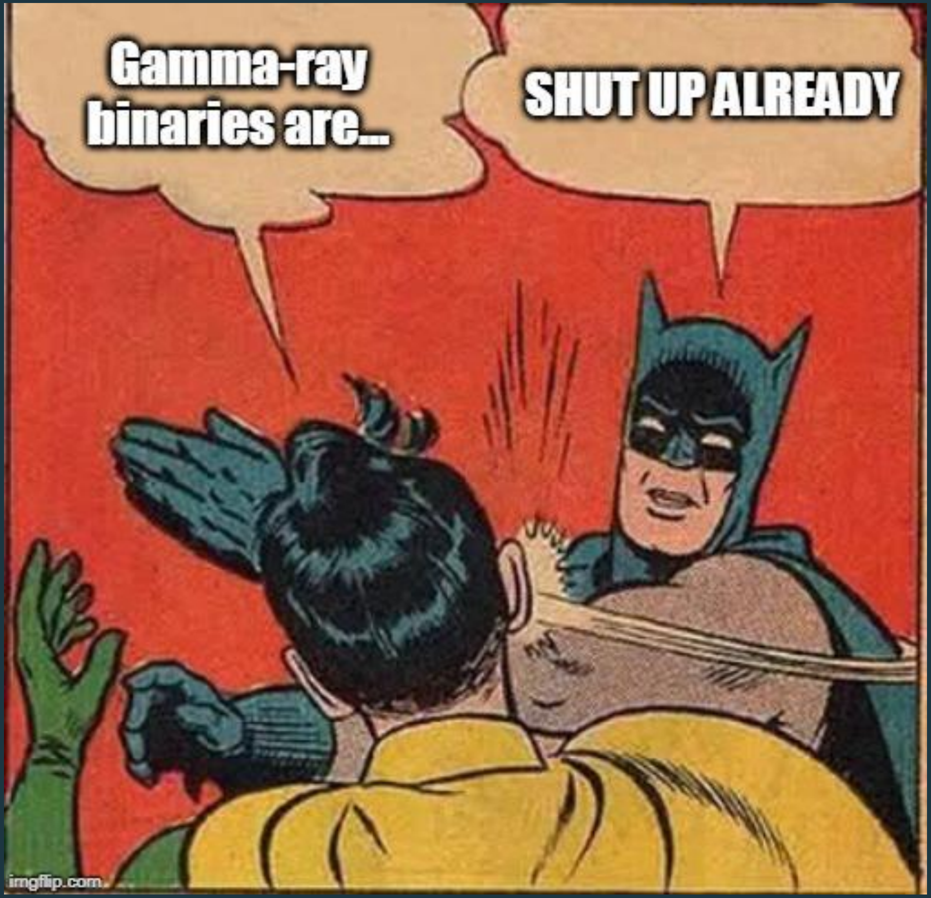
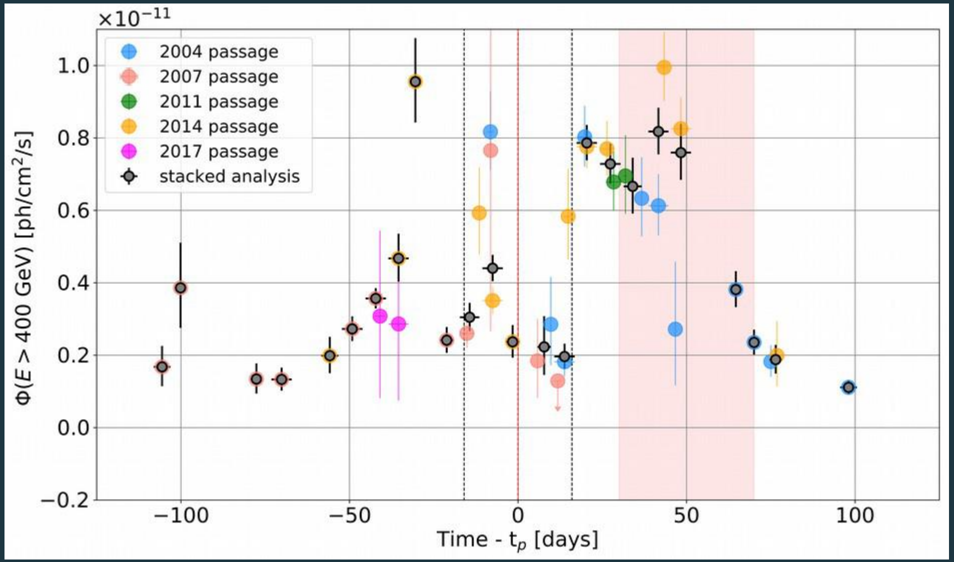


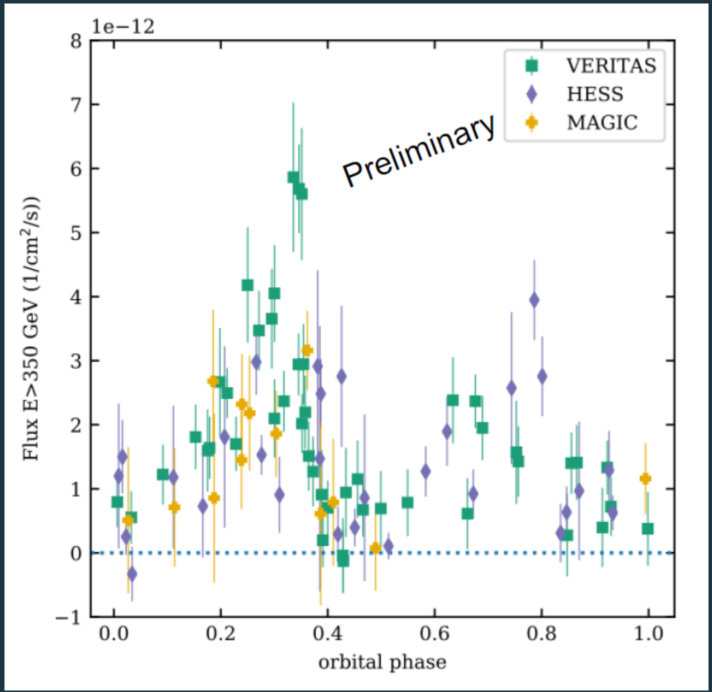
TeV light curves

PSR B1259-63/LS 2883



Stolen from Nukri's talk (GAI4a) on Friday
See also Poster PS3-71

HESS J0632+057

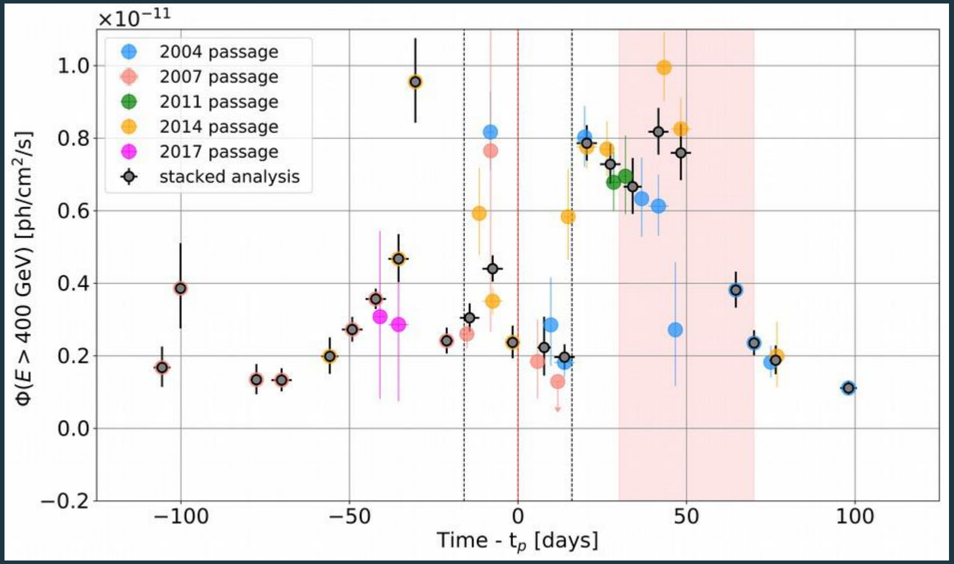


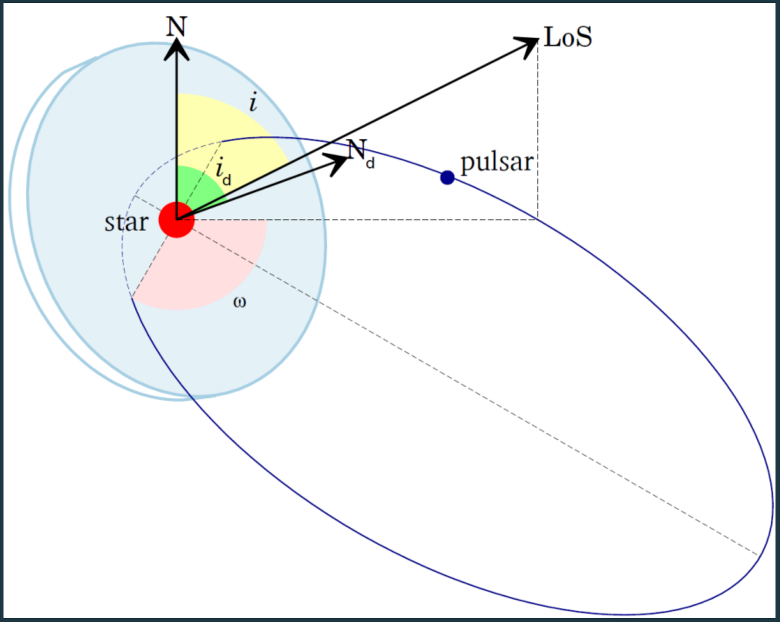
- Variability related to the orbital period
- Often double-peak structure

Stolen from Nukri's talk (GAI4a) on Friday
Previous talk by Gernot (GAI6c)

What causes the dip?

PSR B1259-63/LS 2883

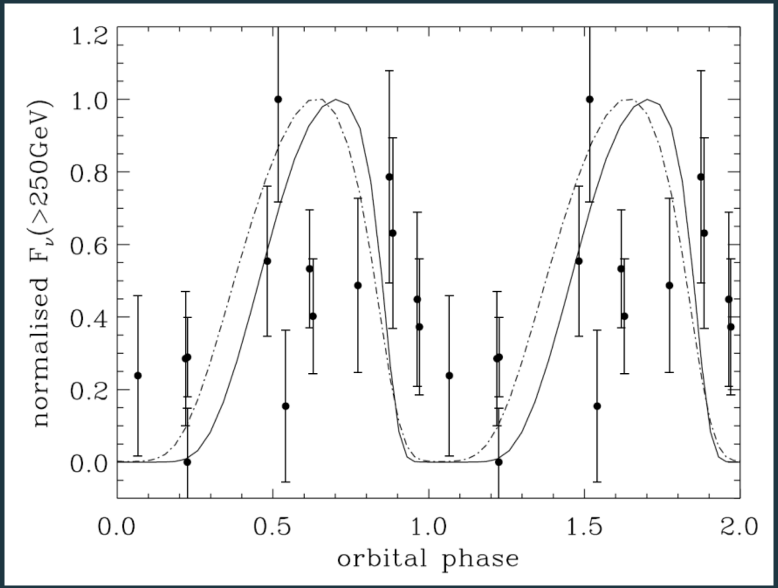




- Naively one would expect highest flux at periastron due to the highest energy density of stellar photons
- But that's where we see the dip

Gamma-gamma absorption

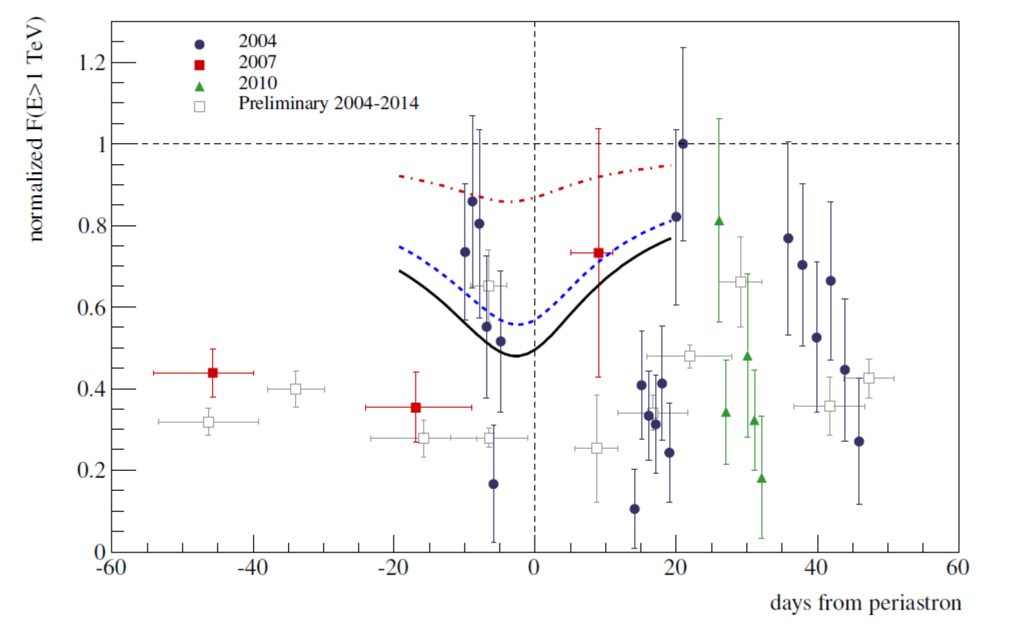
LS 5039



Dubus, 2006

LS 5039: Both location and depth of the minimum can be roughly explained by absorption

PSR B1259-63/LS 2883



Sushch & van Soelen, 2017

PSR B1259-63: Location of the minimum can be explained by absorption but not the depth

Gamma-gamma absorption

$$\tau_{\gamma\gamma} = \int_0^l dl \int_0^{4\pi} (1-\mu)\, d\Omega \int_{\frac{2}{\epsilon_\gamma(1-\mu)}}^{\infty} n_{ph}(\epsilon, \Omega) \sigma_{\gamma\gamma}\left(\epsilon, \epsilon_\gamma, \mu\right) d\epsilon\,; \quad \mu = \cos\theta$$

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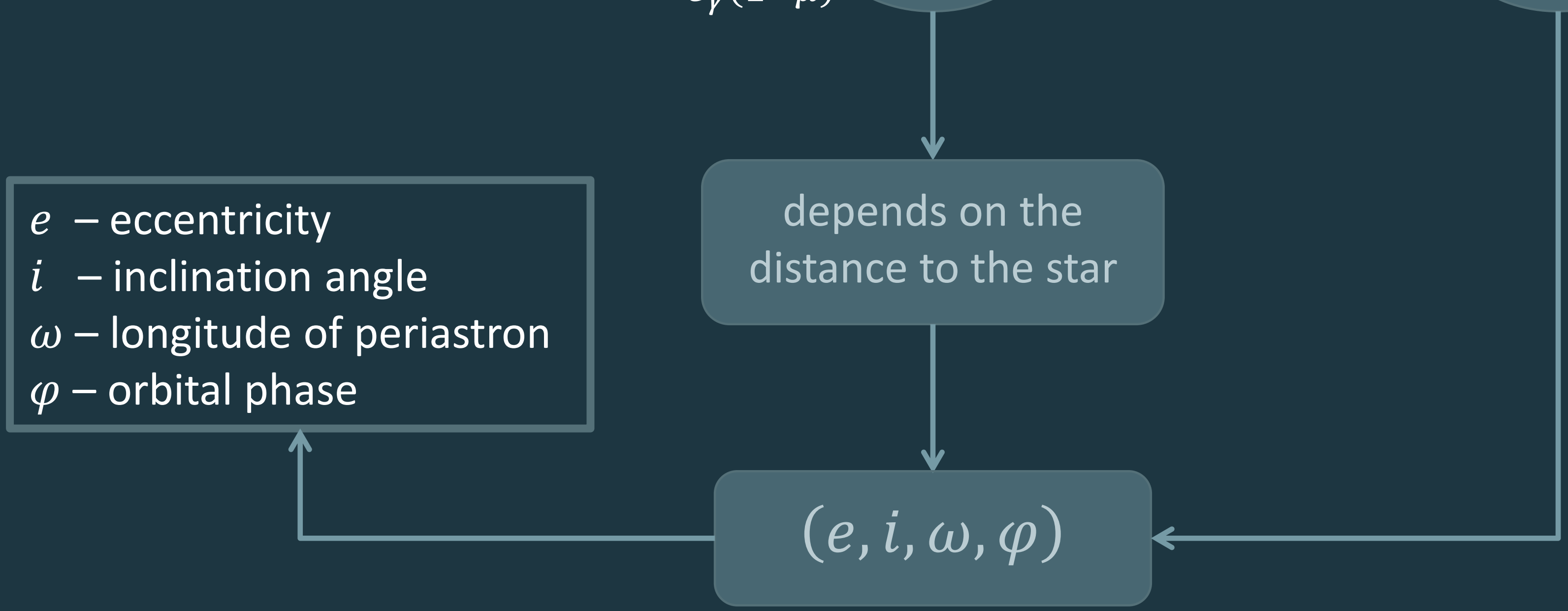
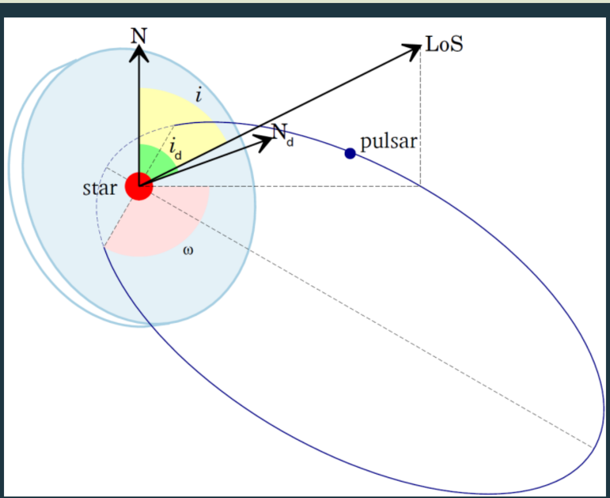
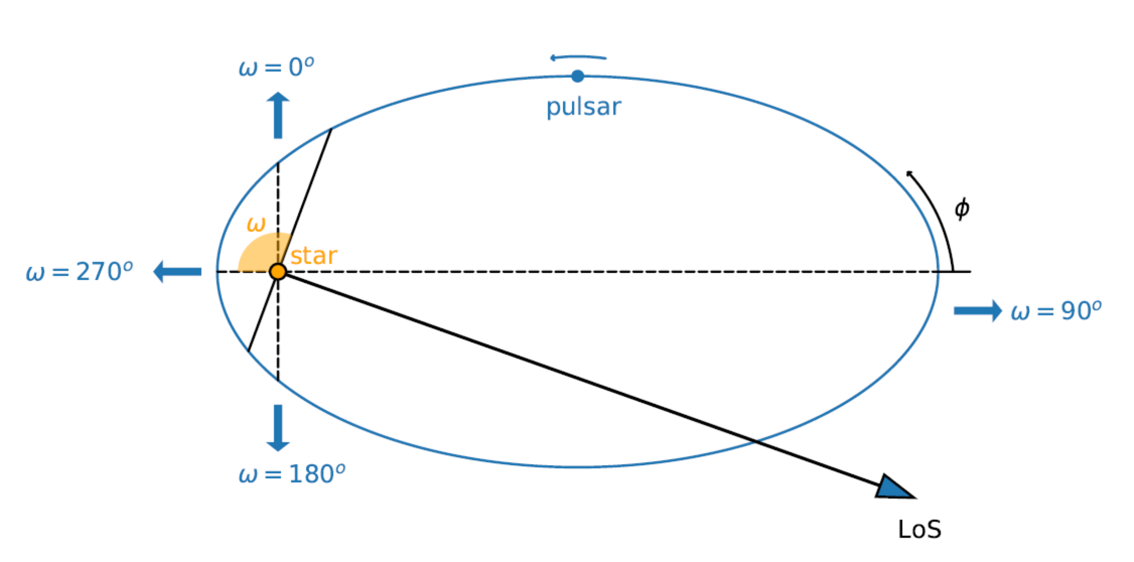


Geometry

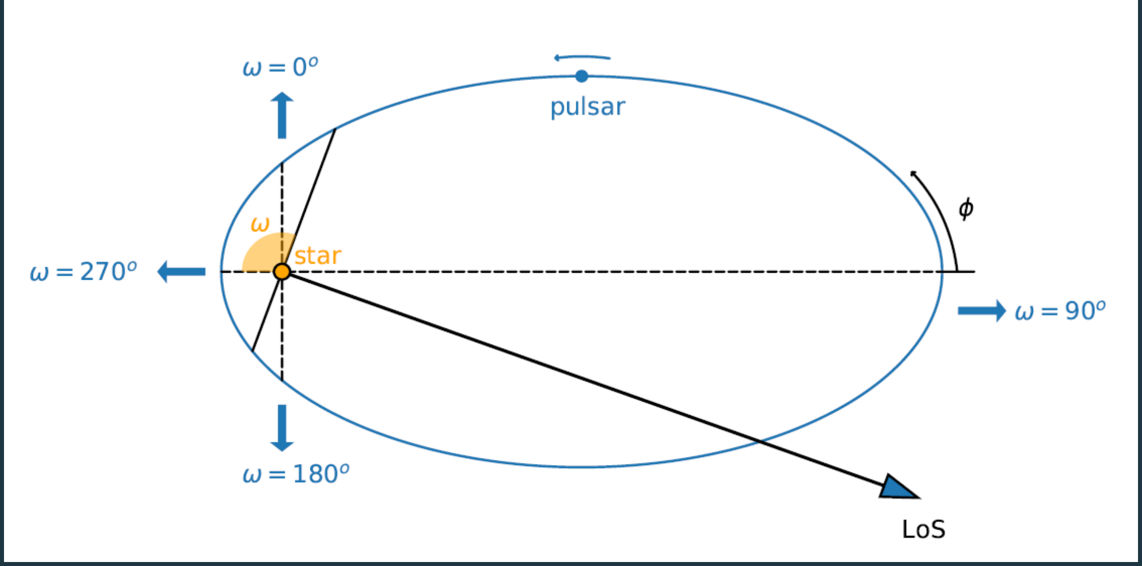
- Inclination – the angle between the normal to the orbital plane and direction towards the observer
- Longitude of periastron – the angle between the ascending node and periastron





Method

- Main assumption: the minimum in the TeV light curve is defined by the highest gamma-gamma absorption
- For a fixed eccentricity we vary inclination (0º, 90º) and longitude of periastron (0º, 360º) and for each combination of (*i, ω*) we calculate the orbital phase at which absorption for a 1 TeV photon would be the highest
- Gamma-gamma absorption is calculated taking into account only stellar photons (without circumstellar disk) and assuming that gamma-ray emission is produced at the pulsar position



PSR B1259-63

Orbit:

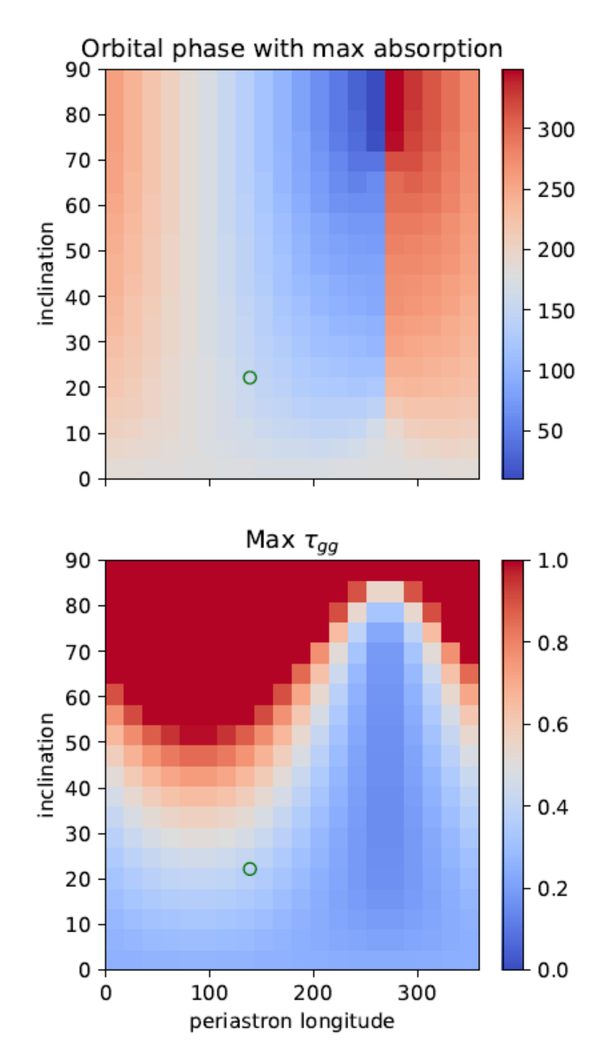
- P_{orb} = 3.4 years
- Eccentricity = 0.87
- Inclination = 22.2 deg
- Longitude of periastron = 138.7 deg

Pulsar:

- P = 48 ms
- $L_{SD} = 8 \times 10^{35}$ erg/s
- $t_c = 3.3 \times 10^5$ years

Star:

- Be star
- $L_{star} = 2.3 \times 10^{38}$ erg/s
- T = 27500 – 30000 K
- $M = 31\ M_{sun}$
- $R = 8.1 – 9.7\ R_{sun}$
- D = 2.3 kpc



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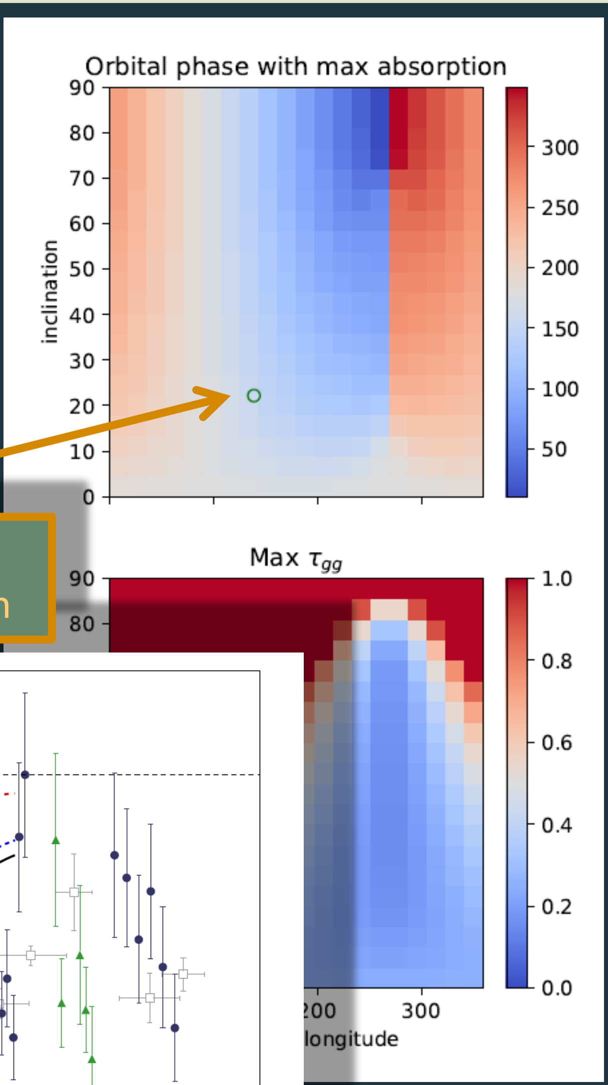
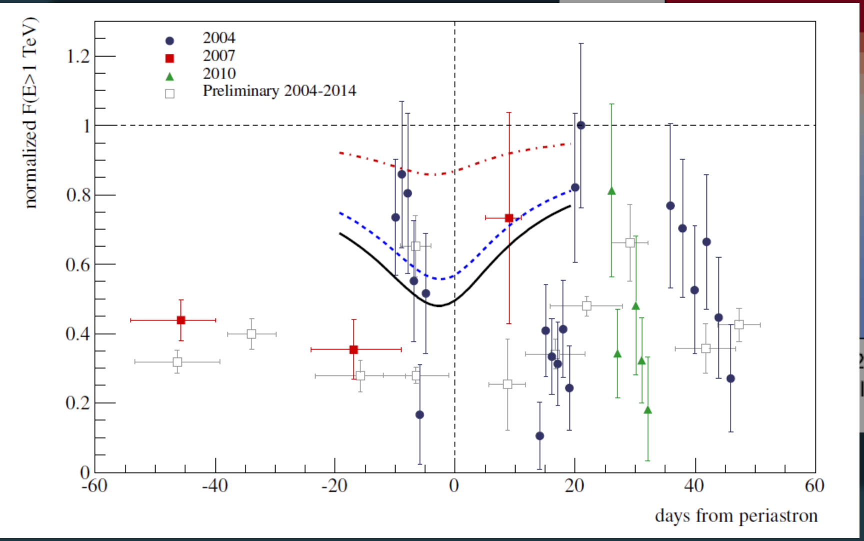
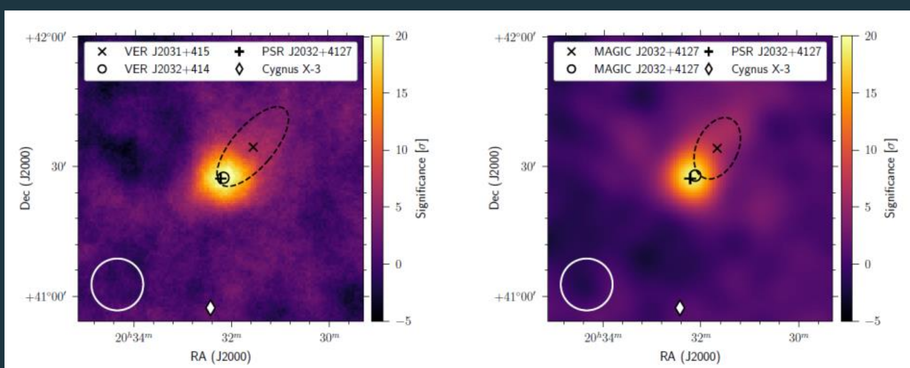


Orbital phase: 154 deg
Time: 2 days before periastron



PSR J2032+4127/ MT91 213

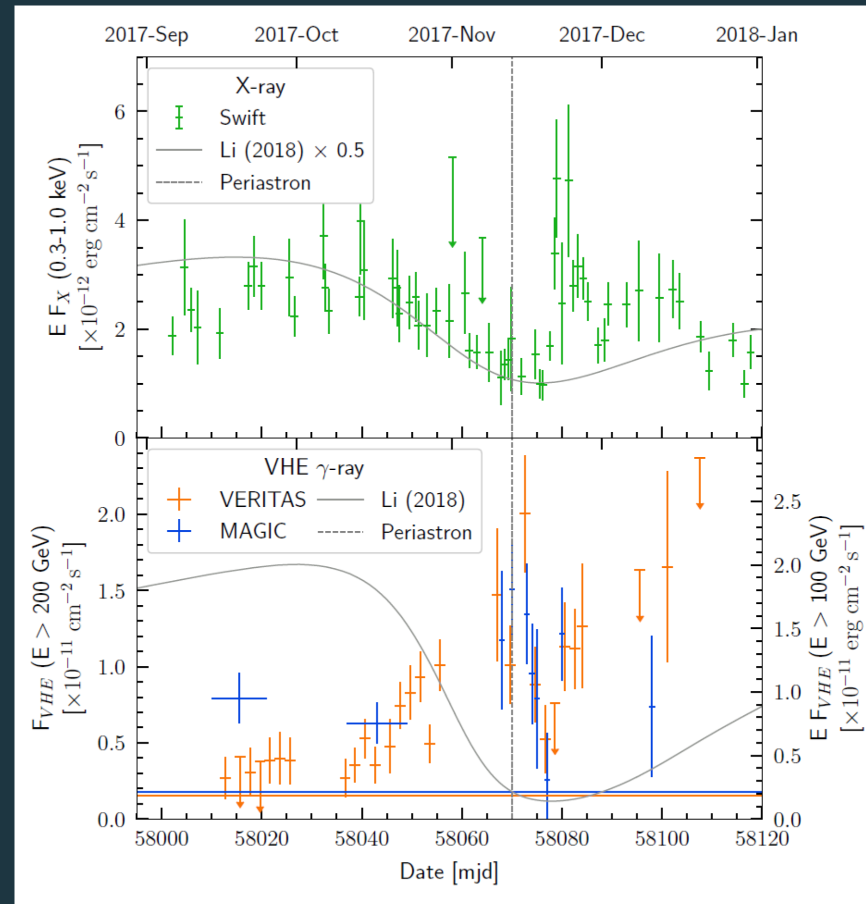
- New member of the class
- Detected in 2017
- Coincident with TeV J2032+413
- Orbital period of 45-50 years
- X-ray dip is not coincident with the gamma-ray dip
- TeV light curve has its minimum about 10-20 days after periastron



(c) VERITAS Fall 2017 sky map

(d) MAGIC Fall 2017 sky map

GAI6e: Tyler Williamson



(b) Periastron

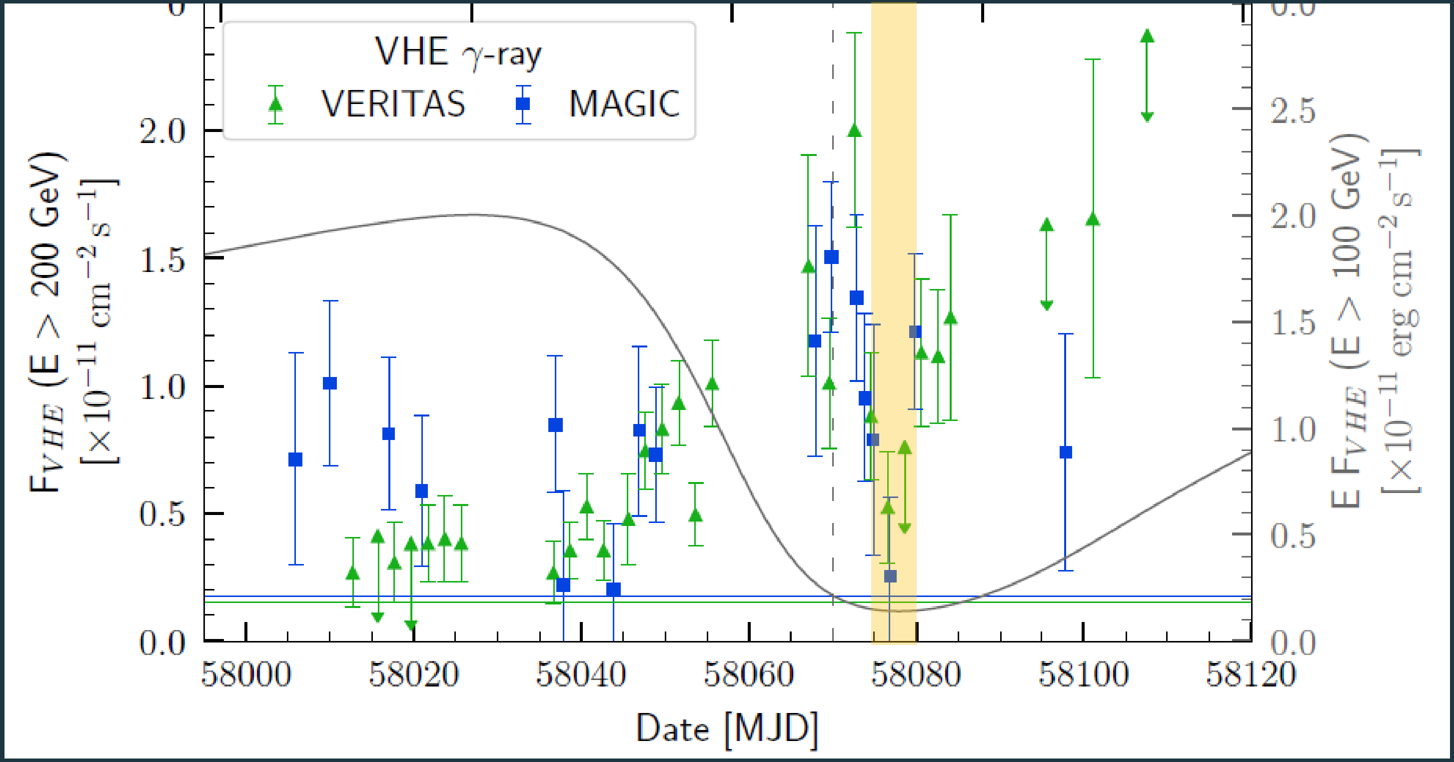
VERITAS & MAGIC, 2018

Orbital solutions

Parameter	Model 1	Model 2	Model 3
Right ascension, α (J2000.0)	$20^{h}32^{m}13\overset{s}{.}119(2)$	$20^{h}32^{m}13\overset{s}{.}119(2)$	$20^{h}32^{m}13\overset{s}{.}119(2)$
Declination, δ (J2000.0)	$41°27'24\overset{''}{.}38(2)$	$41°27'24\overset{''}{.}35(2)$	$41°27'24\overset{''}{.}34(2)$
Epoch of frequency, t_0 (MJD)	55700.0	55700.0	55700.0
Frequency, ν_0 (Hz)	6.980 979(5)	6.980 975(6)	6.980 973(7)
Frequency time derivative, $\dot{\nu}_0$ ($10^{-12}\mathrm{s}^{-2}$)	−0.5396(5)	−0.5538(4)	−0.5617(5)
Orbital period, P_b (d)	16 000	17 000	17 670
Epoch of periastron, T_0 (MJD)	58053(1)	58069(1)	58068(2)
Projected semimajor axis, x (light-second)	7138(48)	9022(216)	16335(3737)
Eccentricity, ϵ	0.936(1)	0.961(2)	0.989(5)
Longitude of periastron, ω (deg)	52(1)	40(1)	21(5)
Mass function, f_m ($M_\odot$)	1.5	2.7	15.0
Glitch epoch, T_g (MJD)	55 810.77	55 810.77	55 810.77
Frequency, $\Delta\nu_g$ (10^{-6} Hz)	1.9064(1)	1.9073(1)	1.9076(1)
Frequency time derivative, $\Delta\dot{\nu}_g$ ($10^{-15}\mathrm{s}^{-2}$)	−0.501(8)	−0.545(7)	−0.564(6)
DM (pc cm^{-3})	114.68(3)	114.67(2)	114.66(2)
DM time derivative, DM1 (pc $\mathrm{cm}^{-3}\mathrm{yr}^{-1}$)	−0.02(1)	−0.01(1)	−0.01(1)
rms timing residual, σ_t (ms)	0.53	0.44	0.42

Ho et al., 2017

PSR J2032+4127: TeV light curve

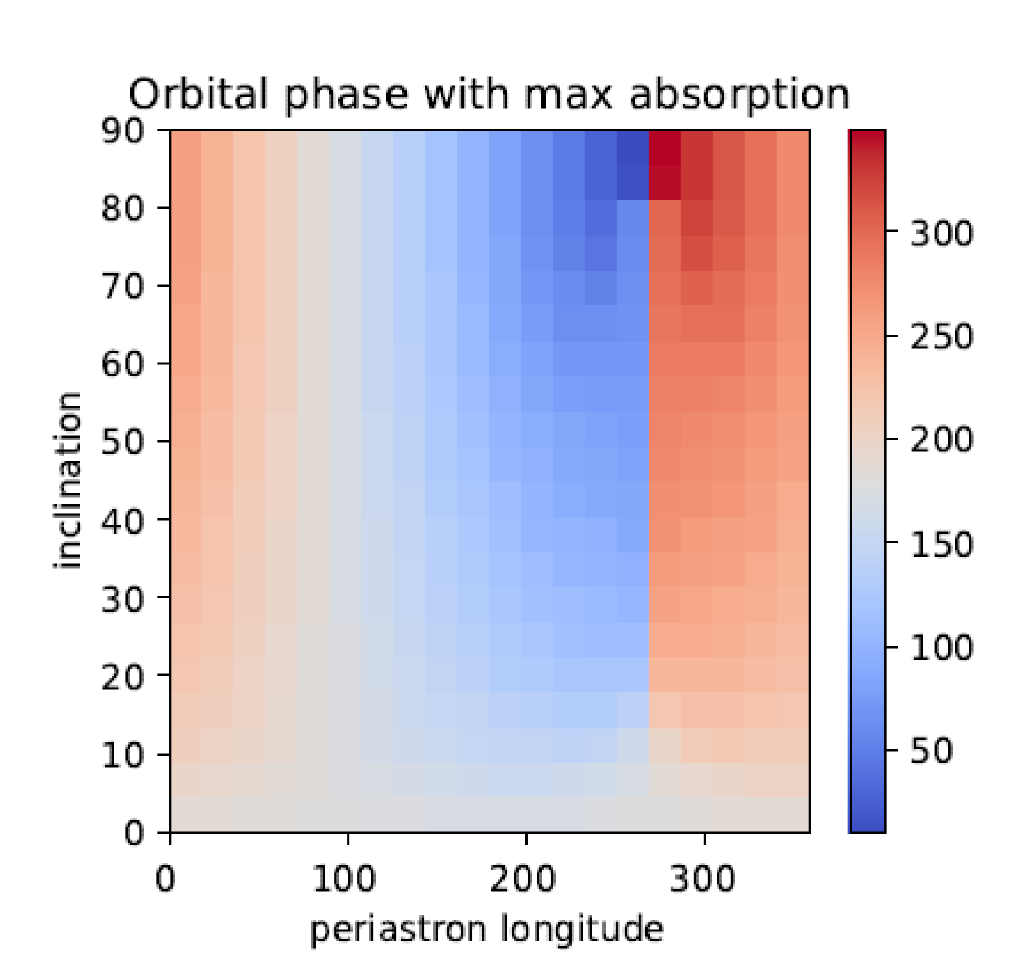


VERITAS & MAGIC, 2018

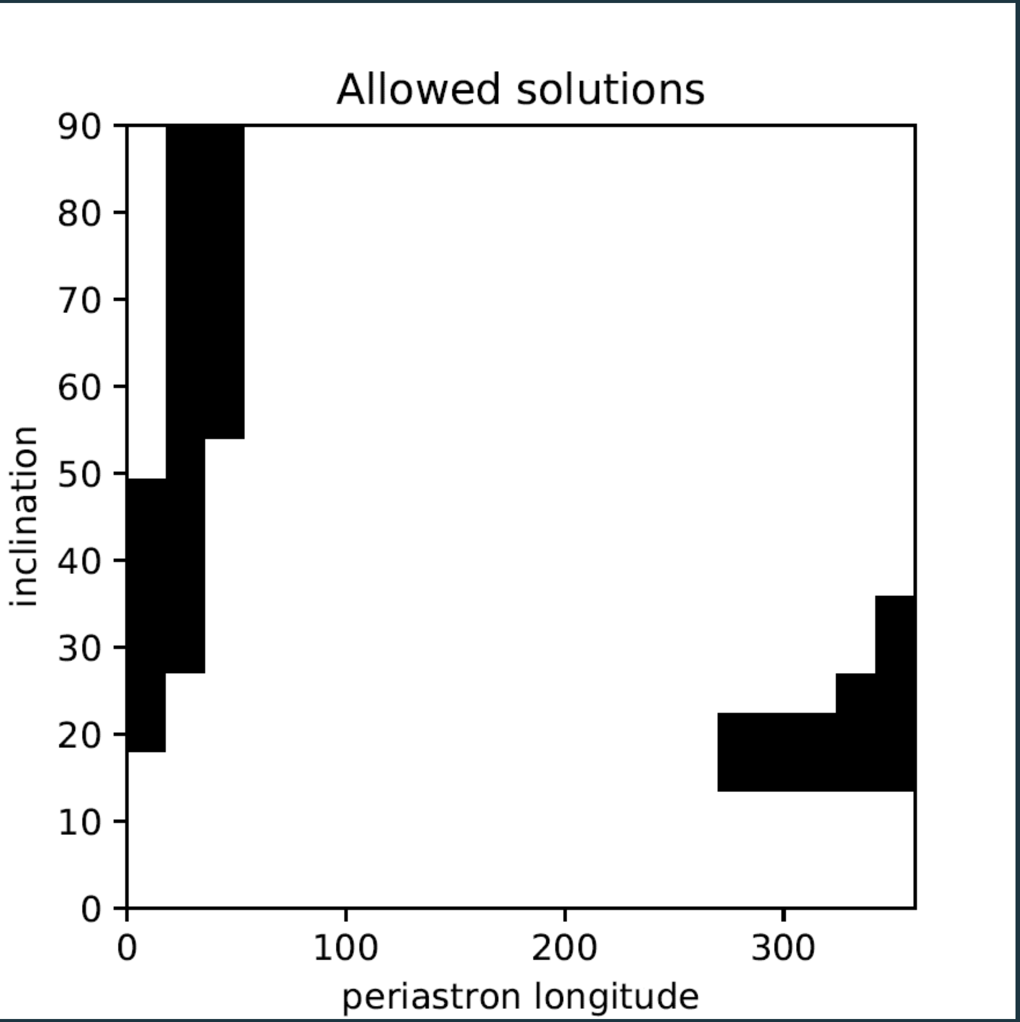
Minimum occurs 10-20 days after periastron

Corresponds to the orbital phase of 216-242 deg for P = 17000 days

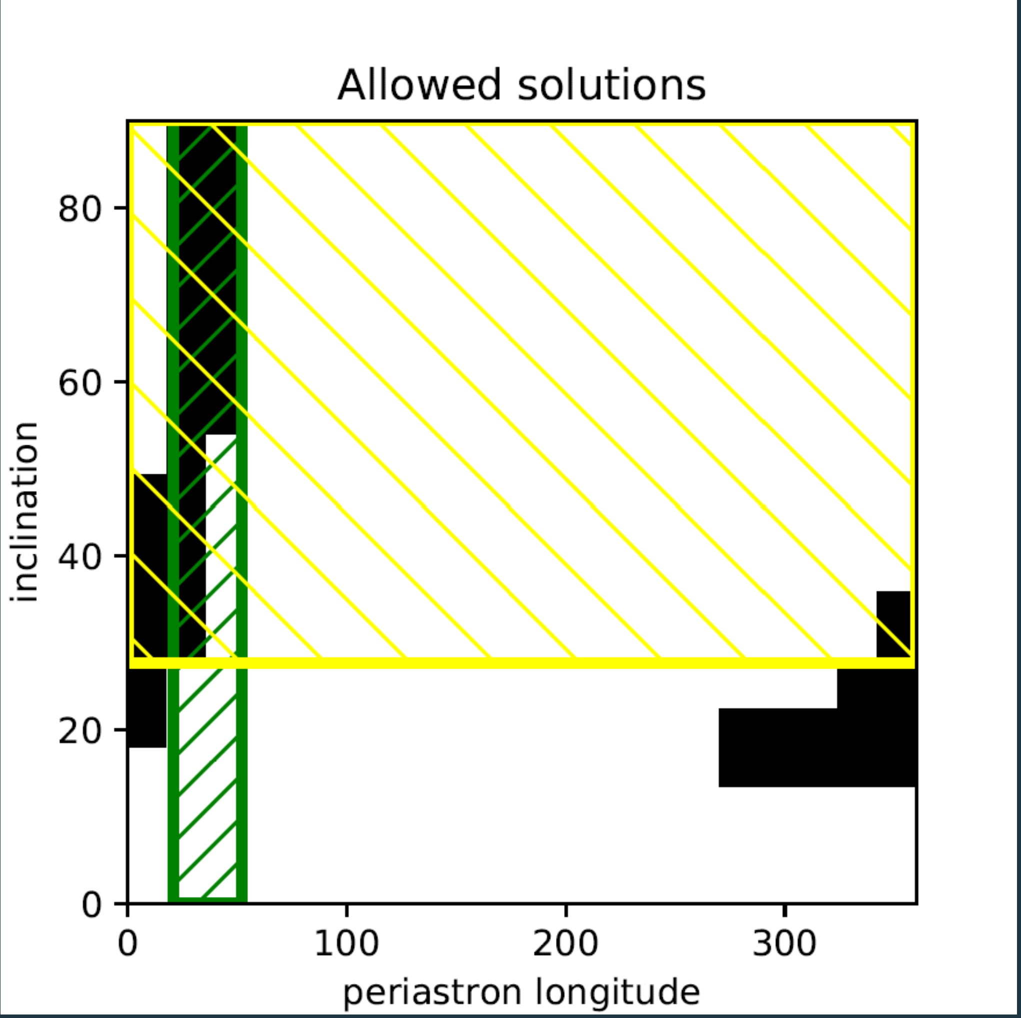
PSR J2032+4127: e = 0.961 (0.936-0.989)



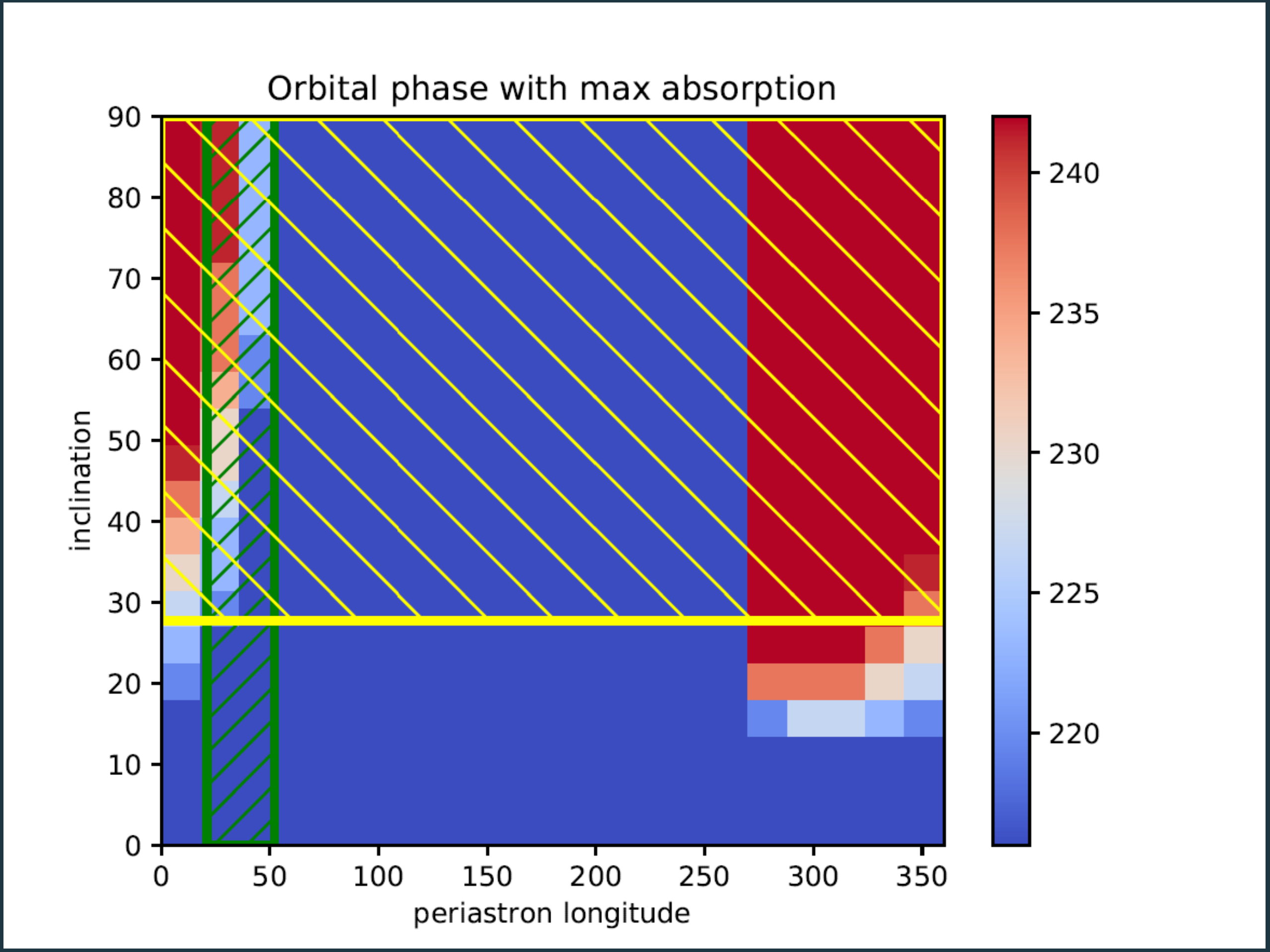
PSR J2032+4127: allowed solutions



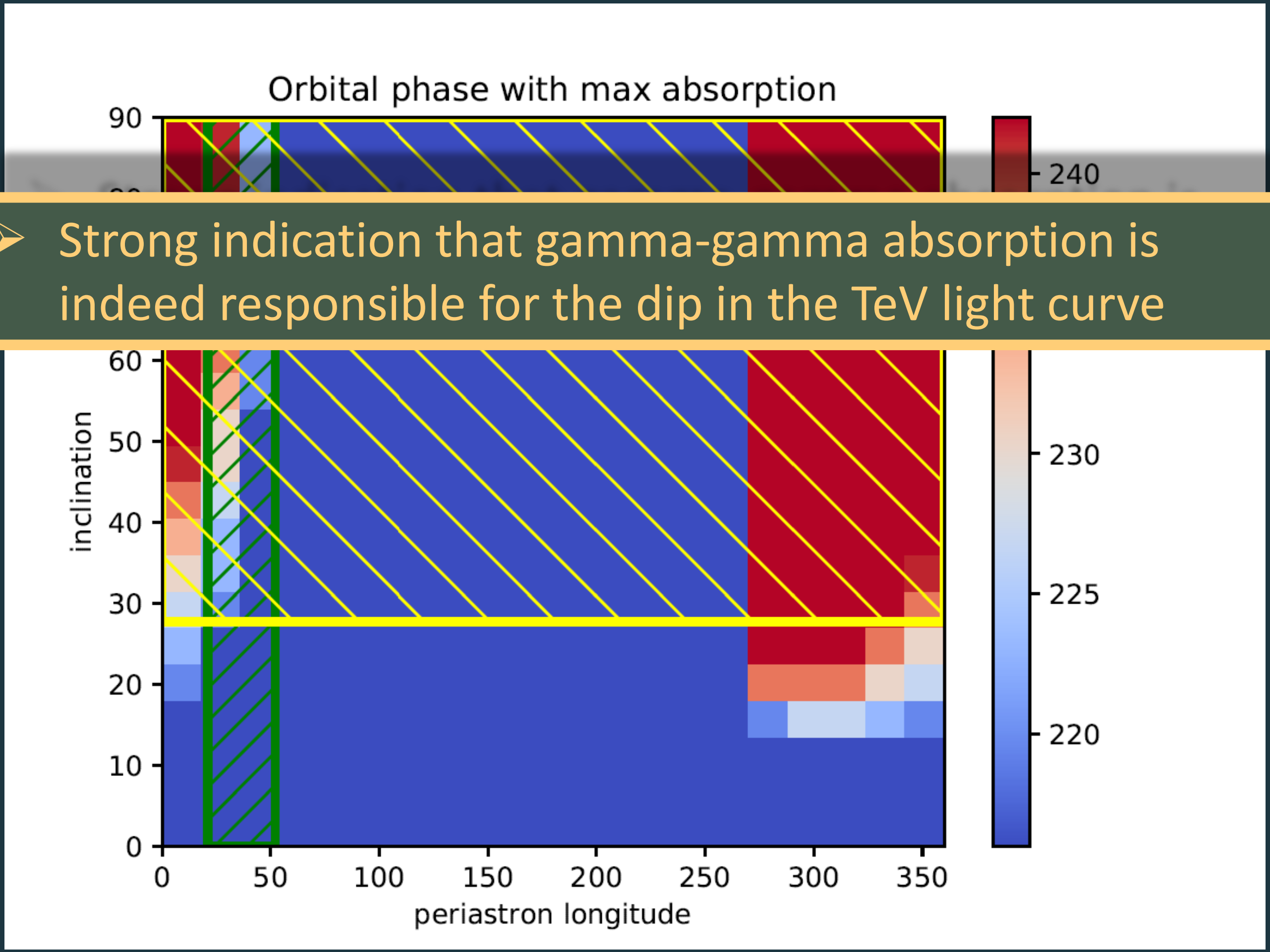
PSR J2032+4127: constraints from timing solutions



PSR J2032+4127: allowed solutions

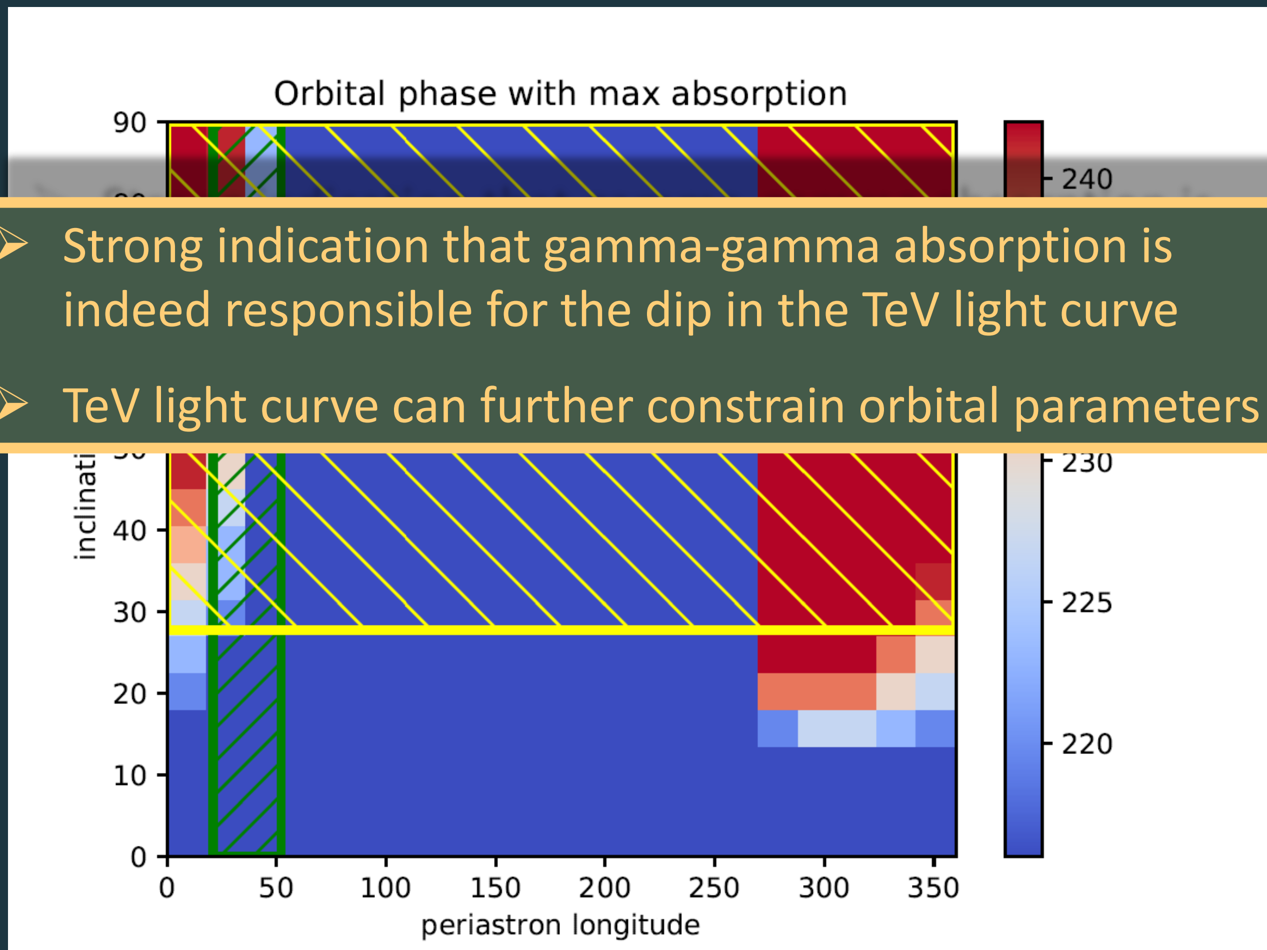


PSR J2032+4127: allowed solutions



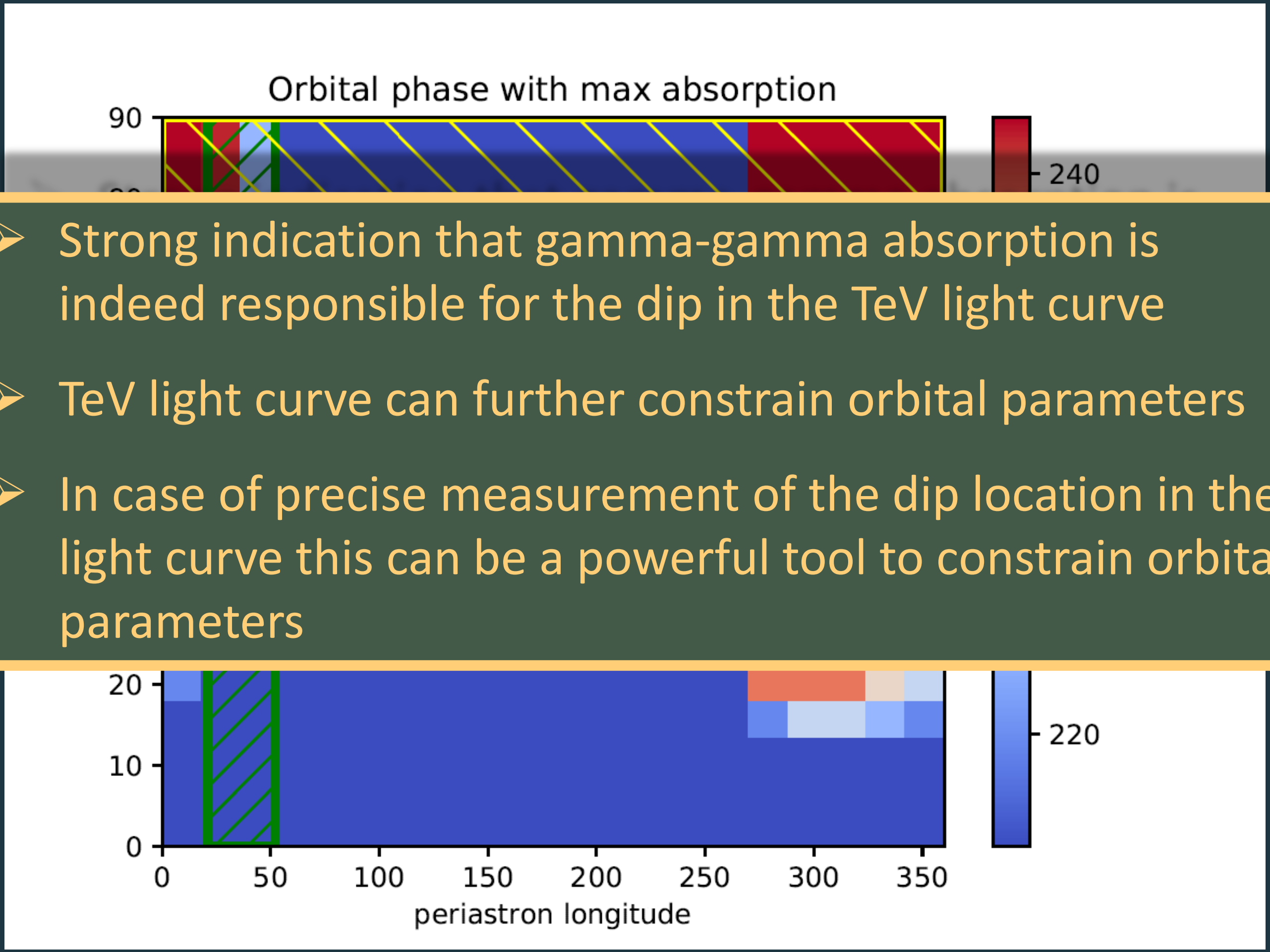
- Strong indication that gamma-gamma absorption is indeed responsible for the dip in the TeV light curve

PSR J2032+4127: allowed solutions



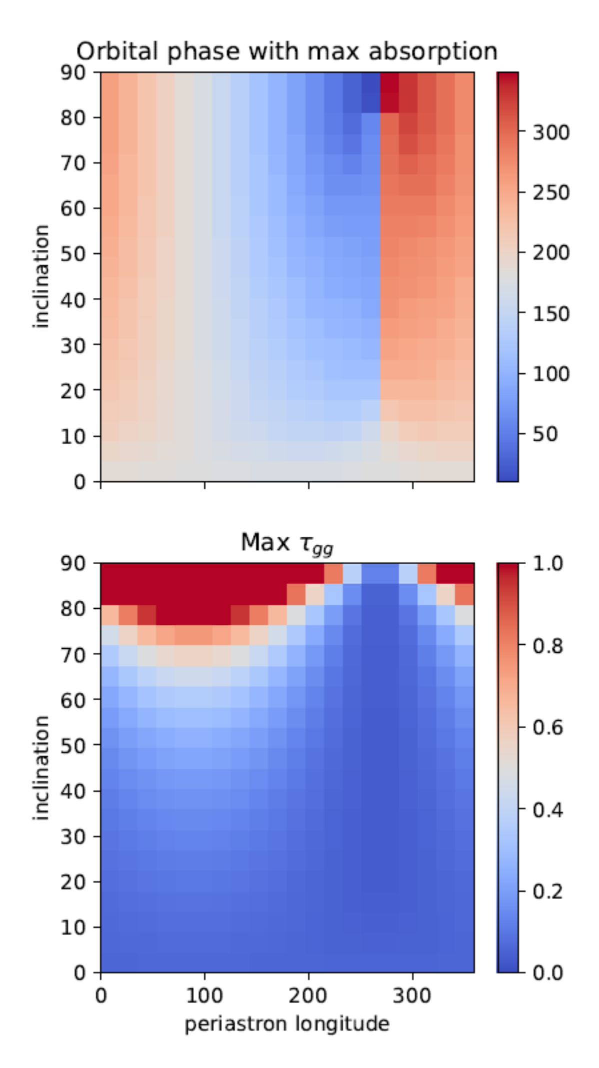
- Strong indication that gamma-gamma absorption is indeed responsible for the dip in the TeV light curve
- TeV light curve can further constrain orbital parameters

PSR J2032+4127: allowed solutions



- Strong indication that gamma-gamma absorption is indeed responsible for the dip in the TeV light curve
- TeV light curve can further constrain orbital parameters
- In case of precise measurement of the dip location in the light curve this can be a powerful tool to constrain orbital parameters

Further constraints on the location of the emitting region



- Level of the dip tells us about the level of absorption, which could farther constrain orbital parameters
- We don't know exactly where gamma-ray emission is produced
- If it is produced closer to the star absorption will be higher

Summary

- If the minimum in the TeV light curves of gamma-ray binaries is associated with the highest gamma-gamma absorption (which seems to be the case), this could constrain orbital parameters of these systems
- Further, the level of required absorption could constrain the location of the emitting region, which might give us insights on where particles are accelerated and where the wind termination shock is formed