TeV and **X-ray** emission from the 50-year period binary **PSR J2032+4127/MT91 213 during periastron passage**

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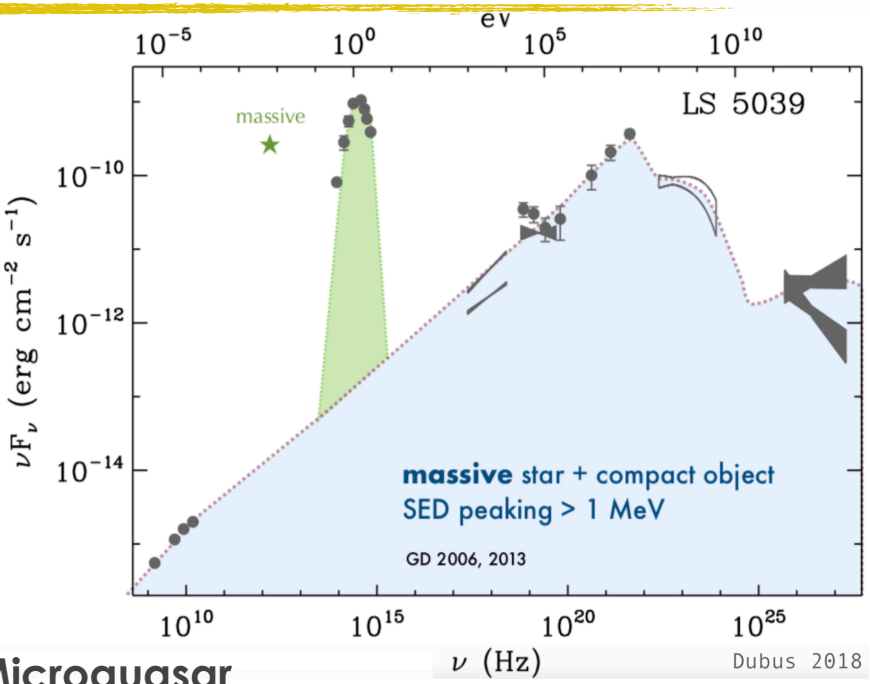
O. Blanch & J. Herrera for **the MAGIC collaboration**

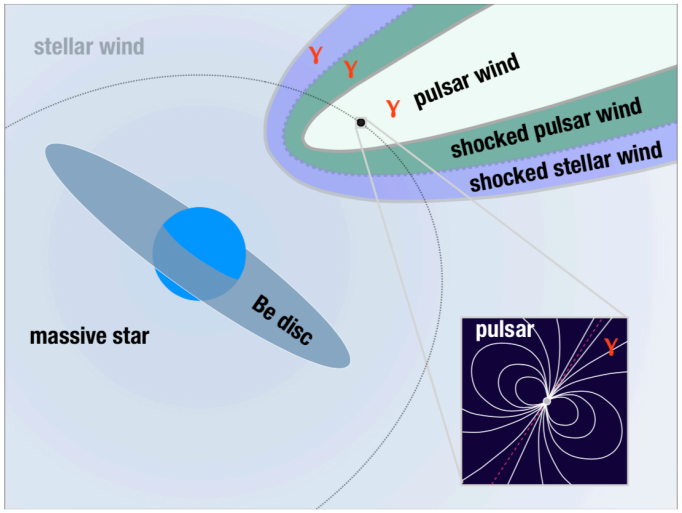
R. Bird & T. Williamson for **the VERITAS collaboration**

Gamma-ray binaries: definition

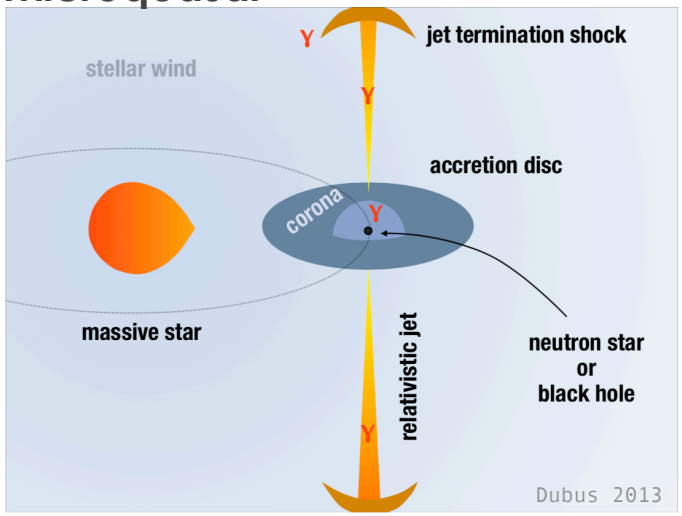
- **Bulk of the non-thermal** emission lies in the **gamma-ray domain** (E>1MeV)
- Massive star O / B(e) + compact object (neutron star/black hole):
  - First gamma binary discovered hosts a pulsar: PSR B1259-63 (Ahahorian et al., 2005)
  - Several microquasars emit HE. Only one confirmed at TeV: SS433, emission from interaction regions jet/nebula (Abeysekara et al.,2018)
  - Nature of compact object? Emission mechanisms?



Pulsar wind



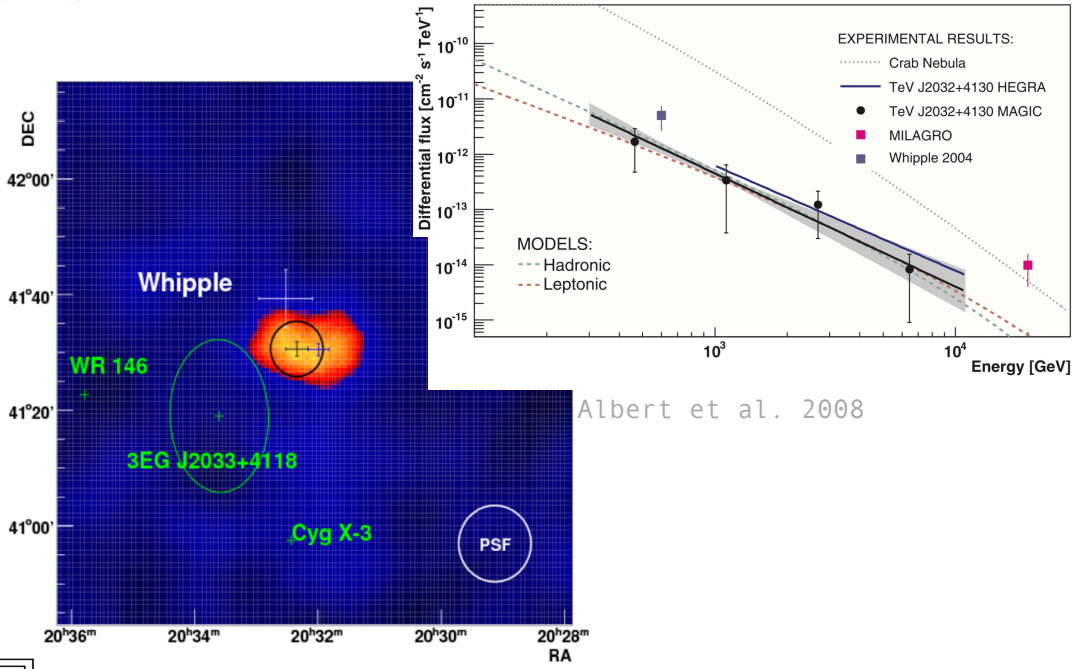
Microquasar



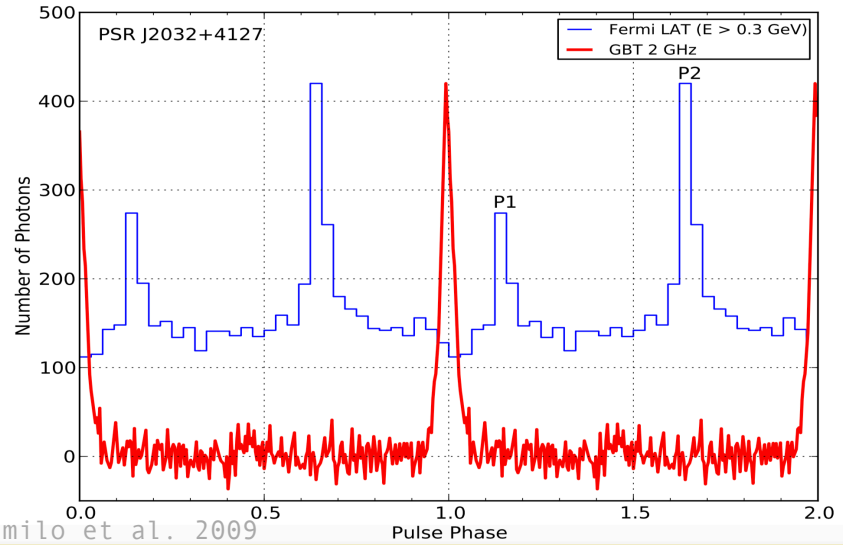
TeV 2032+4130 & PSR J2032+4127

TeV 2032+4130 :

- **First unidentified gamma-ray source** discovered by HEGRA (Aharonian et al. 2002)
- Confirmed by Whipple (Konopelko et al. 2007), MAGIC (Albert et al. 2008) & VERITAS (Aliu et al. 2014)
- **Extended** source of ~6′ width and **hard power-law spectrum** (Γ~2.0±0.3) (Aharonian et al. 2005; Albert et al. 2008a)
- Emission at E> 56 TeV reported by HAWC (Abeysekara et al. 2017), lying in Cygnus Cocoon
- Radio source (Paredes et al. 2007, Martí et al. 2007)



Albert et al. 2008



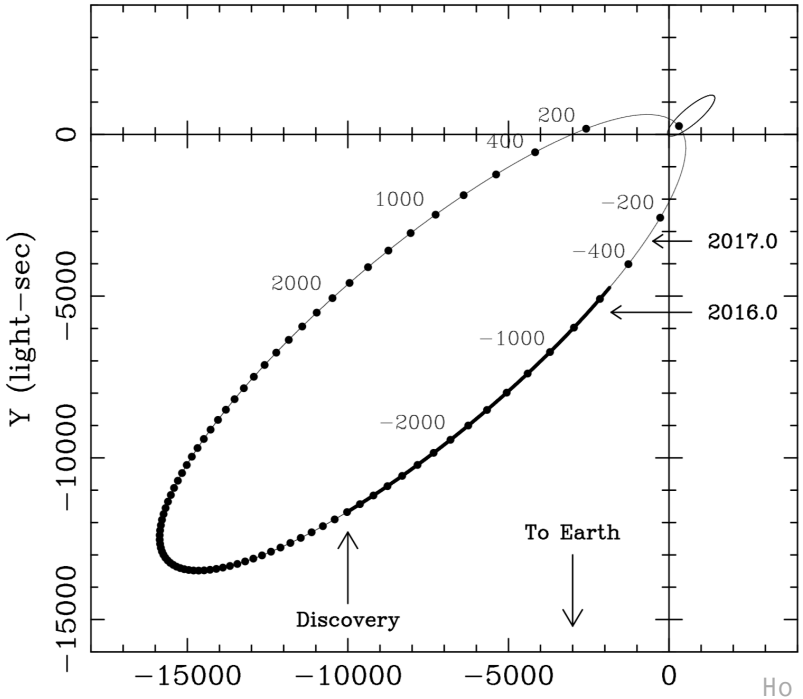
Camilo et al. 2009

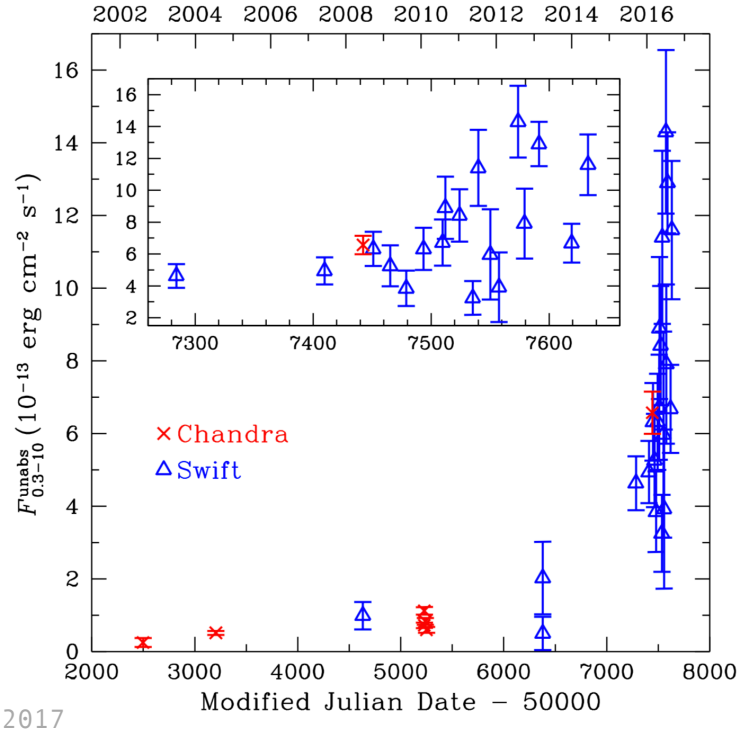
Pulsar PSR J2032+4127

- Discovered in a **blind search by *Fermi*-LAT** (Abdo et al. 2009)
- Young, high spin-down power, P:143 ms,
- Close: 1.7 kpc, inside Cygnus OB2
- Also **radio** pulsar (Camilo et al. 2009)

Identification as a binary system

- **TeV 2032+4130** most likely a **wind nebula driven by the pulsar** PSR J2032+4127 (Bednarek 2003, Camilo et al. 2009)
  - Paredes et al. 2007-> coincident with star 213 in Massey & Thompson (1991) "MT91" survey of massive stars in Cyg OB2 & *Chandra* X-ray source
- **Binary nature**:
  - **PSR 2032+4127 associated to** the massive (15 $M_\odot$) **Be star MT91 213** (Lyne et al. 2005) : PSR 2032+4127/MT91 213
  - **Extremely eccentric** binary (e~0.95)
  - Orbital period: **~50 years** (Ho et al. 2017) -> **periastron passage: November 2017**
  - **Dramatic increase (x10) of X-ray flux in 2016**… what about gamma rays?

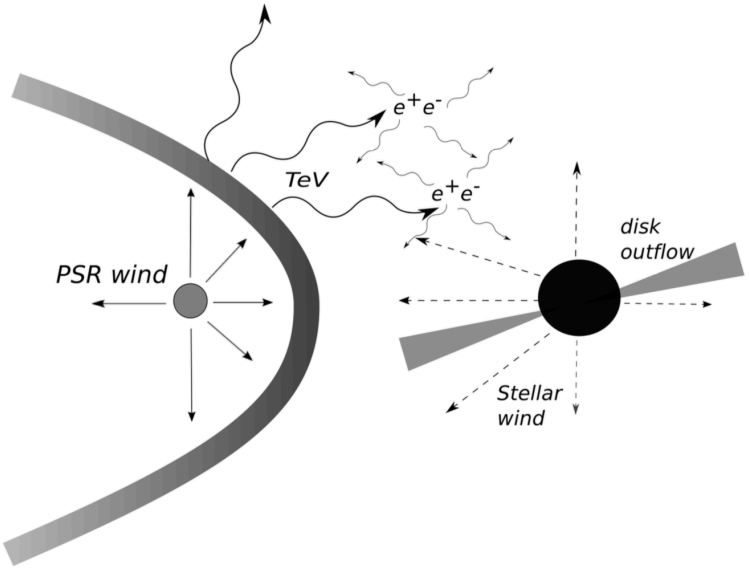


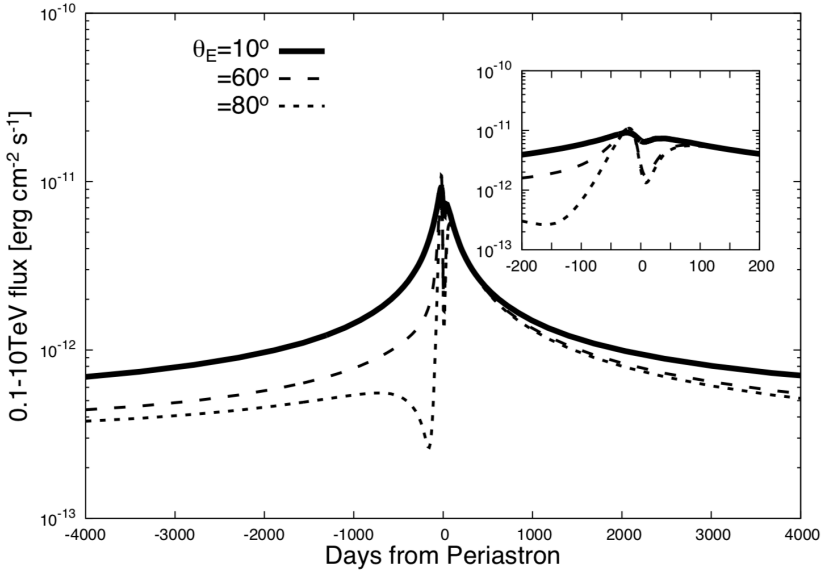


Ho et al. 2017

Gamma ray emission expected

- Similarities with PSR B1259-63
- Gamma rays expected during periastron passage, according to models (Takata et al. 2017)

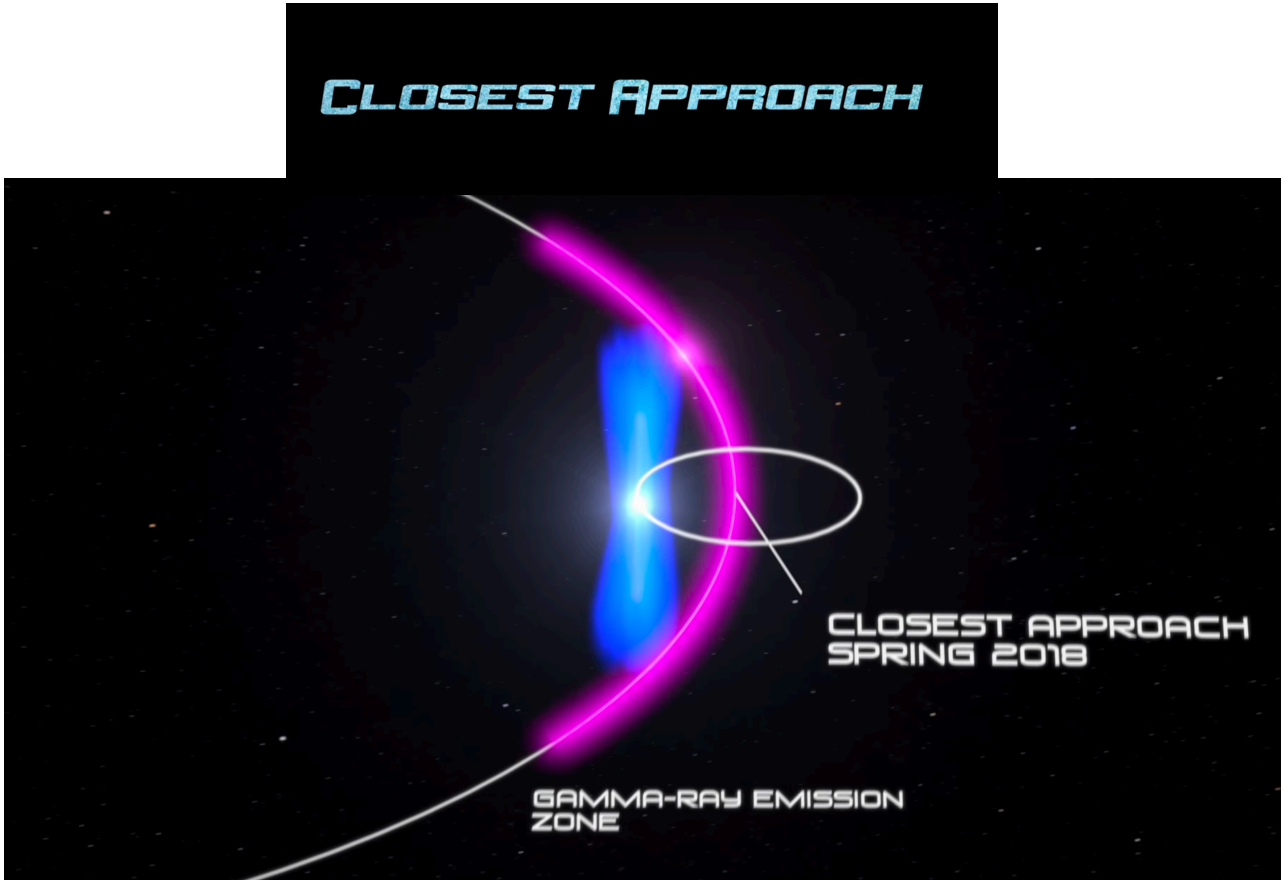




Takata et al. 2017

Great expectations

- Fermi knew how to attract attention to this once-in-a-lifetime event



Coordinated campaign at VHE

- Coordinated **observations between MAGIC and VERITAS** to cover periastron passage

- Two telescopes (Φ=17 m) @Canary Islands
- Energy range: ~30 GeV-100 TeV
- Integral sensitivity @E >290 GeV: ~0.67% of Crab Nebula in 50 h (Alekić et al. 2016)
- Energy resolution: 15-23 % @E>220GeV
- Angular resolution: ~0.07° @250 GeV

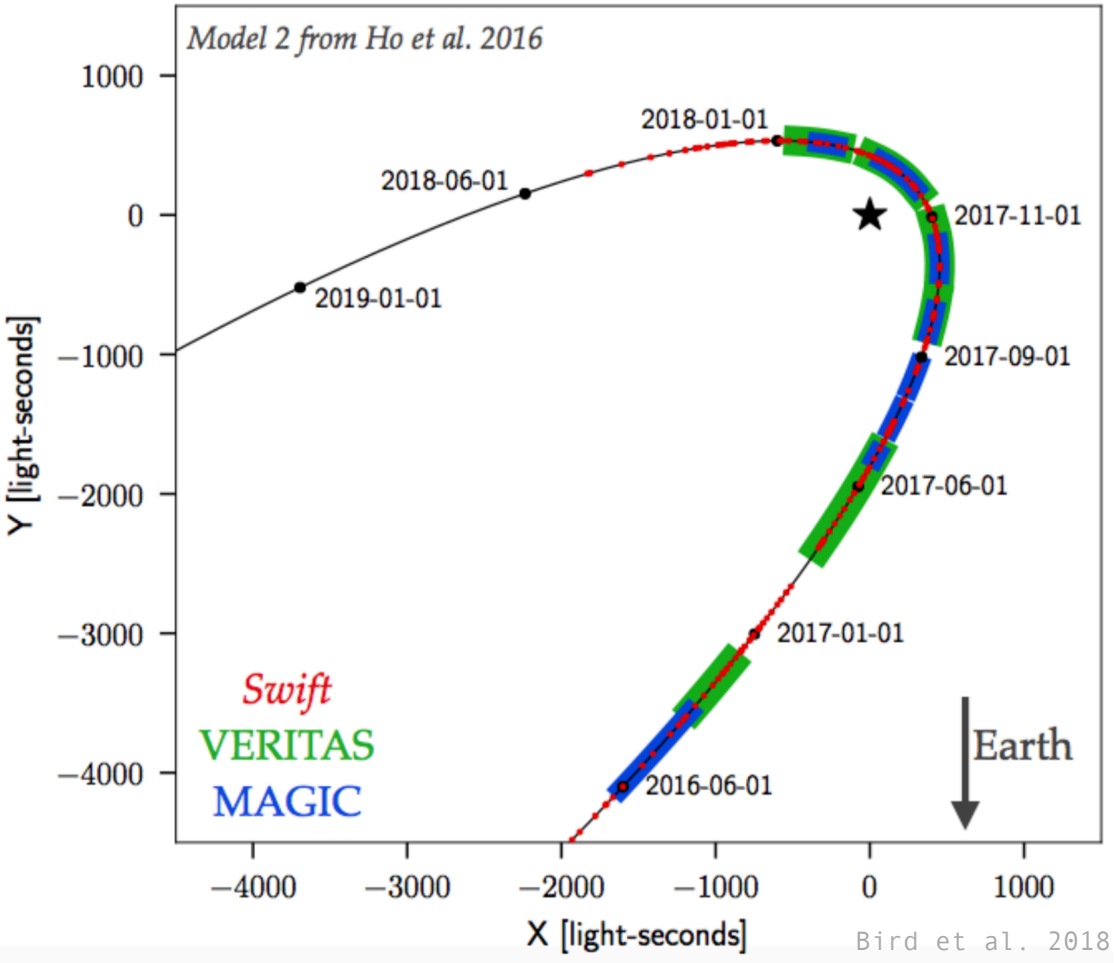
https://magic.mpp.mpg.de/

- Four telescopes (Φ=12 m) @Arizona
- Energy range: ~85 GeV-30 TeV
- Integral sensitivity: 1% of Crab Nebula flux in 25 hours
- Energy resolution: 17 % @ 1TeV
- Angular resolution: ~0.13° @200 GeV

https://veritas.sao.arizona.edu/

VHE observations

- Expected VHE emission during periastron passage (similarly to PSR B1259-63)
- **Since 2016**, **coordinated** observations between **MAGIC** and **VERITAS to cover periastron passage** + **Swift XRT**
  - **MAGIC**: **88 h**
  - **VERITAS**: **130 h**
  - **Swift XRT**: **135 h**
- **Expected periastron passage: November 13, 2017** (MJD 58070)



Increase of flux!

- September 2017 (ATel #10810): TeV gamma-ray flux increased a factor 2 wrt June-August 2017 average

TeV gamma-ray emission from PSR J2032+4127/ MT91 213

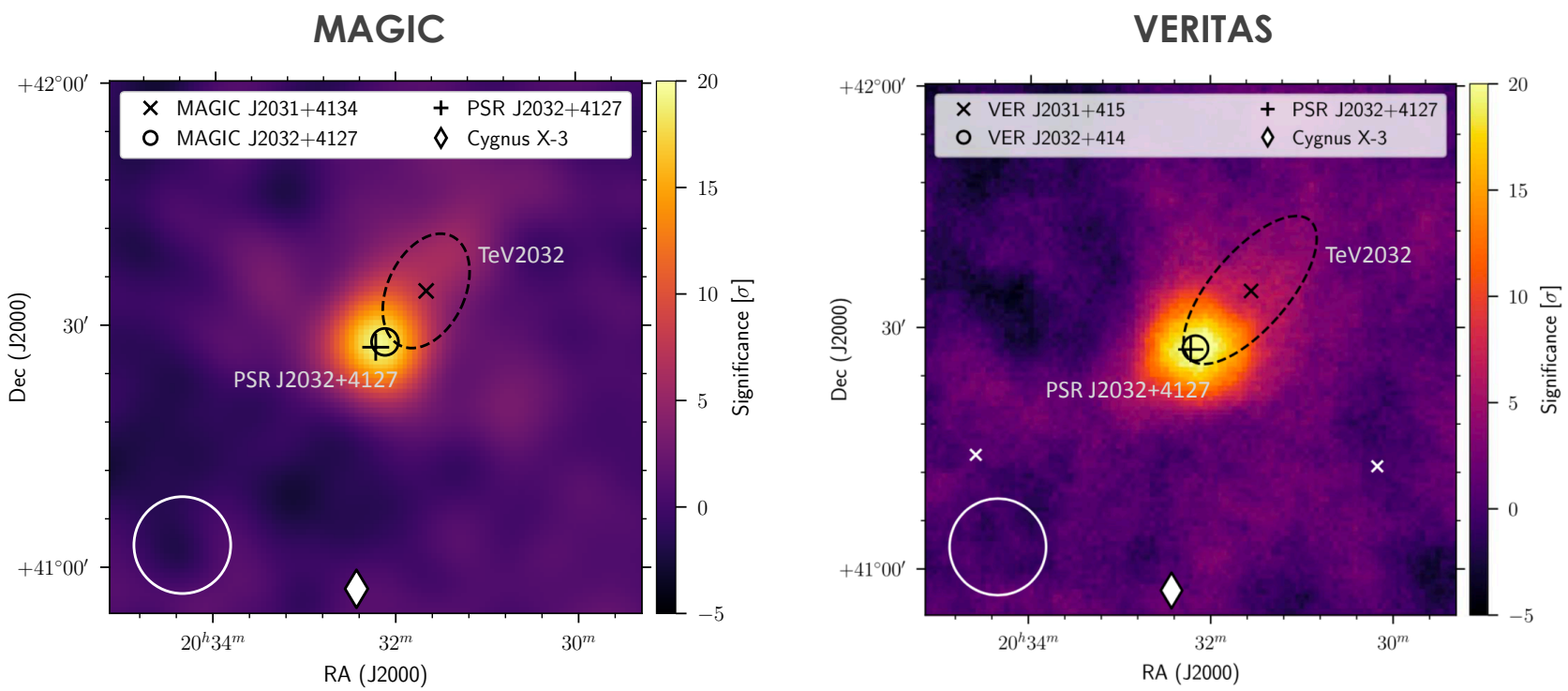
ATel #10810; ***The VERITAS and MAGIC Collaborations***
*on **3 Oct 2017; 17:52 UT***
Credential Certification: Jamie Holder (jholder@physics.udel.edu)

- **November 2017 (ATel #10971)** , periastron passage (MJD 58069.8): flux increased almost a factor 10 wrt the average flux in June-August in **only 1.9 h**

TeV gamma-ray emission from PSR J2032+4127/ MT91 213 at periastron

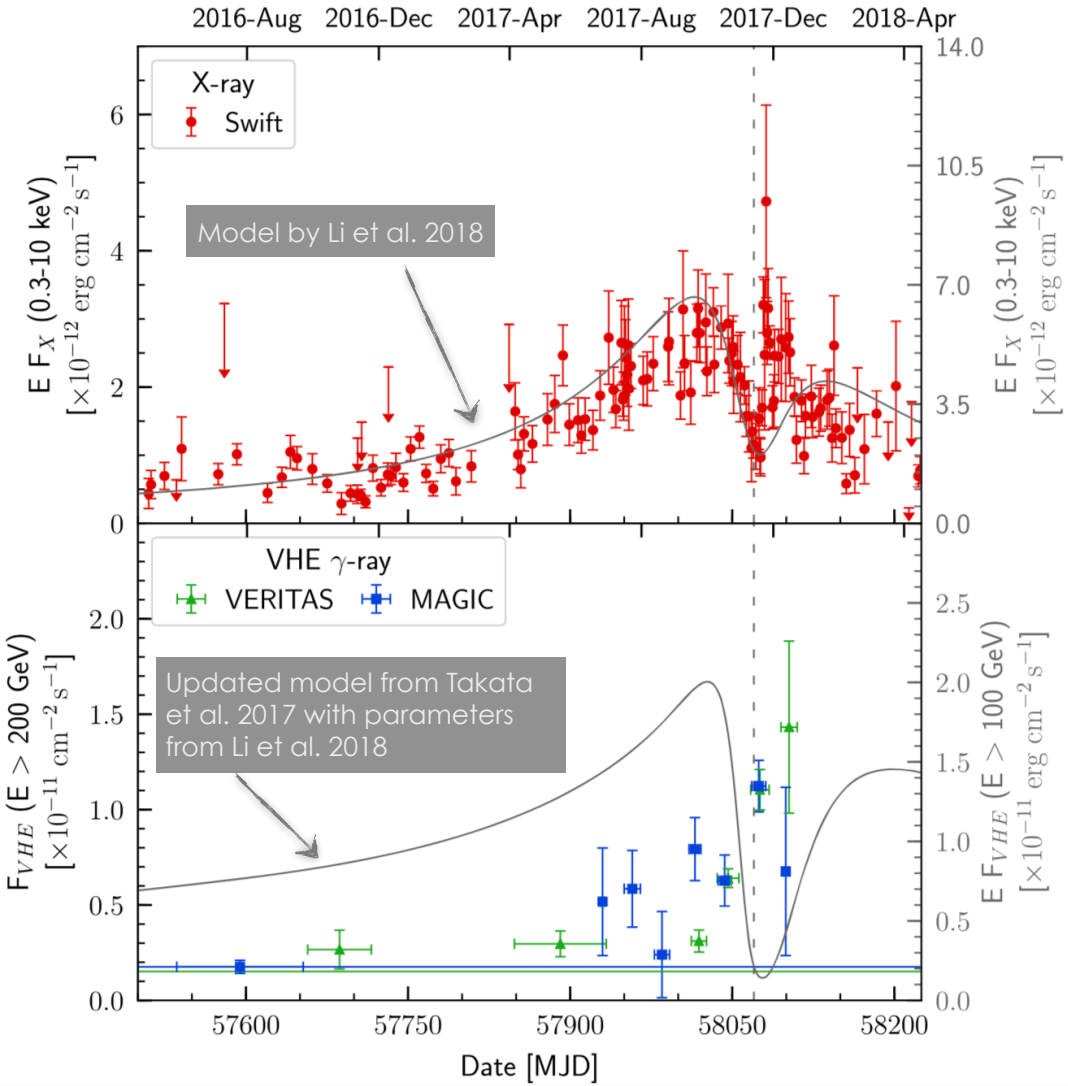
ATel #10971; ***Razmik Mirzoyan for the MAGIC Collaboration and Reshmi Mukherjee for the VERITAS Collaboration***
*on **14 Nov 2017; 20:01 UT***
Credential Certification: Razmik Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de)

VHE detection



- **Significant detection (>20σ)** in both experiments
- **Point-like & variable emission over the PWN baseline** (TeV 2032+4130)
- Offset from the centroid of the extended emission by approximately 10′
- The extended source (TeV 2032+4130) parameters are
  - MAGIC, semimajor axis: 0°.13±0°.01, semiminor axis: 0°.08±0°.01,angle: 34°±2° east of north.
  - VERITAS, semimajor axis: 0°.19±0°.02, semininor axis: 0°.08±0°.01, angle: 41°±4° east of north

Long-term lightcurve at TeV & X-rays



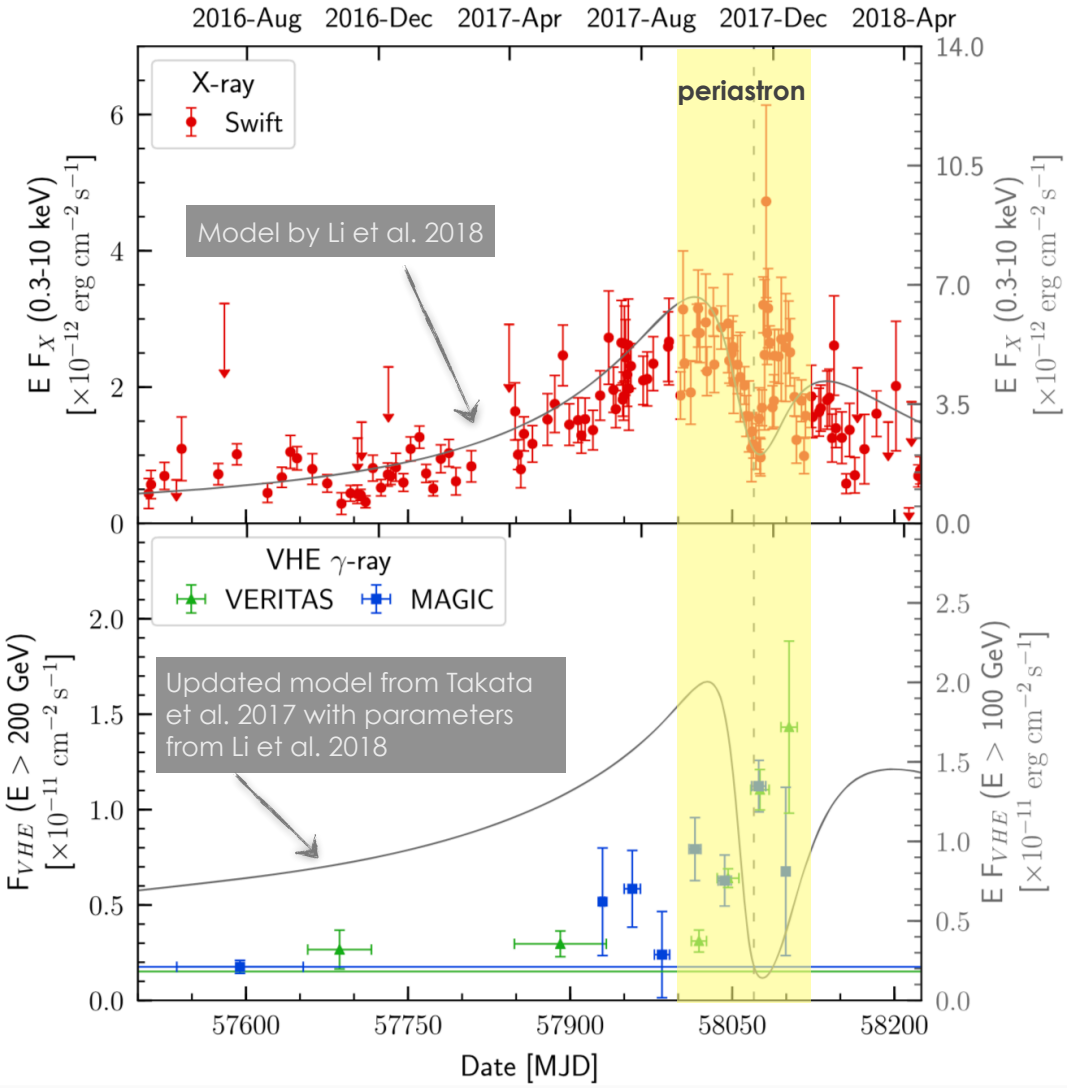
X-rays (0.3-10 keV):

- **Steady increase of flux prior to periastron**
- **Good agreement with models before periastron**
  - **increasing flux** due to radial dependence of the **pulsar wind magnetisation** (Takata et al 2017, Li et al 2018)
- Short timescale variability probably due to clumps in stellar wind (Li et al. 2017)

VHE (E>200 GeV)

- **Sharper flux increase** next to periastron (factor 10) than in X-rays
- **Poor agreement with theoretical model**

Long-term lightcurve at TeV & X-rays



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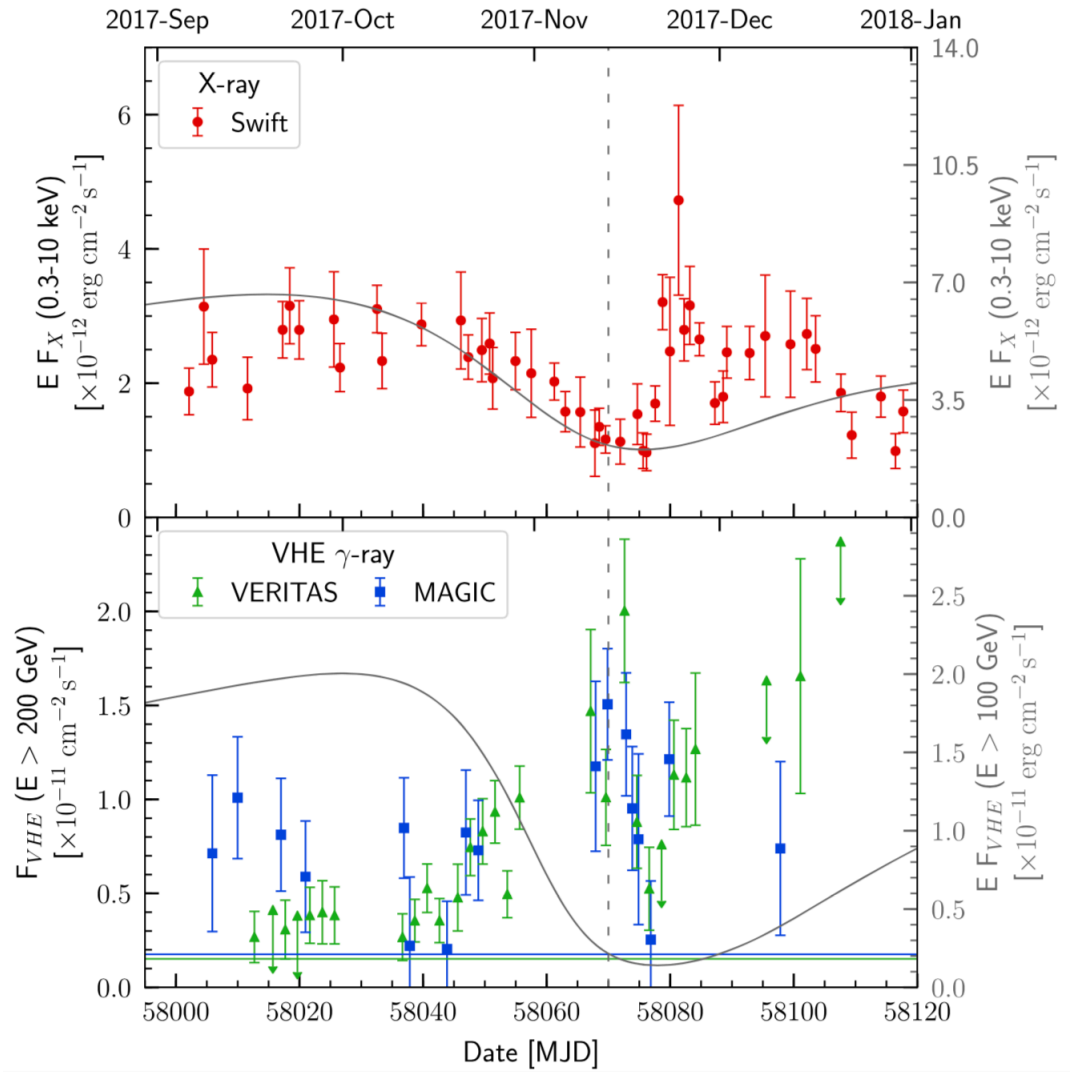
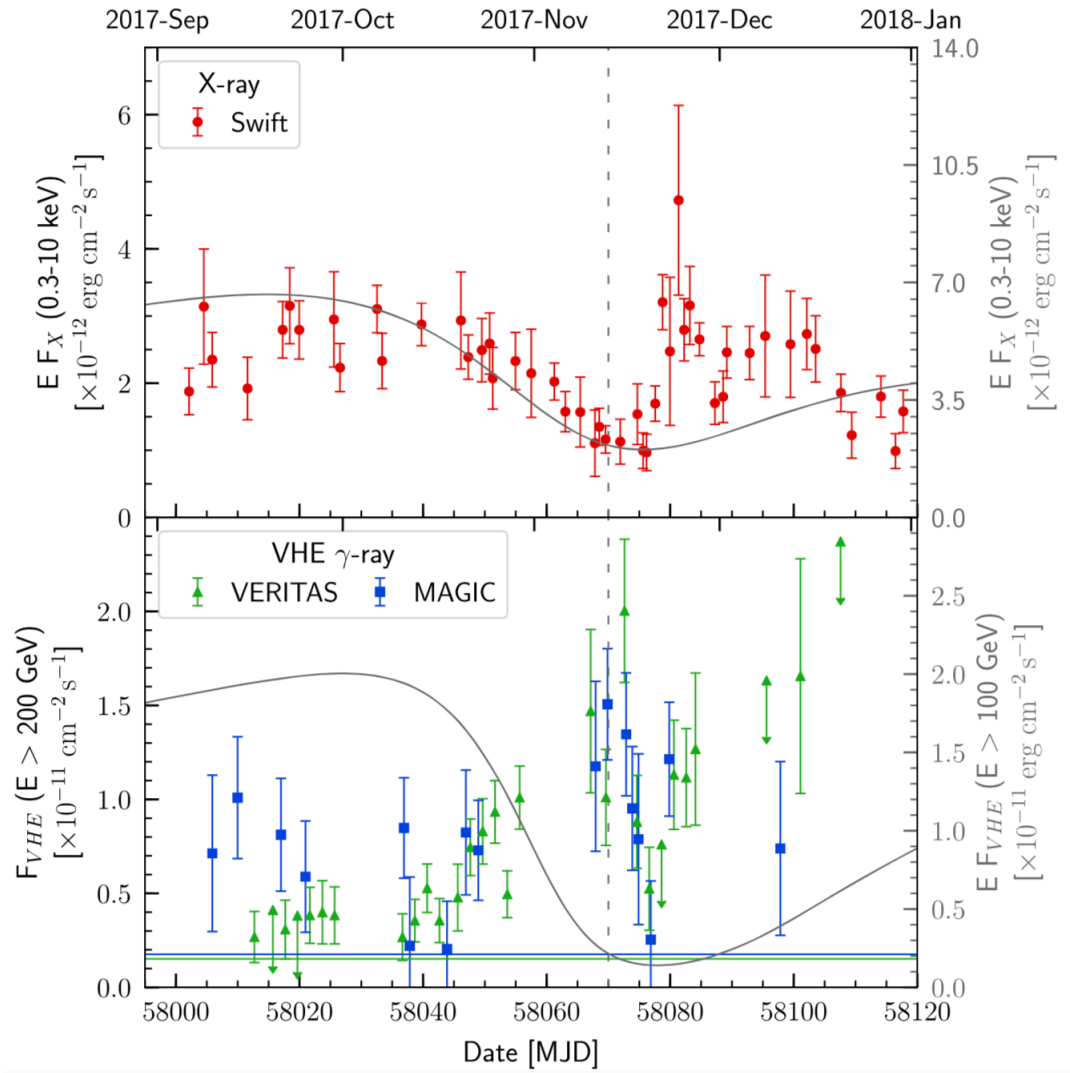
Periastron lightcurve at TeV & X-rays



X-rays (0.3-10 keV):

- **Flux peak** about **30 days before periastron** and gradual decrease, reaching **minimum at periastron**
  - X-ray suppression at periastron due to Doppler boosting effect (Takata et al. 2017)
  - Due to shadowing by Be disk (Coe et al. 2019)
- **Rapid brightening** (**punctual flare** 15 days after periastron) **and recovery** over the next 30 days during superior conjunction:
  - **X-ray brightening** interaction with **circumstellar disk** Be or geometrical effect orientation of the **stellar disk** (Petropoulou, 2018)

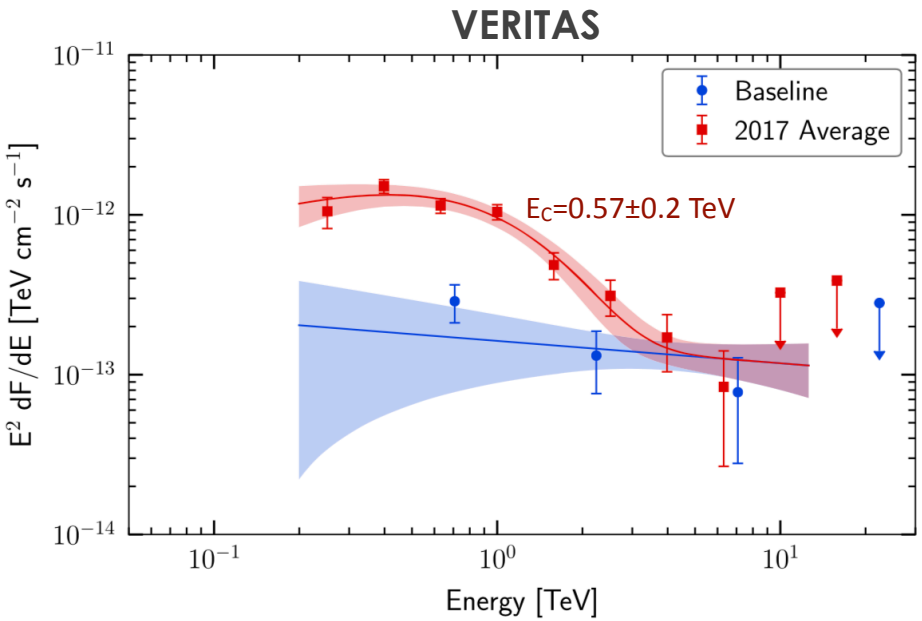
Periastron lightcurve at TeV & X-rays

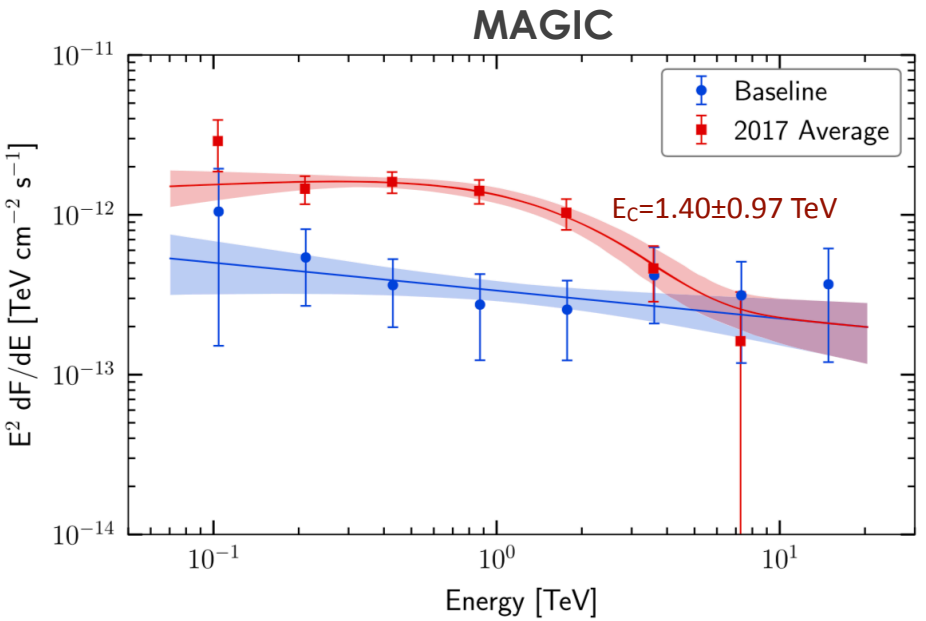


VHE (E>200 GeV):

- Flux **peaked at periastron**
- **Sharp dip 1 week after periastron** compatible with baseline emission
  - likely caused by **γ-γ absorption** (Sushch & van Soelen, 2017), similarly to PSRB1259–63/LS2883
- Flux **recovered** to periastron level few days later
- VHE emission at periastron due Inverse Compton $e^{\pm}$pair cascades (Bednarek et al 2018)
- **Periastron emission not well modeled**

VHE SED during periastron



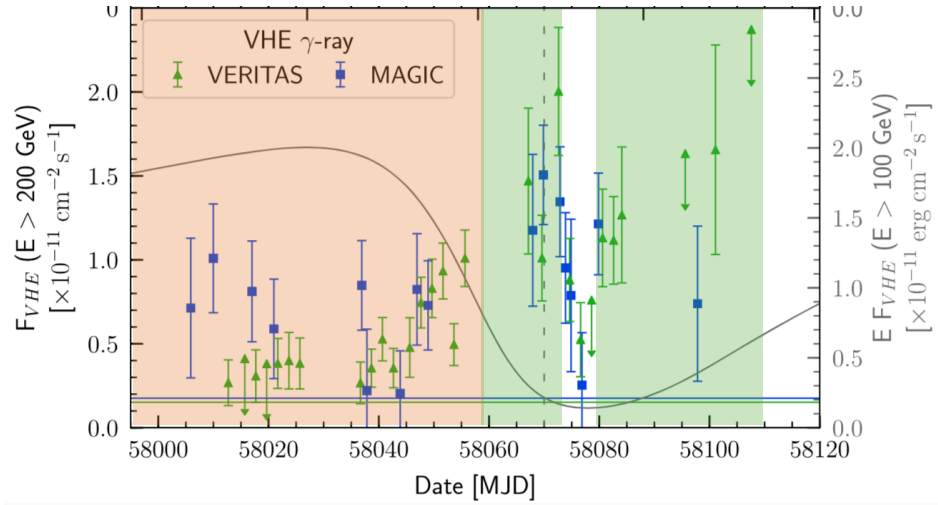


- Spectra reconstructed considering baseline emission
  - **Baseline**: **only steady** emission, **associated to TeV 2032+4130 PWN**
    - Spectral parameters compatible with previous publications
  - **Fall 2017**: include **contributions from both the steady PWN and binary**

- A **joint fit** was conducted to determine the spectral properties of the emission from the **binary above the baseline**

- Statistically significant **cut-off** detected by both experiments
  - Only seen in another gamma-ray binary, LS 5039 (E=8.7± 2.0 TeV), close to inferior conjunction
  - Possible result of cascade emission, Klein-Nishina effects or synchrotron losses
- SED **compatible** with predictions by **Bednarek et al. (2018)**

VHE SED during periastron: low&high states



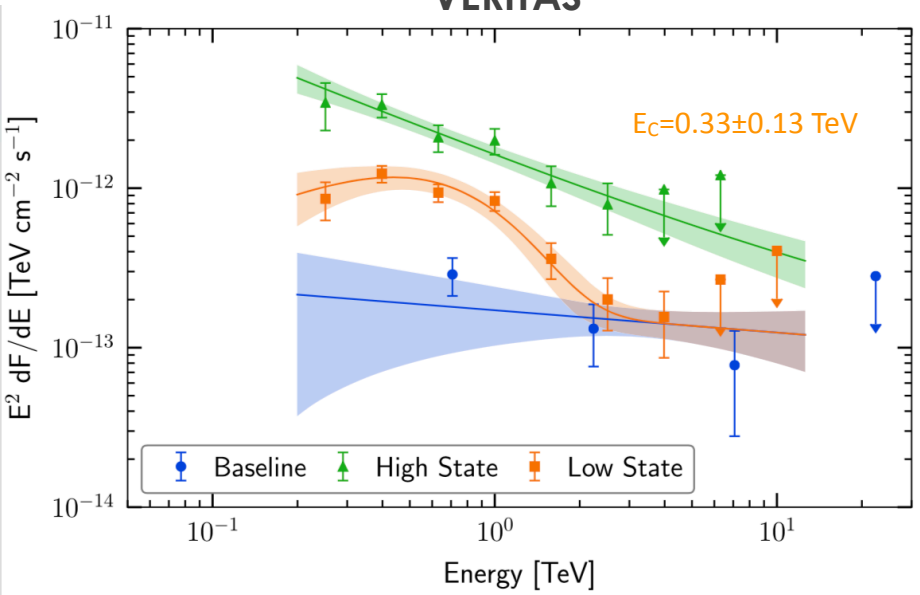
To **search for spectral variability**, we **divide the dataset** into two periods:

- **Low State** (flux < 1×10^{-11}cm^{-2} s^{-1}): MJD 57928-58056
- **High State** (flux < 1×10^{-11}cm^{-2} s^{-1}): MJD 58057-58074 & MJD 58080-58110

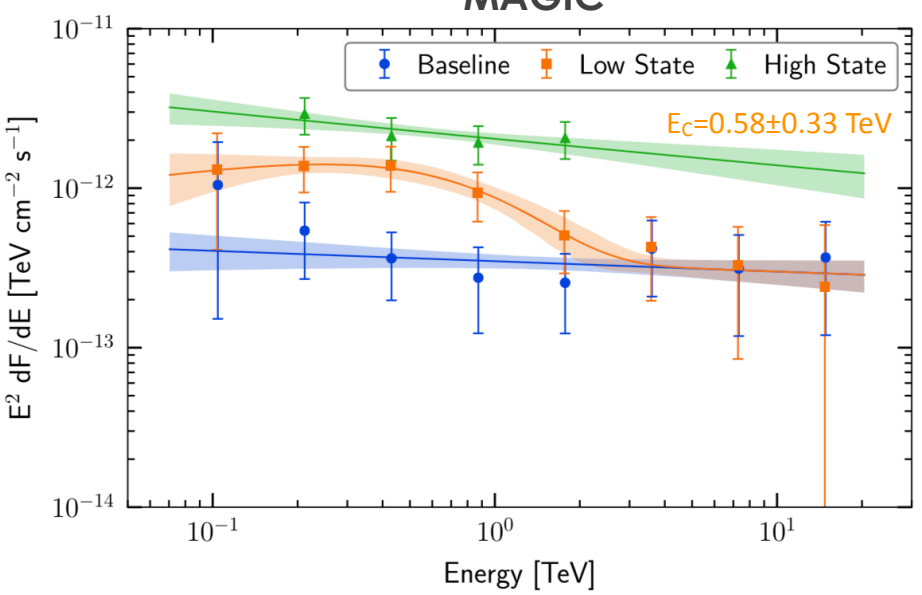
Joint fit conducted to all 3 datasets (baseline, low & high state).

Cut-off in low state for both experiments. No evidence for cut-off in **high state (PWL)**

VERITAS

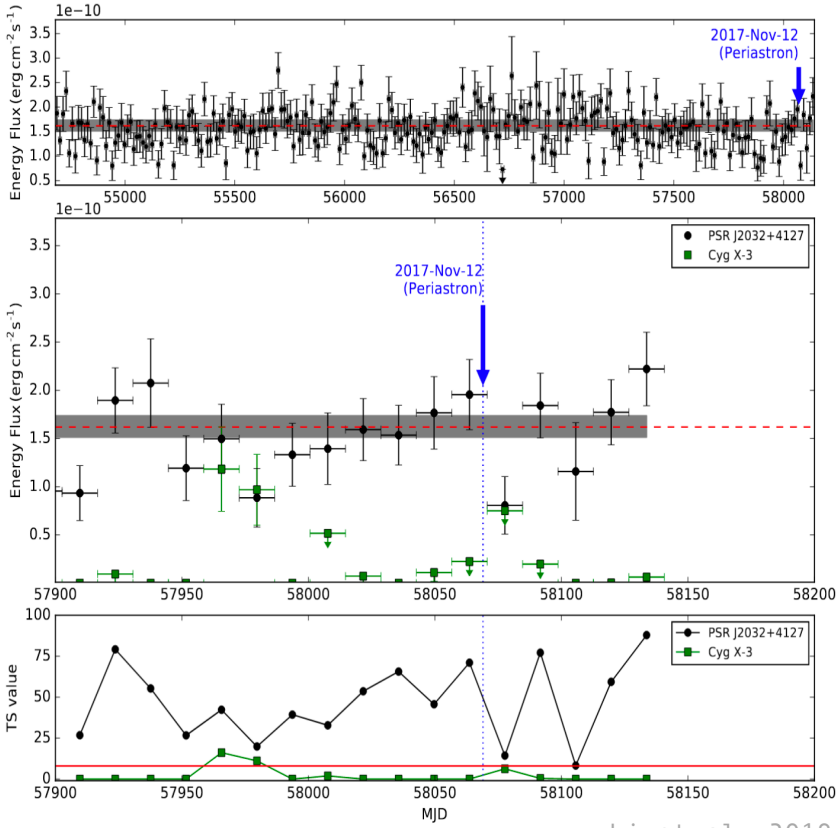


MAGIC



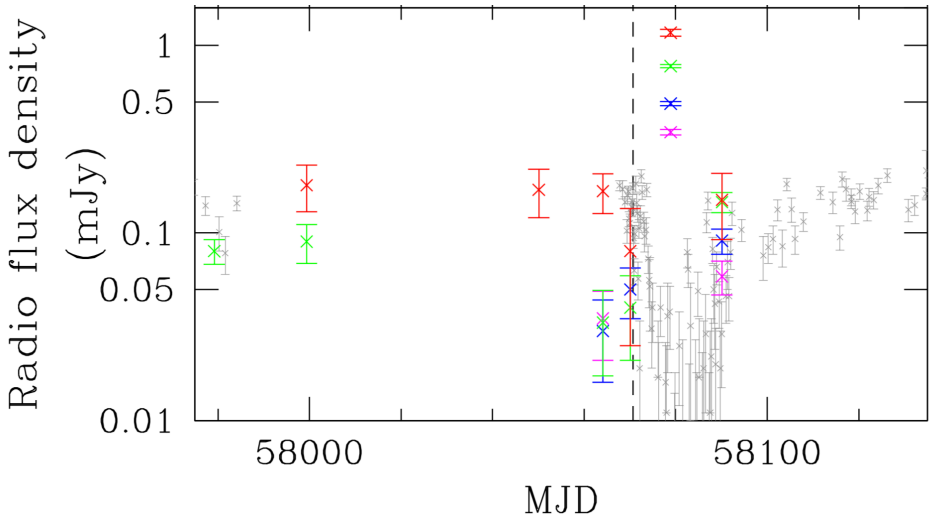
What happened at GeV & radio?

- **No flux variability at GeV** as seen by *Fermi*-LAT in 8 years of data, including periastron passage (Li et al. 2018)
- GeV emission **can be hidden** behind the pulsar's bright magnetospheric emission
  - Pulsar gating technique to recover the predicted GeV modulation



Li et al. 2018

- VLA flux at X-ray peak remained constant since 2009 (Li et al. 2018). Emission from pulsar magnetosphere
- **VLA** (1-10 GHz): discovered an **unpulsed emission one week after periastron**, **contemporaneous** to the the **X-ray flare** (Ng. et al, 2019, arXiv:1907.05749)



Ng. et al, 2019, arXiv:1907.05749

Summary

- **Detection of TeV emission** from PSR J2032+4127/MT91 213 **during periastron passage** by **VERITAS & MAGIC**: a **new gamma-ray binary** (7th)
  - **2nd** system where he nature of the compact object is known (**pulsar**, similarly to PSR B1259-63)
  - Next periastron passage in 2067!
- TeV J2032+4130 might be **pulsar wind nebula** of PSR J2032+4127
  - TeV nebulae also present around other TeV binaries?
- Both **X-ray** and **VHE** gamma rays show **flux increase around periastron**, but **different behavior**
- **Theoretical models need to be revisited**:
  - Models **did not predict X-ray brightening** after periastron and short-timescale variability
  - **Fail** to describe **VHE gamma-ray lightcurve**
- SED modeled conducting simultaneous fits to different components
- **Cut-off in VHE SED for low state during periastron passage**, but not at high state or baseline
  - Only another binary, LS5039, shows an spectral break

for more details: **Abeysekara et al. 2018, ApJL, 867, L19**

Alicia López Oramas for the **MAGIC collaboration**

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NASA/Goddard