# VHE gamma-ray emission from binary systems observed with the MAGIC telescopes





### Alicia López Oramas (IAC)

O. Blanch, E. de Oña Wilhelmi, A. Fernández-Barral, D. Hadasch, J. Herrera, E. Moretti, P. Munar-Adrover, J.M. Paredes, M. Ribó (the MAGIC collaboration), P. Bordas, F. Brun and R. Zanin



## Transients with MAGIC

MAGIO

- A new gamma-ray binary:
- PSR J2032+4107
- Searching VHE emission from massive microquasars
  - SS 433
  - Cygnus X-1
  - Cygnus X-3
- Searching VHE emission from LMXBs
  - V404 Cygni



NASA/Goddard/Feimer



NASA/CXC/M.Weiss

## The MAGIC telescopes







- Two telescopes, 17 m diameter
- Energy threshold (trigger) ~50 GeV
- Integral sensitivity E >290 GeV: (0.67 ± 0.04)% of Crab Nebula flux in 50 hours (Alekić et al. 2016)
- Energy resolution: 15-23 %
- Angular resolution: ~0.1°

## Gamma-ray binaries: what are they?

- Definition:
  - **Bulk of the non-thermal** emission lies in the  $\gamma$ -ray domain (E>1MeV)
  - Only 7 (6+a new one!) display VHE emission
    - Massive star + compact object (2 pulsars, 5 unidentified)
- Recently some **microquasars** detected at **HE**



## **PSR J2032+4127/MT91 213** A NEW GAMMA-RAY BINARY

- TeV 2032+4130 : unidentified source discovered by HEGRA (HEGRA 2002, Aharonian et al. 2005) and confirmed by Whipple (Konopelko et al. 2008), MAGIC , (Albert et al. 2008)
- Pulsar PSR J2032+4127 discovered in blind search by *Fermi*-LAT (Abdo et al. 2009). Young, high spin-down power
- TeV 2032+4130 possibly a wind nebula driven by the pulsar PSR J2032+4127 (Bednarek 2003, Aliu et al. 2014)
- **Binary nature**: PSR 2032+4127 associated to Be star MT91 213 (Lyne et al. 2005)



DEC [deg]

42

41-

- Extremely eccentric binary:
  - Orbital period: ~50 years (Ho et al. 2017)
- Periastron: November 2017 (MJD 58070)
- Monitoring of the source:
  MAGIC +VERITAS joined campaign
  - 53.7 h (2016 May September)
  - 34.2 h (2017 June December)
- September 2017 (ATel #10810):
  - TeV gamma-ray flux increased a factor 2 wrt June-August 2017 average
- 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





### X-rays Swift LC:

- Peaked about 30 days before periastron
- Gradually decreasing, minimum at periastron
- Recovery over the next 30 days (punctual flare 15 days after periastron)

### VHE LC:

- Flux peaked at periastron
- 7 days after periastron: sharp decrease of the flux compatible with the baseline emission. Flux **recovered** to periastron level few days later
- Sharp dip after periastron likely caused by  $\gamma\text{-}\gamma$  absorption

- 2016: only steady emission component was present (associated to TeV 2032+4130)
  2017: include contributions from both the steady and variable sources
- A joint fit was conducted to determine the spectral properties of the emission from the binary above the (baseline) background from the PWN (modeled as a PWL).



### SS433, Cygnus X-1 & Cygnus X

SEARCHING FOR VHE EMISSION FROM MASSIVE MICROQUASARS

NASA/CXC/M.Weiss

## SS433/W50 complex









- Only galactic super-critical accretor
- Persistent hadronic relativistic jets
- Porb ~13 days, Ppre ~162 days
- Embeded in W50 nebula
  - Interaction regions: X-ray & radio non-thermal emission
- Detected at HE (Bordas et al. 2015)
- Prediction of gamma-ray fluxes at E>800GeV due to pp interactions (Reynoso et al. 2008)
- Absorption of putative emission in ~80% of the orbit
  - Best opportunity for observations: Φpre=0.91-0.09

## SS 433/W50 at VHE





- MAGIC + H.E.S.S. campaign
  - No significant excess detected
  - Upper limits (95% C.L.) compatible with predictions by Reynoso et al. 2008

### Hadronic scenario

- Efficiency in transferring jet kinetic power to relativistic protons:
  - We can **constrain**:  $q_p \le 2.5 \times 10^{-5}$

### Leptonic scenario

- Interaction regions:
  - X-rays (synchrotron origin ) -> presence of electrons up to ~50 TeV
  - Expected fluxes (Bordas et al. (2009): roughly at level of the reported ULs
- HE electrons may loose most of their E preventing an efficient production of gamma-rays
- ULs: constrains on the magnetic field: lower limit of 20-25µG

### bremsstrahlung 09.7 lab star + BH

- Highly collimated **one-side jet** (Stirling et al. 2001)
- Surrounded by radio/optical nebula (Gallo et al. 2005, Russell et al. 2007)
- Three transient episodes with AGILE during HS and IS (Bulgarelli et al. 2008, Sabatini et al. 2010, 2013)
- Detected at HE during HS: 7.5yr Fermi-LAT data (Zanin et al. 2016)
- Hint of emission with MAGIC:  $4\sigma$  in 80 min (Albert et al. 2006)
  - Simultaneously with hard X-ray flare
  - During HS and SUPC





collimated iet

synchrotro

lobe

## Cygnus X-1: results



- 100 h (2007-2014) of MAGIC observations mainly at HS (83h)
- No significant excess at either Xray state for steady, orbital or daily basis emission
- No emission above 200 GeV due to interaction between jet and ISM
  - Jet-medium interaction discarded as possible region for VHE emission above MAGIC sensitivity level: not affected by γ-γ absorption
- **Transient emission** (Albert et al. 2007) **still possible** at binary scale

MAGIC coll., 2017, MNRAS, 472, 3474



 $10^{-10}$ 

s<sup>-1</sup>]

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## Galactic jets: Cygnus X-3

### The system

- WR+compact object
- Short orbit: 4.8 h
- Major radio flares during soft state (Szostek et al. 2008)
- HE emission detected: AGILE (Tavani et al. 2009) and Fermi-LAT (Abdo et al. 2009)

### Latest results

- August-September 2016 (radio) flare: 70 h observations during SS
- No steady/transient VHE emission (E>100 and E>300 GeV)
- Not orbital/daily modulation

### Explanation

- Extremely **high absorption** due to the WR
- VHE gamma rays, if produced, are originated inside the binary scale and not at the radio-emitting regions of the jets far from the compact object



MAGIC coll, ICRC Proceedings 2017 (arxiv 1709.01725)



MAGIC, ICRC 2017



## SEARCHING FOR VHE EMISSION FROM LMXBS

## The LMXB V404 Cygni

### The system

- ~1  $M_{\odot}$  star + 9-15  $M_{\odot}$  BH (Khargharia et al. 2010)
- Orbital period: 6.5 days (Casares et al. 1992)

### What happened?

- Major outburst in June 2015 after 26 years in quiescent state
- MAGIC was triggered by INTEGRAL: ~11h between June 18 - 27
- Selection of the flaring times for MAGIC: Bayesian block analysis on the INTEGRAL LC

### Latest results

- 7h distributed in different nights
- No signal detected (0.08σ), UL (E= 200-1250 GeV): 4.8x10<sup>-12</sup> ph cm<sup>-2</sup>s<sup>-1</sup>



## V404 Cygni: discussion



MAGIC Coll. 2017, MNRAS, 471, 1688.

- Evidences of jet emission in optical observations on 26th June:
  - + hint of detection (~4 $\sigma$ ) in Fermi-LAT data (Loh et al. 2016)
  - + giant radio flare
  - + increase of hardness ratio in X-ray band
  - + optical fast variability
  - Jet environment dramatically changed
  - No detection in MAGIC data (~1 hr taken simultaneously)
- Luminosity MAGIC upper limits ~2 × 10<sup>33</sup> erg s<sup>-1</sup> , in contrast with extreme luminosity emitted in X-ray band ~2×10<sup>38</sup> erg s<sup>-1</sup>
- Estimated γ-ray opacity during flaring period & non-detection: inefficient γ-ray emission (0.003%) in V404 Cyg jets if VHE emitter is located r >1×10<sup>10</sup> cm from the compact object.

## Summary



- PSR J2032+4127: a new gamma-ray binary!
  - TeV emission of PSR J2032+4107 during periastron passage. Flux increased factor 10 wrt than baseline measured in June-August.
  - SED described by a EPWL in low state (before periastron) and PWL during high state (during periastron passage). Baseline emission as a PWL
- Search for VHE emission from **microquasars**:
  - No significant excess from SS433/W50 complex. Constrains on particle acceleration and magnetic field
  - No detection of Cygnus X-1 at TeV energies: ULs for steady, daily and separated X-ray states (including phase-folded analysis)
  - Cygnus X-3 shows extremely **high absorption** due to the WR. VHE emission possible **at binary scale**
  - ULs on the LMXB V404 Cygni during the June 2015 major outburst: inefficient γ-ray emission

## Gamma-ray binaries: state-of-the-art

extra



|               | System           | Star spectral<br>type | Compact<br>object | Porb<br>[days] | HE<br>emission | VHE emission |
|---------------|------------------|-----------------------|-------------------|----------------|----------------|--------------|
|               | PSR B1259-53     | Ве                    | 48ms pulsar       | 1236.72        | yes            | yes          |
|               | LS 5039          | ο                     | -                 | 3.91           | yes            | yes          |
|               | LS I +61 303     | Be                    | -                 | 26.49          | yes            | yes          |
|               | HESS J0632+057   | Ве                    | -                 | 315.50         | yes            | yes          |
|               | FGL J1018.6-5856 | 0                     | -                 | 16.58          | yes            | yes          |
| extragalactic | LMC P-3          | ο                     | -                 | 10.2           | yes            | yes          |
| new binary    | PSR J2032+4127   | 8e                    |                   |                | yes            | yes          |

| HE emitters | Cygnus X-1 | Ο  | ВН  | yes | no<br>(4σ hint once) |
|-------------|------------|----|-----|-----|----------------------|
|             | Cygnus X-3 | WR | BHŞ | yes | no                   |
|             | SS 433     | А  | ВН  | yes | no                   |

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