MAGIC results on X-ray binary systems

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on behalf of the MAGIC collaboration
Outline

- Wind/wind or jets?

- GAMMA-RAY BINARIES:
  1. LS I 61°+303
  2. HESS J0632 +057

- MICROQUASARS:
  1. Cygnus X-3
  2. Scorpius X-1
  3. Cygnus X-1
Wind/wind or jets?

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LS I +61° 303

- compact object + Be star of ~12M☉
- unknown nature of the compact object: no pulsar found
- distance 2.0 ± 0.2 kpc
- eccentricity $e = 0.54$ with an orbital period of 26.496 days
- VLBA shows complex radio morphologies coupled with the orbital period → favoring wind/wind interaction rather than jet
- Radio outburst between phase $\Phi = 0.45—0.95$
- X-ray variability in the orbital profiles
LS I +61° 303: at VHEs

- discovered by MAGIC in 2006 as variable source: peaked at 15% crab before apastron ($\Phi=0.6—0.7$), nothing at periastron (Albert et al., 2006)

- Crab-like spectrum $\Gamma = 2.6 \pm 0.2 \pm 0.2$

- VHE periodicity with $P = (26.6 \pm 0.2) \text{ d}$ (Albert et al., 2008)

- significant activity also observed in $\Phi=0.8—0.9$ for some orbital periods (Albert et al., 2008)

- X-ray/VHE correlation ($r \approx 0.8$) (Anderhub et al., 2009)

- no radio/VHE correlation (Albert et al., 2008)
LS I +61° 303: gone?

- VERITAS observed it between October 2008 and December 2010 (8 cycles)

- No detection between October 2008 and December 2009 (Acciari et al. 2011)

- LS I back in Fall 2010. VERITAS detected >5σ between Φ=0.05-0.23 (before periastron) (Acciari et al. 2011)

- MAGIC observed 48.4 hrs between October 2009 and January 2010 (Aleksic et al. 2011 to be submitted in 2 weeks)
LS I +61° 303: MAGIC detection of a low level emission

- overall detection at 6.3σ
- \[ F (E>300 \text{ GeV}) = (1.4\pm0.3\pm0.4) \times 10^{-12} \text{ ph. cm}^{-2}\text{s}^{-1} \]
  \[\rightarrow\] lower than 2005-2007
- variable emission peaking between \( \Phi=0.6-0.7 \) and \( \Phi=0.9-1 \)
- periodicity gone? Not possible to tell
- No spectral variability observed: \( \Gamma = 2.5\pm0.6\pm0.7 \)

Aleksić et al., 2011

to be submitted in 2 weeks
LS I +61° 303: conclusions

- These light curves are NOT in contradiction with VERITAS non-detection: we have longer observation time
- Detection at a low level emission (peak emission factor 2-4 lower)
- No observed spectral change

⇒ same process keeps on producing VHE \( \gamma \)-rays:

1. Less efficient? Due to changes in the stellar wind density which should be visible at other wavelengths
2. More absorption? This should determine spectral features ⇒ disfavored
HESS J0632 +057

- at VHEs
  - Discovered by HESS in 2007: the only unidentified point-like source (<2') in the Galactic scan. (Aharonian et al. 2007)
  - VERITAS non-detection in 2008 \(\Rightarrow\) variability in TeV (Acciari et al., 2011)

- X-rays
  - X-ray source coincident with massive Be star MWC 148
  - X-rays show significant variability
  - claimed periodicity of 310-320 days (Bongiorno et al., 2011)

- radio frequencies (Skilton et al. 2009)
  - radio counterpart with <1 month variability and low flux

- new gamma-ray binary? (Hinton et al., 2009)
HESS J0632 +057: back in February 2011

- Increase in the X-ray flux detected by Swift starting on January 28, 2011 with a peak (factor 3) around February 6 (ATel #3152)

- VERITAS and MAGIC detected significant VHE γ-ray emission on February 7-9 2011

- MAGIC observations (~ 5hrs) yield a > 5σ detection (ATel #3161)
  - estimated VHE γ-ray flux ~3.4% of the Crab flux above 200 GeV
  - no indication of day-by-day variability

- VERITAS estimated VHE γ-ray flux ~ 4% of the Crab flux above 300 GeV (ATel #3153)
Cygnus X-3

- Distance ~ 7 kpc
- Compact object still unknown
- Wolf-Rayet companion star → HMXB
- Short orbital period of 4.8 h
- Tight orbit: $\Omega = 2R_* \quad R_* = 2 \times 10^{11} \text{ cm}$
- Inclination angle: 30°- 60°
- Detected relativistic collimated jets → MQ
- X-ray spectral states resemble the canonical states of the BH MQs: soft state with transient ejections and hard state with persistent jets
Cyg X-3: detection at high-energies

- Fermi/LAT detected 29σ in two periods of high activity: MJD 54750-54820 and 54990-55045
  \[(Abdo \text{ et al.}, \text{Science}, 326, 2009)\]

- HE active periods coincide with the soft state

- Agile the emission peaks as 5 flares
  \[(Tavani \text{ et al.}, \text{Nature 462}, 2009)\]
Cyg X-3: MAGIC observations

- 56 h between March 2006 and August 2009 taken with MAGIC-I

- no VHE signal found: \( F (E > 250 \text{ GeV}) < 2.2 \times 10^{-12} \text{ photons cm}^{-2} \text{ s}^{-1} \) (1.3% Crab flux) \@95\% CL  

- phase-folded analysis yielded to no significant excess events

\( \text{(Aleksić et al., ApJ 2010)} \)
Cyg X-3: MAGIC observations

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Cyg X-3: simultaneously to the HE detection

- **Fermi/LAT**
  - average flux: $1.2 \times 10^{-6} \text{ ph.cm}^{-2}\text{s}^{-1}$
  - $\Gamma_{\text{av}} = 2.7 \pm 0.05 \pm 0.20$
  - peak flux $> 2 \times 10^{-6} \text{ ph.cm}^{-2}\text{s}^{-1}$

- **AGILE**
  - peak flux $1.9 \times 10^{-6} \text{ ph.cm}^{-2}\text{s}^{-1}$
  - $\Gamma = 1.8 \pm 0.2$

- MAGIC ULs are still compatible with the extrapolation of a power-law with $\Gamma_{\text{av}} = 2.7$, but not with the extrapolation of Agile’s 1.8.
Cyg X-3: conclusions

- Non-detection of Cyg X-3 at VHE: ULs at 1.3% crab
- No VHE signal either from persistent (hard state) or transient (soft state) jets
- No VHE detection during the period of enhanced activity in the GeV band
Scorpius X-1

- neutron star and M star of $1.4 \, M_\odot$
- distance $2.8 \pm 0.3$ kpc
- circular orbit with a period of 0.787 days
- Z-type LMXB: X-ray intensity and color variability (variation of the accretion rate?)
- Definition of X-ray spectral states based on the hard versus soft color diagram (CD)
- the CD shows a double-banana shape more than a Z-track
- X-ray spectral states have no orbital dependence
- radio emission and non-thermal X-ray tail detected in the HB

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Di Salvo et al. 2006

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Sco X-1: MAGIC-RXTE observations

- simultaneous campaign with MAGIC and RXTE/PCA in May 2010 for ~ 8 hours spread in 6 nights

- X-ray data used to define the X-ray spectral state: soft and hard colors definition in D’Ai et al. 2007

- 3 nights coincide with the HB

- MAGIC did not detect any signal when the source was in the HB
  \[ F(E>300 \text{ GeV}) < 3.4 \times 10^{-12} \text{ photons cm}^{-2} \text{ s}^{-1} \] @ 95% CL
  2.7% crab flux

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Sco X-1: conclusions

- MAGIC did not detect Sco X-1 above 300 GeV.
- No Sco X-1 detection even in the HB state (where non-thermal emission has been detected in other wavelengths).
- The ULs to the VHE integral flux set ULs to the VHE luminosity to jet power ratio: $L_{\text{VHE}}/L_j < 10^{-3}$. 
Cygnus X-1

- Distance at 2.2 ± 0.2 kpc
- Black hole with O star of (40 ± 10) $M_\odot$
- X-rays
  - Canonical X-ray spectral state of the BH MQs: soft and hard states
  - Fast variability on different timescales
- $\gamma$-rays
  - AGILE detected a flare lasted for 1 day on October 15-16, 2009 at 5.3$\sigma$ (pre-trial). *(Sabatini et al., 2010)*
  - AGILE detected two more 1-day flares on March 24 and June 30, 2010 *(ATel #2512, #2715)*
  - Not confirmed by Fermi/LAT
- VHE $\gamma$-rays
  - MAGIC observed an evidence of signal (4$\sigma$ post-trail) above 150 GeV for 80’ on September 24, 2006 *(Albert et al., 2007)*
Cyg X-1: chasing another flare

- between July 2007 and November 2009 MAGIC observed Cyg X-1 for ~ 100 hrs
- Neither persistent or variable signal was found
- paper coming out soon
Conclusions

- MAGIC detected LS I +61° 303 in a low emission state and demonstrates that there is variability beyond the periodicity.

- MAGIC detected HESS J0632 +057 during the February 2011 outburst at the 3.4% Crab level above 200 GeV (lowest energy detection so far).

- No VHE detection for well-established microquasar candidates.

- The HMXB Cyg X-3 did not show any VHE signal above 250 GeV either in the soft or hard state, or during the period of high-activity in the high-energy band.

- MAGIC did not detect the LMXB Z-type source Sco X-1 above 300 GeV during the HB state.

- MAGIC could not confirm Cyg X-1 evidence of signal.
THANKS
LS I +61° 303

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Cyg X-3: simultaneously to the HE detection

- MAGIC
- AGILE
- Fermi/LAT
- Swift/BAT
- RXTE/ASM
- AMI
- OVRO

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Cyg X-1

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Cyg X-3: X-ray spectral states

X-ray spectral states resemble the canonical states of the BH binaries: soft and hard states

- finer classification using X-ray/radio flux correlations
- huge radio flares mainly in the soft state
Cyg X3: MAGIC results

\[ \frac{dN}{dE} \left[ \text{TeV}^{-1} \text{cm}^{-2} \text{s}^{-1} \right] \]

-10^{-1}
-10^{-2}
-10^{-3}
-10^{-4}
-10^{-5}
-10^{-6}
-10^{-7}
-10^{-8}

MAGIC
Cygnus X-3
56.7 h in 2006 - 2009

Crab flux
10% Crab flux
1% Crab flux
Cyg X-3: MAGIC observations

ToO observations:

- **2006**
  - flares at radio frequencies
  - RATAN-600 alerts:
    - March 10, 2006
    - July 26, 2006

- **2007**
  - monitoring the hard state
  - Swift/BAT > 0.05 cts s\(^{-1}\) cm\(^{-2}\)
  - ASM/BAT < 200

- **2008/2009**
  - flares in the HE band
  - AGILE alerts:
    - April 18, 2008
    - July 18, 2009

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