MAGIC detection of the putative gamma-ray binary HESS J0632+057

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Abstract: The variable gamma-ray source HESS J0632+057 is an excellent candidate for a gamma-ray binary. The putative binary system was discovered as a point-like VHE gamma-ray source by HESS. Later measurements by VERITAS yielding no detection, provided evidence for variable emission in the gamma-ray domain. A variable X-ray source as well as a Be star (MWC 148) are found at the location of the gamma-ray source. Recently a periodic X-ray outburst occurring about every 320 days was reported by Swift\textsuperscript{(3152)}. The putative binary system was observed by the MAGIC stereo system in 2010 and 2011. Our measurements demonstrate significant activity in the gamma-ray ($E > 200$ GeV) band in February 2011. Our detection of the system occurred during an X-ray outburst reported by Swift. Here we present the obtained light curve and spectrum during this outburst and put them into context with the X-ray measurements.

Keywords: gamma-rays, binaries, HESS J0632+057, MAGIC, VHE, TeV, galactic, source

1 Introduction

With the advent of the new generation of Imaging Atmospheric Cherenkov Telescopes (IACTs) such as MAGIC, HESS and VERITAS, a new TeV source class, the gamma-ray binaries, could be established. Only few members of this new class are known. Among these objects LS I +61 303, LS 5039 and PSR B1259−63 are regularly detected in VHE gamma rays\textsuperscript{[1, 2, 3]} and all of these three systems show variable or even periodic, point like VHE (VHE, $E > 100$ GeV) gamma-ray emission\textsuperscript{[4, 5]}. Indeed, all binary systems are expected to be spatial unresolved by the current generation of IACTs.

A recently discovered unidentified, point-like VHE gamma-ray source in the constellation of Monoceros by HESS was assumed to be a gamma-ray binary candidate because of its spatial coincidence with the Be star MWC 148\textsuperscript{[6]}. The system was observed by VERITAS in VHE gamma rays from 2006 to 2009 with sparse sampling and the measurements did not yield any gamma-ray signal\textsuperscript{[7]}. Thus HESS J0632+057 is variable in VHE gamma rays, and as all\textsuperscript{1} of the galactic variable VHE gamma-ray sources known today are associated with binary systems, HESS J0632+057 is a very good binary candidate.

Most recently MAGIC and VERITAS detected VHE gamma-ray emission from the system\textsuperscript{[8, 9]}. Measurements in soft X-rays with XMM-Newton indicate an X-ray source (XMMU J063259.3+054801) at the position of MWC 148\textsuperscript{[10]}. The source exhibits a power-law spectrum with spectral index $\Gamma = 1.26 \pm 0.04$ allowing for an interpretation as synchrotron emission from VHE electrons, although multi-thermal spectra model yield reasonable fits as well. Furthermore, the X-ray source showed a variable flux but without changing the spectral shape. Similar behavior is seen e.g. in the gamma-ray binary LS I +61 303. Later X-ray measurements conducted with Swift resulted in detecting the same source (identical position) but at a different flux level and with a softer spectral index. The variable nature of the X-ray sources indicate a binary system. Very recently Swift observations from 2009 to 2011 yielded a periodic outburst in the X-ray emission from HESS J0632+057 of $P = 321 \pm 5$ days\textsuperscript{[11]}. This is the best evidence for HESS J0632+057 being a gamma-ray binary. Chandra X-ray measurements during the 2011 Feb X-ray outburst did not find any X-ray pulsation in the signal but could demonstrate that the spectrum is softer the higher the flux is\textsuperscript{[12]}. The region of HESS J0632+057 was observed at radio wavelengths, too. The measurements conducted in 2008 with the Very Large Array (VLA) and the Giant Metrewave Radio Telescope (GMRT) at 5 and 1.28 GHz, respectively, detect an unresolved radio source within the position RMS of the VHE gamma-ray source and the Be star MWC 148\textsuperscript{[13]}. The source shows variability on the 5$\sigma$ level. No extended structures were detected at scales of 2 arcseconds, in agreement with the lack of such big structures in the

1. The Crab Nebula is variable in GeV energies but up to now no TeV variability is measured and thus it is not counted among the variable VHE gamma-ray sources.
other known gamma-ray binaries. During the 2011 X-ray outburst very high resolution European Very Long Baseline Interferometry Network (EVN) observations reveal a point-like source coincident with the Be star MWC 148 within 14 milli-arcsec, which evolves into an extended source 30 days later [14]. The peak of the emission is displaced between runs 21 AU, which is larger than the orbit size. The brightness temperature of the source is above $2 \times 10^6$ K. The morphology, size, and displacement on AU scales are similar to those found in the other gamma-ray binaries, supporting a similar nature for HESS J0632+057 [14].

Optical radial velocity measurements were taken on MW 148, to verify if it is a member of a binary system [15]. The fit to the data yielded a lower limit on the possible period of the system of $P > 100$ days. Very recent optical radial velocity measurements during the X-ray outburst of 2011 could only exclude that the X-ray outburst happened during the periastron passage of the putative compact object companion [16]. Thus the verification of the binary nature as well as the determination of the orbital parameters is still a pending task.

In this proceeding, we present the MAGIC measurements of HESS J0632+057 and put them into multiwavelength context.

## 2 Observations

The observations of HESS J0632+057 were performed between 2010 Oct and 2011 Mar using the MAGIC telescopes on the Canary island of La Palma (28.75°N, 17.86°W, 2225 m a.s.l.), from where HESS J0632+057 is observable at zenith distances above 22°. The MAGIC stereo system consists of two imaging air Cherenkov telescopes, each with a 17 m Ø mirror. The observations were carried out in stereo mode, meaning only shower images which trigger simultaneously both telescopes are recorded. The stereoscopic observation mode provides a $5\sigma$ signal above 300 GeV from a source which exhibits 0.8% of the Crab Nebula flux in 50 hours observation time. Thus the stereoscopic observations are a factor of two more sensitive than our single telescope measurements. Further details on the design and performance of the MAGIC stereo system can be found in [17].

## 3 Data Analysis

The data analysis was performed with the standard MAGIC reconstruction software. Events that trigger both telescopes are recorded and further processed. The recorded shower images were calibrated, cleaned and used to calculated image parameters individually for each telescope. The energy of each event was then estimated using look up tables generated by Monte Carlo (MC) simulated $\gamma$-ray events. In another step further parameters, e.g. the height of the shower maximum and the impact parameter from each telescope, were calculated. The gamma hadron classifications and reconstructions of the incoming direction of the primary shower particles were then performed using the Random Forest (RF) method [18]. Finally, the signal selection used cuts in the hadronness (calculated by the RF) and the squared angular distance between the shower pointing direction and the source position ($\theta^2$). The energy dependent cut values were determined by optimizing them on a sample of events recorded from the Crab Nebula under the same zenith angle range and similar epochs than the HESS J0632+057 data. For the energy spectrum and flux, the effective detector area was estimated by applying the same cuts used on the data sample to a sample of MC simulated $\gamma$-rays. Finally, the energy spectrum was unfolded, accounting for the energy resolution and possible energy reconstruction bias [19].

## 4 Results

We detect VHE gamma-ray emission from the HESS J0632+057 data set recorded in 2011 Feb with a significance of about $6\sigma$ in about 6 hours. A positive detection of the system is only found in the 2011 Feb data which is simultaneously taken to the X-ray outburst observed by Swift. No indication of significant emission is found in 2010 Dec or 2011 Mar data. Our light curve indicates a variable VHE gamma-ray source with variability timescales of about one month. A correlation of the VHE gamma-ray emission with the periodic X-ray outburst is suggestive but can not be proven since we only have simultaneous data for the 2011 outburst and the sampling of the LC is too sparse for individual night correlation studies. However, it is evident that only in the time of high X-ray activity the system was detected by MAGIC. In addition, the LC during the gamma-ray activity shows a constant flux and no short time (e.g. day timescale) variability.

The obtained spectrum is compatible with a simple power law and the spectral index is compatible with the one previously reported by HESS. Furthermore the measured flux level is on a similar level as the previous detections and well above the 2006–2009 VERITAS upper limits. The same spectral shape and flux level indicate that the same process might be at work during the HESS detection and the 2011 MAGIC detection. From our measurements we can infer that there was an outburst in VHE gamma rays but, due to the sparse sampling, the duration as well as possible substructures could not be resolved.

## 5 Conclusions

The presented VHE gamma-ray detection of HESS J0632+057 demonstrates that this source is most likely a new gamma-ray binary. The emission might be periodic and the gamma-ray activity takes only place during the 2011 X-ray outburst. The system emits at the same flux level and with the same energy spectrum whenever detected in VHE gamma rays, and the detections available up to
now are separated four years. In case of a periodic modulation with a period of about 320 days, as in X-rays, such a behavior is well expected.

For testing the hypothesis that the VHE gamma-ray and X-ray emissions are both periodic, future measurements in the two energy bands are needed. Fortunately, with the X-ray periodicity these measurements can be planned well in advance.

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