VERITAS and H.E.S.S. observations of the gamma-ray binary HESS J0632+057

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Abstract.

HESS J0632+057 has been recently identified as a new gamma-ray binary system. The source, located in the Monoceros region and associated with the massive Be star MWC 148, shows variability from radio to very high energy (VHE) gamma-rays, displaying a maximum of its non-thermal emission about 100 days after periastron passage (at orbital phases ~ 0.3). We present here the results obtained with the VERITAS and H.E.S.S Cherenkov telescopes spanning a wide time interval from 2004 to 2012. The source is detected at TeV gamma-rays at a high significance level at phases ~ 0.3. We also report for the first time TeV observations belonging to orbital phases never explored so far. The VHE gamma-ray results are discussed in a multiwavelength context, focusing on contemporaneous observations obtained with the Swift-XRT.

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HESS J0632+057: A NEW GAMMA-RAY BINARY

The VHE gamma-ray source HESS J0632+057 [1] is a new member of the elusive class of gamma-ray binaries [2]. These objects are characterized by a peak in their broad-band energy spectrum at MeV-GeV energies, showing variable and usually orbitally modulated high-energy emission. All known gamma-ray binaries are high-mass X-ray binaries, consisting of a compact object orbiting around a massive star of O or Be type. Besides HESS J0632+057, there are only a few binaries clearly identified as VHE gamma-ray sources: PSR B1959-63/LS 2883 [3], LS 5039 [4], LS I +61 303 [5, 6]. In addition, a hint of a VHE flare from Cyg X-1 has been reported [7], and VHE emission from a direction consistent with that of the newly discovered binary 1FGL J1018.6-5856 [8] has been recently found [9].

HESS J0632+057 has been repeatedly observed at X-rays: XMM-Newton detected a hard and variable counterpart of HESS J0632+057 at the position of MWC 148 [2]. Swift-XRT observations showed a softer source [10] and the presence of X-ray outbursts each 321 ± 5 days [11]. An updated analysis of Swift data including observations up to March 2012 shows a somewhat shorter value of this periodic outburst, each ~ 315 days (See Fig. 1). X-ray pulsations from the source were not found in recent Chandra observations [12]. At radio wavelengths, VLT and GMRT observations of the source at 5 and 1.28 GHz detected a variable radio counterpart compatible with both the gamma-ray source and the MWC 148 star position [13]. EVN observations further showed spatially extended radio emission during the X-ray outburst, with the emission peak ~ 10 times...
FIGURE 1. **Left:** Phase-folded X-ray lightcurve using a *Swift*-XRT data-set obtained from 2009 to 2012 (154 compared to 112 flux points in [11]). The X-ray peak at phase $\sim 0.3$ and the subsequent X-ray dip at phase $\sim 0.45$ are clearly seen. **Right:** A z-transformed discrete cross-correlation function analysis (ZCDF, Alexander 1997) provides an orbital period of $P = 315^{+6}_{-4}$ days

larger than the orbit size [14]. In the optical band, observations with the Liverpool telescope have been used to obtain radial velocity measures. Fixing the orbital period to 321 days these data suggest a system with an eccentric orbit ($e \approx 0.83$ with periastron occuring at orbital phases $\sim 0.97$ [15].

**VERITAS AND H.E.S.S. OBSERVATIONS**

VERITAS and H.E.S.S. are ground-based gamma-ray observatories, each consisting of four imaging atmospheric Cherenkov telescopes. The instruments have similar performance, with large effective areas ($> 10^5$ m$^2$) over a wide energy range (100 GeV to 30 TeV) and good energy (15-20%) and angular ($\leq 0.1^\circ$) resolutions. The high sensitivity of H.E.S.S. and VERITAS enable the detection of sources with a flux of 1% of the Crab Nebula in less than 30 hours of observations.

VERITAS observed HESS J0632+057 for a total of 162 h between 2006 December and 2012 January. About 144 h of data passed quality selection criteria. All observations were taken with the source at a fixed offset of 0.5$^\circ$ from the camera center. The energy threshold after analysis cuts ranges between 220 GeV and 450 GeV. The most recent observations, taken in 2011/2012, amount to a total of 34.3 h between November 2011 to January 2012. The analysis of these data provides 163 excess events, implying a detection with a statistical significance of 9.8 $\sigma$.

H.E.S.S. observed the source yearly from 2004 to 2012. The full dataset consists of 47.3 h of observations, which were performed over a large range of zenith angles (28$^\circ$-58$^\circ$). In the 2011/2012 campaign, H.E.S.S. observed the source in December 2011 and February 2012, providing a total of 8.2 h of good quality data-set. Bad weather prevented however most of the observations close to the expected peak. We also report here archival
### Table 1. VERITAS and H.E.S.S. results for the different data-sets

<table>
<thead>
<tr>
<th></th>
<th>Obs. time [h]</th>
<th>(N_{\text{on}})</th>
<th>(N_{\text{off}})</th>
<th>excess</th>
<th>significance [(\sigma)]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>VERITAS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All data</td>
<td>144.2</td>
<td>1525</td>
<td>18310</td>
<td>544</td>
<td>15.5</td>
</tr>
<tr>
<td>2011/2012</td>
<td>34.3</td>
<td>367</td>
<td>2388</td>
<td>163.5</td>
<td>9.8</td>
</tr>
<tr>
<td><strong>HESS</strong></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>All data</td>
<td>47.3</td>
<td>823</td>
<td>11032</td>
<td>270.0</td>
<td>10.4</td>
</tr>
<tr>
<td>2011/2012</td>
<td>8.2</td>
<td>148</td>
<td>1787</td>
<td>53.9</td>
<td>4.9</td>
</tr>
<tr>
<td>phase (\in [0.7 - 0.8])</td>
<td>7.1</td>
<td>93</td>
<td>1228</td>
<td>33.9</td>
<td>4.1</td>
</tr>
</tbody>
</table>

H.E.S.S. observations corresponding to orbital phases unexplored so far. In particular we show new data in the phase range \([0.7 - 0.8]\) (using an orbital period of 315, see above) which were taken in March 2007, January 2008 and October 2009 and amount to \(\sim 7\) h of observing time. Using the Model analysis technique \([16]\) with standard cuts, a \(4.1\sigma\) deviation from the background level is found. A cross-check using a boosted-decision-tree-based Hillas analysis \([17]\) for the same run list, which also makes use of an independent calibration of the raw data, provides compatible results, with a somewhat higher significance of \(4.8\sigma\) in this phase range.

**SUMMARY AND CONCLUSIONS**

VERITAS and H.E.S.S. observations of HESS J0632+057 provide a wide data-set with more than 190 h of observations covering a large fraction of the system orbital phases. The source is detected at TeV energies at a high significance level around phase 0.3. Results are consistent in this phase with observations taken from 2004 to 2012, as.
well as with recent results reported by the MAGIC Collaboration [18]. Archival data taken with H.E.S.S show a $4.1\sigma$ deviation from background events from the direction of HESS J0632+057 at phases $\sim 0.7 - 0.8$, or about half an orbital period later than the peak at phase $\sim 0.3$. Additional TeV data are however required to provide more solid conclusions in this phase range. Finally, an updated X-ray data-set provides a refined system period of $P = 315^{+6}_{-4}$ days. In addition, an updated z-CDF analysis (see, e.g. [19]) with the newest data shows a $4\sigma$ correlation of the X-ray and VHE fluxes.

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