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Recent MAGIC results on Galactic binaries

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X-ray and gamma-ray binaries are systems consisting of a compact object and normally a non-degenerate companion star. Most of these sources have been shown to emit radiation in a broad frequency range, from radio up to X-rays and sometimes gamma rays. We report on recent results in very high-energy gamma rays above 100 GeV obtained by the MAGIC Collaboration for the Galactic X-ray binaries MAXI J1820+070 and 1A 0535+262, and the gamma-ray binary HESS J0632+057. Multiwavelength data at lower energies are also provided for a better contextualisation of the sources.

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1. Introduction

There are a number of binary systems in our Galaxy, typically consisting of a compact object and a non-degenerate companion star, that produce X-ray and gamma-ray emission. Depending on the energy at which their emission peaks, they are called either X-ray or gamma-ray binaries. Two main scenarios have been proposed to explain the observed radiation, one involving matter accretion and jet launching by the compact object (microquasar scenario), and another one in which the compact object is a pulsar that interacts with the star through their winds (pulsar wind scenario).

MAXI J1820+070 is a low-mass microquasar with a black hole that was discovered in X-rays on March 11 2018 (MJD 58188.8) by the MAXI instrument [1]. Soon after its discovery, MAXI J1820+070 reached an exceptionally high X-ray flux peaking at ~ 4 times that of the Crab Nebula in the 15–50 keV range [2, 3]. The distance to the source was set to 2.96 ± 0.33 kpc [4], and an orbital period of 16.4518 ± 0.0002 h was found [5]. Regarding its X-ray state, MAXI J1820+070 followed the usual cycle for microquasars with a black hole in outburst [6], going from a hard spectral state (HS) to a soft state (SS), and back to the HS shortly before going into quiescence [3]. The bottom panel in Fig. 1 allows to visualise the X-ray state evolution of the source throughout the outburst.

HESS J0632+057 is a gamma-ray binary consisting of a compact object and a massive Be-type star. It was discovered in very high-energy (VHE) gamma-rays as an unidentified point-like source during H.E.S.S. observations of the Monoceros region [7], and since then it has been detected at different frequencies from radio to high-energy gamma-rays. The distance to the source was set to 1.1 – 1.7 kpc [8], and the orbital period to $316.8^{+2.6}_{-1.4}$ days from X-ray data [9]. The pulsar-wind scenario has been proposed for HESS J0632+057 [10, 11], although the microquasar scenario cannot be ruled out.

1A 0535+262 is a Be X-ray binary composed of a giant Be-type star and a pulsar. This source has undergone periodic X-ray flares every few years since its discovery in 1975 (see [12] and references therein). In November 2020, it displayed an especially bright X-ray outburst reported by *Swift*/BAT [13] and confirmed by MAXI [14]. This is the brightest X-ray event recorded from this source up to date, reaching a luminosity level of 12 Crab in the 15–50 keV band in 19 November 2020. 1A 0535+262 was detected in radio for the first time during the 2020 outburst [15], indicating the presence of non-thermal emission mechanisms. The distance to the source is 2.1 ± 0.2 kpc [16], and it has an orbital period of 111 ± 0.4 days [17]. Super-critical accretion onto the pulsar during the outburst was reported by [18].

In these proceedings, we provide an overview of the latest results on Galactic binary systems obtained with the MAGIC telescopes at energies above 100 GeV. In particular, we present results on the three sources described above: MAXI J1820+070, HESS J0632+057 and 1A 0535+262. We put these observations into a multi-wavelength context and discuss their physical implications for the different observed sources. The structure of the proceedings is the following: Sect. 2 describes the observations performed. In Sect. 3, the results for each source are shown and a discussion is provided. Finally, a short summary is given in Sect. 4.

Table 1: Summary of the observations of MAXI J1820+070 with the MAGIC telescopes, after data quality cuts. The effective observation time and zenith angle range are shown for each source state, as well as for the whole data set.

Source state	Time [h]	Zenith angle [deg]
Hard State	14.2	21 – 58
HS → SS	4.9	21 – 48
SS → HS	3.4	28 – 56
TOTAL	22.5	21 – 58

2. Observations and data analysis with MAGIC

MAGIC [19] is a stereoscopic system of two Imaging Atmospheric Cherenkov Telescopes located at the Roque de los Muchachos Observatory in La Palma, Spain (29°N, 18°W, 2200 m above sea level). Each telescope has a 17-m diameter mirror dish that collects and focuses light into its focal plane, where a fast photo-multiplier tube camera with a 3.5° field of view is located. The analysis of the MAGIC data presented here was done following the standard procedure described in [20].

2.1 MAXI J1820+070

MAXI J1820+070 was observed with the MAGIC telescopes during the X-ray outburst from March to October 2018, covering the initial HS of the source as well as the state transitions. A total of 22.5 h of data survived the quality cuts, all of them taken under dark conditions. These observations were performed together with the H.E.S.S. and VERITAS Collaborations for an added total of 61 h of good-quality data. In these proceedings we only report on the MAGIC observations, for which a summary can be found in Table 1. We refer the interested reader to an upcoming publication for the details of the joint observational campaign of MAGIC, H.E.S.S. and VERITAS.

2.2 HESS J0632+057

The gamma-ray binary HESS J0632+057 was observed with MAGIC between October 2010 and November 2017, accumulating a total of 68 h of data. Some of these data were already published in [21]. After quality cuts, a total of 57.4 h remain. The data were taken under dark and moderate-to-strong moonlight conditions, and with zenith angles between 38 and 67°. The presence of a bright night sky background for the moon observations increases their energy threshold with respect to dark observations from 147 to 251 GeV. The MAGIC observations of HESS J0632+057 are part of a larger joint campaign with H.E.S.S. and VERITAS.

2.3 1A 0535+262

1A 0535+262 was observed with MAGIC between November 17 and December 19 2020, contemporaneously to the giant X-ray flare. The bulk of the MAGIC observations took place during the peak of X-ray emission around November 19 (MJD 59172). After the data quality selection, which accounts for non-optimal weather conditions, 8.2 h of observations remained for further analysis, all of them done under dark conditions and at zenith angles below 35°.

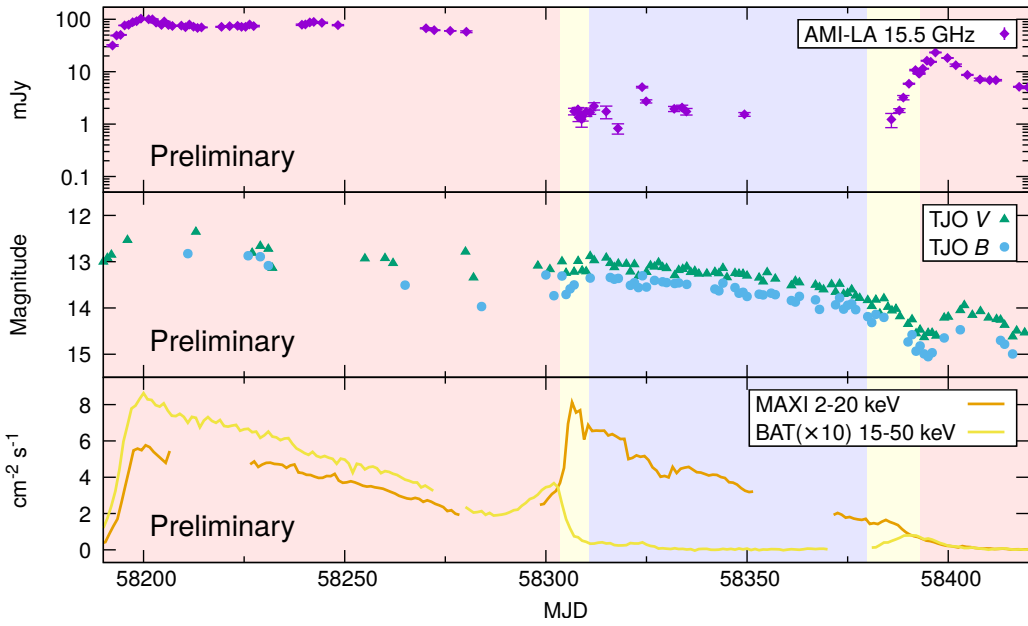


Figure 1: From *top to bottom*: Radio, optical and X-ray light curves of MAXI J1820+070 during its 2018 outburst. The shaded areas correspond to the HS (light red), the HS–SS and SS–HS transitions (yellow), and the SS (light blue). The units of the bottom panel are [$\text{ph cm}^{-2} \text{s}^{-1}$] for MAXI/GSC, and [$\text{counts cm}^{-2} \text{s}^{-1}$] for *Swift*/BAT. The latter fluxes are multiplied by 10 for a better visualisation.

3. Results and discussion

3.1 MAXI J1820+070

The MAGIC observations of the outburst of MAXI J1820+070 do not yield a significant detection of the source, and an integral flux upper limit (UL) above 200 GeV of $2.2 \times 10^{-12} \text{ cm}^{-2} \text{ s}^{-1}$ is obtained for the full data set. This value is computed using a 95% confidence level and assuming a power-law spectrum with index -2.5 .

The light curve of MAXI J1820+070 during the outburst, as seen by different instruments, is shown in Fig.1. Radio data from AMI-LA is taken from [22], while optical data in the *V* and *B* filters from the Joan Oró Telescope (TJO; [23]) are taken from [24]. We also include public light curves from MAXI/GSC¹ and *Swift*/BAT². Without accounting for the radio emission of transient ejections launched during the HS–SS transition, which are dominant throughout the SS [22], the radio and hard X-ray fluxes have similar behaviours. They follow the standard picture of black-hole X-ray binaries, for which steady radio jets in the HS coexist with a hard X-ray emitting corona, both of them disappearing in the SS. These multiwavelength observations, together with the obtained VHE ULs, allow to set constraints on the size and position of a potential gamma-ray emitter in MAXI J1820+070. A detailed discussion on this issue will be given in a future joint publication of MAGIC, H.E.S.S. and VERITAS.

¹http://maxi.riken.jp/star_data/J1820+071/J1820+071.html

²<https://swift.gsfc.nasa.gov/results/transients/weak/MAXIJ1820p070>

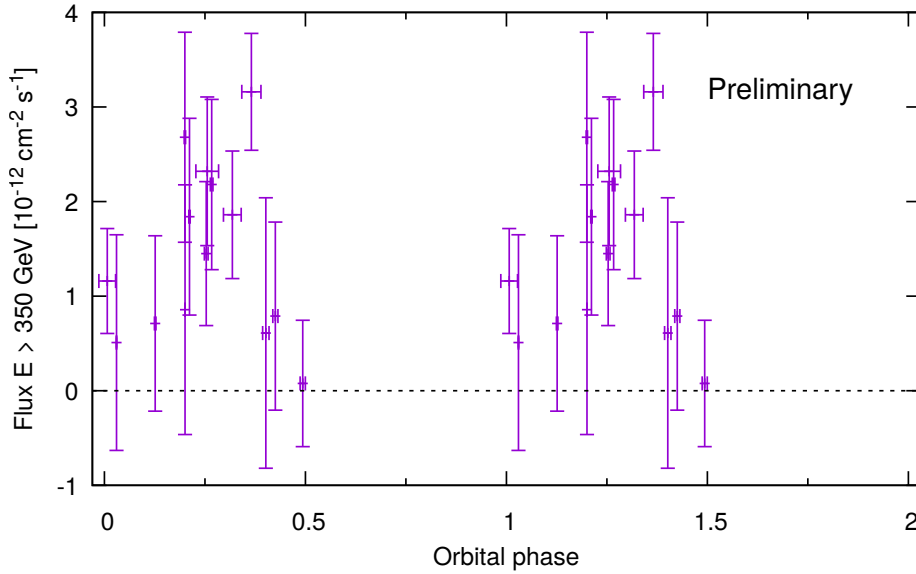


Figure 2: Phase-folded light curve of HESS J0632+057 assuming an orbital period of 316.8 days at energies above 350 GeV, as seen by MAGIC. Two orbits are shown for visualisation purposes.

3.2 HESS J0632+057

The long-term observations of HESS J0632+057 have allowed to better sample its VHE emission along the orbit. The VHE light curve obtained from MAGIC data above 350 GeV is shown in Fig. 2, phase folded with an orbital period of 316.8 days. The observations were mainly done at orbital phases between 0 and 0.5. A maximum in the flux is found in the orbital range 0.2–0.4, and a minimum is present at phases around 0.5.

The results of the HESS J0632+057 analysis are part of a larger long-term observational campaign involving also the H.E.S.S. and VERITAS telescopes. This multi-year sampling of HESS J0632+057 allowed for the first-time determination of the orbital period from VHE data only, consistent with the previously determined X-ray period of 316.8 days [9]. A forthcoming publication will show the combined results of the three Collaborations, and will also include X-ray and optical data. We refer to this upcoming joint publication for a detailed discussion of the observations and the interpretation of the results.

3.3 1A 0535+262

The analysis of the 8.2 h of observations of 1A 0535+262 does not reveal any significant VHE signal in the MAGIC data. The detection significance of the whole data set is 1.3σ (computed following the usual Li&Ma formula [25]). The integral flux UL at energies above 100 GeV is $5.0 \times 10^{-12} \text{ cm}^{-2} \text{ s}^{-1}$ (with a 95% confidence level and an assumed power-law spectral index of -2.6). Fig. 3 shows the light curve of 1A 0535+262 in VHE gamma rays and X-rays, the latter extracted from public *Swift*/BAT³ and MAXI⁴ data. All the individual VHE flux points have a

³<https://swift.gsfc.nasa.gov/results/transients/1A0535p262/>

⁴http://maxi.riken.jp/star_data/J0538+263/J0538+263.html

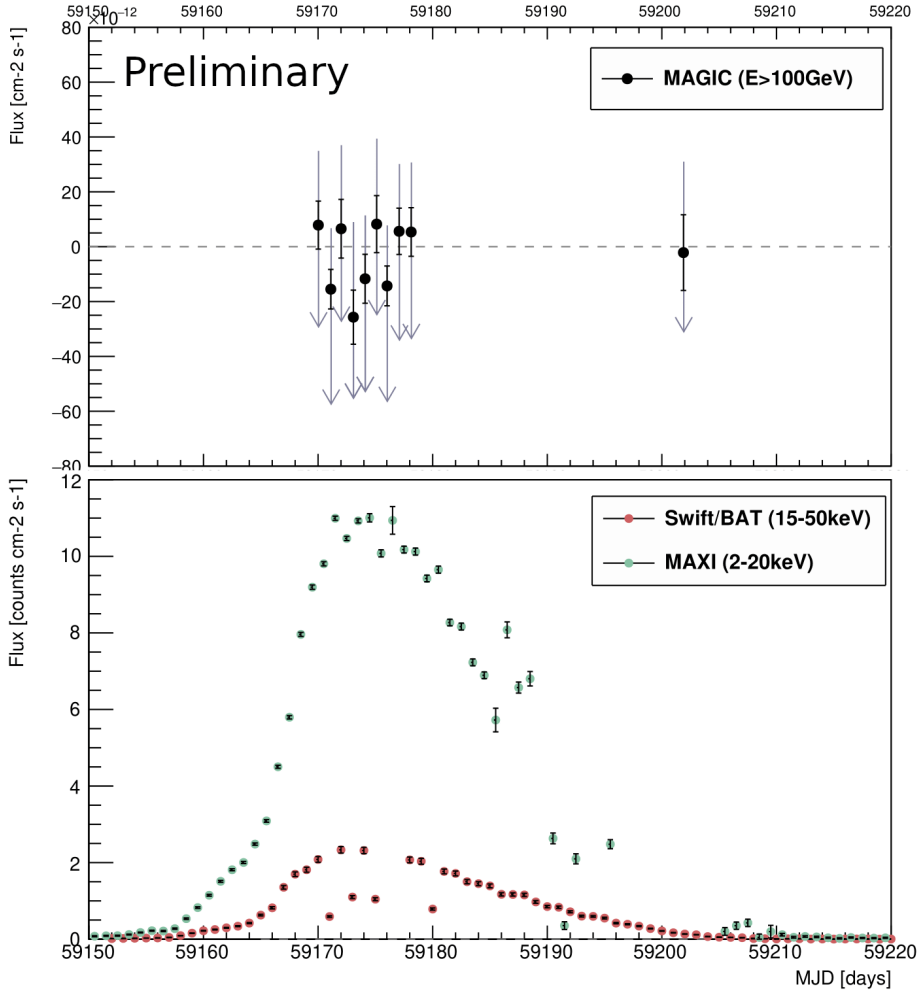


Figure 3: *Top panel:* VHE light curve of 1A 0535+262 above 100 GeV for the source outburst in 2020. The points show the computed fluxes, whereas the grey arrows represent the corresponding ULs at a 95% confidence level. *Bottom panel:* X-ray light curve of 1A 0535+262 as seen by *Swift*/BAT and MAXI in the same time period. Both panels use a daily time binning.

significance below 2.5σ , and the corresponding ULs are also shown.

4. Summary

We have reported on recent VHE gamma-ray obtained with the MAGIC telescopes for the Galactic binary sources MAXI J1820+070, HESS J0632+057 and 1A 0535+262. For the first two sources, upcoming joint publications with H.E.S.S. and VERITAS will provide more details on the results and the corresponding discussion. MAXI J1820+070 is not detected at VHE and flux ULs are computed, which together with the multiwavelength data from radio to X-rays allow to put constraints on a potential VHE emitter in the source. A clear orbital modulation is observed in

HESS J0632+057 at VHE, and the combined MAGIC, H.E.S.S. and VERITAS observations of the source allowed to determine for the first time its orbital period from VHE data only. Finally, the brightest recorded X-ray flare from 1A 0535+262 has not come with detectable VHE emission, and integral flux ULs are reported.

Acknowledgments

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https://magic.mpp.mpg.de/acknowledgments_ICRC2021

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