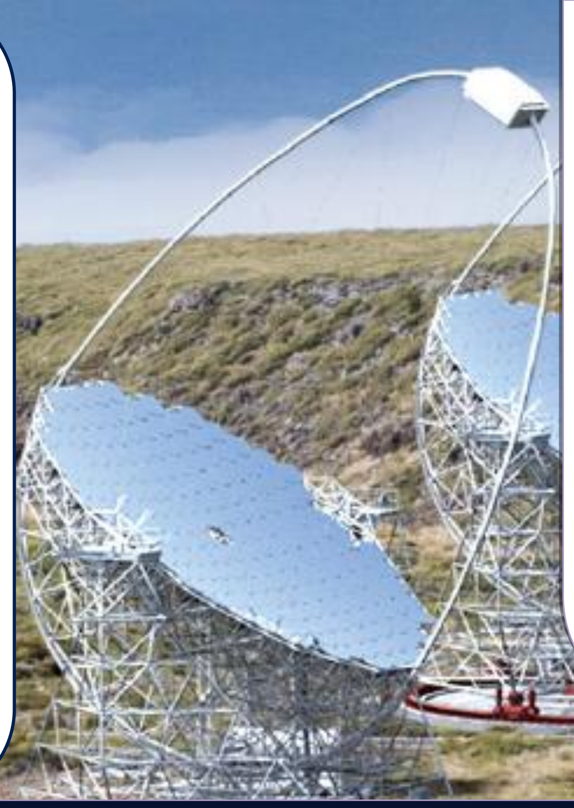
Temporal resolution of transient sources with LST-1: application to HESS J0632+057

A. Aguasca-Cabot[1], P. Bordas[1] and M. Ribó[1] for the CTA-LST Project[2]

[1]Departament de Física Quàntica i Astrofísica, Institut de Ciències del Cosmos (ICCUB), Universitat de Barcelona (IEEC-UB).
[2]See www.cta-observatory.org
Contact: arnau.aguasca@fqa.ub.edu



ICCUB Institut de Ciències del Cosmos · EXCELENCIA MARÍA DE MAEZTU · UNIVERSITAT DE BARCELONA · IEEC · cta cherenkov telescope array

ABSTRACT

The Cherenkov Telescope Array (CTA) prototype Large-Sized Telescope (LST-1) was inaugurated in 2018 and, after its commissioning, it is progressively entering the scientific data taking phase. In this contribution, we present a dedicated study on the capability of LST-1 to probe the very high energy (VHE) emission from galactic transient sources. Making use of numerical simulations of the VHE flux profiles for selected cases, we constrain the minimum time required to obtain a significant detection of the source, requiring a test statistics TS ≥ 4 for every flux point in the simulated source light curve. We apply our algorithm to the gamma-ray binary system HESS J0632+057. Our results suggest that the minimum time-bin in HESS J0632+057 obtained with the LST-1 would be a few minutes at the maximum flux phase (0.3-0.4 and 0.6-0.8), whereas at the minimum flux phase (0.4), it would be of a few hours. We briefly discuss the timing capabilities of LST-1 for galactic transient events.

INTRODUCTION

CTA will provide a much better sensitivity than current VHE facilities. The LST-1 is the first Large-Sized Telescope prototype of CTA, it has an excellent sensitivity between 20 GeV to 3 TeV [1]. The telescope is currently under the commissioning phase in La Palma, Canary Islands.

The galactic transient source HESS J0632+057 is expected to be observed with CTA. HESS J0632+057 is a γ-ray binary system formed by a Be star ($13.2 - 18.2\ M_{\odot}$) and a compact object ($< 2.5\ M_{\odot}$) [2]. The orbital period is $P = 315 \pm 5$ days [3], within which the source displays significant variability. The phase-folded light curve displays a maximum at orbital phase ~ 0.35, a dip in emission right after, and a second peak at a phase of about 0.7 (see Fig. 1).

The average differential energy spectra of HESS J0632+057 at VHE using observations from all orbital phases follows a power law,

$$\emptyset = \emptyset_0 \left(\frac{E}{E_0}\right)^{-\Gamma},$$

with $\Gamma = 2.67 \pm 0.05$, $\emptyset_0 = (4.0 \pm 0.2) \times 10^{-13}\ \mathrm{cm^{-2}\ s^{-1}\ TeV^{-1}}$ and $E_0 = 1$ TeV [5]. The values of the spectral components from [5] are used as nominal in our work. In Fig. 1, we show the flux measurements above 350 GeV as a function of the orbital phase, while the red line indicates the reference fluxes we have used in our simulations to describe the temporal emission of HESS J0632+057. Our light curve is obtained through the parametrization of two generalized gaussian, one for each peak of the light curve.

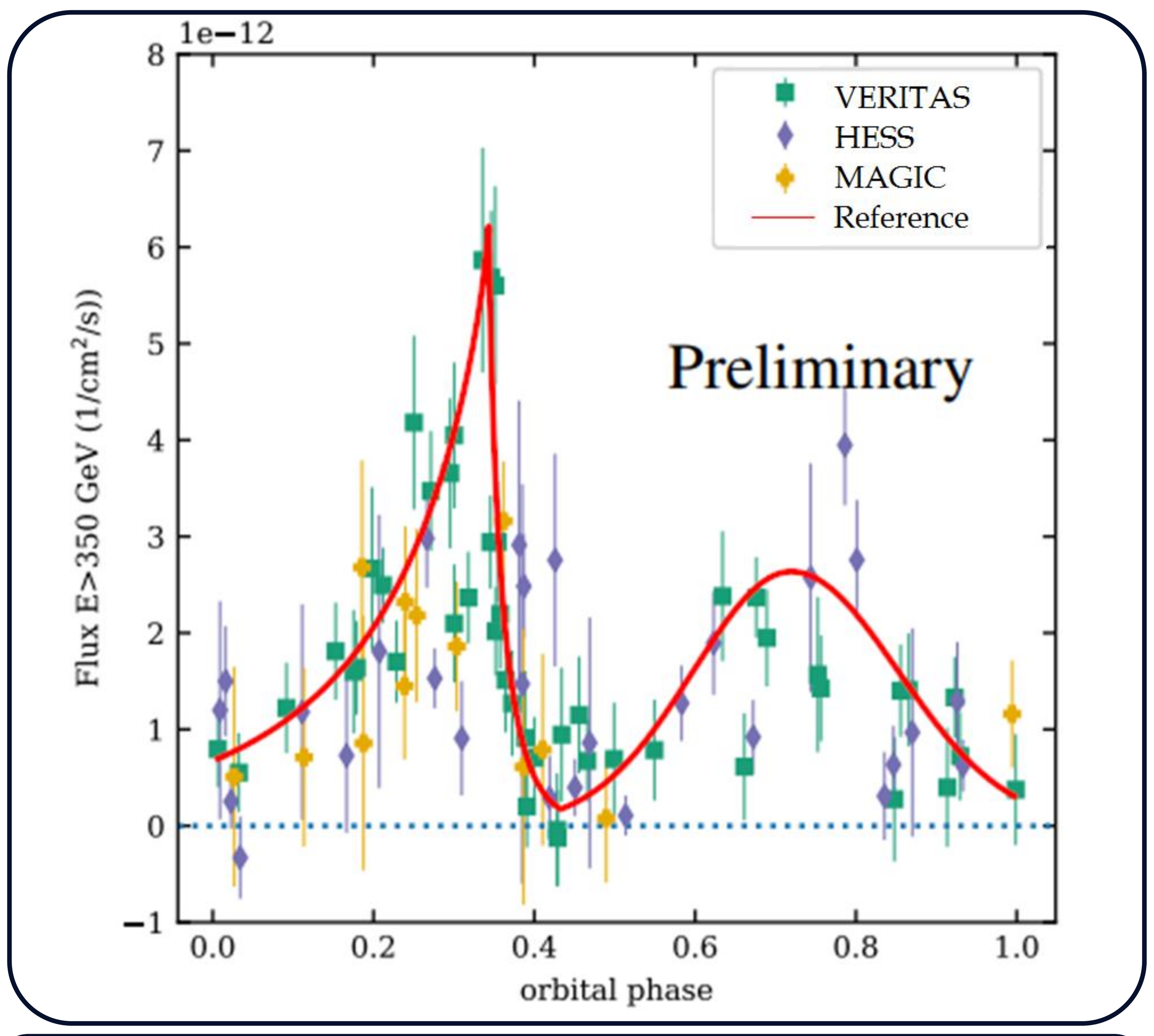


Fig. 1: Observed phase-folded light curve from [4] with the light curve considered in our simulations super-imposed (red line). Figure adapted from [4].

METHODOLOGY

To obtain the best temporal resolution attainable with LST-1 on HESS J0632+057, we simulate the VHE light curve of the source with time-bins chosen such to acquire a source detection significance in each bin of at least $TS = 4$ (approximately 2σ detection). The algorithm works through an iterative process that keeps increasing the number of events used to compute the statistical significance. Spectral variations are considered through slight variations of the reference spectral index of the source (Γ) and the amplitude ($\emptyset_0$) assuming the same integral flux above $E > 350$ GeV. Three different spectral indexes are set in our simulations, one is the nominal value ($\Gamma = 2.67$), and the other two $\Gamma = 2.50$ and 3.00. For each simulation, only one spectral index is used for the whole orbital period.

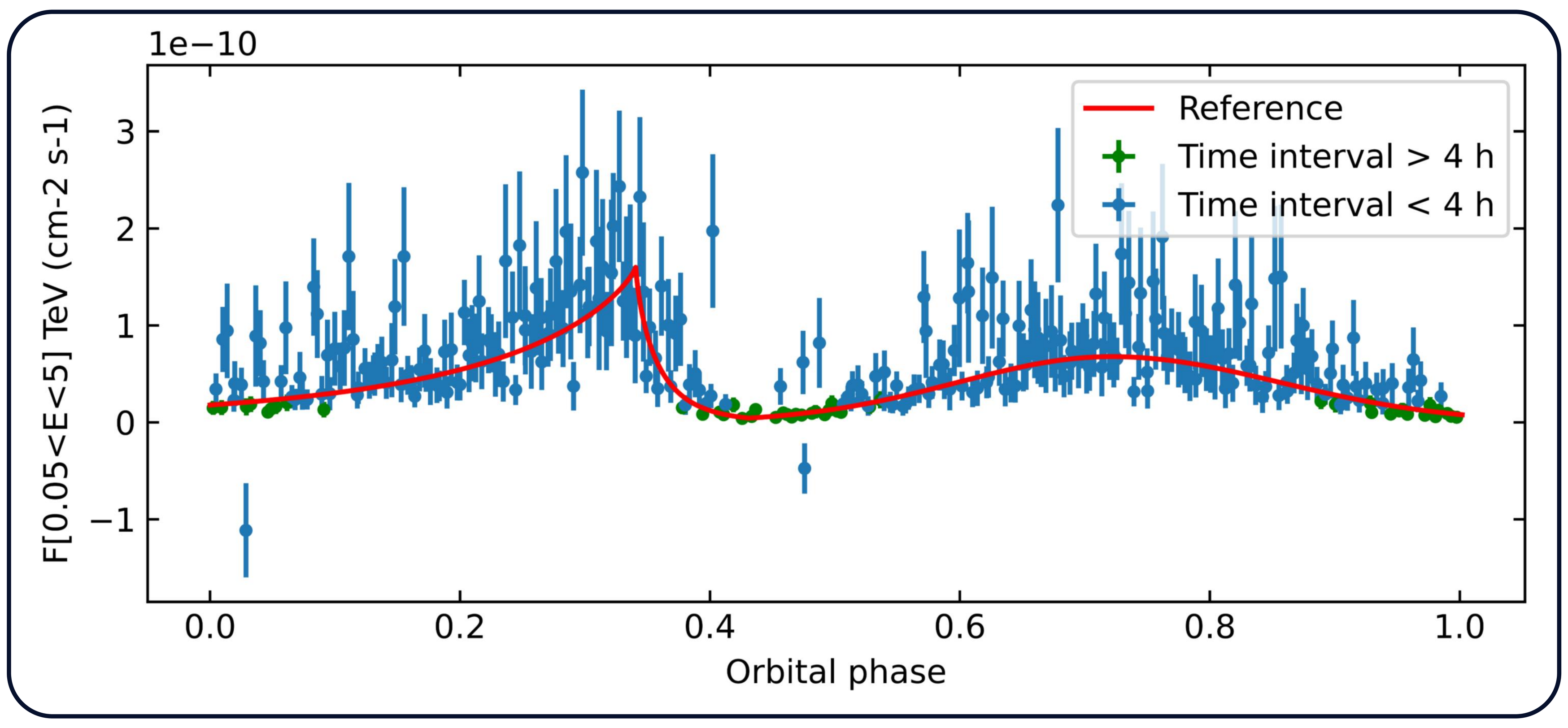


Fig. 2: Simulated light curve. Only one flux per day is shown, which is chosen randomly between the different fluxes obtained in each day. Green and blue dots are fluxes with longer and shorter time intervals than 4 hours, respectively. In addition, the light curve used in our simulations (red line) is displayed.

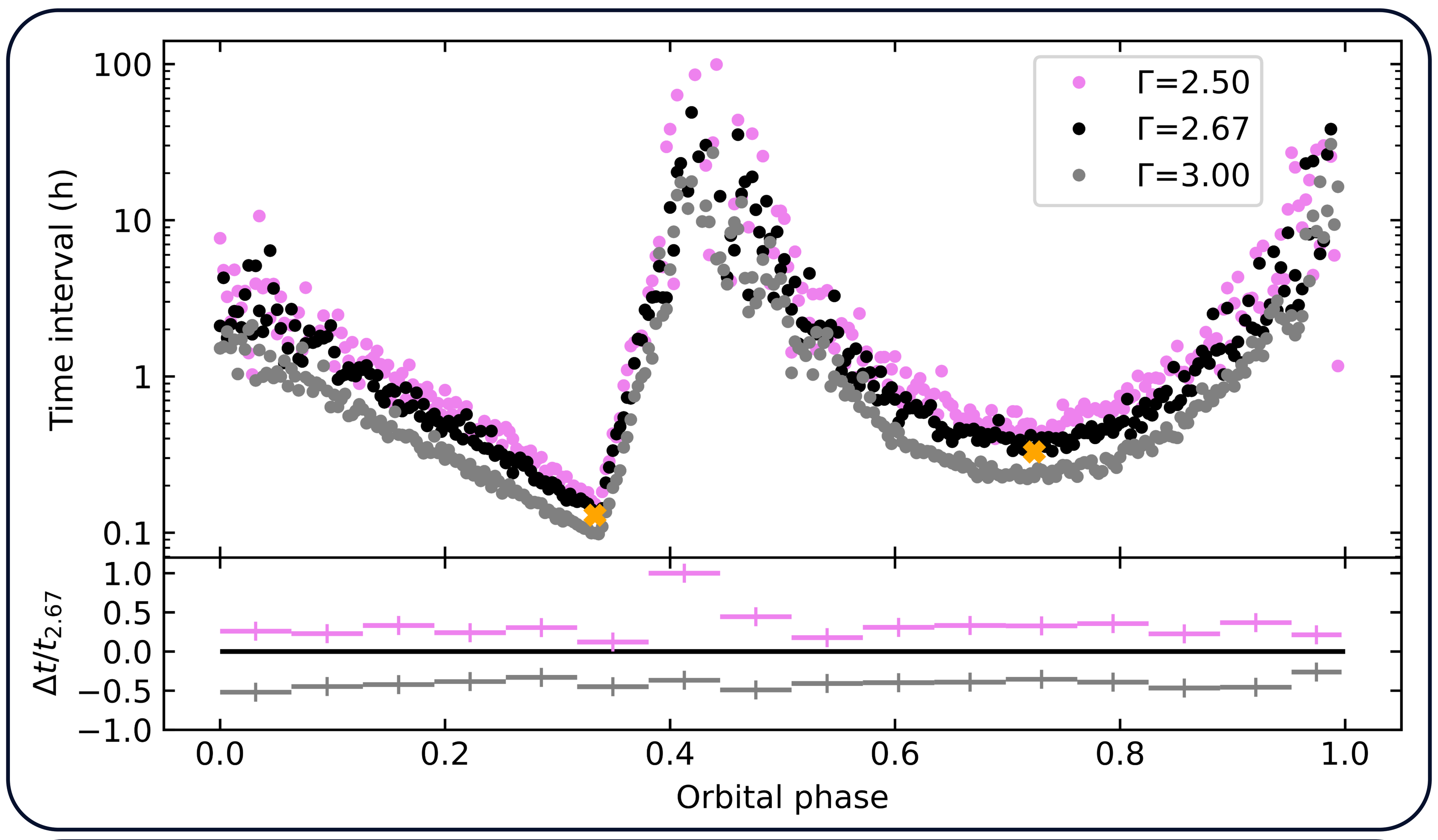


Fig. 3: Average time interval as a function of the orbital phase for spectral indexes $\Gamma = 2.67, 2.50$ and 3.00, represented as black, violet and grey dots, respectively. Each dot has been computed averaging all time intervals of the simulated flux obtained for each day. Orange crosses mark the minimum time interval with $\Gamma = 2.67$ for the first and second peaks. In addition, the relative differences with respect to the time intervals obtained with $\Gamma = 2.67$ for $\Gamma = 2.50$ and 3.00 are shown. The horizontal error bars delimiter the fluxes used for each relative difference value.

RESULTS AND CONCLUSIONS

The obtained simulated light curve for $\Gamma = 2.67$ (see Fig. 2) follows the assumed light curve in our work with some dispersion. The average time interval for each day along the orbital period is shown in Fig. 3 for the different spectral indexes considered. Using the nominal spectral components ($\Gamma = 2.67$), a temporal resolution as short as ~ 10 and ~ 20 minutes is obtained for the first and second peaks, respectively. For the minimum flux phase (see orbital phases $0.4 - 0.5$ in Fig. 2), assuming $\mathrm{F}(E > 350\ \mathrm{GeV}) = 1.7 \times 10^{-13}\ \mathrm{cm^{-2}\ s^{-1}}$ in this stage, LST-1 would require around 40 hours for a 2σ detection (see Fig. 3). On the other hand, the time-bin widths are higher for the harder spectral index ($\Gamma = 2.50$) than with $\Gamma = 2.67$, while the opposite is observed for the softer spectral index ($\Gamma = 3.00$).

To sum up, the detection significance of HESS J0632+057 would depend on its orbital phase and spectral profile. Considering the spectral parameters and the temporal emission studied in this work, LST-1 would require from a hundred hours to a few minutes for a $TS = 4$ detection.

REFERENCES

[1]. Acharya, B. S. et al. (2017).
[2]. Aragona, C. et al. (2010). ApJ, 724(1), 306.
[3]. Aliu, E. et al. (2013). ApJ, 780(2), 168.
[4]. Maier, G. et al. (2019). arXiv:1908.03589.
[5]. Maier, G. (2017). arXiv:1708.04045.

ACKNOWLEDGEMENTS

We gratefully acknowledge financial support from PID2019-104114RB-C33/AEI/10.13039/501100011033, as well from the agencies and organizations listed here: www.cta-observatory.org/consortium_acknowledgments.