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Search for VHE gamma-ray emission from the TDE AT 2021uqv with H.E.S.S.

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Tidal Disruption Events (TDEs) are a relatively young class of transient phenomena, which occur whenever a star approaches a supermassive black hole (SMBH) close enough to be ripped apart by its tidal forces. Part of the stellar debris forms an accretion disk, which in turn may result in a flare of electromagnetic radiation, which is typically detected in optical/UV and X-ray energy bands. Some TDEs have also been detected in radio and non-thermal X-rays, which suggests active particle acceleration to relativistic energies likely in shocks or jets. However, up to now, there are no TDEs detected in gamma rays, neither in the HE (100 MeV - 100 GeV) nor in the VHE (100 GeV - 100 TeV) regime. In 2021, the H.E.S.S. collaboration observed the TDE AT 2021uqv as part of its TDE programme. No significant VHE gamma-ray emission was detected in ∼27 h of observations, and therefore, spectral upper limits are presented. In addition, we also discuss multi-wavelength information available for AT 2021uqv.

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1. Introduction

Stars in the vicinity of a supermassive black hole (SMBH) may be captured and disrupted by the SMBH's tidal forces, producing a phenomenon known as a Tidal Disruption Event (TDE) [1]. Part of the star debris is ejected at high speed and the remaining material forms an accretion disk, which is accompanied by a burst of electromagnetic radiation (note that in the case of SMBHs with mass $\gtrsim 10^8 M_\odot$, the star would be swallowed whole, and no electromagnetic flare would be produced [2]). The flare can be detected in a broad range of the electromagnetic spectrum – from radio to X-ray [3–5]. However, there are no TDEs detected in HE or VHE gamma rays so far.

Twenty years ago, the population of detected TDEs grew at a rate of a few per year. The detections of these events came predominantly from sky surveys in the X-ray band. However, thanks to the development of large-scale optical survey facilities such as ZTF[1], ATLAS[2] and ASAS-SN[3], the rate of discovered TDEs has risen to almost one per month. Optically discovered TDEs are typically reported via the Transient Name Server (TNS)[4]. Multi-wavelength follow-up information as well as TDEs discovered in other wavelengths are often published via the Astronomer's Telegram (ATel)[5] or the Gamma-ray Coordinates Network (GCN)[6].

At first glance, an optical light curve from a TDE can be similar to the ones from supernova (SN) explosions or active galactic nuclei (AGNs). There are several features that help to classify the event as a TDE and distinguish it from almost all SNe and AGN flares [6, 7]: located in the nucleus of the host galaxy; a relatively long rise time and a smooth power-law decline of the light curve; a hot, blue continuum and very broad emission lines in the spectrum. However, as measuring the photometric and spectroscopic characteristics requires time, a TDE classification usually takes a relatively long period of time, from several days to several months. Although TDEs can be detected in different wavelengths on timescales from several months to several years, long classification times can hinder multi-wavelength coverage.

A large number of TDE detections motivated the construction of TDE catalogues, the performance of statistical studies, the improvement of the classification procedure and the expansion of our knowledge about this transient phenomenon. It also significantly increased the interest in TDE exploration generally in the scientific community, including the High Energy Stereoscopic System (H.E.S.S.) since VHE gamma rays can be produced in non-thermal processes such as inverse Compton or particle interaction with surrounding matter. Naturally, the most promising VHE emitter candidates are jetted (non-thermal) TDEs like Swift J164449.3+573451 [8], which are very rare events and only four are known up to now. However, detection of radio emission in thermal TDEs suggests ongoing particle acceleration in e.g. relativistic or non-relativistic outflows [3]. Detection of VHE gamma-ray emission from a TDE would give valuable information about particle acceleration in this kind of transients and their environment.

The first H.E.S.S. TDE follow-up observation was performed in autumn 2021 resulting in the data taken for the TDE AT 2021uqv that is reported in this proceeding.

[1] https://www.ztf.caltech.edu/
[2] https://atlas.fallingstar.com/
[3] https://asas-sn.osu.edu/
[4] https://www.wis-tns.org/
[5] https://www.astronomerstelegram.org/
[6] https://gcn.gsfc.nasa.gov/

2. AT 2021uqv observation and data analysis

The optical transient AT 2021uqv was detected with the Zwicky Transient Facility (ZTF) [9, 10] at the position of RA = $00^{h}\,32^{m}\,39.88^{s}$ Dec = $+22^\circ\,32'\,56.04''$ on July 29, 2021 (MJD 59424) [11]. It was classified as a TDE based on its location at the nucleus of the host galaxy and spectroscopic characteristics – a blue continuum and broad emission lines, typical optical features of TDEs [6]. The classification information appeared on the TNS website on the 4th of October (MJD 59491) together with a report about the AT 2021uqv X-ray detection with *Swift*-XRT [13]. AT 2021uqv was detected in the X-ray band with $\sim 3\sigma$ on August 28th (MJD 59454) and $\sim 4.3\sigma$ on October 2nd (MJD 59489) with an exposure time of 1.61 ks and 3.11 ks, respectively. According to the report, the X-ray spectrum obtained on October 2nd was fitted with an absorbed blackbody model and resulted in a flux of about 2×10^{-13} erg/cm^2/s in the 0.3 - 1 keV energy range. Observations on September 15th (1.73 ks) as well as in the period of November - January did not reach the detection limit of 3σ.

The obtained spectral shape suggests the thermal nature of the X-ray emission. In the literature, there are examples of TDEs exhibiting both thermal and non-thermal X-ray components (e.g. XMMSL1 J074008.2−853927 [14]). However, existing *Swift*-XRT data would not allow for firm identification of the presents of the non-thermal component due to low statistics (~0.007 count/s) and exposure. Taking into account the proximity of the host galaxy (SDSS J003239.88+223256.0) with a redshift of 0.106 and the detection of relatively bright X-ray emission, follow-up observations with H.E.S.S. were triggered.

H.E.S.S. is an array of five Imaging Atmospheric Cherenkov Telescopes (IACTs). It is located at an altitude of 1800 m a.s.l. on the Khomas Highland in Namibia and consists of two types of telescopes. Four 12 m-dish telescopes (CT 1-4) are situated in the corners of a square with 120 m side length and the fifth telescope (CT 5, 28 m dish in diameter) is placed in the middle of the array. AT 2021uqv observations with H.E.S.S. were ongoing from October 10th to November 11th and resulted in approximately 27 h of good quality data. The H.E.S.S. observation is illustrated in Figure 1, which also shows a general timeline of the event including *Swift*-XRT and UVOT observations.

H.E.S.S. data from CT 1-4 telescopes obtained during the follow-up campaign that satisfy standard quality selection criteria [15] were analysed using the ImPACT reconstruction procedure [16], which employs an image-template-based likelihood fitting. The hadronic background produced by cosmic rays is rejected using a machine learning algorithm [17]. All results were cross-checked using an independent calibration and analysis chain [18]. No significant VHE gamma-ray emission was found at the position of AT 2021uqv. Figure 2 shows the differential upper limits derived above the energy threshold of 316 GeV at the 95% confidence level assuming a photon index of −2 [19]. As seen on the plot, the upper limits in the VHE gamma-ray range are at the same level as the observed X-ray flux shown in Figure 1, limiting the contribution of the non-thermal component in the overall X-ray emission.

Moreover, an analysis has been performed using *Fermi*-LAT data in a time range covering the H.E.S.S. observation. The analysis was performed with the python package fermipy 1.1.2 [20]. The instrument response function employed in the analysis is `P8R3_SOURCE_V3`. The isotropic spectral template `iso_P8R3_SOURCE_V3_v1.txt` and the Galactic interstellar emission model

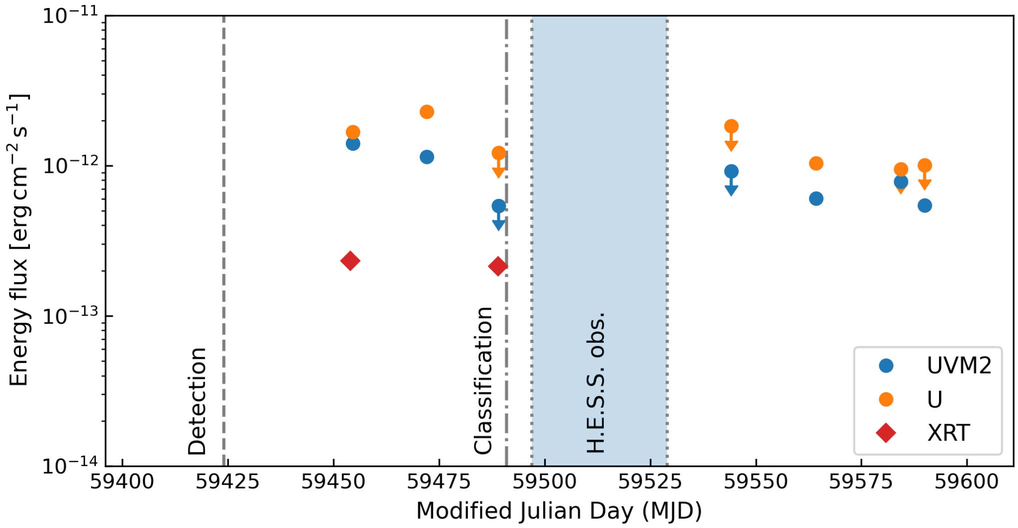

Figure 1: A general timeline of the AT 2021uqv event. Dashed and dash-dotted lines show the discovery and classification dates. The blue-shaded area signifies the time period when H.E.S.S. observations were conducted. Two *Swift*-XRT observations that yielded a detection are marked with red diamonds. Data from two *Swift*-UVOT filters are shown with blue (UVM2, 1928 Å) and orange (U, 3465 Å) colours. Here, *Swift* data were analysed with `HEASOFT 6.29` [12]. *Swift*-XRT spectra were fitted with the absorbed blackbody model with a temperature of ~50 eV. It has to be noted that the fit quality is rather poor, resulting in a reduced χ^2 value of 7.57/67 and 4.63/27 for August 28th (MJD 59454) and October 2nd (MJD 59489), respectively.

`gll_iem_v07.fits` were used. The analysis was performed in the 100 MeV to 100 GeV energy range. The region of interest was chosen to be $20° \times 20°$. All source model parameters were frozen except for the normalisation of all sources within 3 degrees of the source position, the isotropic diffuse component and the normalisation of AT 2021uqv. The photon index of AT 2021uqv was fixed to −2. No significant emission could be identified in the *Fermi*-LAT data. The differential upper limits, extracted for the 95% confidence level and photon index of −2, are shown together with the H.E.S.S. upper limits in Figure 2.

3. Summary and outlook

TDEs are a relatively poorly studied class of transient events. For a long time, only a handful of events were known. Only in the past few years, the development of optical transient search facilities has significantly increased the number of TDE detections and given a push for the growth of interest in this field of research.

In the autumn of 2021, H.E.S.S. performed a follow-up observation of AT 2021uqv, an optically detected TDE with bright thermal X-ray emission detected with *Swift*-XRT. No evidence of VHE gamma-ray emission was found in the data collected during ~27 h of observations in October–November. Also, no significant signal was found in HE gamma-ray analysis using *Fermi*-LAT data from the same time period as the H.E.S.S. observations.

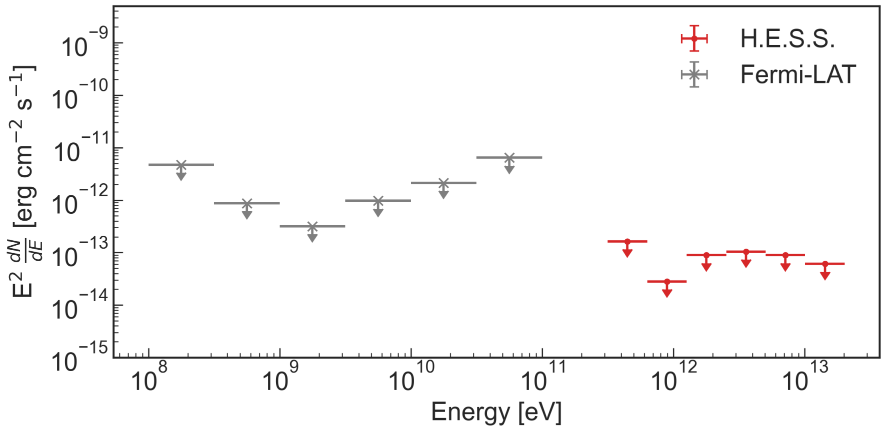

Figure 2: H.E.S.S. and *Fermi*-LAT differential upper limits assuming a photon index of −2. Both upper limits are calculated for the time period of H.E.S.S. observations, from October 10th to November 11th.

Starting in 2022, the H.E.S.S. Legacy programme was established as a long-term key science plan that serves as an observation strategy for the upcoming years. According to this programme, a significant part of the available observation time is allocated for time-domain science including the TDE observation programme. The H.E.S.S. collaboration is interested in following up on the nearby non-thermal TDEs, i.e. the ones, which show a sign of active particle acceleration. This way, H.E.S.S. follow-up observations can be triggered for the TDEs, which fulfil at least one of the following criteria: detection of radio emission, non-thermal X-rays, HE or VHE gamma-ray emission, and coincidence with neutrino events.

The major obstacle to triggering H.E.S.S. observations of TDEs is the lack of multi-wavelength information that indicates the presence of non-thermal emission as well as theoretical modelling of VHE gamma-ray emission production. Therefore, we would like to encourage multi-wavelength follow-up observations of TDEs by other instruments and publicly report the results, for example via channels such as the GCN, ATel, AstroNote etc. In combination with improved theoretical predictions, it would help to trigger VHE instruments and further improve the observation strategy.

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