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The first observation of an optical counterpart to a Short GRB from the Czech Republic: GRB 160927A

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We present the earliest observations of the short Gamma-Ray Burst, GRB 160927A, by the D50 telescope from the Ondřejov Observatory. The 50-cm robotic telescope reacted to the alert of GRB 160927A and started obtaining unfiltered images 40 seconds after the trigger with a total exposure of 7230 seconds. The magnitude obtained by D50 reached 22.4 ± 0.3 mag not corrected for the galactic foreground extinction of 0.2 mag. We obtained the temporal decay index with $\alpha = 0.93 \pm 0.03$ and the spectral slope with $\beta = 0.68 \pm 0.2$.

KEYWORDS:
Gamma ray: bursts

1 | INTRODUCTION

Gamma-ray bursts (GRBs) bear a formidable attribute of the brightest and most energetic events observed in the distant Universe (Kumar & Zhang, 2015). Since the first detections of GRBs by the Vela satellites during the 1960s, some questions concerning these events have been answered, however, many new inquiries have been established as well.

The central engine collimates a high-energetic narrow jet, which then pierces through the circumstellar matter producing γ-rays in the dense regions and a less energetic afterglow in the sparser regions further away from the central engine. Also, the radiation leaving the GRB must travel through the intergalactic and galactic foreground, resulting in significant changes in the observed spectrum (Rácz et al., 2017).

The duration of GRBs is distinguished by the time it takes to accumulate 90 % of the observed photons, known as T_{90}. There are two major groups of GRBs: short and long. However, this simple classification had been called into question by adding a third group of intermediate GRBs (Horváth, 1998). Long-duration GRBs are widely accepted to be related to the core-collapse of massive stars (Hjorth, Sollermann, & Moller, 2003; Stanek, Matheson, & Garnavich, 2003), and help to indicate large structures of the Universe (Mészáros, Bagoly, & Vavrek, 2000) leading to the discovery of the largest known structure in the Universe, the Hercules-Corona Borealis Great Wall found in 2014 (Horváth, István, Bagoly, Zsolt, Hakkila, Jon, & Tóth, L. V., 2015).

On the other hand, no hypothesis about the originator of short GRBs has been proven yet. Although, on August 17, 2017, the Advanced LIGO and Advanced Virgo gravitational-wave detectors observed a binary neutron star system, which was associated with the trigger of the Fermi-GBM telescope by GRB 170817A 1.7 seconds after the GW detection. This joint observation supported the hypothesis of a neutron star merger and its association with short gamma-ray bursts (Abbott et al., 2017). However, Horváth (Horváth et al., 2018) classified it as an intermediate burst.

Additionally, GRBs are not only distinguished by their duration. Hence, observed prompt emission, negligible spectral lag and harder spectra are all common properties for short GRBs. Generally, the prompt emission refers to the activity of the central engine, where the first 1-2 seconds of the long events show similar spectral evolution as for the short bursts. Short GRBs are found to be generally less energetic than long GRBs with their isotropic equivalent energy, E_{iso} , of the order of 10^{49}-10^{51} and to occur at a lower redshift (D'Avanzo, 2015).

The Neil Gehrels *Swift* Observatory was launched in 2005 and consists of three main instruments: the Burst Alert Telescope (BAT), the X-ray Telescope (XRT), and the UV/Optical

[0]**Abbreviations:** GRB, Gamma-ray burst; XRT, X-Ray Telescope; BAT, Burst Alert Telescope

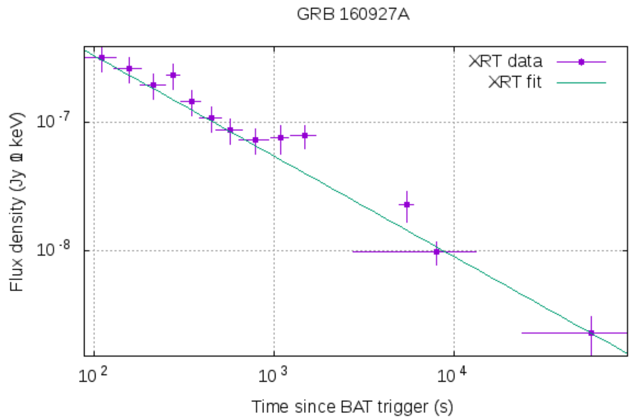

FIGURE 1 XRT data of GRB 160927A

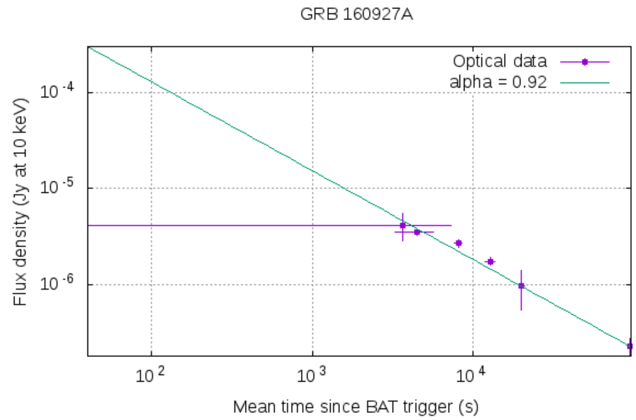

FIGURE 2 Optical data of GRB 160927A

Telescope (UVOT). Each instrument was designed to detect specific energy ranges: 15-150 keV for the BAT, 0.3-10 keV for the XRT , and 170-600 nm for the UVOT. All of *Swift*'s discoveries are immediately transmitted to the ground, where it alerts other observatories in order to join the space telescope in observing the GRB counterparts. The main objectives of the mission were to determine the origin of GRBs, to classify GRBs and search for new types, to study the interaction of the ultra-relativistic outflows of GRBs with their surrounding medium, and finally to use GRBs to study the early universe out to redshift greater than 10 (Gehrels et al., 2004). Since its launch it has observed more than a thousand GRBs (Barthelmy, Barbier, & Cummings, 2005; Burrows, Hill, & Nousek, 2005; Roming, Kennedy, & Mason, 2005).

In this paper, we examine the optical observation of the Short Gamma-ray burst by the D50 telescope along with other observations of GRB 160927A around the globe.

2 | GRB 160927A DETECTION

2.1 | Swift detection

At 18:04:49 UT, the *Swift* Burst Alert Telescope (BAT) triggered and located GRB 160927A. *Swift* slewed immediately to the BAT-derived position, allowing the X-ray afterglow (see Fig. 1) to be discovered readily with the *Swift* X-ray telescope (Gibson et al., 2016) with a 3.7" accurate position, which was later refined to 1.7". Hence, the refined position (Evans, 2016) of the burst was:

RA (J2000): 17h 04m 58.22s
Dec (J2000): +17d 19' 55.1"

A single peaked structure was observed in the BAT light curve with a duration of about 0.5 seconds. The light curve was modelled with a temporal power-law decay index α of

$$\alpha = 0.99 \pm 0.075.$$

Additionally, the spectrum formed from the photon counting mode data was also fitted with an absorbed power-law with a photon spectral index of

$$\beta = 1.72 \pm 0.23$$

(Page et al., 2016). The UVOT took a finding chart exposure of 150 s with the White filter starting 84 s after the BAT trigger. However, no conclusive afterglow candidate was found in the initial data products (Gibson et al., 2016).

3 | D50 TELESCOPE

D50 is one of the two robotic telescopes that reacts to GRB alerts operating at Ondřejov observatory near Prague, Czech republic (at lat: 49°54′33.8″N, long:14°46′52.9″E). It is the larger of the two telescopes with a diameter of 50 cm compared to the 2×20 cm diameter of the second telescope, BART, and therefore, capable of observing fainter objects.

The telescope is a reflector with Newton-type optical construction with field corrector and is driven by RTS2 (Kubánek, 2010), a system for autonomous robotic telescopes. The first tests of the telescope took place in 2008. The optical path consists of an 0.5 m parabolic primary mirror of 1975 mm focal length, a 100 mm elliptical secondary and a four-lens corrector TeleVue Paracorr. The telescope is equipped with with a EMCCD camera Andor iXon Ultra 888 that contains a format of 1024×1024 13 μm pixels, which provides a field of view of 20×20 arcmin. Another part of the detection system is the FLI CFW-5 filter wheel with standard Johnson-Bessel UBVRI photometric filters.

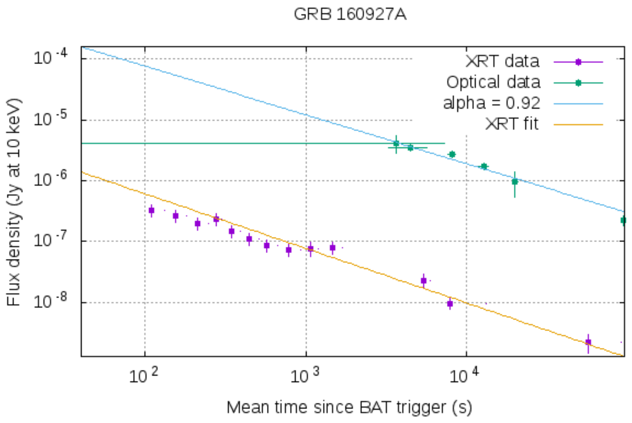

FIGURE 3 XRT and Optical data

4 | D50 OBSERVATION

The D50 telescope reacted to the alert 40 seconds after the trigger. It was the first ground telescope to react to the alert and locate the GRB. Immediately after the alert, it started obtaining 10 second unfiltered images with a total exposure of 7230 seconds, 25 10-second images and 349 20-second images. The estimated brightness of the object reached the unfiltered magnitude of 22.4 mag without applying the galactic foreground extinction of 0.2 mag (Schlegel, Finkbeiner, & Davis, 1998). The image with the exposure mean time 81 minutes after the burst can be seen in Figure 4 . We did not detect any new sources within or near the XRT error circle in the combined 25 10-second frame with mean exposure time of 124 seconds after the trigger and 3-sigma limit of $R > 20.5$. The light curve with the data of the optical afterglow follows a power-law decay with an temporal index of

$$\alpha = 0.93 \pm 0.03$$

(see Fig. 2 and Fig. 3) The spectral index β calculated from the combined XRT and Optical data was $\beta = 0.64$. Consequently, by averaging our result with the photon spectral index calculated by Lien (Lien et al., 2016), we obtained:

$$\beta = 0.68 \pm 0.2$$

By using the fireball model, we obtain the following parameters:

$$\alpha = \frac{3p-3}{4} \quad (1)$$

and

$$\beta = \frac{p-1}{2}, \quad (2)$$

with an electron power-law distribution $p = 2.24$, which could imply an afterglow expansion via slow cooling into an interstellar medium (ISM) environment (Greiner et al., 2018; Piran, 1999).

5 | OBSERVATIONS BY DIFFERENT TELESCOPES

As was previously stated, the D50 telescope was the first telescope on the ground to observe the faint afterglow of GRB 160927A. However, the burst was also detected by other observatories around the globe.

Approximately 55 minutes after the burst, the 1.5-m telescope RTT150 from the TUBITAK National Observatory in Turkey observed the event using TFOSC. The telescope obtained four 600s exposures in SDSS-r filter, however, in very poor weather conditions. The estimated magnitude was 22.3 (Tkachenko et al., 2016).

Next, the 3.6m Telescopio Nazionale Galileo (TNG) equipped with DOLORES started the observations in SDSS-r filter 2.13 hours after the burst. It took series of 5 images with the total exposure of 900 seconds and measured the magnitude was 22.6 ± 0.1 (D'Avanzo et al., 2016).

The 2.56-m Nordic Optical Telescope (NOT) equipped with the ALFOSC camera began its observations started 3.33 hours after the trigger. It obtained 5 300-second images in SDSS r-band and a magnitude of 23.07 ± 0.1 at median time of 3.56 hours after the burst (Xu et al., 2016).

Lastly, the GROND detector, mounted at the 2.2 m MPG telescope at ESO La Silla Observatory in Chile, started observing GRB 160927A 5 hours and 21 minutes after the GRB trigger during astronomical twilight. After 22.4 minutes of total exposure, the estimated AB magnitude in the GROND r-band reached 23.9 ± 0.4 with the mid-time of 5.58 hours (Wiseman, Bolmer, & Greiner, 2016).

6 | CONCLUSIONS

In conclusion, the detection of GRB 160927A by the D50 telescope marks the first-ever, short GRB observation in the Czech republic. D50 was also the first ground telescope to start the observation of the GRB 40 seconds after the *Swift*/BAT issued the trigger. After obtaining 25 10-second and 349 20-second unfiltered images, the final combined image provided a detection of an optical counterpart which, corrected for the galactic foreground extinction, was estimated to R = 22.2 ± 0.3. Combining the data from other observatories, we obtained the temporal decay index $\alpha = 0.93 \pm 0.03$ and the Optical-to-XRT spectral index $\beta = 0.68 \pm 0.2$. These numbers are consistent with a scenario of a fireball expanding in a slow cooling regime into a constant density interstellar matter.

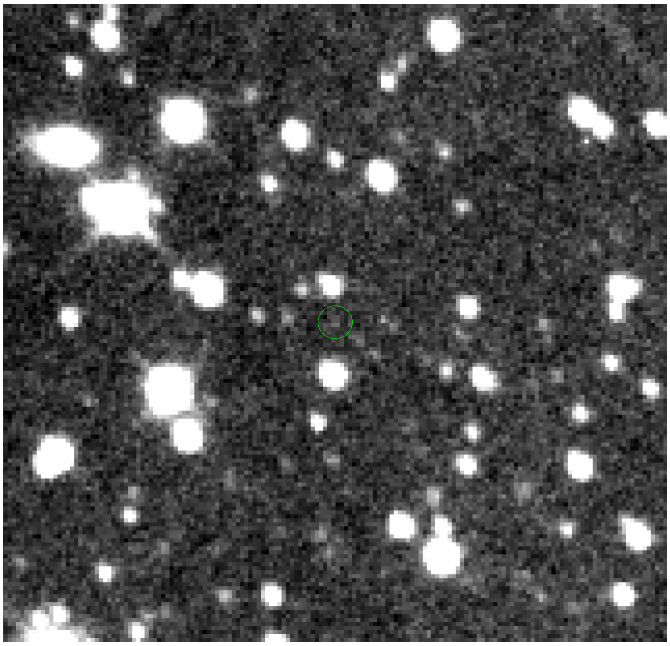

FIGURE 4 Image of the GRB 160927A afterglow taken by D50 telescope.

Author contributions

ŠT wrote the paper text, MJ provided image analysis and discussion, JŠ managed the data and observations. All three authors contributed equally to the paper.

Financial disclosure

None reported.

Conflict of interest

The authors declare no potential conflict of interests.

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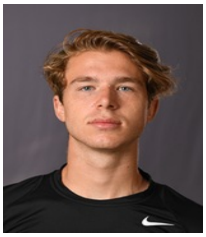

Šimon Trčka is an undergraduate student of Physics at the University of Rhode Island. Early in May, he began one of his two internships working with Martin Jelínek at Ondřejov Observatory near Prague, Czech republic. He will then move on to Tautenburg to work with Dr. Eike Guenther at the Karl Schwarzschild Observatory.

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