Constraints on Optical Emission of FAST-detected FRB 20181130B with GWAC Synchronized Observations

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Abstract

Multiwavelength simultaneous observations are essential to the constraints on the origin of fast radio bursts (FRBs). However, it is a significant observational challenge due to the nature of FRBs as transients with a radio millisecond duration, which occur randomly in the sky regardless of time and position. Here, we report the search for short-time fast optical bursts in the Ground-based Wide Angle Camera (GWAC) archived data associated with FRB 20181130B, which were detected by the Five-hundred-meter Aperture Spherical radio Telescope and recently reported. No new credible sources were detected in all single GWAC images with an exposure time of 10 s, including images with coverage of the expected arrival time in optical wavelength by taking the high dispersion measurements into account. Our results provide a limiting magnitude of 15.43 ± 0.04 mag in the R band, corresponding to a flux density of 1.66 Jy or 8.35 mag in AB system by assuming that the duration of the optical band is similar to that of the radio band of about 10 ms. This limiting magnitude makes the spectral index of $\alpha < 0.367$ from optical to radio wavelength. The possible existence of longer-duration optical emission was also investigated with upper limits of 0.33 Jy (10.10 mag), 1.74 mJy (15.80 mag), and 0.16 mJy (18.39 mag) for the durations of 50 ms, 10 s, and 6060 s, respectively. This undetected scenario could be partially attributed to the shallow detection capability, as well as the high inferred distance of FRB 20181130B and the low fluence in radio wavelength. The future detectability of optical flashes associated with nearby and bright FRBs are also discussed in this paper.

Unified Astronomy Thesaurus concepts: Radio bursts (1339); Astronomical techniques (1684); Radio transient sources (2008); Optical observation (1169); Magnetic stars (995); Neutron stars (1108); Photometry (1234)

1. Introduction

Fast radio bursts (FRBs) are bright, cosmological origin, and millisecond-duration bursts in radio wavelengths (Lorimer et al. 2007; Thornton et al. 2013; Bassa et al. 2017; Macquart et al. 2020). After the discovery of the first FRB (Lorimer et al. 2007), a number of dedicated facilities have been conducted to search FRBs, such as the Parkes telescope (e.g., Bhandari et al. 2018), the updated Molonglo Observatory Synthesis Telescope (e.g., Farah et al. 2018), the Australian Square Kilometre Array Pathfinder (e.g., Shannon et al. 2018), the Canadian Hydrogen Intensity Mapping Experiment (CHIME; The CHIME/FRB Collaboration et al. 2018), the Deep Synoptic Array (Kocz et al. 2019; Ravi et al. 2019), the Green Bank Telescope (Masui et al. 2019), Arecibo (Spitler et al. 2014; Patel et al. 2018), and the Five-hundred-meter Aperture Spherical radio Telescope (FAST; Nan et al. 2011; Li et al. 2019). All these efforts result in an increasing rate of new FRB detections. Among them, more than 20 repeating FRBs have been reported. Particularly, the physical origin of the repeating FRB 20121102A was identified to be with a low-metallicity star-forming dwarf galaxy at a redshift 0.19273 (Bassa et al. 2017; Tendulkar et al. 2017). Another repeating FRB 20190523A was found to be associated with a more massive but low specific star formation rate (Ravi et al. 2019). The identification of the counterpart of the brightest radio bursts from SGR 1935+2154 as a magnetar in our Galaxy by HXMT (Li et al. 2021) and INTEGRAL (Mereghetti et al. 2020) with short-duration X-ray bursts suggests that at least a fraction of FRBs are connected with newborn magnetized neutron stars (e.g., Weltman & Walters 2020; Zhang 2021). More bursts with similar characteristics need to be detected in the future to confirm this conclusion.

Recently, a new large sample with 535 FRBs was presented by CHIME/FRB Collaboration et al. (2021) that were detected by the CHIME survey, including 61 bursts from 18 previously reported repeating sources and 474 one-off bursts. Though an increasing catalog of theories and models is developing to explain the physical nature of FRBs (e.g., see the review of Platts et al. 2019; Xiao et al. 2021), the origin of FRBs remains a mystery.

Multiwavelength observations are expected to place constraints on the emission mechanism of FRBs (e.g., Nicastro et al. 2021).
A bright optical counterpart associated with an FRB is model dependent (e.g., Zhang 2017; Ghisellini & Locatelli 2018; Beloborodov 2020; Nicastro et al. 2021). However, considering that the estimated FRB event rate is as high as 3600 FRBs/sky/day at >0.63 Jy at 350 MHz and 5 ms burst width (Chawla et al. 2017), one would expect to detect some astrophysical optical transients with a millisecond timescale accompanying FRBs under some extreme conditions (e.g., Lyutikov & Lorimer 2016, 2020; Platt et al. 2019; Yang et al. 2019; Beloborodov 2020; Margalit et al. 2020). For example, the single-zone inverse Compton (IC) scattering in the pulsar magnetosphere model (Yang et al. 2019) predicts a bright millisecond optical emission under extreme conditions. Beloborodov (2020) predicted that a radio burst could turn into a bright optical flash with a timescale of ≤1 s when a repeating magnetic flare from a young magnetar strikes the wind bubble in the tail of a previous flare. Gamma-ray bursts and their multiwavelength afterglow could also be detected accompanied by FRBs due to double neutron star mergers (e.g., Totani 2013; Zhang 2014; Wang et al. 2016, 2018). Besides, there are also models to predict long-duration optical emission associated with FRBs, for example, Type Ia supernovae were predicted to be related to FRBs with a model of a binary white dwarf merger (Kashiyama et al. 2013). A long-duration optical emission associated FRB may be produced by the two-zone IC scattering process (Yang et al. 2019).

On the other hand, considering the complex observational characteristics of FRBs occurring with a millisecond duration at random times and positions on the sky, it is a challenge searching the optical emission simultaneously at the time when the FRB is detected. No positive results have been reported in searching the optical emission simultaneously at the time when random times and positions on the sky, it is a challenge.

During the burst of FRB 20181130B, it chanced that the same field was also being monitored by the Ground-based Wide Angle Camera (GWAC). The total observations for this field lasted for more than 4 hours with a cadence of 15 s. This is a great opportunity to search for any short-duration optical emission in the images obtained by GWAC synchronized observations.

In this paper, we report the search for the short-duration optical emission in the GWAC data covering the FRB 20181130B burst time. The GWAC observation and data reduction related to FRB 20181130B are presented in Section 2. The results and the discussion are given in Section 3. A summary will be presented in Section 4.

2. GWAC Observations and Data Processing

The GWAC system, as one of the main ground-based facilities of the Space-based Multi-band Astronomical Variable Objects Monitor (SVOM) mission (Wei et al. 2016), is an optical transient survey located at Xinglong Observatory, China. This system is aiming to detect various short-duration astronomical events including the electromagnetic counterparts of gamma-ray bursts (Wei et al. 2016), gravitational waves (Turpin et al. 2020), and stellar flares (Xin et al. 2021) by imaging the sky at a cadence of 15 s down to \( R \approx 16.0 \) mag.

During the survey, each unit was assigned to imaging a given field-of-view optical telescope with a high temporal resolution and a radio telescope when an FRB is being detected.

After the first FAST discovery of a fast radio burst, FRB 20181123B (Zhu et al. 2020), recently three new FRBs detected by FAST were reported (Niu et al. 2021) during the Commensal Radio Astronomy FAST survey (CRAFTS). Among them, FRB 20181130B was detected by FAST in M11 beam ID on 13:01:27.034 UT on 2018 November 30 at high galactic latitude (Niu et al. 2021). The duration is \( 9.52_{-5.94}^{+7.26} \) ms. The observed peak flux density and the measured fluence are \( \sim 20.6 \) mJy and 0.168 Jy ms, respectively. The dispersion measure is 1705.5 ± 6.5 pc cm\(^{-3}\), corresponding to an estimated maximum redshift of \( z \sim 1.83 \) and a luminosity of \( 1.6 \times 10^{42} \) erg s\(^{-1}\) (Niu et al. 2021).\(^9\) The best coordination is R.A. = 00:39:07.85, decl. = 19:24:31.7, J2000 (Niu et al. 2021). The uncertainty of this location was not presented in the literature (Niu et al. 2021). However, one beam covers the sky area with a diameter of 2/5 (Jiang et al. 2020), which could be taken as a maximum value for the error circle for the search of its optical counterpart. The pointing error could be neglected since the pointing errors of the 19-beam receiver in different sky positions are less than 16" and the standard deviation of pointing errors is 7.9" (Jiang et al. 2020). Thus, with the above consideration, the value of 1/3 as the radius of the uncertainty of the localization is adopted in this work.

\(^9\) However, one should note that the real distance of the source is uncertain with a value being less than the estimate.

\(^{10}\) SVOM is a China–France satellite mission dedicated to the detection and study of gamma-ray bursts (GRBs)
the literature (Wang et al. 2020; Han et al. 2021; Xin et al. 2021).

FRB 20181130B was detected (Niu et al. 2021) in the radio region at 13:01:27.034 UT (denoted as $T_0$) on 2018 November 30. During the burst, GWAC was operating in survey mode. A large area of sky with about 2200 deg$^2$ was monitored by four GWAC units. Thanks to the large field of view, the location of FRB 20181130B was coincidentally covered by one sky grid that was monitored synchronously by camera G043 in the #4 unit. The total observation time lasted from 10:18:33.1 UT to 14:42:14.9 UT, covering the FRB outburst time. During the observations, there was no prompt alert produced by the GWAC transient alert system for any new optical source around this position.

When FRB 20181130B was detected, the exposure time for image #0731 obtained by G043 had just finished and the data were being read out from the camera. However, due to the large dispersion measurement of 1705.5 ± 6.5 pc cm$^{-3}$ (Niu et al. 2021), the expected delay time between the FAST radio burst and the optical millisecond-scale emission was estimated to be within 3.1329–3.1569 s after considering the uncertainty of the dispersion measure (Niu et al. 2021). In other words, it is possible that the associated optical emission was detected in images taken before the radio burst for this epoch, corresponding to a time window of 13:01:23.877 ($T_0$) and 13:01:23.901 UT ($T_1$), which is exactly covered by the effective exposure time of GWAC image #0731 (from 13:01:15:738 to 13:01:25:738 UT). All these time series are displayed in Figure 1.

As shown in Figure 2, nine consecutive images of GWAC around the burst time are displayed. All these images are labeled with the observation series number and aligned with each other. The size for each image is about 11′.6 × 11′.6 with the north at the top and the east at the right. A yellow circle with a radius of 1′3 in the center of each frame shows the sky region where the position of FRB 20181130B is uncertain. A very bright source nearby the error circle labeled as S1 is marked in image #0727, which is a cataloged dwarf source (J003902.54+192431.5) identified from the Gaia Dr2 catalog (Gaia Collaboration et al. 2018) whose position is R.A. (J2000) = 00:39:02.523, decl. (J2000) = +19:24:31.493. The G magnitude and the distance for S1 is 11.9022 ± 0.0003 and 531.23142 pc, respectively. This object could be excluded from association with FRB 20181130B due to the nature of the source.

We performed an offline pipeline to search the GWAC archived images for possible short-lived optical counterparts around the time of this burst. First, all GWAC images have been corrected of bias, dark, and flat-field in a standard manner using the IRAF12 package. Second, a custom-designed pipeline developed with python and shell scripts was used to search for any new optical transients in an error circle of radius 1′3 around the best position of FRB 20181130B by comparing with astronomical catalogs including USNO B1.0 (Monet et al. 2003) with a typical limit magnitude of $V = 21$ mag, Gaia DR2 (Gaia Collaboration et al. 2018) with a limit magnitude of $G = 18$ mag, and Pan-STARRS DR1 (Chambers et al. 2016) whose typical limit magnitude is $r < 21.5$ mag for a single image or $r < 23.2$ mag for stacked images. All the above catalogs are deeper than the detection limit of each GWAC single image. As shown in Figure 2, none of any new credible optical transients were detected in image #0731 as well as in all other single frames. All images also have been investigated by human eyes confirming the above conclusion of nondetection. All these results are shown in Table 1 and Figure 3. In the upper panel of Figure 3, the detection magnitude for each frame during our observations is displayed. The x-axis is the time in seconds relative to the event time, the y-axis is the 3σ limit magnitude. There is a global trend of the detection limit during the whole observation. The detection limit became deeper since the start observation due to the change of the background noise. Since the time of about 3000 s before the event time, the limit magnitude became relatively stable. The lower panel of Figure 3 shows the histogram of each limit magnitude shown in the upper panel. As displayed with red dotted line, a Gaussian distribution fit the data well with $\mu = 15.43$ mag and $\sigma = 0.04$ mag. The Kolmogorov–Smirnov (K-S) test was adopted for the fitting above yielding a $p$-value of 0.3303, which was larger than the critical value of 0.05 as a null hypothesis for a normal distribution. This limit magnitude corresponds to a value of $\sim 15.8$ mag in the AB natural system after considering the correction of Galactic extinction of 0.108 mag (Schlafly & Finkbeiner 2011) in the $R$ band along the line of sight.

We also apply a difference image analysis via the HOTPANTS package (Becker 2015) to search for any new sources or variables during the burst time, taking image #0730 as a reference.

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11 The estimation is based on the reference of the arrival time at $\nu = 1.5$ GHz.

12 IRAF is distributed by the National Optical Astronomical Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.
Figure 4 shows the residual image obtained by the subtraction of consecutive images #0731 and #0730. No new credible source or variable were found in the residual image.

3. Results and Discussion

There is a growing catalog of the many different theories proposed for FRBs (Platts et al. 2019). Any optical emission mechanisms and the brightness in the optical band associated with FRBs are highly uncertain. In this work, we first focused on the search for prompt short-time (10 ms–10 s) optical emission associated with FRB 20181130B, and then also performed a search for long-duration transients. All the optical flux limits and the corresponding AB magnitudes derived in this work for each scenario in the following discussion are summarized in Table 2.

3.1. Prompt Optical Emission

We first consider scenarios where the optical emission has the same duration as the FRB. In these models (Yang et al. 2019), the single-zone IC scattering in the pulsar magnetosphere model predicts the highest optical flux density and the optical counterpart having the same duration as the radio band. In this model, the radio radiation is produced by coherent curvature radiation of high-energy electrons, while the optical radiation is produced by IC scattering in the same region as the radio radiation. With Equation (12) in Yang et al. (2019), $\frac{F_{\nu, IC}}{F_{\nu, 0}} \simeq 5 \times 10^{-5} n_0 \times \left(\frac{\mu_{\perp}}{10^{15}}\right)\left(\frac{B}{10^{-3} G}\right)\left(\frac{P}{10\text{ ms}}\right)^{-1}$, one could roughly estimate the optical flux with radio flux based on the parameters of pulsars including magnetic strength $B$, the period of the pulsar $P$, the multiplicity $\mu_{\perp}$ resulting from the electron–positron pair cascade (Yang et al. 2019), and the fraction of the...
Table 1

| Start Time (T) (JD-24584530.0) | T − T0 (s) | T − T1 (s) | T − T2 (s) | 3σ (mag) | Image |
|-------------------------------|------------|------------|------------|----------|-------|
| 3.041501                      | −101.345   | −98.2121   | −98.1881   | 15.378   | 0725  |
| 3.041675                      | −86.312    | −83.1791   | −83.1551   | 15.413   | 0726  |
| 3.041849                      | −71.278    | −68.1451   | −68.1211   | 15.440   | 0727  |
| 3.042022                      | −56.331    | −53.1981   | −53.1741   | 15.389   | 0728  |
| 3.042196                      | −41.297    | −38.1641   | −38.1401   | 15.445   | 0729  |
| 3.042370                      | −26.264    | −23.1311   | −23.1071   | 15.454   | 0730  |
| 3.042543                      | −11.316    | −8.1831    | −8.1591    | 15.423   | 0731  |
| 3.042717                      | 3.717      | 6.8499     | 6.8739     | 15.485   | 0732  |
| 3.042890                      | 18.664     | 21.7969    | 21.8209    | 15.413   | 0733  |
| 3.043064                      | 33.698     | 36.8309    | 36.8549    | 15.430   | 0734  |
| 3.043238                      | 48.732     | 51.8649    | 51.8889    | 15.487   | 0735  |
| 3.043411                      | 63.679     | 66.8119    | 66.8359    | 15.465   | 0736  |
| 3.043585                      | 78.712     | 81.8449    | 81.8689    | 15.452   | 0737  |
| 3.043758                      | 93.660     | 96.7929    | 96.8169    | 15.441   | 0738  |

Note. The filter is in the white band. The exposure time was 10 s for each frame. T0 is the burst time of FRB 20181130B derived from Niu et al. (2021). T1 and T2 are the expected times for optical emission associated with this event by considering the uncertainty of the dispersion measurement, respectively. All these magnitudes were in the Vega system and not corrected for the Galactic extinction of $A_K = 0.108$ mag (Schlafly & Finkbeiner 2011).

Electrons/positrons $\eta$. For simplicity, assuming $\eta_{\gamma} = 1$, using the extreme parameters with $B \sim 10^{15} \text{ Gauss}$, $P \sim 1 \text{ ms}$, and $\mu_{\pm} \sim 10^3$, the optical flux can be as high as $F_{\nu, \text{opt}} \sim 5 \times 10^{-2} F_{\nu, \text{radio}}$. However, we also noted that if we use typical values of a Galactic pulsar with $B = 10^9 \text{ Gauss}$, $P = 1 \text{ s}$, and $\mu_{\pm} \sim 10^2$, the optical flux would be about $F_{\nu, \text{opt}} \sim 5 \times 10^{-8} F_{\nu, \text{radio}}$. In the case of FRB 20181130B, $F_{\nu, \text{radio}}$ was reported as $\sim 20.6$ mJy (Niu et al. 2021). One could expect that the optical flux would be $F_{\nu, \text{opt}} \sim 1.0 \text{ mJy}$ for the extreme case or $1.0 \times 10^{-6} \text{ mJy}$ for the typical Galactic pulsar case.

Observationally for FRB 20121102A, the measured duration is 9.52$^{+5.94}_{-3.08}$ ms (Niu et al. 2021). The optical duration timescale is around 10 ms. Following Yang et al. (2019), the optical flux density could be given with $F_{\nu, \text{opt}} = \left( \frac{T}{\tau_{\text{ms}}} \right)^2 \times \left( \frac{10^{8.32 - 0.4\sigma}}{4.4} \right)$ Jy, where $\tau_{\text{ms}}$ is the optical pulse duration in milliseconds and $T_{\text{opt}}$ is the normalized exposure time of 60 s. With an optical pulse duration of $\sim 10$ ms, a GWAC exposure time of 10 s, and the typical limit magnitude of 15.8 mag in the AB natural system, the optical flux limit $F_{\nu, \text{opt}}$ would be deduced to be $\sim 1.66$ Jy, which is higher than the optimistic estimate of the optical flux (1.0 mJy) by a factor of about 1660 or 8.0 magnitudes.

Other models (Yang et al. 2019) including IC scattering in one-zone emission from masers in an outflow or in two-zone emission by Galactic energetic electrons, or the model for optical emission produced from the intrinsic mechanism of FRBs, predict optical fluxes too low to be detected by GWAC-like facilities. For example, under the consideration of one coherent mechanism, curvature radiation by bunches (Katz 2014, 2018; Kumar et al. 2017; Ghisellini & Locatelli 2018; Yang & Zhang 2018), the optical flux is predicted by Yang et al. (2019) to be between $F_{\nu, \text{opt}} \simeq \left( \frac{\nu_{\text{opt}}}{\nu_{\text{radio}}} \right)^{-1.6} F_{\nu, \text{radio}}$ and $F_{\nu, \text{opt}} \simeq \left( \frac{\nu_{\text{opt}}}{\nu_{\text{radio}}} \right)^{-2(p+4)/3} F_{\nu, \text{radio}}$ with $p \geq 2$, where $p$ is the electron energy index. Based on the above model, the predicted value of $F_{\nu, \text{opt}}$ should be between $3.0 \times 10^{-11}$ Jy and $8.0 \times 10^{-21}$ Jy. This prediction of the brightness of the associated optical emission is fainter by about 11 orders of magnitude and is a big challenge to be detected.

Figure 3. Upper: the 3σ upper limit magnitude of optical emission for FRB 20181130B derived from GWAC data relative to the burst time (Niu et al. 2021) in seconds. The y-axis is the upper limit magnitude that was calibrated to the USNO B1.0 catalog. Lower: a statistics with a histogram plot in blue for the limit magnitude. The red dotted line shows the fitting result with a Gaussian distribution. The K-S test gave a p-value of 0.3303.

On the other hand, as discussed by Hardy et al. (2017), the duration of any optical bursts can last up to 5 times longer than that of associated FRBs, by assuming that the FRB mechanism follows a similar behavior to the Crab pulsar, in which some optical pulses have been detected (Shearer et al. 2003; Slowikowska et al. 2009; Mignani 2010; Shearer et al. 2012). If this is the case for FRB 20181130B, the optical emission duration can be as long as 50 ms. The optical flux limit $F_{\nu, \text{opt}}$ would be estimated to be 0.33 Jy.

By multiplying the flux density limit of 1.66 Jy by the duration of the optical emission of 10 ms, we obtained the maximum simultaneous optical fluence of 16.6 Jy ms for FRB 20181130B. Assuming that the emission in the optical and radio frequencies had the same intrinsic source, the broadband spectral slope $\alpha (\nu, \propto \nu^{-\alpha})$ from optical to radio wavelengths for FRB 20181130B is smaller than 0.367. With the same method, we also calculate three other FRBs whose prompt optical observations were obtained in the literature. They are FRB 20042813 (Lin et al. 2020), FRB 20181228D (Farah et al. 2019; Tingay & Yang 2019), and FRB 20121102A (Hardy et al. 2017).
optical flux density can be constrained to 1.74 mJy for a GWAC single exposure (10 s), which is still about 1 order of magnitude shallower than the predicted value of the model above. On the other hand, since the predicted duration may be as long as $10^4$ s according to the pulsar nebula (e.g., SNR) model (Yang et al. 2019), we investigate the possible longer-duration optical emission by stacking the 405 images after the eruption times. The observation duration for these images was from 13:01:14 UT to 14:42:15 UT on the same night. The total coverage time is 6060 s, and the effective exposure time is 4040 s. There is no new source around the best position (Niu et al. 2021) down to the $3\sigma$ upper limit magnitude of 17.8 mag in the $R$ band or 18.39 mag in the AB system, calibrated to the SDSS catalogs. This upper limit magnitude corresponds to 0.16 mJy, which is close to the predicted maximum discussed above.

### 3.3. Optical Emission Associated with Future Local FRBs

Much effort has been devoted to searching for multiwavelength counterparts (see the recent review of Nicastro et al. 2021). There are generally three strategies: (1) standard triggered follow-up observations (e.g., Petroff et al. 2015; Bhandari et al. 2018), similar to the observation strategy for optical afterglow of gamma-ray bursts; (2) target search for repeating FRBs (e.g., Scholz et al. 2016; Hardy et al. 2017) or periodic FRBs (e.g., Kilpatrick et al. 2021); (3) simultaneous observations with wide-field telescopes (e.g., Tingay & Yang 2019).

Here we presented a simultaneous observation by GWAC covering the entire period of the expected optical emission of FRB 20181130B after taking into account its high dispersion measurements. Our analysis shows that no optical emission was detected in the single image or stacked image. The estimated distance of FRB 20181130B is $z \sim 1.83$ (Niu et al. 2021), which makes the event to be by far one of the highest redshift in the FRB catalog. The radio peak fluxes and fluence make FRB 20181130B located in the faint part of the distribution of distance and observed fluence (see Figure 2 of The CHIME/FRB Collaboration et al. 2020).

However, one should note that the average value for most known FRBs is at the level of about 10 Jy ms (e.g., Shannon et al. 2018; The CHIME/FRB Collaboration et al. 2020). Most of the detected FRBs are at a distance of about $10^{-10}$ pc. Theoretically, the short-duration optical flashes accompanying these typical FRBs are still expected to be detected with future efforts. For example, a bright optical flash with a timescale of 1 s is expected, as proposed by Beloborodov (2020), with the model that the blast wave strikes the wind bubble in the tail of a preceding flare in frequent repeaters, though the expected rate is a small fraction of the FRB rate. Considering the uncertainty of the optical emission predicted by various models (e.g., Platts et al. 2019; Nicastro et al. 2021), observations in the future to search and validate the optical emission associated with the FRBs would be optimized in the following aspects: (1) faster optical cadence down to a subsecond timescale; (2) deeper detection capability for one exposure time with large-aperture telescopes; (3) wide-field view; (4) commensal observing between optical and radio facilities; (5) multitelescope monitor of the same sky located at a long distance to distinguish the contamination from cosmic rays, artificial objects, or other instrument defects; (6) target monitoring for those repeaters or periodic events. Among those FRBs, the

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**Table 2**

| Mid-time (s) | Optical Duration | Flux Limit | AB Magnitude | Images |
|--------------|------------------|------------|--------------|--------|
| 0            | 10 ms            | 1.66 Jy    | 8.35         | single |
| 0            | 50 ms            | 0.33 Jy    | 10.10        | single |
| $\geq$10 s   | 1.74 mJy         | 15.80      | single       |        |
| 3030.5       | 6061 s           | 0.16 mJy   | 18.39        | stacked|

Note. The AB magnitude in the fourth column is derived with the equation $m = -2.5 \log_{10}(F_{\nu}/3631\text{Jy})$ where $F_{\nu}$ is the value in the third column for each line.
**Table 3**

| ID   | Opt. Fluence (Jy ms) | Radio Fluence (Jy ms) | $\nu_{\text{opt}}$ (Hz) | $\nu_{\text{radio}}$ (Hz) | $\alpha$ | Event       | Reference               |
|------|----------------------|-----------------------|-------------------------|-----------------|--------|-------------|-------------------------|
| 1    | 16.6                 | 0.168                 | 4.0e14                  | 1.5e6           | 0.367  | FRB 20181130B | This work               |
| 2    | 4.4e3                | 1.5e6                 | 4.0e14                  | 6.6e9           | -0.435 | FRB 200428    | Lin et al. (2020)       |
| 3    | >2000                | >24                   | 4.0e14                  | 0.835e9         | 0.338  | FRB 20181228D | Farah et al. (2019), Tingay & Yang (2019) |
| 4    | 0.046                | 0.6                   | 4.0e14                  | 1.36e9          | -0.204 | FRB 20121102A | Hardy et al. (2017)     |

Note. Note that optical frequency for all events adopted here is set to the same that has a negligible impact on the our constraints.

Figure 5. The level of constraints for the spectral indices $\alpha$ from optical to radio wavelengths for four FRBs with their radio fluence. The four FRBs are FRB 200428 (Lin et al. 2020), FRB 20181228D (Farah et al. 2019; Tingay & Yang 2019), FRB 20121102A (Hardy et al. 2017), and FRB 20181130B in the red triangle studied in this work. The detailed data are summarized in Table 3.

most anticipated detection is for those nearby (or low-dispersion measure (DM)) and brighter FRBs, such as the energetic FRB 20180110A with a fluence of about 390 Jy ms, or the brightest radio burst from SGR 1935+2154 ($\sim$220 kJy ms; The CHIME/FRB Collaboration et al. 2020) with a distance of 9.5 kpc (Bochenek et al. 2020), or the recently reported repeating FRB 20200120E (Bhardwaj et al. 2021), which was found to be from M81 at 3.6 Mpc.

Given the high sensitivity of FAST, CRAFTS tends to detect more distant and fainter FRBs (e.g., Zhang 2018; Niu et al. 2021). However, it is still anticipated that some of the bright, nearby FRBs may be detected. GWAC is located at Xinglong Observatory in China, which is near the location of FAST. Due to the similar visibility of the sky, the observation field of GWAC can always be selected to cover the same field of view of FAST in order to observe the same sky simultaneously. Furthermore, GWAC has a plan to upgrade parts of cameras equipped with complementary metal oxide semiconductor by increasing the temporal resolution to 1 s, which is more advantageous for detecting short-timescale transients (<1 s) such as fast optical emission associated with FRBs, by decreasing the background noise and shortening the dead time greatly compared to the CCD used currently. If some bright nearby FRBs were detected by FAST, then the high temporal resolution and simultaneous observations of GWAC will detect the associated fast optical bursts or make better constraints on their brightness.

On the other hand, if counterpart events were rare in the local universe, with characteristics of high cadence, large FoV, and long-term operation, a blind search by GWAC can also increase the detectability of short-living optical counterparts, although its detection capability is shallow. Similar discussion for the future searching strategy is also presented by Chen et al. (2020). For example, taking the all-sky event rate of around 250 per day estimated for FRBs like the Lorimer-burst (Lorimer et al. 2007), about 1.3 bursts would be seen in the GWAC field each hour after the full system has been set with an FoV of about $\sim$5000 deg$^2$ (Wei et al. 2016). Following the discussion by Lyutikov & Lorimer (2016), the optical brightness would be expected to be 12.6 mag or 9.72 mag for a 15 or 1 s cadence, respectively, by adopting the parameter of the radio peak flux density $F_p=30$, the optical duration $\tau=15$ ms, and the ratio between optical flux and radio flux $\eta=1$. Such brightness shall be detectable by the GWAC system.

4. Summary

In this paper, we report on synchronized observations with GWAC during the outburst time of FRB 20181130B. There is no new source in the error circle around the best position in either single or stacked images. The optical flux limits obtained by our observations are 1.66 Jy (8.35 mag), 0.33 Jy (10.10 mag), 1.74 mJy (15.80 mag), and 0.16 mJy (18.39 mag) for optical emission durations of 10 ms, 50 ms, 10 s, and 6060 s, respectively. All images also have been investigated by eye confirming the above conclusion of nondetection. Due to the nature of FRB 20181130B with a long distance and low radio fluence, the optical fluxes predicted by the FRB model for the fast optical bursts (10 ms to 10 s) are too low to be well constrained by our observations. However, the optical flux limit after stacking GWAC images is almost comparable to the maximum level of long-duration optical emission predicted by pulsating nebulae (e.g., SNR) models (Yang et al. 2019). We also discuss the characteristics of the most FRBs detected to date. If the GWAC system is updated in the future and the observing strategy is optimized by overlaying the same sky field with that of FAST, it is highly anticipated that better constraints on the optical brightness associated with nearby bright FRBs could be derived.

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