Detectability Analysis of Fast Radio Burst Optical Counterparts in Future Chinese Wide-Field Telescopes: A Postprint

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Abstract

Fast radio bursts (FRBs) are one of the most rapidly developing fields in astronomy in recent years. Theoretically, FRBs may possess optical counterparts on millisecond-to-hour timescales. FRB optical counterparts could potentially be detected by future Chinese wide-field telescopes, such as the China Space Station Telescope (CSST), the 2.5;m Wide Field Survey Telescope (WFST) — a collaboration between the University of Science and Technology of China and Purple Mountain Observatory — and Earth 2.0 (ET). FRB optical counterparts are typically categorized into millisecond-timescale optical counterparts, hour-timescale optical counterparts, and optical afterglows. The former two can be produced by the high-energy extensions of FRBs or inverse Compton scattering between FRB radio emission and high-energy electrons, with detection rates being closely related to the optical-to-radio flux ratio η_ν. For millisecond-timescale optical counterparts, the detection rates of WFST, CSST, and ET can reach hundreds per year under optimal conditions. When $\eta_\nu \sim 10^{-3}$, the annual detection rates for WFST and CSST are only of order unity, while that for ET is 19.5. For hour-timescale optical counterparts, under optimal conditions where the supernova remnant age is 5 years and η_ν is approximately 10^{-6}, the annual detection rate can exceed 100. The X-ray counterpart of FRB 200428 indicates that FRBs may produce relativistic outflows and generate optical afterglows through interaction with the interstellar medium. By combining the energy of FRBs, their distribution in the universe, and the standard afterglow model, the detectability of FRB afterglows can be investigated. When the total-to-radio energy ratio is similar to that of FRB 200428 ($\zeta = 10^5$), the annual detection rates for CSST, WFST, and ET are 1.3, 1.0, and 67, respectively.

Detectability of Fast Radio Burst Optical Counterparts with Future Chinese Wide-Field Telescopes

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Abstract

Fast radio bursts (FRBs) represent one of the most rapidly developing fields in astronomy in recent years. Theoretically, FRBs may produce optical counterparts with timescales ranging from milliseconds to hours. These optical counterparts could potentially be detected by future wide-field telescopes in China, including the China Space Station Survey Telescope (CSST), the 2.5-meter Wide Field Survey Telescope (WFST) jointly operated by the University of Science and Technology of China and Purple Mountain Observatory, and Earth 2.0 (ET). FRB optical counterparts are typically categorized into millisecond-timescale, hour-timescale, and optical afterglow components. The first two types may originate from the high-energy extension of FRBs or from inverse Compton scattering between FRB radio emission and high-energy electrons, with detection rates strongly dependent on the optical-to-radio flux ratio . For millisecond-timescale optical counterparts, the detection rates for WFST, CSST, and ET could reach hundreds per year under optimal conditions. When 10^{-3}, the annual detection rates for WFST and CSST are on the order of one, while ET's annual detection rate reaches 19.5. For hour-timescale optical counterparts, under ideal conditions where the supernova remnant age is 5 years and 10^{-6}, the annual detection rates could exceed 100. The X-ray counterpart of FRB 200428 suggests that FRBs may generate relativistic outflows that interact with the interstellar medium to produce optical afterglows. By combining FRB energy distributions, their cosmic distribution, and the standard afterglow model, we can investigate the detectability of FRB afterglows. When the total-to-radio energy ratio is similar to that of FRB 200428 ($= 10^5$), the annual detection rates for CSST, WFST, and ET are 1.3, 1.0, and 67, respectively.

Keywords: stars: fast radio bursts, stars: neutron stars, stars: magnetars

1 Introduction

Fast radio bursts (FRBs) are millisecond-duration, extremely energetic (up to 10^{39} erg) radio transients of extragalactic origin. To date, over 600 FRBs have been reported, among which 25 are repeating sources (hereafter "repeaters").

Due to their high energies and short durations, FRB models are predominantly associated with neutron stars, such as magnetars, binary neutron star mergers, and collisions between neutron stars and asteroids. Notably, FRB 200428, associated with the Galactic magnetar SGR 1935+2154, confirmed that magnetars can produce FRBs, though whether extragalactic FRBs share the same origin as their Galactic counterparts remains unclear.

Beyond radio wavelengths, FRB 200428 is the only FRB with multi-wavelength counterparts, including a pair of X-ray counterparts that establish the connection between FRBs and magnetars and confirm the existence of relativistic outflows. Theoretically, FRBs may also produce optical counterparts with durations spanning milliseconds to hours. Millisecond-scale optical emission could arise from the intrinsic high-energy extension of FRBs or from inverse Compton (IC) scattering between FRB radiation and high-energy electrons in the neutron star magnetosphere. Shock maser mechanisms may produce optical flares on second timescales, while interactions between magnetar flares could generate optical radiation. If FRBs are embedded in supernova remnants (SNRs), IC scattering between FRBs and high-energy electrons in the SNR could produce optical flares lasting several hours. Similarly, interactions between outflows and the interstellar medium (ISM) can produce optical counterparts with comparable durations.

Observational searches for FRB optical counterparts have been conducted through two primary approaches. First, simultaneous optical and radio observations of known repeaters have been performed. FRB 121102 was observed with TNT, MAGIC, D50, and GTC telescopes with exposure times of 0.1–77.01 ms, yielding optical flux limits of 0.33–10 mJy during which over a dozen radio bursts were detected. FRB 180916B was similarly monitored, with Kilpatrick et al. providing a 30-second exposure limit of i-band magnitude mi > 24.7 and a time delay lower limit of 2.2 s. For FRB 190520B, simultaneous observations captured 11 bursts with 40.1 ms exposures, setting an optical flux upper limit of 29 mJy. Second, wide-field surveys have searched for second- to hour-timescale optical counterparts. Thousands of ZTF exposures covering the positions of FRB 180916B and FRB 20200120E yielded no detections, and searches in Gaia and PTF data were similarly unsuccessful. To date, no confirmed FRB optical counterpart has been found; the only potential candidate is AT 2020hur detected by MASTER-Kislovodsk, which was positionally coincident with FRB 180916B, though detailed observational information remains lacking.

Driven by the development of time-domain astronomy, China is constructing or planning several wide-field optical survey telescopes, including WFST, CSST, and ET. This paper estimates the detection rates of FRB optical counterparts for these facilities. Section 2 summarizes the main parameters and capabilities of these future Chinese wide-field telescopes. Section 3 predicts the detectability of various FRB optical counterparts, including millisecond- and hour-timescale emissions and optical afterglows. Finally, Section 4 presents our summary and discussion. Throughout this study, we adopt the standard ΛCDM cosmology with $H_0 = 67.8\ \mathrm{km} \cdot \mathrm{s}^{-1} \cdot \mathrm{Mpc}^{-1}$, $\Omega\ = 0.308$, and $\Omega\_\Lambda = 0.682$.

2 Future Chinese Optical Survey Telescopes

The China Space Station Survey Telescope (CSST) is a large space-based astronomical facility under construction for China's manned space program. With a 2-meter aperture, CSST will operate in co-orbit with the space station and is scheduled for launch in late 2023. It will be equipped with a wide-field optical survey module, a terahertz module, a multi-channel imager, an integral field spectrograph, and an exoplanet coronagraph. The wide-field optical survey module covers 1.1 deg^2 with an angular resolution of 0.15 arcseconds, targeting precision cosmology as its primary science goal. The instrument features 30 CCDs: 18 imaging CCDs covering NUV, u, g, r, i, z, and y bands, and 12 slitless spectroscopic CCDs (GU, GZ, GI). Over its planned 10-year survey, CSST will cover 17,500 deg^2, with each sky region visited once per CCD for 150-second exposures. Stacked 2\$×\$150 s exposures will reach an r-band limiting magnitude of approximately 26. CSST aims to conduct high-resolution, large-area multi-color imaging and slitless spectroscopic surveys, enabling breakthroughs in dark matter, dark energy, galaxy formation and evolution, and exoplanet detection.

The 2.5-meter Wide Field Survey Telescope (WFST), jointly built by the University of Science and Technology of China and Purple Mountain Observatory, is located at Saishiteng Mountain in Lenghu, Qinghai Province. With its large field of view, high precision, and broad wavelength coverage, WFST features a 2.5-meter aperture and u, g, r, i, z filters, reaching a limiting magnitude of 22.95 in 30-second exposures. Simulation studies indicate that WFST could discover over ten thousand pre-peak supernovae in its first year of operation, with nearly a hundred having early multi-color observations. During its operation, WFST will be the most efficient ground-based optical imaging survey facility in the northern hemisphere, providing high-precision photometry and astrometry for monitoring moving objects, variable sources, and transient searches, while complementing the southern-sky coverage of LSST to achieve all-sky time-domain monitoring.

Earth 2.0 (ET) is a space telescope under development to search for exoplanets across various orbital periods, particularly Earth-like planets around Sun-like stars. ET consists of six 30-cm transit telescopes and one microlensing telescope, each equipped with four 9k × 9k pixel CMOS detectors. Each transit telescope has a 500 deg^2 field of view, all pointing in the same direction. Stacked 10-second exposures from the six transit telescopes will reach a limiting magnitude of 20.6. Table 1 summarizes the key parameters of these telescopes, including aperture, field of view, typical exposure times, and limiting magnitudes in each band.

3 Detection Capabilities for FRB Optical Counterparts

3.1 Millisecond-Timescale Optical Counterparts

Theoretically, FRB emission can extend from radio to optical wavelengths with similar millisecond timescales. Given the extremely high brightness temperatures of FRBs, their origin is generally attributed to coherent radiation mechanisms, primarily coherent curvature radiation and maser mechanisms. Coherent curvature radiation occurs when relativistic charged particles move along magnetic field lines, producing strongly beamed emission from tangential acceleration. Observationally, FRB spectra follow power laws with flux density f_ $^{-1 \cdot 6}$. Theoretically, shorter optical wavelengths weaken coherence in curvature radiation, causing spectral cutoff, yielding f_ ,opt/f_ ,radio 10^{-10}. Maser mechanisms involve stimulated emission amplification in the radio band, typically occurring over narrow energy ranges, making optical emission weak. In weak masers, f_ ,opt 10^{-9} f_ ,radio, while strong masers produce even weaker optical radiation.

Alternatively, if FRBs originate from magnetars, their radio emission may interact with high-energy electrons in the magnetosphere through inverse Compton scattering, producing optical radiation. Newborn pulsars have spin periods of tens of milliseconds and small magnetospheric radii (hundreds of meters to thousands of kilometers), yielding optical bursts on millisecond timescales. The luminosity depends on magnetic field strength B, spin period P, etc. Under optimal conditions where FRBs are produced in magnetars with B 10^{14} G [8]:

f_ ,opt 5×10^{-5} _γ (_±) (B/10^{14} G) (10 ms/P) f_ ,radio

where _γ is the ratio of electron Lorentz factor γ 10^3 pairs to total electrons, and _± is the pair multiplication factor in cascades, far exceeding the high-energy extension of FRBs themselves. Therefore, detectable millisecond optical counterparts are dominated by inverse Compton scattering between FRBs and high-energy electrons in magnetospheres, with typical flux f_ ,opt 5×10^{-5} f_ ,radio. Considering pulsar parameter ranges (B 10^{10}–10^{15} G, P 0.001–10 s, _± 10^2–10^4), the optical-to-radio flux ratio spans _ 5\$×10$^{\{-13\}-5\times10}$\{-2\}\$.

Wide-field optical telescopes typically have exposure times of 10 s, far longer than millisecond timescales. The detection rate for millisecond FRB optical counterparts can be estimated as:

N_{ms},opt = N_{FRB}(> F_{lim},radio) × (Ω/Ω_{sky}) × (t_{exp}/Δt_{FRB}) × _

where Ω is the telescope field of view, N_{FRB} is the cumulative FRB detection rate as a function of radio flux density F_ ,radio. We use the flux-dependent cumulative rate from CHIME [39]:

N_{FRB}(> F_ ,radio) = 818^{+229} $_{194}$ (F_ ,radio/5 Jy · ms^{-1})$^{-1 \cdot 4}$ sky^{-1} · d^{-1}

where Ω_{sky} = 41,252.96 deg^2 is the full sky area and F_{lim},radio is the radio flux limit derived from optical telescope sensitivity: F_{lim},radio = Δt_{FRB} × f_{lim},radio = Δt_{FRB} × f'*{lim},opt/ _ . Since t*{exp} Δt_{opt} for millisecond counterparts, the effective optical flux limit f'*{lim},opt = f*{lim},opt × t_{exp}/Δt_{opt}, where Δt_{opt} is the millisecond optical counterpart duration. Assuming Δt_{opt} Δt_{FRB}, we have F_{lim},radio = t_{exp} × f_{lim},opt/ _ . The optical flux limit f_{lim},opt is converted from limiting magnitudes. Using parameters from Table 1, we calculate detection rates for each facility, presented in Table 2 for various _ values.

In the most optimistic case (_ = 5 × 10^{-2}), WFST and CSST could detect hundreds of events per year (one every 1–2 days), while ET's detection rate reaches thousands, thanks to its large field of view and relatively short exposure time. However, Gaia and ZTF observations constrain _ < 10^{-3}, corresponding to annual detection rates of 1 for WFST and CSST, and 19.5 for ET. For the typical value _ = 5 × 10^{-5}, ET would detect one event every 3 years, WFST one per 59 years, and CSST one per 105 years. For curvature radiation and synchrotron masers with _ 10^{-9}–10^{-10}, the expected annual detection rates are <10^{-8}, making them effectively undetectable.

3.2 Hour-Timescale Optical Counterparts

The Galactic FRB 200428 originated from magnetar SGR 1935+2154, which is embedded in a supernova remnant [40], consistent with FRB-SN association models. If most FRBs originate from magnetars surrounded by SNRs, radio emission may produce optical radiation through inverse Compton scattering with high-energy electrons in the SNR. Since scattering occurs in the outer SNR shell, the optical emission duration is [8]:

Δt_{opt} = 2.5 × 10^4 s (t/5 yr) (M/M_)$^{-1}$/^{2} (E/10^{51} erg)^1/^{2} _{IC}$^{-1}$/^{2}

where t is the SNR age, M is the ejecta mass, E is the SN kinetic energy, and _{IC} is the angle swept by the FRB during its duration. The typical timescale t = 5 yr is adopted because FRBs cannot penetrate very young SNRs due to free-free absorption. For young SNRs, optical emission lasts for hours and increases with SNR age.

The optical flux has two cases [8]:

f_ ,opt 10^{-6} _γ (t/5 yr)^2 (M/M_)$^{-1}$ f_ ,radio (Case 1)
f_ ,opt 10^{-6} _γ (t/5 yr) (E/10^{51} erg)$^{-1}$ f_ ,radio (Case 2)

where Case 1 applies when the FRB duration is determined by the line-of-sight crossing time, and Case 2 when determined by the jet opening angle _j. For SGR 1935+2154 (age = 3.6 kyr [44]), _ = 7.7 × 10^{-12}. We estimate hour-timescale detection rates using equations (3)–(4). Since Δt_{opt} exceeds typical exposure times, we use flux directly. The radio flux limit is F_{lim},radio = Δt_{FRB} × f_{lim},radio = Δt_{FRB} × f_{lim},opt/ _ , with Δt_{FRB}

= 5 ms (the median from CHIME samples [2]). Estimated detection rates are listed in Table 2.

Under optimal conditions (SNR age = 5 yr), Case 1 and Case 2 yield _ = 8.8×10^{-6} and 2.2×10^{-6}, respectively, with annual detection rates shown in columns 6–7 of Table 2. Most rates exceed 100 per year, with CSST achieving the highest rates (1–4 per day) thanks to its exceptional sensitivity (deep limiting magnitude). However, for SNRs similar to SGR 1935+2154, the annual detection rate falls below 10^{-5}, making detection virtually impossible.

3.3 Afterglow Detection Capabilities

The X-ray counterpart of FRB 200428 indicates that FRBs produce high-energy radiation likely originating from high-velocity outflows associated with the burst. Similar to multi-wavelength afterglow emission in gamma-ray bursts (GRBs), relativistic outflows from magnetar activity may dissipate kinetic energy through interactions with the surrounding ISM, generating radiation from optical to X-ray and gamma-ray bands.

We calculate potential long-timescale afterglow emission from FRBs using the standard GRB external shock synchrotron afterglow model [45–47]. The relativistic outflow is described as a fireball with total energy E_{tot} and bulk Lorentz factor γ_0. The shock dissipation partitions energy between electrons and magnetic fields with equipartition parameters _e and _B, respectively, with non-thermal electrons following a power-law distribution with index p and ambient medium density n_0. For long-timescale afterglows, microscopic details such as jet composition do not significantly affect the radiation calculation. Observational constraints on FRB radiation mechanisms suggest bulk Lorentz factors of at least 100, so we adopt γ_0 = 100 [48]. Radio pulsar observations indicate low radio radiation efficiency, particularly for high-energy pulsars, suggesting that the total kinetic energy of FRB outflows could significantly exceed the FRB energy itself.

Interaction with the ISM produces forward shock (FS) and reverse shock (RS) emission, characterized by broken power-law spectra with three characteristic frequencies: the minimum synchrotron frequency _m (corresponding to electrons with minimum Lorentz factor), the cooling frequency _c, and the self-absorption frequency _a. The spectral peak flux is denoted f_ ,max. The deceleration timescale t_×, when the RS crosses the ejecta (for non-magnetized ejecta), is approximately:

t_× (l(1+z)/2c$\gamma^{8\ 3}$) (E_{tot}/10^{47} erg)$^{1\ 3}$ (γ_0/100)$^{-8\ 3}$ (1+z) s

where z is redshift, l = (3E_{tot}/4πn_{{{0m}}{{pc}}}^{2})$^{1\ 3}$ *is the Sedov length, m_p is proton mass, and c is vacuum light speed. Larger initial bulk Lorentz factors yield smaller t×.* For E_{tot} = 10^{47} erg, *γ0 = 100, and n_0 = 1 cm^{-3}, t×* 3 s.

Using the standard model, we calculate FRB afterglow radiation. At shock crossing time t_×, the forward shock spectrum and peak energy are [11]:

^f_m,× = 4.1 × 10^{16} _e,$_{1}$$^{1\ 2}$ _B,$_{2}$ n_0$^{1\ 2}$ γ*0*^{4} *(1+z)*$^{-1}$ *Hz*
^f_c,× = *7.5* × *10*^{19} *_B,*$_{2}$$^{-3\ 2}$ *n_0*$^{-5\ 6}$ *E*{tot},$_{47}$$^{-2\ 3}$ (1+z)$^{-1}$ Hz
^f_a,× = 7.4 × 10^{8} _B,$_{2}$$^{1\ 5}$ n_0$^{3\ 5}$ E_{tot},$_{47}$$^{-2\ 5}$ (1+z)$^{-1}$ Hz
f^f_ ,max,× = 7.8 × 10^{-6} _B,$_{2}$$^{1\ 2}$ n_0$^{1\ 2}$ E_{tot},$_{47}$ L_{27} (1+z) Jy

where Q_x denotes Q/10^x (e.g., _B,$_{2}$ = _B/10^{-2}, _e,$_{1}$ = _e/10^{-1}, E_{tot},$_{47}$ = E_{tot}/10^{47}). The superscript f indicates forward shock quantities, and D_L is luminosity distance. For typical parameters _e = 0.1, _B = 0.01, p = 2.5, the scaling relations are:

For t < t_×: ^f_a t^{5}, ^f_m t^{0}, ^f_c t^{-2}, f^f_ ,max t^{3}
For t > t_×: ^f_a t^{0}, ^f_m t$^{-2\ 3}$, ^f_c t$^{-1\ 2}$, f^f_ ,max t^{0}

Compared to GRBs, magnetar bursts have lower total energies, so FRB outflows become non-relativistic within hours, with bulk Lorentz factor γ (3E_{tot}/32πn_{{{0m}}_{{pc}}}^{5}t^{3})$^{1\ 8}$. After this transition, the forward shock spectrum and peak flux are modified to:

^f_a t^{5}, ^f_m t^{-3}, ^f_c t$^{-1\ 2}$, f^f_ ,max t

Figure 1 [Figure 1: see original paper] shows example light curves for typical parameters with E_{tot} = 10^{47}, 10^{45}, and 10^{43} erg, and redshifts z = 0.001, 0.01, and 0.1. FRB optical afterglow durations range from seconds to hours. Higher outflow energies produce later and longer-lasting afterglow peaks: peaks appear at 1 s, 5 s, and 30 s for E_{tot} = 10^{43}, 10^{45}, and 10^{47} erg, respectively. Lower redshifts yield higher fluxes and brighter magnitudes. The figure also indicates 10-second ET limiting magnitude (black solid line), 30-second g-band WFST limiting magnitude (dark blue dashed line), and 150-second g-band CSST limiting magnitude (gray dotted line). For E_{tot} = 10^{47} erg, afterglows are detectable even at z = 0.1; for E_{tot} = 10^{45} erg, only those with z < 0.01 are visible; for E_{tot} = 10^{43} erg, detection is difficult even at z < 0.001. Since telescope exposure times range from 10–150 s, detection capability depends on afterglow duration relative to exposure time. When afterglow duration exceeds exposure time, standard sensitivity limits apply; when shorter, effective sensitivity scales inversely with duration. Due to the complex relationship between afterglow duration and parameters like E_{tot}, Monte Carlo simulations are required to assess detection capabilities.

We simulated 1,000,000 FRBs at various redshifts following the cosmic FRB distribution. The redshift upper limit was set to 20, though most simulated sources have z < 5. While some studies suggest FRB distributions follow star formation rate density (SFRD) with significant time delays, recent CHIME results indicate FRBs roughly trace SFRD [51]. Therefore, we adopt the SFRD distribution:

ϕ(z) = ϕ_0 (1+z)$^{2\cdot 7}$ / [1 + ((1+z)/2.9)$^{5\cdot 6}$] SFRD(z)/SFRD(0) where ϕ_0 is the FRB burst rate. For FRBs with energies >10^{39} erg, ϕ_0 = 7.3^{+8} • ^{8} $_{3\cdot 8}$ × 10^{4} bursts • Gpc^{-3} • yr^{-1} [51]. We use UV and infrared SFRD measurements [52]:

SFRD(z) = (1+z)^{2} • ^{7} / [1 + ((1+z)/2.9)^{5} • ^{6}] M_ • yr^{-1} • Mpc^{-3}

We then simulated radio-band energies E_{rad} for each FRB using a Schechter function energy distribution [51, 53]:

ϕ(E_{rad}) dE_{rad} (E_{rad}/E{rad})^α exp(-E*{rad}/E*_{rad}) dE_{rad}

where E*_{rad} is the exponential cutoff energy (lg E*_{rad} = 41.4 ± 0.5 from CHIME) and α = -1.3^{+0} • ^{7} $_{0\cdot 3}$ is the low-energy index. Our energy lower limit is 10^{39} erg.

We estimated relativistic outflow total energy E_{tot} from the simulated radio energies and generated optical afterglow light curves using the standard model. We assume the ratio E_{tot}/E_{rad}. For FRB 200428, E_{tot}/E_{rad} = E_X/E_{rad} 10^{5} [54].

Figure 2 [Figure 2: see original paper] shows the peak time versus flux scatter plot for = 10^{5}. Among our 10^{6} simulated FRBs, 383 have average fluxes exceeding CSST g-band sensitivity, 189 exceed WFST g-band sensitivity, and 57 exceed ET white-light sensitivity.

When afterglow duration exceeds telescope exposure time, sensitivity follows standard calculations; when shorter, effective sensitivity scales inversely with duration. To quantitatively assess detection capabilities, we calculated average fluxes over the first 10 s, 30 s, and 150 s for each afterglow. Figure 1 shows examples of these averages. Before the peak, longer exposures yield larger average fluxes; after the peak, longer exposures yield smaller averages, though the decline in average flux is slower than the light curve decline.

Finally, we normalized using the FRB burst rate from CHIME [51] and accounted for each telescope's field of view to obtain afterglow detection rates:

R_{FRB},opt = (T/1 yr) × (Ω/Ω_{sky}) × *0^z*{max} [ϕ(z)/(1+z)] × P_{FRB} × [dV(z)/dz] dz

where T is observation time, Ω is telescope sky coverage, ϕ(z) is the FRB rate from equation (16), z_{max} is the integration limit (matching our simulation), (1+z)$^{-1}$ accounts for cosmic expansion, and dV(z)/dz = 4πcD_L^{2}(z)/[H_0√(Ω_m(1+z)^{3} + Ω_Λ)] is comoving volume. P_{FRB} is the detection fraction from our 10^{6} simulations. Assuming T = 1 yr, we calculated annual detection rates (Table 3) for = 10^{4}, 10^{5}, and 10^{6}.

For = 10^{5}, using average flux as the detection criterion, WFST, CSST, and ET have annual detection rates of 1.3, 1.0, and 67, respectively. Using peak flux approximately doubles these rates. CSST achieves the highest detection fraction (3.83 × 10^{-4}) due to its superior sensitivity, but ET's vastly larger field of view yields the highest annual rate. If $= 10^4$, all telescopes except ET detect <1 event per year, with CSST expected to detect only 2.4 events over its 10-year survey. If $= 10^6$, WFST and CSST rates increase to 4.7 and 3.8 per year, respectively, while ET detects 16 per month. Thus, detections from WFST, CSST, and ET can constrain the total-to-radio energy ratio.

4 Discussion and Conclusions

This study investigates the detectability of theoretically predicted FRB optical counterparts with future Chinese wide-field telescopes: CSST, WFST, and ET. For millisecond-timescale counterparts, optimal conditions (_ $= 5 \times 10^{-2}$) yield annual detection rates of hundreds to thousands. However, Gaia and ZTF observations constrain _ $< 10^{-3}$, corresponding to annual rates of 1.1, 0.6, and 19.5 for WFST, CSST, and ET, respectively. For hour-timescale counterparts, optimal conditions (5-year-old SNR, _ 10^{-6}) produce annual rates >100, with CSST detecting 1–4 per day. For SNRs similar to SGR 1935+2154, rates fall below 10^{-5}, making detection nearly impossible. For afterglows from relativistic outflow-ISM interactions (second- to hour-timescales), with 10^5 similar to FRB 200428, CSST, WFST, and ET have annual rates of 1.3, 1.0, and 67, respectively.

Our analysis shows that short exposures and large fields of view favor detecting short-timescale optical counterparts, while higher sensitivity is more effective for hour-timescale counterparts. Consequently, ET achieves the highest rates for millisecond counterparts and second- to hour-timescale afterglows, while CSST excels for hour-timescale counterparts. Survey design aiming to detect more sub-second optical transients should prioritize short exposures and larger fields of view, particularly using CMOS or EMCCD detectors to achieve millisecond exposures, which would dramatically improve millisecond counterpart detection.

FRB optical counterpart identification remains challenging. Their short durations typically appear as single data points, easily confused with cosmic ray hits and other contaminants. It is possible that existing surveys like Gaia have detected such transients but could not scientifically confirm or report them. CSST's multi-filter scanning mode, which revisits fields multiple times within an hour, may provide better sampling of hour-timescale counterparts, enabling confirmation through light curves and colors. Studies of hour-timescale counterpart variability and colors will aid candidate selection from future CSST data. Additionally, arcsecond-localized FRBs from DSA-100 and ASKAP, and arcminute-localized FRBs from CHIME, will facilitate counterpart identification. Some studies have discussed the unique image characteristics of millisecond optical bursts that may aid candidate filtering, though practical effectiveness requires further investigation. The most reliable identification would come from simultaneous optical and radio observations, suggesting coordination with FAST and other radio telescopes as an optimal strategy for studying the underlying physics.

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References: The reference list is preserved as provided in the original manuscript.

Note: Figure translations are in progress. See original paper for figures.