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Investigating Fast Radio Bursts with H.E.S.S.: Multi-Wavelength Follow-Up and Constraints on Gamma-Ray Emission

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Fast Radio Bursts (FRBs) are brief, highly energetic radio flashes of unknown origin. Their high luminosity, short duration, and large dispersion measures suggest an extragalactic origin, potentially linked to extreme astrophysical objects such as magnetars. The growing number of detected FRBs, including repeating sources, has driven extensive multi-wavelength follow-up efforts. While FRB 20200428A has been associated with the Galactic magnetar SGR 1935+2154, no other FRB has yet been conclusively linked to a multi-wavelength counterpart. In this contribution, we present the follow-up program developed by the High Energy Stereoscopic System (H.E.S.S.) to search for gamma-ray counterparts to FRBs. We provide an overview of FRB observations conducted by H.E.S.S. from 2015 to 2022, including targeted follow-ups and coordinated multi-wavelength campaigns with radio and X-ray observatories. Among the observed FRBs, 10 have well-determined redshifts ranging from 0.11 to 0.49. No significant very high energy (VHE) emission was detected, allowing us to place constraints on VHE luminosity across different timescales.

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1. Introduction

Fast radio bursts (FRBs) are transient radio pulses of short duration (nanoseconds to seconds) and high luminosity (10^{38} to 10^{46} erg/s), originating from distances ranging from a few Mpc to several Gpc [1, 2]. Discovered serendipitously with the Parkes Telescope [3, 4], they are now routinely observed by radio facilities such as CHIME [5], with over 1,000 bursts from 700 sources reported [see e.g. FRB catalogs 6, 7]. A small fraction (2–3%) of FRBs have been observed to repeat [8], but it is unknown whether all FRBs are intrinsically repeating. Repeating FRBs have been detected from 110 MHz [9] to 8 GHz [10], with some sources showing periodic activity cycles. The physical distinction between repeating and non-repeating FRBs remains an open question.

Distances to FRBs are estimated via dispersion measures and localization methods. 24 FRBs have been securely associated with host galaxies, with redshifts between 0.03 and 1.02 [11, 12]. Most FRBs are of extragalactic origin, leading to expected high-energy attenuation due to EBL absorption. Notably, a Galactic FRB-like burst was detected in April 2020 from the magnetar SGR 1935+2154 [13], temporally coinciding with multiple X-ray outbursts. This event marked the first and so far only FRB-like emission observed within our Galaxy.

Understanding the electromagnetic counterparts of FRBs across the spectrum is crucial to constraining their physical origin, energetics, emission mechanisms, and possible connection to high-energy phenomena. Despite intensive efforts, multi-wavelength counterparts have largely remained undetected, with the notable exception of SGR 1935+2154. There, coincident X-ray emission offered the first observational evidence linking FRB-like events to magnetars and hinting at underlying non-thermal emission mechanisms [14–17].

The High Energy Stereoscopic System (H.E.S.S.), located in the Khomas Highlands of Namibia, is currently the only VHE gamma-ray observatory in the southern hemisphere capable of responding rapidly to transient phenomena. The array comprises one 28 m and four 12 m imaging atmospheric Cherenkov telescopes, sensitive to gamma rays in the ~30 GeV–100 TeV energy range [18]. Since 2015, H.E.S.S. has implemented a dedicated program to search for very-high-energy (VHE) gamma-ray counterparts to FRBs [19].

This program follows two main observational strategies:

- **Target of Opportunity (ToO) follow-ups:** Rapid-response observations triggered by alerts from radio or X-ray observatories. These are designed to search for delayed gamma-ray afterglows associated with FRBs.

- **Coordinated multi-wavelength campaigns:** Simultaneous observations of known FRB sources, including repeaters, in collaboration with radio and X-ray instruments. These aim to detect persistent or transient emission and to characterize the host environment.

In this proceedings contribution, we present an overview of the 12 FRB sources observed with H.E.S.S. between 2015 and 2023, summarizing both rapid follow-up campaigns and multi-wavelength observational efforts conducted in coordination with facilities such as MeerKAT and Swift.

2. ToO follow-up observations

The first strategy in the H.E.S.S. FRB programme is to conduct automatic follow-up observations of FRBs received as external alerts. H.E.S.S.'s ToO alert system receives transient alerts from the Parkes [20] and the UTMOST radio telescopes [21] and applies a set of pre-defined criteria to determine when and how to schedule follow-up observations. The criteria are set to maximize science cases defined by the H.E.S.S. transients programme [19]; for FRB alerts, the system is configured to react to both prompt and afterglow triggers. Since 2015, H.E.S.S. has been involved in the follow-ups of three FRBs and two magnetars.

Murriyang follow-ups: FRB 20150418A and FRB 20150215 H.E.S.S. conducted its first VHE gamma-ray follow-up campaign on two FRBs discovered by the Parkes telescope as part of the SUPERB survey: FRB 20150215A and FRB 20150418A [22]. FRB 20150215A was detected on February 15, 2015, with a DM of 1105.6 ± 0.8 pc cm^{-3} and follow-up observations by H.E.S.S. occurred 6.3 and 9.3 days later [23]. No gamma-ray signal was detected, and a 99% C.L. flux upper limit of $\Phi_\gamma(E > 1\mathrm{TeV}) < 6.38 \times 10^{-14} \mathrm{erg\,cm^{-2}s^{-1}}$ was set [23]. FRB 20150418A was observed on April 18, 2015, and showed a fading radio afterglow, later associated with an elliptical host galaxy at $z = 0.492 \pm 0.008$ [24]. H.E.S.S. observations began 14.5 hours after the burst and lasted 1.4 hours under good observational conditions [24]. No significant gamma-ray emission was detected, and a 99% C.L. flux upper limit of $\Phi_\gamma(E > 350\ \mathrm{GeV}) < 1.33 \times 10^{-12} \mathrm{cm^{-2}s^{-1}}$ was derived using the Feldman-Cousins method [24, 25].

UTMOST follow-up: FRB 20190806A UTMOST was the first facility to issue real-time FRB alerts [21, 26], prompting H.E.S.S. to implement an automatic follow-up system to minimize latency. UTMOST alerts are filtered by H.E.S.S. using signal-to-noise (S/N > 10), human-vetted importance (importance = 1), and dispersion measure ($\mathrm{DM} < 1000\ \mathrm{pc/cm^3}$) to focus on nearby sources not heavily attenuated by the EBL. Observations are triggered if visibility and darkness conditions are met within 6 hours of the alert. The first successful follow-up, FRB 20190806A, was triggered by UTMOST on August 6, 2019, with $\mathrm{DM} = 388.5\ \mathrm{pc/cm^3}$ and inferred redshift $z < 0.32$ [27]. H.E.S.S. observations began 4.5 hours later and lasted 2 hours with the CT1–4 telescopes [19]. No VHE gamma-ray signal was detected, but upper limits were derived, marking the first fully automated H.E.S.S. FRB response chain. Figure 1 shows the flux integral upper limits as a function of the time difference between the gamma-ray observation and the radio burst detection for the Murriyang and the UTMOST follow-ups.

Magnetar observations H.E.S.S. conducted follow-up observations of magnetars due to their possible connection to FRB progenitors [28, 29]. Following the April 2020 detection of a Galactic FRB-like burst from SGR1935+2154 by CHIME and STARE2 [30, 31], H.E.S.S. observed the source for 2 hours, coinciding with multiple X-ray bursts [14, 32]. No significant VHE gamma-ray emission was detected; a 99% C.L. upper limit of $\Phi_\gamma(E > 420, \mathrm{GeV}) < 1.27 \times 10^{-12}, \mathrm{cm^{-2}s^{-1}}$ was set [29]. On October 10, 2020, a short burst from the newly discovered magnetar SGR 1830−0645 triggered H.E.S.S. observations [33]. No VHE signal was found, and an upper limit of $\Phi_\gamma(E > 284, \mathrm{GeV}) < 1.78 \times 10^{-12} \mathrm{cm^{-2}\ s^{-1}}$ was derived. Differential upper limits are shown in Figure 2; no VHE source was detected at this location in the H.E.S.S. Galactic Plane Survey [34].

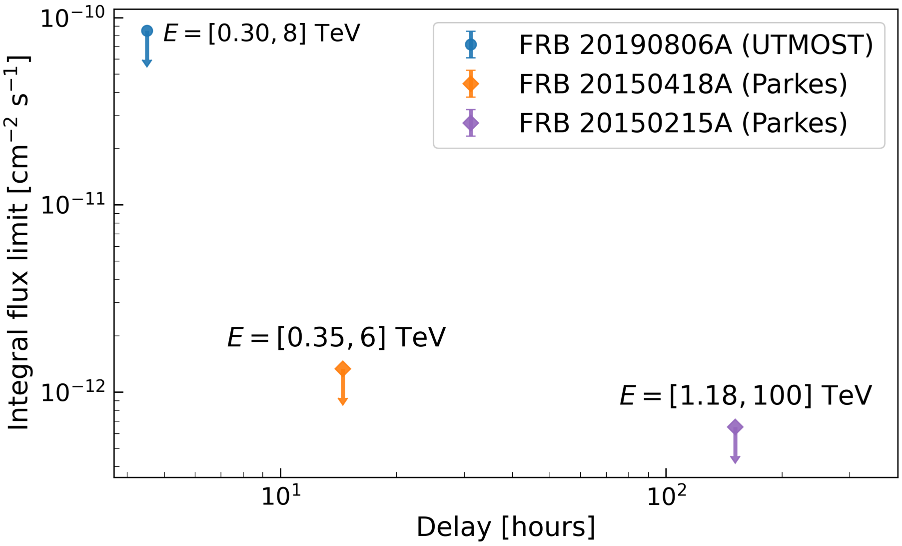

Figure 1: H.E.S.S. observation delays in hours, relative to the radio burst detection of three FRBs by Parkes and UTMOST. Flux integral upper limits are shown for each FRB within the energy range depicted in the figure. The assumed energy spectrum for these calculations follows an E^{-2} profile. The timescales used to derive these limits correspond to the H.E.S.S. observation durations for each source, as specified in the main text.

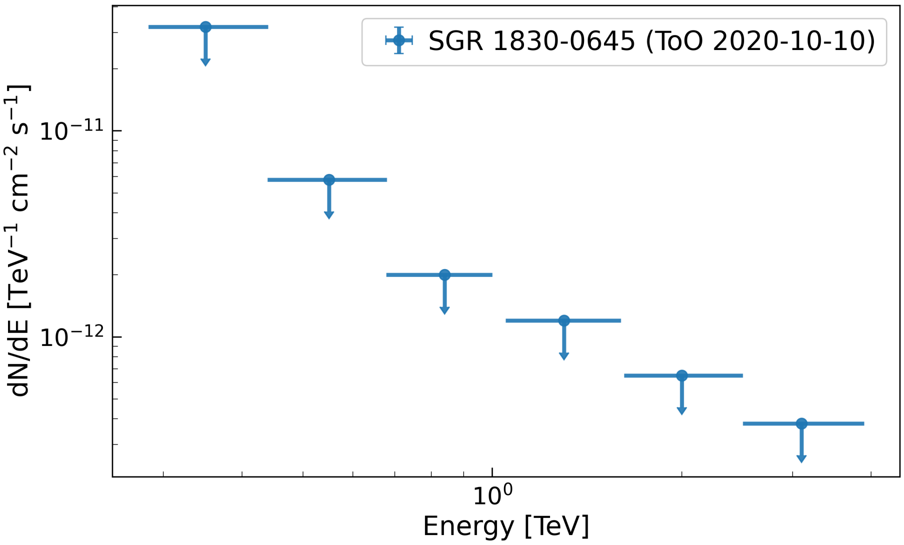

Figure 2: Differential 99% C.L. upper limits derived from the H.E.S.S. observational data taken during the ToO observation of SGR 1830−0645.

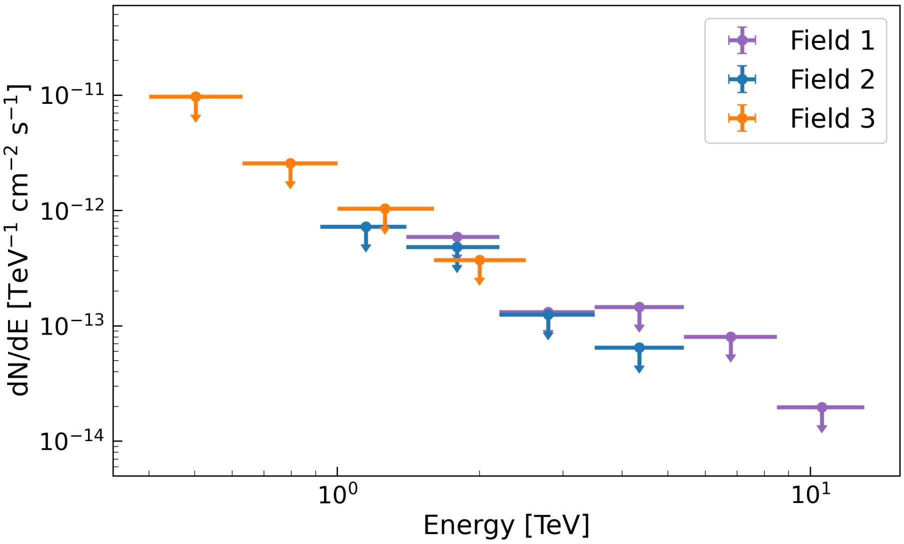

Figure 3: Differential 99% C.L. upper limits derived from the H.E.S.S. observational data taken on Field 1, 2, and 3 during the DWF campaign. The timescales used to derive these limits correspond to the H.E.S.S. observation durations for each source, as specified in the main text and in **??**.

3. Multiwavelenght campaigns

H.E.S.S.'s second FRB search strategy involves participating in coordinated multi-wavelength (MWL) campaigns targeting known FRB sources to study their environments and capture simultaneous emission across radio, X-ray, and VHE gamma-ray bands. Since 2019, H.E.S.S. has joined four such campaigns, including Deeper Wider Faster (DWF), two with MeerKAT, and one led by INTEGRAL. The latter was led by the INTEGRAL gamma ray instrument on September 24 – 28, 2017, but also involved the participation of radio (Effelsberg, Nancay, Arecibo, GBT) and optical observatories. H.E.S.S. conducted observations on the nights of the 26th and 27th of September 2017, contemporaneous with the MAGIC telescopes [35]. However, no FRB was detected by any instrument; therefore, the data collected by H.E.S.S. will not be presented in the following.

Deeper Wider Faster campaign The DWF campaigns are coordinated multi-wavelength and multi-messenger efforts focused on fast transients, including FRBs [36]. H.E.S.S. participated in the June 23–29, 2019 campaign, targeting three pre-defined fields containing NGC 6101, NGC 6744, and the host galaxy of FRB 20180924B [37]. The campaign involved simultaneous observations with numerous facilities and aimed to detect FRBs and potential VHE counterparts. H.E.S.S. observations, conducted under moderate moonlight, also supported the commissioning of moonlight-mode operations. No FRBs were detected during the campaign, and no significant VHE gamma-ray signal was observed from any field. 99% C.L. upper limits were derived for each night and from the combined data set, as shown in Figure 3.

MeerKAT campaigns H.E.S.S. has participated in FRB observation campaigns led by the MeerKAT radio telescope since 2019 [38, 39]. In 2019, simultaneous observations with MeerKAT and Swift targeted the southern repeating FRB 20171019A; no gamma-ray, radio, or X-ray emission

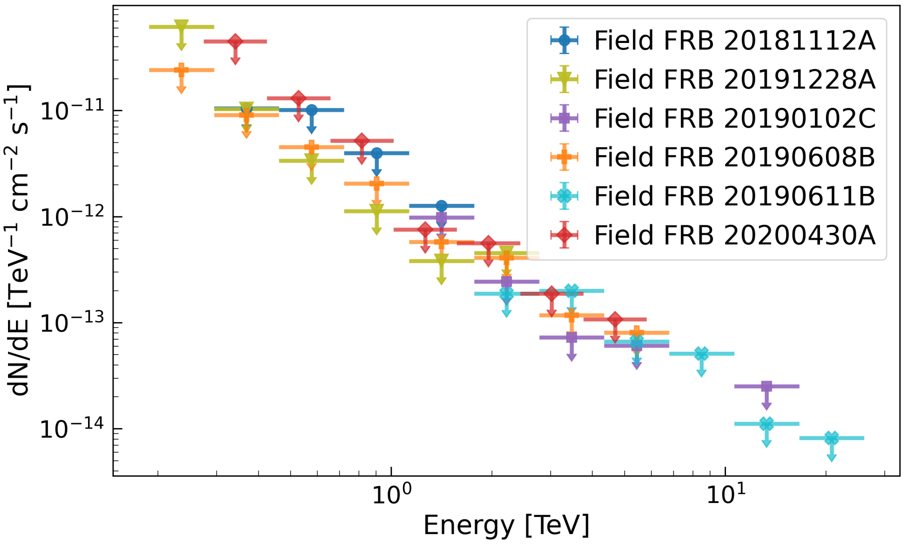

Figure 4: Differential 99% C.L. upper limits derived from the H.E.S.S. observational data taken on the targets of the MeerKAT campaign of 2019. The timescales used to derive these limits correspond to the H.E.S.S. observation durations for each source, as specified in the main text.

was detected[40]. H.E.S.S. set a 95A second joint campaign in 2021 targeted seven FRBs across three epochs, with coordinated observations by MeerKAT, H.E.S.S., Swift, ATOM, and MeerLicht. No persistent gamma-ray or radio emission was detected from any of the targeted sources. Differential gamma-ray upper limits from these H.E.S.S. observations are shown in Figure 4, covering six FRB fields.

4. Conclusions

The H.E.S.S. collaboration has conducted extensive FRB follow-up observations, targeting both localized and repeating sources, as well as magnetars, across multiple wavelengths No significant VHE gamma-ray emission was detected, but upper limits were derived, contributing to the global effort alongside VERITAS [41, 42]. For nine localized FRBs observed by H.E.S.S., VHE luminosity upper limits range between 10^{44} and 10^{48} erg s^{-1} after EBL correction, based on redshifts from 0.11 to 0.49. These limits are consistent with Fermi-LAT constraints [43], although predicted luminosities at TeV energies may lie below H.E.S.S.'s sensitivity [44]. Comparative X-ray upper limits for FRBs like 20121102 and 20220912A are much lower, at the 10^{41} erg s^{-1} level [45, 46]. Theoretical models predict VHE burst energies up to 10^{48} erg [47], detectable by H.E.S.S. only if the source is within 100 Mpc[29]. Konus-Wind and optical/X-ray follow-ups of other FRBs constrain emission ratios relative to the radio burst [48]. H.E.S.S.'s role is vital, particularly in the Southern Hemisphere, for constraining prompt VHE emission and testing multi-wavelength scenarios. Future radio surveys from SKA and CHIME/CHORD will increase the number of well-localized FRBs [5, 49, 50]. With the Cherenkov Telescope Array Observatory (CTAO), an order of magnitude improvement in sensitivity will enable probing FRB luminosities down to 10^{42}–10^{43} erg s^{-1}, enhancing the search for VHE counterparts.

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