Highlights of Spanish Astrophysics XI, Proceedings of the XV Scientific Meeting of the Spanish Astronomical Society held on September 4–9, 2022, in La Laguna, Spain. M. Manteiga, L. Bellot, P. Benavidez, A. de Lorenzo-Cáceres, M. A. Fuente, M. J. Martínez, M. Vázquez- Acosta, C. Dafonte (eds.), 2023

Constraining VHE and optical emission from Fast Radio Bursts with the MAGIC telescopes.

Jiménez Martínez, I.[1] **for the MAGIC Collaboration**

[1] Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT)

Abstract

Fast Radio Bursts (FRBs) are radio transients characterized by bright radio pulses of millisecond duration. Most of them show dispersion measures (DMs) consistent with extragalactic progenitors, something that has been confirmed with multiple high-resolution localizations and associations. Even if multiple theories have been proposed to explain the origin of FRBs, magnetars are currently the prime progenitor candidates: this is supported by the successful association of a FRBs source with the galactic magnetar SGR 1935+2154, which proves that at least some of them are originated in this kind of source. These sources are well known emitters of fast, bright, non-thermal emission. Flares have been associated with both fast optical and high-energy gamma-ray emission. MAGIC, a system of two 17 m diameter imaging atmospheric Cherenkov telescopes located in the island of La Palma, is technically well suited to constrain their multi-wavelength emission. MAGIC started observing FRBs back in 2016 in both the very-high-energy (VHE, E $>$ 100 GeV) and optical bands, coordinating with radio instruments. This is a report on the status of several joint campaigns between MAGIC and other observatories to constrain both the optical and VHE gamma-ray emission simultaneous to FRBs.

1 Introduction

1.1 Fast Radio Bursts

Fast Radio Bursts (FRBs) are a kind of astrophysical transient that consists on fast, bright radio flashes. They were first discovered with the Parkes Radio Telescope in Australia in 2007 [5]. Since then, over 600 FRB sources have been detected, displaying a wide range of characteristics. So far, 24 of them exhibit a repeating behaviour but others do not, which may suggest different emission mechanisms. At least 2 of the repeaters also display periodic states of activity: FRB 20121102A [9] and FRB 20180916B [1], with periods of 157 [8] and 16.35 [2] days respectively. For this kind of FRB sources (repeaters), young magnetars are the prime candidates (and perhaps also for non-repeating ones). This is supported by the detection of FRBs coming from the galactic magnetar SGR 1935+2154, which was the first known FRB emitter associated to a known source within our galaxy. In case of the non-repeaters, more cataclysmic scenarios have been proposed like merging of neutron stars [11].

Most FRB emitters have been identified to come from outside of our galaxy by studying their dispersion measures (DMs): depending on from where and from how far away the FRB was produced with respect to Earth, the pulse gets more dispersed by the free electrons in our galaxy (different column depths) the farther away the source is, which has a direct effect on the delay of the pulse observed in different frequencies. Given that there is a maximum dispersion measure in any given direction within our galaxy (that can be explained by the models of free galactic electrons), if a significantly greater dispersion is observed, then we are looking at an extragalactic event. This is one of the main reasons why these events remain a mystery: most of them come from cosmological distances and yet we observe them with such a great brightness that the energy involved in their production must be huge. Another reason is that they have only been detected in radio and very few of them simultaneous to other wavelengths. Nevertheless, several multi-wavelength campaigns are being proposed for these targets.

1.2 The potential of MAGIC telescopes in detecting FRBs counterparts

The MAGIC telescopes are 2 IACTs located in Roque de los Muchachos, in La Palma, Spain. They have 17 m diameter reflectors composed of tessellated mirrors and are sensitive to gamma-rays between 25 GeV and 30 TeV.

1.2.1 MAGIC's potential to detect fast VHE bursts

In 2020 two bursts were detected almost simultaneously in radio and X-rays for the galactic magnetar SGR 1935+2154 [7].

Magnetars show very diverse transient activity with short, large and giant flares. For the moment there is no link between short flares and high energy (HE) emission, but giant flares (GFs) have been detected by Fermi-LAT (E $>$ 1 GeV). This proves that these sources have the energy budget to emit in HE. If there is an even higher energy present, MAGIC could not only detect the flare, but thanks to its higher collection area it would be more sensitive than Fermi-LAT over very-short timescales ($\sim$minutes).

1.2.2 MAGIC's potential to detect fast optical bursts

Current magnetar models support the possibility of observing optical bursts. In fact, ultra-fast optical emission was detected some years ago and it may be associated with a SGR [10]. MAGIC has a special setup called Central Pixel in the central pixel of each camera that works as a fast optical photometer [3]

1.2.3 FRB 121102

It was the first repeating source of FRBs. It was observed by MAGIC in 2017 in both VHE and optical and by Arecibo in radio [6]. Five radio bursts were detected simultaneous to MAGIC observations. No counterpart was found for any of the pulses, but the emission was constrained in both VHE and optical. A bright 12ms optical flash occurred 4.3 s before one FRB but it was consistent with irreducible background (2.2σ). Still MAGIC was able to provide the strongest upper limits by then.

2 Sources

Since then, we focus on these known repeaters:

SGR 1935+2154: This soft gamma repeater (SGR) is the first FRB emitter associated to a known source. It is located within our galaxy (9.0±2.5 kpc), which has allowed it to be detected in both radio and X-rays.

FRB 20200120E: It is the closest known extragalactic source of FRBs, it is a repeater and it is located in a globular cluster of M81. The fact that it is located in a globular cluster challenges the current models that support that FRBs originate from young magnetars. Instead, in [4], authors propose that this FRB source is a highly magnetized neutron star, formed by accretion-induced collapse of a white dwarf or by a merger of compact stars in a binary system.

FRB 20180916B: This FRBs source is a repeater, and it is the first one observed to have periodic episodes of activity with repeating bursts over 4 days every 16.35±0.18 days.

3 Observations

Because of the nature of this transient (it is observed in radio) we exclusively focus on strictly simultaneous multi-wavelength coverage with both radio (for galactic and extragalactic sources) and X-rays (only for the galactic SGR due to extinction).

SGR 1935+2154: We have performed several campaigns totaling 43.5h of observation time, but no burst has been detected simultaneous to our observations so far, so we keep pursuing active states via ToO requests.

FRB 20200120E: We have performed a deep campaign of 17h simultaneous to 3 large radio antennas (in 3 different frequencies), but no FRBs were detected.

FRB 20180916B: We performed a short campaign of 2.4h together with radio, soft and hard X-rays and a FRB was detected simultaneous to our observations. Unfortunately, no burst was detected in X-rays, optical nor VHE; but we are providing differential and integral upper limits on the persistent VHE emission, integral VHE upper limits within the 10ms window surrounding the TOA, optical light curves covering 200ms around the TOA with an integration window of 2ms and optical upper limits.

4 Summary and discussion

The versatility of MAGIC allows it to act as a "triple threat": It can operate as a VHE telescope for bursts and persistent emission and as a fast optical telescope for optical bursts, all at the same time. Even with the bad luck of recent years (COVID and a volcano eruption in the island of La Palma) we have been able to gather a very significant amount of strictly simultaneous multi-wavelength data on several FRB repeaters, although the number of simultaneous bursts is still very limited. Unlike other major observatories, the time investment on this project is relatively minor compared with other MAGIC proposals, while its discovery potential is enormous. We will continue triggering multi-wavelength campaigns of these close-by repeaters with MAGIC (in the optical and VHE), radio antennas and X-ray satellites, hoping for a positive detection and a high-impact result.

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