Constraints on Fast Radio Burst emission in the aftermath of Gamma Ray Bursts

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CSIRO Parkes 64m radio telescope

Outline

Introduction

Physical origin of FRBs is still unknown

Many FRB progenitor models advocate scenarios that hint to a possible association with GRBs, e.g.:

Many models consider **magnetars as possible FRB sources**, supported by the association of FRBs with SGR 1935+2154

(CHIME/FRB Coll. et al. 2020, Bochenek et al. 2020, Mereghetti et al. 2020)

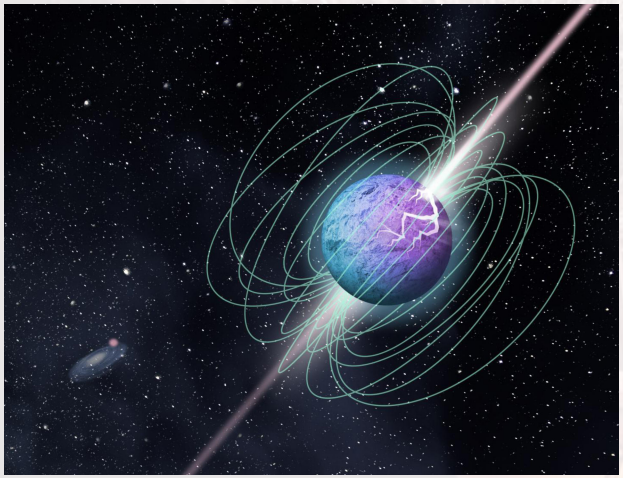


Image credit: McGill University Graphic Design Team

Observations of GRB emission, in particular in the X-ray band, point towards **magnetars as plausible candidates as GRB central engines**

(Dai & Lu 1998, Zhang & Meszaros 2001, Metzger et al. 2011)

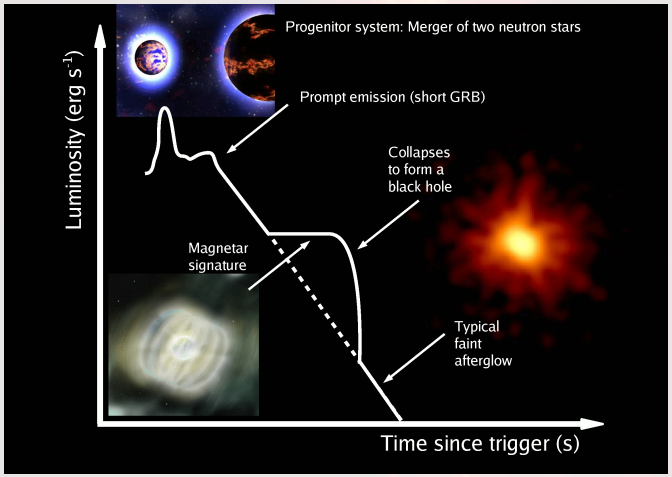


Image credit: Antonia Rowlinson/University of Leicester/NASA/Swift

Do FRBs and GRBs have a common progenitor?

Search for GRB/FRB association with archival data

GRBs

- We considered all GRBs (long and short) detected by Swift until March 2023
- We selected the GRBs with Swift/XRT detection (position known with accuracy $\sigma_{\rm GRB} \lesssim 5''$) $\rightarrow$ 1276 GRBs

FRBs

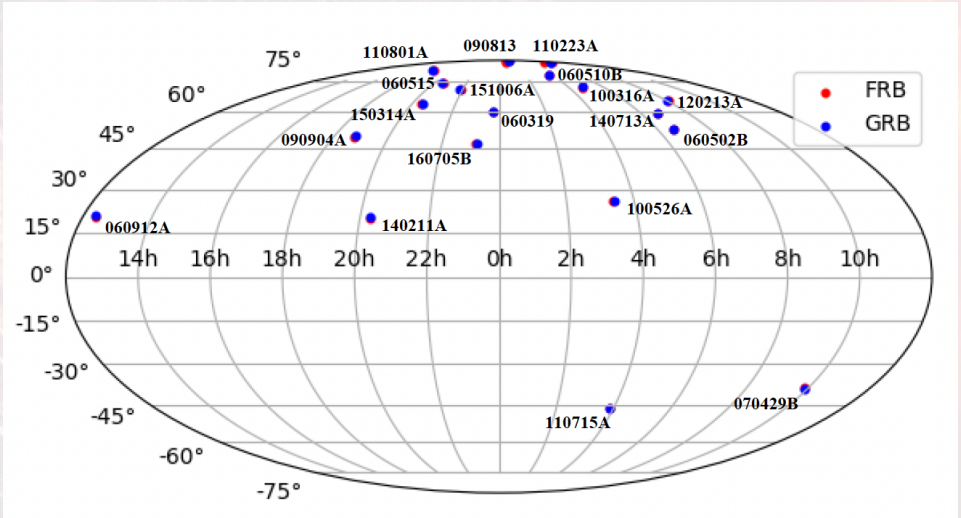
- We considered all the FRBs from the FRBSTATS Catalogue available until March 2023
- We selected the ones with an accuracy in the localization $\sigma_{\rm FRB} \leq 30'$ $\rightarrow$ 633 FRBs (516 FRBs discovered by CHIME)

We searched for GRBs spatially coincident with FRBs and we further required that:

- the FRBs follows the GRB event (temporal constraint)
- the GRB redshift $z_{\rm GRB}$ is at least lower than the FRB redshift $z_{\rm FRB}$, as estimated from the dispersion measure (distance constraint)

Catalogues cross-match

When requiring spatial and temporal constraints, we found **21 positive matches** (in 2 cases, the same GRB matches two different, close by FRBs)



When additionally requiring $z_{GRB} \leq z_{FRB}$ we found **two, low significance matches**:

- Long **GRB 110715A** at z_{GRB}=0.82, and the non-repeating **FRB 20171209A**, discovered by Parkes, with $z_{FRB} = 1.17$ (see also Wang et al. 2020);
- Short **GRB 060502B** at an estimated redshift z_{GRB}=0.287, and the non-repeating **FRB 20190309A**, discovered by CHIME, with $z_{FRB} = 0.32$ (see also Lu et al. 2024)

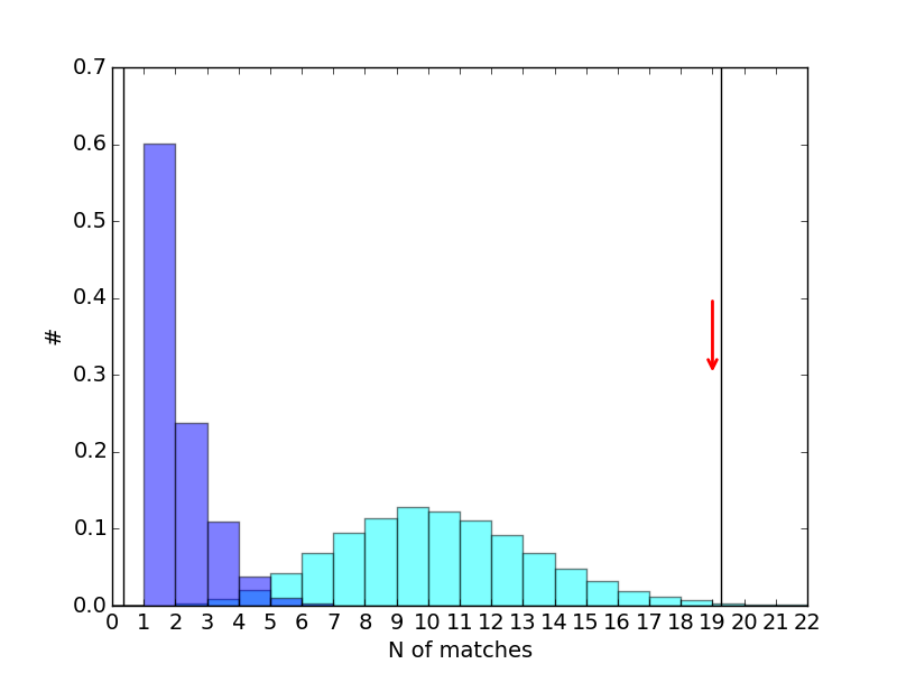
Chance probability of FRB/GRB association

Which is the probability of having a specific number of GRB-FRB association just by chance?

We performed 10^5 realizations of two synthetic populations of GRBs and FRBs

- Each synthetic population contains 1276 GRBs and 516 FRBs
- We assumed isotropic and homogeneous distribution of sources in space; FRBs: simulations restricted to the Northern hemisphere (CHIME observable sky)
- Uncertainty in the sky localization
  - GRBs: negligible;
  - FRBs: randomly extrated from a gaussian distribution with μ=14.9' and σ=6.2' (observed distribution for well localized CHIME FRBs)
- Redshift randomly extracted from the FRB and GRB redshift distributions
- Random time occurrence
  - GRBs: from Nov 20, 2004 to March 21, 2023;
  - FRBs: from July 25, 2018 to November 28, 2022

Chance probability of FRB/GRB association



- Spatial and temporal constraints
- Spatial, temporal and distance constraints

Number of matches found with catalogues cross-match is consistent at a 3-σ level with expectations from chance coincidences

Can we rule out the association between GRBs and FRBs with current observations?

How likely is to detect a FRB from a GRB if they are associated?

Assumption: **every GRB is associated with an FRB**

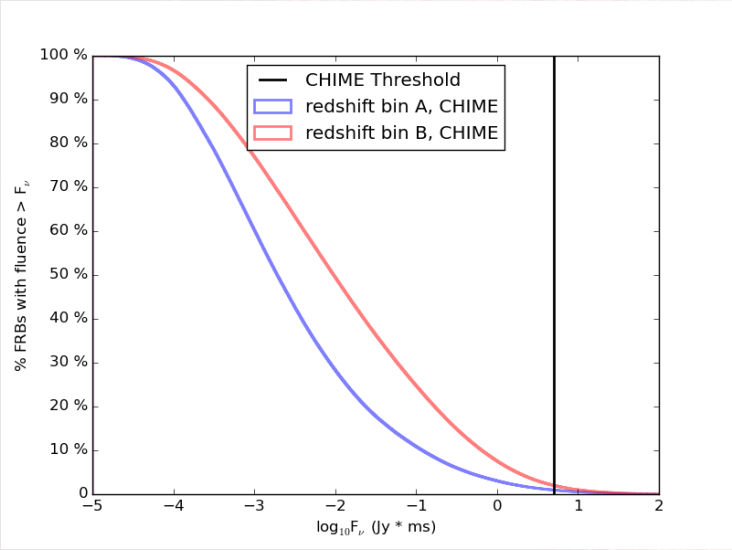
We generated a synthetic population of 10^6 FRBs

- Only non-repeating FRBs are considered; no a-priori time delay between FRBs and GRBs is choosen
- Redshift drawn from the redshift distribution of Swift GRBs
- rest-frame isotropic energy ($E_{\rm rest,400}$) drawn from the energy distribution derived by Hashimoto et al. 2022
  - Schechter function
  - FRBs from the first CHIME catalog, divided in several subsamples filling different redshift bins
  - two different sets of redshift bins ("redshift A" and "redshift B")
- Observed fluence in the CHIME frequency band (400 MHz - 800 MHz) estimated as:

$$\mathrm{F}_\nu = \frac{(1+\mathrm{z})^{2-\gamma}\mathrm{E}_{\rm rest,400}}{4\pi \mathrm{d}_\mathrm{L}^2(\mathrm{z})\Delta\nu}$$

FRB detection rates - I

- We compared the fluence of simulated FRBs with the CHIME detection threshold F_{lim}=5 Jy ms $\rightarrow P_{FRB}$



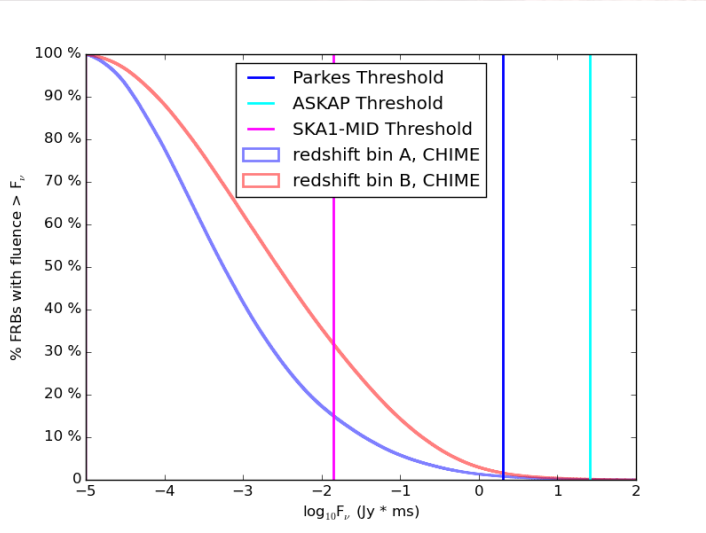
- We estimated the FRB detection rate considering P_{FRB}, the Swift GRB detection rate and the instrument field of view (fov) and duty cycle (DC)

DC	fov deg^2	Det. rate yr^{-1}
100	240	[5-11]$\times 10^{-3}$

- The **absence of a clear association** between FRBs in the current (4 years) CHIME catalog and Swift GRBs **cannot exclude that the two phenomena have a common progenitor**

FRB detection rates - II

We performed the same analysis also considering Parkes, ASKAP and SKA1-MID (observed fluence at 1.4 GHz)



	F_{lim} Jy ms	DC	fov deg^2	Det. rate yr^{-1}
Parkes	2	100	0.6	$[1\text{-}2]\times10^{-5}$
ASKAP	26	100	150	$[4\text{-}8]\times10^{-4}$
SKA1-MID	0.014	20	20	$[1\text{-}3]\times10^{-3}$

The expectations for joint detection rates with other current/future radio facilities are comparable to CHIME performances

- To increase the probability of having a joint detection more efficient GRB detectors are also needed, e.g. THESEUS (Amati et al. 2018)
- THESEUS (launching 2037) will detect ∼10 times more GRBs than Swift, potentially enabling joint detection within a ∼ 10-year timeframe

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Background image: astrometry.fas.harvard.edu/skymaps/

Conclusions

- We performed a comprehensive search for possible association between FRBs and GRBs, looking into archival data
- We identified only two, low significant matches; number of matches consistent with expectations from chance coincidence
- **The absence of any unambiguous association so far cannot exclude that the populations of FRBs and GRBs are connected, given the characteristics of current detectors**
- **Future observations with next generation of GRB and FRB detectors will be key to put more stringent constraints on the GRB-FRB association**