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Fast Radio Bursts from Magnetar Glitches

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Abstract. Both non-CHIME and CHIME fast radio bursts (FRBs) were subjected to statistical analysis and the ensuing outcome point to a strong statistical evidence for the existence of two categories of FRB events — high luminosity and low luminosity ones, with a large fraction of the repeaters falling into the latter category. The median values of radio-luminosity of the FRBs corresponding to these categories are $\sim 10^{43}$ erg/s and $\sim 10^{40}$ erg/s, respectively. We put forward a simple theoretical model to explain the observed bimodality in the FRB luminosity wherein the majority of FRBs are linked to magnetar glitches that entail abrupt increase in the Goldreich-Julian charge density as well as sudden decrease in the light-cylinder radius. These lead to release of bunched charge particles to flow along the open field lines just outside the light-cylinder, giving rise to the FRB phenomena. In the present study, we have considered relativistic effects resulting from glitches like emission of gravitational waves and the plausibility of observing the Gertsenshtein-Zel'dovich effect due to the ambient magnetic field.

Keywords: Fast Radio Bursts, Magnetars, Glitches, Gravitational Waves, Gertsenshtein-Zel'dovich effect

Introduction. Fast Radio Bursts (FRBs) are bright and transient radio sources appearing sporadically from random directions and lasting for about a few to hundreds of milliseconds [1–12]. FRBs have so far been detected in the radio waveband 110 MHz to 8 GHz. Their extra-galactic origin is inferred from the observed large dispersion measures (DMs) associated with the FRBs. A fraction of the FRBs happen to be repeaters e.g. FRB 20121102A and FRB 20180916B. The all-sky FRB event rate is very high and is estimated to be about 10^4 [6].

Methods and materials; results. We have assumed the universe to be described by a Friedmann-LeMaitre-Robertson-Walker (FLRW) model and that the time dependent luminosity density is represented by a power law spectrum so that,

$$L_\nu = L_0(t)\nu^{-\alpha},$$

where $L_0(t)$, α , ν and t are the time-dependent source luminosity parameter, spectral index in the radio range, frequency, and time in the rest frame of the source, respectively.

Then, the observed flux density and the fluence are related to the intrinsic FRB parameters as follows,

$$S_{\nu_0}(t_0) = \frac{((1+z)^{1-\alpha}\nu_0^{-\alpha}L_0(t))}{4\pi D^2}$$

and, integrating the above over the time,

$$F_{\nu_0} = \int_{t_0}^{t_0 + \Delta t_0} S_{\nu_0}(t') dt',$$

respectively, where z , ν_0 , t_0 and $D(z)$ are the source cosmological redshift, observed frequency, cosmic time in the observer's rest frame and the FLRW luminosity distance of the source, respectively, with the rest frame time t of the transient source being related to the observer's rest frame time t_0 by the equation, $a(t_0)/a(t) = 1 + z$, $a(t)$ being the FLRW scale factor. In our studies, we have used the following values for the FLRW model parameters: $H_0 = 73.04$ km/s/Mpc, $\Omega_{m,0} = 0.28$ and $\Omega_{\Lambda,0} = 0.72$.

The FRB luminosity density at a particular frequency, say 300 MHz, is given by,

$$L_{300} = 4\pi D^2 (1 + z)^{\alpha-1} S_{\nu_0} \left(\frac{\nu_0}{300 \text{ MHz}} \right)^\alpha$$

while the FRB energy and energy density are given by,

$$E = 4\pi D^2 (1 + z)^{\alpha-2} F_{\nu_0} \nu^{\alpha_0} \left[\frac{\nu_1^{1-\alpha} - \nu_2^{1-\alpha}}{\alpha - 1} \right]$$

and,

$$u_{FRB} \sim \frac{E}{l^3} > \frac{E}{(c\Delta t)^3},$$

respectively, l being the size of the FRB region.

Transient Name Server (TNS) website <https://www.wis-tns.org> was used to obtain data related to non-CHIME FRBs. These transient events were largely detected using telescopes like the Australian Square Kilometre Array Pathfinder (ASKAP), Parkes, Arecibo, etc. The FRB data pertaining to the Canadian Hydrogen Intensity Mapping Experiment (CHIME) was taken from the CHIME/FRB first catalog paper from the CHIME data website <https://www.chime-frb.ca/catalog>.

The CHIME catalog only lists lower bounds to the fluence and flux density of individual radio transients. Hence, we have employed in our statistical analysis a new technique that involves dimensionless as well as dimensional quantities that make use of the ratio of measured fluence to flux density as well as various other measured and estimated physical quantities related to the FRBs so that we may compare the results for both non-CHIME as well as CHIME FRBs [13].

Based on our analysis, we conclude that the non-CHIME FRBs come in two distinct categories: low and high luminosity density events, based on the peak L_{300} distribution. The low luminosity density category is mostly dominated by repeating FRB events, while most of the non-repeaters belong to the high luminosity density category. The distribution of the ratio of peak L_{300} to E also displays a similar bimodality with regards to repeaters and non-repeaters. This feature is shared by the CHIME FRBs as well, strengthening our conclusion favoring the existence of two

distinct categories of FRB events wherein repeaters tend to be associated with lower values of radio luminosity density events [14]. The brightness temperature and u tend to be larger for the high luminosity category.

Conclusion. Very early on in this field of research, magnetars have been linked with the FRB phenomena [15–17].

In recent times, magnetar glitches have been associated with FRBs [18, 19]. Previously, we had put forward a simple model based on magnetar glitches to explain the bi-modality in FRB luminosity [13, 14].

The model describes FRB emission by using the effect of magnetar glitches, wherein the angular speed changes from ω to $\omega + \delta\omega$, on the Goldreich-Julian charge density and also on the sudden decrease in the light-cylinder radius, the combination of which entails an abrupt release of bunched charge particles to flow along the open field lines just outside the new light-cylinder.

The bi-modality emerges if one considers for the higher FRB luminosity category a polar magnetic field of $B_p \sim 10^{15}$ Gauss and $\delta\omega/\omega \sim 3 \times 10^{-5}$ as against the values $B_p \sim 10^{14}$ Gauss and $\delta\omega/\omega \sim 2 \times 10^{-5}$, respectively, for the weaker category. Of course, with a larger value of glitch, $\delta\omega/\omega \sim 10^{-4}$ $\delta\omega/\omega \sim 10^{-4}$, the higher luminosity category FRBs can follow from magnetars with $B_p \sim 10^{14}$ Gauss. In this model, curvature radiation along open field lines being responsible for the FRB emission, it is expected that the ensuing radiation is linearly polarized and therefore would undergo Faraday rotation as it propagates through intervening plasma that is threaded with magnetic field. Therefore, in the SKA era, measurements of both rotation measure and dispersion measure corresponding to over $\sim 10^3$ FRBs would lead to a significant progress in our understanding of IGM magnetic fields.

In this study, we report that the magnetar glitches can lead to emission of gravitational waves (GWs) with typical wave amplitude $h \sim 10^{-4} \delta\omega/\omega$ in the vicinity of the light cylinder. We also consider the plausibility of observing the electromagnetic waves ensuing from such GWs propagating in the magnetosphere due to the Gertsenshtein-Zel'dovich effect.

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