On the magnetoionic environments of fast radio bursts

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ABSTRACT

Observations of the Faraday rotation measure, combined with the dispersion measure, can be used to infer the magnetoionic environment of a radio source. We investigate the magnetoionic environments of FRBs by deriving their estimated average magnetic field strengths along the line of sight \(\langle B_\parallel \rangle\) in their host galaxies and comparing them with those of Galactic pulsars and magnetars. We find that for those FRBs with RM measurements, the mean \(\langle B_\parallel \rangle\) is \(1.77^{+1.48}_{-1.48}\) \(\mu G\) and \(1.74^{+1.55}_{-1.42}\) \(\mu G\) using two different methods, which is slightly larger but not inconsistent with the distribution of Galactic pulsars, \(1.00^{+1.51}_{-0.60}\) \(\mu G\). Only six Galactic magnetars have estimated \(\langle B_\parallel \rangle\). Excluding PSR J1745–2900 that has an anomalously high value due to its proximity with the Galactic Centre, the other three sources have a mean value of \(1.70\) \(\mu G\), which is statistically consistent with the \(\langle B_\parallel \rangle\) distributions of both Galactic pulsars and FRBs. There is no apparent trend of evolution of magnetar \(\langle B_\parallel \rangle\) as a function of age or surface magnetic field strength. Galactic pulsars and magnetars close to the Galactic Centre have relatively larger \(\langle B_\parallel \rangle\) values than other pulsars/magnetars. We discuss the implications of these results for the magnetoionic environments of FRB 121102 within the context of magnetar model and the model invoking a supermassive black hole, and for the origin of FRBs in general.

Key words: pulsars: general - stars: neutron - radio continuum: transients

1 INTRODUCTION

Fast radio bursts (FRBs) are millisecond-duration coherent emissions of extragalactic/cosmological origin (e.g. Lorimer et al. 2005; Thornton et al. 2012; Chatterjee et al. 2017; Bannister et al. 2014; Prochaska et al. 2014; Marcote et al. 2018). The physical origin(s) of these events are unknown.

The polarization properties of FRBs may shed light on the magneto-ionic environment and the physical mechanisms of FRBs. Only a small fraction of FRBs have polarization measurements, but the data show a perplexing picture (Petroff et al. 2018): whereas some bursts show a nearly 100% linear polarization percentage, some others have moderate or even negligible polarization degrees. Faraday rotation measures (RM) can be measured for those events with linear polarizations. The first observed repeating source, FRB 121102, has a very large, varying Faraday rotation measure (RM) of the order of \(10^5\) rad m\(^{-2}\) (Chatterjee et al. 2017; Marcote et al. 2018). On the other hand, other sources, either apparently non-repeating (FRB 180924, FRB 181112 and FRB 190102, Bannister et al. 2019; Prochaska et al. 2019) or repeating (FRB 180301 and FRB 180916.J0158+65, The CHIME/FRB Collaboration et al. 2019; Luo et al. 2020), show a much smaller (by 2-4 orders of magnitude) RM.

When combined with the dispersion measure (DM), the RM can be used to infer the average magnetic field strength along the line of sight (LOS) in the host galaxy of the FRB. For FRB 121102, this is \(B_\parallel \sim 1\) mG, which is several orders of magnitude higher than that of the interstellar medium (Michilli et al. 2018). In the literature, two scenarios have been discussed to account for such an extreme magnetoionic environment. One scenario invokes a strongly magnetized neutron star (or magnetar), which injects a highly magnetized wind to the medium forming a magnetar wind nebula (MWN). The large RM of FRB 121102 may be interpreted within the framework of such...

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a MWN (Piro & Gaensler 2013; Metzger et al. 2019). The second scenario invokes a source in the vicinity of a supermassive black hole (Michilli et al. 2013; Zhang 2018a), the only known location where an extremely high RM has been observed (Eatough et al. 2013).

Motivated by the recent intriguing observations of an FRB-like burst associated with a hard X-ray burst from a Galactic magnetar SGR 1935+2154 (Bochenek et al. 2020; The CHIME/FRB Collaboration et al. 2020; Li et al. 2020; Mereghetti et al. 2020; Ridnaia et al. 2020; Tavani et al. 2021), we compare the $B_1$ values derived from FRB observations with those of Galactic magnetars and pulsars as an effort to diagnose the origin of $B_1$ of FRBs. The results are presented in Section 2. The implications of the results on the origin of FRBs are discussed in Section 3. The results are summarized in Section 4.

2 MAGNETOIONIC ENVIRONMENTS OF GALACTIC PULSARS, MAGNETARS, AND FRBS

2.1 Galactic pulsars and magnetars

The average magnetic field strength (i.e. the absolute value) along the line of sight (LOS) may be derived by combining the measurements of RM and DM of radio pulses (e.g. Manchester 1972, 1974; Han et al. 2006; Noutsos et al. 2008; Han et al. 2018):

$$\langle B_0 \rangle = 1.23 \frac{\text{RM}}{\text{DM}} \mu G,$$

where RM is in units of rad m$^{-2}$ and DM is the dispersion measure in units of pc cm$^{-3}$. For Galactic pulsars (data are quoted from Manchester et al. 2005), the contribution to RM from the plasma associated with the source is negligible, so that $\langle B_0 \rangle$ can be used to map the magnetic field structure of the Galaxy (Han & Qiao 1994). The RM term $\text{RM}_{\text{iono}}$ originated from the Earth’s ionosphere (Sotomayor-Beltran et al. 2013) is 0.5–3 rad m$^{-2}$. The RMs for most Galactic pulsars are larger than 10 rad m$^{-2}$. For pulsars that have DM $\sim 100$ pc cm$^{-3}$, the variability of the ionospheric RM only slightly affects $\langle B_0 \rangle$ and can, hence be neglected. The $\langle B_0 \rangle$ of Galactic pulsars are calculated with Equation (1) and plotted in Figure 1.

We consider whether Galactic magnetars can host a more extreme magneto-ionic environment than pulsars. According to theory, a young magnetar may power an MWN, which may be more magnetized than a regular pulsar wind nebula. In an expanding MWN, the DM and RM would generally decrease with time (Metzger et al. 2013; Yang & Zhang 2013; Piro & Gaensler 2018; Margalit & Metzger 2018; Metzger et al. 2019), suggesting that one may observe a trend of decreasing $\langle B_0 \rangle$ with time or surface magnetic field strength. Among over twenty observed magnetars, there are six sources that emitted polarized radio waves to allow $\langle B_0 \rangle$ to be measured (The CHIME/FRB Collaboration et al. 2020; Lower et al. 2020; see Kaspi & Beloborodov 2017 for a review).

In Figure 1(a) and (b), we plot $\langle B_0 \rangle$ as a function of magnetar surface magnetic field $B_s$ and characteristic age for these six radio magnetars. The characteristic age is close to real age under the assumptions that the initial spin period of the pulsar is much less than its current period and that pulsar spindown is dominated by dipolar magnetic braking. The surface magnetic field configuration is likely more complicated but the exact strength of the surface field is difficult to infer from observations. For simplicity, we use $B_3$ as a proxy of the magnetar surface magnetic field and study how $\langle B_3 \rangle$ depends on it. For comparison, we also select some pulsars that are within 0.5 kpc from the magnetars. The distance between a pulsar and a magnetar is calculated by combining their radial distances inferred from DM measurements and their transverse distance measured based on their celestial coordinates. The distance to Swift J1818.0–1607 is estimated to be 4.8 kpc (according to the YMW16 electron density model, Yao et al. 2017) or 8.1 ± 1.6 kpc (according to NE2001 electron density model, Cordes & Lazio 2002). Another source, SGR 1935+2154, has an unknown distance, but one may assume that the SGR is physically related to a supernova remnant SNR G57.2+0.8, which has a distance of 9.0 ± 2.5 kpc (Zhong et al. 2020; Zhou et al. 2020).

Figure 1(a) shows that except the magnetar PSR J1745–2900, whose abnormally large $\langle B_0 \rangle$ may be related to its proximity with the Galactic super-massive black hole, the other five magnetars have $\langle B_3 \rangle$ consistent with the pulsar $\langle B_0 \rangle$ distribution (two within 1σ, one slightly outside the 1σ region). Indeed some regular pulsars have larger $\langle B_0 \rangle$ values than magnetars. Compared with normal pulsars within 5 kpc, the five magnetars also do not have systematically higher $\langle B_0 \rangle$ values. Figure 1(b) plots $\langle B_3 \rangle$ against pulsar age. One can see that PSR J1745–2900 is not the youngest but has the highest $\langle B_3 \rangle$, further suggesting that its abnormal $\langle B_0 \rangle$ is related to its special environment. For the five magnetars, there is also no trend of decreasing $\langle B_0 \rangle$ with characteristic age.

In view of the abnormally high $\langle B_0 \rangle$ of the magnetar PSR J1745–2900, we also investigate the relationship between $\langle B_0 \rangle$ and the distance of pulsars from the Galactic Centre. The results are shown in Figure 1(c). The $\langle B_0 \rangle$ values for the magnetar PSR J1745–2900 and two pulsars close to it (PSR J1746–2849 and PSR J1746–2856) have $\langle B_0 \rangle$ significantly exceeding those of Galactic pulsars, further suggesting that it is the special location near the Galactic centre that caused the abnormally high $\langle B_0 \rangle$. The Galactic Centre super-massive black hole likely provides the strong local magnetic field. The magnetar PSR J1745–2900 indeed shows a larger $\langle B_0 \rangle$ than the pulsars. This may suggest that the magnetar may contribute to an additional $\langle B_0 \rangle$ value. However, due to the large uncertainty of the distance measurements from the Galactic Centre (noticing the large error bars of the red dots), this conclusion cannot be firmly drawn. It is interesting to note that at distances beyond 1 kpc, $\langle B_0 \rangle$ is essentially independent of distance from the Galactic Centre.

The $\langle B_1 \rangle$ distribution of Galactic pulsars can be fitted with a log normal function, as shown in Figure 2. The mean value of $\log \langle B_1 \rangle$ is $\mu_{\text{pulsar}} = -0.002$ with a standard deviation of $\sigma_{\text{pulsar}} = 0.40$ for the log normal distribution. Excluding the Galactic Centre magnetar PSR J1745–2900, the other five magnetar sources have a mean $\langle B_1 \rangle$ of 1.84 $\mu$G, which is statistically consistent with the pulsar $\langle B_1 \rangle$ distribution.
2.2 FRBs

For a source at cosmological distances, the observed total RM_{obs} consists of contributions from several different terms,

\[ \text{RM}_{\text{obs}} = \text{RM}_{\text{iono}} + \text{RM}_{\text{Gal}} + \text{RM}_{\text{IGM}} + \text{RM}_{\text{HG, sr}}, \]

(2)

where \( \text{RM}_{\text{Gal}} \) is the Galactic component, \( \text{RM}_{\text{IGM}} \) is contributed from the intergalactic medium (IGM), and \( \text{RM}_{\text{HG, sr}} \) is contributed by the host galaxy and the FRB source as measured in the Observer’s frame. The true value of the latter in the rest frame of the host galaxy is

\[ \text{RM}_{\text{HG, sr}} = \text{RM}_{\text{HG, sr}}(1 + z)^2, \]

(3)

where \( z \) is the redshift.

In order to determine \( \text{RM}_{\text{Gal}} \), we identify the RM of the known NRAO VLA Sky Survey (NVSS) sources \( \text{Taylor et al.} \) (2009). The closest sources are \( \lesssim 2^\circ \) away from the position of FRBs. For the FRB sources located in the survey blind regions, we identify the RM based on their closest pulsars \( \text{Han et al.} \) (2018). Alternatively, a simulation result of Galactic RM is given by \( \text{Oppermann, et al.} \) (2015), even though the simulation results are based on some inputs and assumptions. The strength of intergalactic magnetic fields is much lower. A safe upper limit is \( \sim 10^{-9} \text{ G} \) \( \text{Dai et al.} \) (2002; \text{Ando} & \text{Kusenko} \) (2010; \text{Dermer et al.} \) (2011; \text{Arlen et al.} \) (2014), which gives \( \text{RM}_{\text{IGM}} \lesssim 1 \text{ rad m}^{-2}, \) so that it can usually be neglected. After subtracting the contributions from \( \text{RM}_{\text{iono}} \) and \( \text{RM}_{\text{Gal}} \), one can finally derive \( \text{RM}_{\text{HG, sr}} \) and \( \text{RM}_{\text{HG, sr}}^{\text{Loc}} \).

The observed DM also consists of several terms:

\[ \text{DM}_{\text{obs}} = \text{DM}_{\text{Gal}} + \text{DM}_{\text{halo}} + \text{DM}_{\text{IGM}} + \text{DM}_{\text{HG, sr}}, \]

(4)
Figure 2. The parallel magnetic field strength \( \langle B_\| \rangle \) of FRBs within their host galaxies. Left: Subtracted the Galactic DM contribution by the method of NE2001. The light blue crosshairs in the upper-left corner is for FRB 121102. The light blue diamonds are other repeating FRBs. The purple squares are apparently non-repeating FRBs. The black dashed line is the mean value of \( \langle B_\| \rangle \) for FRBs except FRB 121102. The grey zone is the 1-\( \sigma \) region of the distribution. Right: Same as the left but for the method of YMW16.

Figure 3. Histograms of the log normal distribution of \( \langle B_\| \rangle \) for FRBs (red) and pulsars (blue). The colored solid lines are magnetars: SGR 1935+2154 (purple), XTE J1810–197 (yellow), PSR J1622–4950 (blue), Swift J1818.0–1607 (orange), 1E 1547.0–5408 (green) and PSR J1745–2900 (red). The black solid and dashed lines are the best fitting for FRBs and pulsars. The light blue vertical line shows the \( \langle B_\| \rangle \) of FRB 121102. Left: The Galactic DM contribution is subtracted using NE2001; Right: The Galactic DM contribution is subtracted using YMW16.

where DM_{Gal} can be derived from the Galactic electron density models. However, the two well-known Galactic electron density models NE2001 and YWM16, give quite different results sometimes (Cordes & Lazio 2002; Yao et al. 2017). In the following discussion, we consider the electron density models. However, the two well-known Galactic electron density models, separately. The DM associated with the Milky Way halo is adopted as DM_{halo} = 30 ± 15 pc \( cm^{-3} \) according to Dolag et al. (2015). The average value of the IGM component is \( \langle B_\| \rangle \) for FRBs (red) and pulsars (blue). The colored solid lines are magnetars: SGR 1935+2154 (purple), XTE J1810–197 (yellow), PSR J1622–4950 (blue), Swift J1818.0–1607 (orange), 1E 1547.0–5408 (green) and PSR J1745–2900 (red). The black solid and dashed lines are the best fitting for FRBs and pulsars. The light blue vertical line shows the \( \langle B_\| \rangle \) of FRB 121102. Left: The Galactic DM contribution is subtracted using NE2001; Right: The Galactic DM contribution is subtracted using YMW16.

\[ \frac{3 \pi H_0 \Omega_m f_{\text{IGM}}}{8 \pi G m_p} \int_0^z \frac{\chi(z)(1+z)dz}{\left[ \Omega_m (1+z)^3 + \Omega_\Lambda \right]^2} \]  

where the free electron number per baryon in the universe is \( \chi(z) \approx 7/8 \) and the fraction of baryons \( f_{\text{IGM}} \) \( \sim 0.83 \). For a distant cosmological FRB, the DM is mainly contributed by IGM rather than Milky Way or the host galaxy, in contrast to the RM that has a significant contribution from the host. The \( \Lambda \)CDM cosmological parameters are taken as \( \Omega_m = 0.315 \pm 0.007, \Omega_\Lambda h^2 = 0.02237 \pm 0.00015, \) and \( H_0 = 67.36 \pm 0.54 \text{ km s}^{-1}\text{Mpc}^{-1} \) (Planck Collaboration et al. 2018). The remaining term in Eq. (4) is DM_{HG, sr} in the observer frame. The intrinsic value in the source frame is related to it by

\[ DM_{\text{IGM}, sr} = (1 + z)DM_{\text{HG, sr}}. \]  

In practice, DM_{HG, sr} is difficult to derive from the observed DM_{Obs}, even if the redshift of the FRB is precisely known because there is a large scatter of DM_{IGM} around Eq. (4) due to the large scale structure fluctuation (McQuinn 2014). Several FRB sources have measured redshifts, so that their DM_{IGM} and uncertainties can be derived (McQuinn 2014). As a result, we can calculate DM_{HG, sr} and its uncertainty \( \delta DM_{\text{HG, sr}} \) directly. For the sources without precise redshift measurements, we adopt the opposite approach, to consider the distribution of DM_{HG, sr} based on host galaxy
models. Following a generic constraint by Li et al. (2020a), we assume that $\Delta M_{\text{DM}} = 85 \pm 35 \, \text{pc cm}^{-3}$, which is consistent with the results of the average DM contribution from the host galaxy in the local frame e.g., Xu & Han (2013) and Luo et al. (2018).

The average magnetic field for the host galaxy along the LOS can then be derived as

$$\langle B_i \rangle = 1.23(1 + z) \frac{\Delta M_{\text{HG}}}{\Delta M_{\text{DM}}} \mu \text{G},$$

where for the redshift we either adopted the spectroscopic value if measured, or estimated using Eq. (6) with error properly introduced.

Based on the FRB catalog (Friscat.org), in Table 1 we list all the FRBs with both RM and DM measured. According to Eq. (6), we estimate $\langle B_i \rangle$ for these FRBs. The results are listed in Tables 1 and 2, where $\Delta M_{\text{DM}}$ is derived using the NE2001 and YMW16 models, respectively. Several sources have $\Delta M_{\text{HG}}$ smaller than $\Delta M_{\text{DM}}$ and $\Delta M_{\text{DM}}$, which differ from FRB 121102 whose $\Delta M_{\text{HG}}$ and $\Delta M_{\text{DM}}$ are comparable. We show the lower limits for these sources. The distribution of $\langle B_i \rangle$ is also presented in Figure 3, which can be also fitted with a log normal function when FRB 121102 is excluded. The mean value derived by the two Galactic electron density models are $\mu_{\text{FRB}} = 0.25$, $\sigma_{\text{FRB}} = 0.78$ (NE2001) and $\mu_{\text{FRB}} = 0.24$, $\sigma_{\text{FRB}} = 1.00$ (YMW16), respectively. These values are slightly higher but not inconsistent with the distributions of both Galactic pulsars and magnetars.

3 IMPLICATIONS FOR THE MODELS OF FRBS

The results presented above can shed light on the origin of FRB 121102. Both FRB 121102 and PSR J1745–2900 have abnormally large $\langle B_i \rangle$ in their respective categories. The abnormally large RM and $\langle B_i \rangle$ of PSR J1745–2900 among the Galactic magnetars is attributed to its proximity to the Galactic Centre. It is therefore tempting to attribute the abnormally large RM and $\langle B_i \rangle$ of FRB 121102 to its special environment, likely a putative supermassive black hole provided by its local environment. Indeed, Zhang (2018b) suggested that a neutron star whose magnetosphere is sporadically reconstructed by a supermassive black hole can be the source of repeating bursts. Another argument in favor of this is that FRB 121102 seems to be a very active repeating FRB source (e.g. Petroff et al. 2016). In Table 1 we list all the FRBs with a mean value of 1.00 $\mu$G, consistent with the distribution of pulsars.

Another interesting observation is that the repeaters in our sample (FRB 121102 excluded) are not systematically more magnetized than apparently non-repeating (one-off) FRBs. This is very likely due to that most non-repeating FRBs are actually repeaters. If most of them are due to a different type of progenitor system, that system should also produce a similar magneto-ionic environments as repeaters.

4 SUMMARY

We have investigated the magneto-ionic environments of the Galactic pulsars/magnetars and FRBs by making use of the measured RM and DM from these sources. We investigated the $\langle B_i \rangle$ of magnetars as a function of age or surface magnetic field strength and find no apparent trend. The $\langle B_i \rangle$ of pulsars can be well fitted by a log normal distribution with a mean value of $1.00_{-0.51}^{+1.51} \mu$G. The mean $\langle B_i \rangle$ of Galactic magnetars (except PSR J1745–2900 at the Galactic Centre) is $1.70 \mu$G, consistent with the distribution of pulsars.

The $\langle B_i \rangle$ distribution of FRB sources is investigated and fitted with a lognormal function. The mean value of $\langle B_i \rangle$ derived by the two methods are $1.77_{-0.31}^{+0.51} \mu$G and $1.74_{-1.48}^{+1.82} \mu$G. The $\langle B_i \rangle$ of FRBs is also consistent with that of Galactic magnetars. FRB 121102 has an extraordinary excess from the FRB $\langle B_i \rangle$ distribution.
Table 1. DM (subtracted by NE001) and RM of FRB and magnetar sample

| Source | $DM_{\text{access}}$ (pc·cm$^{-3}$) | $z$ | $DM_{\text{MC}}$ (pc·cm$^{-3}$) | $RM_{\text{DM}}$ (rad m$^{-2}$) | $RM_{\text{IGM}}$ (rad m$^{-2}$) | $\langle B \rangle$ (µG) |
|--------|------------------------------------|-----|-------------------------------|-------------------------------|-------------------------------|----------------------|
| FRB 121102 | 374 | 0.193 | 140 ± 85 | (0.9 – 1.0) × 10$^5$ | (0.9 – 1.0) × 10$^5$ | 989.4 – 1084.1 |
| FRB 180916.0158+65 | 119 | 0.034 | 73.8 ± 15 | –114 ± 0.6 | 206.0 ± 17.7 | 0.5 ± 0.3 |
| FRB 180924 | 290.92 | 0.321 | 15.8 | 14 ± 1 | 7.1 ± 15.4 | 0.7 ± 0.7 |
| FRB 181112 | 457.27 | 0.476 | 42.9 | 10.9 ± 0.9 | –22.5 ± 5.8 | 1.0 ± 0.4 |
| FRB 190102 | 276.3 | 0.291 | 28.3 | 110 ± 17 | –12 ± 10 | 1.2 ± 0.8 |
| FRB 110523 | 549.78 | 0.56 ± 0.17 | 54.3 ± 31.8 | 186.1 ± 1.4 | 188.6 ± 19.3 | 6.7 ± 4.8 |
| FRB 150215 | 648.4 | 0.68 ± 0.18 | 50.7 ± 26.2 | 3.3 ± 12.2 | 3.0 ± 27.3 | 0.1 ± 0.1 |
| FRB 150418 | 557.7 | 0.57 ± 0.17 | 54.0 ± 31.7 | 36 ± 52 | –211 ± 59 | 7.6 ± 5.8 |
| FRB 150807 | 199.6 | 0.15 ± 0.02 | 73.8 ± 31.3 | 12.0 ± 7 | 1.3 ± 8 | 0.03 ± 0.03 |
| FRB 160102 | 2553.1 | 3.05 ± 0.41 | 21.0 ± 9.8 | –220.6 ± 6.4 | –249.3 ± 12.7 | 59.5 ± 18.6 |
| FRB 171209 | 1414.4 | 1.56 ± 0.41 | 33.2 ± 19.4 | 121.6 ± 4.2 | 115.5 ± 9.2 | 5.1 ± 2.4 |
| FRB 180301 | 342 | 0.33 ± 0.11 | 64.2 ± 22.4 | 520 ± 570 | 504.5 ± 546.2 | 9.7 ± 13.9 |
| FRB 180309 | 188.73 | 0.14 ± 0.02 | 74.8 ± 31.9 | < 150 | 142.8 < | < 2.7 ± 9 |
| FRB 180311 | 1495.7 | 1.66 ± 0.41 | 32.0 ± 15.7 | 4.8 ± 7.3 | –17.5 ± 10.3 | 1.8 ± 1.2 |
| FRB 180714 | 1809.92 | 1.28 ± 0.25 | 37.2 ± 17.5 | –25.9 ± 5.9 | 55.2 ± 21.4 | 0.3 ± 0.3 |
| FRB 190303.J1353+48 | 163.4 | 0.11 ± 0.02 | 76.9 ± 33.8 | –504.4 ± 0.4 | 498.5 ± 12 | 9.0 ± 6.3 |
| FRB 190604.J1435+53 | 490.65 | 0.50 ± 0.15 | 56.8 ± 32.2 | –18 ± 1 | 15.7 ± 1.4 | 3.2 ± 0.7 |
| FRB 190608 | 271.5 | 0.24 ± 0.10 | 68.5 ± 26.4 | 353 ± 2 | 370.3 ± 9.6 | 8.3 ± 2.8 |
| FRB 190611 | 234.57 | 0.19 ± 0.09 | 71.2 ± 38.5 | 20 ± 4 | 15.9 ± 12.1 | 0.3 ± 0.3 |
| FRB 190711 | 506.7 | 0.52 ± 0.16 | 56.1 ± 32.2 | 9 ± 2 | 56.0 ± 16 | 1.9 ± 1.4 |
| FRB 191108 | 506.1 | 0.51 ± 0.16 | 56.1 ± 26.2 | 474 ± 3 | 47.7 ± 22.6 | 16.6 ± 5.8 |

References: Bannister et al. (2013), Caleb et al. (2018), The CHIME/FRB Collaboration et al. (2020), Chatterjee et al. (2017), The CHIME/FRB Collaboration et al. (2019), Connors et al. (2020), Dav et al. (2020), Domcke et al. (2021), Kraus et al. (2018), Luo et al. 2020, Macquart et al. (2020), Manchester et al. (2003), Marcote et al. (2015), Marcote et al. (2020), Masui et al. (2015), Michilli et al. (2018), Oskowski et al. (2018), Petroff et al. (2015), Prochaska et al. (2018), Ravi et al. (2016), Tendulkar et al. (2017)

121102 is discussed in the framework of both a supermassive black hole and an MWN. In connection with PSR J1745–2900, the latter possibility is tempting. The magnetar model requires extreme conditions for the source of FRB 121102. In general, magnetars behind all FRBs (both repeating and apparently non-repeating) remains a plausible possibility.

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DATA AVAILABILITY

The data underlying this article are available in the article.

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Table 2. DM (subtracted by YMW16) and RM of FRB and magnetar sample

| Source          | DM$_{\text{YMW16}}$ (pc cm$^{-3}$) | z        | DM$_{\text{HGP,et}}$ (pc cm$^{-3}$) | RM$_{\text{YMW16}}$ (rad m$^{-2}$) | RM$_{\text{HGP,et}}$ (rad m$^{-2}$) | ($B_{\|}$) ($\mu$G) |
|-----------------|----------------------------------|----------|----------------------------------|----------------------------------|----------------------------------|-----------------|
| FRB 121102      | 374                              | 0.193    | 140 ± 85                         | (0.9 – 1.0) $\times 10^5$        | (0.9 – 1.0) $\times 10^5$        | 989.4 – 1084.1  |
| FRB 180916.10158+65$^a$ | 19.2                              | 0.034    | –                                 | –                              | –                              | –               |
| FRB 180924      | 303.77                           | 0.321    | 28.7                             | 14 ± 1                          | 7.1 ± 15.4                      | 0.7 ± 0.1       |
| FRB 181112      | 530.24                           | 0.476    | 115.8                            | 10.9 ± 9.6                      | –22.5 ± 5.8                     | 1.0 ± 0.4       |
| FRB 190102      | 290.29                           | 0.291    | 42.3                             | 110                             | –17 ± 12                        | 1.0 ± 0.8       |
| FRB 110523      | 560.3                            | 0.58 ± 0.17 | 53.9 ± 41.2                     | –186.1 ± 1.4                    | –188.6 ± 19.3                   | 6.8 ± 4.9       |
| FRB 150215      | 782.8                            | 0.83 ± 0.19 | 46.5 ± 21.9                     | –3.3 ± 12.2                     | 3.0 ± 27.3                      | 0.1 ± 0.1       |
| FRB 150418      | 420.66                           | 0.42 ± 0.13 | 60.0 ± 27.6                     | 36 ± 52                         | –211 ± 59                      | 6.1 ± 2.5       |
| FRB 150807      | 211.01                           | 0.17 ± 0.08 | 72.9 ± 12.0                     | 12.0 ± 7                        | –1.3 ± 8                       | 0.03 ± 0.03     |
| FRB 160102      | 2553.1                           | 3.05 ± 0.41 | 21.0 ± 15.6                     | –220.6 ± 6.4                    | –243.9 ± 12.7                   | 59.5 ± 18.6     |
| FRB 171209      | 1192.4                           | 1.30 ± 0.25 | 37.0 ± 14.7                     | 121.6 ± 4.2                     | 115.5 ± 9.2                     | 4.1 ± 1.8       |
| FRB 180301      | 240                              | 0.20 ± 0.10 | 70.7 ± 37.0                     | 52.0 – 57.0                     | 504.5 – 546.2                   | 8.8 – 11.5      |
| FRB 180309      | 263.42                           | 0.17 ± 0.08 | 73.5 ± 33.3                     | < 150                           | 142.8 ± 8.6                     | < 2.8 ± 2.0     |
| FRB 180331      | 1508.9                           | 1.67 ± 0.41 | 31.8 ± 21.2                     | 4.8 ± 7.3                      | –17.5 ± 10.3                    | 1.8 ± 1.7       |
| FRB 180714      | 1214.92                          | 1.32 ± 0.25 | 35.0 ± 15.6                     | –25.9 ± 5.9                     | 55.2 ± 21.4                     | 0.3 ± 0.1       |
| FRB 190303J1353+48 | 170.4                            | 0.11 ± 0.02 | 76.3 ± 45.5                     | –504.4 ± 0.4                    | 498.5 ± 12                      | 9.1 ± 5.4       |
| FRB 190604J1435+53 | 498.65                           | 0.51 ± 0.15 | 56.4 ± 32.3                     | –16 ± 1.1                       | 15.7 ± 1.4                      | 0.7 ± 0.2       |
| FRB 190608      | 282.08                           | 0.25 ± 0.10 | 67.8 ± 36.2                     | 353 ± 2                         | 370.3 ± 9.6                     | 8.4 ± 6.6       |
| FRB 190611      | 247.73                           | 0.24 ± 0.10 | 70.2 ± 32.0                     | 20 ± 4                          | 15.9 ± 12.1                     | 0.3 ± 0.1       |
| FRB 190711      | 520.49                           | 0.21 ± 0.10 | 55.6 ± 32.1                     | 9 ± 2                           | 56.0 ± 16                       | 1.9 ± 0.8       |
| FRB 191108      | 515.1                            | 0.53 ± 0.16 | 55.7 ± 32.1                     | 474 ± 3                         | 497.7 ± 22.6                    | 16.8 ± 11.9     |

$^a$If we assume DM$_{\text{halo}}$ = 30 pc cm$^{-3}$, the YMW16 model places FRB 180916.10158+65 within the Milky Way halo.
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