Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY

MNRAS **458,** L19–L23 (2016) doi:10.1093/mnrasl/slv124

Non-cosmological FRBs from young supernova remnant pulsars

Liam Connor,[1,2,3] Jonathan Sievers[4,5] and Ue-Li Pen[1,6,7]★

[1] *Canadian Institute for Theoretical Astrophysics, University of Toronto, M5S 3H8 Ontario, Canada*
[2] *Department of Astronomy and Astrophysics, University of Toronto, M5S 3H8 Ontario, Canada*
[3] *Dunlap Institute for Astronomy and Astrophysics, University of Toronto, Toronto, ON M5S 3H4, Canada*
[4] *Astrophysics and Cosmology Research Unit, School of Chemistry and Physics, University of KwaZulu-Natal, Durban, South Africa*
[5] *National Institute for Theoretical Physics, KwaZulu-Natal, South Africa*
[6] *Canadian Institute for Advanced Research, Program in Cosmology and Gravitation*
[7] *Perimeter Institute for Theoretical Physics, 31 Caroline St. N., Waterloo, ON, N2L 2Y5, Canada*

Accepted 2015 August 24. Received 2015 August 7; in original form 2015 May 19

ABSTRACT

We propose a new extra but non-cosmological explanation for fast radio bursts (FRBs) based on very young pulsars in supernova remnants. Within a few hundred years of a core-collapse supernova, the ejecta is confined within ∼1 pc, providing a high enough column density of free electrons for the observed 375–1600 pc cm^{-3} of dispersion measure (DM). By extrapolating a Crab-like pulsar to its infancy in an environment like that of SN 1987A, we hypothesize such an object could emit supergiant pulses sporadically which would be bright enough to be seen at a few hundred megaparsecs. We hypothesize that such supergiant pulses would preferentially occur early in the pulsar's life when the free electron density is still high, which is why we do not see large numbers of moderate DM FRBs ($\lesssim$300 pc cm^{-3}). In this scenario, Faraday rotation at the source gives rotation measures (RMs) much larger than the expected cosmological contribution. If the emission were pulsar-like, then the polarization vector could swing over the duration of the burst, which is not expected from non-rotating objects. In this model, the scattering, large DM, and commensurate RM all come from one place which is not the case for the cosmological interpretation. The model also provides testable predictions of the flux distribution and repeat rate of FRBs, and could be furthermore verified by spatial coincidence with optical supernovae of the past several decades and cross-correlation with nearby galaxy maps.

Key words: pulsars: general – supernovae: general.

1 INTRODUCTION

The mystery of fast radio bursts (FRBs) has garnered substantial interest from the radio community. High-energy astrophysicists have tried to model their burst source, observers would like to measure a large population of them, and cosmologists hope to use them as a probe of the intergalactic medium (IGM). However, their relative scarcity (only ∼ dozen have been observed so far) and their apparent transient nature mean that we still do not know their position on the sky to better than a few arcminutes, and their radial position could be anything from terrestrial to cosmological (Kulkarni et al. 2014).

These objects are highly dispersed, with dispersion measures (DMs) (∼375–1600 pc cm^{-3}) far exceeding the expected contribution from our own Galaxy's interstellar medium (ISM; 10–100 pc cm^{-3}) and leading to the interpretation that FRBs are cosmological (Lorimer et al. 2007; Thornton 2013). Various emission mechanisms have been proposed at a wide range of source locations, including merging white dwarfs (Kashiyama, Ioka & Mészáros 2013) and neutron stars (Totani 2013), supergiant pulses from extragalactic neutron stars (Cordes & Wasserman 2016), blitzars (Falcke & Rezzolla 2014), magnetars (Popov & Postnov 2010; Lyubarsky 2014; Pen & Connor 2015), and flaring Galactic stars (Loeb, Shvartzvald & Maoz 2014). Though presently, there are more theoretical models for FRBs than actual sources discovered, constraints on such theories are rapidly emerging. This is due to recent polarization data, multifrequency coverage, and their being observed by several telescopes at various locations on the sky (Bower et al. 2014; Petroff et al. 2015).

On top of event rates (∼10^4 day^{-1} sky^{-1}) and high DMs, explanations of FRBs must now account for temporal scattering, and polarization states. They should predict or explain Faraday rotation and time dependence of linear polarization. The rotation measure (RM) of our Galaxy has been mapped, and the intergalactic RM is constrained to be less than 7 rad m^{-2} (Oppermann et al. 2015). The

★ E-mail: pen@cita.utoronto.ca

observed temporal scattering is problematic for an IGM interpretation, due to the unrealistically small length-scales required in the IGM for ∼ms scattering (Luan & Goldreich 2014).

In this Letter, we propose a new non-cosmological but extragalactic solution to the FRB problem: supergiant pulses from newly formed pulsars in supernova remnants (SNRs). The dense ionized environment of the SNR can provide 300–2000 pc cm^{-3} of dispersion if the pulses are observed within ∼100 yr of the core-collapse supernova. In our picture, the large DM and scattering all come from the same place, and generically accounts for substantial Faraday Rotation and polarization angle swings. These features were included to account for recent polarization measurements of a new FRB (Masui et al. 2015) which may exhibit a polarization vector swing and whose RM is $\sim 2 \times 10^2$ rad m^{-2}. These are not expected in a cosmological interpretation of the DM.

2 SUPERNOVA REMANTS

Of order 10^{51} erg of kinetic energy is released during a supernova, a fraction of which is converted into thermal energy after shock heating of the ejecta plasma. Though the shock-heated ejecta atoms are fully ionized after the explosion, the density is high enough that ionized atoms can soon recombine. This phase of low ionization comes to an end when the remnant expands into the surrounding ISM, causing a reverse shock wave that re-ionizes the ejecta. Though this is the basic narrative, observations (Zanardo et al. 2014) as well as simulations (Potter et al. 2014) of SN 1987a have shown the morphological and ionization properties of SNRs in the decades and centuries after the explosion are nuanced and difficult to model. That said, in general the expanding shell left behind should be able to provide enough free electrons along the line of sight for unusually large DMs. If we assume a toy model in which a sphere expands at $v_{\rm ej}$, then the radius $R(t) \approx v_{\rm ej} t$. Therefore, the DM we expect can be calculated as

$$\mathrm{DM} \approx \frac{x_e M_{\rm ej}}{m_p \frac{4\pi}{3} v_{\rm ej}^2 t^2}, \tag{1}$$

where x_e is the ionization fraction, $M_{\rm ej}$ is the ejecta mass, and $m_{\rm p}$ is the mass of a proton. Assuming ∼10 $M_\odot$ of material is ejected at $v_{\rm ej} \sim 3-8 \times 10^3$ km s^{-1} and an ionization fraction of ∼20 per cent, the DM goes from several thousand pc cm^{-3} immediately after the reverse-shock ionization, to several hundred pc cm^{-3} after 50–100 yr (Zanardo et al. 2014). We point out that while the difference between a sphere of H II, which we have assumed, and a thin shell makes a small difference for DM, it could have a large effect of plasma frequency – something we discuss in Section 3. In the context of SNR 1987a, Zanardo et al. (2014) found that a possible pulsar could have DMs between 100 and 6000 pc cm^{-3}, after ∼25 yr, though no compact object has yet been observed in that remnant.

Another potentially important feature of the SNR environment is its magnetic field. The exact magnitude of any detection of Faraday rotation has implications for the possible source location. For instance, in the circumnuclear picture, one would expect RMs $\sim 10^{3-5}$ rad m^{-2} (Pen & Connor 2015), similar to that of the Milky Way's Galactic Centre magnetar J1745−29. In the cosmological scenario, if the Faraday rotation came from the same place as the DM – namely the IGM – then we would only expect a few rad m^{-2} of RM (Oppermann et al. 2015).

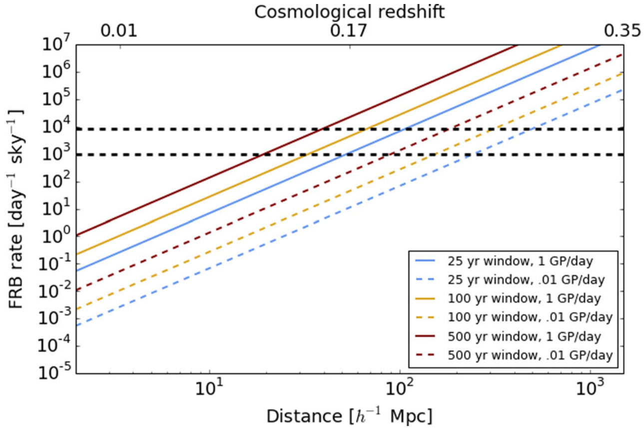

Figure 1. Daily FRB rate per sky based on local core-collapse supernova event rate, plotted against distance. We assume early in the pulsar's life there is a window, either 25, 100, or 500 yr when the SNR can provide a large enough electron column density to explain the high DMs of the observed bursts. We also include a rate of giant pulses of either one per day or one per hundred days. We have assumed 20 per cent of core-collapse supernovae leave behind a visible pulsar. The horizontal black lines are the 99 per cent confidence bounds for the FRB rate found by Rane et al. (2016).

The Faraday effect rotates the polarization vector by an angle $\phi = \mathrm{RM}\,\lambda^2$, where

$$\mathrm{RM} = \frac{e^3}{2\pi m^2 c^4} \int_0^L n_e(l) B_\parallel(l)\, \mathrm{d}l. \tag{2}$$

We can therefore make a rough estimate of the RM of a remnant pulsar with DM. Using Burke & Graham-Smith (2014), we get

$$\mathrm{RM} \approx 0.81\ \mathrm{rad\,m^{-2}} \times \frac{\langle B_\parallel \rangle}{1\,\mu\mathrm{G}} \times \frac{\mathrm{DM}}{1\ \mathrm{pc\,cm^{-3}}}. \tag{3}$$

Though there is a large uncertainty in evolution of the magnetic field strength and added uncertainty in $\langle B_\parallel \rangle$ given $B_\parallel$ is not necessarily positive, typical values in our Galaxy are 0.2–1 μG. For instance, the Crab and Vela have ∼0.92 and ∼0.56 μG, respectively. This gives RMs between 80 and 1200 rad m^{-2} for an SNR pulsar with FRB-like DMs, which is consistent with Masui et al. (2015).

2.1 Event rates

2016MNRAS.455.2207R: the daily FRB rate has been estimated at $3.3^{+5.0}_{-2.5} \times 10^3$ sky^{-1} (Rane et al. 2016). If we start from the local core-collapse supernova event rate, $\Gamma_{\rm CC}$, and include objects out to some distance $d_{\rm max}$, we expect the following daily FRB rate,

$$\Gamma_{\rm FRB} \sim \frac{4}{3}\pi d_{\rm max}^3 \times \Gamma_{\rm CC} \times \eta\, \tau_{\rm ion} \gamma_{\rm GP}, \tag{4}$$

where $\tau_{\rm ion}$ is the window in years when the SNR is sufficiently dense and ionized to provide the observed DMs, $\gamma_{\rm GP}$ is the daily rate of giant pulses above $\sim 10^{36}$ erg, and η is the number of core-collapse supernovae that leave behind a visible pulsar. From Taylor et al. (2014), we know $\Gamma_{\rm CC} \sim 3 \times 10^{-4}$ d^{-1} $(h^{-1}\mathrm{Mpc})^{-3}$, so if we take $d_{\rm max}$ to be 100 h^{-1}Mpc and $\tau_{\rm ion} \sim 100$ yr, we require one giant pulse every 10–20 d, assuming one-fifth of this SNe population leaves behind a visible pulsar. In Fig. 1, we show the event rate as a function of distance, varying two parameters: the effective high-DM window and the rate of giant pulses.

From Fig. 1, we can see even in our most conservative estimate, when the SNR only has a 25 yr window and emits giant pulses once every2010vaoa.conf..129P 100 d, the volume necessary for the highest daily FRB rate is still non-cosmological. By this, we mean the DM contribution from the IGM is less than ∼200 pc cm^{-3}. If the SNR FRBs are within a hundred h^{-1}Mpc, then DM$_{\rm IGM}$ is less than ∼10 per cent of the total dispersion of a typical burst.

If FRBs really are giant pulses, then they should repeat stochastically, and while none of the radio follow-ups for observed sources has seen an FRB repeat, this could be because they have not observed for long enough. We point out that FRB 140514, the first burst observed in real-time, was found during a follow-up observation of FRB 110220 and the two were found within a beam-width of one another. FRB 140514 had a lower DM than 110220 by 380 cm pc^{-3}, and though Petroff et al. (2015) show that it was not very unlikely that one would find a new FRB given their integration time, if it were the same source our model could explain the discrepancy. Indeed, a re-analysis by Maoz et al. (2015) found that the two bursts were far more likely to be the same repeating source than had been previously claimed. Given FRB 110220 would have been emitted over three years earlier, we would expect its DM generically to be higher, but the amount would depend on the inner structure of the SNR and its expansion speed. We discuss repetition furthermore in Section 3.

2.2 Young SNR pulsars

About a dozen pulsars in our Galaxy are known to emit extremely energetic, short-duration radio pulses which can be many orders of magnitude brighter than the pulsar's regular emission. Some of these objects exhibit a rare tail of supergiant pulses, whose brightness temperatures exceed the Planck temperature, $\gtrsim 10^{32}$ K (Cordes et al. 2004), which we will take as a working definition of supergiant. Indeed the largest known brightness temperature, $T_{\rm b}$, in the Universe came from a giant pulse from the Crab, with $T_{\rm b} \sim 2 \times 10^{41}$ K (Taylor et al. 2014). Though there are only ∼100 h of published giant pulse data from the Crab, it is known that the supergiant pulse tail does not obey the standard power-law fall off in amplitude (Mickaliger et al. 2012).

Given the relatively high frequency of core-collapse supernovae in the local Universe, the young rapidly rotating pulsars such events leave behind could emit giant pulses bright enough to be observed at hundreds of megaparsecs. These supergiant pulses would require $10^{36–37}$ erg of output, assuming and observed flux density of 0.3–5 Jy and ∼500 MHz of bandwidth over 1 ms. Though this is ∼ billions of times brighter than an average pulse, it is negligible compared to a pulsar's total rotational energy, $E_{\rm rot} \sim 10^{49–50}$ erg and even the pulsar's spin-down luminosity. We also point out that given its relative proximity, this model requires a couple orders of magnitude less energy than cosmological FRBs, located beyond a Gpc.

The polarization properties of giant pulses are also consistent with those of observed FRBs. Giant pulses are known to be highly polarized, switching between strong Stokes V and purely linearly polarized states often in an unpredictable way. The only published FRB prior to (Masui et al. 2015) with full-pol information was FRB 140514 and was found to have ∼20 per cent circular polarization and no detectable linear polarization (Petroff et al. 2015). If FRBs were coming from a pulsar-like emission mechanism, one might see nearly pure Stokes V or linear-pol states. Another consequence of pulsar-like emission is that FRBs could exhibit polarization angle swings over the burst duration, which may have been observed by Masui et al. (2015). Unfortunately, to date, all other published FRBs were detected with systems that recorded only Stokes I.

3 PREDICTIONS

In Table 1, we summarize the observational consequences of ours and several other models as best we can. As one might expect, the most striking differences in predictions has to do with the distance of FRBs, for example, the cosmological FRB models differ mainly in their expected counterpart and not much else.

The young SNR pulsar model makes several predictions that will be addressed with more data, particularly with full polarization observations and large field-of-view surveys. The latter will provide a large sample of FRBs whose flux and DM statistics can give us information about their location. Since in the SNR FRB picture, most of the DM is intrinsic, the sources do not need to be at cosmological distances. This means the flux distribution is given by a Euclidean universe that is only weakly dependent on DM, $N(>S) \propto S^{-3/2}$, assuming the bursts are standard candle-like. Wide-field surveys like the Canadian Hydrogen Intensity Mapping Experiment (CHIME; Bandura 2014, whose FRB backend will observe steadily for several years), UTMOST,[1] or the Hydrogen Intensity mapping and Realtime Analysis eXperiment could observe as many as $\sim 10^{3–4}$ per year, which would allow for detailed population statistics. An instrument like CHIME will not only give us large numbers of DMs and fluxes, but will also allow us to measure various polarization properties and frequency scintillation.

Since we have proposed that FRBs come from young pulsars in SNRs, it is possible that the corresponding supernova was observed in recent decades in the optical. If the pulsars were younger than ∼60 yr old, they could be localized at the ∼arcsecond level and matched against catalogued Type II supernovae, though we would need a large sample of FRBs, given the incompleteness of recorded supernovae. With current data, the location of FRBs has been too poorly constrained to say anything meaningful about overlap with historic SNe or coincident galaxies; out to ∼150 h^{-1}Mpc, there are a number of galaxies in a Parkes beam and therefore one would expect as many supernovae anyway in the last century, even though it would unlikely have been observed. However, better localization or a cross-correlation between a large sample of FRBs and nearby galaxies could help support the non-cosmological extragalactic FRB hypothesis.

We also point out that while FRBs seem not to repeat regularly, it is not known that they never repeat. Though the statistics of giant pulses from local pulsars are mostly Poisson (Sallmen et al. 1999), it is possible that the supergiant pulses we require from very young SNR pulsars are not. If their statistics were of a Poisson process, then there are already limits on the repeat rate, given the ∼100 h of follow up, however if their statistics were more like earthquakes, the brightest pulses could burst intermittently and turn off for extended periods. It is possible that FRBs could repeat every 5–500 d. If they were to repeat, it is possible that their DMs, RMs, and scattering properties could change noticeably on months/years time-scales. Unlike standard pulsars whose RMs and DMs are constant to a couple decimal places, young SNR pulsars like the Crab and Vela have shown significant – and sometimes correlated – variation in such properties (Rankin et al. 1988). As discussed in Section 2.1, FRB 140514 had a DM that was several hundred pc cm^{-3} smaller than FRB 110220 and the two were found within a beam-width of one another. Though this could have just been a spatial coincidence of two separate objects, our SNR FRB model could account for

[1] http://www.caastro.org/news/2014-utmost

Table 1. This table summarizes a number of FRB models by classifying them as cosmological, extragalactic but non-cosmological, Galactic, and terrestrial. The seven columns are potential observables of FRBs and each row gives their consequence for a given model [Blitzars (Falcke & Rezzolla 2014), compact object mergers (Mickaliger et al. 2012; Totani 2013), exploding primordial black holes (Barrau, Rovelli & Vidotto 2014), bursts from magnetars (Lyubarsky 2014), edge-on disc galaxies (Xu & Han 2015), circumnuclear magnetars (Pen & Connor 2015), supernova remnant pulsars, stellar flares (Loeb et al. 2014), and terrestrial radio frequency interference (RFI) (Hippke, Domainko & Learned 2015)]. For the latter, we subdivide the RFI into planar RFI (2D) coming from the earth's surface, and 3D RFI coming from objects like satellites. Since scintillation only affects unresolved images, cosmological sources that are not scattered near the source will not scintillate in our Galaxy, while non-cosmological sources whose screens are intrinsic will. For Faraday rotation and scintillation, we assume the RM and SM comes from the same place as the DM, e.g. the IGM for cosmological sources, though such models could introduce a more local Faraday effect or a scattering screen. The question mark implies that that particular model's prediction is unknown. Even though all models have to explain the observed 375–1600 pc cm^{-3}, some models predict a wider range of DM. For instance, in the circumnuclear magnetar or edge-on disc scenarios, there ought to be bursts at relatively low DM that simply have not been identified as FRBs. In our supernova remnant model, DMs should be very large early in the pulsar's life, though this window is short and therefore such high DM bursts would be rare.

Location	Model	Galactic scintillation	Faraday rotation	$\frac{\mathrm{d}\ln N_{\mathrm{FRB}}}{\mathrm{d}\ln S_\nu}$	Counterpart	DM range (pc cm^{-3})	Pol angle swing
Cosmological ($\gtrsim$1 h^{-1} Gpc)	Blitzars	×	$\lesssim$7 rad m^{-2}	?	Gravitational waves	300–2500	×
	Merging COs	×	$\lesssim$7 rad m^{-2}	?	Type Ia SNe, X-ray, γ-ray	300–2500	×
	Primordial BHs	×	$\lesssim$7 rad m^{-2}	?	∼TeV	300–2500	×
	Magnetar flare	×	$\lesssim$7 rad m^{-2}	?	∼ms TeV burst	300–2500	√
Extragalactic, local ($\lesssim$200 h^{-1} Mpc)	Edge-on disc	√	50–500 rad m^{-2}	−3/2	?	10–2000	?
	Nuclear magnetar	√	10$^{3-5}$ rad m^{-2}	−3/2	None	10–3000	√
	SNR pulsar	√	20–10^3 rad m^{-2}	−3/2	Archival CC SNe or nearby galaxy	10^2–10^4	√
Galactic ($\lesssim$100 kpc)	Flaring MS stars	√	RM$_{\mathrm{gal}}$	−3/2	Main-sequence star	$\gtrsim$300	×
Terrestrial ($\lesssim$10^5 km)	RFI	×	$\lesssim$RM$_{\mathrm{ion}}$	$\begin{cases}-1/2 \text{ if 2D} \\ -3/2 \text{ if 3D}\end{cases}$	None	?	×

such a change in DM while other models (cosmological, edge-on galaxy, etc.) cannot.

We also predict that such repeated bursts could have vastly different polarization states, similar to the giant pulses from pulsars in the Galaxy. Another consequence of polarized pulsar-like emission would be a polarization angle swing. Given the FRBs would be rotating, the angle of the linear polarization vector could change throughout the pulse – a phenomenon that is seen in many galactic pulsars, often repeatably (Becker et al. 2006). Therefore, models that explain FRBs as rapidly rotating compact objects could predict a swing in the polarization angle throughout the burst.

Depending on the relationship between the giant pulse rate and SNR age and environment, there may exist a short window in the pulsar's life when DMs are larger than could be achieved in the IGM at redshifts $z \lesssim 2.5$. Naïvely, we would expect the average pulse energy to decay with time along with its period. It would be therefore possible, albeit rare, that an FRB have a DM of $\sim$10^4 pc cm^{-3}. In general, we expect the distribution of DMs to be peaked somewhere around the observed FRBs (500–800 pc cm^{-3}), but with weight at intermediate DMs, when the ejecta has significantly expanded and at very high DMs. In several non-cosmological FRB models, there should be a number of low-DM FRBs (Pen & Connor 2015; Xu & Han 2015), which must be explained away with non-identification bias. However in our picture, we do not expect the pulsar to emit supergiant pulses indefinitely and therefore we do not expect to be able to see these objects when the SNR has expanded and the DMs would be moderate. In the Katz (2015) treatment of the SNR FRB, it is assumed that the supergiant pulse rate is time independent, a scenario that the observed $\frac{\mathrm{dlog}N}{\mathrm{dlog}DM}$ has already cast doubt on. But since the DM distribution depends on birth spin rate and the dependence of luminosity with period, both of which are unknown, we do not attempt to predict it concretely. The Crab would need to emit giant pulses in excess of several GJy to be seen at the distances we are proposing – which is several orders of magnitude brighter than what has been observed – and we postulate that is because it is too old.

Beyond the varying DM distributions produced by the location, density, and time dependence of the dispersing electrons, their plasma frequency can give interesting constraints on the nature of FRBs. Since

$$\omega_p = \sqrt{\frac{n_e e^2}{m_e \epsilon_o}}, \tag{5}$$

we expect FRBs dispersed by the diffuse IGM to have very low plasma frequencies while Galactic models, e.g. flaring stars, should predict large ω_{p}. This can be verified in in precise measurements of the pulse arrival time as a function of frequency. If $k^2c^2 = \omega^2 - \omega_{\mathrm{p}}^2$, then the λ^2 arrival time dependence is only true in the limit where $\omega \gg \omega_{\mathrm{p}}$. Therefore, plasma frequency can be used to test FRB models by looking for deviations in the data. This probe was also pointed out by Katz (2015), who shows the dispersion index for $\Delta t \propto \nu^\alpha$ differs from −2 by $\frac{6\pi n_e e^2}{m_e \omega^2}$. In the SNR model, a $\sim$50 yr SNR expanding at $\sim$3000 km s^{-1} would have a plasma frequency of $\lesssim$10 MHz and an arrival delay within 4×10^{-5} of −2.0 at 1.4 GHz, which is consistent with present measurements.

Another interesting path for studying extragalactic radio bursts, cosmological or otherwise, is scintillation. Only objects of small angular size scintillate, which is why stars twinkle and planets do not: turbulent cells in the ionosphere can resolve planets but not stars. The same is true for extragalactic objects scintillating in the Milky Way, where objects larger than $\sim$10^{-7} arcsec do not scintillate at ~GHz. This is why so few quasars scintillate (Dennett-Thorpe & de Bruyn 2002).

While several explanations for this scintillation exist (Narayan 1992; Pen & Levin 2014), we are concerned with the observational effects and not the physics. Using Thompson, Moran & Swenson (1986), we can estimate the angular size of an extragalactic object,

$$\theta \approx \left(\frac{2c\tau\,(R_{\rm obj} - R_{\rm sn})}{R_{\rm sn} R_{\rm obj}} \right)^{1/2}, \qquad (6)$$

where $R_{\rm obj}$ is the distance to the source, $R_{\rm sn}$ is the distance to the screen, and τ is the scattering time-scale. For the case of FRBs, we take τ to be ~10 ms. In the cosmological case, if the MS scattering were from an extended galactic disc along the line-of-sight (see McQuinn 2014) halfway between us and the source, then the angular broadening of an object at 2 Gpc is ~150 microarcsec. If the screen were within 1 kpc of the same object then the broadening is ~80 nanoarcsec. Therefore, scintillation from our own Galaxy should only occur for cosmological FRBs whose millisecond scattering is close to the source. For an SNR FRB, the screen would have to be within a few hundred parsecs of the object, which we generically expect. We include this feature in Table 1 where each column is estimated based on the medium that is causing the high DM, e.g. the IGM for cosmological models.

4 CONCLUSIONS

Evidence is emerging suggesting FRBs are not only extraterrestrial but extragalactic. Though the simplest interpretation of their high DMs is a cosmological one, we find this model less compelling in the light of past scattering measurements and potential Faraday rotation and pol-angle swing in a new FRB (Masui et al. 2015). In this letter, we offer a more nearby solution. We have gone through a model in which FRBs are really supergiant pulses from extragalactic SNR pulsars, within a couple hundred megaparsecs. The SNR environment is sufficiently dense and ionized to provide DMs $\gtrsim$500 pc cm^{-3} as well as RMs $\gtrsim$50 rad m^{-2}, only the first of which could be replicated by the IGM.

The environment could also provide ~ms scattering at 1 GHz, as has been observed in Galactic SNR pulsars. That makes this picture self-contained in the sense that the young remnant environment can account for the dispersion and scattering measure seen in FRBs. It predicts a higher Faraday rotation than the IGM, but not as high as galactic centres. The repetition rate is related to the distance, and could be from days to years. By extrapolating Crab-like giant pulses back to the pulsar's first century or so, we have proposed that such objects can emit extremely energetic bursts sporadically. If these are similar to giant pulses from Galactic pulsars, they could be highly polarized, either linearly or circularly, and if they were to repeat their polarization state may change drastically. Given the object's rotating nature, polarization angles would be likely to swing during the pulse. The distinct polarization properties have been seen in at least one burst and may be end up being generic properties of FRBs (Masui et al. 2015).

ACKNOWLEDGEMENTS

We thank NSERC for support. We also thank Bryan Gaensler, Niels Oppermann, Giovanna Zanardo, and Chris Matzner for helpful discussions.

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