Large Host-galaxy Dispersion Measure of Fast Radio Bursts

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Abstract

Fast radio bursts (FRBs) have excessive dispersion measures (DMs) and an all-sky distribution, which point toward an extragalactic or even a cosmological origin. We develop a method to extract the mean host galaxy DM (DMHG,loc) and the characterized luminosity (L) of FRBs using the observed DM−flux data, based on the assumption of a narrow luminosity distribution. Applying Bayesian inference to the data of 21 FRBs, we derive a relatively large mean host DM, i.e., ⟨DMHG,loc⟩ ~ 270 pc cm−3 with a large dispersion. A relatively large DMHG of FRBs is also supported by the millisecond scattering tails of some FRBs and the relatively small redshift z = 0.19273 of FRB 121102 (which gives DMHG,loc ~ 210 pc cm−3). The large host galaxy DM may be contributed by the interstellar medium (ISM) or a near-source plasma in the host galaxy. If it is contributed by the ISM, the type of the FRB host galaxies would not be Milky Way−like, consistent with the detected host of FRB 121102. We also discuss the possibility of having a near-source supernova remnant, pulsar wind nebula, or H II region that gives a significant contribution to the observed DMHG.

Key words: intergalactic medium − radio continuum: general

1. Introduction

Fast radio bursts (FRBs) are mysterious astronomical radio transients with short intrinsic durations (~1 ms), large dispersion measures (DM > 200 pc cm−3), and an all-sky distribution (Lorimer et al. 2007; Keane et al. 2012, 2016; Thornton et al. 2013; Burke-Spolaor & Bannister 2014; Spitler et al. 2014, 2016; Masui et al. 2015; Petroff et al. 2015; Ravi et al. 2015, 2016; Champion et al. 2016; Caleb et al. 2017; Chatterjee et al. 2017). Recently, thanks to the precise localization and multi-wavelength follow-up observations of the repeating source FRB 121102 (Chatterjee et al. 2017; Marcote et al. 2017; Tendulkar et al. 2017), the distance scale of millisecond FRBs has been finally settled to a cosmological scale at z = 0.19273 (Tendulkar et al. 2017). The large DM excess of other FRBs with respect to the Galactic value and their high Galactic latitudes also suggest that most, if not all, FRBs should have an extragalactic (e.g., >10 Mpc), and likely a cosmological (e.g., >100 Mpc), origin.

The host galaxies of FRBs carry important information regarding the progenitor of FRBs. For FRB 121102, optical imaging and spectroscopy indicate a dwarf galaxy with a mass of M ~ (4−7) × 107 M⊙ as the host galaxy. The H I flux of the host galaxy suggests a star formation rate of SFR ~ 0.4 M⊙ yr−1 (Tendulkar et al. 2017). No information about the host galaxies of other FRBs is available. One possible way to derive FRB host galaxy information is to extract the host galaxy DM from data. Yang & Zhang (2016) proposed a method to derive DMHG using the measured DM and z of a sample of FRBs. However, the z values of most FRBs are not obtained so far.

In this Letter, we further develop a method to apply DM and flux of FRBs to infer DMHG. This method is applied to the current FRB sample with 21 sources. Through Bayesian inference, we derive a relatively large mean host galaxy DM, ⟨DMHG,loc⟩, for FRBs. We also provide two pieces of supporting evidence for a large value of DMHG: millisecond duration of scattering tails for some FRBs and DMHG,loc ~ 210 pc cm−3 for FRB 121102.

2. Method

For an FRB, the observed DM has three contributions (e.g., Lorimer et al. 2007; Keane et al. 2012; Thornton et al. 2013; Deng & Zhang 2014; Gao et al. 2014; Murase et al. 2016; Yang & Zhang 2016), i.e.,

\[ \text{DM}_{\text{obs}} = \text{DM}_{\text{MW}} + \text{DM}_{\text{HG}} + \text{DM}_{\text{IGM}}. \]

which are from the Milky Way (MW), the FRB host galaxy (which itself includes the contributions from the interstellar medium (ISM) in the host galaxy and a near-source plasma), and the IGM, respectively. According to the Galactic pulsar data, DM_{MW} can be estimated for a localized FRB (Cordes & Lazio 2003), so one can define the extragalactic (or excess) DM of an FRB as

\[ \text{DM}_{\text{IGM}} \equiv \text{DM}_{\text{obs}} - \text{DM}_{\text{MW}} = \text{DM}_{\text{IGM}} + \text{DM}_{\text{HG}}, \]

which can be treated as an observed quantity. The local DMs of FRB host galaxies may be assumed to have no significant evolution with redshift of z < 1, i.e., ⟨DMHG,loc⟩ ~ const, where ⟨DMHG,loc⟩ is the average value of the rest-frame host galaxy DM within a certain redshift bin. Due to cosmological time dilation, the observed host DM value reads DM_{HG} = DM_{HG,loc}/(1 + z) (Ioka 2003). Considering the local inhomogeneity of the IGM (McQuinn 2014), we define a mean DM of the IGM as (Deng & Zhang 2014; Yang & Zhang 2016)

\[ \langle \text{DM}_{\text{IGM}} \rangle = \frac{3cH_0 \Omega_{\text{b}} f_{\text{IGM}}}{8\pi G m_p} \int_0^\infty \frac{f_\gamma(z') (1 + z')}{\sqrt{\Omega_m (1 + z')^3 + \Omega_\Lambda}} dz', \]

\[ \approx \frac{3cH_0 \Omega_{\text{b}} f_{\text{IGM}}}{8\pi G m_p} \left[ z + z^2 \left( \frac{1}{2} - \frac{3\Omega_m}{4} \right) + O(z^2) \right], \]
where \( f_\nu(z) = (3/4)\nu_1^{1/2} \chi_{c,\text{H}}(z) \nu_1 + (1/8)\nu_2^{1/2} \chi_{c,\text{He}}(z) \), \( \nu_1 \sim 1 \) and \( \nu_2 \sim 4 - 3\nu_1 \sim 1 \) are the hydrogen and helium mass fractions normalized to 3/4 and 1/4, respectively, and \( \chi_{c,\text{H}}(z) \) and \( \chi_{c,\text{He}}(z) \) are the ionization fractions for hydrogen and helium, respectively. For \( z < 3 \), one has \( \chi_{c,\text{H}}(z) \approx \chi_{c,\text{He}}(z) \approx 1 \), due to full ionization of both hydrogen and helium (Meiksin 2009). Therefore, one has \( f_\nu(z) \approx f_\nu = 7/8 \). We adopt the flat ΛCDM parameters recently derived from the Planck data: \( H_0 = 67.7 \text{ km s}^{-1} \text{ Mpc}^{-1} \), \( \Omega_m = 0.31 \), \( \Omega_\Lambda = 0.69 \), and \( \Omega_b = 0.049 \) (Planck Collaboration et al. 2016). For the fraction of baryon mass in the intergalactic medium, we adopt \( f_{\text{GM}} = 0.83 \) (Fukugita et al. 1998; Shull et al. 2012). In fact, due to IGM inhomogeneity, the fluctuation of individual measurements is expected (McQuinn 2014). Since the formation and evolution of the different galaxies are essentially independent at a given redshift \( z \), \( \Delta \Omega \) for different lines of sight would have a Gaussian distribution. As a result, the inhomogeneity of the IGM may affect the scatter, but not the mean trend of the DM-flux relation, especially when the sample size is large enough.

For an FRB with an intrinsic frequency-dependent isotropic-equivalent luminosity \( L_\nu(v) \), the observed flux is given by \( F_\nu dv = L_\nu dv/4\pi d_L^2 \). The luminosity distance of the FRB may be given by

\[
d_L \approx \left( \frac{L_{\text{iso}}}{4\pi v F_\nu} \right)^{1/2},
\]

where \( L_{\text{iso}} \equiv \nu L_\nu \) is the characteristic isotropic-equivalent luminosity (the true luminosity should be \( L = \Delta \Omega/4\pi L_{\text{iso}} \), where \( \Delta \Omega \) is the beaming solid angle), and \( v \approx 1.4 \text{ GHz} \) is the characteristic frequency of FRBs.\(^3\) For a flat universe, one has

\[
d_L = \frac{c}{H_0}(1 + z) \int_0^z \frac{1}{\sqrt{\Omega_m (1 + z')^3 + \Omega_\Lambda}} dz',
\]

\[
\approx \frac{c}{H_0} \left[ z + z^2 \left( 1 - \frac{3\Omega_m}{4} \right) + O(z^2) \right].
\]

For \( z \lesssim 1 \), according to Equations (2)-(5), we can obtain approximately \( \Delta M_{\text{DM}} \approx A d_L \), where \( A \equiv 3H_0^2\Omega_m/\pi F_\nu \). Therefore, one has the DM-E\( \rightarrow F \) relation:

\[
\langle \Delta M_{\text{DM}} \rangle \approx \frac{A}{4\pi} L_{\text{iso}}^{1/2} v^{-1/2} F_\nu^{-1/2} + \langle \Delta M_{\text{DM}} \rangle_{\text{loc}}.
\]

As shown in Equation (6), \( \langle \Delta M_{\text{DM}} \rangle \propto F_\nu^{-1/2} \) for \( F_\nu \ll F_{\nu,\text{crit}} \), and \( \langle \Delta M_{\text{DM}} \rangle \approx A^2 L_{\text{iso}}^{1/2} F_\nu^{1/2} \) for \( F_\nu \gg F_{\nu,\text{crit}} \), where \( F_{\nu,\text{crit}} \approx A^2 L_{\text{iso}}^{1/2} F_\nu^{1/2} \). One can numerically solve Equations (2)-(5) and use the observed DM-E\( \rightarrow F \) relation to fit the current sample of 21 FRBs.\(^6\) We take the FRB data from the FRB Catalog of Petroff et al. (2016)\(^7\) and ignore the effect of interstellar scintillation.

\(^3\) Strictly speaking, a proper \( k \)-correction is needed to derive a more rigorous \( d_L \). However, the FRB spectral shape is not well constrained. Since the FRB emission seems to peak around 1 GHz and since the FRB redshift is not very high, our approximate treatment is justified.

\(^6\) The three bursts reported by Caleb et al. (2017), similar to the original “lorimer” burst (Lorimer et al. 2007), only have the lower limits of the peak fluxes reported. In our analysis, these lower limits are used. Our conclusion of a large host galaxy DM remains valid if one adopts larger peak flux values for these bursts.

\(^7\) http://www.astronomy.swin.edu.au/pulsar/frbcat/

Except FRB 121102, other FRBs (mostly detected with Parkes) are not observed to repeat. If all FRB sources repeat, most bursts may be below the sensitivity of the Parkes telescope, and the detected one may be one of the brightest pulses. For this reason, we take the brightest pulse of the repeater to define its peak flux at 1.4 GHz.\(^8\)

We apply the Bayesian inference to extract \( \langle \Delta M_{\text{DM}} \rangle_{\text{loc}} \) from the observed \( DM_{\rightarrow F} \) relation using the software emcee.\(^9\) The log likelihood for the fitting parameters is determined by the \( \chi^2 \) statistics, i.e.,

\[
\chi^2(L_{\text{iso}}, \langle \Delta M_{\text{DM}} \rangle_{\text{loc}}, f) = \sum_i \frac{(L_{\text{iso},i} - \langle \Delta M_{\text{DM}} \rangle_{\text{loc},i})^2}{\sigma_i^2 + \sigma_{\text{sys}}^2(f)},
\]

where \( i \) represents the sequence of an FRB in the sample, \( \sigma_i \) represents the error of \( L_{\text{iso},i} \), \( \sigma_{\text{sys}} \equiv f(\Delta \Omega_{\text{DM}}) \) is the system error, and \( f \) is a fitting parameter reflecting the uncertainty of the model. At first, we use the uninformative priors on \( \log(L_{\text{iso}}), \langle \Delta M_{\text{DM}} \rangle_{\text{loc}}, \text{ and } \text{ln} f \). Combining the priors with the definition of log likelihood from above, one can obtain the log-probability function. Then we initialize the walkers in a tiny Gaussian ball around the maximum likelihood result and sample the probability distribution. We then get the projections of the posterior probability distributions of the model fitting parameters in Figure 1.

The analysis results are shown in Figure 1. We have \( \log(L_{\text{iso}}/\text{erg s}^{-1}) = 42.99^{+0.24}_{-0.45} \) (under the assumption of a constant \( L_{\text{iso}}/\langle \Delta M_{\text{DM}} \rangle_{\text{loc}} = 267.00^{+172.53}_{-110.68} \text{ Pcm}^{-3} \), and \( \text{ln} f = -0.79^{+0.21}_{-0.18} \). Our results show that FRBs may have a large host galaxy DM, although with a large dispersion. To apply this method, we have to assume that the isotropic-equivalent luminosity of the FRBs has a characteristic value \( L_{\text{iso}} \), which requires that \( L_{\text{iso}} \) has a narrow distribution \( \Phi(L_{\text{iso}}) \). We perform a series of Monte Carlo simulations to test how narrow the isotropic luminosity function needs to be in order to correctly derive the prior \( \langle \Delta M_{\text{DM}} \rangle_{\text{loc}} \) with \( \sim 1 \sigma \) accuracy. We find that for a power-law distribution \( \Phi(L_{\text{iso}}) \propto L_{\text{iso}}^{-\alpha} \), one needs to have \( \alpha > 3 \); for a Gaussian distribution, one needs to have \( \Phi(L_{\text{iso}}) \propto N(L_{\text{iso},\text{mean}} < 0.3 L_{\text{iso},\text{mean}}) \).

Our derived relatively large value of \( \langle \Delta M_{\text{DM}} \rangle_{\text{loc}} \) is supported by two other independent pieces of evidence.

First, for Galactic pulsars, the scattering time is found to be \( \tau \ll 10^{-3} \text{ ms} \) for \( |b| \gtrsim 30^\circ \) (e.g., Cordes et al. 2016). However, some FRBs with \( |b| > 30^\circ \) have measured scattering time of a few milliseconds (Petroff et al. 2016), suggesting that scattering happens outside the MW. The scattering contribution from the IGM is calculated to be negligibly small, so that most of the scattering would occur in the FRB host galaxy (Luan & Goldreich 2014; Xu & Zhang 2016). Observations show that a larger scattering tail corresponds to a larger DM, e.g., \( \hat{\tau} = 2.98 \times 10^{-7} \text{ ms} \Delta M_{\text{DM}}^{1/2}(1 + 3.55 \times 10^{-3} \Delta M_{\text{DM}}^{1/2}) \) for Galactic pulsars (Cordes et al. 2016), a fact that is understandable with the turbulence theories (Xu & Zhang 2017). If one assumes that the FRBs’ hosts have a similar relation, for the millisecond scattering time, one would require \( \Delta M_{\text{DM}} \gtrsim 280 \text{ PC cm}^{-3} \). This is consistent with our derived results.

\(^8\) If one instead takes an average value of peak fluxes to denote the peak flux of FRB 121102, the inferred \( \langle \Delta M_{\text{DM}} \rangle_{\text{loc}} \) from our analysis is even larger than reported, so our conclusion of a large host galaxy DM remains valid.

\(^9\) http://dan.iel.fm/emcee/current
Second, the host-galaxy DM of FRB 121102 may be inferred based on the data. FRB 121102 was localized to a ∼0.1 arcsecond precision by Chatterjee et al. (2017). The observed dispersion measure is DM_{obs} = 558 pc cm^{-3}. According to the location of FRB 121102, Tendulkar et al. (2017) identified an extended source coincident with the burst, which is a host galaxy at z = 0.19273. Adopting the Planck cosmological parameters and f_{IGM} = 0.83, one derives DM_{IGM} ≈ 164 pc cm^{-3} (subject to local fluctuations; McQuinn 2014). The MW contribution is DM_{MW} ≈ 218 pc cm^{-3} in the observation direction (Chatterjee et al. 2017). So one may derive
\[ DM_{HG} = DM_{obs} - DM_{MW} - DM_{IGM} \approx 176 \text{ pc cm}^{-3} \quad (8) \]
and
\[ DM_{HG,\text{loc}} = (1 + z)DM_{HG} \approx 210 \text{ pc cm}^{-3} \quad (9) \]
for FRB 121102. Such a value is also consistent with our fitting results and previous constraints (Tendulkar et al. 2017).

3. Discussion

The above results suggest that the FRB host galaxies have a relatively large value of DM. There could be two possible contributions to such a large DM: the ISM in the host galaxy and the near-source plasma.

For the case of a host ISM, one immediate inference is that the type of the host galaxies of most FRBs would not be MW-like disk galaxies. The reason is that for disk galaxies, FRBs would be most likely emitted from high galactic latitudes, which gives rise to negligible DM values.\(^{10}\) Indeed, the host galaxy of FRB 121102 was identified as a dwarf galaxy (Tendulkar et al. 2017), which is consistent with our expectation. However, our inferred value is still somewhat larger than the simulated host galaxy DM for various types of galaxies (Xu & Han 2015), suggesting that a near-source plasma may be needed.

For the case of a near-source plasma, we consider the contributions from a supernova remnant (SNR), a pulsar wind nebula (PWN), and an H II region. First, in a thin shell approximation, the DM value through a young SNR may be estimated by (see also Katz 2016; Piro 2016; Metzger et al. 2017; Piro & Burke-Spolaor 2017)
\[ DM_{\text{SNR}} = \frac{M}{4\pi\mu m_p R^2} \frac{\varepsilon}{\mu m} \]
\[ = 272 \text{ pc cm}^{-3} \frac{M}{M_\odot} \left( \frac{R}{0.1 \text{ pc}} \right)^{-2}, \quad (10) \]
where \( M \) and \( R \) are the SNR mass and radius, respectively, and \( \mu m = 1.2 \) is the mean molecular weight. Note that the SNR DM does not depend on the thickness of the thin shell. The DM variation of the SNR during an observation time \( \Delta t \) is given by
\[ \Delta DM_{\text{SNR}} = \frac{M v}{2\pi\mu m m_p R^3} \Delta t \]
\[ = 16.7 \text{ pc cm}^{-3} \frac{M}{M_\odot} \left( \frac{R}{0.1 \text{ pc}} \right)^{-3} \times \left( \frac{v}{3000 \text{ km s}^{-1}} \right) \left( \frac{\Delta t}{1 \text{ year}} \right), \quad (11) \]
where \( v \sim (3000-30,000) \text{ km s}^{-1} \) is the characterized SNR velocity. The age of the SNR may be estimated as \( T \approx R/v \approx (3-30) \text{ year} (R/0.1 \text{ pc}) \). In principle, it is possible to expect that the host DM is dominated by a supernova ejecta. However, there are two caveats for this possibility. (1) The thin

\(^{10}\) If FRB sources are associated with the center of galaxies, DMs from disk galaxies could be large in general.
shell model predicts a secular variation in DM, which needs to be confirmed by long-term observations. (2) For an age-independent event rate (the time delay between SN and FRB is uniformly distributed for FRBs), the cumulative distribution of DMs of FRBs should satisfy \( N(>\text{DM}) \propto \text{DM}^{-1/2} \) if the observed DM is dominated by the SNRs associated with the FRBs. However, the statistical results of the observed FRBs obviously deviate from this relation (Katz 2016).

Next, we consider the DM contribution from a PWN. Some authors suggested an association of FRBs with young pulsars (Connor et al. 2016; Cordes & Wasserman 2016), while some others suggested an association of FRBs with magnetar giant flares (Popov & Postnov 2010; Kulkarni et al. 2014). While these models are greatly constrained by available observations (Tendulkar et al. 2016; Lyutikov 2017), we nonetheless consider the DM contribution from a pulsar/magnetar wind. A relativistic electron–positron pair plasma is expected to stream out from the magnetosphere, and the number density of the wind at radius \( r \) is given by (e.g., Murase et al. 2016; Cao et al. 2017; Dai et al. 2017)

\[
\frac{n_w(r)}{\text{cm}^{-3}} \simeq \frac{\dot{N}_w}{4\pi r^2 c} = \mu_{\pm} n_{\text{GI}}(r_{\text{LC}}) \left( \frac{r}{r_{\text{LC}}} \right)^{-2},
\]

where \( r_{\text{LC}} \) is the radius of the light cylinder, \( \mu_{\pm} \) is the classical Goldreich–Julian magnetic field strength, and \( R_{\text{LC}} \) is the pulsar/magnetar wind radius. The DM of the pulsar/magnetar wind is given by (e.g., Cao et al. 2017)

\[
\text{DM}_w \simeq \int_{R_{\text{sh}}}^{R_{\text{LC}}} 2\Gamma(r) n_w(r) dr
\]

\[
\simeq 3\Omega_L \mu_{\pm} n_{\text{GI}}(R_{\text{LC}}) R_{\text{LC}} \left[ 1 - \left( \frac{R_{\text{sh}}}{R_{\text{LC}}} \right)^{-2/3} \right]
\]

\[
\simeq 146 \text{ pc cm}^{-3} \left( \frac{\mu}{10^6} \right)^{2/3} \left( \frac{B_p}{10^{14} \text{ G}} \right)^{4/3}
\times \left( \frac{P}{0.3 \text{ s}} \right)^{-1/3} \left( \frac{R_{\text{sh}}}{0.1 \text{ pc}} \right),
\]

where \( R_{\text{sh}} \) is the radius of the shock, \( P \) is the rotation period, \( \Omega_L \sim \left( L_{\text{sd}}/N_w m_e c^2 \right)^{1/3} \) is the relativistic wind Lorentz factor at the light cylinder, and \( L_{\text{sd}} = B_p^2 R_{\text{LC}}^6 Q/6 \) is the pulsar/magnetar spin-down luminosity. The wind Lorentz factor at radius \( r \) may be given by \( \Gamma(r) \sim \Gamma_L (r/R_{\text{LC}})^{1/3} \). On the other hand, in the shock, electron–positron pairs are thermalized. They would undergo cooling and may become non-relativistic. For the PWN with its age much longer than the spindown time \( T_{\text{sd}} \), the DM from these thermalized particles is given by

\[
\text{DM}_{\text{sh}} \simeq \frac{\dot{N}_w T_{\text{sd}}}{4\pi R_{\text{sh}}^2} = \frac{3c^2 \mu_I}{2\pi B_p R_{\text{sh}}^2} \simeq 3 \times 10^{-5} \text{ pc cm}^{-3} \left( \frac{\mu_I}{10^6} \right) \left( \frac{B_p}{10^{14} \text{ G}} \right)^{-1}
\times \left( \frac{R_{\text{sh}}}{0.1 \text{ pc}} \right)^{-2},
\]

where \( I \simeq 10^{45} \text{ g cm}^2 \) is the moment of inertia, \( N_w T_{\text{sd}} \) is the electron–positron pair number ejected over the spindown time \( T_{\text{sd}} \), which does not depend on \( \Omega \). Notice that the DM contribution from the thermalized pairs in the shock could be ignored. Therefore, the total DM from PWN is \( \text{DM}_{\text{PWN}} = \text{DM}_w + \text{DM}_{\text{sh}} \approx \text{DM}_w \). The pulsar/magnetar wind may provide a significant contribution to DM if \( \mu_{\pm} \) is large enough.

Recently, Zhang (2017) proposed a unified interpretation of FRBs in the so-called “cosmic comb” model, which invokes the interaction between an astrophysical plasma stream and a foreground regular pulsar. Since cosmic combs more easily happen in slow (\( P \sim 1 \text{ s} \)) and low-field (\( B \sim 10^{12} \text{ G} \)) pulsars, the DM contribution from the near-source plasma is \( \text{DM}_{\text{PWN}} \sim 0.003 \text{ pc cm}^{-3} \). Therefore, in the cosmic comb model, the large host galaxy DM might result from the host galaxy ISM or the near-source plasma of the stream source in front of the pulsar toward Earth.

At last, we consider the DM contribution from an H II region in the host galaxy, assuming that an FRB is embedded in a Strömgren sphere. The DM contributed by a Strömgren sphere may be estimated as

\[
\text{DM}_{\text{H II}} \approx n R_{\text{str}} \left( \frac{3N_u n}{4\pi \alpha_{\text{OB}}} \right)^{1/3} = 540 \text{ pc cm}^{-3} \left( \frac{N_u}{5 \times 10^{49} \text{ s}^{-1}} \right)^{1/3} \left( \frac{n}{100 \text{ cm}^{-3}} \right)^{1/3},
\]

where \( n \) is the gas number density in the H II region, \( N_u \) is the rate of ionizing photons from a star, \( \alpha_{\text{OB}} \) is the recombination rate, and \( R_{\text{str}} \equiv (3N_u/4\pi \alpha_{\text{OB}} n)^{1/3} \) is the Strömgren radius. We assume that there is an O5 star in the H II region, so that \( \alpha_{\text{OB}} = 2.6 \times 10^{-13} \text{ cm}^3 \text{ s}^{-1} \) for \( T = 10^4 \text{ K} \), and the Strömgren radius is \( R_{\text{str}} = 5.4 \text{ pc} \). We note that the Strömgren radius is much larger than the projected size of \( \lesssim 0.7 \text{ pc} \) of the FRB 121102 radio persistent emission source (Marcote et al. 2017).

An FRB may be absorbed by the H II region via free–free absorption. In the Rayleigh–Jeans limit, the free–free absorption coefficient is given by (e.g., Luan & Goldreich 2014)

\[
\alpha_{\text{ff}} = \frac{4}{3} \left( \frac{2\pi}{3} \right)^{1/2} \frac{Z^2 e^4 n_e n_i \bar{g}_{\text{ff}}}{c \pi m_e c^2 \nu^2},
\]

\[
\bar{g}_{\text{ff}} = \sqrt{\frac{3}{\pi}} \left[ \ln \left( \frac{(2k_B T)^{3/2}}{(\pi e^2 m_e^2 c^2 / \nu^2)} \right) - \frac{5}{2} \right],
\]

where \( n_e \) and \( n_i \) are the number densities of electrons and ions, respectively, \( \gamma = 0.577 \) is Euler’s constant, and \( \bar{g}_{\text{ff}} \) is the Gaunt factor. For an H II region, one may assume \( n_e = n_i = Z = 1 \). The optical depth for the free–free absorption is \( \tau \sim \alpha_{\text{ff}} R_{\text{str}} \), which gives

\[
\tau \simeq 0.018 \left( \frac{n}{100 \text{ cm}^{-3}} \right)^{4/3} \left( \frac{T}{10^4 \text{ K}} \right)^{-1.5} \left( \frac{\nu}{1 \text{ GHz}} \right)^{-2},
\]

where we have taken \( \alpha_{\text{ff}} = 2.6 \times 10^{-13} \text{ cm}^3 \text{ s}^{-1} \) and \( \bar{g}_{\text{ff}} = 6.0 \) for \( T = 10^4 \text{ K} \) and \( \nu = 1 \text{ GHz} \). Therefore, such a H II region is optically thin for FRBs.

In summary, we show that the current FRB observations imply large host galaxy DM values, e.g., \( \text{DM}_{\text{host,loc}} \gtrsim 200 \text{ pc cm}^{-3} \). Such a large DM may be contributed by the host ISM or a
near-source plasma. Such a result poses requirements to FRB progenitor models.

For the models invoking young energetic pulsars and magnetars (e.g., Connor et al. 2016; Cordes & Wasserman 2016; Murase et al. 2016, 2017; Piro 2016; Yang et al. 2016; Dai et al. 2017; Kashiyama & Murase 2017; Metzger et al. 2017) or collapse of new-born supramassive neutron star (e.g., Falcke & Rezzolla 2014; Zhang 2014), a near-source SNR, PWN, or H II region would give an important contribution to the observed DM. Also irregular star-forming galaxies (e.g., the host galaxy of FRB 121102) do not have a disk-like structure, and would provide a relatively large host DM. So these models are more consistent with the large host DM inferred from this Letter. For the models invoking compact object mergers (e.g., Totani 2013; Zhang 2016; Wang et al. 2016), the contribution from a near-source plasma may not be important (except for “prompted” mergers that have a short time delay from star formation). Some of these systems may also have a large offset from the host galaxy, which may not give a large local DM. However, since mergers can happen in elliptical or early-type host galaxies, a relatively large DM_{HI,loc} may arise from a large free electron column from the extended halo of these galaxies.

In our analysis, we ignored the effects of interstellar scintillation and host galaxy evolution. Interstellar scintillation, if significant, may affect the detectability of FRBs (Cordes et al. 2017). In our analysis, we introduced one parameter to denote the instrumental systematic errors in our simulations. This factor may partially account for the uncertainty of FRB flux introduced from interstellar scintillation. The evolution of the FRB host galaxy might lead to the DM evolution of the ISM component in the host galaxy, which depends on the host-galaxy morphology, mass, and star formation. However, if DM_{HI,loc} is dominated by the contribution from the near-source plasma, the cosmological evolution effect of the host galaxies may be smeared.

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