

# A $\tau$ -DM relation for FRB hosts?

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## ABSTRACT

It has been proposed that measurements of scattering times ( $\tau$ ) from fast radio bursts (FRB) may be used to infer the FRB host dispersion measure (DM) and its redshift. This approach relies on the existence of a correlation between  $\tau$  and DM within FRB hosts such as that observed for Galactic pulsars. We assess the measurability of a  $\tau$ -DM<sub>host</sub> relation through simulated observations of FRBs within the ASKAP/CRAFT survey, taking into account instrumental effects. We show that even when the FRB hosts intrinsically follow the  $\tau$ -DM relation measured for pulsars, this correlation cannot be inferred from FRB observations; this limitation arises mostly from the large variance around the average cosmic DM value given by the Macquart relation, the variance within the  $\tau$ -DM relation itself, and observational biases against large  $\tau$  values. We argue that theoretical relations have little utility as priors on redshift, e.g., for purposes of galaxy identification, and that the recent lack of an observed correlation between scattering and DM in the ASKAP/CRAFT survey is not unexpected, even if our understanding of a  $\tau$ -DM<sub>host</sub> relation is correct.

## 1. INTRODUCTION

Fast radio bursts (FRBs) are luminous millisecond-duration radio pulses from extragalactic sources, currently detected up to  $z \gtrsim 1$  (S. D. Ryder et al. 2023). Their specific origin is yet unclear, and they appear to arise from a variety of galactic environments, from dwarf to massive galaxies (A. C. Gordon et al. 2023; D. M. Hewitt et al. 2024; T. Eftekhari et al. 2024; K. Sharma et al. 2024; FRB Collaboration et al. 2025).

As opposed to pulsars in the Milky Way, the extragalactic nature of FRBs makes them unique probes of the cosmic material intersected by their light on its way from the source to our

telescopes (in addition to the Milky Way and their host galaxy) . In particular, the observable referred to as dispersion measure (DM) denotes the column density of free electrons along an FRB sightline. The total DM is a well-measured quantity owing to its frequency dependent ( $\nu^{-2}$ ) delay on the arrival time of the radio signal, and the fraction of DM contributed by the Milky Way can be inferred from models based on observations (J. M. Cordes & T. J. W. Lazio 2002; J. M. Yao et al. 2017). Furthermore, the average contribution from cosmic structure, i.e., the joint effect of the IGM and the intervening collapsed structure along the sightline, is a tracer of redshift and it is parameterized by the Macquart relation (J.-P. Macquart et al. 2020), which depends on, and can be used to probe, cosmological parameters (W. Deng & B.

Zhang 2014; B. Zhou et al. 2014; A. Walters et al. 2018; C. W. James et al. 2022b; Y.-Y. Wang et al. 2025, see also the recent review by M. Glowacki & K.-G. Lee 2024). However, large variance around the Macquart relation is observed, and the cosmic contribution is further degenerate with the dispersion induced by the host galaxy (e.g., S. K. Ocker et al. 2022; K.-G. Lee et al. 2023; I. S. Khrykin et al. 2024). These two effects result in the observed DM not being a precise predictor for the redshift of the FRB.

Recently, J. M. Cordes et al. 2022 (see also S. K. Ocker et al. 2022) proposed that the DM contribution from FRB hosts may be inferred from the measurement of the FRB scattering timescale ( $\tau$ ), as is the case for Milky Way pulsars (e.g., R. Ramachandran et al. 1997; N. D. R. Bhat et al. 2004; J. M. Cordes et al. 2016, although see Q. He & X. Shi 2024 for an alternate two-population scenario). These authors assumed that scattering is dominated by the host galaxy (in agreement with recent findings by S. K. Ocker et al. 2025 and L. Mas-Ribas et al. 2025) and proposed a theoretical  $\tau$ -DM model based on parameters designed to describe the interstellar medium (ISM) of the Milky Way from pulsar observations (i.e., their cloudlet model). A precise estimate of host DM would result in better constraints for the host redshift and the cosmic contribution which, in turn, would reduce the uncertainties in cosmological studies (see also L. Bernales-Cortes et al. 2025; C. Leung et al. 2025, for constraints on host DM from galaxy observables other than scattering).

However, no relation between scattering and dispersion measure has been observed to date for FRB hosts. In particular, D. R. Scott et al. (2025) have recently analyzed a sample of 35 high-time-resolution FRBs detected within the Australian Square Kilometre Array Pathfinder (ASKAP; A. W. Hotan et al. 2021) under the Commensal Real-time ASKAP Fast Transients

(CRAFT; K. W. Bannister et al. 2019; H. Cho et al. 2020; D. R. Scott et al. 2023) survey, with 29 of these FRBs identified to a host galaxy with redshift, and they did not find any correlation between these two observables (their section 4.2.2 and Figure 5). Thus, this raises the question of whether a relation between host scattering and dispersion measure actually exists, and/or if it exists but its measurement is impeded due to instrumental effects/biases.

Motivated by the aforementioned unknowns, we investigate here the observability of such a host  $\tau$ -DM relation by simulating observations of FRBs and assuming there exists an intrinsic relation between the two variables. Because instrumental effects may be important and a lack of correlation was just reported within the CRAFT survey, we consider the ASKAP telescope for modeling the observations. Our main conclusions, however, do not depend on the specific choice of instrument.

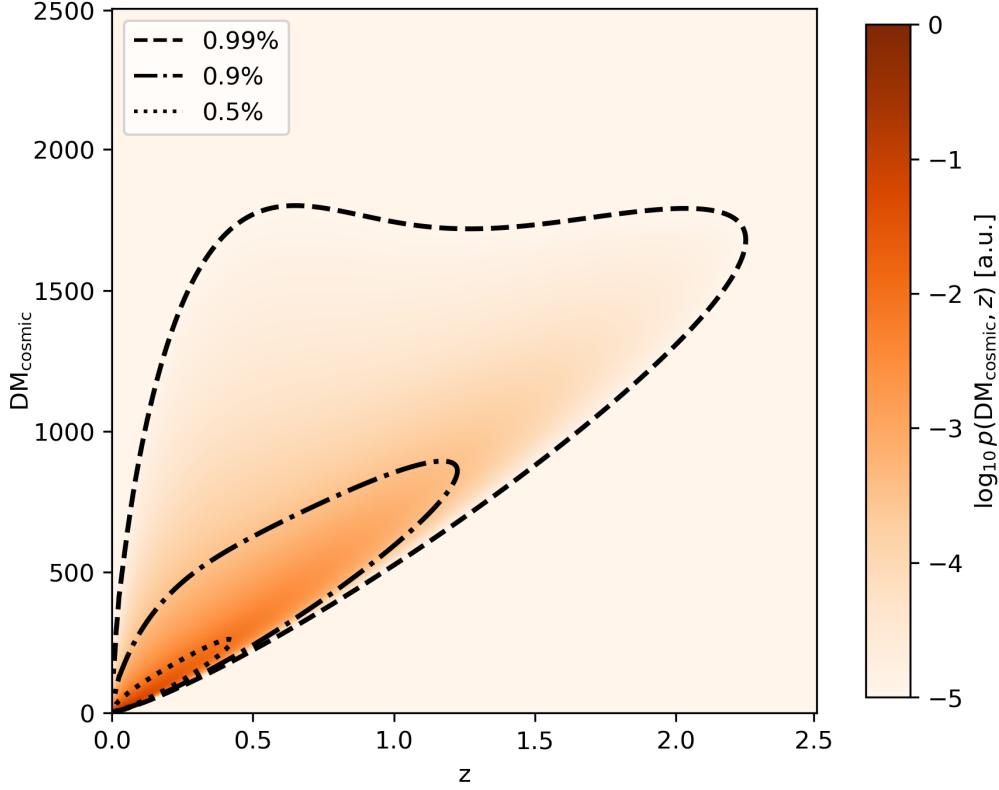
We detail the construction of mock FRBs in Section 2 and present our results in Section 3. We discuss these results and finally conclude in Section 4. When not explicitly stated, DM is in units of pc cm<sup>-3</sup> and the scattering timescale in milliseconds.

## 2. MOCK FRBS

We create 25 000 mock FRBs by first sampling pairs of  $\text{DM}_{\text{cosmic}}$  and FRB redshift  $z$  from the  $p(z, \text{DM}_{\text{cosmic}})$  distribution illustrated in Figure 1. This distribution is computed with the `zDM` code<sup>4</sup> (C. W. James et al. 2022a; J. X. Prochaska et al. 2023; J. Baptista et al. 2023) within the FRB library (J. X. Prochaska et al. 2025), taking into account the characteristics of the CRAFT/ICS 1.3 GHz observations (K. W. Bannister et al. 2019)<sup>5</sup>. The values of the dis-

<sup>4</sup> <https://github.com/FRBs/zdm>

<sup>5</sup> CRAFT has two other frequency bands but we consider this one for simplicity. This choice does not affect our conclusions.



**Figure 1.**  $p(z, \text{DM}_{\text{cosmic}})$  distribution considering the characteristics of the CRAFT/ICS 1.3 GHz instrument, and used to create the redshift and cosmic DM values for the 25 000 mock FRBs. The black lines denote the 50, 90 and 99 percent contours.

tribution arise from the best-fit model parameters of J. L. Hoffmann et al. (2025), but with the host galaxy DM contribution, and FRB scattering, artificially set to zero. To obtain  $\text{DM}_{\text{host}}$  for each of the previous FRBs, we sample from a log-normal distribution centered at  $\log_{10} \text{DM}_{\text{host}} = 1.8$  and with  $\sigma \log_{10} \text{DM} = 0.6$ . These values are expressed in the frame of the host, while in the frame of the observer they are suppressed by a redshift factor such that  $\text{DM}_{\text{host}}^{\text{obs}} = \text{DM}_{\text{host}}/(1+z)$ . The corresponding scattering times are assumed to be produced only by the host and to arise from the  $\tau$ -DM relation for MW pulsars presented in J. M. Cordes et al. (2022). In particular, each value is drawn from a log-normal distribution centered at the

value given by

$$\begin{aligned} \tau_{\text{host}}(\text{DM}_{\text{host}}, \nu) &= 5.7 \times 10^{-7} \text{ ms } \nu^{-\alpha} \text{ DM}_{\text{host}}^{1.5} \\ &\times (1 + 3.55 \times 10^{-5} \text{ DM}_{\text{host}}^3), \end{aligned} \quad (1)$$

with  $\sigma \log_{10} \tau_{\text{host}} = 0.76$  and  $\nu = 1$  GHz. Here above, we have multiplied the original pulsar equation by a factor of three to account for the difference between spherical and plane waves (J. M. Cordes et al. 2022), and  $\tau_{\text{host}}$  and  $\text{DM}_{\text{host}}$  are again expressed in the frame of the FRB host. The DM contribution from the Milky Way for each FRB is finally obtained by sampling a normal distribution centered at  $\overline{\text{DM}}_{\text{MW}} = 80 \text{ pc cm}^{-3}$  and with  $\sigma = 50 \text{ pc cm}^{-3}$ , with a minimum  $\text{DM}_{\text{MW}} = 20 \text{ pc cm}^{-3}$  (adopting moderately different values than these here does not impact our results). With the above quantities, we obtain the total observed DM for each FRB

as

$$\text{DM}_{\text{FRB}} = \frac{\text{DM}_{\text{host}}}{1+z} + \text{DM}_{\text{cosmic}} + \text{DM}_{\text{MW}} . \quad (2)$$

We next include the effect of observational bias on the signal-to-noise ratio (SNR) considering DM smearing as

$$\text{DM}_{\text{smear}} = 8.3 \mu\text{s BW} \nu^{-3} \text{DM}_{\text{FRB}} , \quad (3)$$

where  $\text{BW} = 1 \text{ MHz}$  for CRAFT/ICS. The true SNR is then

$$\left[ \frac{\text{SNR}}{\text{SNR}_{\text{ins}}} \right]^4 = \frac{t_s^2 + \text{DM}_{\text{smear}}^2}{t_s^2 + \text{DM}_{\text{smear}}^2 + [\tau_{\text{host}}(1+z)^{-3}]^2} , \quad (4)$$

where  $\text{SNR}_{\text{ins}}$  is given by the instrument and  $t_s = 1.182 \text{ ms}$  is the sampling time (J. L. Hoffmann et al. 2025). We require this procedure because the zDM code has already accounted for the time-smearing in the numerator on the right-hand-side of Eq. 4, but not the additional smearing due to scattering. FRBs with resulting SNR below a given threshold are assumed to be undetectable.

With the dispersion measure created for all mock FRBs, we can now obtain the value of  $\text{DM}'_{\text{host}}$  that would be inferred from observations. The contributions of the Milky Way and the cosmic material are not known with precision, so we estimate their averages. The cosmic contribution to DM is estimated by adopting the average value of the Macquart relation (J.-P. Macquart et al. 2020) at the redshift of the FRBs ( $\overline{\text{DM}}_{\text{cosmic}}(z)$ ) as is common procedure in the literature, assuming that  $z$  is known. For the Milky Way value, we again adopt  $\overline{\text{DM}}_{\text{MW}} = 80 \text{ pc cm}^{-3}$  for all FRBs. Quantitatively, the inferred host DM equates

$$\frac{\text{DM}'_{\text{host}}}{1+z} = \text{DM}_{\text{FRB}} - \overline{\text{DM}}_{\text{cosmic}}(z) - \overline{\text{DM}}_{\text{MW}} . \quad (5)$$

### 3. RESULTS

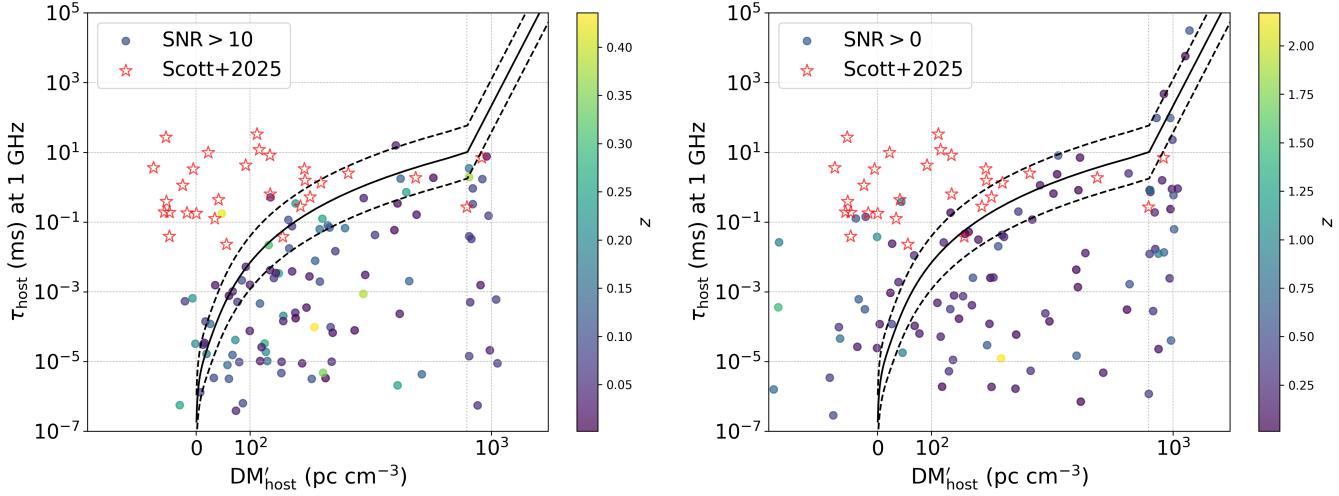
Figure 2 shows 100 random FRBs selected from the sample of 25 000 mock FRBs, with

an SNR threshold  $\text{SNR} = 10$  in the left panel, and  $\text{SNR} = 0$  in the right one. DM values below  $500 \text{ pc cm}^{-3}$  (marked with a vertical dotted line) are plotted in linear space and logarithmic above, for visualization. To convert from the observed to the host frame, we assumed that the FRB redshift is known. This redshift is denoted by the color code; because  $\text{DM}_{\text{host}}$  depends on  $\text{DM}_{\text{cosmic}}$  via Equation 5, and the latter depends on redshift, one may envisage a relation between the redshift and  $\text{DM}_{\text{host}}$ , although this is not apparent in our plots (we revisit this point in Section 3.1). Overall, the intrinsic correlation between the scattering and the dispersion measure represented by the black lines (mean and 1-sigma uncertainties, respectively, from MW pulsars) appears largely washed out, especially for the  $\text{SNR} > 10$  case, where the observations are biased against high scattering time values. The majority of data points appear below the pulsar relation. This is largely driven by the asymmetry toward large DM values around the Macquart relation in the  $p(z, \text{DM}_{\text{cosmic}})$  distribution in Figure 1. In other words, assuming cosmic DM values from the Macquart relation often results in overestimated DM values for the host as expected from the pulsar relation. Furthermore, these data differs significantly from the CRAFT (D. R. Scott et al. 2025) observations denoted by the stars.

Figure 3 illustrates the distributions of Pearson (linear)<sup>6</sup> correlation coefficients between  $\log_{10} \tau$  and  $\log_{10} \text{DM}$  for  $10^5$  realizations<sup>7</sup> of ten (upper panels) and one hundred (lower panels) FRB host observations drawn from our mock dataset. This figure shows that when there is a

<sup>6</sup> Given the large scatter in the data, we expect the use of the Spearman correlation to yield similar results although not explicitly tested.

<sup>7</sup> For this calculation we use only data where DM is positive. Our results do not change when considering instead linear values (positive and negative) for the two observables in the correlation calculations.



**Figure 2.** Scattering time against dispersion measure for a random set of 100 FRB hosts selected from the sample of 25 000 mock FRBs, with an SNR threshold  $\text{SNR} = 10$  in the left panel, and  $\text{SNR} = 0$  in the right one. DM values below  $500 \text{ pc cm}^{-3}$  (dotted vertical line) in the horizontal axis are plotted in linear scale, and logarithmic above, for visualization. The colors indicate the redshift of the host, with different scale ranges between the two panels. The intrinsic correlation between the scattering and the dispersion measure represented by the black lines (mean and 1-sigma uncertainties, respectively, from MW pulsars) appears largely washed out, especially for the  $\text{SNR} > 10$  case, where the observations are biased against high  $\tau$  values. The stars represent the CRAFT data by D. R. Scott et al. (2025), for comparison.

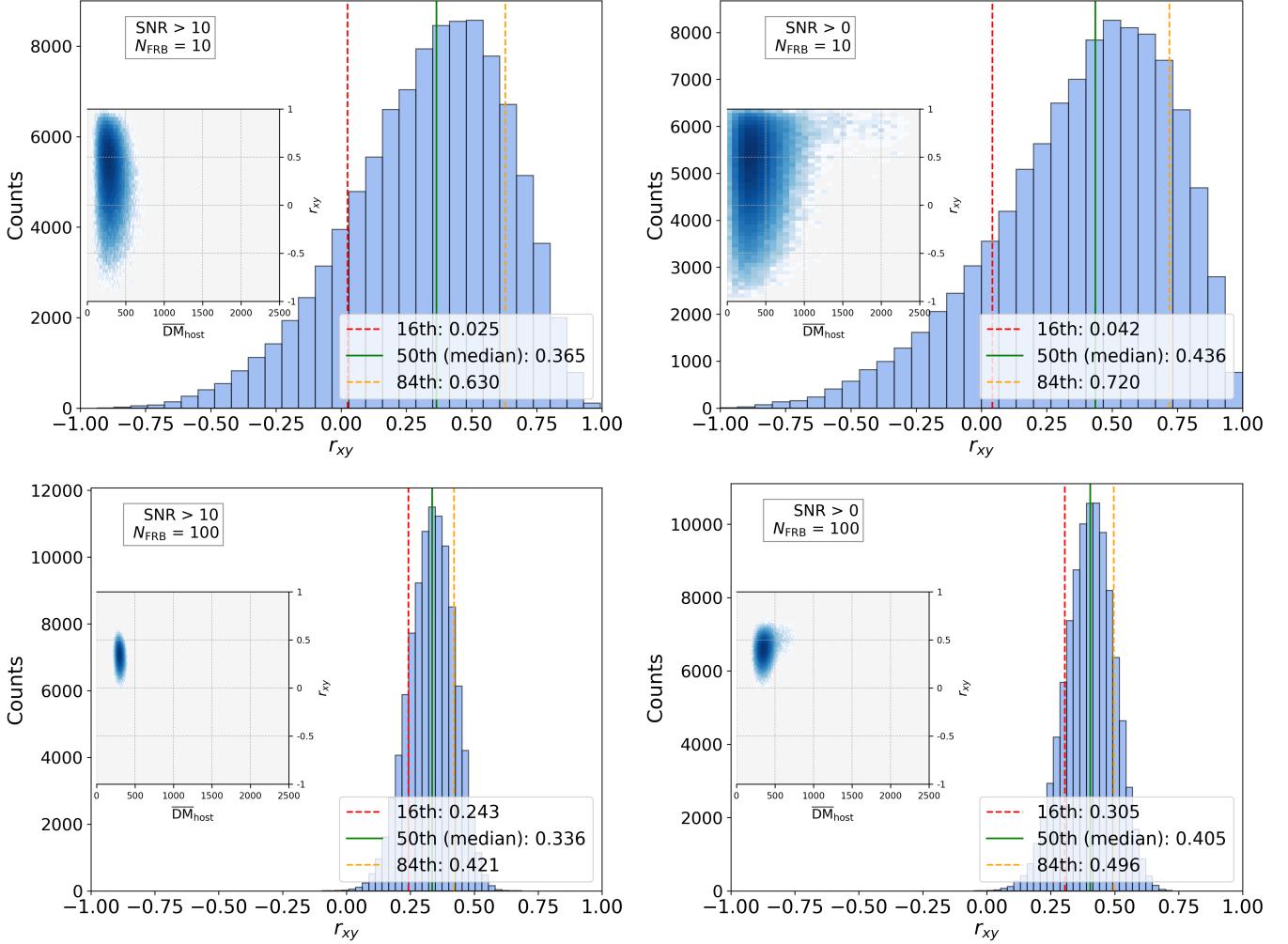
statistically significant number of measurements (one hundred), the correlation coefficient is well constrained to a low value ( $r_{XY} \sim 0.4 \pm 0.1$ ), as opposed to the wide distributions for the case of only ten data points ( $r_{XY} \sim 0.4 \pm 0.3$ ). Also, when there is an SNR threshold, large DM (and scattering) values are not included as they are below the threshold, which further suppresses the possibility of measuring the intrinsic  $\tau$ -DM relation (i.e., this reduces the median correlation coefficient by  $\sim 0.1$ ). The inset figures show the mean host dispersion measure in each set of measurements, demonstrating that the largest correlation values in the distributions are notably contributed by realizations that contain significantly high DM measurements. Overall, all distributions peak below a correlation coefficient of  $r_{XY} = 0.44$ , indicating that the majority of observational sets do not show a correlation between the two parameters.

In addition to the mock FRBs with an intrinsic correlation mimicking the one for MW pul-

sars, we have created another dataset of mocks based on the model by J. M. Cordes et al. (2022) for comparison. In brief, this model makes use of a parameterization of the physical conditions in the MW ISM to obtain a relation between scattering and dispersion measure. Quantitatively, this expression equates

$$\tau(\text{DM}, \nu) = 48.03 \mu\text{s} \nu^{-4} A_\tau \tilde{F} G \text{DM}^2, \quad (6)$$

where  $A_\tau \approx 1$ ,  $\tilde{F}$  parametrizes the density fluctuations driven by ISM turbulence, and  $G$  is the geometric term accounting for the relative positions of the FRB, the scattering material and the observer (see S. K. Ocker et al. 2022, for detailed descriptions of these parameters). Following these authors, we express the product  $\tilde{F}G$  as a uniform distribution  $X \sim U(0.01, 10)$  in units of  $(\text{pc}^2 \text{ km})^{-1/3}$ . Because we sample from this distribution spanning two decades when computing the scattering given DM values, this range is expected to already wash out the relation between the two observables of interest.



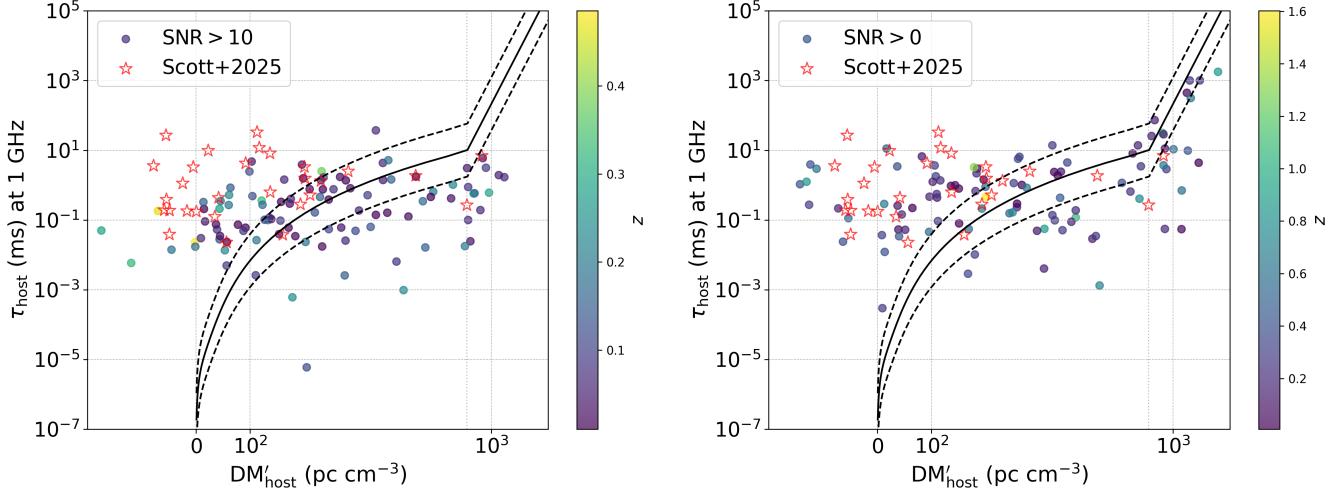
**Figure 3.** Distributions of correlation coefficients between  $\tau$  and DM for  $10^5$  realizations of ten (upper panels) and one hundred (lower panels) FRB host observations drawn from our mock dataset. All distributions peak below a correlation coefficient of 0.4, indicating that the majority of observational sets do not show a correlation between the two parameters. Only measurements containing DM values much larger than the typical host average may show an apparent correlation (inset figures), but a statistically significant number of observations and an SNR threshold rapidly demonstrate that a correlation is non-existent.

As for the pulsar case, the results for this relation are shown in Figure 4 and in the Appendix in Figure 7, where we find similar conclusions as before. In this case, however, the simulated data does match the parameter space covered by the CRAFT measurements better than with the pulsar relation.

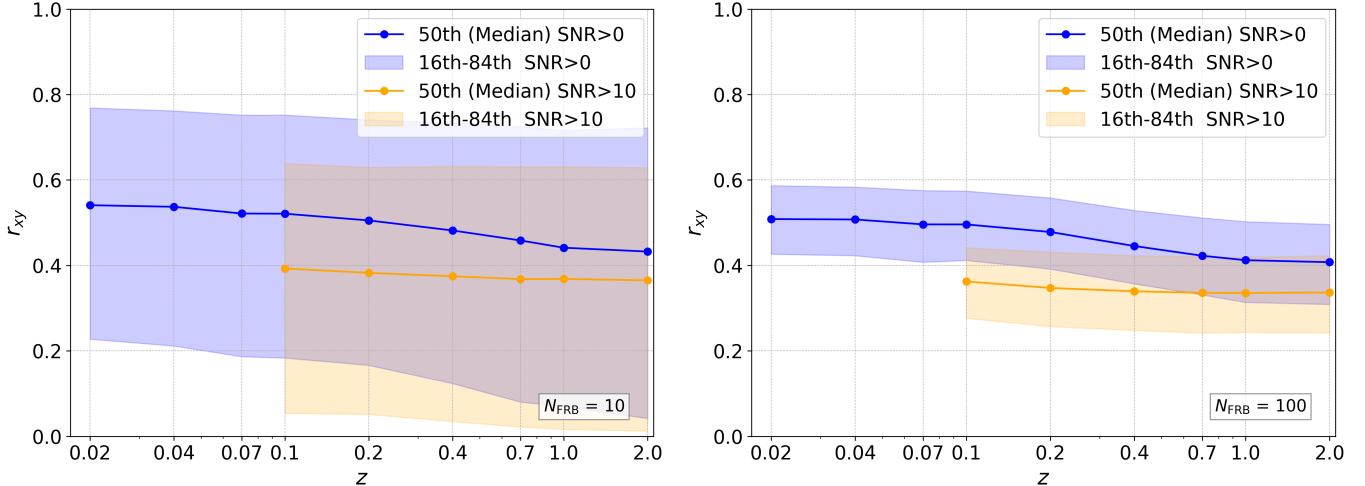
### 3.1. Observability dependence on $z$ and $\text{DM}_{\text{FRB}}$

In the previous section we found that the observability of a  $\tau$ – $\text{DM}_{\text{host}}$  relation is more likely when the data contains large  $\text{DM}_{\text{host}}$  (and cor-

responding  $\tau$ ) values. We examine here the dependence of such a measurability on two other observables connected to  $\text{DM}_{\text{host}}$  to further explore this finding: a) Because the variance of  $\text{DM}_{\text{cosmic}}$  around the Macquart relation is a major contributor for washing out the internal  $\tau$ – $\text{DM}_{\text{host}}$  relation, observations at (very) low redshift ( $z \lesssim 0.1$ ), where the  $\text{DM}_{\text{cosmic}}$  variance is low (Figure 1), may aid at detecting the relation of interest; b) Because the source redshift in a) is typically not known, one may, a priori,



**Figure 4.** Same as Figure 2 but considering the  $\tau$  – DM $^2$  relation arising from the cloudlet model by J. M. Cordes et al. (2022) and a uniform distribution for their geometric and turbulent parameters.



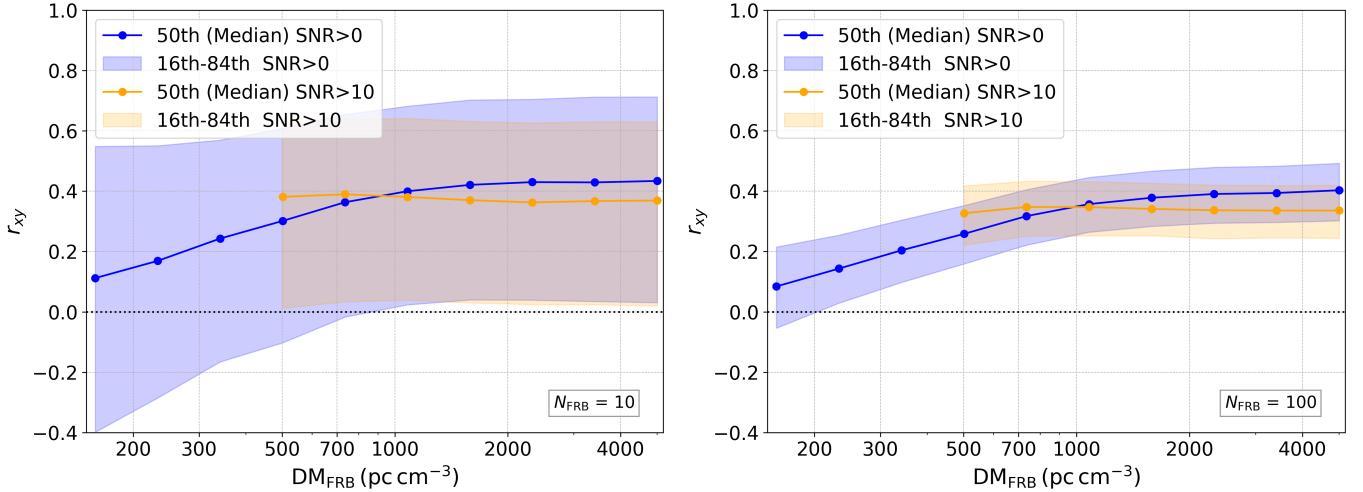
**Figure 5.** Correlation coefficient with respect to FRB redshift for the two SNR cuts (SNR> 10 in orange and SNR> 0 in blue) and number of FRBs per observation ( $N= 10$  in the left panel and  $N= 100$  in the right one). The SNR> 10 cases do not extend below  $z = 0.1$  because of the small number of data points in those subsamples. The region  $z > 2$  effectively shows the same results as  $z = 2$ .

consider a selection based on total  $\text{DM}_{\text{FRB}}$  to obtain a similar effect. Specifically, the quantity of interest is the extragalactic DM and not the total DM, but in our formalism the two are just different by a constant.

Figure 5 illustrates the dependence of the correlation coefficient on FRB redshift for the same SNR thresholds and number of FRBs per observation as before. The SNR> 10 cases do not extend below  $z = 0.1$  because of the small number

of data points in those subsamples. Overall, a slight increase of about 0.1 in correlation coefficient at low  $z$  is visible for the SNR> 0 case, but the median values are still far from a confident detection of a correlation ( $r_{xy} < 0.6$ ).

Figure 6 displays the correlation coefficients with respect to  $\text{DM}_{\text{FRB}}$ . The SNR> 0 cases, which contain a large enough number of data points in each subset, show a reduction of  $\sim 0.2 - 0.3$  in the correlation values from



**Figure 6.** Correlation coefficient with respect to  $\text{DM}_{\text{FRB}}$  for the two SNR cuts ( $\text{SNR} > 10$  and  $\text{SNR} > 0$ ) and number of FRBs per observation ( $N = 10$  and  $N = 100$ ). The  $\text{SNR} > 10$  cases do not extend below  $z = 0.1$  because of the small number of data points in those subsamples.

the largest to the smallest  $\text{DM}_{\text{FRB}}$ . Although lower  $\text{DM}_{\text{FRB}}$  values generally correspond to lower redshifts, which as just shown above may slightly boost the detectability, these also imply that the  $\text{DM}_{\text{host}}$  values are (on average) reduced. This reduction of  $\text{DM}_{\text{host}}$  has a stronger effect than that of redshift and drives the decline of the correlation towards low  $\text{DM}_{\text{FRB}}$ .

Figures 8 and 9 correspond to the two aforementioned calculations for the Cordes et al. model, which yields the same conclusions just stated for the pulsar relation.

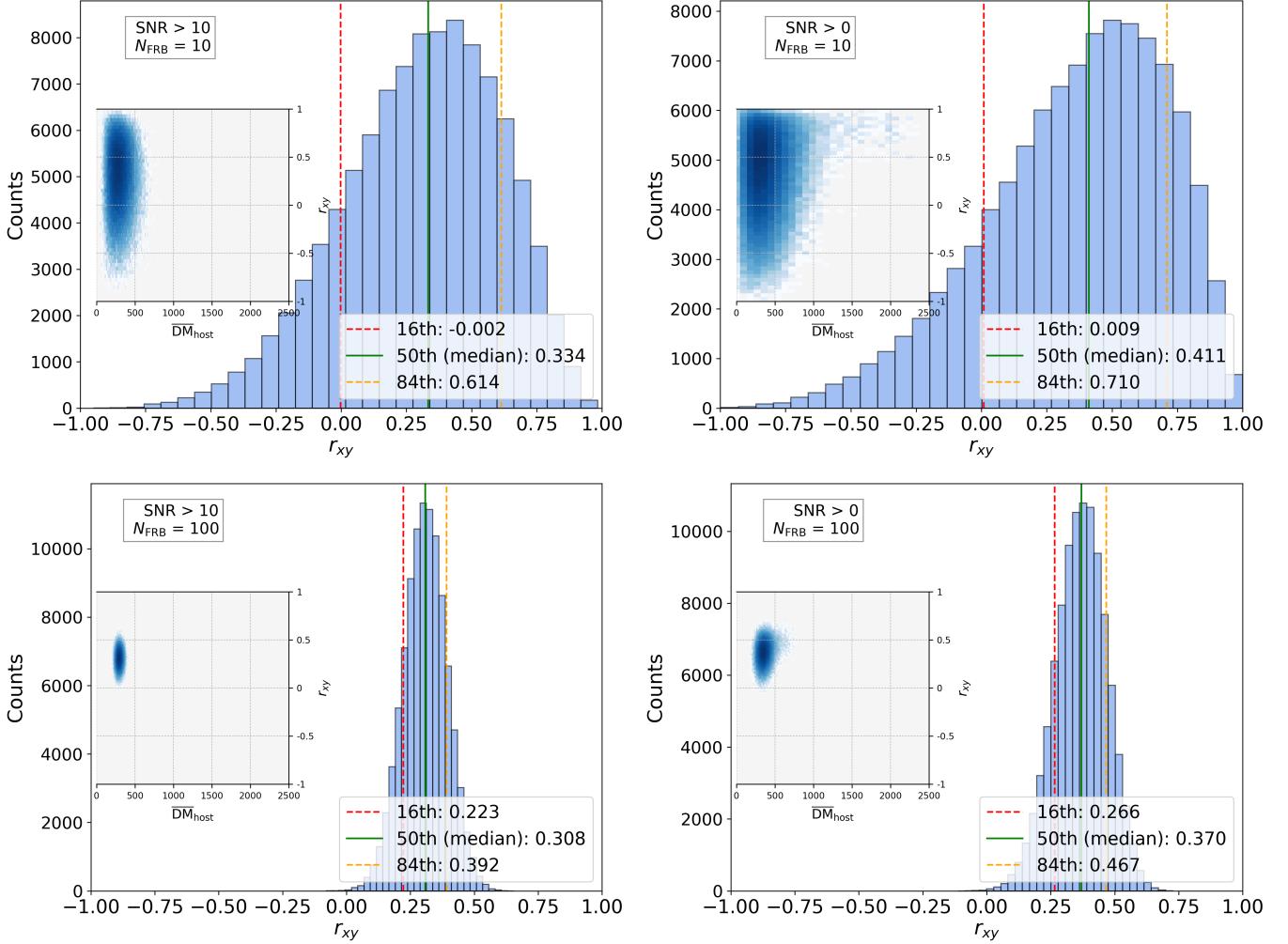
#### 4. CONCLUSIONS

In this paper we have explored the observability of a  $\tau$ - $\text{DM}$  relation for FRB hosts which, if existent, could aid at determining the host redshift and reducing uncertainty in cosmological studies that depend on the cosmic DM contribution. We have created a large mock FRB host dataset by assuming that there exists an intrinsic  $\tau$ - $\text{DM}_{\text{host}}$  relation as that observed for pulsars, as well as one that follows the modeling by J. M. Cordes et al. (2022). To account for instrumental systematics, we have considered observations of such FRBs within

the ASKAP/CRAFT survey. Our results can be summarized as follows:

- 1 Even when a tight relationship between scattering and dispersion measure from the host exists, this is generally not visible/measurable from FRB observations, due to fluctuations in DM from the Milky Way, intervening halos and the IGM.
- 2 Only observations including a wide range in  $\text{DM}_{\text{host}}$  that spans to large values may enable the measurement of a correlation between the two variables resembling that observed for pulsars. Observations, however, are biased against high scattering (and in turn DM) values, thus hindering a possible actual measurement.

The lack of an observable relationship between scattering and dispersion measure in FRBs cautions against the use of relations based on Milky Way parameters. Conversely, this also means that the observed lack of a correlation, as found by D. R. Scott et al. (2025), does not argue against the existence of an intrinsic  $\tau$ - $\text{DM}_{\text{host}}$  relation, such as that proposed by J. M. Cordes et al. (2022).



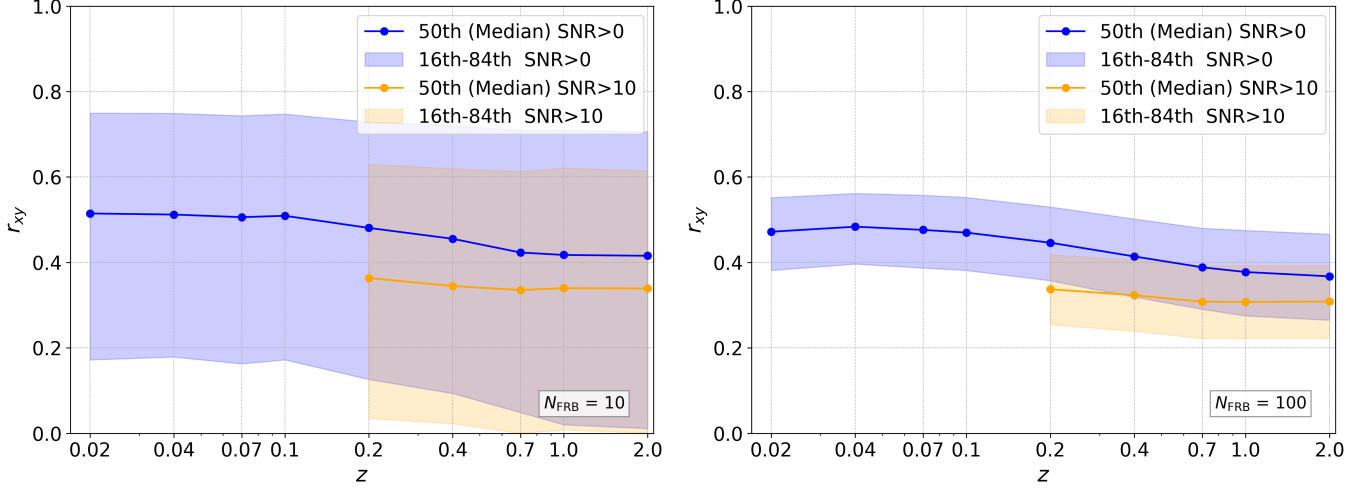
**Figure 7.** Same as Figure 3 but considering the  $\tau$ – $\text{DM}^2$  relation arising from the clouddlet model by J. M. Cordes et al. (2022) and a uniform distribution for their geometric and turbulent parameters.

## ACKNOWLEDGMENTS

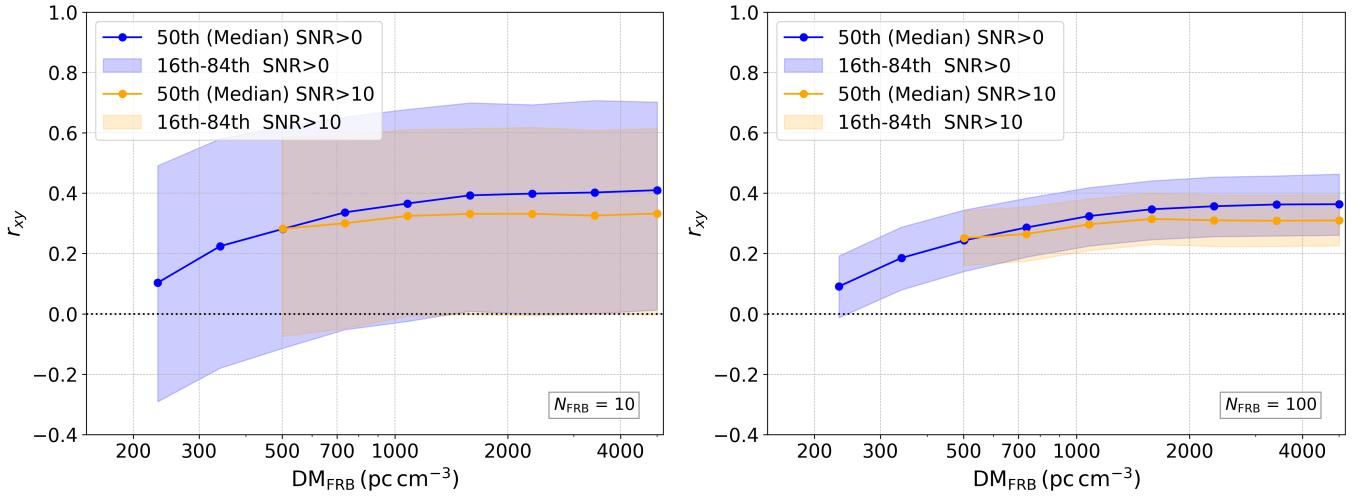
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up (F4) team, acknowledges support from NSF grants AST-1911140, AST-1910471, and AST-2206490. C.W.J acknowledges support through Australian Research Council (ARC) Discovery Project (DP) DP210102103.

## APPENDIX



**Figure 8.** Same as Figure 5 but considering the  $\tau - \text{DM}^2$  relation arising from the cloudlet model by J. M. Cordes et al. (2022) and a uniform distribution for their geometric and turbulent parameters.



**Figure 9.** Same as Figure 6 but considering the  $\tau - \text{DM}^2$  relation arising from the cloudlet model by J. M. Cordes et al. (2022) and a uniform distribution for their geometric and turbulent parameters.

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