MNRAS: MN-20-5012-L.R1: Response to the Second Referee Report

Dear Editor,

We thank the referee for their review of our manuscript and the included references within. We have revised our paper accordingly. The most significant change has been the addition of a section that discusses the issue of unresolved sub-bursts in our sample in the context of our model, titled "Unresolved bursts and slope vs. drift rate ambiguity". In addition, we have removed a fit from the range of fits for FRB 20121102A that was performed with only a single point; this updates the red range shown in Figure 1, and a sentence that explains this has been added to the third paragraph of Section 2.2.

In this report the comments from the referee are displayed in bold and our response is in plain text. Changes made to the manuscript are highlighted in yellow.

We hope that our revised manuscript will prove satisfactory.

Sincerely,
M. A. Chamma

Reviewer's Comments:

This manuscript describes a relation between the duration and frequency drift of sub-bursts from repeating sources of fast radio bursts (FRBs). The authors interpret the relation as evidence for a dynamical and relativistic model that they have published earlier. I think the results are of definite interest and warrant publication. I share with the other reviewer the concern that systematics might affect the results and I would like to see this possibility discussed in a little more detail. I appreciate the effort that has gone into considering a range of dispersion measure values but I would also like to see a discussion of how FRBs being unresolved can change the measured number of sub-burst and their durations. The manuscript is well-written and clear, I only have a few minor suggestions to improve clarity; see my per-section comments below. I commend the public release on GitHub of all software used to produce the results discussed in this manuscript and I look forward to the analysis of additional bursts from repeating sources of FRBs in this framework in future papers.

Point 1:

There are various ways by which a train of sub-bursts from a FRB can be unresolved in data, which can lead to an underestimate of the number of sub-bursts in a burst envelope and an overestimate of sub-burst durations. For example, limited time resolution (e.g., the 1-ms time resolution CHIME/FRB data used in this analysis vs. the 10 us time resolution of the data from Michilli et al. 2018 and Gajjar et al 2018; cf. the panels in Fig. 1 of Michilli et al. 2021; https://ui.adsabs.harvard.edu/abs/2021ApJ...910..147M/abstract and Fig. 1a and 1b in Bhardwaj et al. 2021; https://ui.adsabs.harvard.edu/abs/2021ApJ...910L..18B/abstract), intrachannel smearing from incoherent dedispersion, limited S/N of a detection (see Fig. 7 in Gourdji et al. 2019; http://adsabs.harvard.edu/abs/2019ApJ...877L..19G) and blending of multiple components through scatter-broadening (see, e.g., Section 4.3 in Day et al. 2020; https://ui.adsabs.harvard.edu/abs/2020MNRAS.497.3335D/abstract). I think it would be good to make the reader aware of these possibilities and discuss how these effects might have influenced your sub-burst duration and slope measurements. For example, I suspect that in your Figure 8 burst 23 might be unresolved but made up of multiple sub-bursts and that correlation 23 is measuring the drift rate of the burst envelope rather than the sub-burst slope of the individual components.

Response:

We are grateful for the examples provided and have added a Section titled "Unresolved bursts and slope vs. drift rate ambiguity" to Section 3 ("Results and Discussion") that summarizes these examples (borrowing from the referee's comment) as well as explains

the connection between the slope and drift rate measurements in the context of our model. The essential detail is that Equation 1 of the paper will apply to not only slope measurements but also the drift rate of groups of sub-bursts when variations in the proper delay time $\tau'_{\rm D}$ are small. The physical interpretation in the context of our model is that groups of sub-bursts arise from groups of emitting samples that are 'close' to each other but distinct in their emission, so that they all respond to the triggering signal with nearly the same delay. The samples do not necessarily need to be close in space; samples far apart but along the line of sight will have almost coincident bursts if the time delay after the arrival of the trigger is the same. It is difficult to be specific without knowing the underlying emission mechanism but possible scenarios include fragmented clumps of emitting material, or, in the context of Dicke's superradiance, distinct groups of entangled material.

Point 2:

I suggest to only refer to the Transient Name Server names of the sources throughout the manuscript, as those names will likely be the ones that stick: FRB20121102A, FRB20180814A and FRB20180916B. This will make it easier in the future to find this paper when someone searches for the source names. (The old names could be mentioned once in a footnote.)

Response:

We have updated the manuscript and figures accordingly.

ABSTRACT:

Point 3:

"Our results also suggest that the sub-burst slope law is a proper criterion for dedispersing waterfalls of repeating FRBS, leading to a DM rooted on a simple physical model resting on the relativistic nature of FRBs.": I think this is a bit overstated and confusing, because you need to dedisperse to undo the effect of dispersion in the interstellar and intergalactic media and this delay will be dominant, see also my comment below.

Response:

We have removed this sentence from the abstract and updated the relevant sentences in Section 3 (pg. 5, first paragraph) and the first paragraph of the Conclusion. As pointed out, other effects are more dominant and selecting a single DM for a cohort of bursts is

only useful when simplifying studies that require a large sample of bursts (such as this one) and in general is nonphysical.

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1. INTRODUCTION:

Point 4:

'a "happy trombone" effect': one more example are bursts 24 and 25 from FRB20180916B, separated by about 60 ms, see Extended Data Figure 1 in https://ui.adsabs.harvard.edu/abs/2020Natur.582..351C/abstract.

Response:

We have added this example.

Point 5:

"this significant finding reveals": I suggest to remove "significant" and leave it up to the reader to judge for themselves.

Response:

Agreed.

Point 6:

"which our proposed FRB model is ultimately inspired by": instead of "our proposed FRB model" maybe write "this proposed FRB model" or the "FRB model proposed by Rajabi et al. (2020)."

Response:

This was accidentally left over from the previous round and has been corrected.

Point 7:

"burst temporal duration exhibits a fair amount of scattering at a given frequency": I suspect you mean "scatter" here (i.e., scatter around a mean

value) and not scattering/scatter-broadening from encountering inhomogeneities in the interstellar medium; please clarify.

Response:

The sentence has been updated to the following:

"Although the measurements of burst temporal duration exhibit a fair amount of scatter at a given frequency (which could also be inherent to $\tau'_{\rm w}$ in equation (2)), the predicted behaviour is consistent with the observations."

Point 8:

"This can be asserted, for example, from Figure 3 (top panels) of Hessels et al. (2019).": Note that Josephy et al. (2019; https://ui.adsabs.harvard.edu/abs/2019ApJ...882L..18J/abstract) and Caleb et al. (2020; https://ui.adsabs.harvard.edu/abs/2020MNRAS.496.4565C/abstract) show this trend over an even wider frequency range for FRB20121102A and that Pastor-Marazuela et al. (2021; https://arxiv.org/pdf/2012.08348.pdf) show the trend for FRB20180916B.

Response:

We have added the suggested references to the relevant sentence.

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2. BURST ANALYSIS:

Point 9:

- **"might stack the individual sub-bursts": maybe "superimpose" describes it better than "stack?"**
- **"too aggresive of a dedispersion": maybe replace with "overdedispersion?"**

Response:

We have adopted these suggestions.

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3. RESULTS AND DISCUSSION:

Point 10:

"at first appears to avoid the discontinuity": The language here is a bit confusing as "at first appears" implies that on a second look you'll find out that it does not avoid the discontinuity. Maybe change to "Measuring the sub-burst angle from the data instead of the slope avoids a discontinuity around $\theta = 0$ or π, where its magnitude approaches infinity. Sub-burst angle and slope can be directly converted."

Response:

The intent of this sentence was to highlight that while measuring angle instead of slope may initially appear to be favorable since it avoids the discontinuity, there is no avoiding the uncertainty due to the discontinuity in the physical quantity (the slope) that is actually of interest. We have updated the sentence accordingly.

Point 11:

"Importantly, this result suggests that the sub-burst slope law is a proper criterion for dedispersing waterfalls of repeating FRBs, leading to a DM rooted on a simple physical model resting on the relativistic nature of FRBs.": I see what you're trying to say here, but it is a bit misleading: there is a DM for each burst/source from dispersion by traveling through the interstellar and intergalactic media and then on top of this there is additional variation that you here claim is based on the relativistic motion. The dispersion delay will be much larger than the delay from the sub-burst slope. Please make this more clear in the text.

Response:

Following Point 3 we have updated this sentence to the following:

"The similarities in the values for A between the three sources also suggests that the sub-burst slope law can become a suitable method for making small simplifying adjustments to the DM of waterfalls of repeating FRBs, once the dominant dispersion effects due to the interstellar and intergalactic media are accounted for. The resulting choice of DM would have the advantage of being rooted on a simple physical model resting on the relativistic nature of FRBs, and can be used to simplify analyses with large sample sizes by avoiding the complexity that can arise when choosing a DM based on the S/N or other structure criteria."

As well as the relevant sentence in the conclusion:

"Additionally, this result suggests that the sub-burst slope law may be a useful tool for simplifying studies that require large samples of FRBs, by providing a single small

adjustment DM to dedisperse waterfalls to without the complexity of verifying each burst's DM."

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4. CONCLUSION:

Point 12:

"our earlier models based on Dicke's superradiance": quote the paper here, i.e., something like "the model by Rajabi et al. (2020)."

Response:

We have updated this sentence with references.
