Detection of a bright burst from the repeating FRB 20201124A at 2GHz

2022. 6. 6 Fast Radio Bursts and Cosmic Transients

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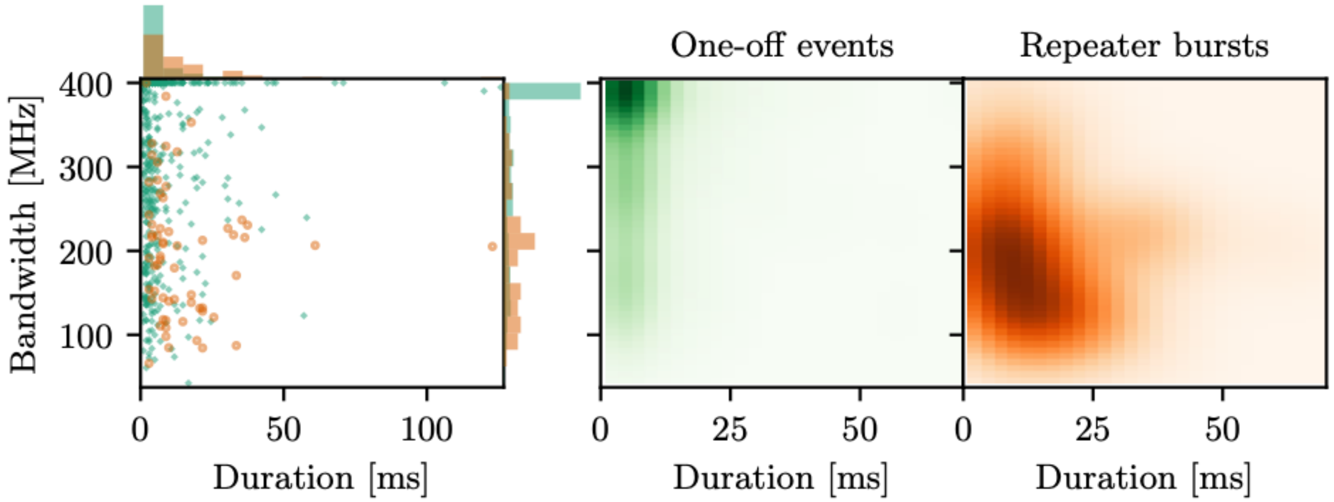
Introduction

- Detection of FRBs at different frequencies and over wider bandwidths is important for studying mechanism of FRBs
- Most of detections were made at 400-800 MHz or 1.4 GHz
- There are roughly 2 types of FRBs : one-off and repeating

Introduction

Do repeating FRBs and non repeating FRBs generate from
same population? or different population?
(= are repeating FRBs and non repeating FRBs essentially the same? or different?)

➡ We haven't got decisive answer yet.



Pleunis et al. (2021a) : Bandwidths and durations of the FRBs. FRBs are separated into one-off events (green) and repeater bursts (orange). The panels on the right show smoothed and normalized distributions of all one-off events (green) and all repeater bursts (orange), respectively.
One-off and repeating FRBs seem to have different trend.

Introduction

Aimed to nearby and bright repeating FRBs

・FRB 20200120E

・FRB 200428 (SGR1935+2154)

→ No detection.

FRB 20201124A

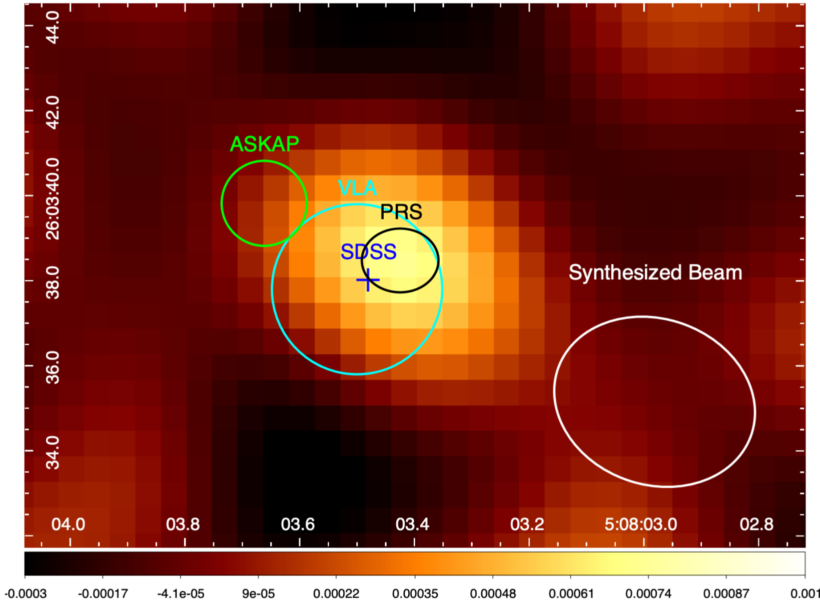
Characteristic

・Repeating FRB
・z ~ 0.0979 (Wen-Fai Fong+2021)
・One of the most active FRB sources
・Persistent radio source

・> 1000 bursts were found in <u>the active phase from April to June 2021</u> (Xu et al. 2021, Hilmarsson et al. 2021)
・<u>A few bursts from this FRB was detected on Jan 28, 29</u>

➡ We observed this FRB.

Wharton et al. 2021a



650 MHz map showing the persistent radio source with the 5 sigma source position uncertainty (black), the ASKAP (green) and VLA/realfast (cyan) burst localizations, the location of SDSS J050803.48+260338.0 (blue cross), and the uGMRT synthesized beam shape (white).

Observation

・ We observed this FRB with the 64-m radio dish of the Usuda Deep Space Center (UDSC)/JAXA for <u>8 hours</u> on February 18

・Frequency :
Sband (4ch, 2194 - 2322MHz)
Xband (4ch, 8374 - 8502MHz)

https://www.isas.jaxa.jp/about/facilities/usuda.html

Table 1. Frequency assignment

ch (S band)	central frequency	ch (X band)	central frequency
0	2210 MHz	4	8390 MHz
1	2242	5	8422
2	2274	6	8454
3	2306	7	8486

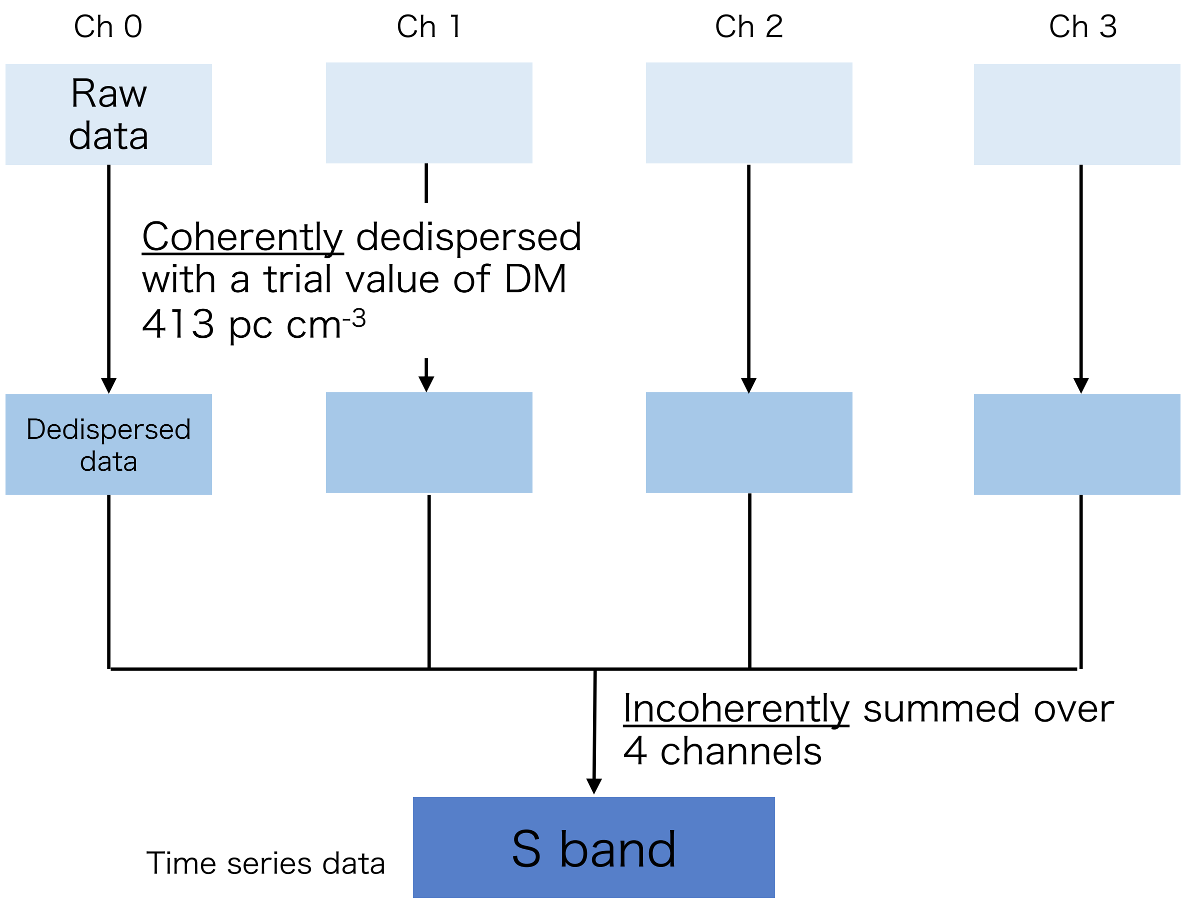
Analysis

1. The data in each channel are coherently dedispersed, and then incoherently summed over 4 channels for the S band and X band, separately.

2. With 1ms integration, we searched burst candidates.

   Threshold : S/N = 10
   ⇔Peak fluxes ≥ 3.2 Jy for the S band
   ≥ 5.1 Jy for the X band

Analysis flow



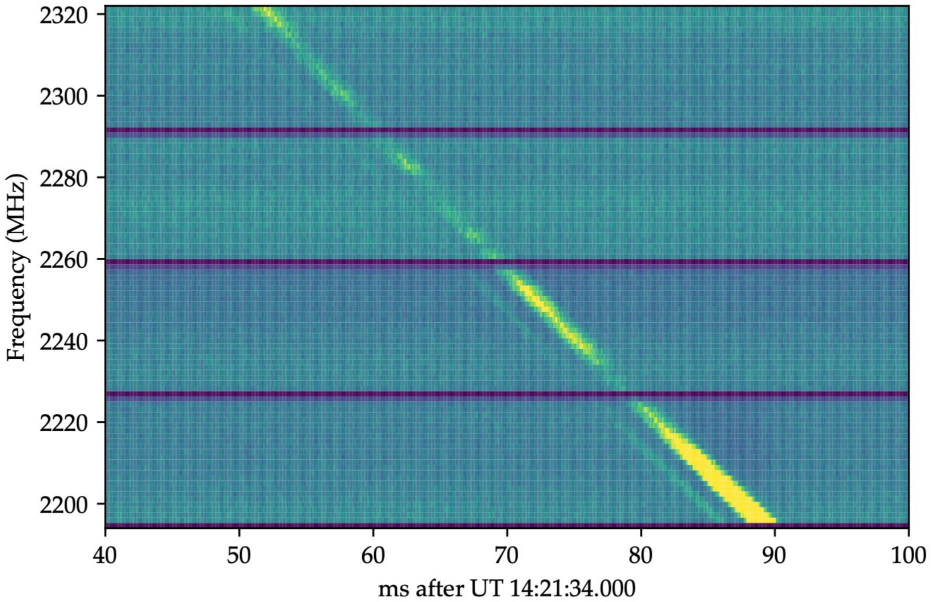
The same procedure was performed for the X band.

Results

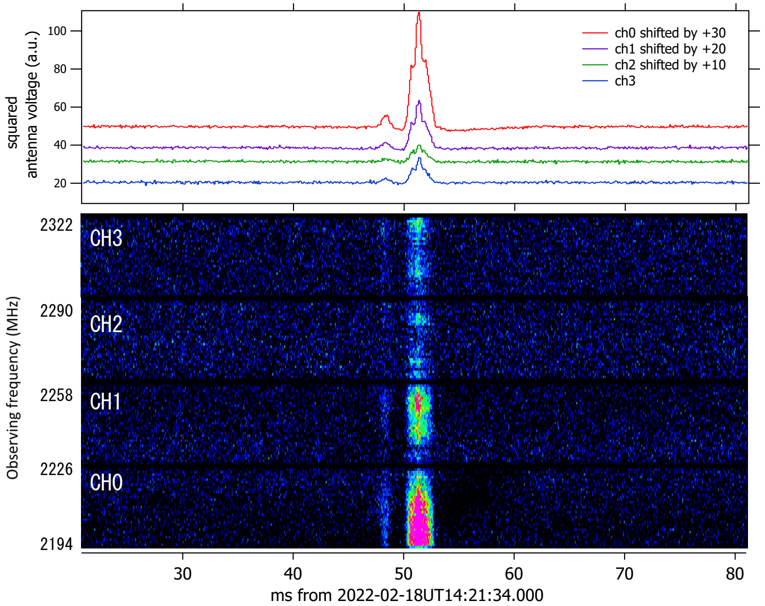
We detected one bright FRB!

We reported this burst to Atel (ATel #15285). We are preparing to publish letter paper.

- Pulse-width : 1.5ms
- A sub-structure having a peak ~10% around 3 ms prior to the main component.
  Similar with previous bursts from FRB20201124A (e.g., Marthi et al.2022; Main et al. 2022)



Dedispersion



Upper : Time series of squared antenna voltages at the S band.
Lower : Waterfall plot of the detected FRB event

DM Determination

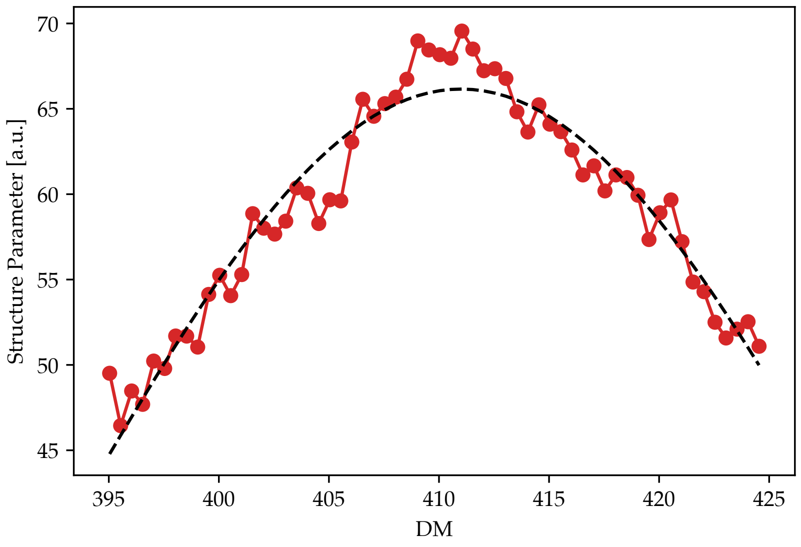
Optimize DM to maximize *structure parameter*, which represents steepness of bursts.

$$\text{Structure Parameter} = \frac{1}{n}\sum_{i}^{n}\left|\frac{S_i - S_{i+1}}{\Delta t}\right|. \qquad (1)$$

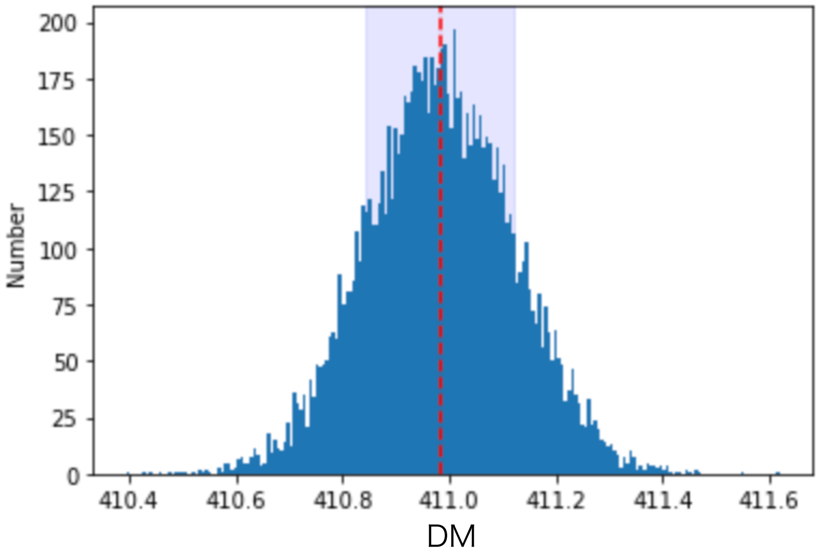
Gajjar et al. 2018

n : number of on–pulse bins, S_i is the flux at the i th bin, Δt : the time resolution

1. We calculated *structure parameter* with each DM after integration of Δt = 100 us.

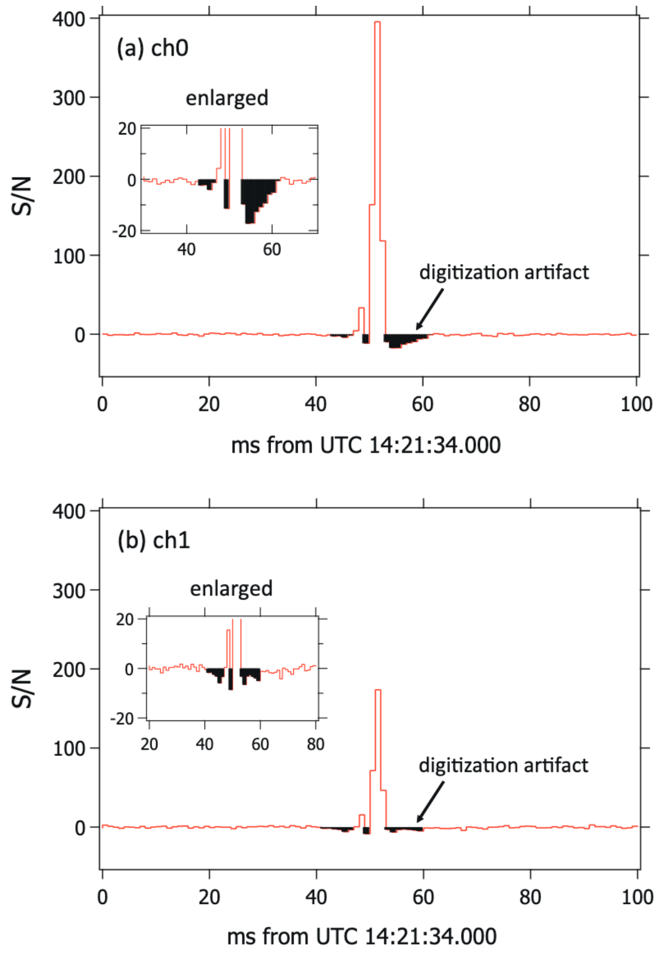


2. Bootstrapping
Took the data points obtained at random, allowing for overlap, and calculated the DM of the center from the Gaussian fitting. Repeating this process, we determined the optimal DM.



Result
DM = 410.98 ± 0.14

Digitization artifact



The S/N time profiles for (a) ch 0 and (b) ch 1.
The hatched areas show digitization artifacts.

・A dip in the noise floor around the burst, which represents digital artifact (Jenet and Anderson 1998) due to a finite bit size of the digitization system and results in the flux/fluence underestimations

・No dip for ch 2 and ch 3.

・Estimations for
the peak flux >119 Jy
the fluence > 199 Jy ms
for the S band, summing up 4 channels incoherently.

Flux/Fluence estimation for the burst

ch	central frequency	flux*	fluence*
0	2210 MHz	> 269 Jy	> 486 Jyms
1	2242	> 118	> 209
2	2284	37	67
3	2306	53	95

*11%uncertainly

Discussion

<u>We compared energy densities and rest-frame intrinsic duration.</u>

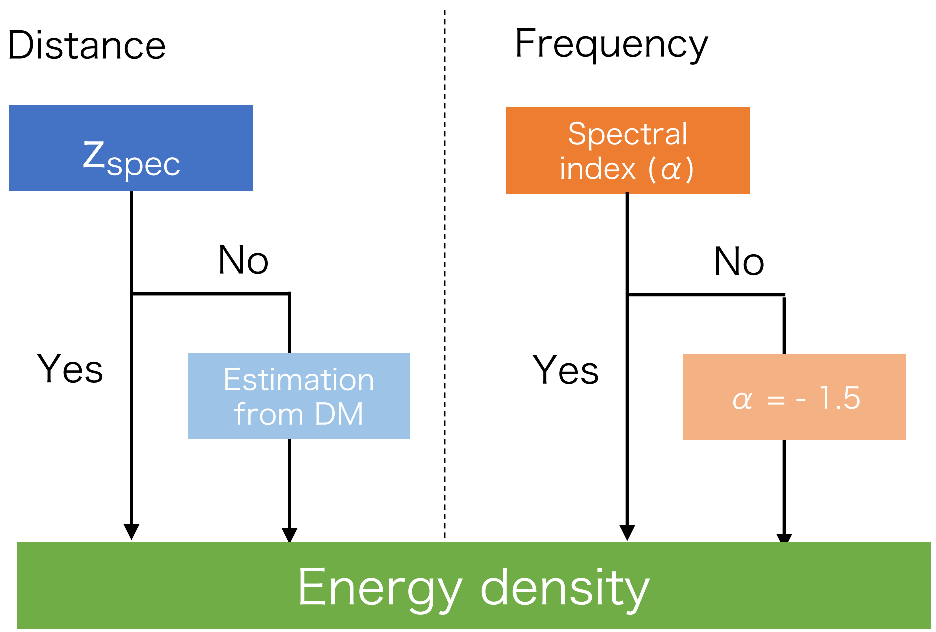
The comparison samples were from the FRBCAT Project (Petroff et al. 2016).

FRBs are detected at different frequencies and different redshifts.
To compare fairly, we estimated...

1. Energy densities

・Estimation of distance

・Conversion to energy densities at a unified rest-frame frequency of 1.83 GHz using measured power-law spectra α of FRBs. ($F_\nu \propto \nu^\alpha$), where F is the fluence.



Discussion

<u>We compared energy densities and rest-frame intrinsic duration.</u>

2. Rest-frame intrinsic duration

Removed instrumental broadening effects

$$w_{\mathrm{obs}}^2 = w_{\mathrm{int}}^2 + w_{\mathrm{smear}}^2 + w_{\mathrm{sample}}^2$$

Observed duration	Intrinsic duration. This is divided by (1+z)	Broadening due to smearing	Broadening due to finite time sampling

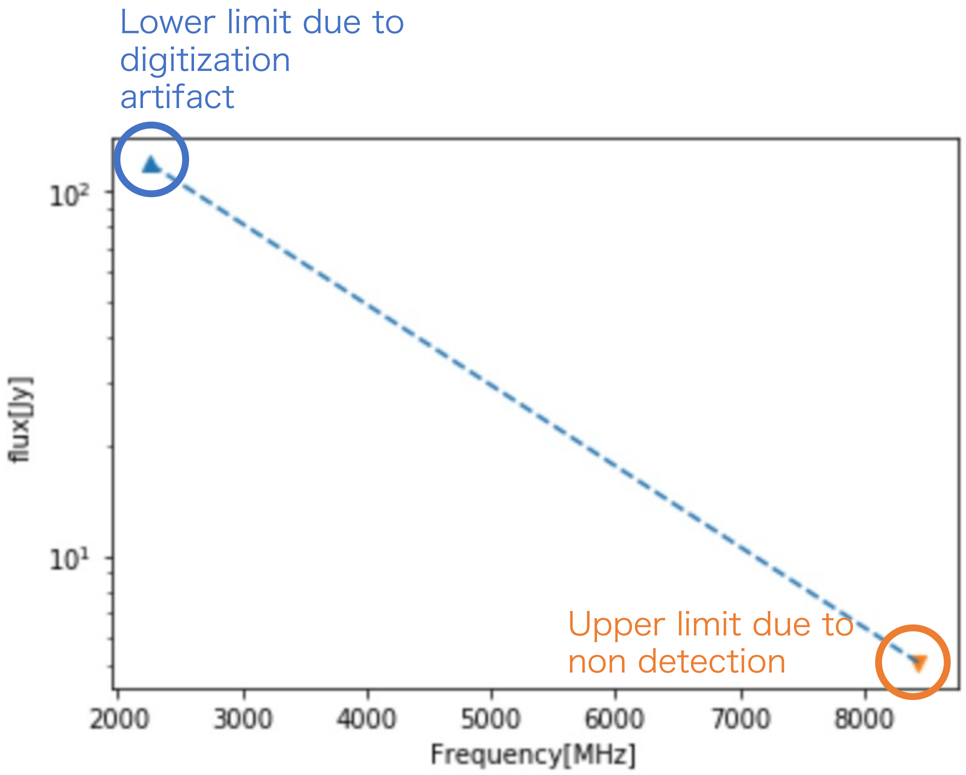
After excluding FRBs that satisfy equation : $DM_{obs} - DM_{halo} - DM_{ISM} - DM_{host} < 0$,
the comparison sample includes a total of <u>11 repeating FRB sources with 144 repeats</u> and <u>77 one-off FRBs.</u>

Discussion

We applied the same methods to the burst detected in this work.

- z_{spec} = 0.0979 (Fong et al. 2021)
- The observed fluence of F_ν > 486 Jy ms at 2.21 GHz
- The spectral index of $\alpha < -2.39^{+0.36}_{-0.44}$ ($F_\nu \propto \nu^\alpha$).

- log E_ν > <u>32.3 ± 0.1 erg Hz^{-1}</u>
- w_{int} is 1.5/(1 + z_{spec}) ~ <u>1.4 ms</u>

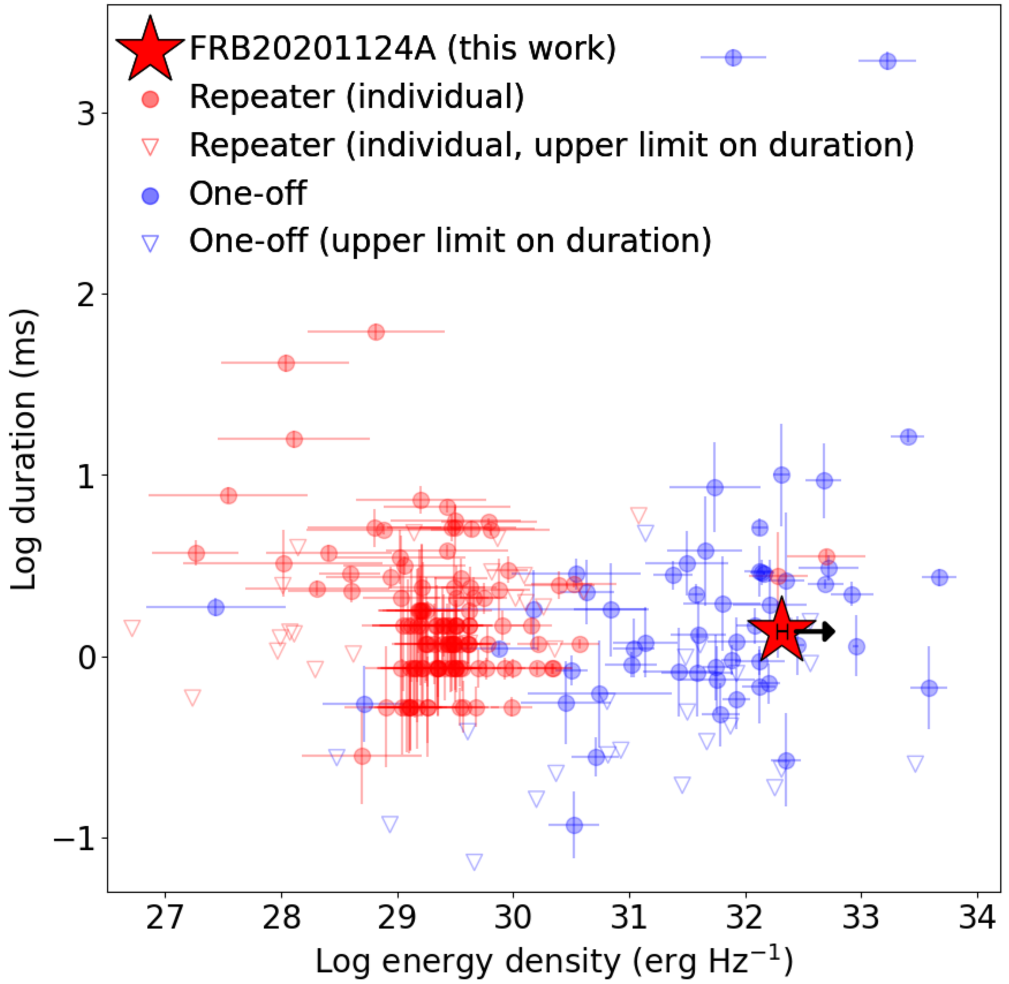


α estimation of the burst detected in this work

Discussion

<u>The detected burst shows one of the highest energy densities of repeating FRBs</u>.
The energy density is comparable to those of the bright population of one-off FRBs.

Our result highlights that repeating FRBs can be as bright as the population of one-off FRBs.



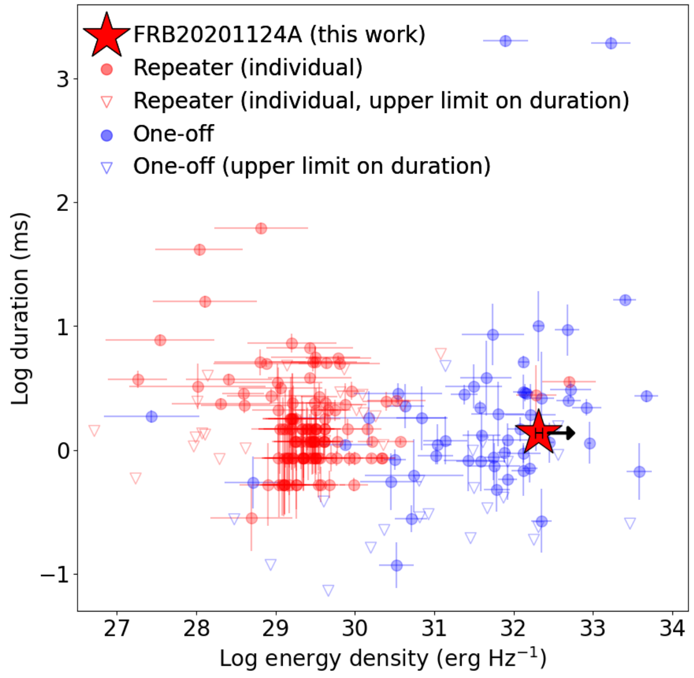
Rest-frame intrinsic duration as a function of energy density at rest-frame 1.83 GHz of FRBs. The arrow indicates the lower limit of the energy density.

Discussion

The burst detected in this work (> 486 Jy ms) is one of the brightest events from this FRB.
The detected frequency (~2.2-2.3 GHz) is one of the highest ranges.

① The volumetric occurrence rate of one-off FRBs likely exceeds that of cataclysmic progenitor candidates (Ravi 2019)
② Repeating FRBs are fainter than one-off events (e.g., Hashimoto et al. 2020, Kim et al. 2022 submitted).
→Some repeating FRBs might have been missed due to sensitivity limitations, which would mislead the FRB classification.

The detected bright repeating FRB might support the hypothesis that some one-off events are a part of repeating bursts (e.g., Ravi 2019; Kumar et al. 2019; Chen et al. 2022).



Summary

・Simultaneous 8-hour observations in the S and X bands

・The frequency of the detection is the highest end of the multi-wavelength coverage of repeating FRB 20201124A. The fluence is comparable to the brightest events detected from this FRB.

・We calculated lower limit of flux/fluence due to the digitization artifact

・More observation may change the classification.

Appendix

K-correction

$$L_{\nu_{\rm rest}} = \frac{4\pi d_l(z)^2}{(1+z)^{2+\alpha}} \left(\frac{\nu_{\rm rest}}{\nu_{\rm obs}}\right)^{\alpha} E_{\nu_{\rm obs}}, \qquad (6)$$

Novak et al. 2017

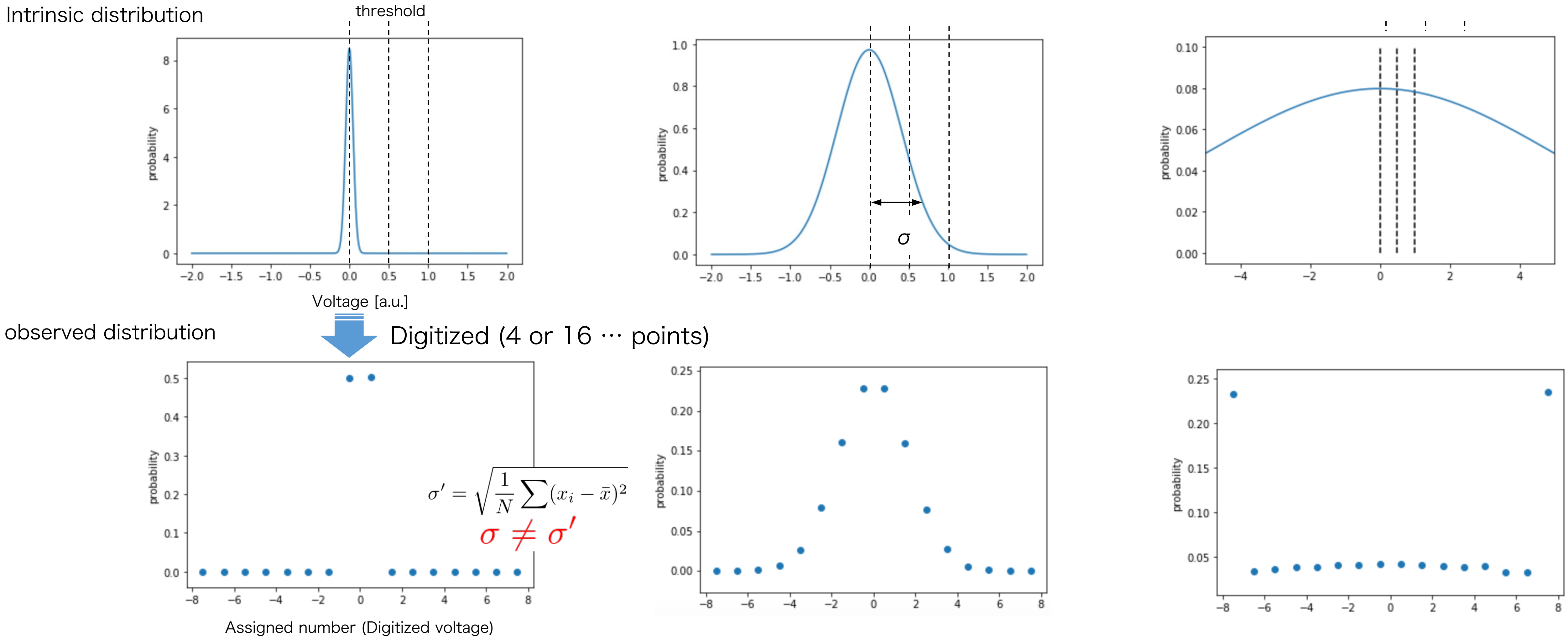
Luminosity (energy density)

Observed fluence

The 1.83 GHz is decided such that the width of the k-correction distribution is minimized for the FRBCAT sample.
The correction is the term which corrects difference of enegy between in host and observer due to redshift.

K-correction : $\frac{1}{(1+z)^{2+\alpha}} \left(\frac{\nu_{\rm rest}}{\nu_{\rm obs}}\right)^{\alpha}$

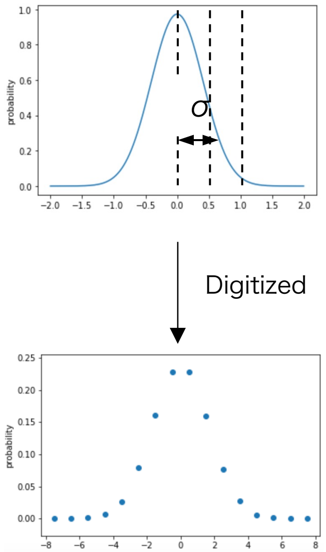
FRB20201124A : digitization artifact



<u>Summary : The shape of distribution and σ changes by sampling.</u>

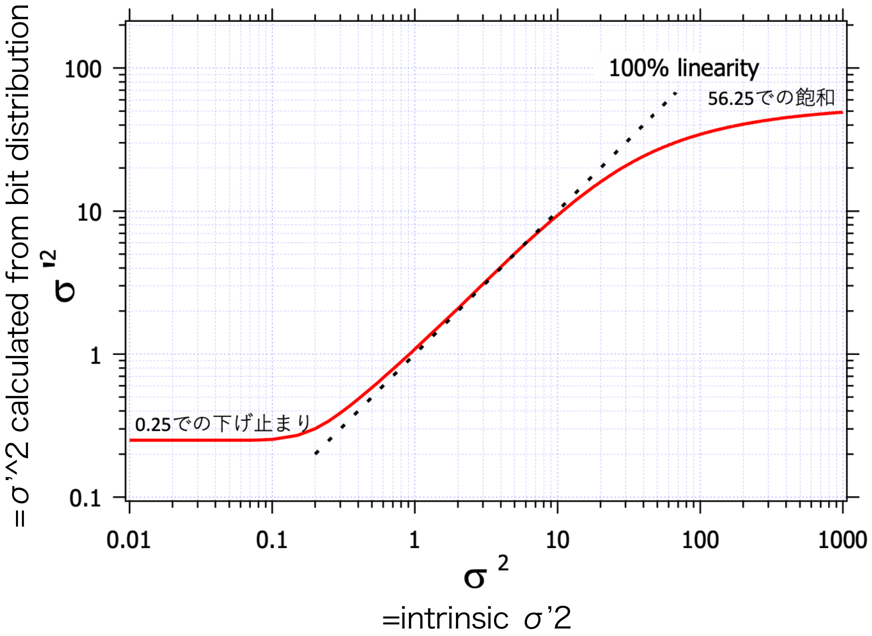
FRB20201124A : digitization artifact

Return from observed std σ' to intrinsic std σ to correct the digitization artifact.



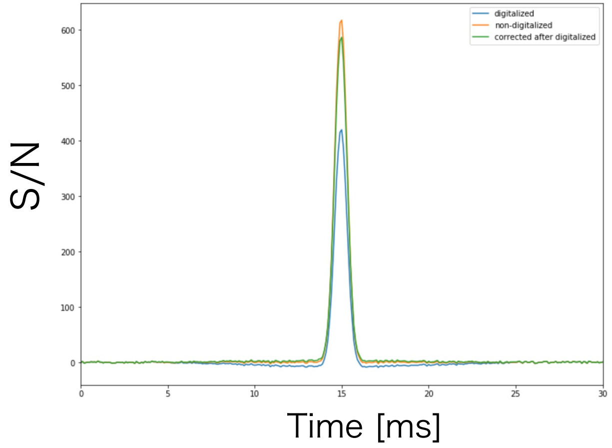
$$\sigma' = \sqrt{\frac{1}{N}\sum (x_i - \bar{x})^2}$$

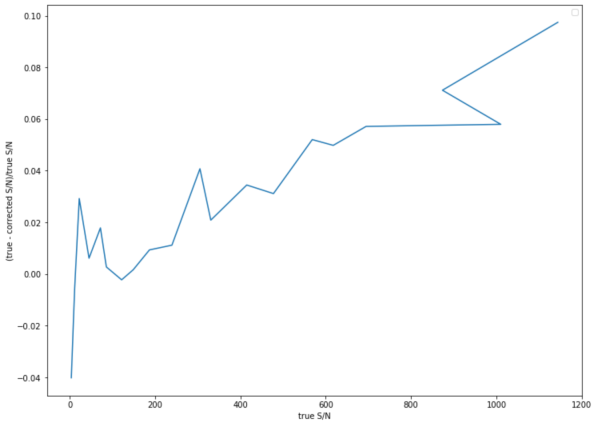
Made by Terasawa-san



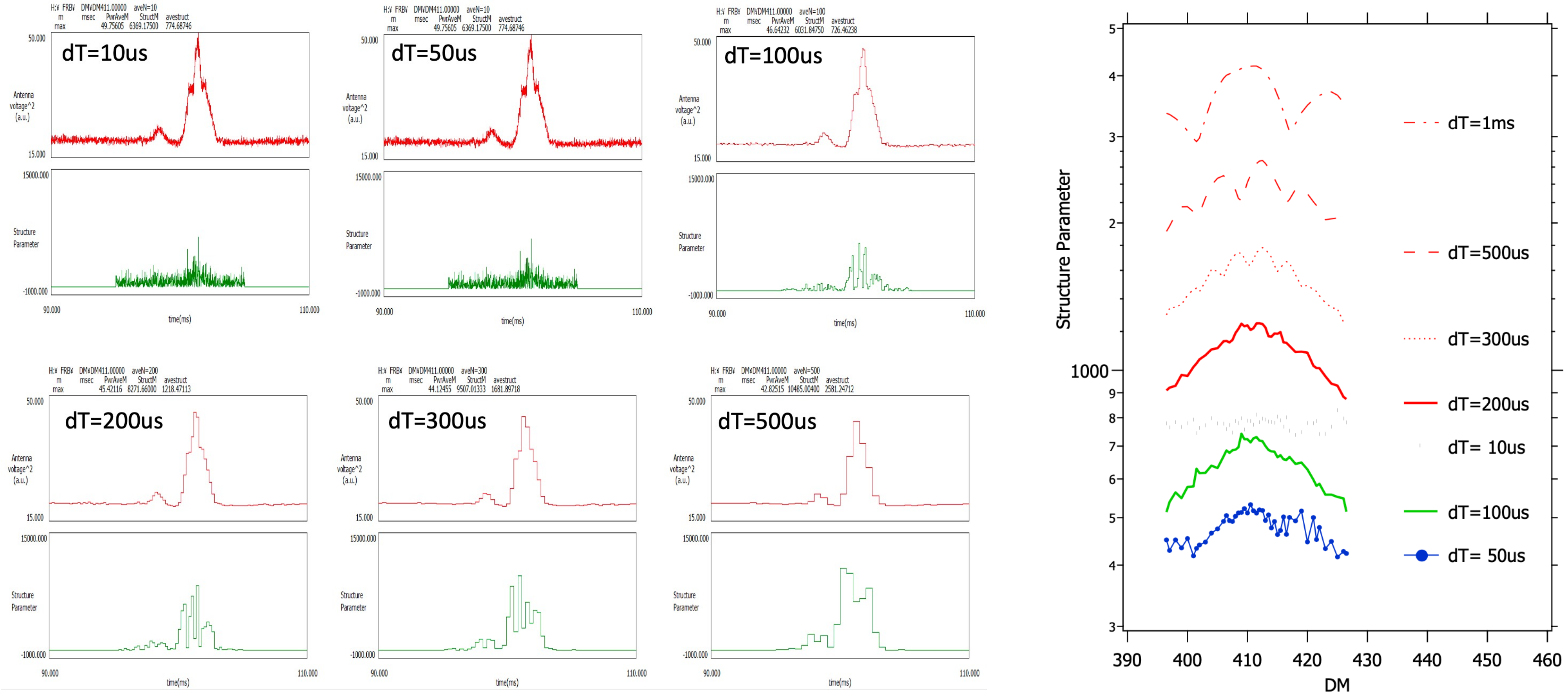
Correct

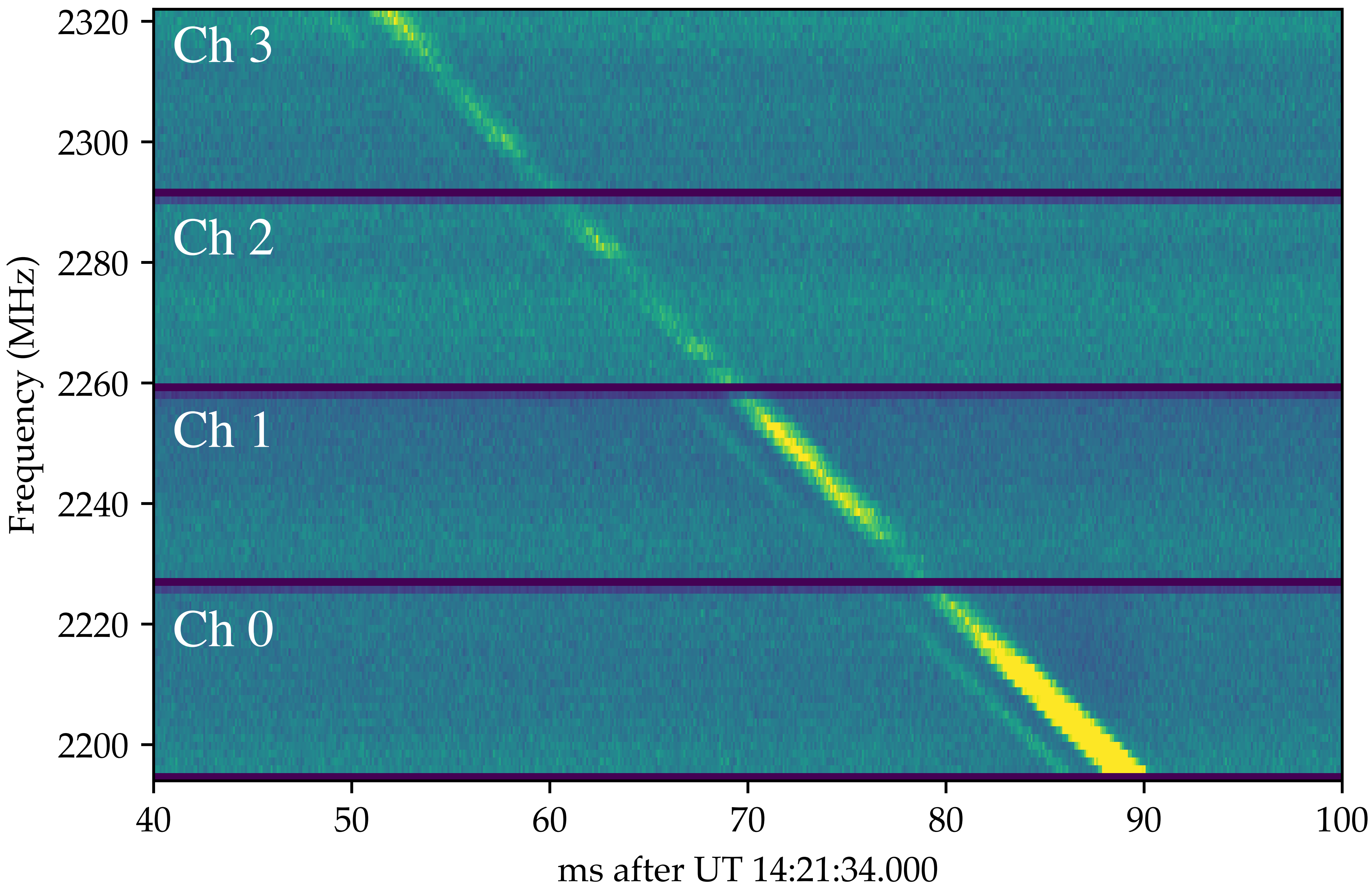
1. Calculate σ from the bit distribution of simulated data every few ms
2. Multiplying the data at that time by σ / σ'.





<u>Summary</u> : We were able to correct the dent of noise, but were unable to determine the dependence of the peak decrement on the time width of the input bursts, etc. In the next letter, we decided not to correct this effect and write a lower limit for flux.


dT=10us
dT=50us
dT=100us
dT=200us
dT=300us
dT=500us
Antenna voltage^2 (a.u.)
Structure Parameter
time(ms)
Structure Parameter
DM
dT=1ms
dT=500us
dT=300us
dT=200us
dT= 10us
dT=100us
dT= 50us



Ch 3
Ch 2
Ch 1
Ch 0
2320
2300
2280
2260
2240
2220
2200
Frequency (MHz)
40
50
60
70
80
90
100
ms after UT 14:21:34.000