LOFAR Transient Buffers

How a LOFAR station normally works

1) Many LOFAR antennas detect a radio signal



2) Voltages pass through analog signal chain

Filters / Amplifiers

3) Digitize signals

14 bits (12 for L1)

200 MHz (5ns)

Digitizer

4) channelize

0 MHz ... 224 chan ... 100 MHz

Fourier Transform (~ 5 us integration time)

5) beamformer

time shift and sum

.....

time shift and sum

Output: beamlets

What are the Transient Buffers?



The Transient Buffers

- Circular RAM Buffer

- Continuously stores the last 4.1 s of digitized voltages
  - *Before* channelization
  - *Before* beamforming
  - 5 s for L1

- Needs external signal to trigger a data dump
  - E.g. a detected lightning flash on lightningmaps.org or detected CR
  - Trigger a “data dump”
  - Dump the ram-buffer to hard-drive
    - This takes a few minutes, during which no other TBuff data can be recorded
    - Took ~20 mins for LOFAR1 (depending on settings)

Why Transient Buffers?

- Channelizing integrates over ~5 μs
  - Therefore smoothing-over any faster-varying signal

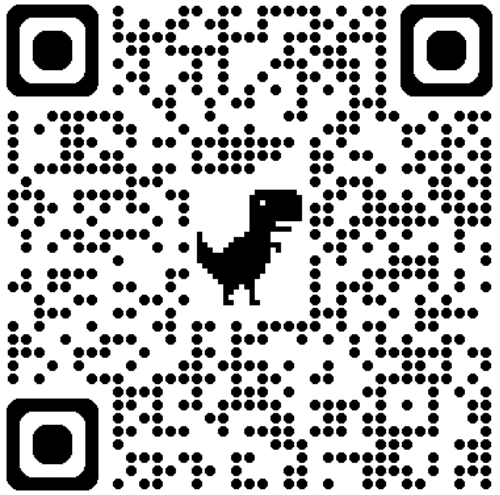
- Beamforming focuses on one location
  - What if signal comes from random location?

- Use TBuffs if need:
  - High-time resolution
  - Observe entire sky simultaneously

- Science Cases:
  - Cosmic ray air showers
  - Lightning

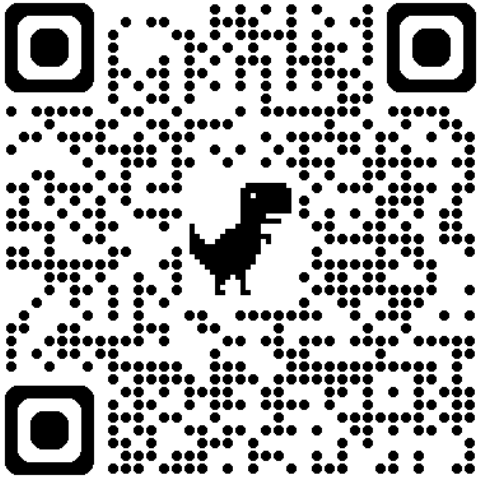
Code and Data

- LoLIM ： LoFAR Lightning Imaging
  - Package written in Python and Cython
  - Focused on lightning science
  - Has general tools to read and process TBuff data
  - Only developed by myself, thus may have bugs
  - Github: https://github.com/Bhare8972/LOFAR-LIM



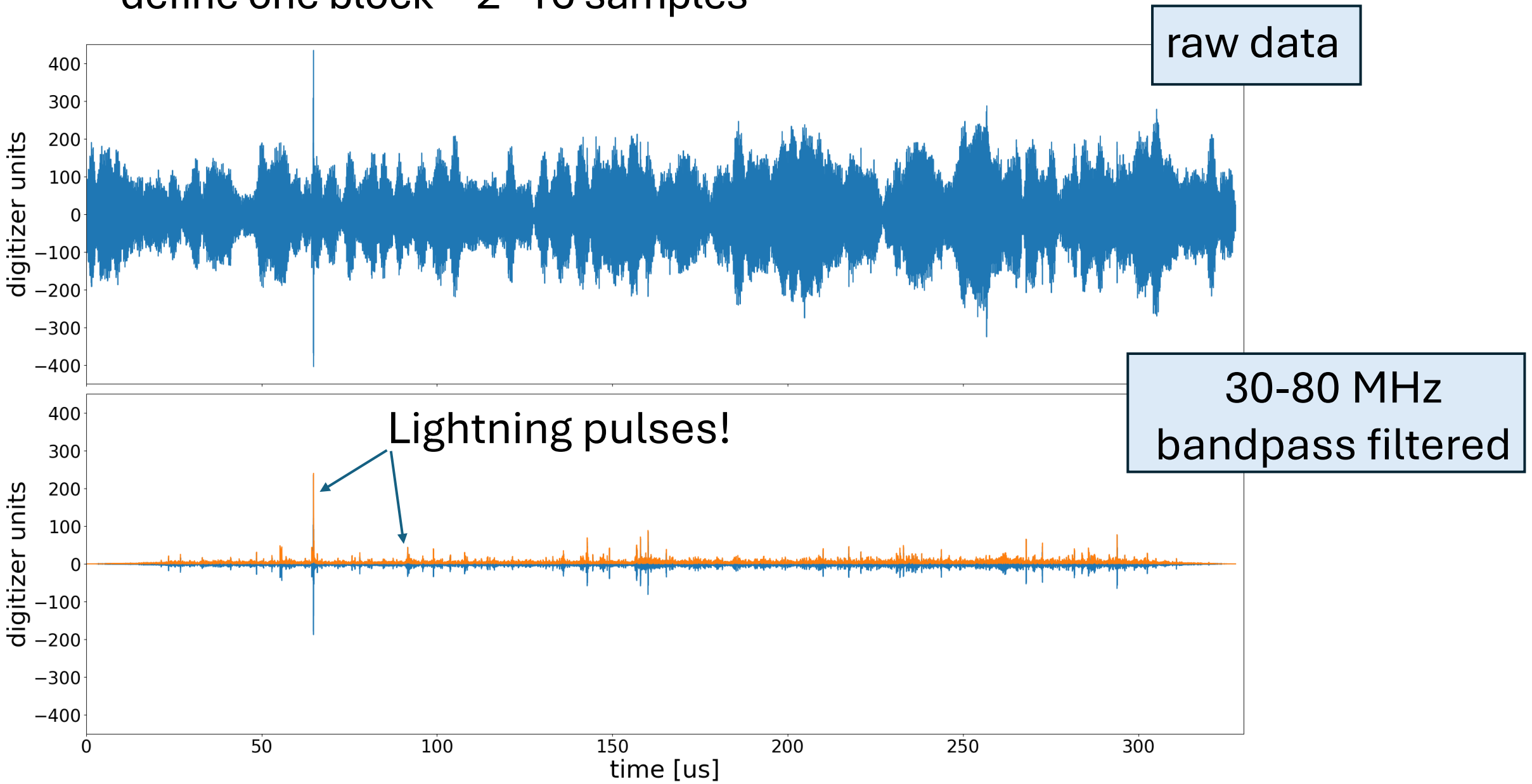
- Cosmic ray group also maintains a code base

- Example dataset
  - and install instructions, and example code
  - https://www.astro.rug.nl/~hare/public/other/LOFAR_dataSchool/



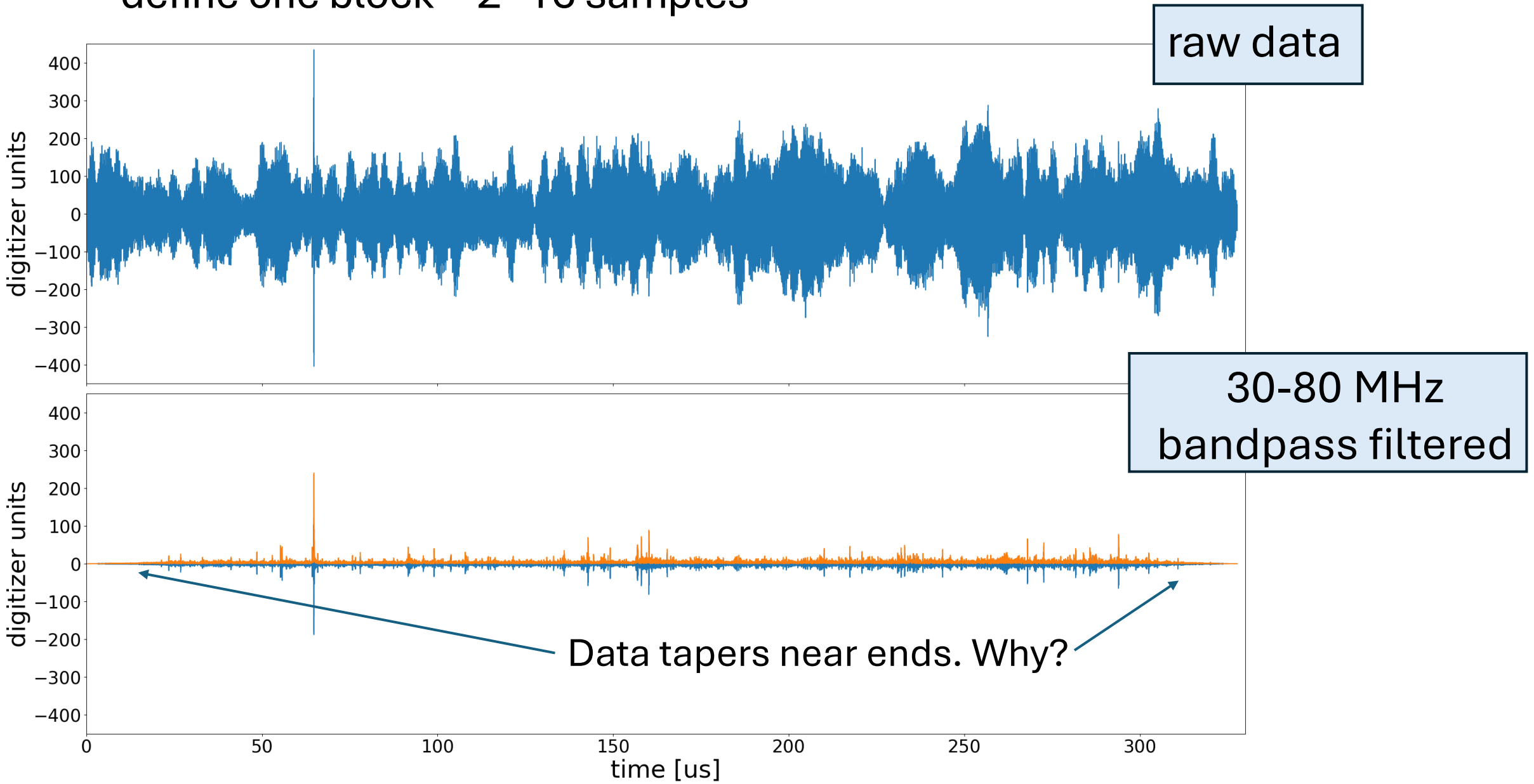
Example of one block of data

define one block = 2^16 samples



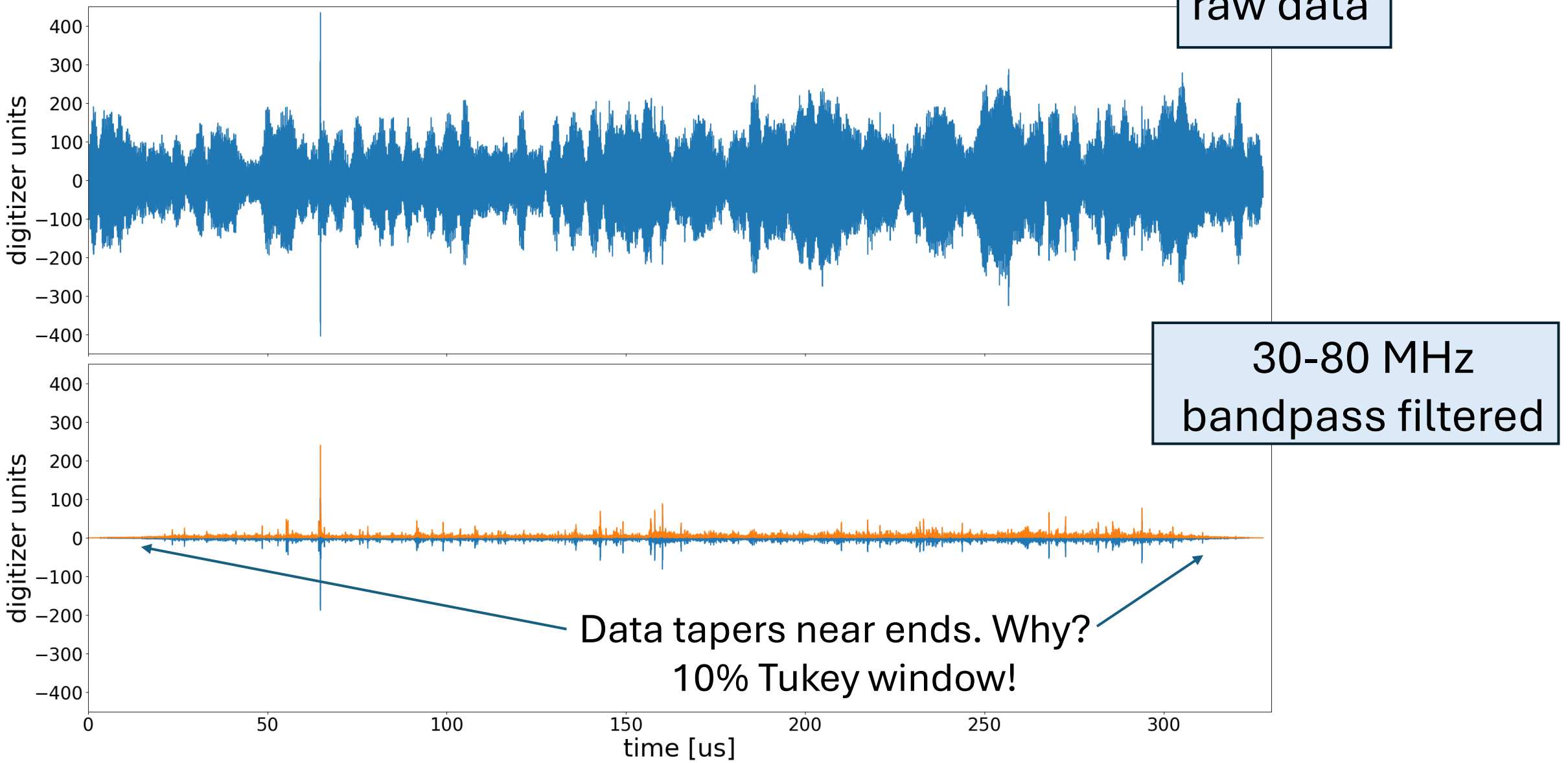
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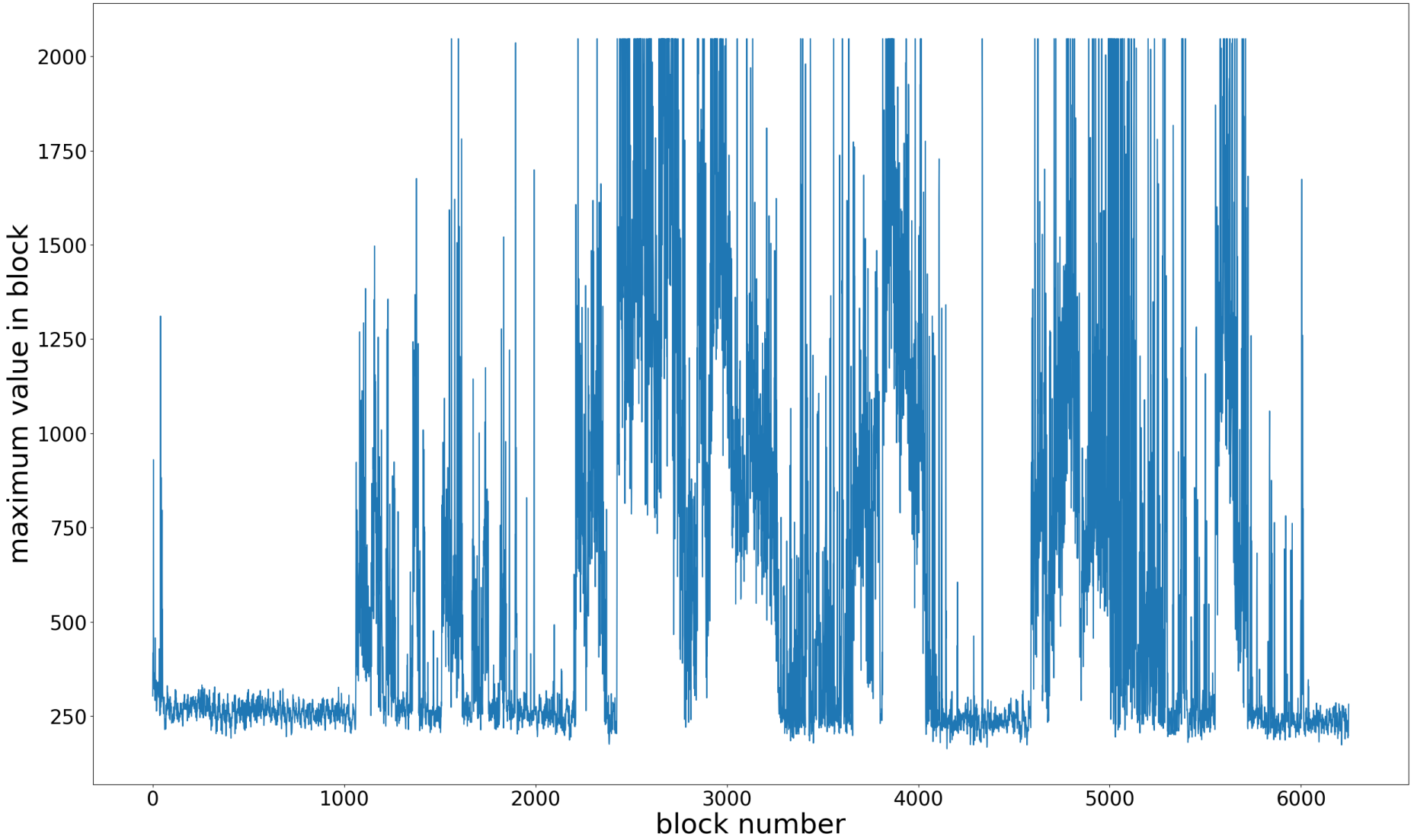
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How do we find the lightning in a datafile?

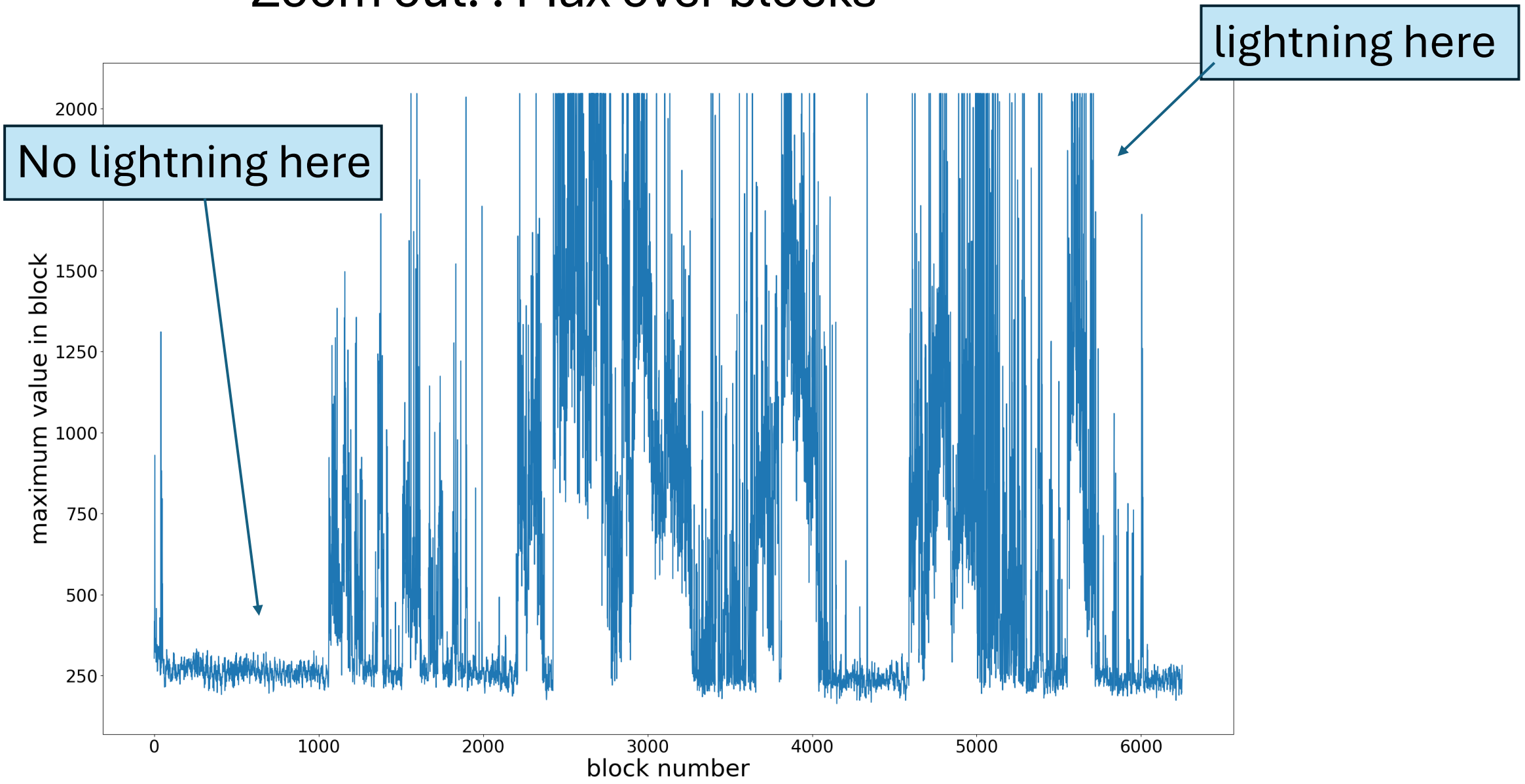
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Zoom out! : Max over blocks



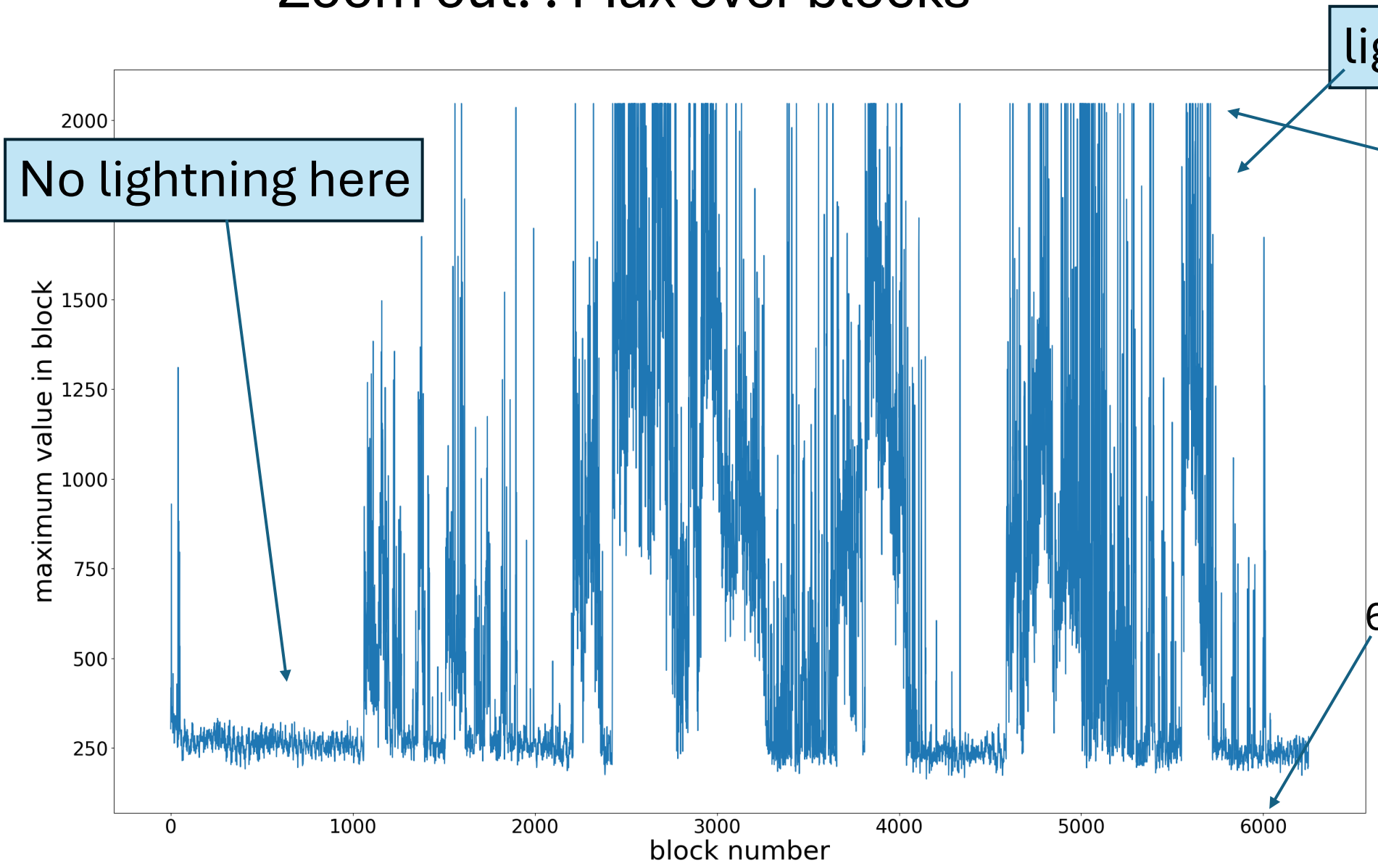
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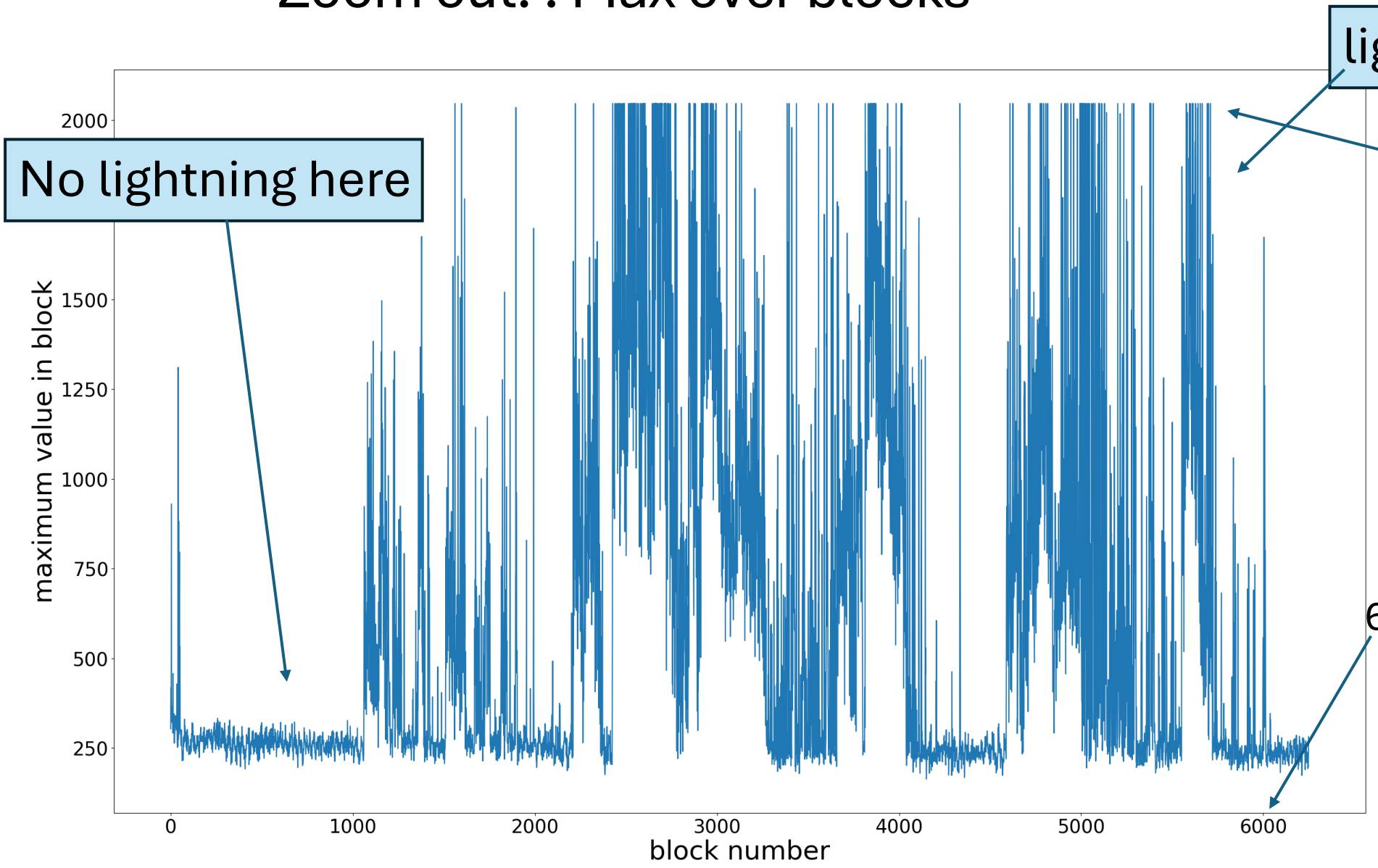
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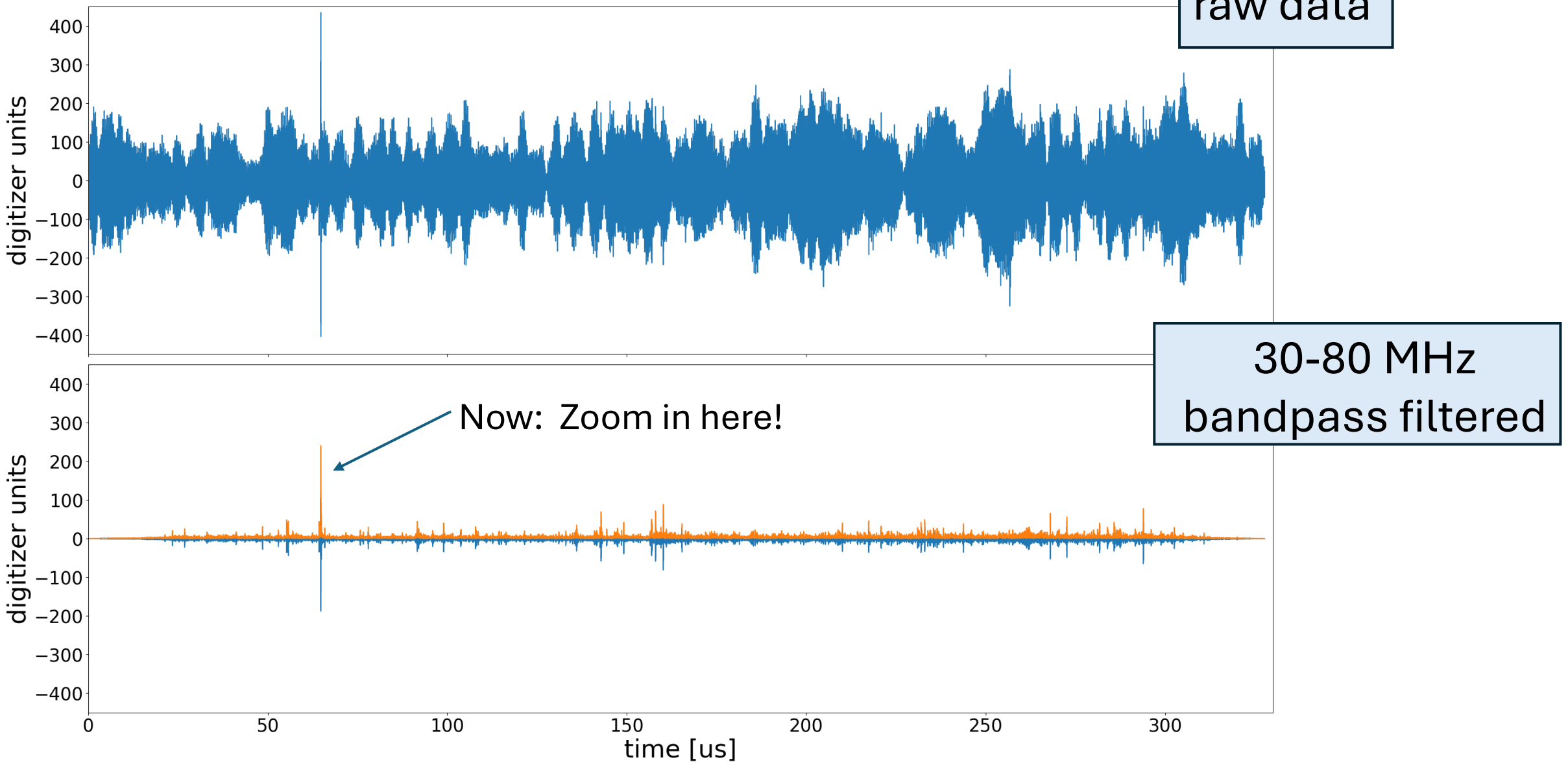
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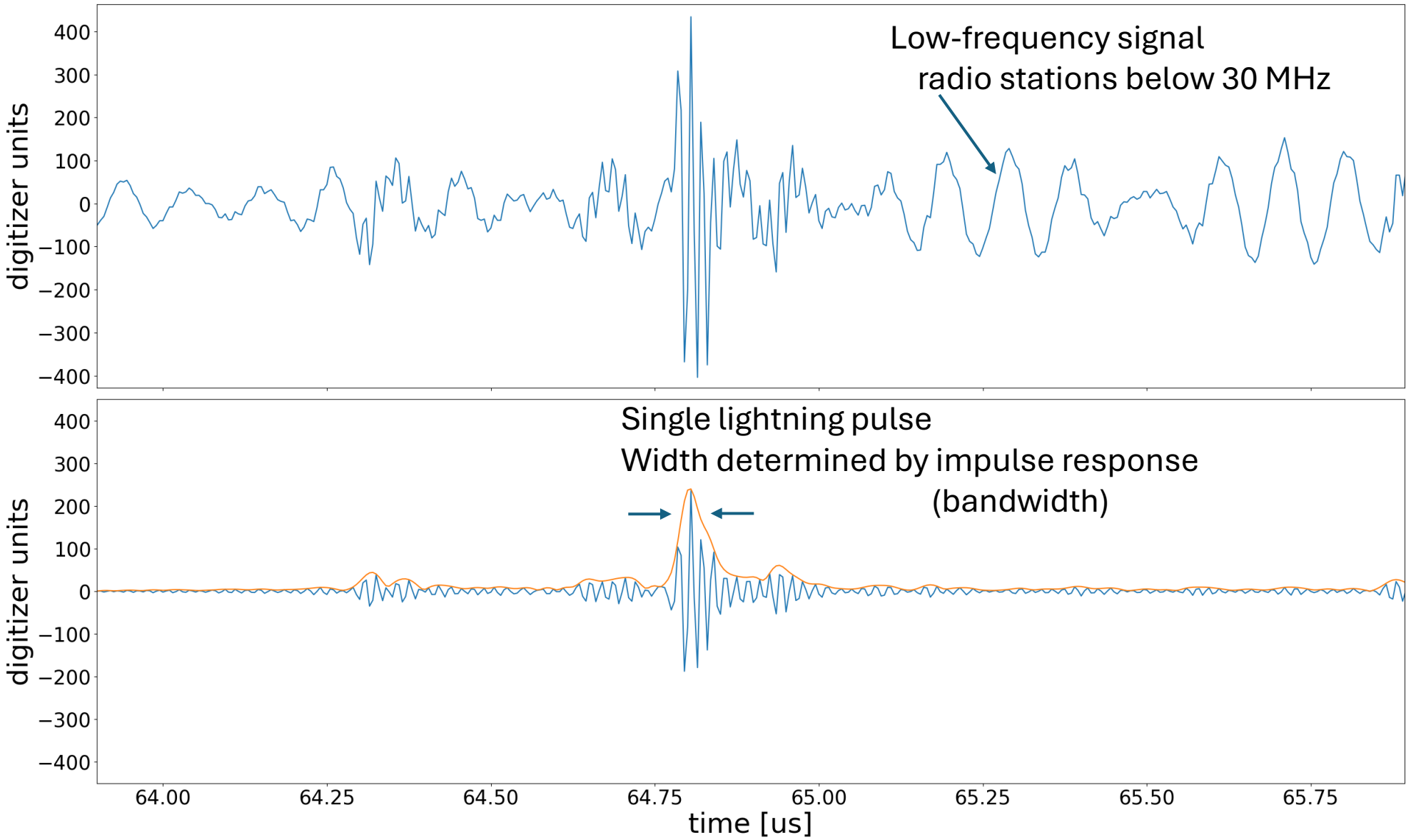


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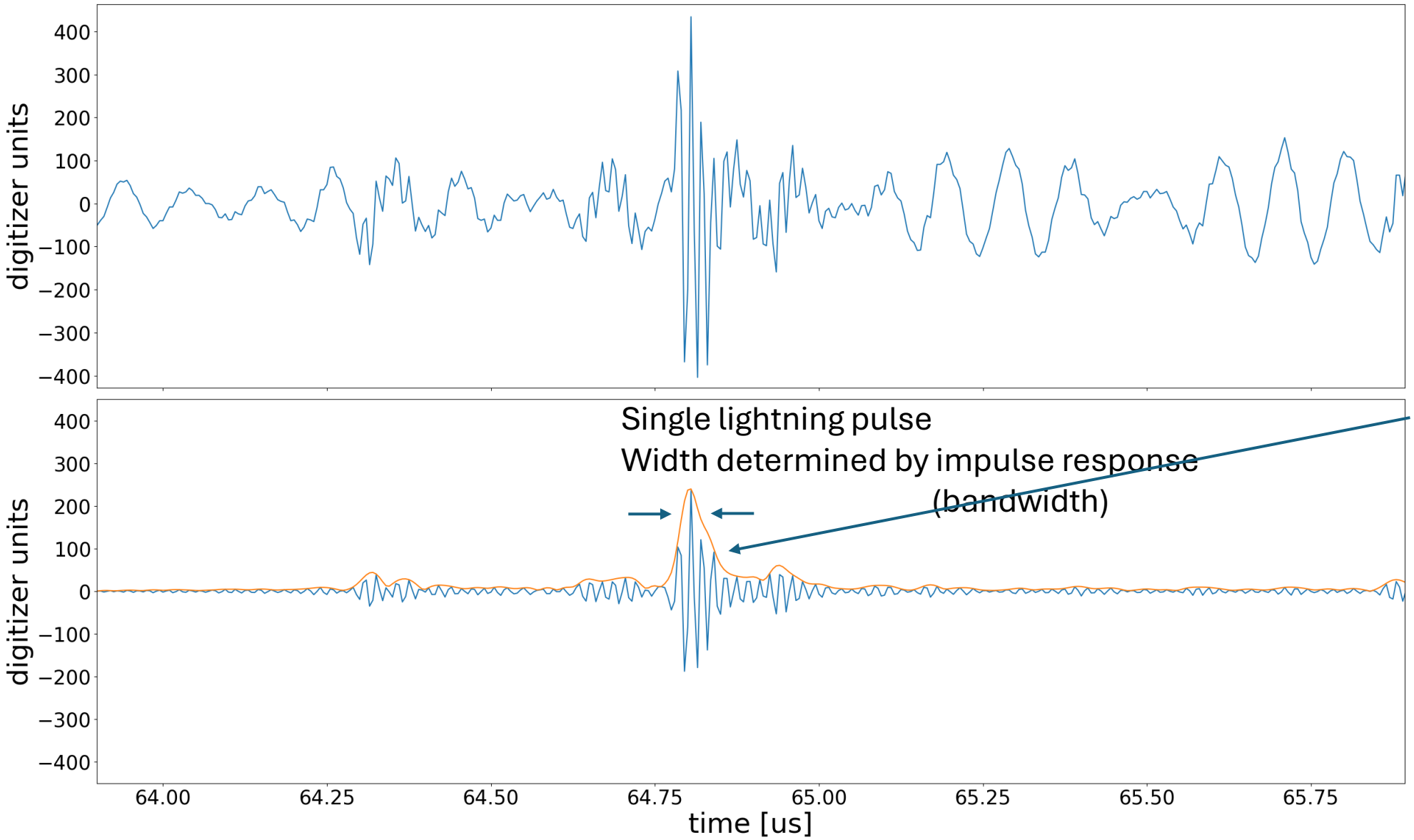
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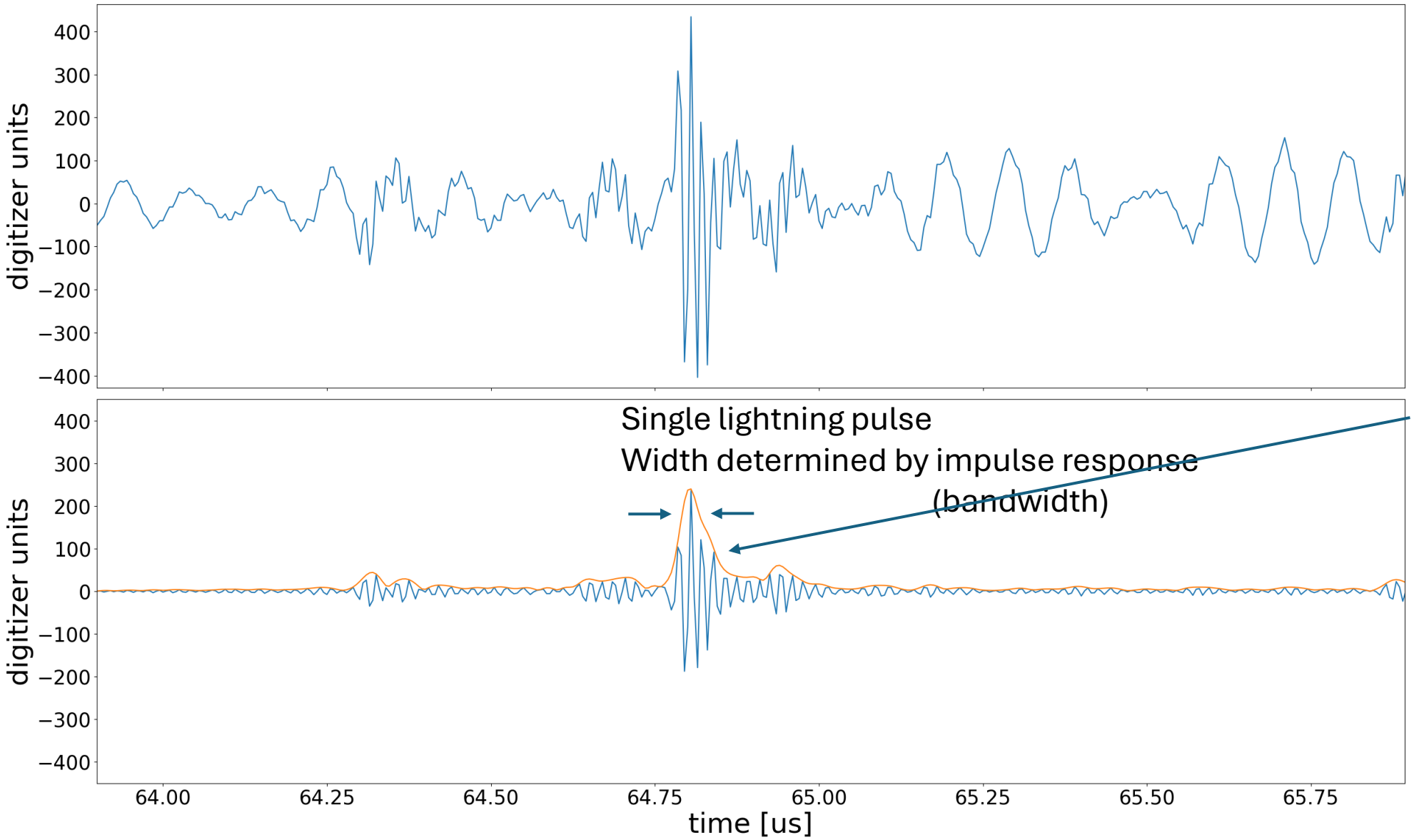
Zoom to a single lightning pulse



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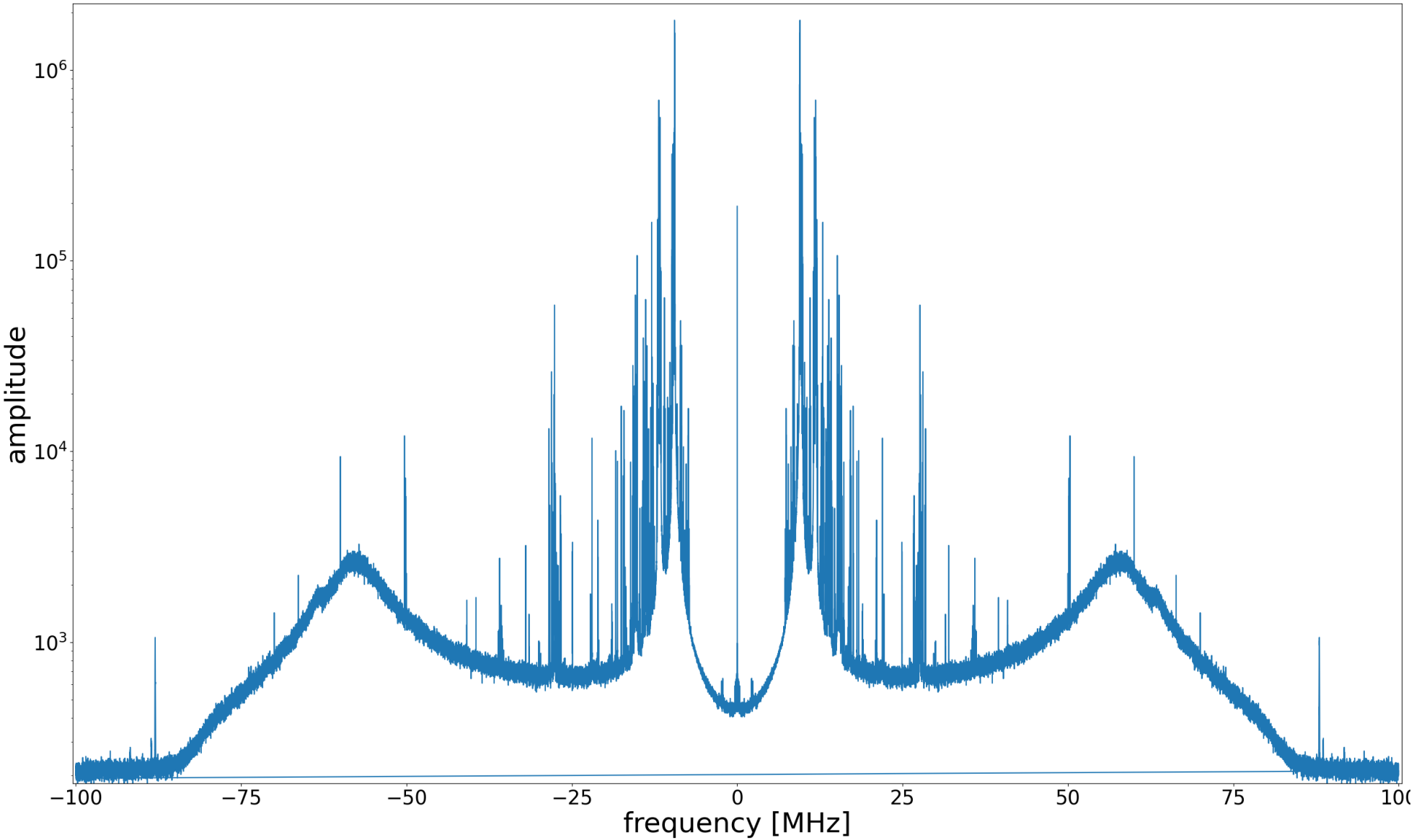


Zoom to a single lightning pulse



Fourier Transform

and Hilbert envelopes



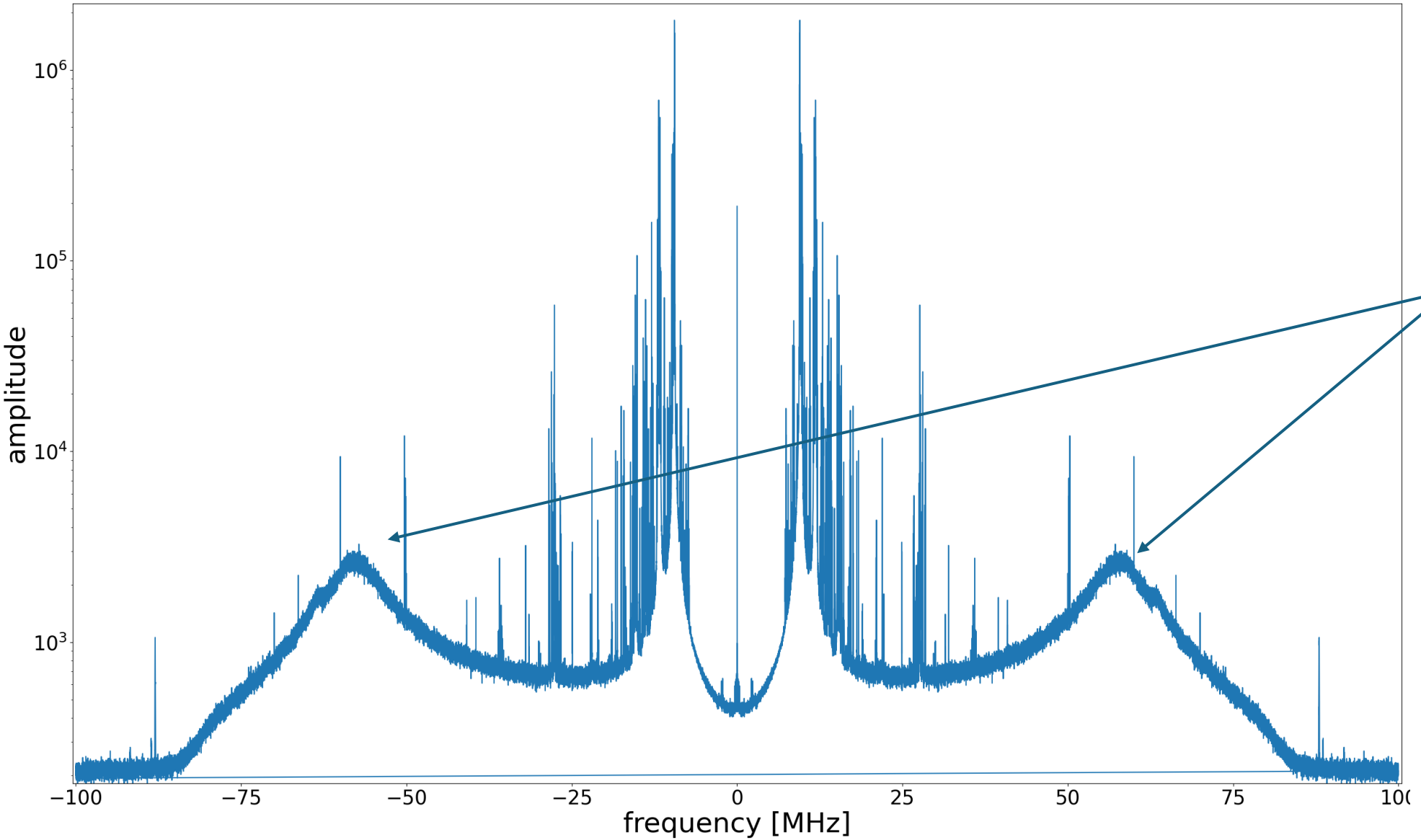
< | FFT | >

Ave. of abs. val. of FFT of many blocks

Why abs. val before average?

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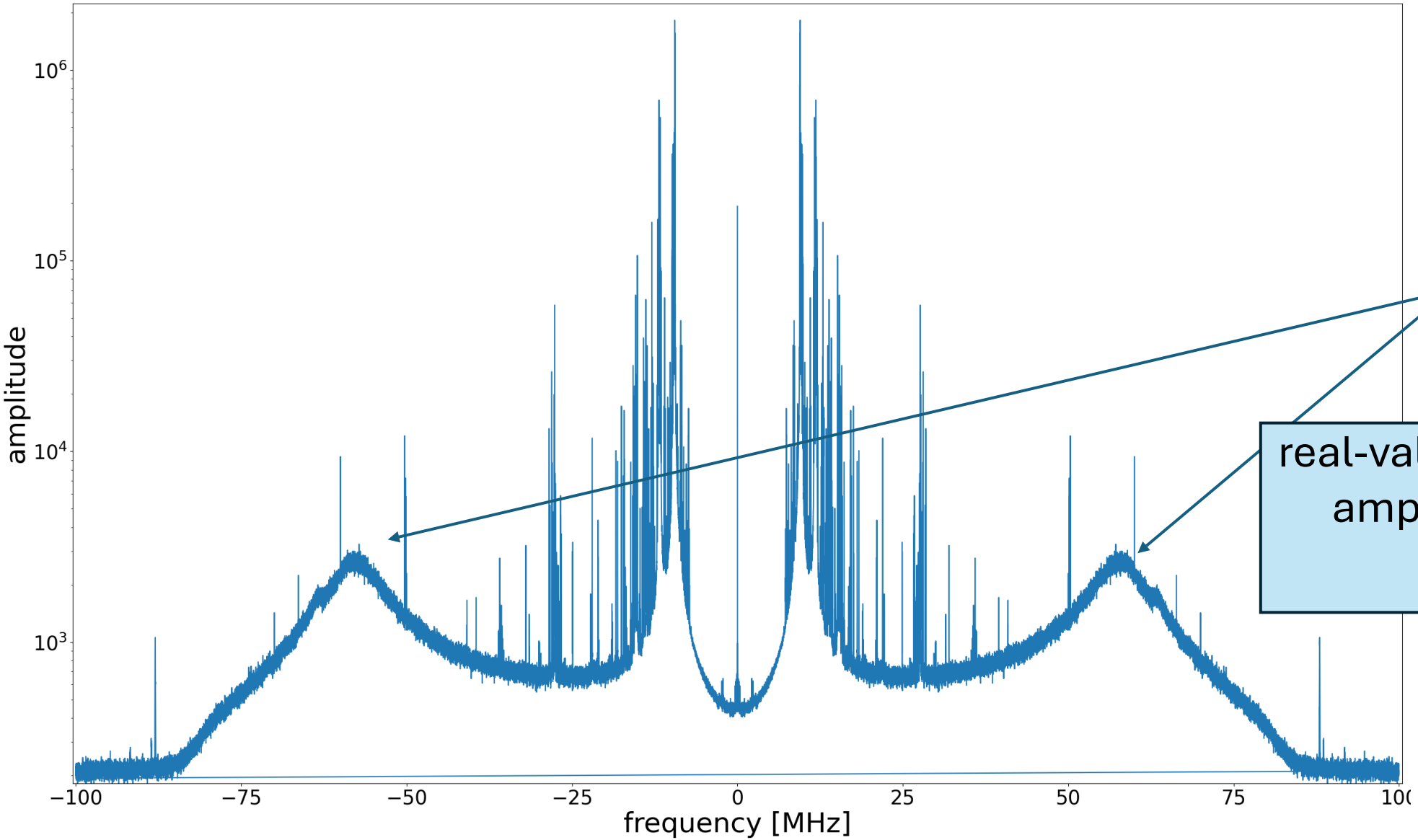
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real-valued data has same amplitude for + and – freqs.



Fourier Transform

and Hilbert envelopes

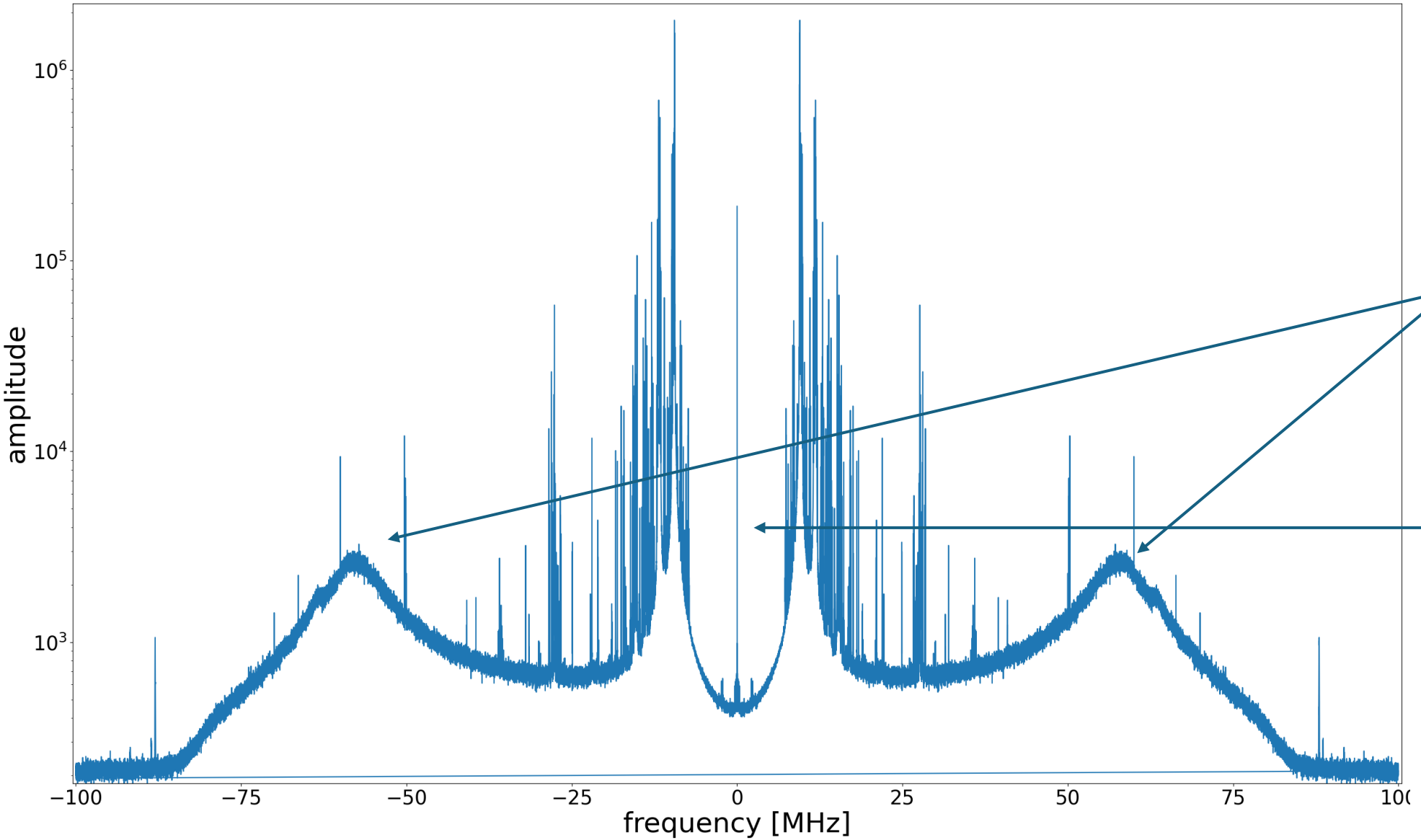
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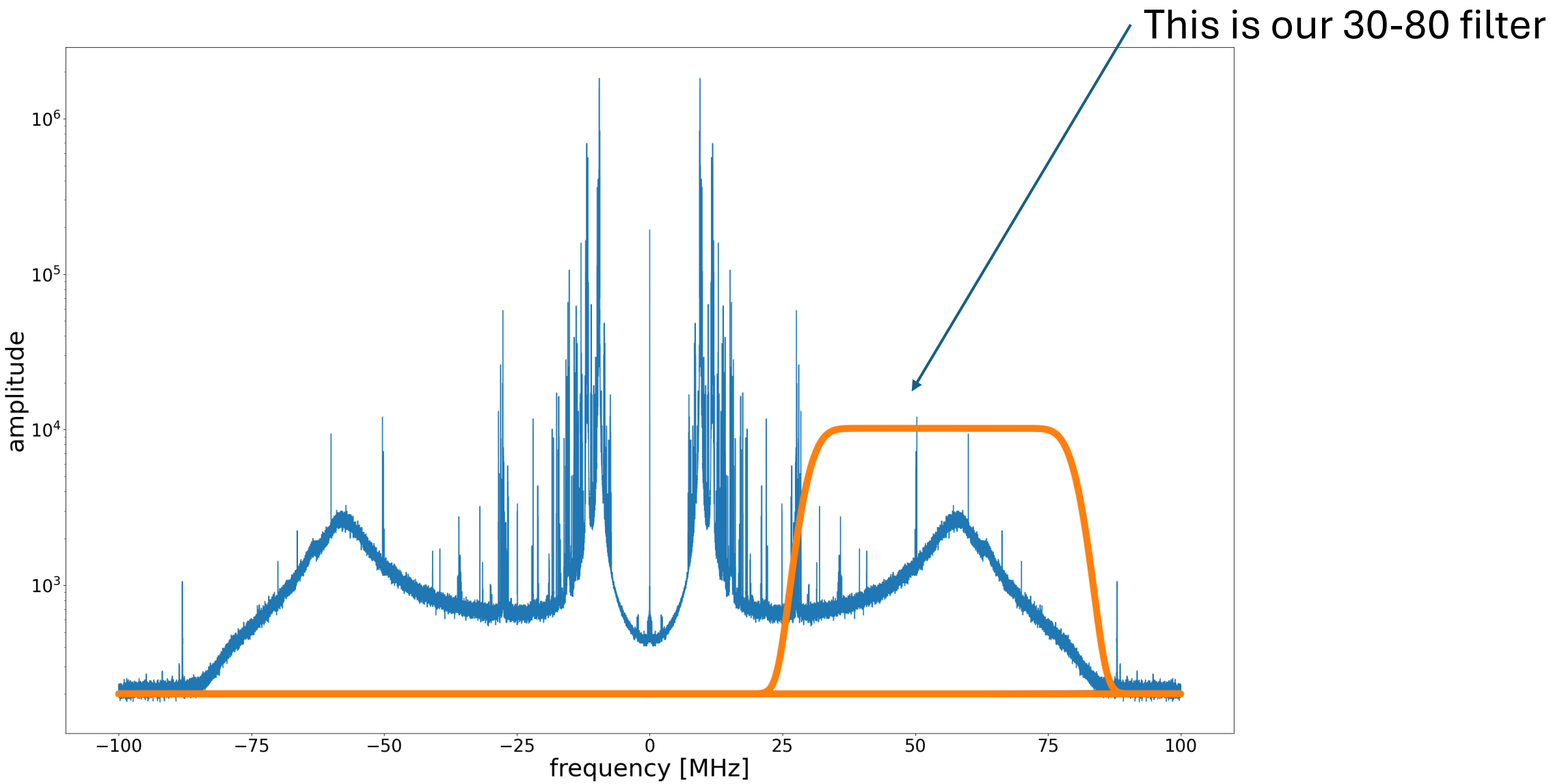
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What does this mean?



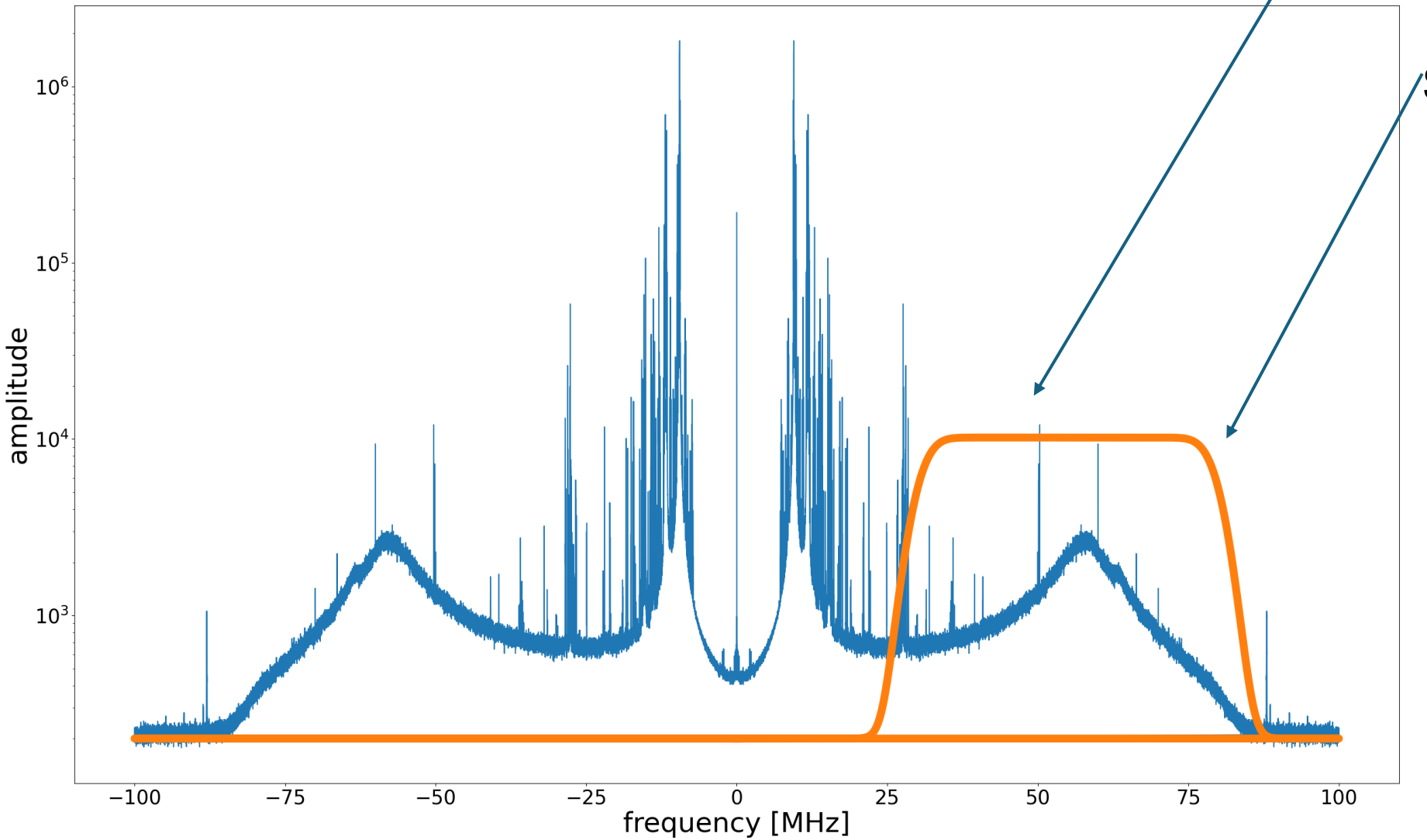
Fourier Transform

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Fourier Transform

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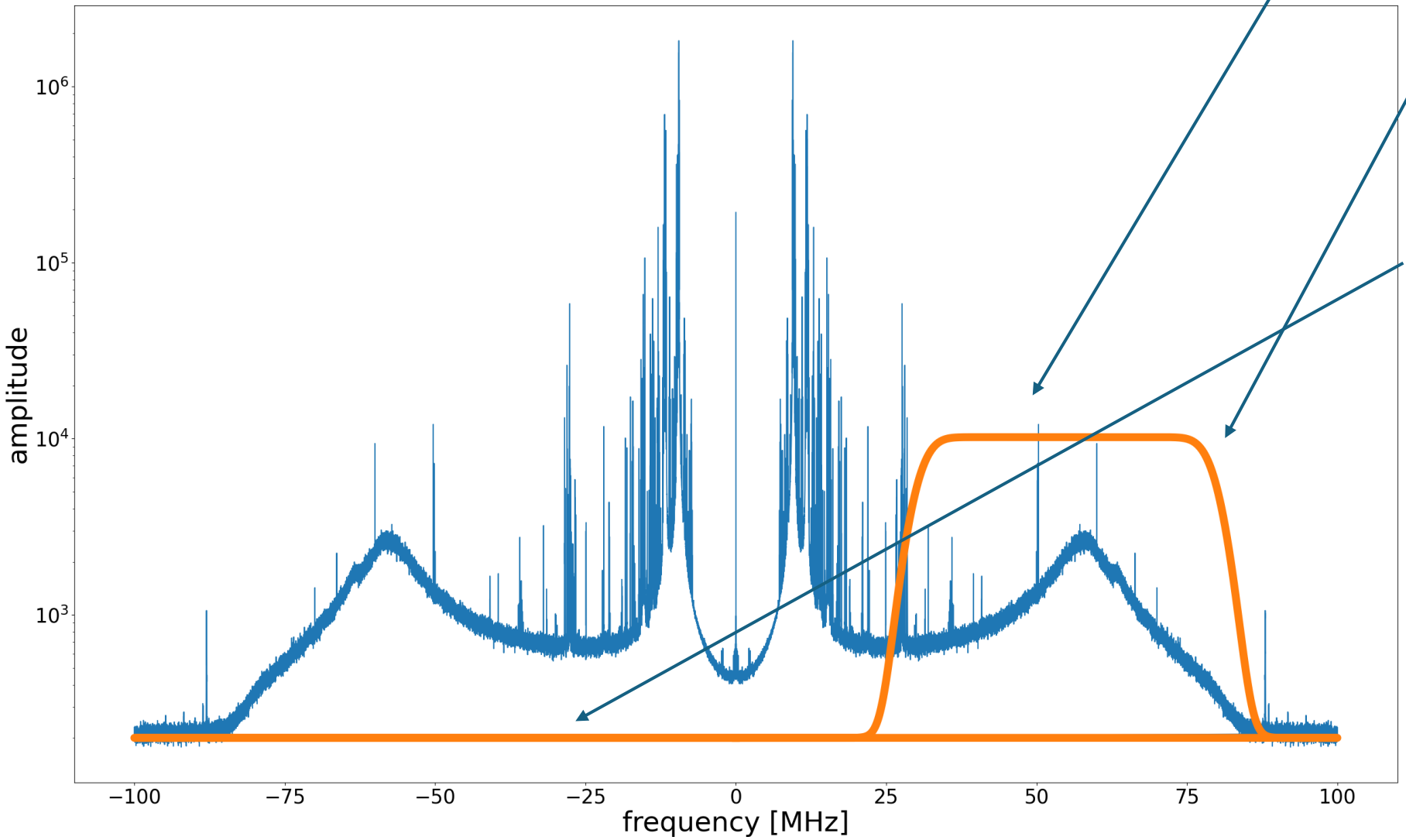
This is our 30-80 filter

Smooth-ish roll-off

why?

Fourier Transform

and Hilbert envelopes



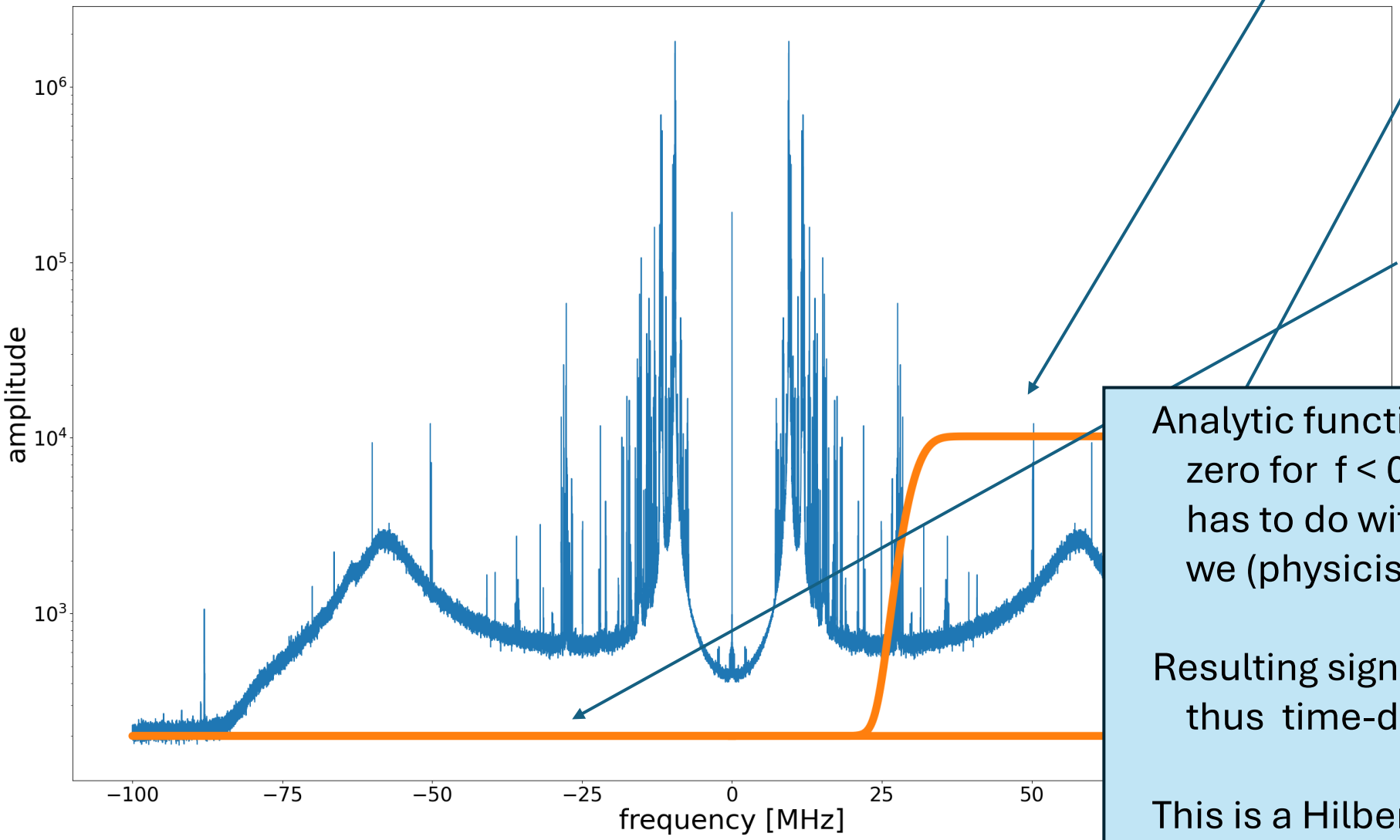
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Zero for freqs. <0
why?

Fourier Transform

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Zero for freqs. <0
why?

Analytic functions
zero for f < 0
has to do with preserving causality
we (physicists) like analyticity

Resulting signal not symmetric around f=0
thus time-domain no longer real-valued

This is a Hilbert transform

Hilbert Transforms

- Reconstruct imaginary component of signal
  - Such that result is an analytic function
  - Analytic functions are easier to work with
  - Also referred as “complex voltages”

    (since normally measured voltage is real-valued)
- Multiple ways to perform a Hilbert transform
  - My favorite: set negative frequencies to zero

- Abs. val. of the analytic signal is then the Hilbert envelope

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Math:

$S(t) = A(t)\, e^{i(2\pi\nu t + \theta(t))}$: analytic signal

$A(t)$: pos. real-valued amplitude

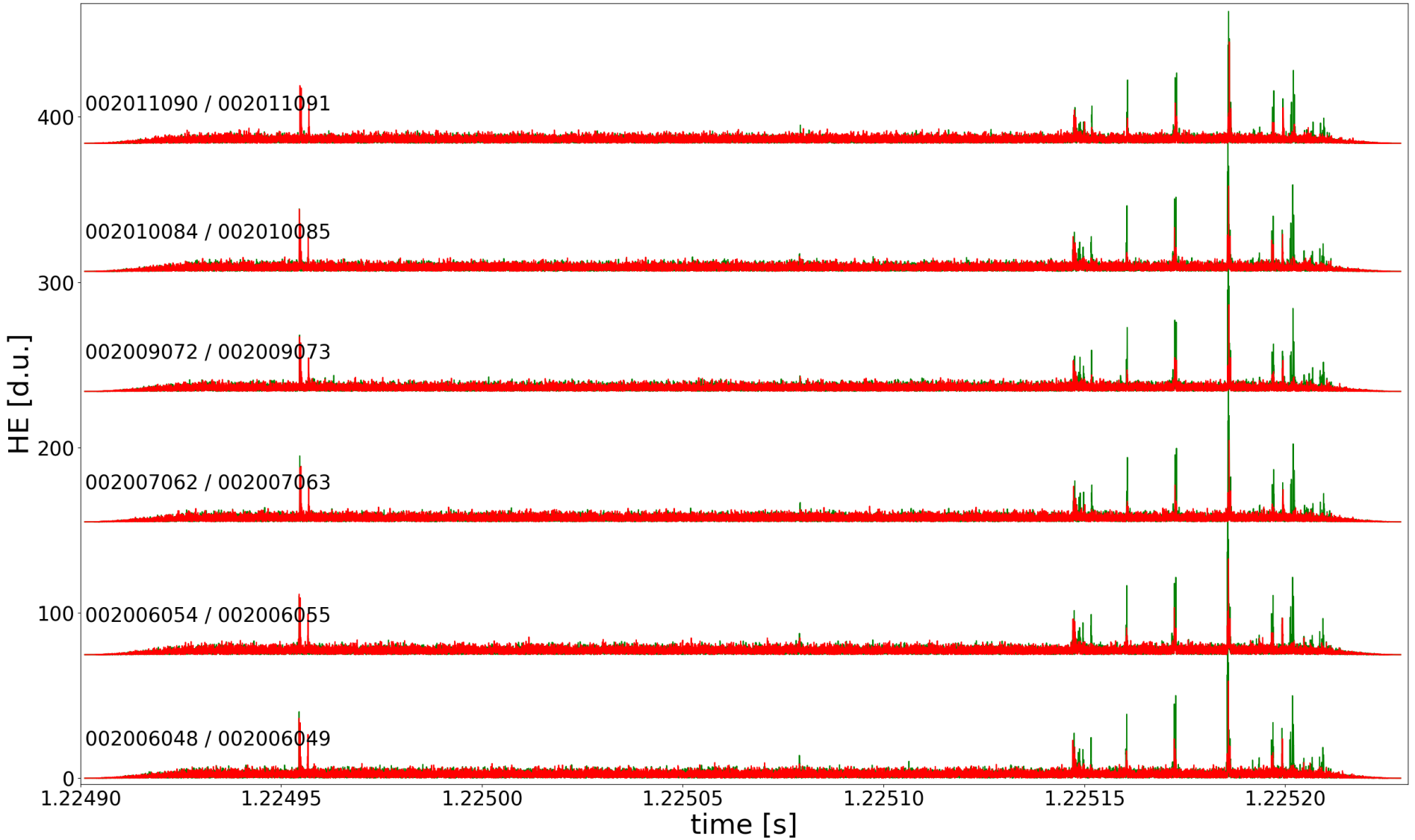
$\theta(t)$: phase

Thus:

$|S(t)| = |A(t)| \;\; |\, e^{i(2\pi\nu t + \theta(t))}| = A(t)$

Many antennas, H.E. only

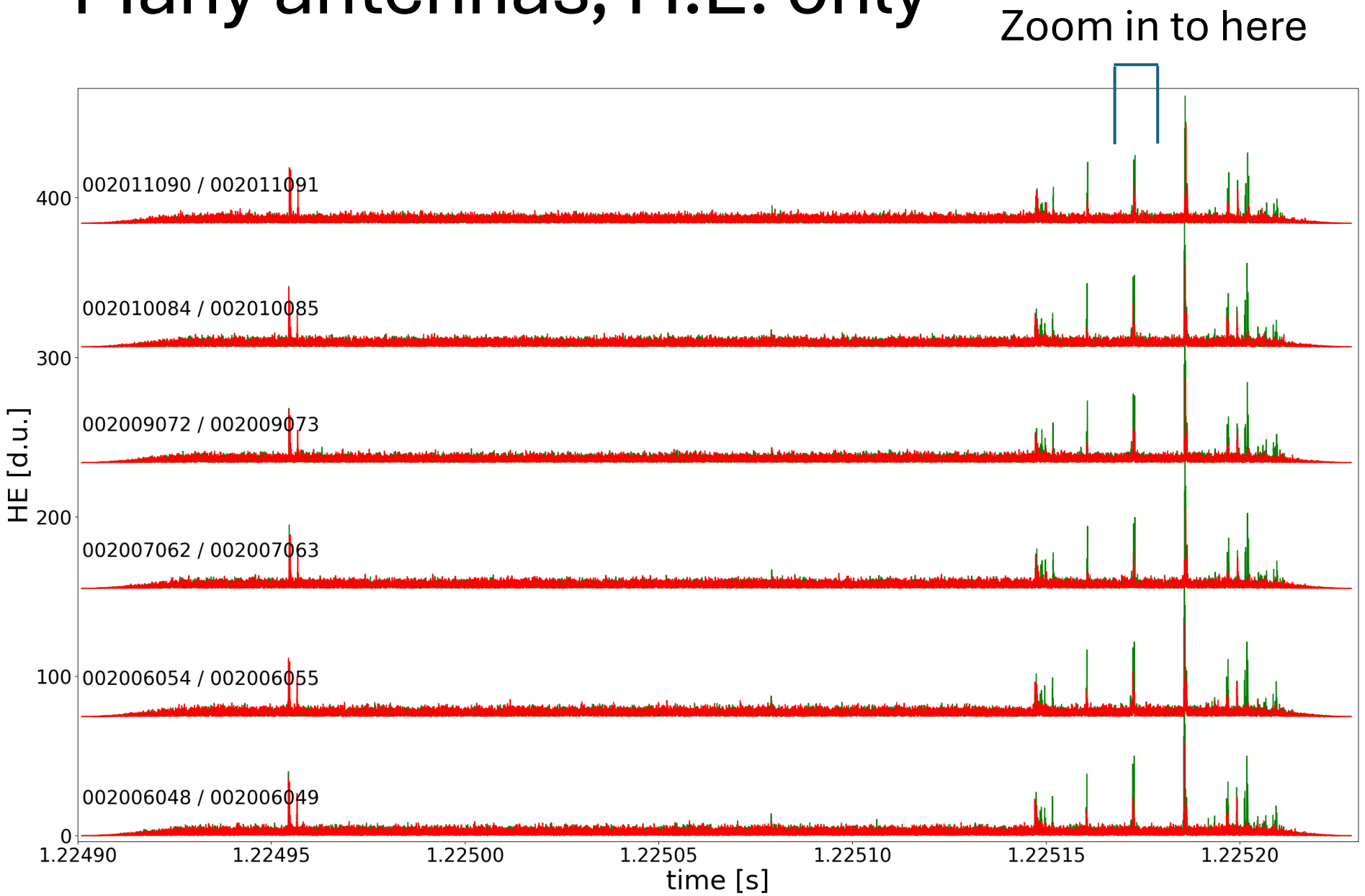
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6 LBA, CS002

red vs green
Y vs X dipole

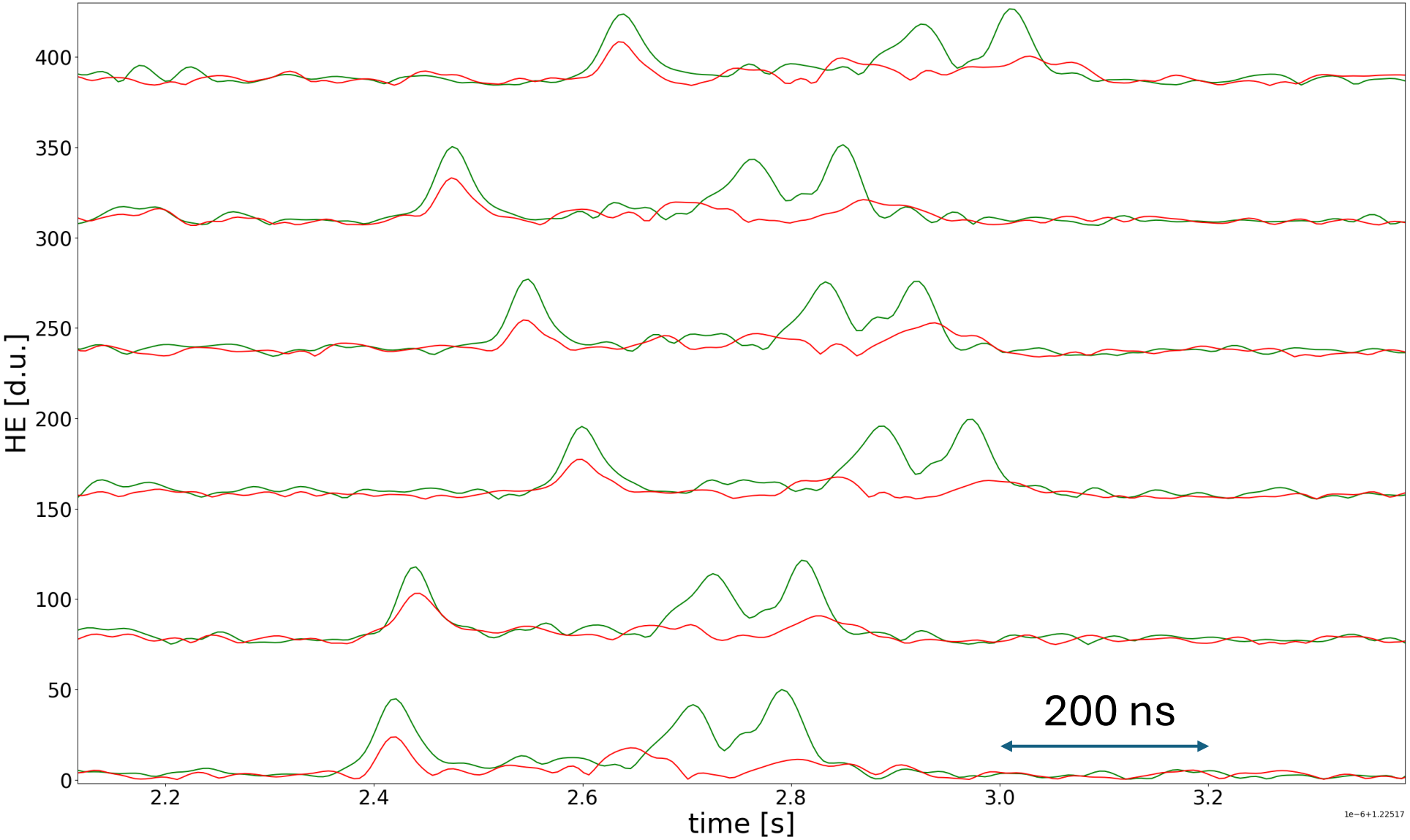
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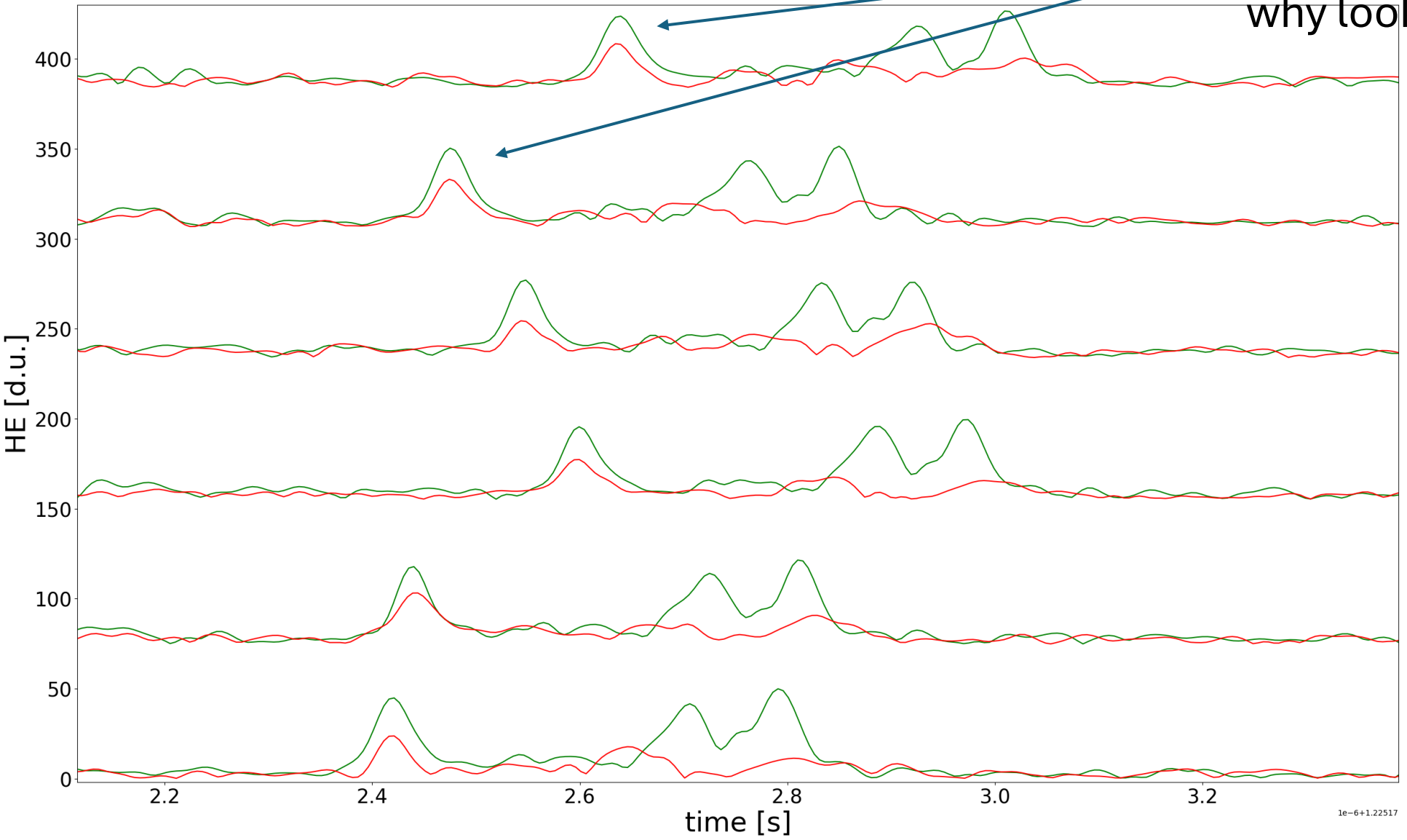
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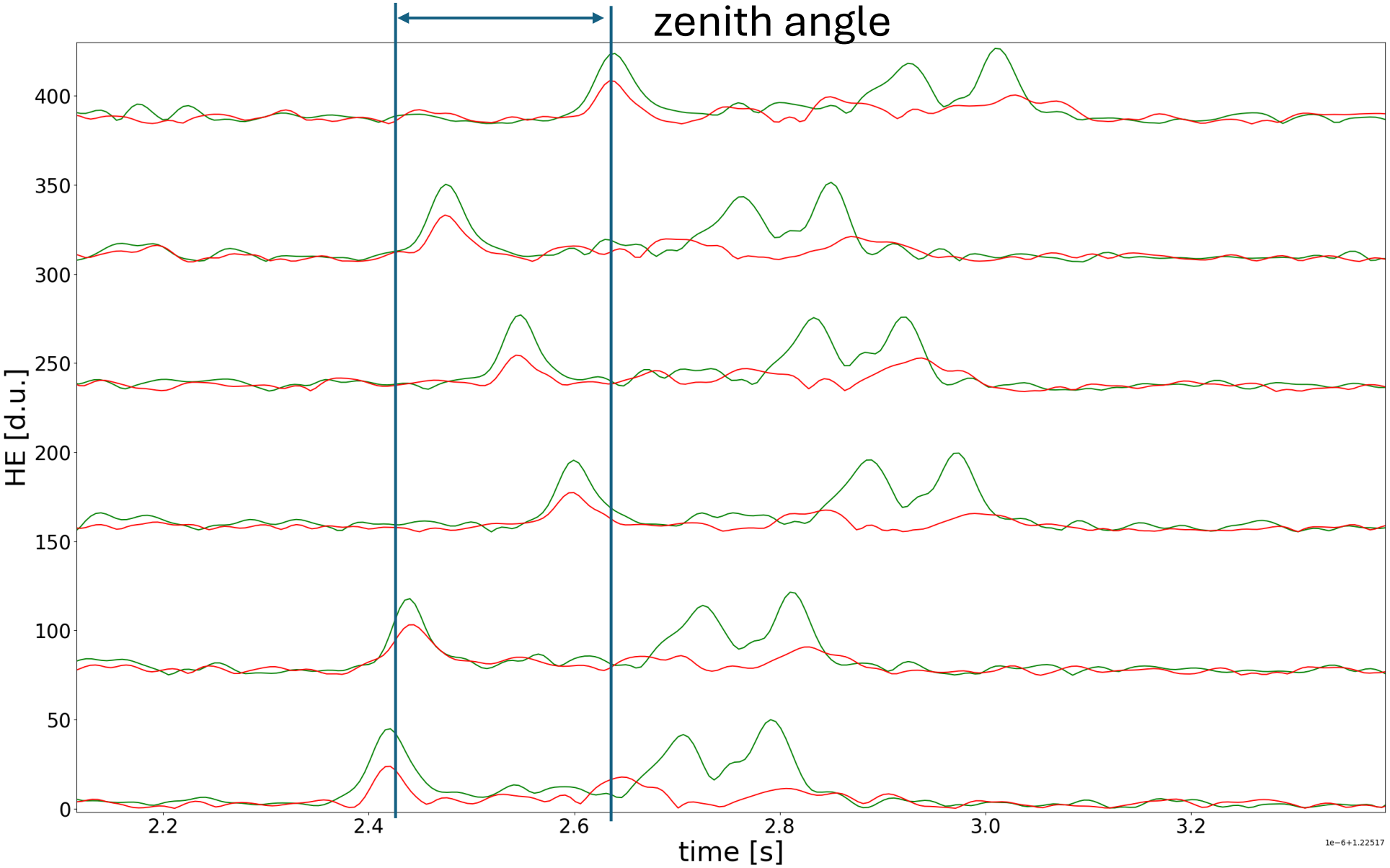
Many antennas, H.E. only

Why do pulses change time?
why look like a sin ?

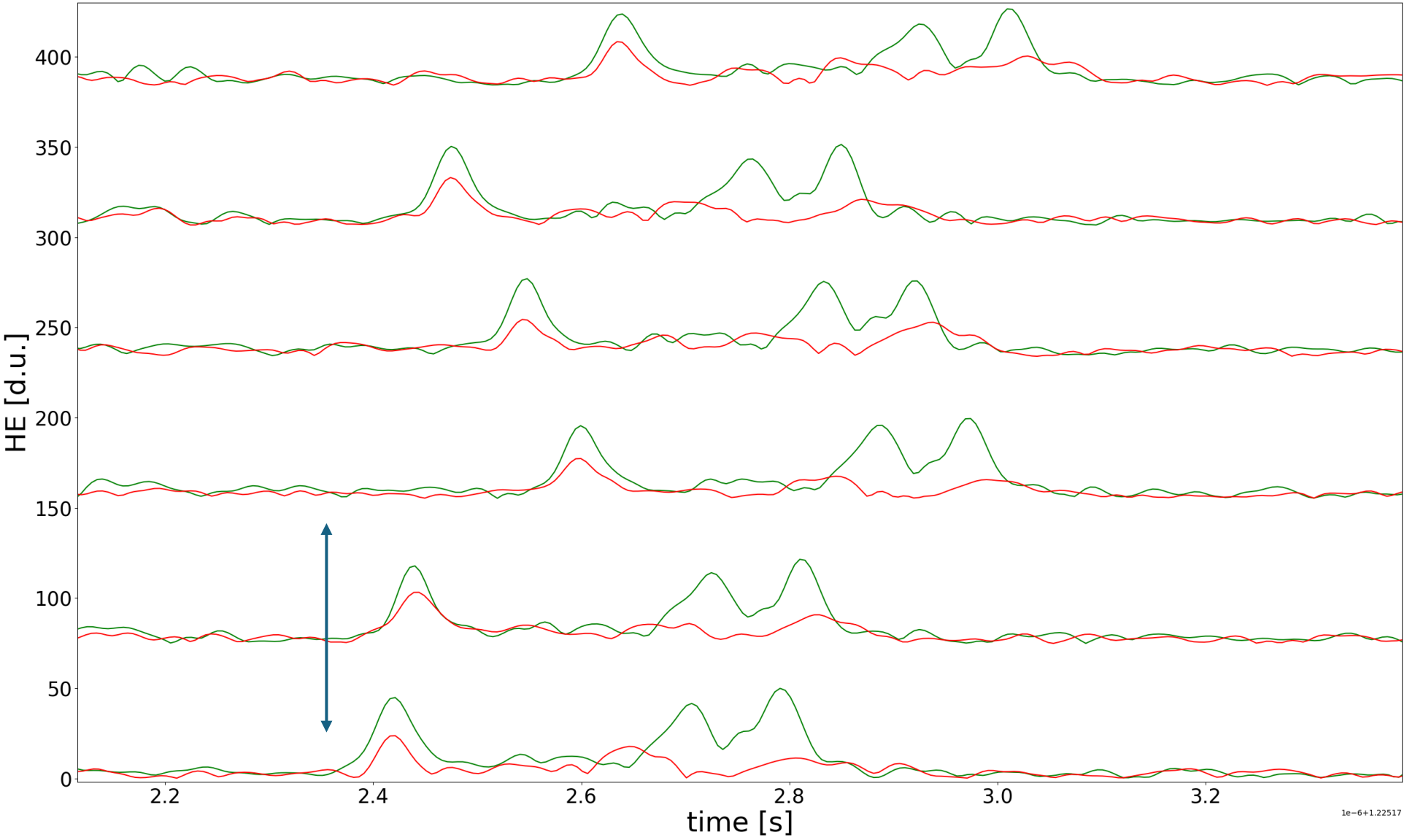


Many antennas, H.E. only

Max difference (amplitude) proportional to signal zenith angle



Many antennas, H.E. only



Earliest (phase) gives azimuth angle

Conclusion

- Explained what TBuffs are
- A few simple signal analysis techniques
- Simplest method to find direction to a signal