Summer 2019 Report

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Abstract

In Summer 2019, I was supervised by Ue-Li Pen, at the University of Toronto, as part of the 16-week SURP program, funded by NSERC and CITA. I worked on analysing baseband data with the main goal of descattering FRBs.

Contents

1 Introduction

1.1 Descattering [1]

When we observe pulses, they are scattered by the interstellar medium (ISM). Descattering is a tool to remove such propagation effects from the data. It relies on three main assumptions.

1. The observed data, E_{obs}, is a convolution of the intrinsic pulse of the source, E_{int}, and the impulse response function of the ISM, g. The goal of descattering is to isolate the intrinsic pulse.

To get the intrinsic pulse, we define a trial and reference pulse and take their Fourier transforms. We then need to assume that

2. The trial and reference pulse have (approximately)the same impulse response function g. This implies that these two pulses should be as close to one another in time as possible.

3. The reference pulse is impulsive (delta function-like).

Then, taking the Fourier transform, by the convolution theorem:

$$\tilde{E}_{obs} = \mathcal{F}\left(E_{obs}\right) = \mathcal{F}\left(E_{int} * g\right) = \tilde{E}_{int}\tilde{g}$$

Thus, upon defining a trial and a reference pulse, we may divide them out, and if the assumptions hold, we get:

$$\frac{\tilde{E}_{obs}^{trial}}{\tilde{E}_{obs}^{ref}/|\tilde{E}_{obs}^{ref}|} = \left(\frac{\tilde{E}_{int}^{trial}}{\tilde{E}_{int}^{ref}/|\tilde{E}_{int}^{ref}|}\right)\left(\frac{\tilde{g}^{trial}}{\tilde{g}^{ref}/|\tilde{g}^{ref}|}\right) = \tilde{E}_{int}^{trial}|\tilde{g}|$$

Before attempting descattering, an important step is to first correlate the trial and reference pulses: If they do not correlate, we know descattering will not work, because it means that g is too different in each pulse, and thus our second assumption does not hold. Robert Main et al. showed in their paper that the correlation decreases as a function of δt between the

trial and reference pulses (Figure 5 in [1]).

Here is the result of the descattering of a giant pulse from B1957+20:

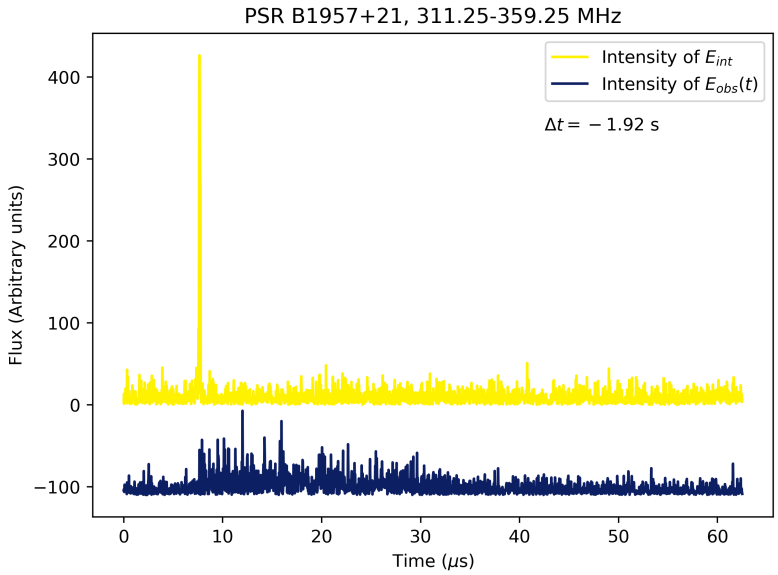

Figure 1: In blue is the scattered giant pulse of PSR B1957+20. In yellow is the descattered pulse. The data is from Arecibo.

When it comes to descattering FRBs, the idea was to use different parts of the FRB pulse as the trial and reference pulses. This implies, first and foremost, that to see a correlation between the trial and reference, one would have to be a copy i.e an echo of the other. This, on its own, is already a very important discovery. Echos were never observed in FRBs until now.

2 Methods

2.1 Baseband Derotation

CHIME baseband data comes in two polarisations. Since the data comes in as a timestream, the polarisations get mixed due to various effects. First of all, the polarisations get mixed during propagation due to Faraday Rotation. Next they get mixed due to the difference in

length of the polarisation cables (cable delay). We can correct the data for these effects and then most of the pulse will end up in one of the two polarisations.

2.2 Correlation

There are many different ways to correlate. We can dechannelize baseband data by taking the inverse FT and then correlate the resulting timestreams. We can also correlate every frequency channel and obtain a correlation waterfall. Each of these methods deliver a different message about the data.

It is only after correlation is seen that we can try descattering.

For step by step methods, refer to the following pages for: polarisation derotation, and correlation.

3 Results for Events 32328347 and 25281508

3.1 Event 32328347

I first derotated the baseband data with $RM = 30.919$. The detailed plots can be found here.

This FRB is heavily scattered and very bright. It has 2 peaks in addition to the main peak, which we knew were very unlikely to be echos. As expected, we found no correlation between the subpulses. All the correlation plots can be found here. Since there is no correlation, there is no point running this data through the descattering code (althought I did, with no results. I did not save the plots).

This pulse was mainly used as a second test that everything works.

3.2 Event 25281508

This FRB has 4 peaks, which makes it an interesting candidate for descattering as some of those pulses could be echos.

This FRB's DM was a bit overcorrected. I first had to fix the DM with a correction of -0.069. The correction is done by maximising the first eigenvalue of the SVD of the data. Details can be found here.

The next step is derotation, which was done with $RM = -67.261$. Results and details can be found here. The next step is correlation. It seems like a weak correlation does indeed exist. It is very unlike the other flat correlations from the other FRB or other subpulses for this FRB. All the correlations for this FRB can be found here.

Here is the intensity of Event 25281508 after DM correction. We define the pulses as such:

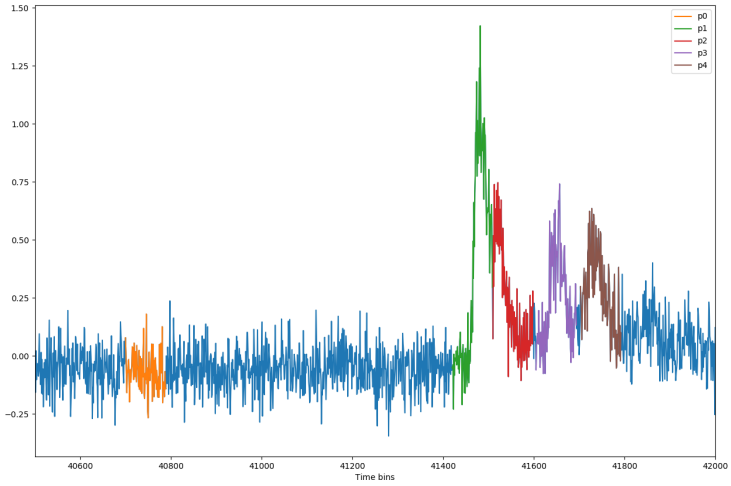

Figure 2: I thought P2 might be an echo of P1, but a more likely scenario seems to be that P1 and P2 are in fact one double-peaked pulse and the following pulses might be its echo.

All correlations were flat except the imaginary part of P1 and P2 correlated with P4, where we see a faint double bump:

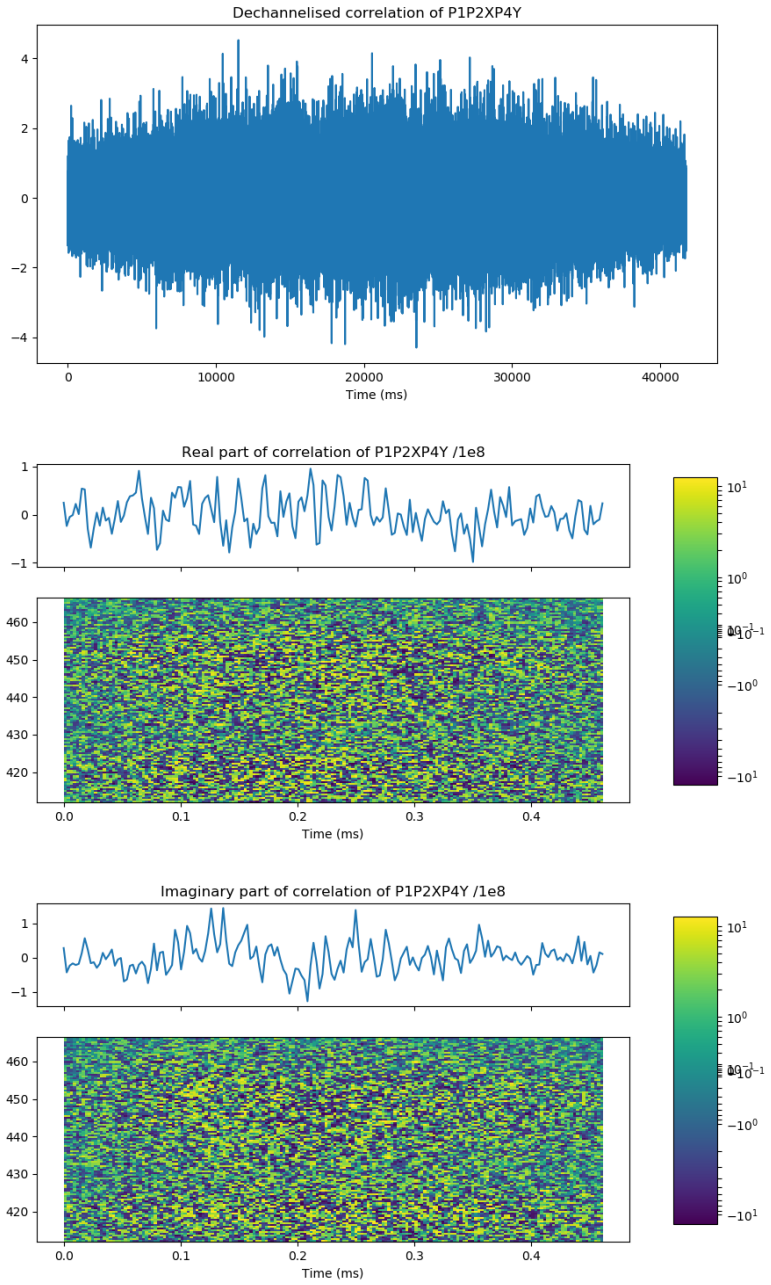

Figure 3: The timestream correlation seems to be flat. The real part of the frequency-wise correlation is flat on average, but in the waterfall, notice very bright diagonal strikes around 0.1 and 0.3 ms. The imaginary part clearly shows two bumps, a pattern no other correlation seems to exhibit.

4 Discussion

This project mainly allowed for the developement of the pipeline that produces all of these plots. The promising result observed with event 25281508 might be turned into something more useful if we clean the data as much as possible and increase signal to noise. This FRB is proof that this project is not completely crazy but that there is real hope in finding what we're looking for.

5 Conclusion

Currently, there are tons of baseband data that waits to be processed. During this upcoming year, I will process data regularly to find more such suitable candidates to run the pipeline on.

References

[1] R. M. et al., "Descattering of giant pulses in psr b1957+20," 1703.05176, 2017. 1, 2

A Appendix