FAST RADIO BURST SEARCH ALGORITHM

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What’s FRB?

FRB ,Fast Radio Burst is a high energy physical phenomenon happened in our universe.

- Happened suddenly
- High Energy

How do we detect FRB?

PROPERTY OF FRB

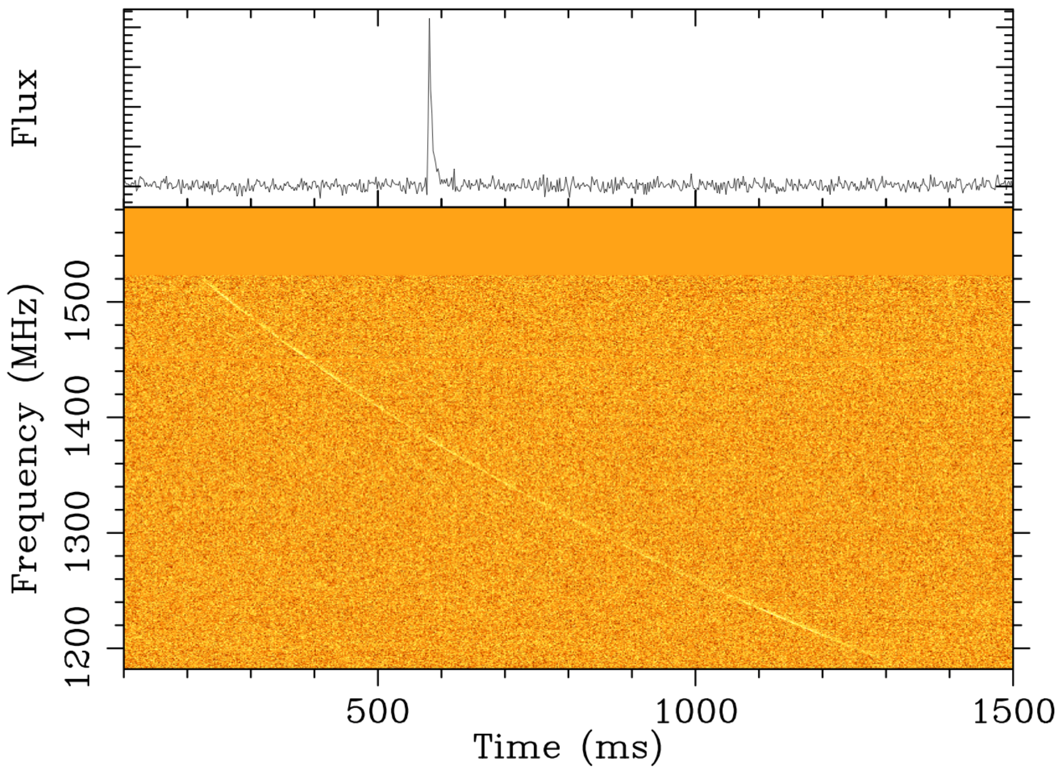
- Dispersion
- Scatter
- Scintillation

DISPERSION

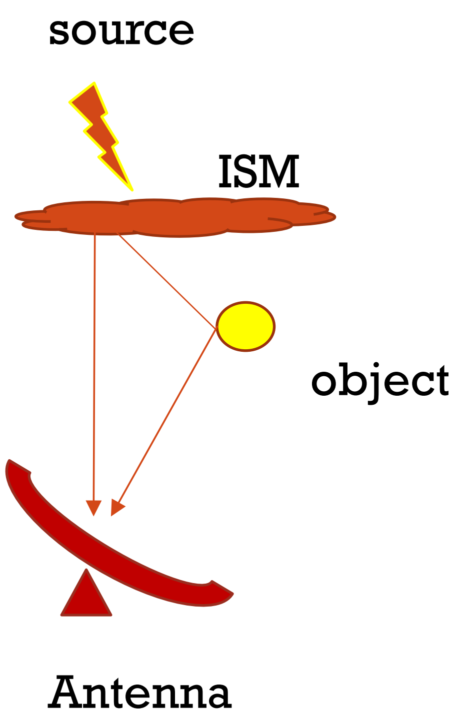
Dispersion Measure:

$$DM = \int_0^d n_e dl$$

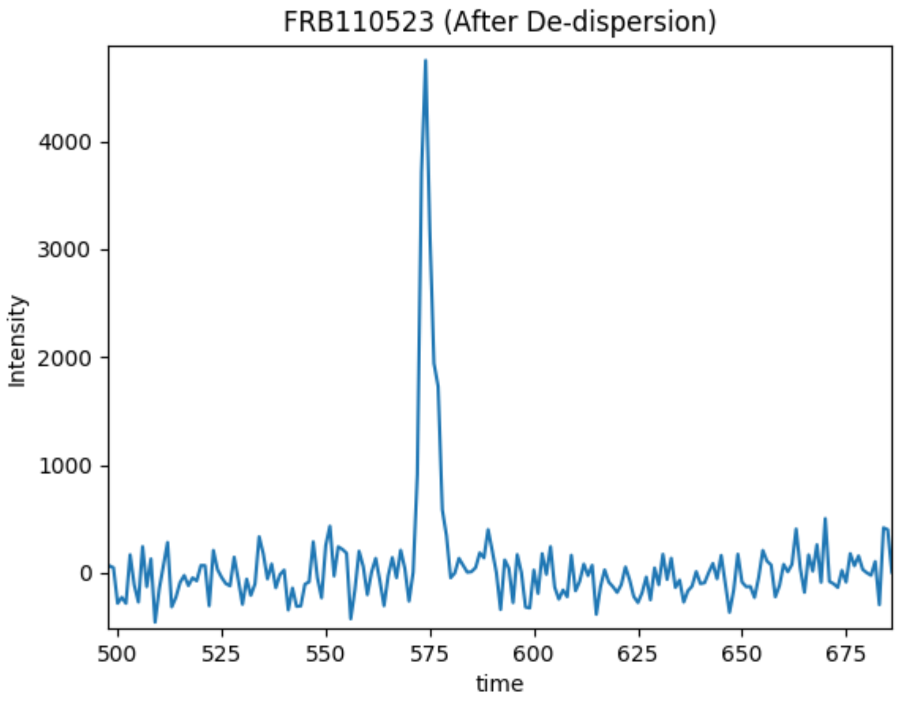
$$\Delta t = 4.15 \times 10^{-6} \text{ms} \cdot DM \times (f_{ref}^{-2} - f_{chan}^{-2})$$



SCATTER

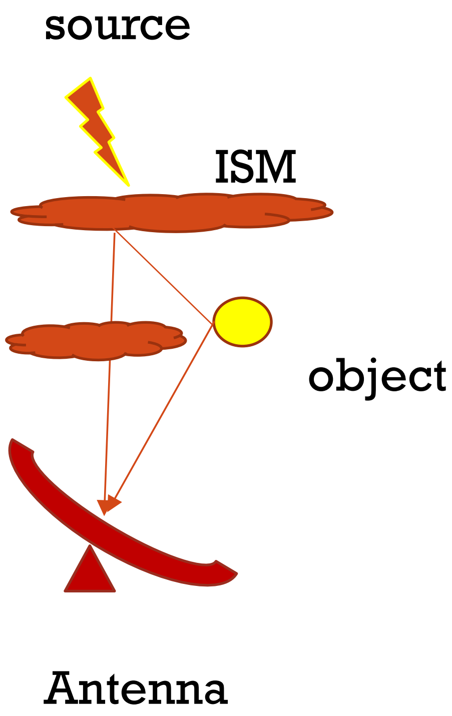


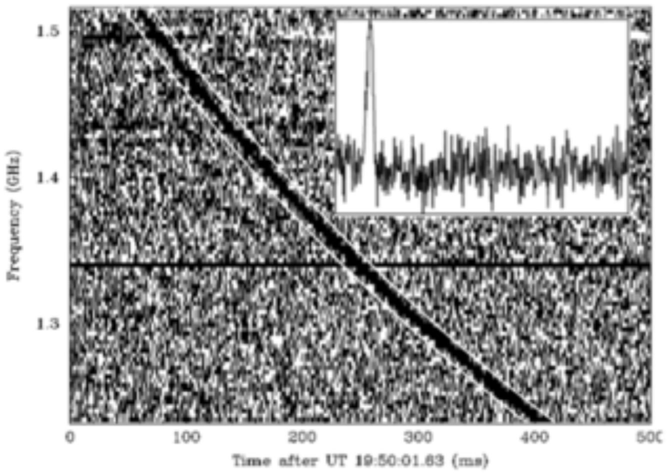
source
ISM
object
Antenna

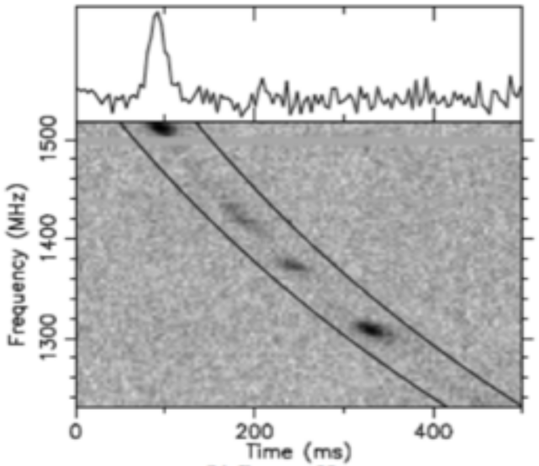


FRB110523 (After De-dispersion)
Intensity
time
4000
3000
2000
1000
0
500
525
550
575
600
625
650
675

SCINTILLATION

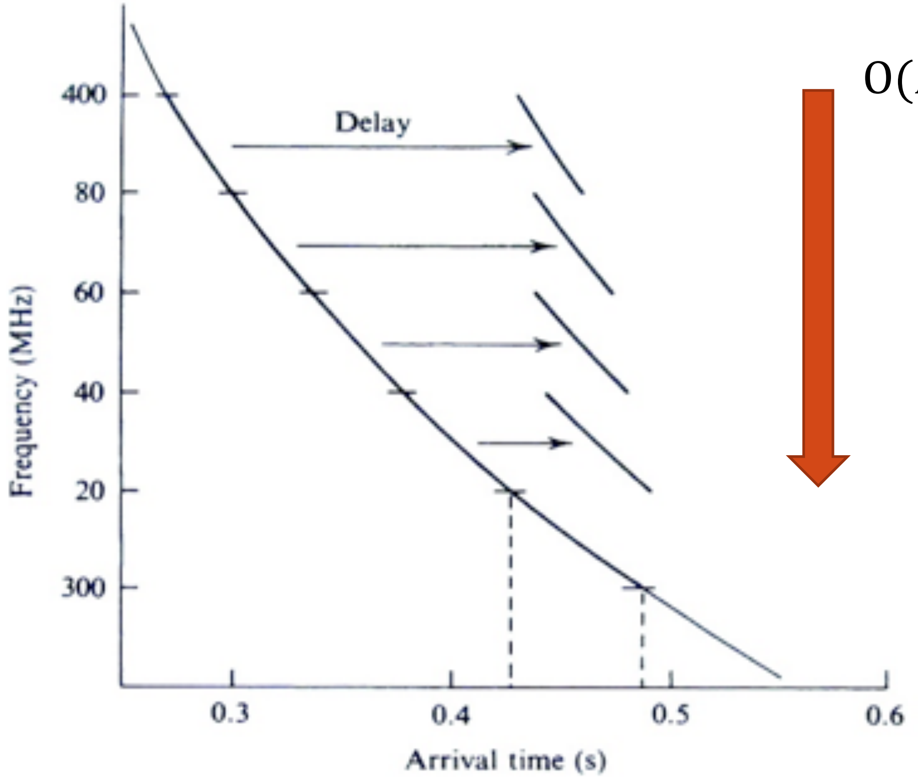






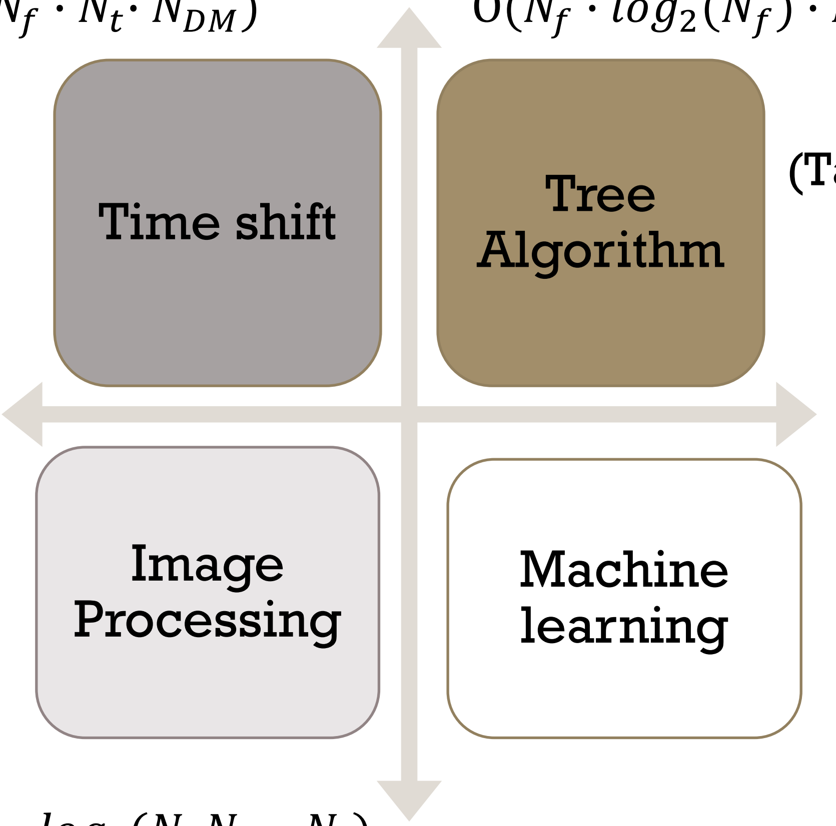
(b) Peryton 08

TRENDS FOR PULSE SEARCH ALGORITHMS



$O(N_f \cdot N_t \cdot N_{DM})$

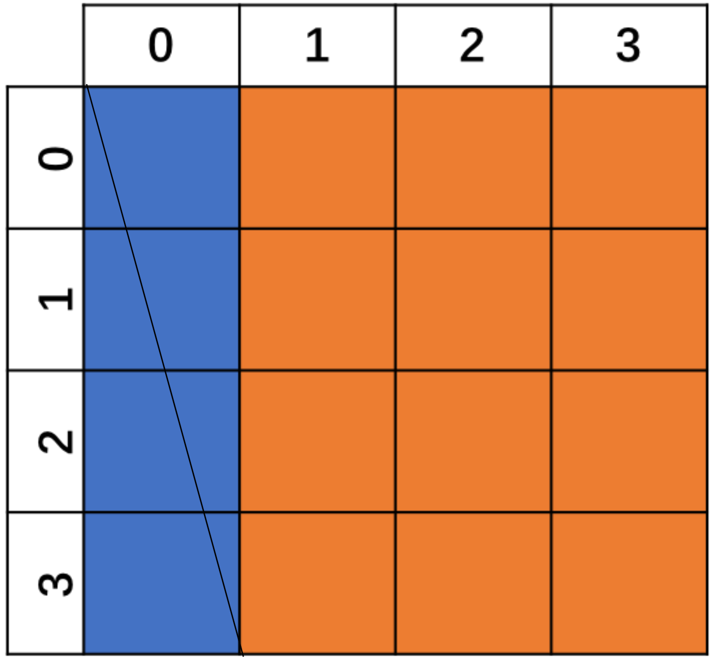
$O(N_f \cdot log_2(N_f) \cdot N_t)$



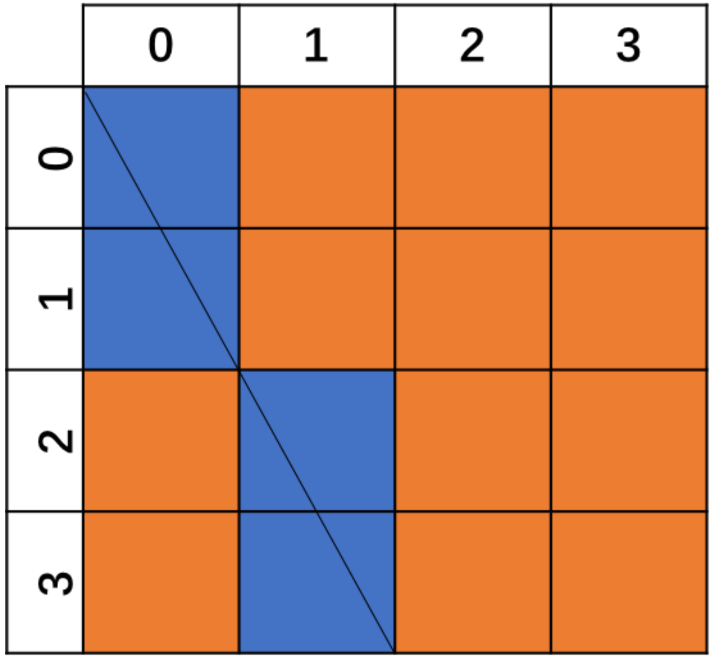
(Taylor, J. H. 1974, A&AS, 15, 367).

$O(N_f \cdot N_{t'} \cdot log_2(N_f N_{t'}) \cdot N_t)$
$=O(2 \cdot N_{t'} \cdot N_f \cdot log_2(N_f) \cdot N_t)$
$= O(k \cdot N_f \cdot log_2(N_f) \cdot N_t)$

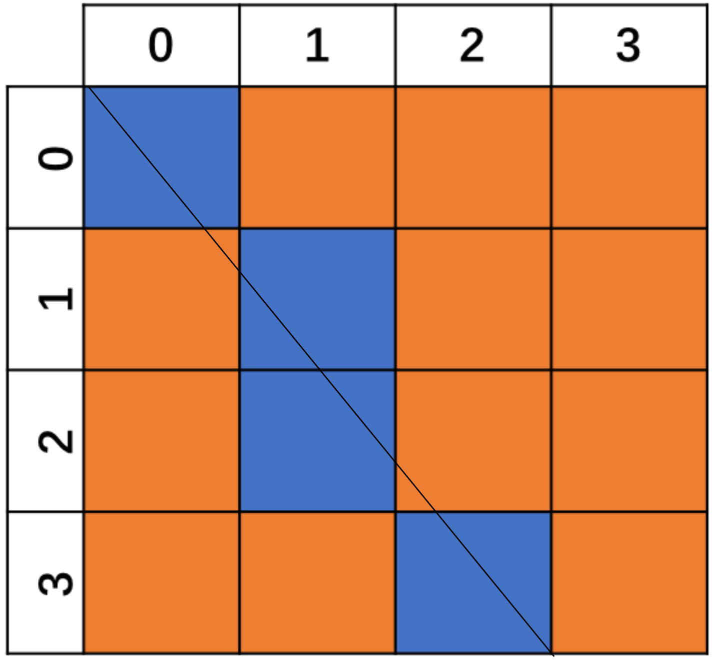
HOW DOES TREE ALGORITHM ACCELERATE?



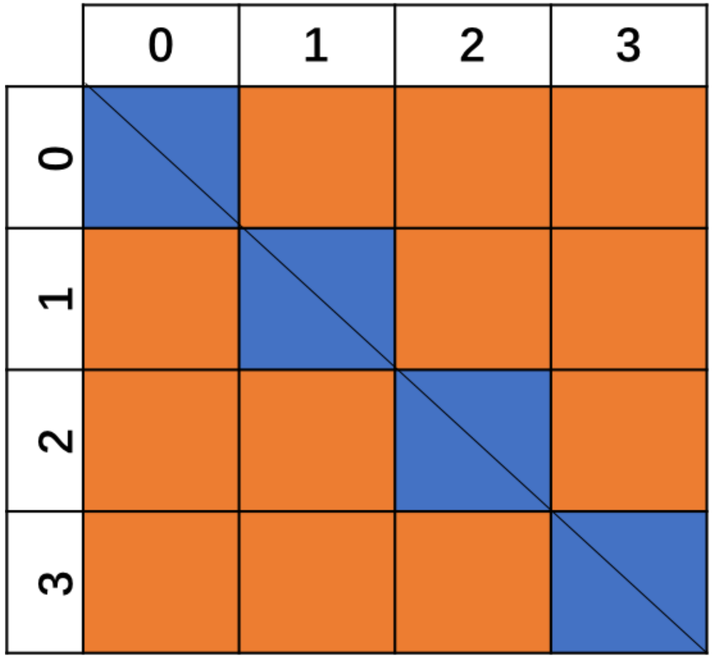
Time Delay = 0



Time Delay = 1



Time Delay = 2



Time Delay = 3

$$S_0 = (0,0) + (1,0) + (2,0) + (3,0)$$

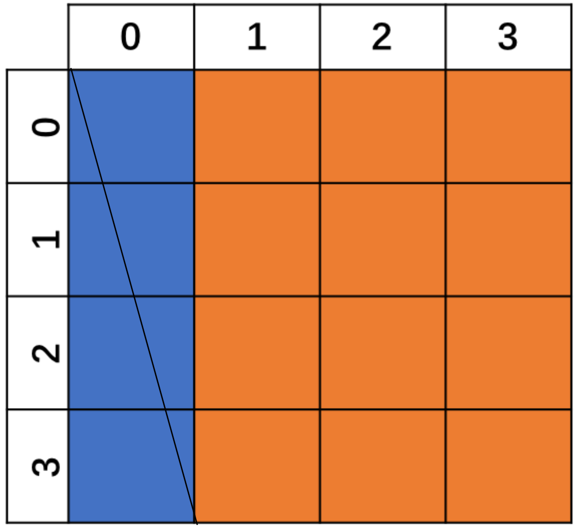
$$S_1 = (0,0) + (1,0) + (2,1) + (3,1)$$

$$S_2 = (0,0) + (1,1) + (2,1) + (3,2)$$

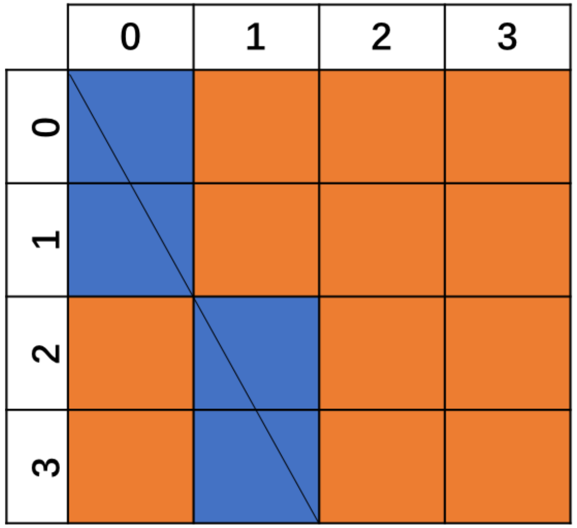
$$S_3 = (0,0) + (1,1) + (2,2) + (3,3)$$

$O(N_f \cdot N_t \cdot N_{DM})$

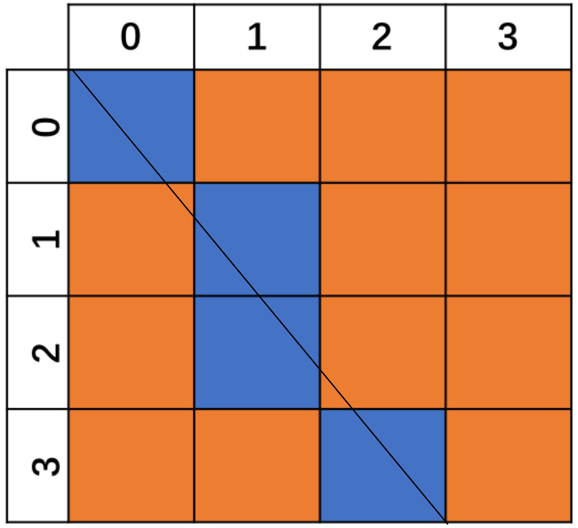
In this situation, N_t is 1



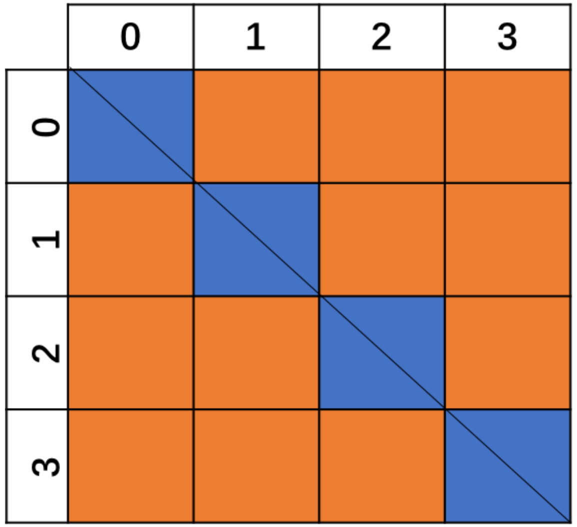
Time Delay = 0



Time Delay = 1



Time Delay = 2



Time Delay = 3

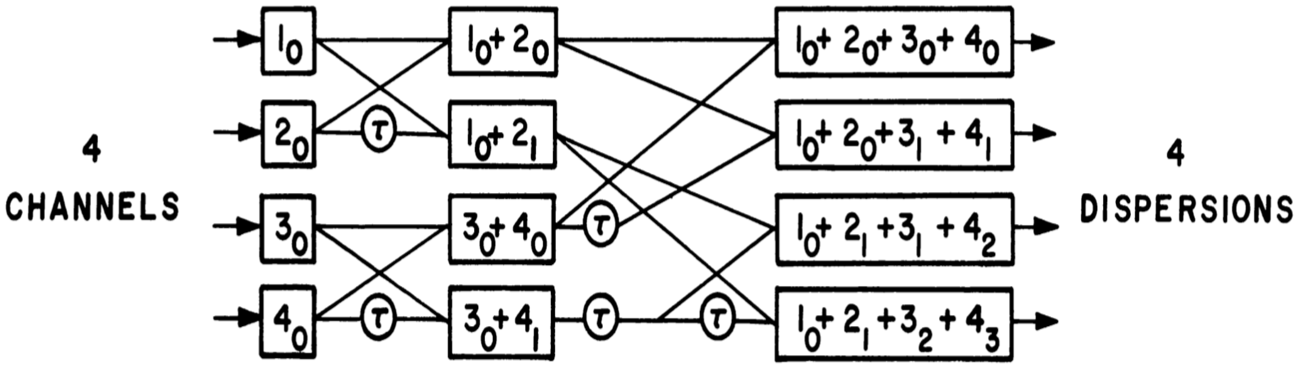


Figure 1 Block diagram of a 4 channel digital dispersion filter. Detected signals from a 4 channel receiver are input at the left; de-dispersed output signals are taken from the right. Rectangles represent summations, and circles represent unit delays. The indicated operations are performed from right to left.

$$O(N_f \cdot log_2(N_f) \cdot N_t)$$

In this situation, N_t is 1

FDMT
Barak Zackay , [The Astrophysical Journal, 835:11 (13pp), 2017 January 20]

INTRODUCTION TO A NEW IDEA TO SEARCH FAST RADIO BURST

2 Dimensional FFT Algorithm!

Collaborator : Ue-li Peng, Xuelei Chen, Yichao Li, Jayanth Chennamangaiam ,Dan Werthimer ,

Jack Hickish ,Casey law , Vishalkumar Rasiklal Gajjar

,Greg Hellbourg .etc.

BRIEF REVIEW : PROPERTIES OF 2D FFT

Sinusoidal Waves

In 1D the Fourier transform is based on a decompostion into functions $e^{j2\pi ux} = \cos 2\pi ux + j \sin 2\pi ux$ which form an orthogonal basis. Similarly in 2D

$$e^{j2\pi(ux+vy)} = \cos 2\pi(ux+vy) + j \sin 2\pi(ux+vy)$$

The real and imaginary terms are sinusoids on the x, y plane. The maxima and minima of $\cos 2\pi(ux+vy)$ occur when

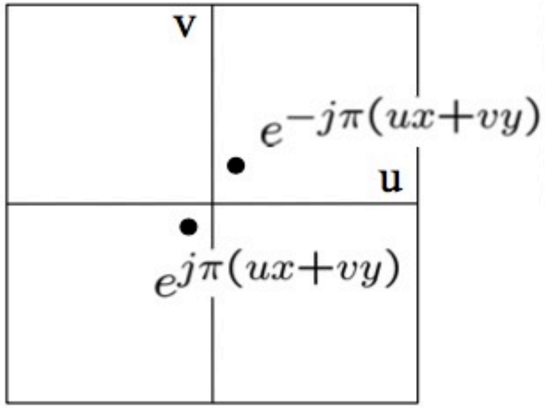
$$2\pi(ux+vy) = n\pi$$

write $ux + vy$ using vector notation with $\mathbf{u} = (u, v)^\top, \mathbf{x} = (x, y)^\top$ then

$$2\pi(ux+vy) = 2\pi\mathbf{u}.\mathbf{x} = n\pi$$

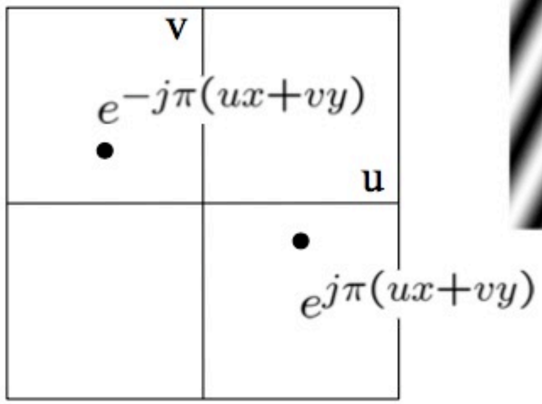
are sets of equally spaced parallel lines with normal $\mathbf{u}$ and wavelength $1/\sqrt{u^2+v^2}$.

To get some sense of what basis elements look like, we plot a basis element --- or rather, its real part --- as a function of x,y for some fixed u, v. We get a function that is constant when (ux+vy) is constant. The magnitude of the vector (u, v) gives a frequency, and its direction gives an orientation. The function is a sinusoid with this frequency along the direction, and constant perpendicular to the direction.

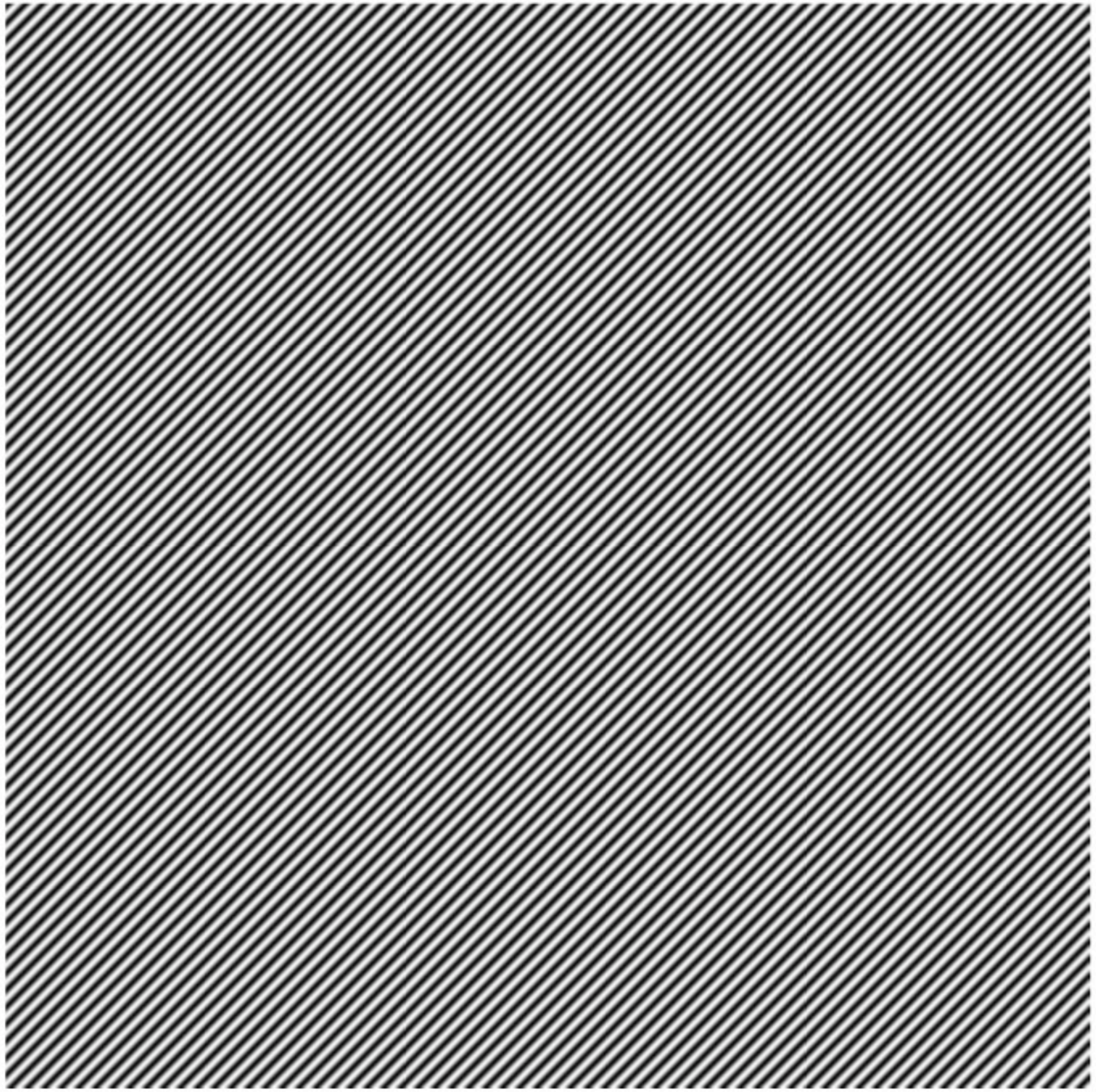


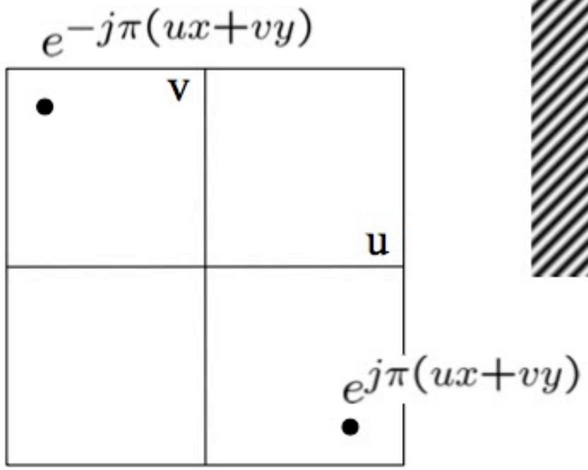
slide: B. Freeman

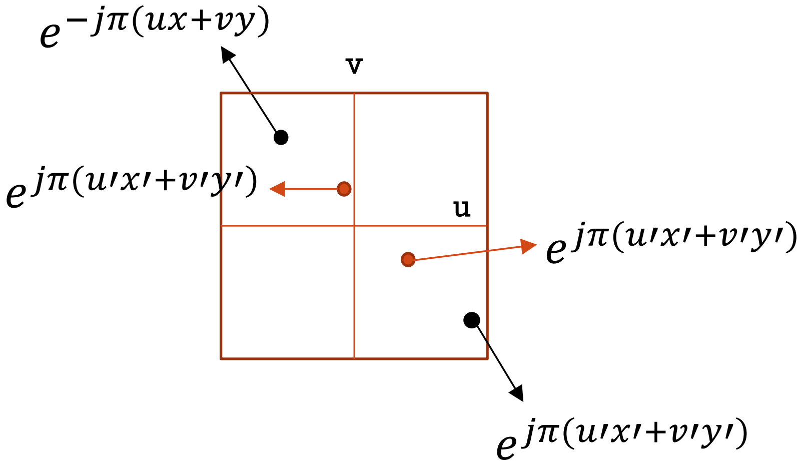
Here u and v are larger than in the previous slide.

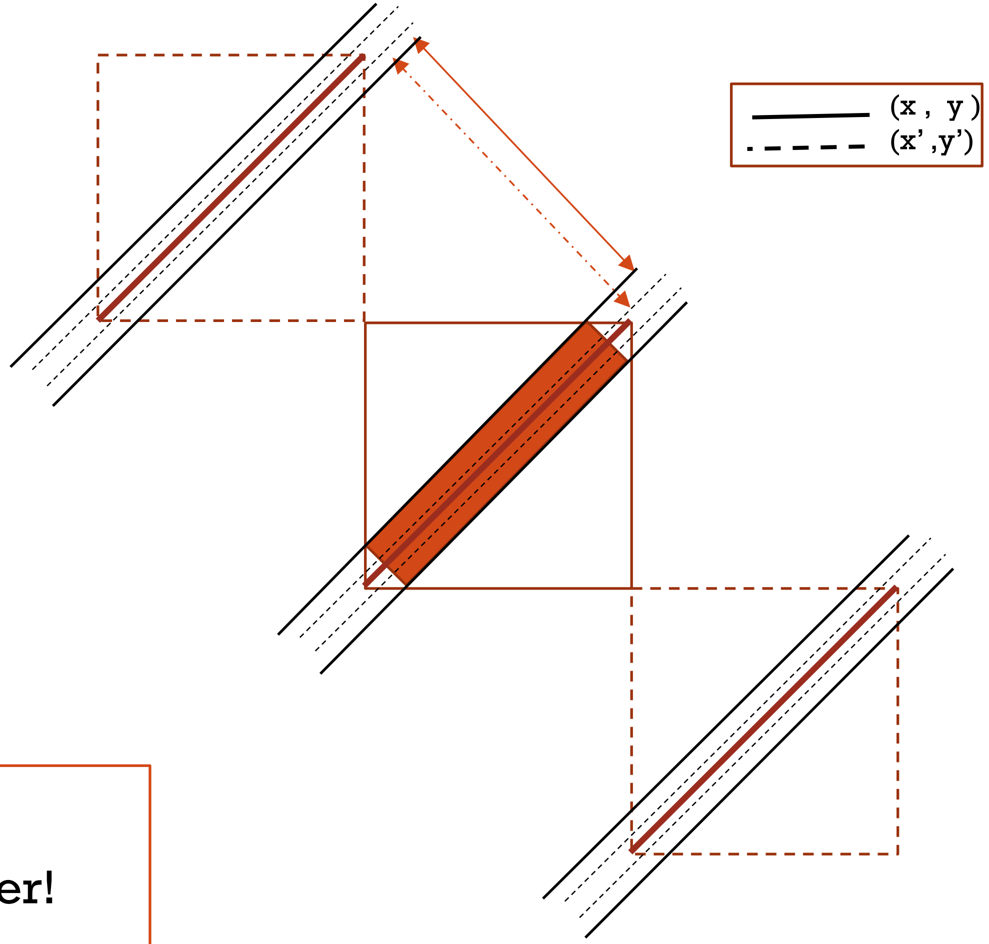


And larger still...





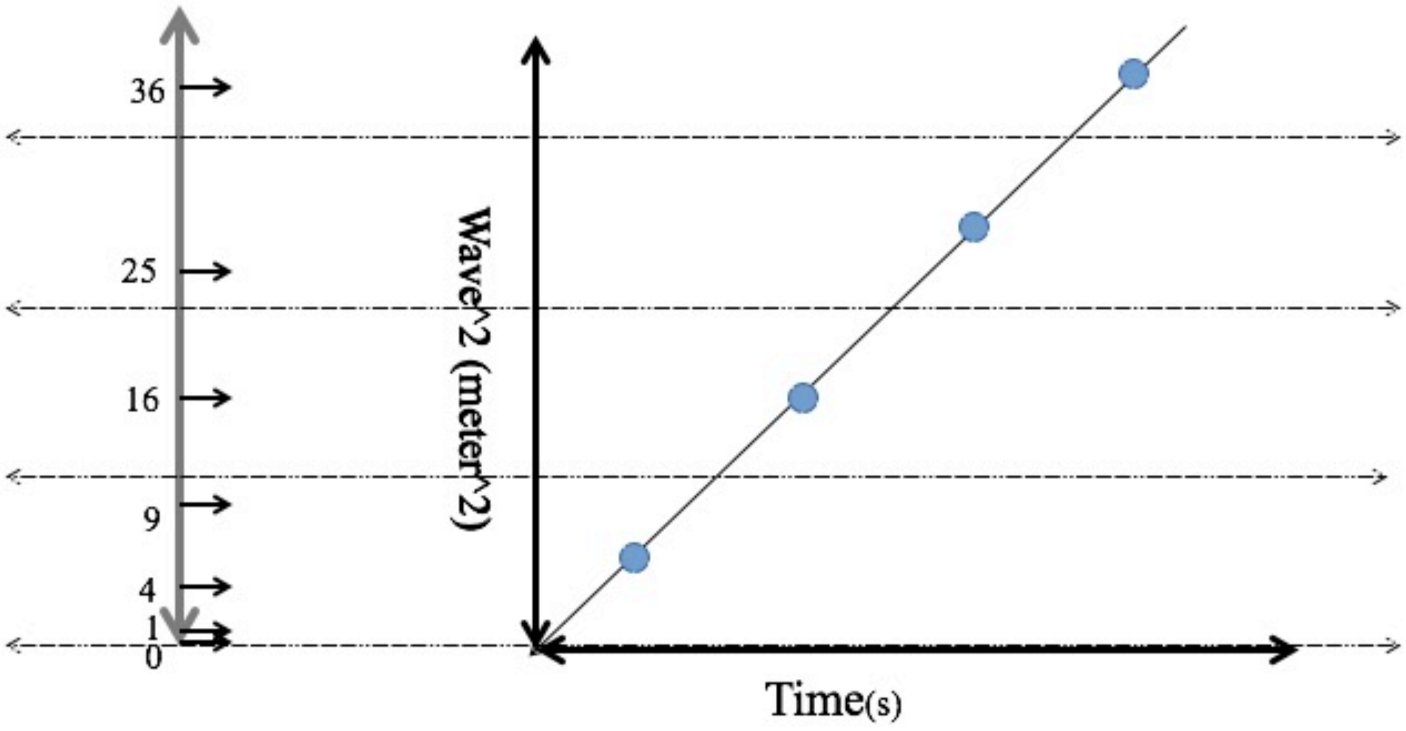




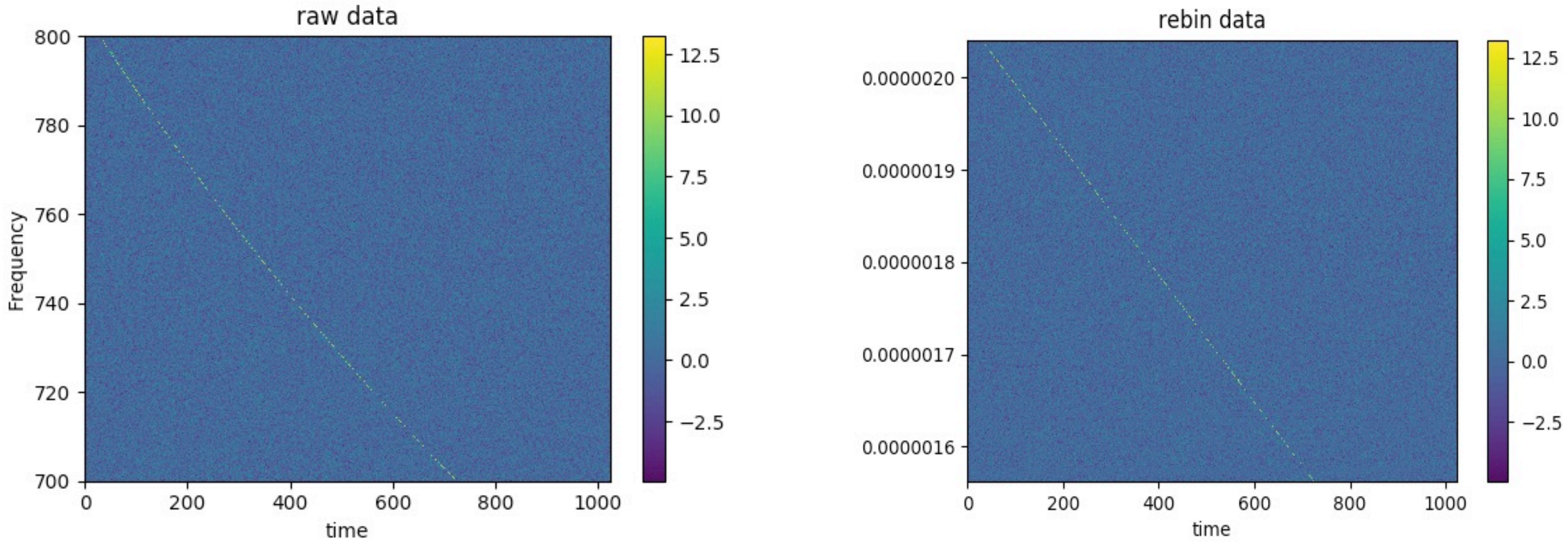
- Line(x,y) ⊥ Line(u,v)
- Line(u,v) is always go cross center!

RE-BIN:

$$\Delta t = 4.15 \times 10^{-6} \mathrm{ms} \cdot \mathrm{DM} \times (f_{\mathrm{ref}}^{-2} - f_{\mathrm{chan}}^{-2})$$



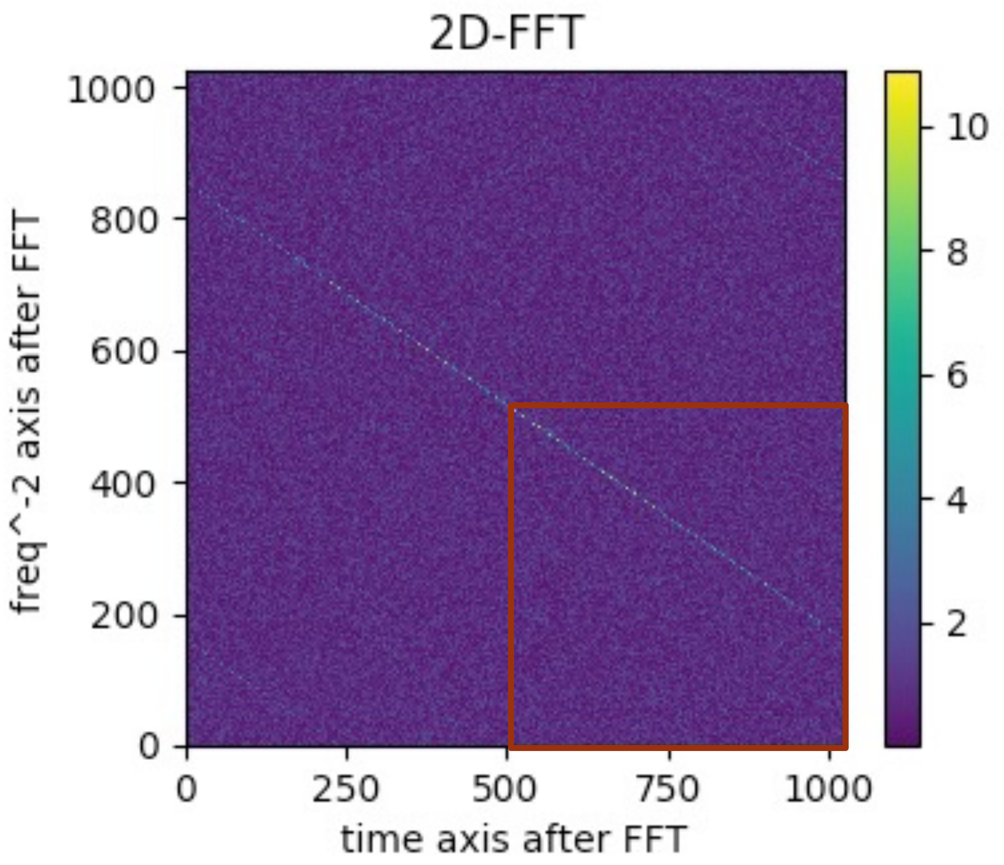
RE-BIN:

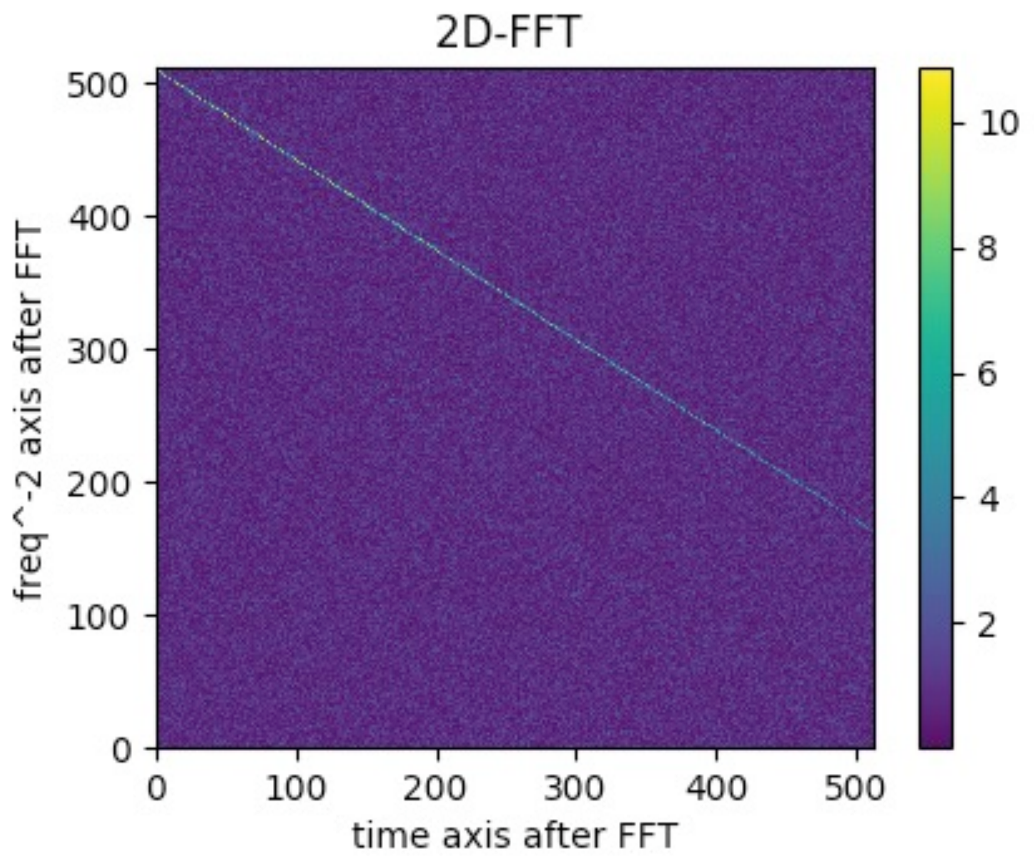


raw data
Frequency
800
780
760
740
720
700
0
200
400
600
800
1000
time
12.5
10.0
7.5
5.0
2.5
0.0
−2.5
rebin data
0.0000020
0.0000019
0.0000018
0.0000017
0.0000016
0
200
400
600
800
1000
time
12.5
10.0
7.5
5.0
2.5
0.0
−2.5

DM = 350

2D-FFT:

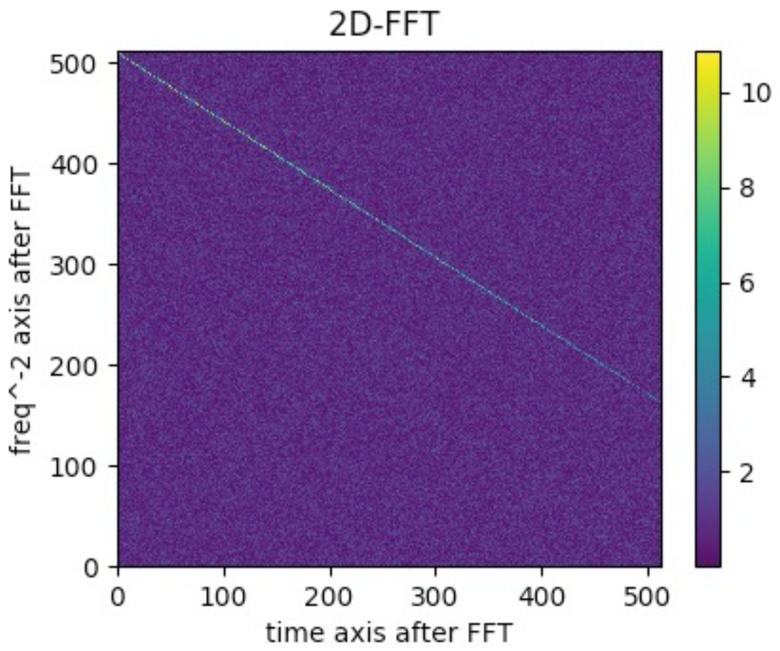


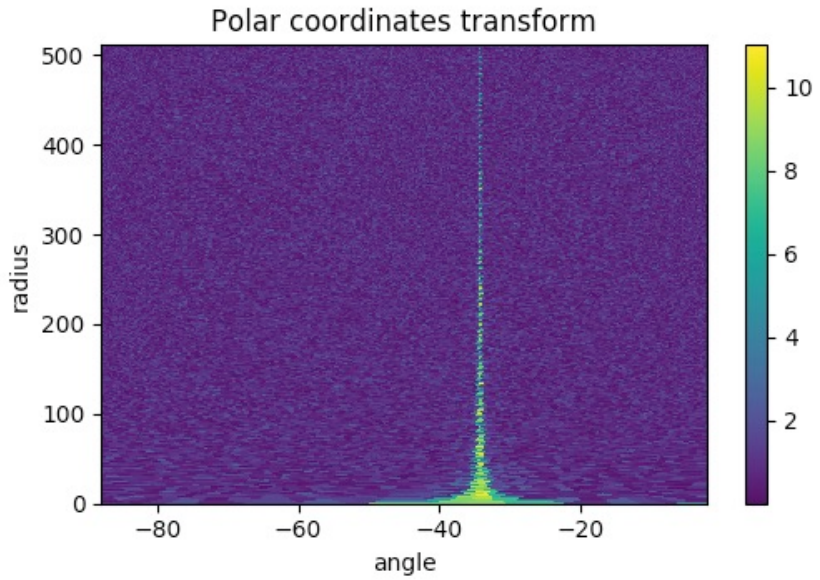


- The straight line in re-bin map will become a straight line go cross center in 2D-FFT map.
- Each angle present a special DM signal line .
- Signal line after FFT should not appear in First and third quadrant. So we only need the 2nd or 4th quadrant data. (it's conjugate to each other.)

POLAR COORDINATES CONVERT:

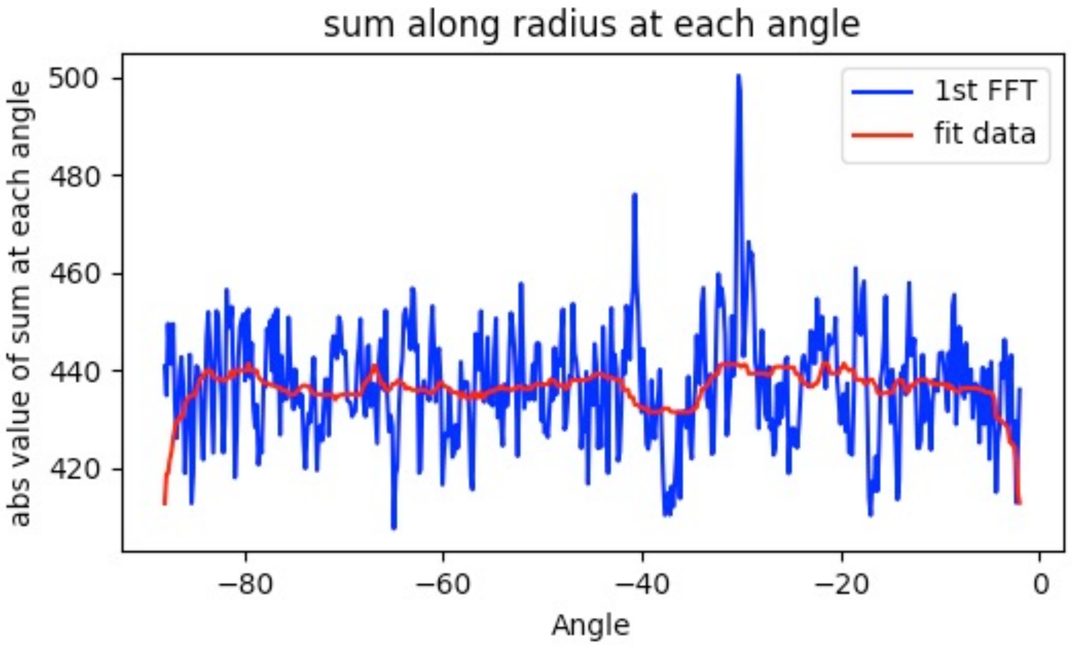
- Take the center of map as original point
- Calculate angle and radius length
- Interpolate the data with the coordinates . Finally we can Get the polar coordinates matrix, and could plot it with angle and radius axis.



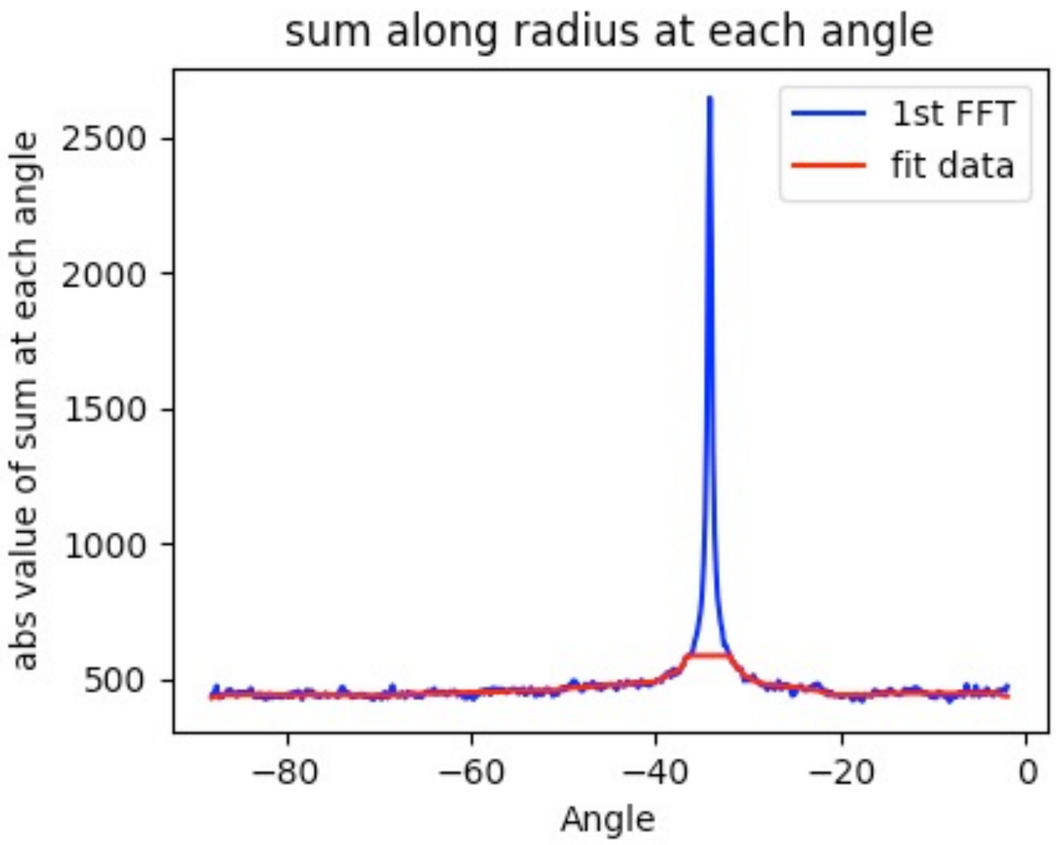


SUM IT UP!

- Sum it up along the radius axis from -90~0 degree.
- Calculate SNR.
- Compare SNR with threshold



Theoretical Input SNR is 32



Theoretical Input SNR is 320

DM CALCULATE

$$\Delta t = 4.15 \times 10^{-6} ms \cdot DM \times (f_{ref}^{-2} - f_{chan}^{-2})$$

We usually use $C = 4.15 \times 10^{-6} ms \cdot MHz^2 \cdot pc^{-1} \cdot cm^3$. If we assume k_1 stand for the slope of original line, and denote k_2 be the slop of line after 2-D FFT, and k_3=cot(θ)= $\frac{1}{k_2}$, We could get:

$$k_1 \cdot unit(k_1) = \frac{f_{chan}^{-2}}{\Delta t} = \frac{1}{C \cdot DM} \tag{2}$$

Here k_1, k_2, k_3 are from geometry, they only stand the digital value of the slop.If we want using it to calculate the DM ,we should add a unit of them when calculate slope. The $unit(k_1)$in equation (2) is:

$$unit(k_1) = \frac{max(f^{-2}) - min(f^{-2})}{N_{bins}} \cdot \frac{1}{t_{samp}} \tag{3}$$

As two lines perpendicular to each other, the two slopes k_1, k_2 are also obeyed one rule:

$$k_1 = \frac{-1 \cdot N_{bins}}{k_2 \cdot N_{tsamp}} \tag{4}$$

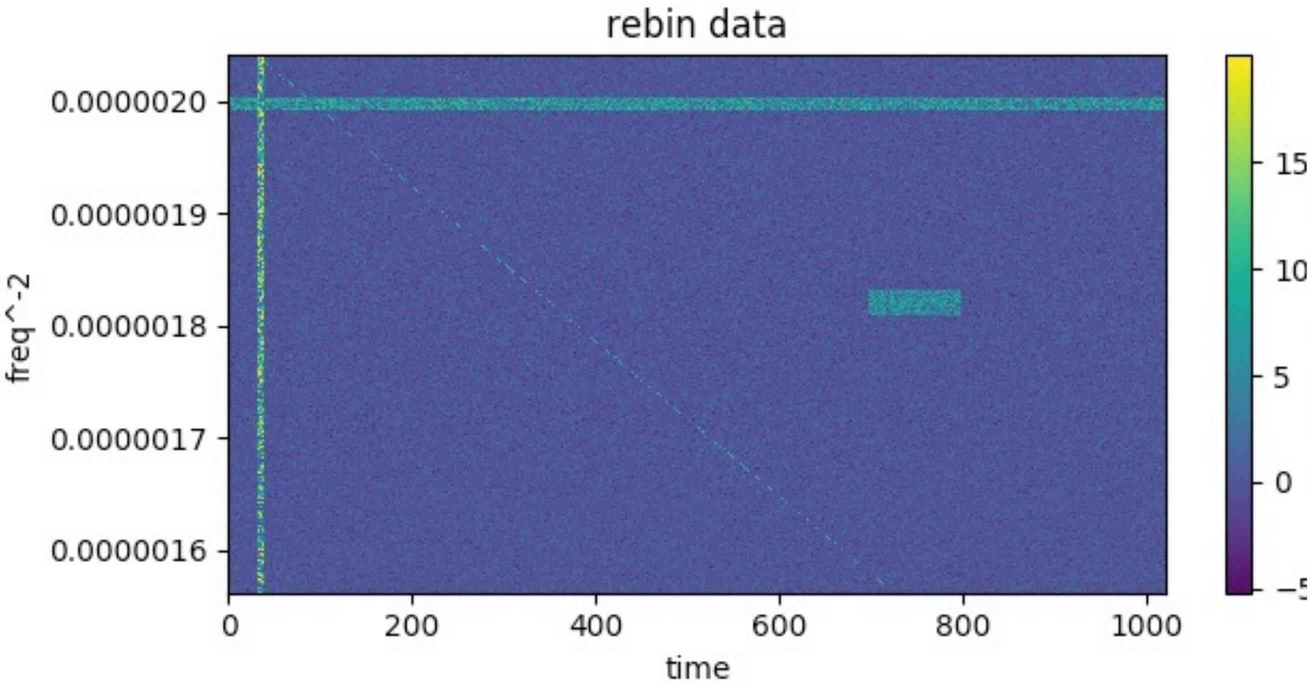
From (2)(3)(4), we could get relationship between DM and k_2:

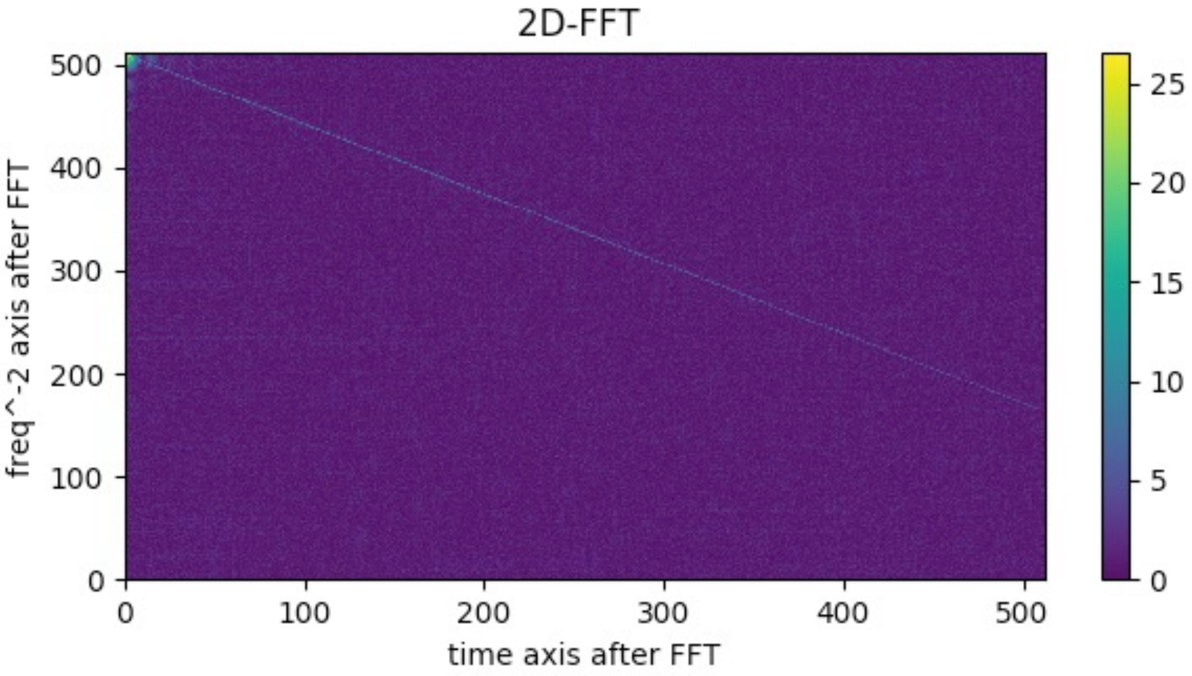
$$DM = \frac{-1}{C} \cdot \frac{N_{tsamp} \cdot t_{samp}}{max(f^{-2}) - min(f^{-2})} \cdot k_2 \tag{8}$$

ADVANTAGE OF THIS METHOD:

$$O(N_f \cdot N_{t'} \,.\, log_2(N_f N_{t'}) \cdot N_t)$$
$$=O\left(2 \cdot Nt_{'} \cdot N_f \cdot log_2(N_f) \cdot N_t\right)$$
$$= O\left(k \cdot N_f \cdot log_2(N_f) \cdot N_t\right)$$

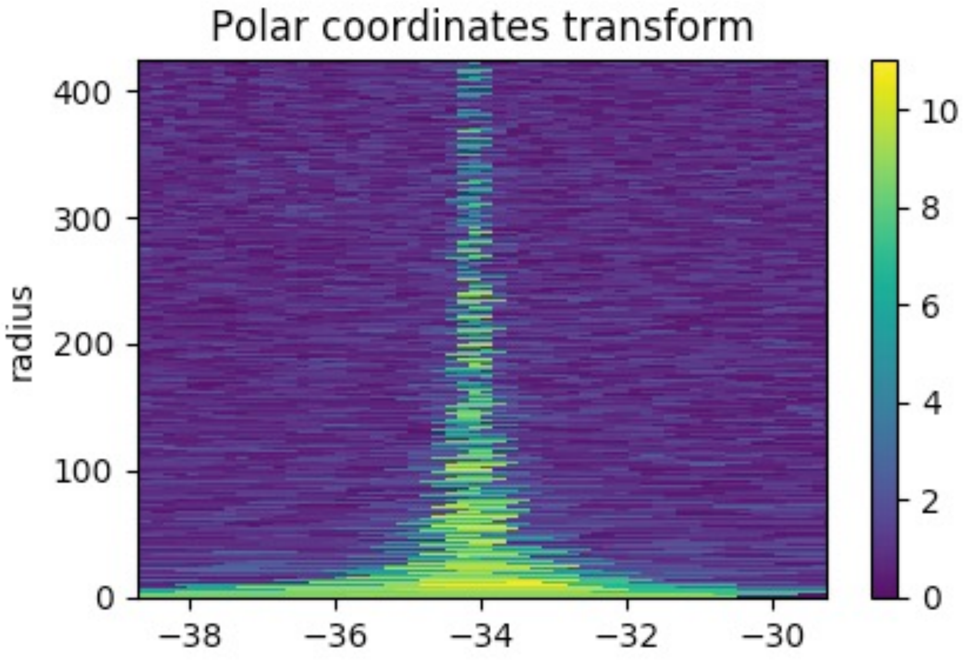
- Compute complexity, this method is equal to tree algorithm
- Easy to remove RIF.
- Easy to Parallel . (GPU)

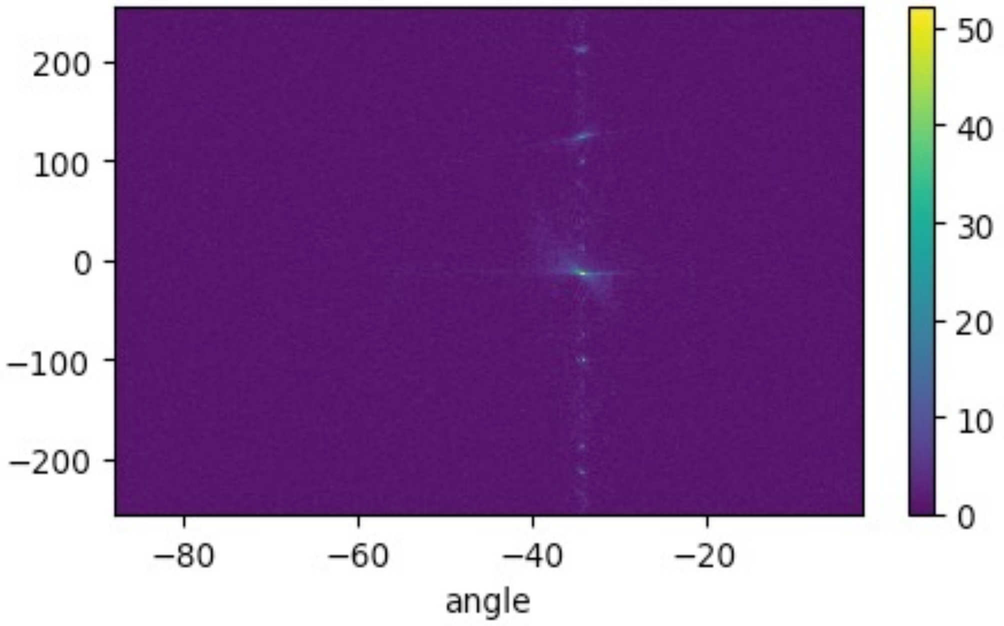




PROSPECT IN FUTURE:

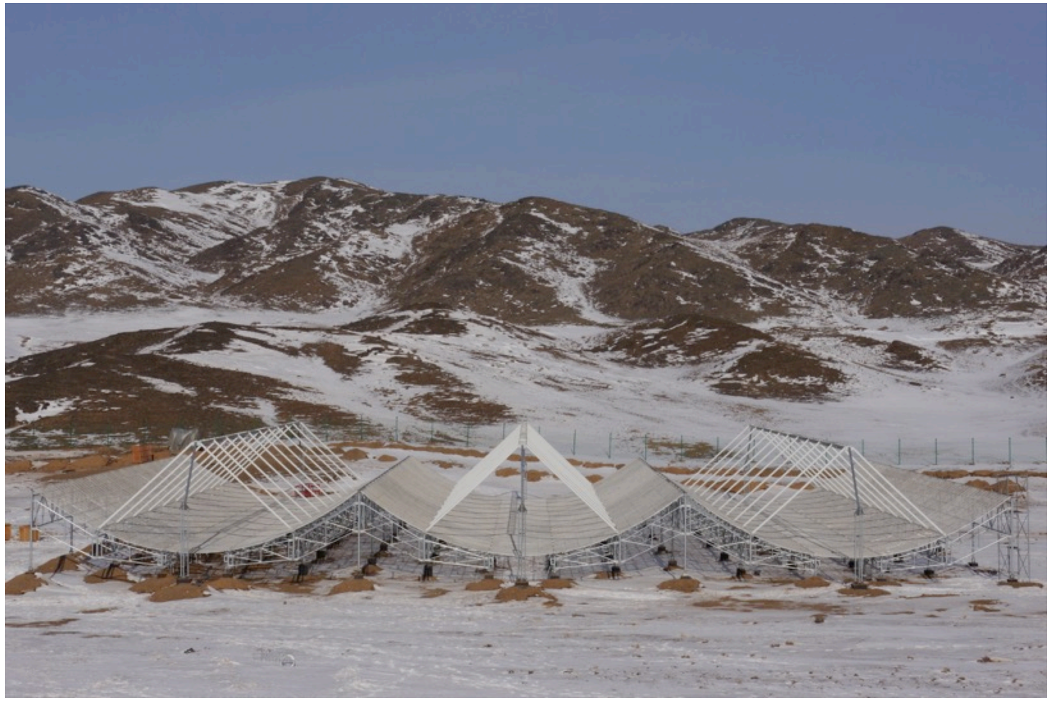
- Try second 1-D FFT to improve SNR
- Try 2-D FFT first then do Radon transform to search a line.
- Or try Radon transform directly to search a line or curve in frequency-time map.





ADVERTISEMENT TIME!
TIAN LAI ARRAY!

In Xinjiang, North western China. We build 3 telescope cylinder + 16 dishes interferometer .

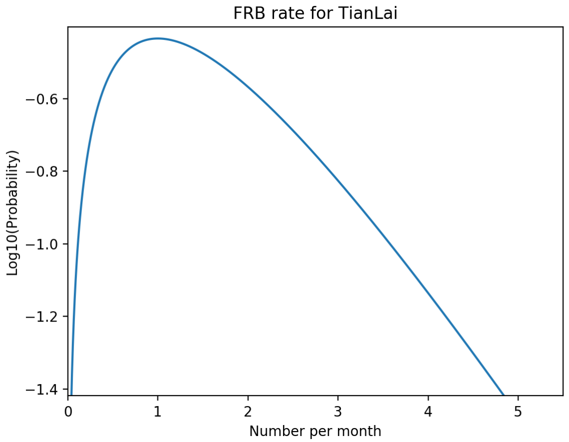


$96\times2=192$ inputs

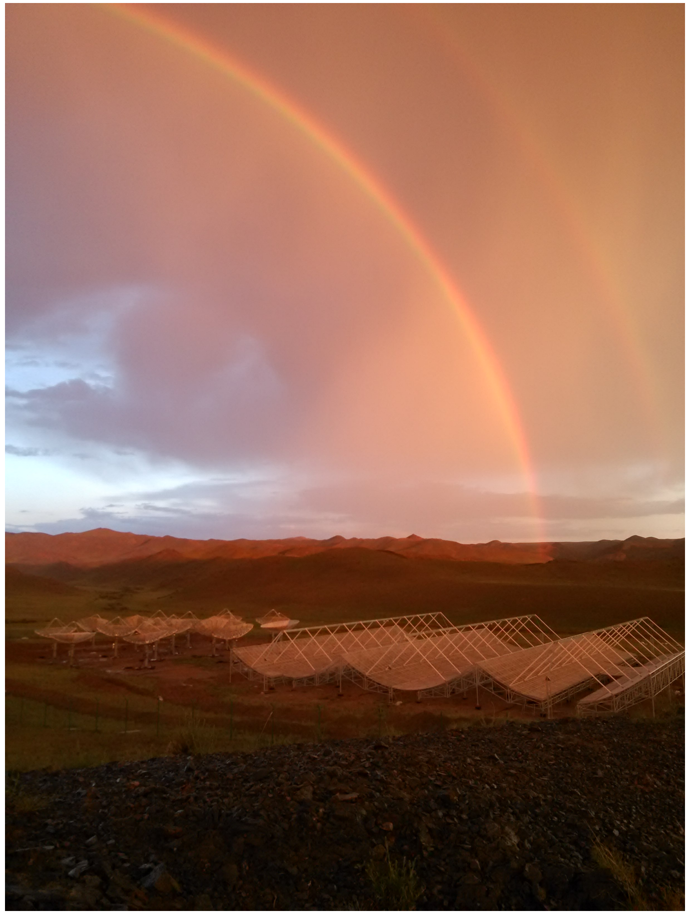
$16\times2=32$ inputs

TELESCOPE PARAMETER FOR FRB

Band Width : 100MHz
Frequency: 700-800MHz
Cylinder Scale: L 40m , Diameter 15m
Dish Scale: Diameter 6 m
FOV: 160 Deg^2
Time Resolution: 50ms
Beam number: 32<N<96

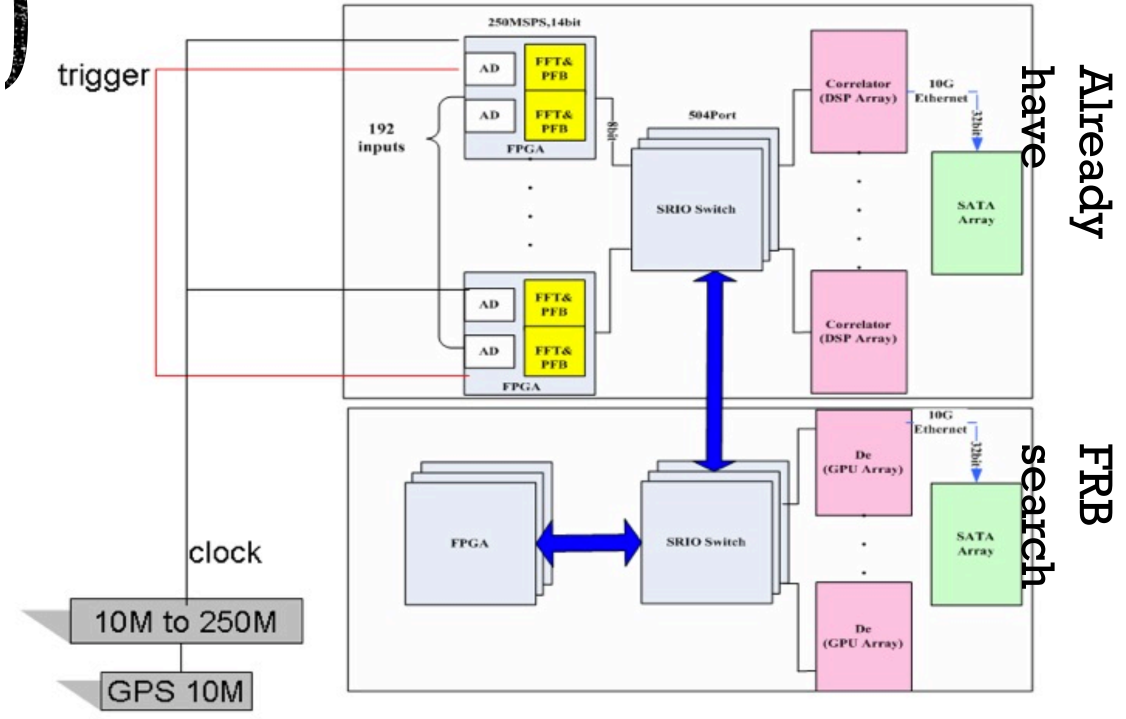


Above 95% confident interval, We could see 0.05~4.5 FRB Per Month!

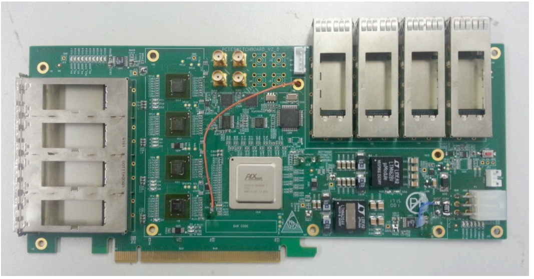


DIGITAL BACKEND(PLAN)

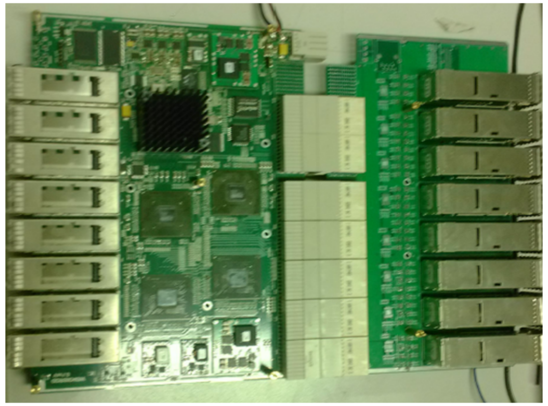
- Using SRIO to make a data copy.
- Beamforming by FPGA(GD2FPGA designed by IACAS).
- De-dispersion are processed by GPU Array.
- High speed SRIO switch.
- GPU server SRIO NIC



GD2FPGA



GPU server NIC



SRIO Switch

THANK YOU!