GMRT transients search and related issues

Jayanti Prasad

National Center for Radio Astronomy
Pune, India (411007)

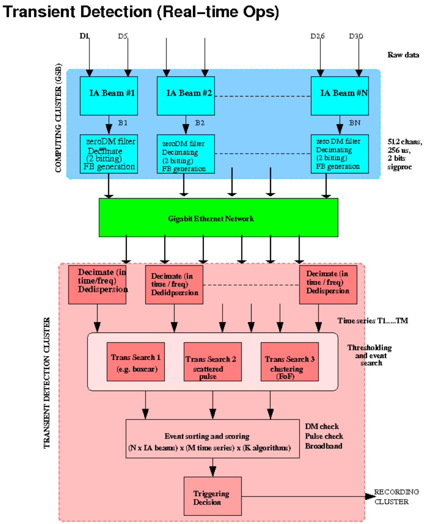
September 3, 2009

Introduction

A typical transients search pipeline consists of

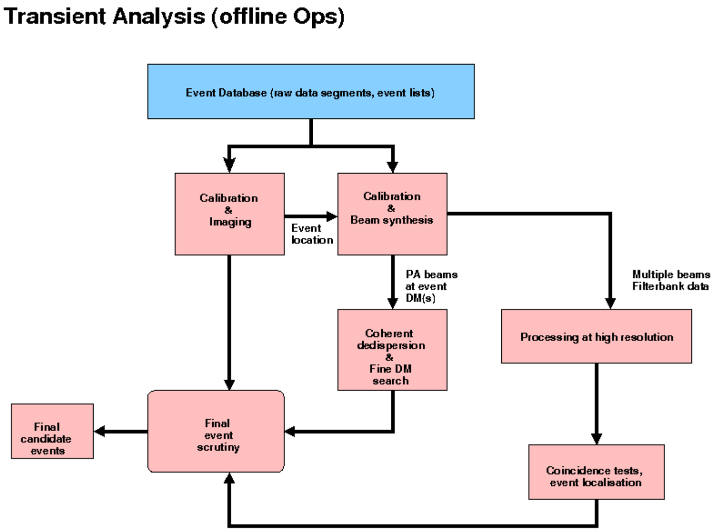
1. Dedispersion
2. Matched filtering
3. Thresholding
4. Diagnosis

Online



Transient Detection (Real–time Ops)
D1
D5
D26
D30
Raw data
COMPUTING CLUSTER (GSB)
IA Beam #1
IA Beam #2
IA Beam #N
B1
B2
BN
zeroDM filter Decimate (2 bitting) FB generation
zeroDM filter Decimating (2 bitting) FB generation
zero DM filter Decimating (2 bitting) FB generation
512 chans, 256 us, 2 bits sigproc
Gigabit Ethernet Network
TRANSIENT DETECTION CLUSTER
Decimate (in time/freq) Dedispersion
Decimate (in time / freq) Dedidpsersion
Decimate (in time / freq) Dedispersion
Time series T1.....TM
Trans Search 1 (e.g. boxcar)
Trans Search 2 scattered pulse
Trans Search 3 clustering (FoF)
Thresholding and event search
Event sorting and scoring
(N x IA beams) x (M time series) x (K algorithms)
DM check
Pulse check
Broadband
Triggering Decision
RECORDING CLUSTER

Offline


Transient Analysis (offline Ops)
Event Database (raw data segments, event lists)
Calibration & Imaging
Event location
Calibration & Beam synthesis
PA beams at event DM(s)
Multiple beams Filterbank data
Coherent dedispersion & Fine DM search
Processing at high resolution
Final candidate events
Final event scrutiny
Coincidence tests, event localisation

False alarms

- The probability of a Gaussian noise signal with zero mean and σ variance, crossing a threshold T (probability of false alarms) is given by

$$P(T) = \int_T^\infty \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{x^2}{2\sigma^2}\right) = \frac{1}{2} Erfc\left(\frac{T}{\sigma\sqrt{2}}\right) \quad (1)$$

- The joint probability of false alarms for N antennas is given by

$$P^A(T) = \left[\frac{1}{2} Erfc\left(\frac{T}{\sigma\sqrt{2}}\right)\right]^N \quad (2)$$

Now if we add the signals from N antennas incoherently then the joint probability of false alarms

$$P^B(T) = \frac{1}{2} Erfc\left(\frac{T}{\sigma}\sqrt{\frac{N}{2}}\right) \quad (3)$$

If we break N antennas into p incoherent sub-arrays each with N/p antennas

$$P^c(T) = \left[\frac{1}{2} Erfc\left(\frac{T}{\sigma}\sqrt{\frac{N}{2p}}\right)\right]^p \tag{4}$$

What is the best combination for a given number of antennas N and threshold T ?

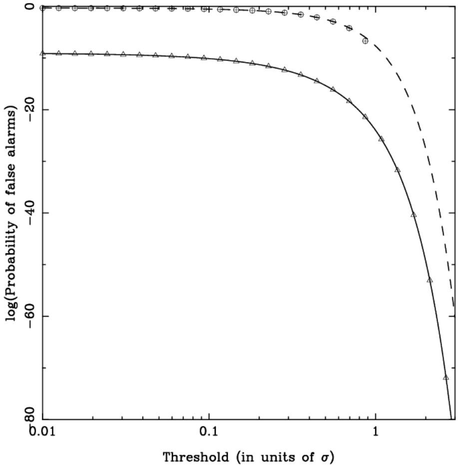


Figure: 1. Probabilities of false alarms $P^A(T)$ (solid line) and $P^B(T)$ (dotted line). . Symbols represent the fraction of events observed above the threshold in a simulated Gaussian noise.

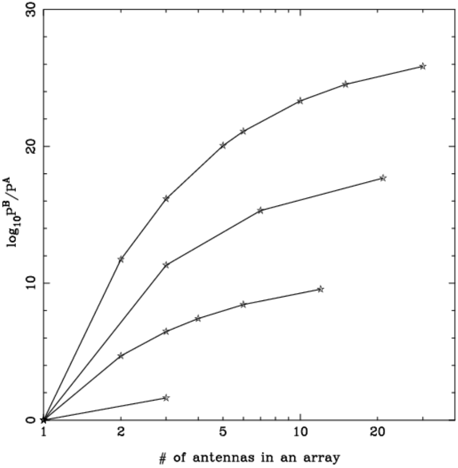


Figure: 2.Probabilities of false alarms P^B and P^A as a function of the number of antennas in a beam for $T = 3\sigma$, for a given number of total antennas. The curves from the top are for the total number of antennas $N = 30, 21, 12$ and 3 respectively.

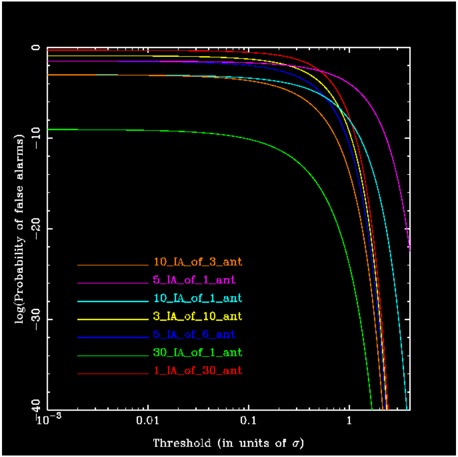


Figure: 3. Probability of false alarms $P^c(T)$ for p incoherent sub-arrays of N antennas. Note that the number of antennas in an IA array is important for high value of threshold.

Single pulse simulations

- How the difference between the actual DM and trial DM changes the
  1. location
  2. width and
  3. Amplitude (SNR)

  of a pulse for a given set of parameters $W, \nu, n_{chan}, t_{samp}$ etc.
- How the amplitude of a given pulse changes with the size of smoothing window.
- How zero-dm filtering change the shape and size of a pulse.

- Dispersion delay:

$$\tau_f(\mathrm{DM}) \approx K \left[\left(\frac{\mathrm{MHz}}{f} \right)^2 - \left(\frac{\mathrm{MHz}}{f_h} \right)^2 \right] \left(\frac{\mathrm{DM}}{\mathrm{pc\ cm^{-3}}} \right) \mathrm{sec} \qquad (5)$$

where $K = 4.154553 \times 10^3$

- Pulse location:

$$\bar{\tau}(\mathrm{DM}) = \frac{\tau_{f_h} + \tau_{f_l}}{2} = \frac{\tau_{f_l}}{2} \qquad (6)$$

If the true dispersion measure of a pulse is DM and we dedisperse it with a trial dispersion measure DM+dDM then shift in the location of the pulse is given by

$$\Delta\bar{\tau} = \frac{K}{2} \left(\frac{\mathrm{MHz}}{f_c} \right)^3 \left(\frac{\Delta f}{\mathrm{MHz}} \right) \left(\frac{\mathrm{dDM}}{\mathrm{pc\ cm^{-3}}} \right) \mathrm{sec} \qquad (7)$$

If in place of considering the highest frequency channel as the reference i.e., there is no delay for this channel, we consider any other channel f_{ref} as reference

$$\tau_f(\mathrm{DM}) \approx K \left[\left(\frac{\mathrm{MHz}}{f} \right)^2 - \left(\frac{\mathrm{MHz}}{f_{ref}} \right)^2 \right] \left(\frac{\mathrm{DM}}{\mathrm{pc\ cm}^{-3}} \right) sec \tag{8}$$

if $f_{ref} = f_c, f_l = f_c - \Delta f/2, f_h = f_c + \Delta f/2$ we get

$$\bar{\tau}(\mathrm{DM}) = \frac{\tau_{f_h} + \tau_{f_l}}{2} = \frac{K}{2} \frac{3\Delta f^2}{2(f_c^2 - \Delta f^2/4)^2} \mathrm{MHz}^2 \left(\frac{\mathrm{DM}}{\mathrm{pc\ cm}^{-3}} \right) \tag{9}$$

then the shift is of the order of Δf^2.

- Pulse width: If the intrinsic pulse width is W then the observed pulse width can be defined as

$$\begin{aligned} \mathrm{w} &= \mathrm{W} + (\tau_{f_l} - \tau_{f_h}) \\ &= K \left(\frac{\mathrm{MHz}}{f_c}\right)^3 \left(\frac{\Delta f}{\mathrm{MHz}}\right) \left(\frac{\mathrm{DM}}{\mathrm{pc\ cm^{-3}}}\right) \mathrm{sec} \end{aligned} \tag{10}$$

If the true dispersion measure of a pulse is DM and we dedisperse it with a trial dispersion measure DM+dDM then the change in the width of the pulse is given by

$$\Delta \mathrm{w} = K \left(\frac{\mathrm{MHz}}{f_c}\right)^3 \left(\frac{\Delta f}{\mathrm{MHz}}\right) \left(\frac{\mathrm{dDM}}{\mathrm{pc\ cm^{-3}}}\right) \mathrm{sec} \tag{11}$$

- **Pulse amplitude:** For a rectangular bandpass function and for a Gaussian shape pulse with width W c the ratio of measured peak flux $S(\delta DM)$ to true flux S to for a DM error δDM is

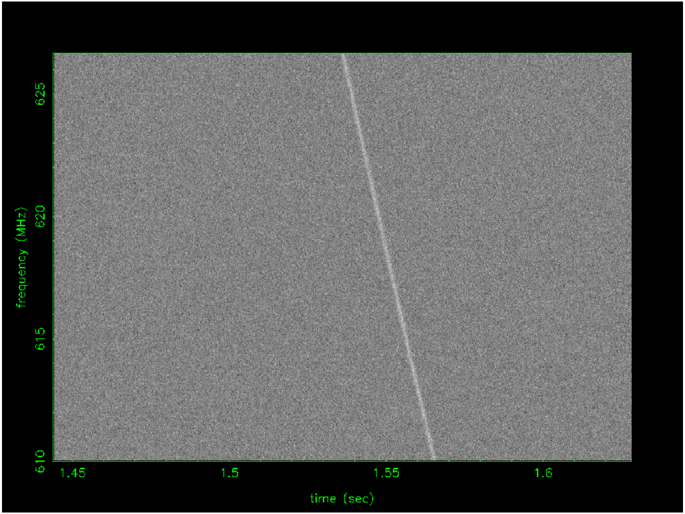
$$\frac{S(\delta DM)}{S} = \frac{\sqrt{\pi}}{2\xi} erfc(\xi) \tag{12}$$

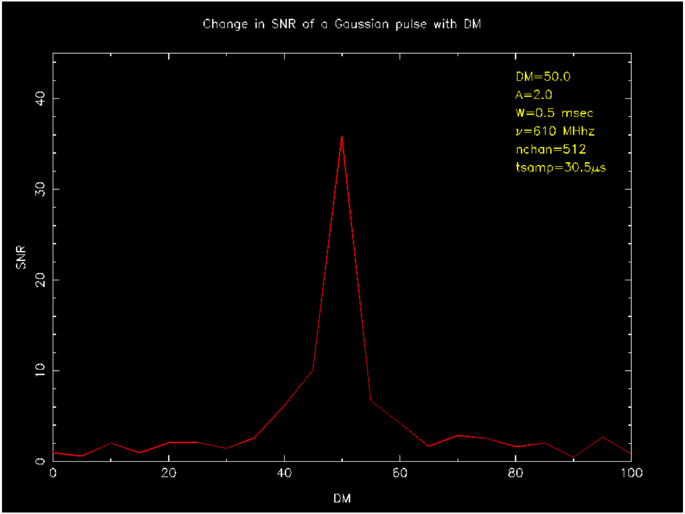
where

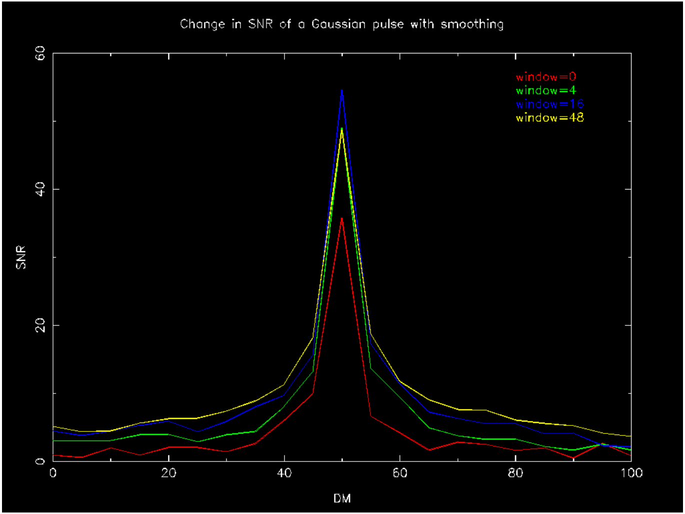
$$\xi = 6.91 \times 10^{-3} \delta DM \frac{\delta\nu}{MHz} \frac{msec}{W} \left(\frac{Ghz}{\nu}\right)^2 \tag{13}$$

(Cordes & McLaughlin 2003)

Simulations

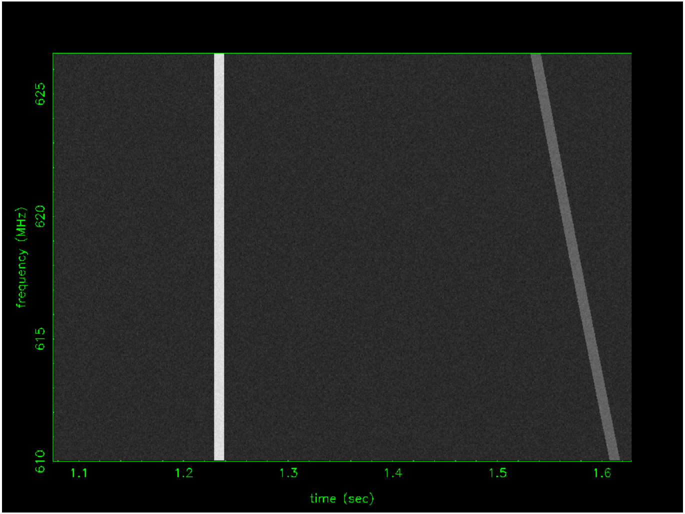



Change in SNR of a Gaussian pulse with DM
DM=50.0
A=2.0
W=0.5 msec
ν=610 MHhz
nchan=512
tsamp=30.5μs
SNR
0
10
20
30
40
0
20
40
60
80
100
DM

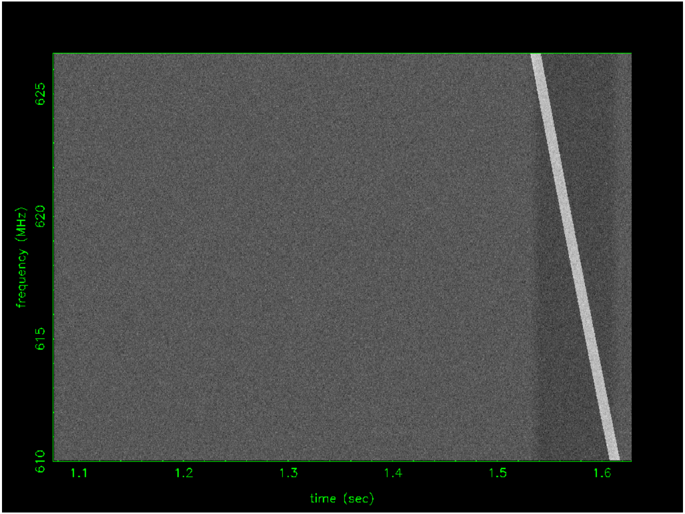


Change in SNR of a Gaussian pulse with smoothing
window=0
window=4
window=16
window=48
SNR
DM
0
20
40
60
0
20
40
60
80
100

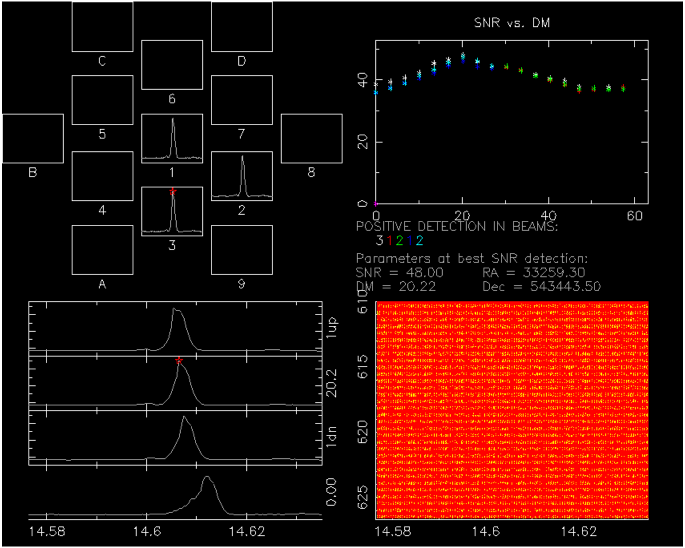
Broad Band RFI



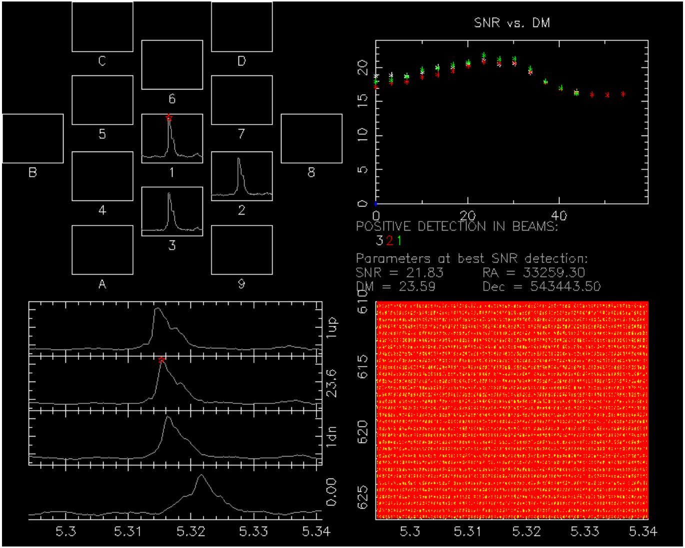
Broad Band RFI removed with zeron DM filtering



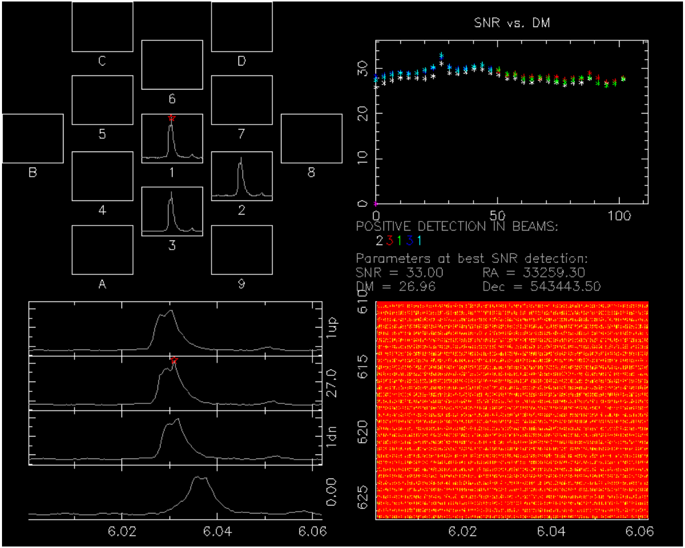
Giant pulse search:



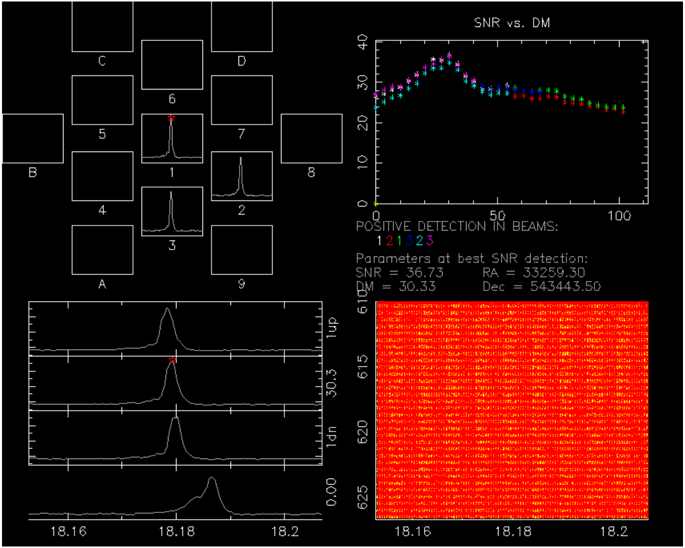
Giant pulse search..



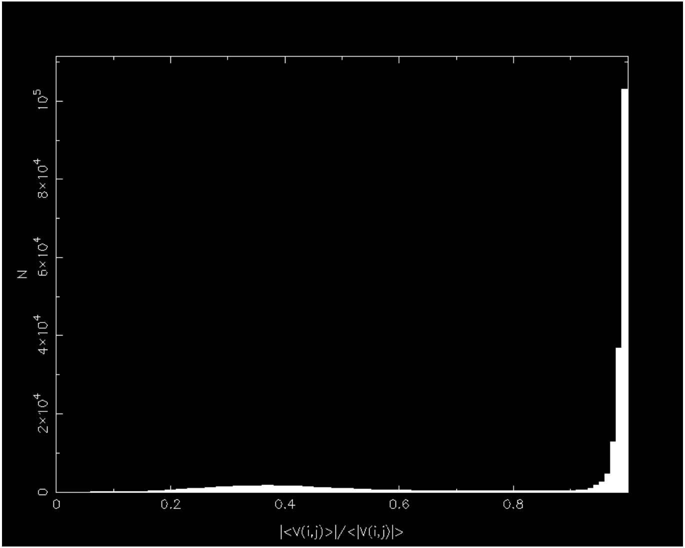
Giant pulse search..



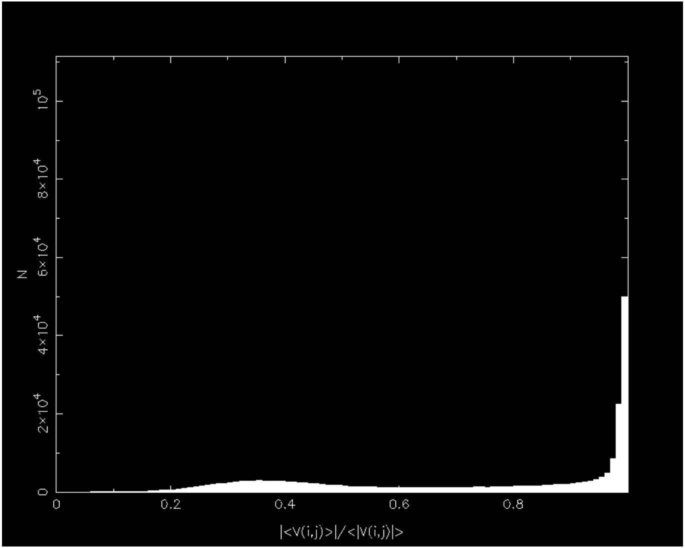
Giant pulse search..



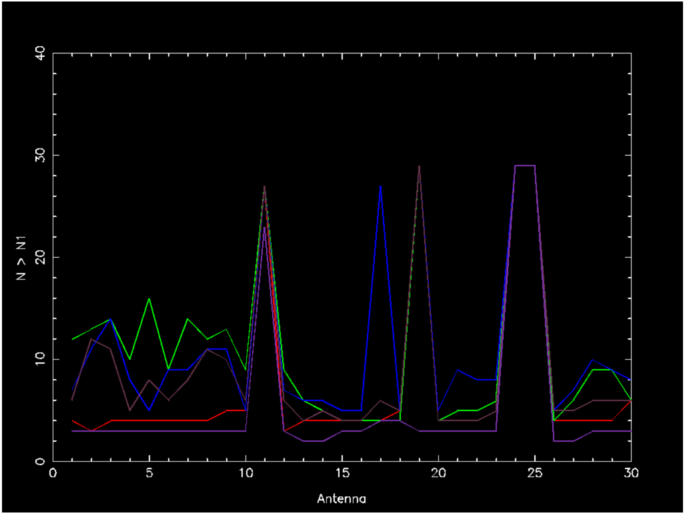
Time averaging visibilities (Flux calibrator)



Time averaging visibilities (Phase calibrator)



Bad Antennas



Thank You !