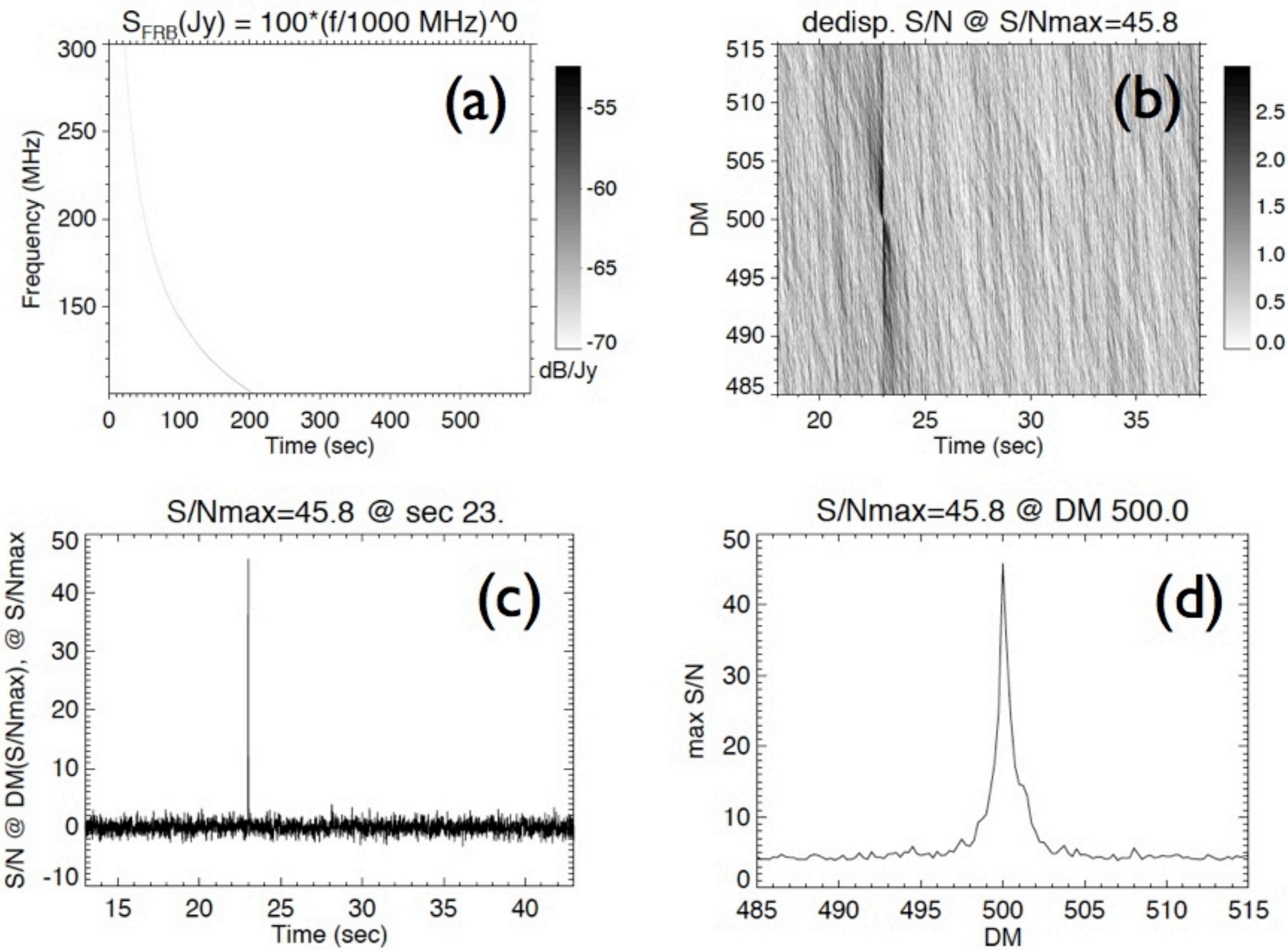
Additional simulations of Crab Giant Pulses + technical considerations

P. Zarka, 7-8/2018



S_FRB(Jy) = 100*(f/1000 MHz)^0
(a)
Frequency (MHz)
Time (sec)
dB/Jy
dedisp. S/N @ S/Nmax=45.8
(b)
DM
Time (sec)
S/Nmax=45.8 @ sec 23.
(c)
S/N @ DM(S/Nmax), @ S/Nmax
Time (sec)
S/Nmax=45.8 @ DM 500.0
(d)
max S/N
DM

We found that :

- with the full array (2e5 antennas) in single polarization and resolutions of 10 msec x 25 kHz across the 100-300 MHz band, a flat spectrum of 100 Jy is easily detected (at 45 σ for DM=500 or 1000, marginally dependent of DM). See Figure.

- spectrum flattening slightly improves detection (+5 to 10% sensitivity), smoothing significantly improves detection (+15 to 20% sensitivity). Both together provide the best result (S/N increased by ~25%).

- a 10x longer scattering tail reduces sensitivity by 30-40%

- with a short/medium scattering tail, an FRB with flat spectrum down to 30 Jy (or f^{-1} spectrum with 10 Jy at 1 GHz) is detected at 10-20 σ level.

- the S/N varies as $N^{1/2}$ with GRAND phase 1 we are at the detection limit of an FRB (30 Jy, f^0) or (10 Jy @ 1 GHz, f^{-1}) with a short scattering tail, but below the detection limit with a medium/long scattering tail (a flux ~3 x higher – i.e. (100 Jy, f^0) or (30 Jy @ 1 GHz, f^{-1}) – is detectable).

- no detection at the above level is possible with the test array. A flux density 10x larger is required (300 Jy, f^0) or (100 Jy @ 1 GHz, f^{-1}).

- as the recorded dynamic spectrum is large (60000 points in time x 8000 frequencies), no detection is possible below a S/N of 5-6 because there will always be noise peaks at this level in the data. Significant detection implies S/N > 6-7.

- restricting to the band 200-300 MHz marginally modifies (<10% difference in S/N) the detectability while reducing by x4 the dispersive time window. A possibly efficient method (not yet tested) should consist in detecting the FRB independently in 2 frequency bands and use coincidence for confirming detection. These bands can be disjoint (e.g. 100-200 and 200-300 MHz) or interleaved (e.g. consisting of (i) all odd MHz and (ii) all even MHz = 1 MHz square window convoluted with a Dirac comb at odd or even frequencies). The latter ensures (i) similar sensitivity in the 2 bands, and (ii) enough individual channels (of 25 kHz width) per band to have a ~0 intersection between the 2 bands. This should allow to reduce the minimum detectable S/N.

- 2x worse resolutions in (t,f), i.e. (20 msec x 50 kHz) reduces the S/N by 20-30%. Further integration strongly reduces the S/N. Detection of (30 Jy, f^0) FRB remains possible even at 100 msec x 200 kHz but becomes polluted by many false positives.

No influence of RFI has been considered. RFI should be mitigated before detection.

FRB detectability seems thus possible with GRAND at intensity levels comparable to the Lorimer [1] burst (30 Jy). The major uncertainty is the FRB spectrum – and even existence – at low-frequency, i.e. the turnover frequency. FRB may be from totally absent (if $f_{turnover} > 300$ MHz) or relatively strong (if the spectrum increases in f^{-n} with $n >> 1$). The expected large FoV should bring sensible constraints to FRB popupations if $f_{turnover}$ is low enough.

Detection algorithms can be further improved, and applied offline or online depending on the computing power and storage capacity.

Complementary simulations of FRB and Crab Giant Pulses detection with GRAND

We found that :

• with the full array, we can detect FRBs at DM = 500 down to 30 Jy (with a flat spectrum). With the Phase 1 array ~100 Jy (flat) or a spectrum in f^{-1} reaching 10 Jy at 1 GHz is needed. This corresponds to the first and stronger FRB detected (Lorimer et al., 2007).

• with these values, a S/N up to 13 is reached in the band 60 – 200 MHz, up to ~10 in the band 110-200 MHz, and ≤7-8 in the band 150 – 200 MHz. The latter seems insufficient for FRB detection.

• resolutions δt δf = 10 msec 25 kHz provides the best sensitivity. It is degraded by 20-40% with 20 msec x 50 kHz resolutions.

• a scattering time of several msec to tens of msec (at 100 MHz, varying in λ^4) improves detectability compared to a short pulse.

• the use of 2 interleaved bands slightly improves detectability, reduces the rate of false positives, and in particular it seems to make (30 Jy, flat) FRB detectable (at low S/N ~4-5 in each band) with δf up to 100 kHz. If it is absolutely necessary to use such a broad bandwidth, this may be a way of retaining sensitivity, but sensitivity is larger with narrower channels (~25 kHz).

• Crab Giant Pulses are very easily detectable at all resolutions and total bandwidth with the full and phase 1 arrays. GPs much stronger than a few 100s Jy will be detectable with the test array.

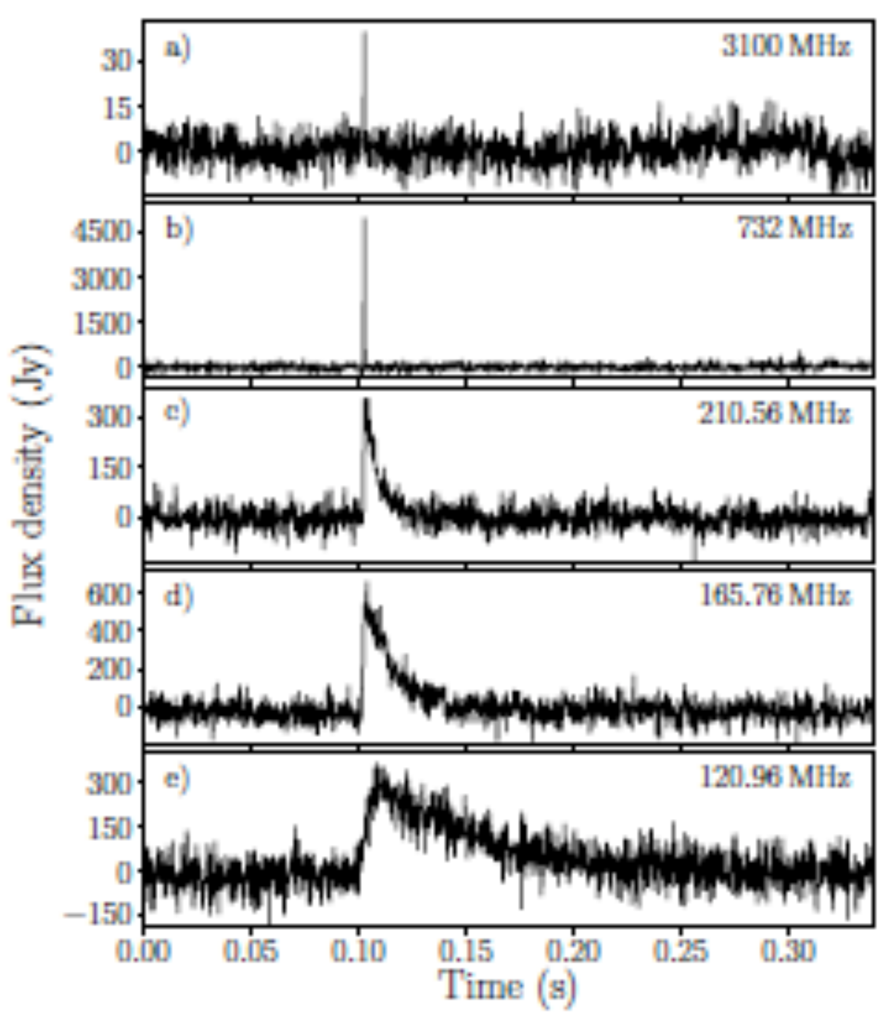
• MWA paper by Meyers => reasonable values for Crab GP fluence ~1 Jy.sec, scatteting tail length ~10 msec @ 100 MHz

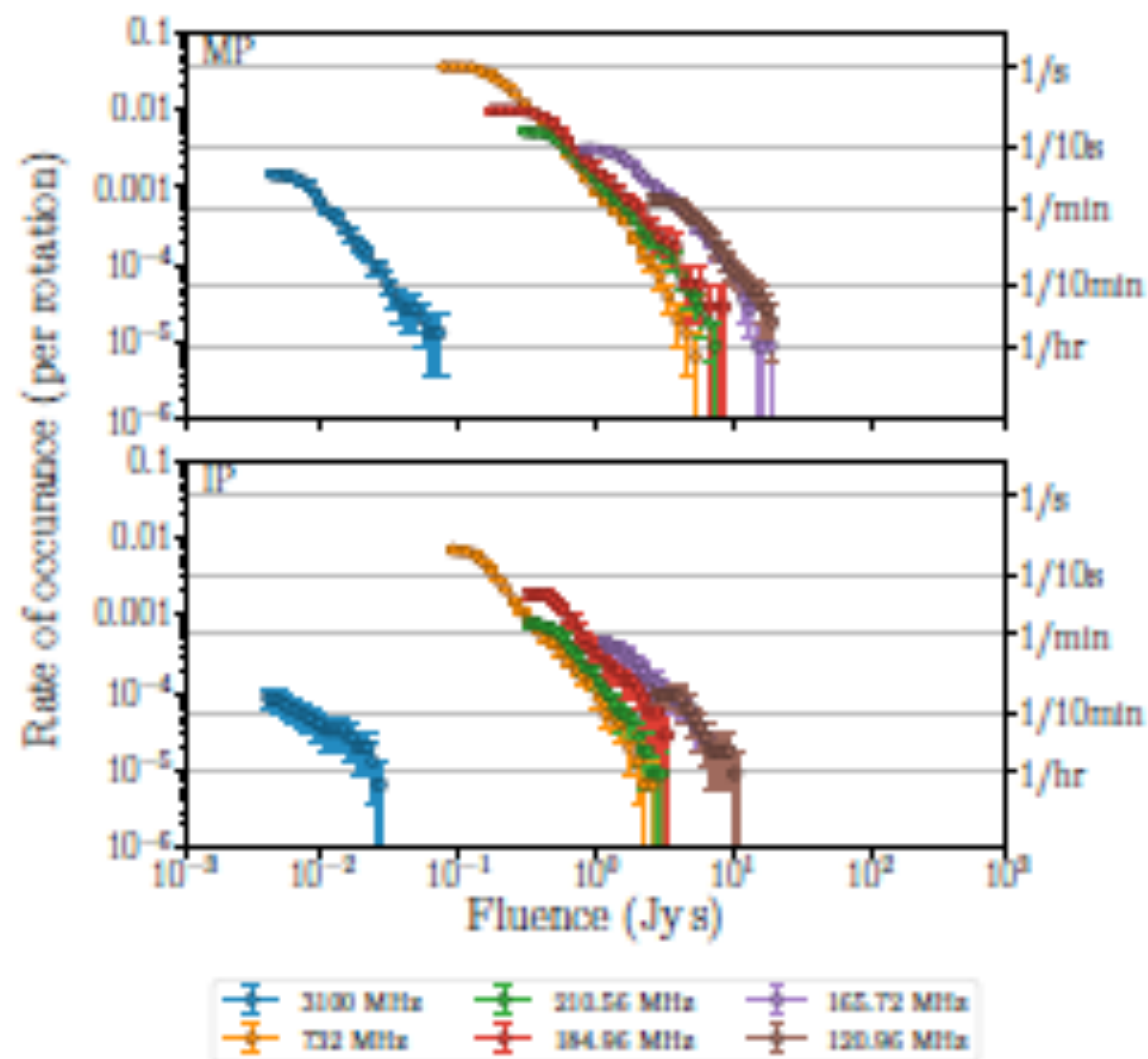
Draft version April 4, 2018
Preprint typeset using LaTeX style AASTeX6 v. 1.0

SPECTRAL FLATTENING AT LOW FREQUENCIES IN CRAB GIANT PULSES

B. W. Meyers[1,2], S. E. Tremblay[1], N. D. R. Bhat[1], R. M. Shannon[2], F. Kirsten, M. Sokolowski[1], S. J. Tingay and S. I. Oronsaye[1]
International Centre for Radio Astronomy Research (ICRAR), Curtin University
1 Turner Ave., Technology Park,
Bentley, 6102, WA, Australia

S. M. Ord
Commonwealth Scientific and Industrial Research Organisation (CSIRO)
Corner Vimiera & Pembroke Roads
Marsfield, 2122, NSW, Australia





Additional simulations of Crab Giant Pulses + technical considerations (7-8/2018)

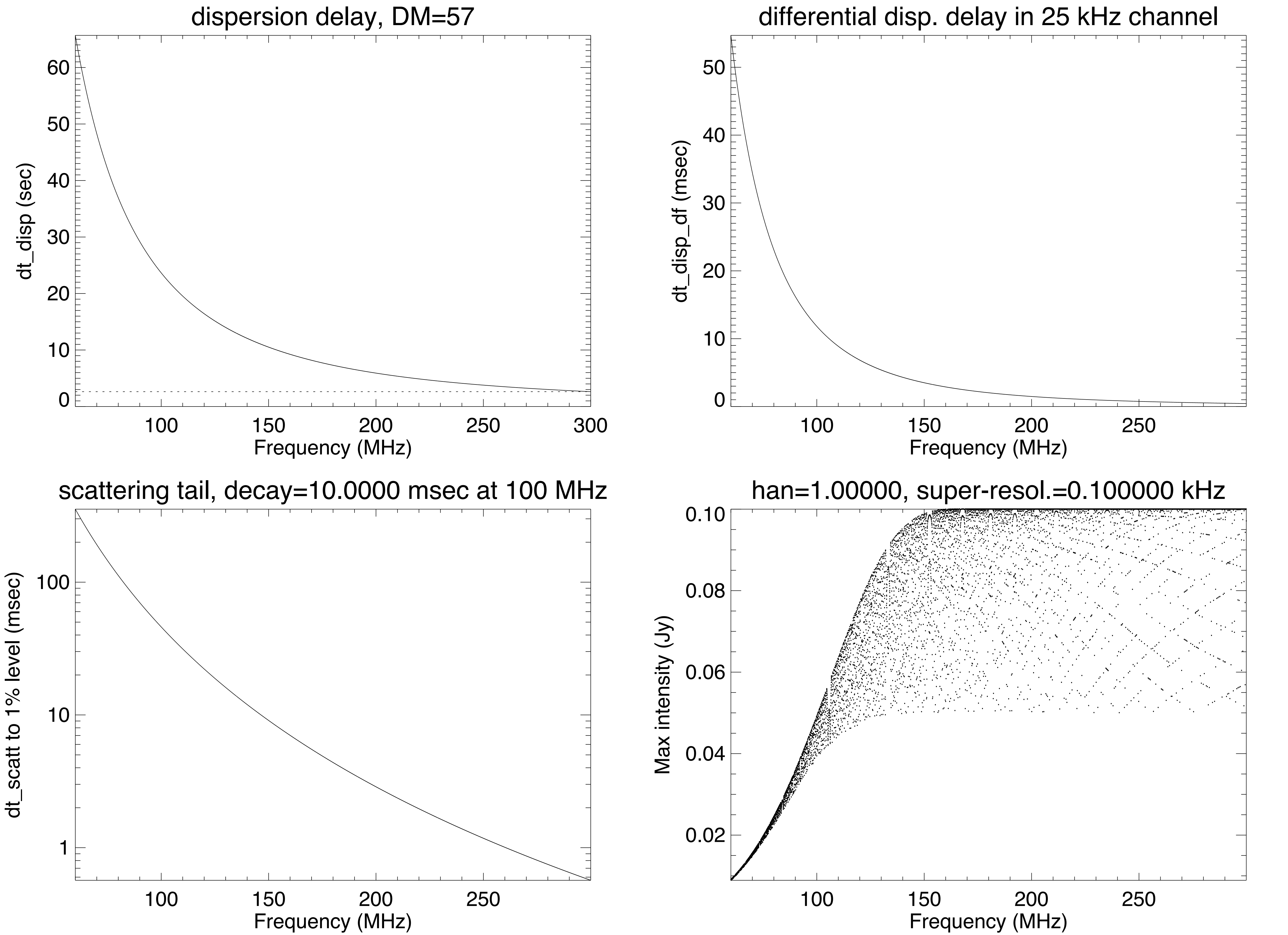
- S/N = 50-60 σ detection with 2^{e}5 antennas x 2 polar, 10 msec x 25 kHz, little dependent of frequency range (100-200 MHz Ok)

- S/N reduces with t-f integration beyond 10 msec x 25 kHz

- better not to use the band <100 MHz (larger dispersion, differential dispersion, and scattering)

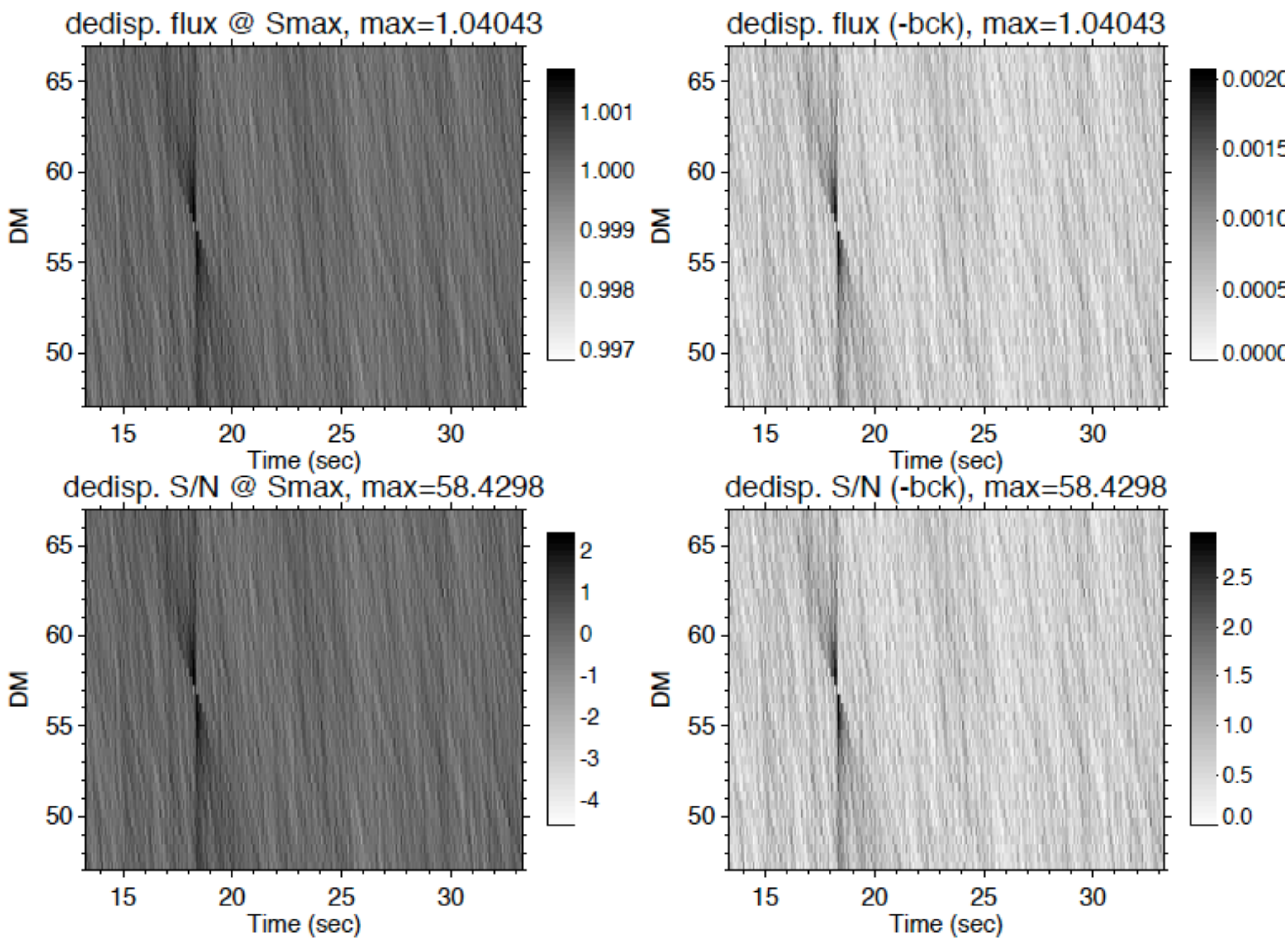
- scattering tail ~50 msec @ 100 MHz, 3 msec @ 200 MHz

- with 300 antennas, S/N / 26 => ~2σ => need to gain a factor 3 for detection (stronger pulses, 5 msec integration)



dispersion delay, DM=57
dt_disp (sec)
0
10
20
30
40
50
60
100
150
200
250
300
Frequency (MHz)
differential disp. delay in 25 kHz channel
dt_disp_df (msec)
0
10
20
30
40
50
100
150
200
250
Frequency (MHz)
scattering tail, decay=10.0000 msec at 100 MHz
dt_scatt to 1% level (msec)
1
10
100
100
150
200
250
Frequency (MHz)
han=1.00000, super-resol.=0.100000 kHz
Max intensity (Jy)
0.02
0.04
0.06
0.08
0.10
100
150
200
250
Frequency (MHz)

DETECT_FRB, 'gp_grand_57',1000.,100.,-0.7, 200,300, 0,0, DM_test, 632, 'dipole', 'gp_grand_57_df1_nb', /flat, /smo SNRmax = 52
DETECT_FRB, 'gp_grand_57',1000.,100.,-0.7, 100,200, 0,0, DM_test, 632, 'dipole', 'gp_grand_57_df2_nb ', /flat, /smo SNRmax = 58
DETECT_FRB, 'gp_grand_57',1000.,100.,-0.7, 60,200, 0,0, DM_test, 632, 'dipole', 'gp_grand_57_df3_nb ', /flat, /smo SNRmax = 53
DETECT_FRB, 'gp_grand_57',1000.,100.,-0.7, 60,100, 0,0, DM_test, 632, 'dipole', 'gp_grand_57_df4_nb ', /flat, /smo SNRmax = 18
DETECT_FRB, 'gp_grand_57',1000.,100.,-0.7, 200,300, 0.020,0.050, DM_test, 632, 'dipole', 'gp_grand_57_int1_nb ', /flat, /smo SNRmax = 42
DETECT_FRB, 'gp_grand_57',1000.,100.,-0.7, 200,300, 0.050,0.100, DM_test, 632, 'dipole', 'gp_grand_57_int2_nb ', /flat, /smo SNRmax = 29



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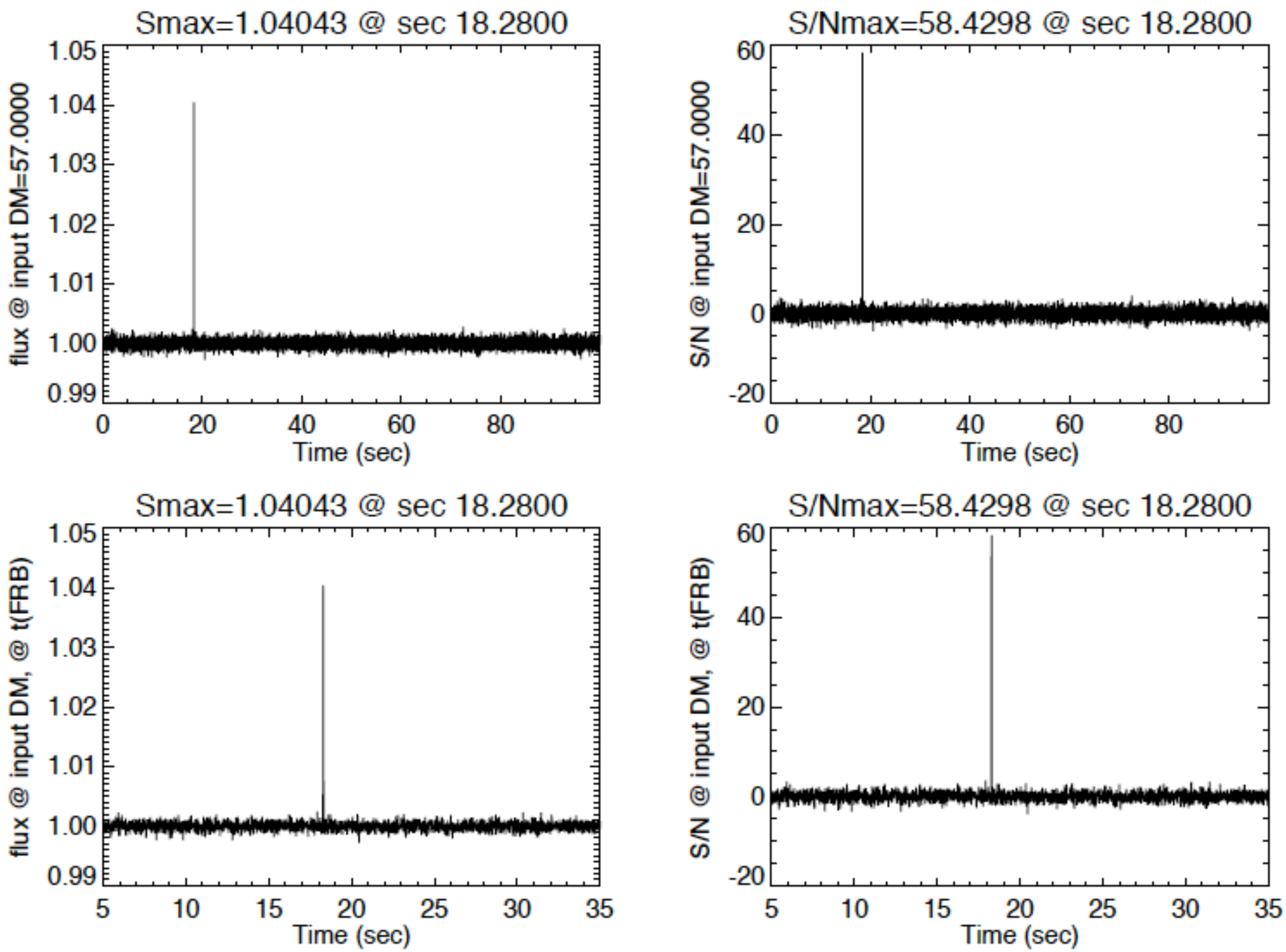

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- 3 FRB detected at 111 MHz with 100 msec x 2.5 MHz (Aeff ~ 30000 m^2), S/N ~ 6 – 9
- tests TBD soon with NenuFAR
- synergy with HF simultaneous observations for tests
- possible detection of many pulsars of period >10-20 msec

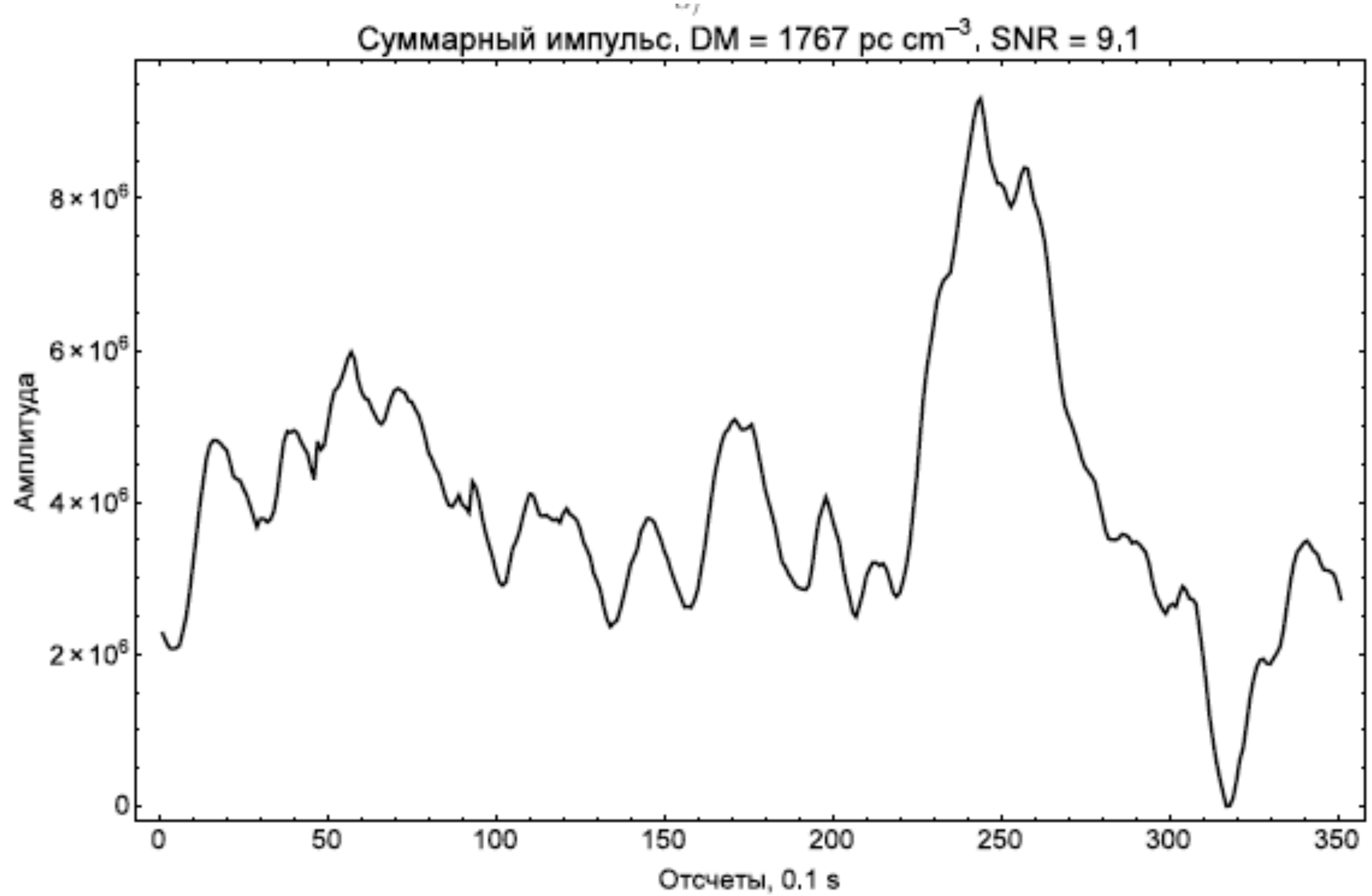
Detection of Fast Radio Bursts at the LPA LPI Radio Telescope

A.E. Rodin, V.A. Fedorova, V.A. Samodourov, and S.V. Logvinenko

Pushchino Radio Astronomy Observatory
Astrospace Centre, P.N. Lebedev Physical Institute, Russian Academy of Sciences
Pushchino, Moscow Region, 142290 Russia
E-mail: rodin@prao.ru

Received May 23, 2018

Abstract. We present results of searching for single pulse signals at the LPA LPI radio telescope at a frequency of 111 MHz in 2012–2018. Areas around FRB 121102 ($\alpha = 05^{\mathrm{h}}32^{\mathrm{m}}$, $\delta = 33°05'$) and $\alpha = 05^{\mathrm{h}}32^{\mathrm{m}}$, $\delta = 41°40'$ were analysed. We detected three radio bursts with $DM = 247$, 570, and 1767 $\mathrm{pc\,cm^{-3}}$.



• 25 kHz resolution => 40 μsec time window (20000 samples @ 2 nsec => 16384) for FFT ; integrate 125-250 power spectra before transmission

• reduce data rate via :

- send only 100-200 MHz band = 4000 x 25 kHz
- df prop. f^3 (differential dispersion) => reduce to <2000 effective channels
- white the spectrum by Galactic background slope => 8 bits

=> results in a rate = 2000 bytes / 5-10 msec = 200-400 kbytes / sec / antenna (2 polar)