Matthew Bailes + HITRUN team.

A Population of Fast Radio Bursts at Cosmological Distances

D. Thornton,[1,2]* B. Stappers,[1] M. Bailes,[3,4] B. Barsdell,[3,4] S. Bates,[5] N. D. R. Bhat,[3,4,6] M. Burgay,[7] S. Burke-Spolaor,[8] D. Champion,[9] P. Coster,[2,3] N. D'Amico,[7,10] A. Jameson,[3,4] S. Johnston,[2] M. Keith,[2] M. Kramer,[9,1] L. Levin,[5] S. Milia,[7] C. Ng,[9] A. Possenti,[7] W. van Straten[3,4]

Searches for transient astrophysical sources often reveal unexpected classes of objects that are useful physical laboratories. In a recent survey for pulsars and fast transients, we have uncovered four millisecond-duration radio transients all more than 40° from the Galactic plane. The bursts' properties indicate that they are of celestial rather than terrestrial origin. Host galaxy and intergalactic medium models suggest that they have cosmological redshifts of 0.5 to 1 and distances of up to 3 gigaparsecs. No temporally coincident e- or gamma-ray signature was identified in association with the bursts. Characterization of the source population and identification of host galaxies offers an opportunity to determine the baryonic content of the universe.

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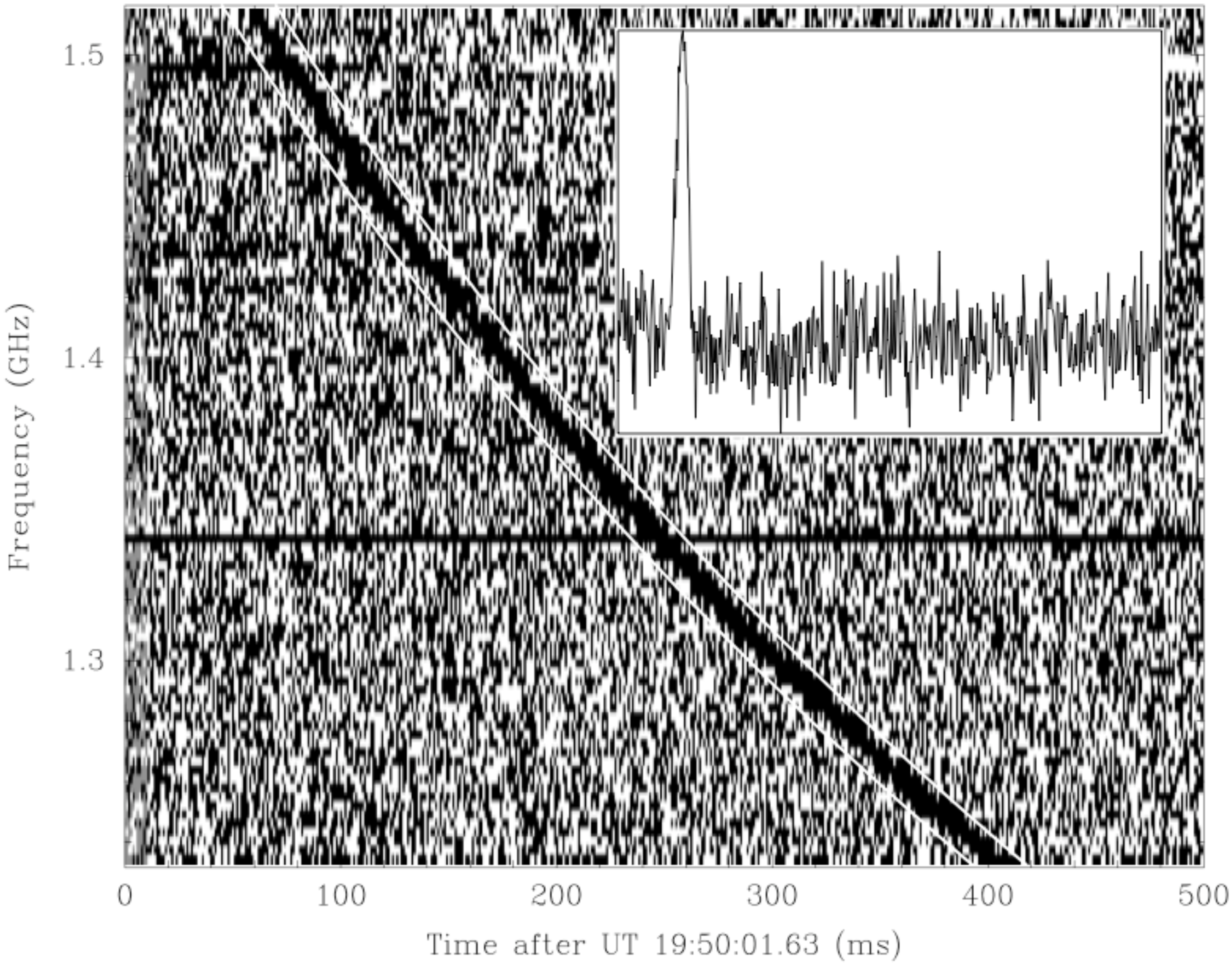
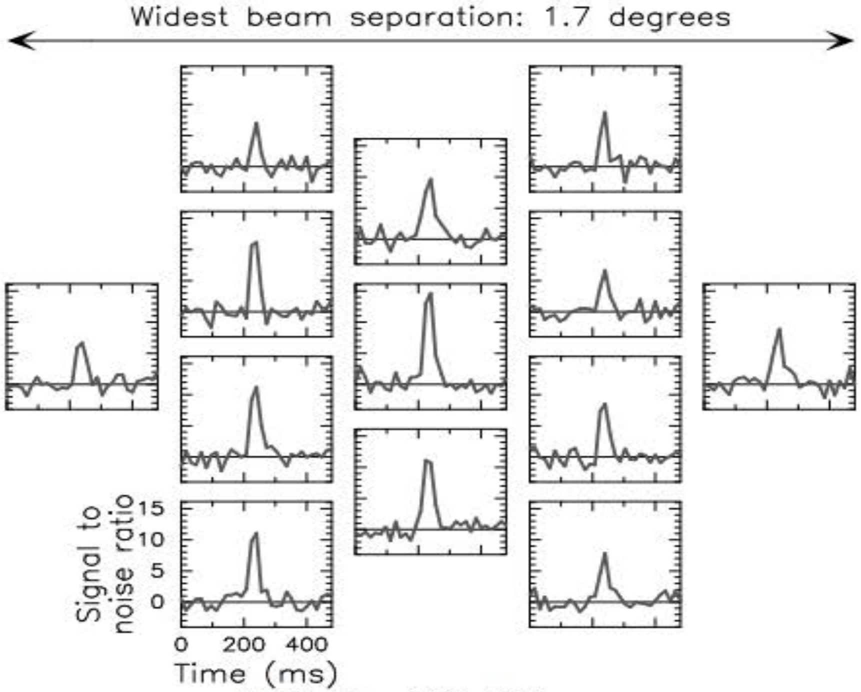
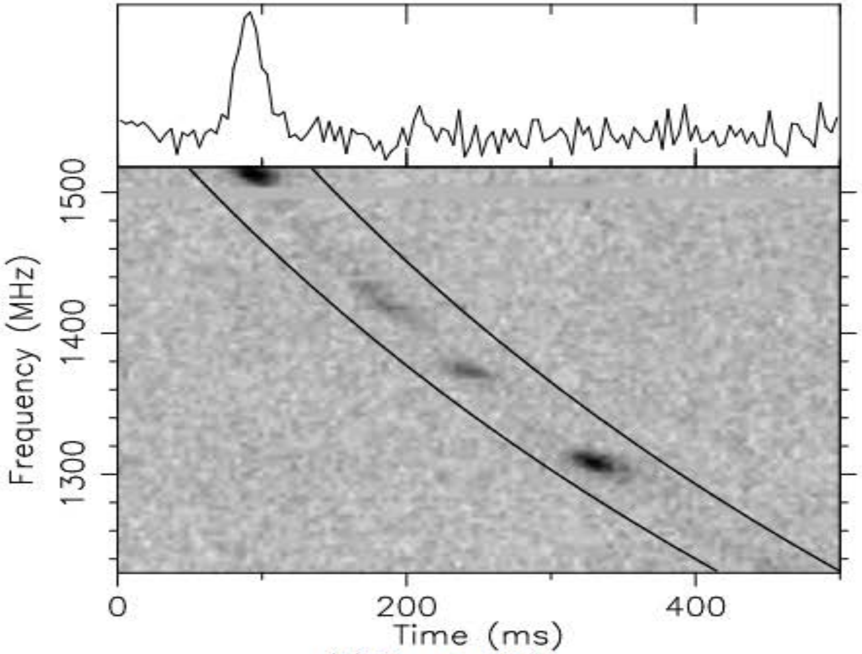
LORIMER BURST (2001 data, published in Lorimer et al. 2007)

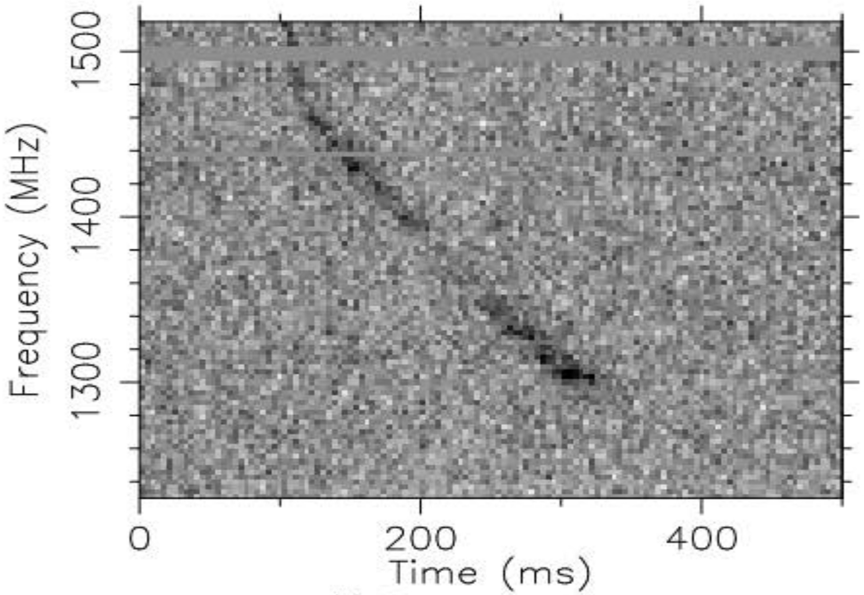




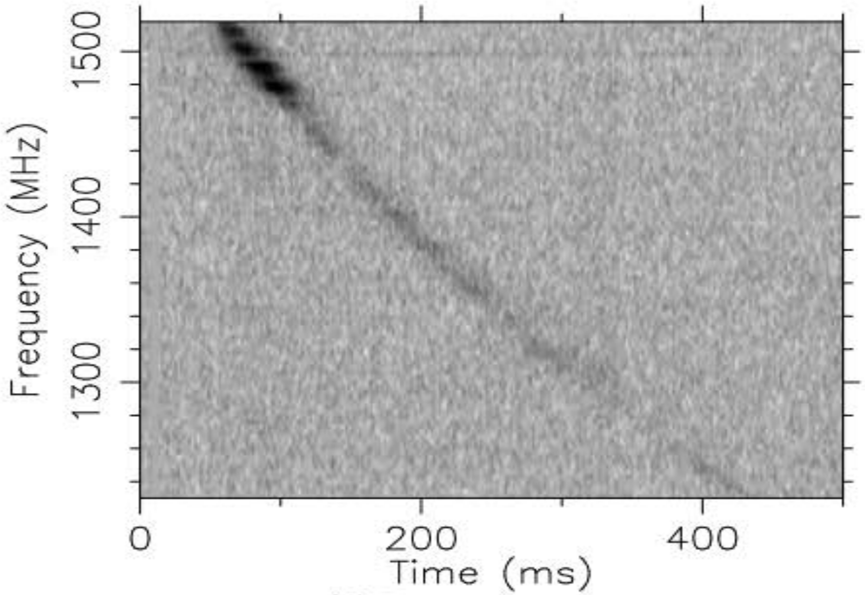
(a) Peryton 08 in 13 beams



(b) Peryton 08



(c) Peryton 06

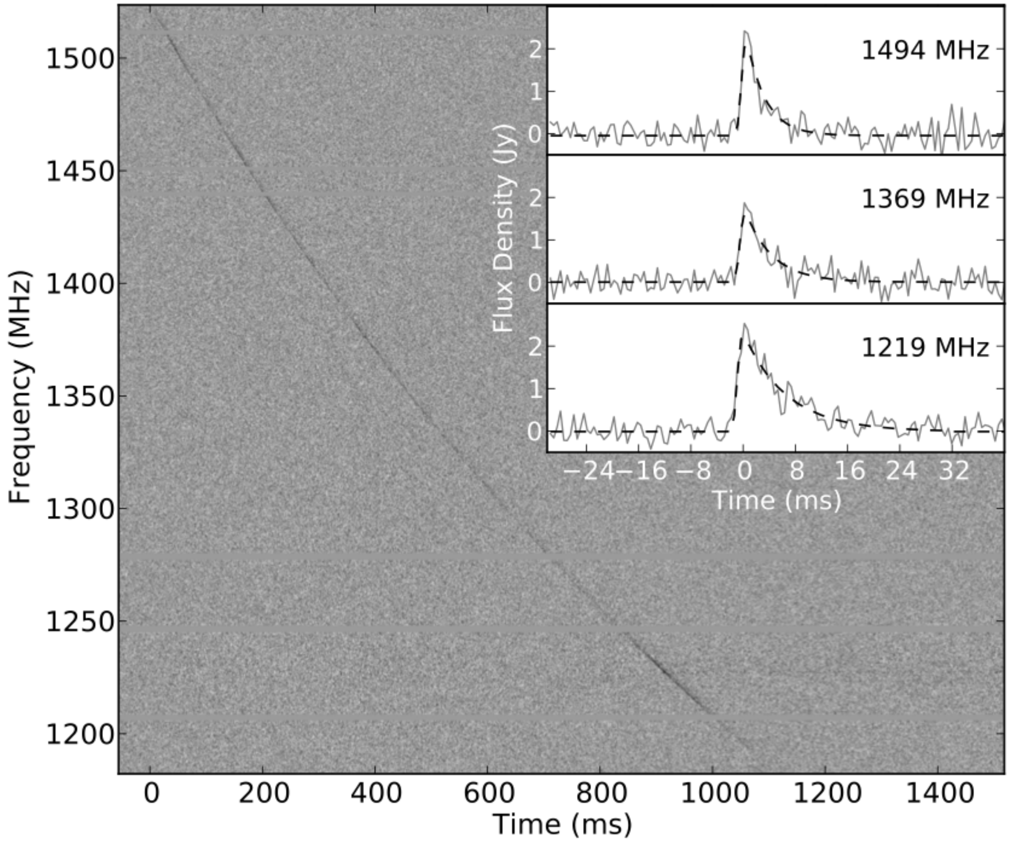


(d) Peryton 15

EMBARGOED – Thornton et al 2013 (in prep)

FRB 110220 – the brightest

- DM = 944 cm^{-3} pc; W = 5.6 ms
- Evidence of scatter broadening



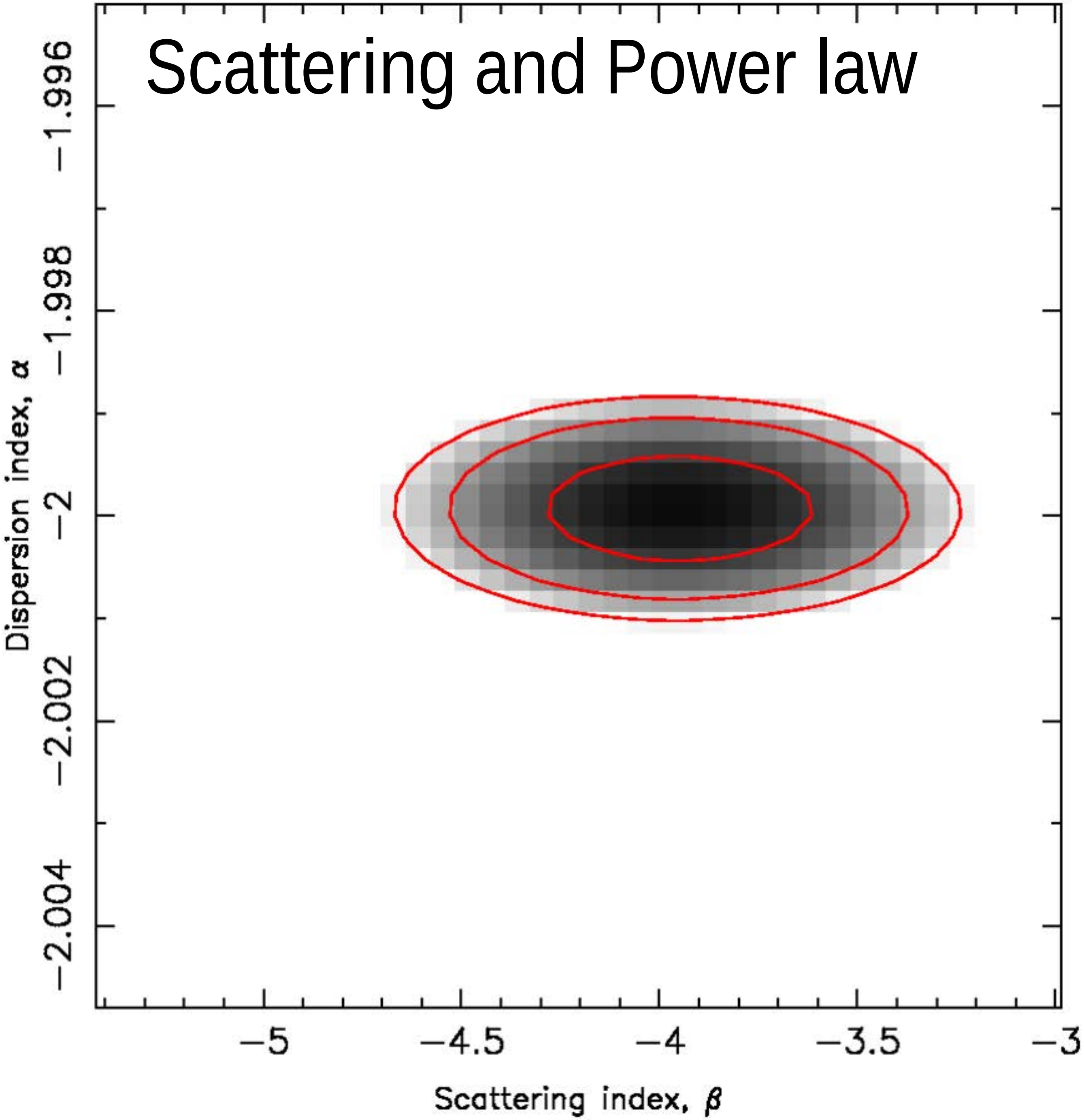
- Bright enough to fit the pulse shape as a fn. of frequency to find dispersion & scattering indices

$$\delta t \propto \nu^{-2.003\pm0.006}$$

$$W \propto \nu^{-4\pm0.4}$$

Intrinsic width unresolved!

Scattering and Power law



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More bursts

- DMs
  - 995 pc/cc
  - 723 pc/cc
  - 1103 pc/cc
  - 553 pc/cc
- + 8(!) more

Spitler et al.

Petroff et al.

Shannon/Ravi

Bannister/Burke-Spolaor

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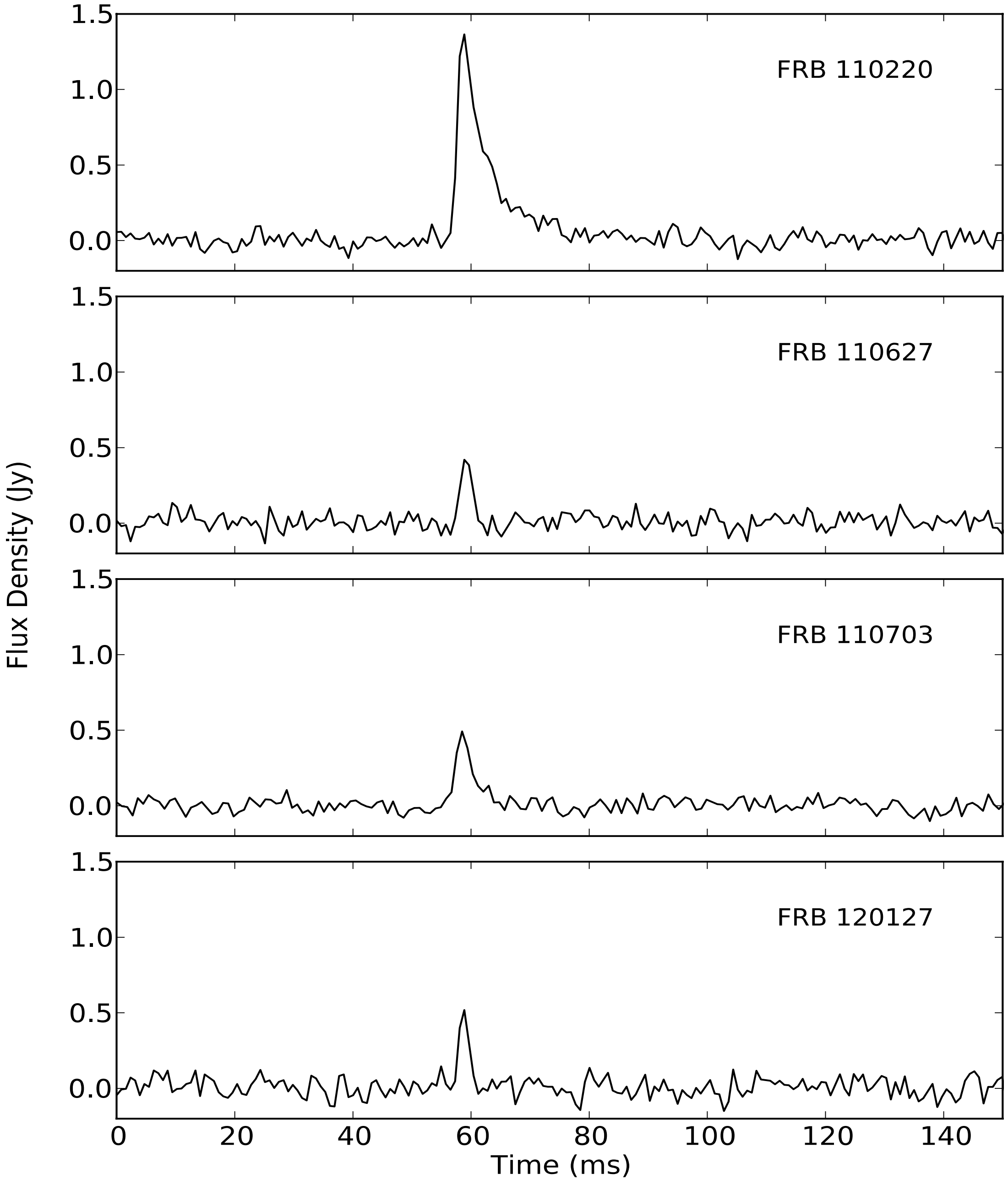

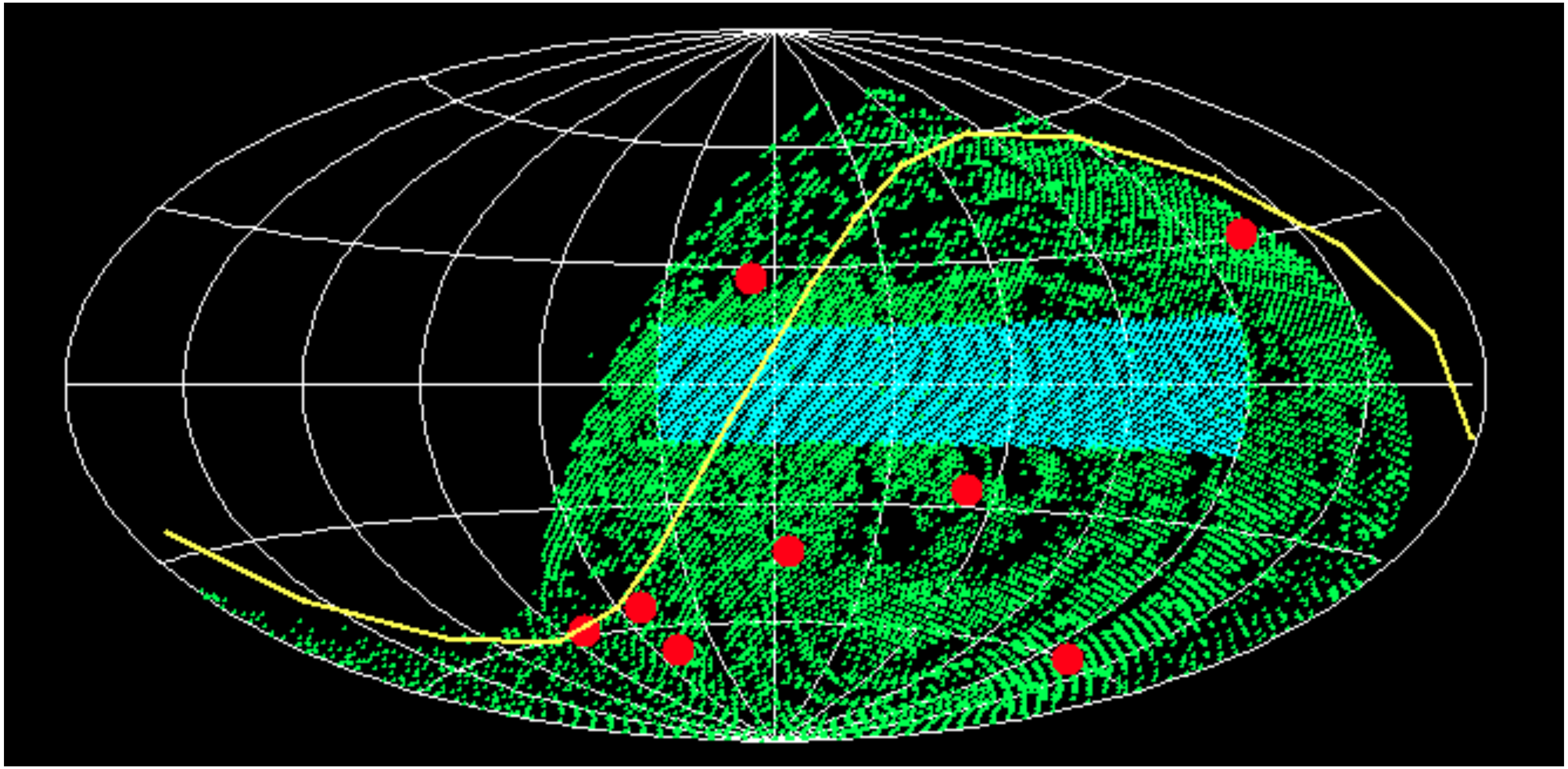

Green: High-Lat = 4.5 mins/pt. Sky south of dec 0

Blue: Med-Lat = 9 mins/pt. |gb|<15 & 240 < gl < 30

Red: FRB locations

Yellow: Ecliptic plane

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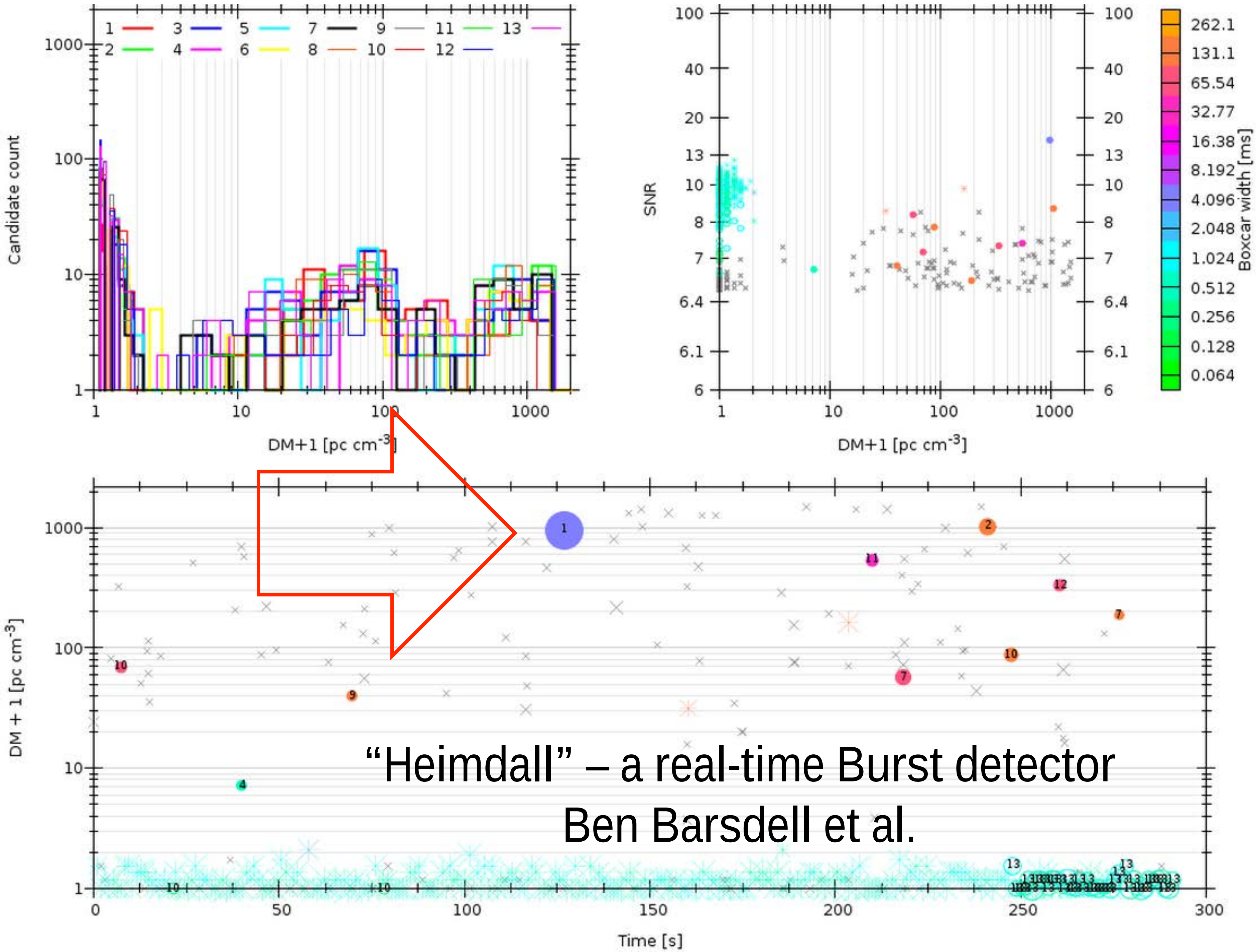

“Heimdall” – a real-time Burst detector

Ben Barsdell et al.

Murchison Widefield Array?

To appear in ApJL

Prospects for the Detection of Fast Radio Bursts with the Murchison Widefield Array

Cathryn M. Trott[1,2], Steven J. Tingay[1,2] and Randall B. Wayth[1]

International Centre for Radio Astronomy Research, Curtin University, Bentley WA 6845, Australia

cathryn.trott@curtin.edu.au

Event rate between 110/day and 0.1/day!

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Miscellaneous Radio Astronomy

A Search for Transient Events at 843 MHz

S. W. Amy, M. I. Large, *School of Physics, University of Sydney*
A. E. Vaughan, *School of Mathematics, Physics, Computing and Electronics, Macquarie University*

Abstract: The Molonglo Observatory Synthesis Telescope is equipped with a transient event monitoring system which operates during normal synthesis observations. The device is

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Amy's Rate (single channel FRB detector).

12-hour observation. Sample counts show that the rate is 1.7×10^{-2} events s^{-1} sr^{-1}, or 163 events yr^{-1} $(sq.deg)^{-1}$, and this can be taken as an upper limit on the rate of celestial radio pulses at 843 MHz, having an energy density $\geq 10^{-28}$ J m^{-2} Hz^{-1}, and $\tau \sim 5$ ms (excluding known pulsars). Previous searches for radio

163/365*40,000 ~ 18,000 events/sky/day

Thornton rates ~ 10,000 events/sky/day

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Molonglo Radio Telescope
Anne Green (Sydney)
Duncan Campbell-Wilson →
Dick Hunstead (Sydney)
Tim Bateman (CASS)
Russ McWhirter (Haystack)
Andrew Jameson (Swinburne)
Matthew Bailes, Ewan Barr, Chris Flynn, Evan
Keane, Fabian Jankowski (Swinburne)
Manisha Caleb (ANU), Nie Jun (Urumqi)

Background

- MOST is the largest radio telescope in Australia: 5xPKS, 4xASKAP
- Development work on digital back-end began around 2005: PFB + correlator, 100 MHz BW, 700-1100 MHz
  - Project backend stalled.
- August 2012 Swinburne floated alternative correlator solution: GPU cluster, with fast sampling (10 Gb/s, 10 GbE)

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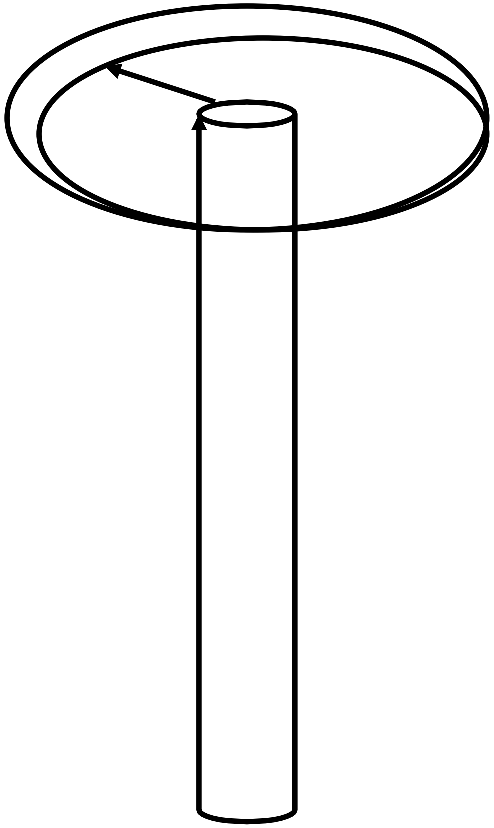
Smallest element:



- RH Circular Polarisation
- 843 MHz
- ~20 cm apart
- 0.2 x 11 metres wide
- ~2.2 m^2 "telescope"
- 7,744 ring antennae
- ~18,000 m^2
- Sensitivity ~ 0.3-0.5 x PKS

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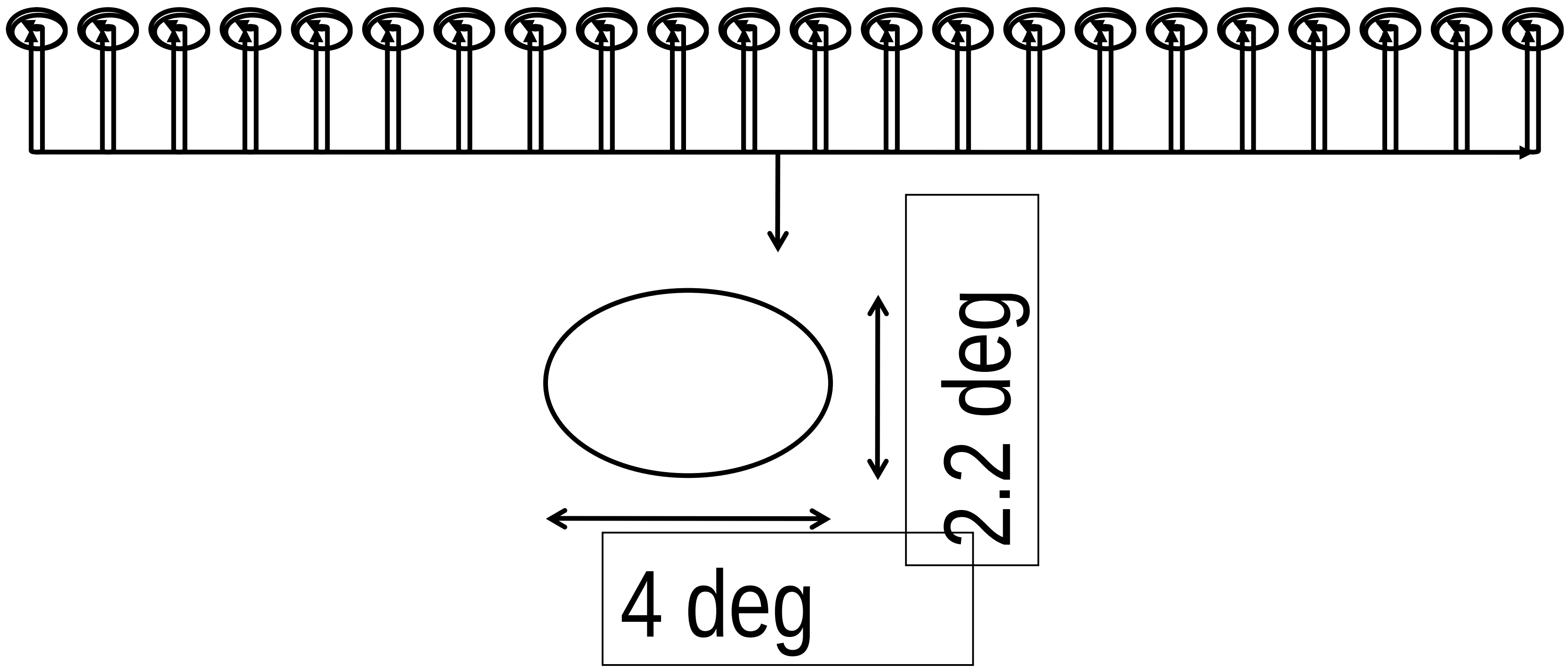
“Add by 22 = Phased array Beam”



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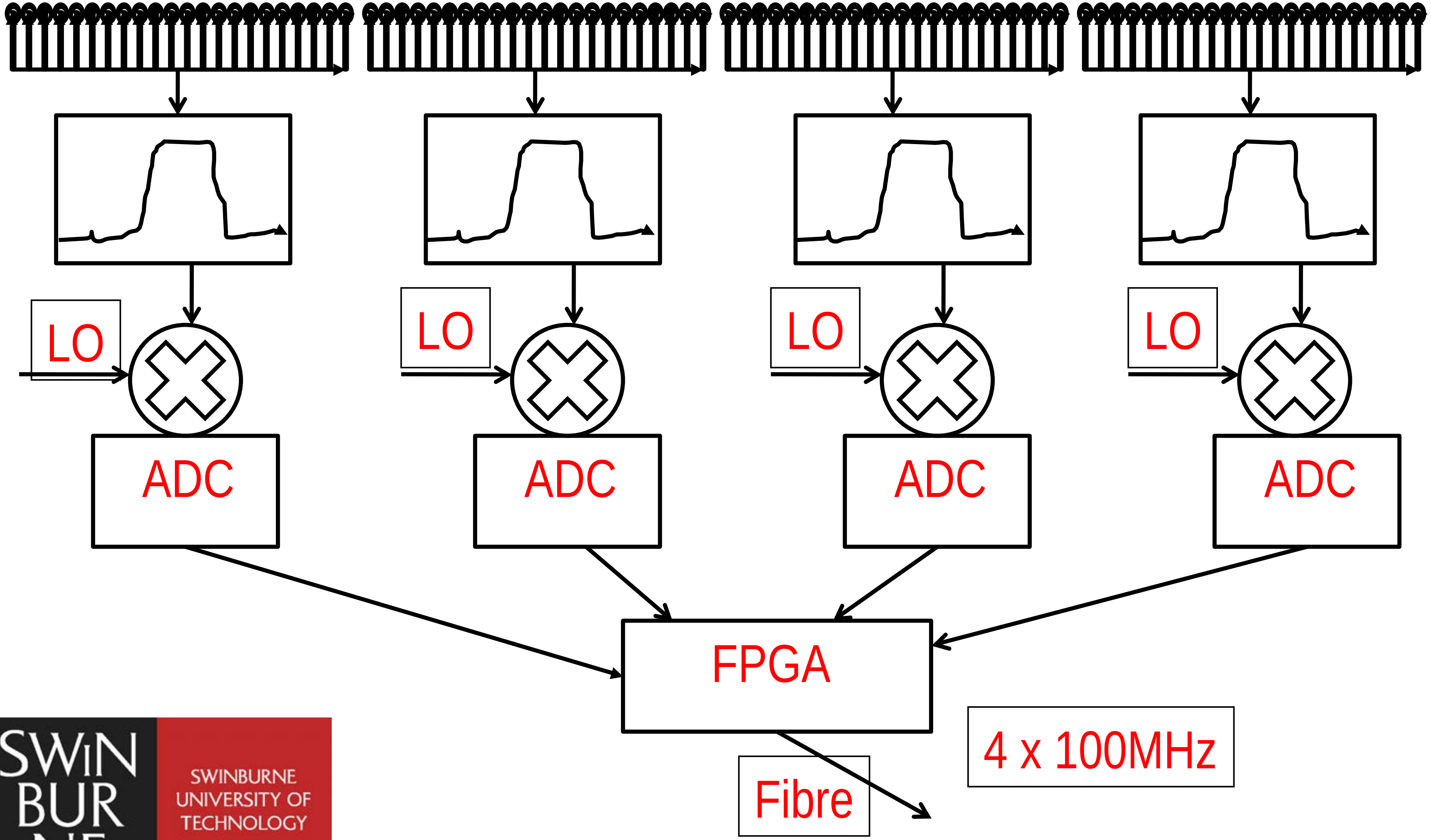
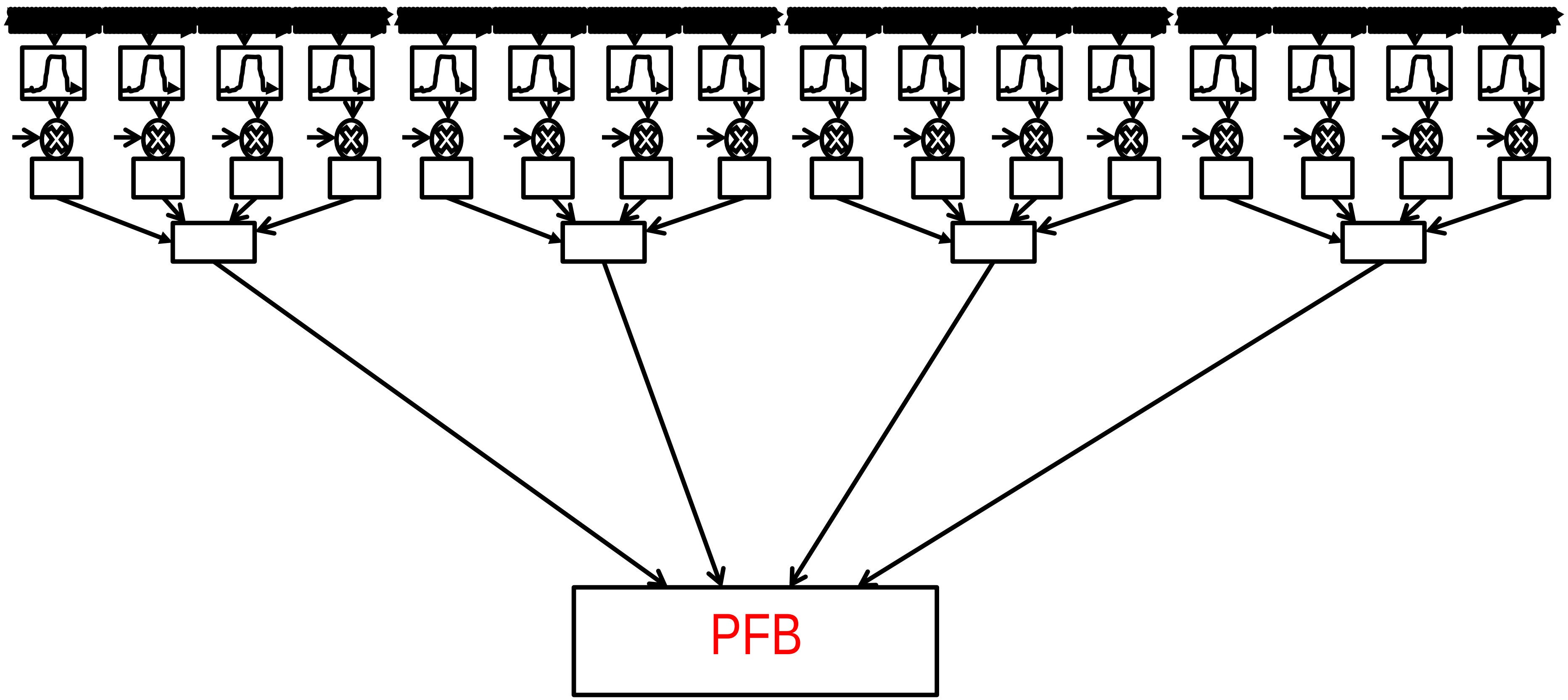
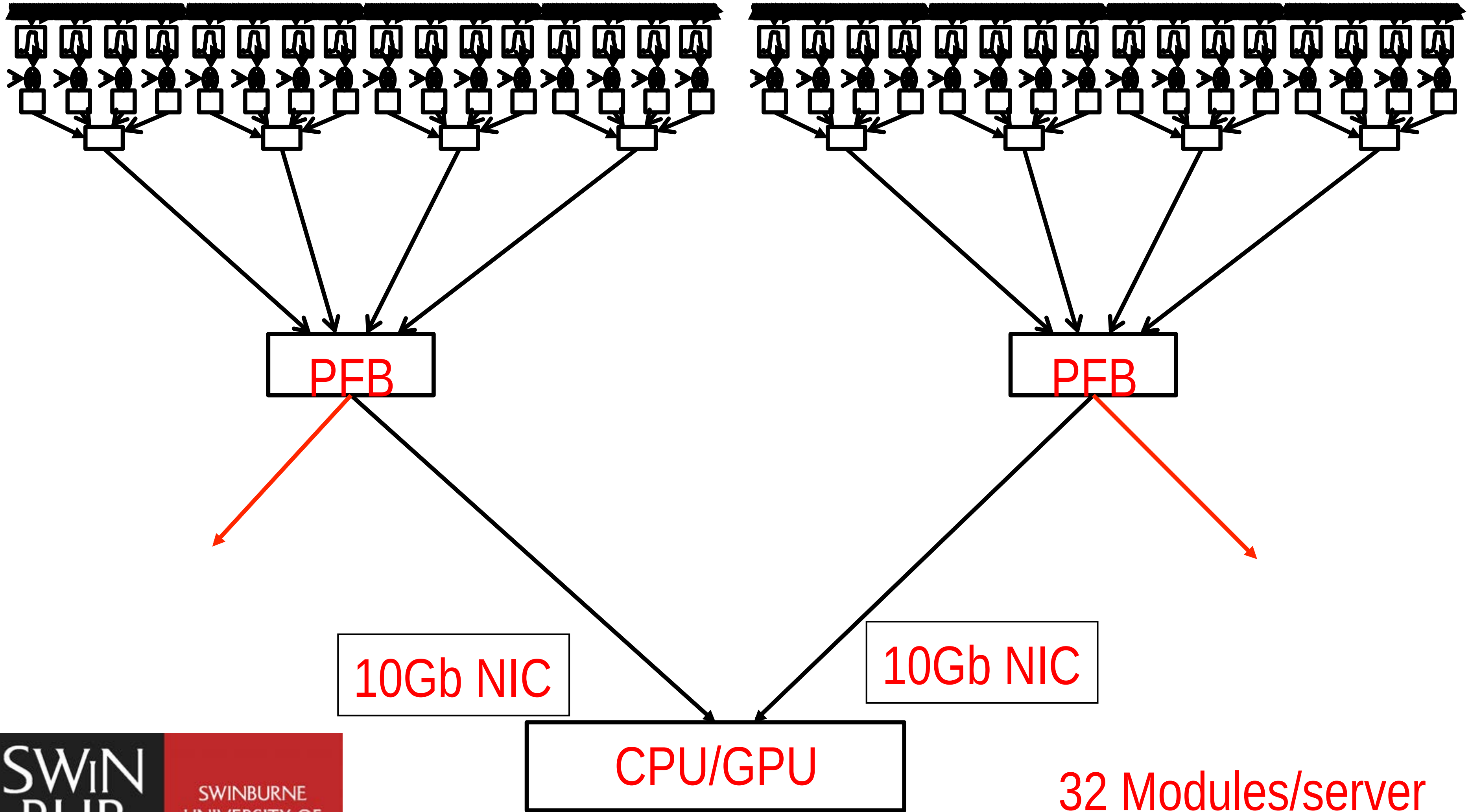
Receivers take 4 “Modules” = 1 “Bay”



4 x 4 modules = Hex



New CPU/GPU Design (dual 10Gb NIC)



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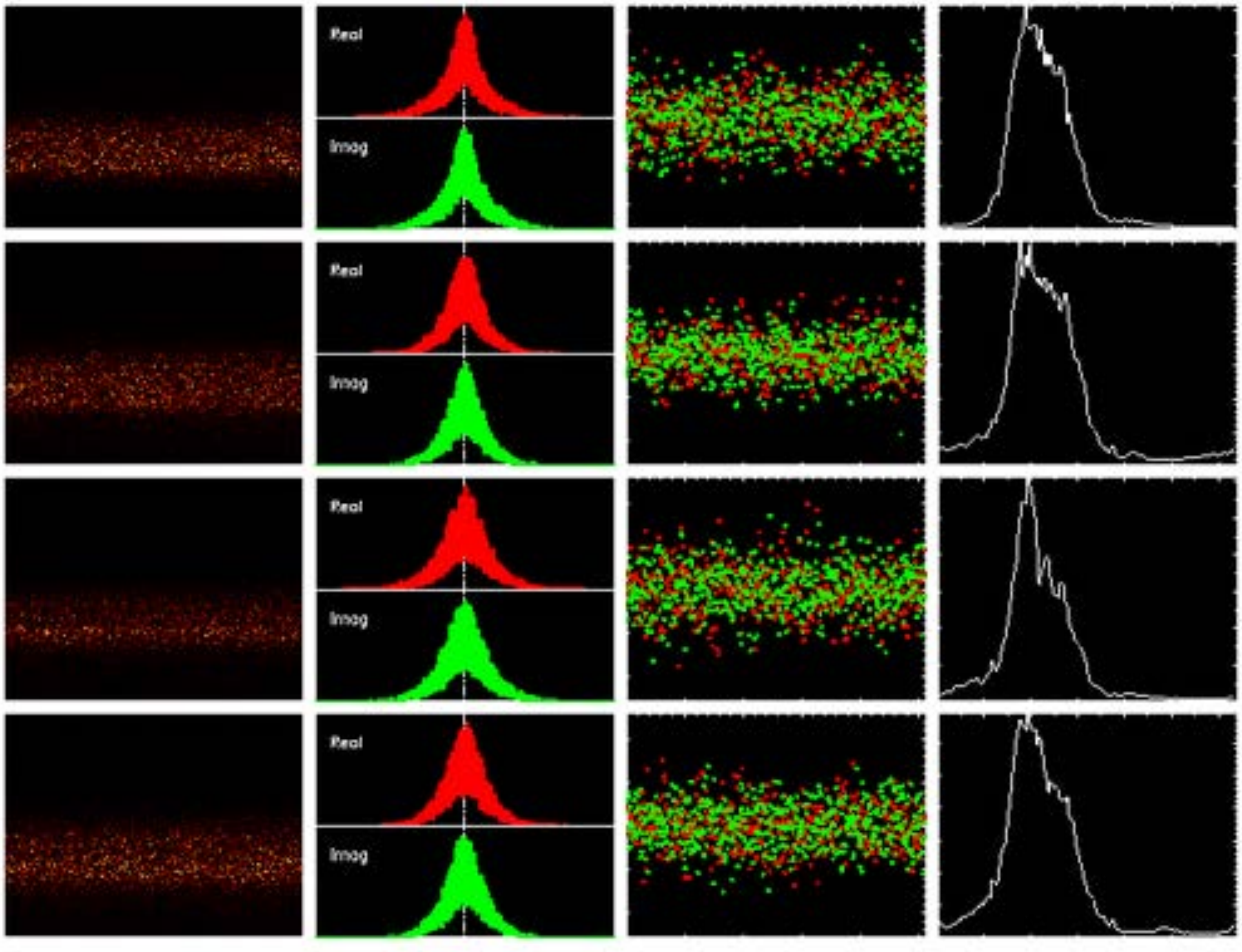
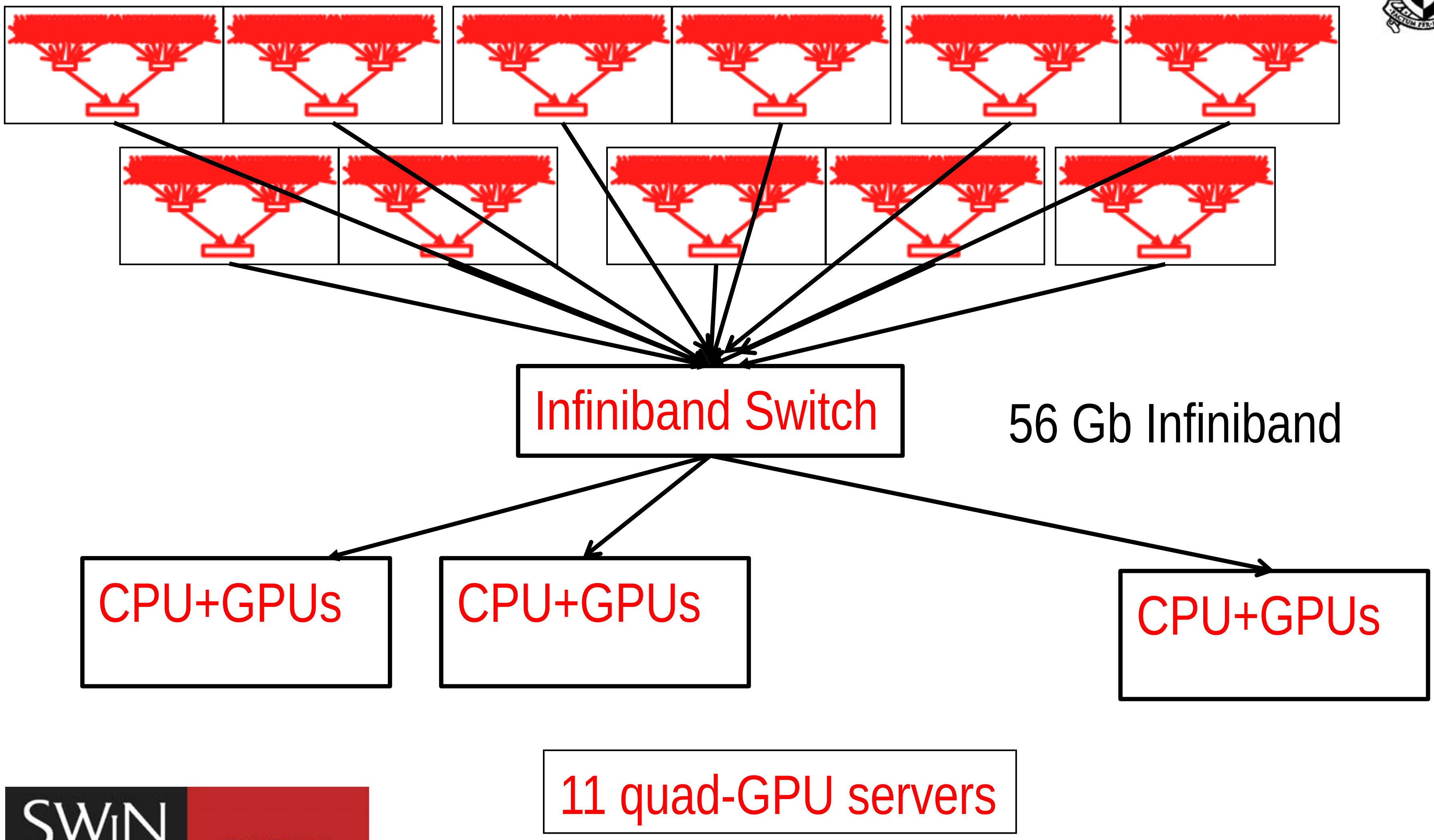
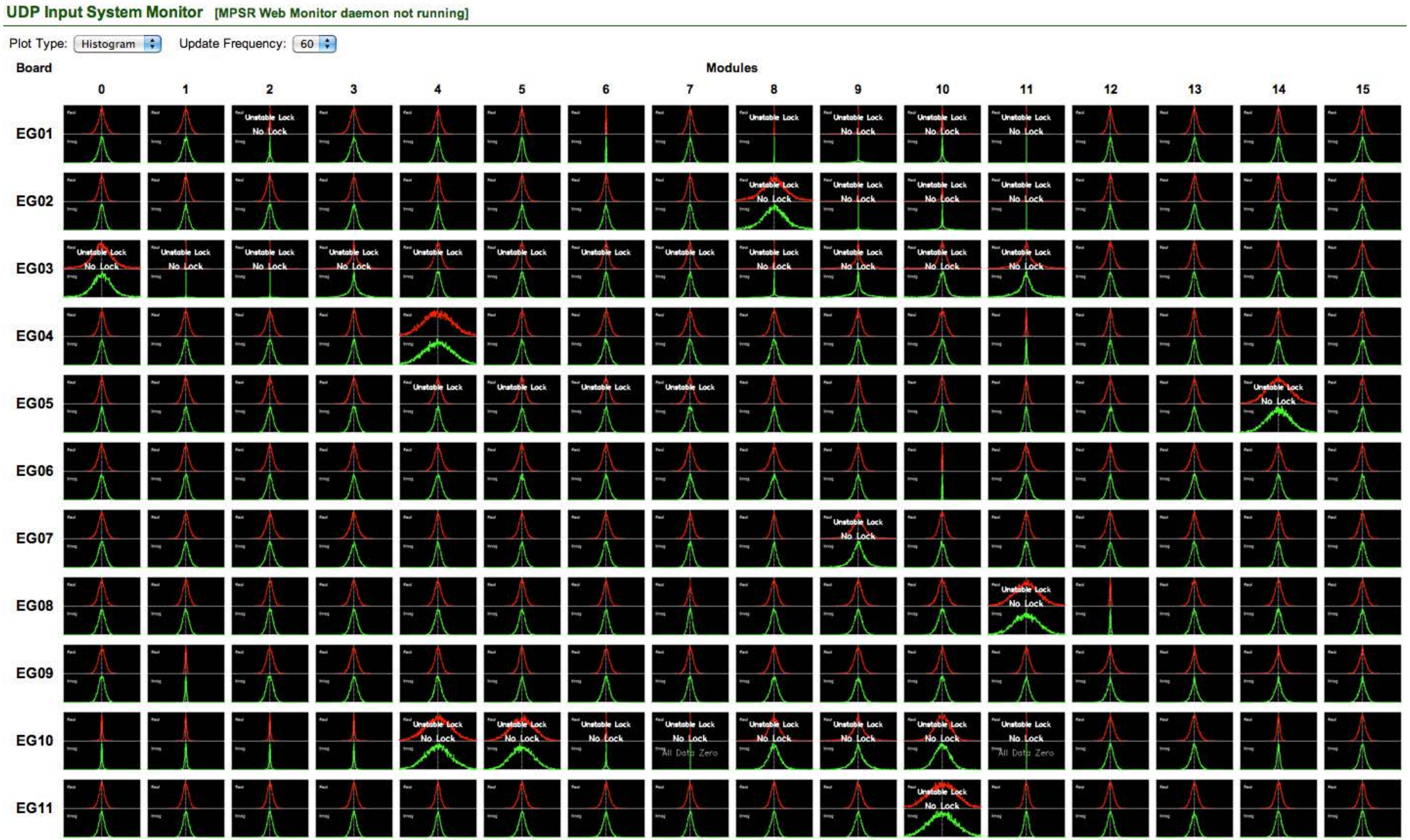
Example of new RX board on sky!



New Design (dual 10Gb NIC)





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Novel Parts (DAQ nodes)

22 GB/s
1.9 PB/d!

- Perform a spectral kurtosis analysis (how non-Gaussian are my voltages?) on GPUs
- Replace by gaussian random noise.
- Apply FIR filter for delay correction.
  - Corner turn voltages via RDMA on Infiniband.
- Can then:
  - Form tied array beam
  - Form fan beams (and search for bursts)
  - Dedisperse any pulsar
  - Run an FX correlator

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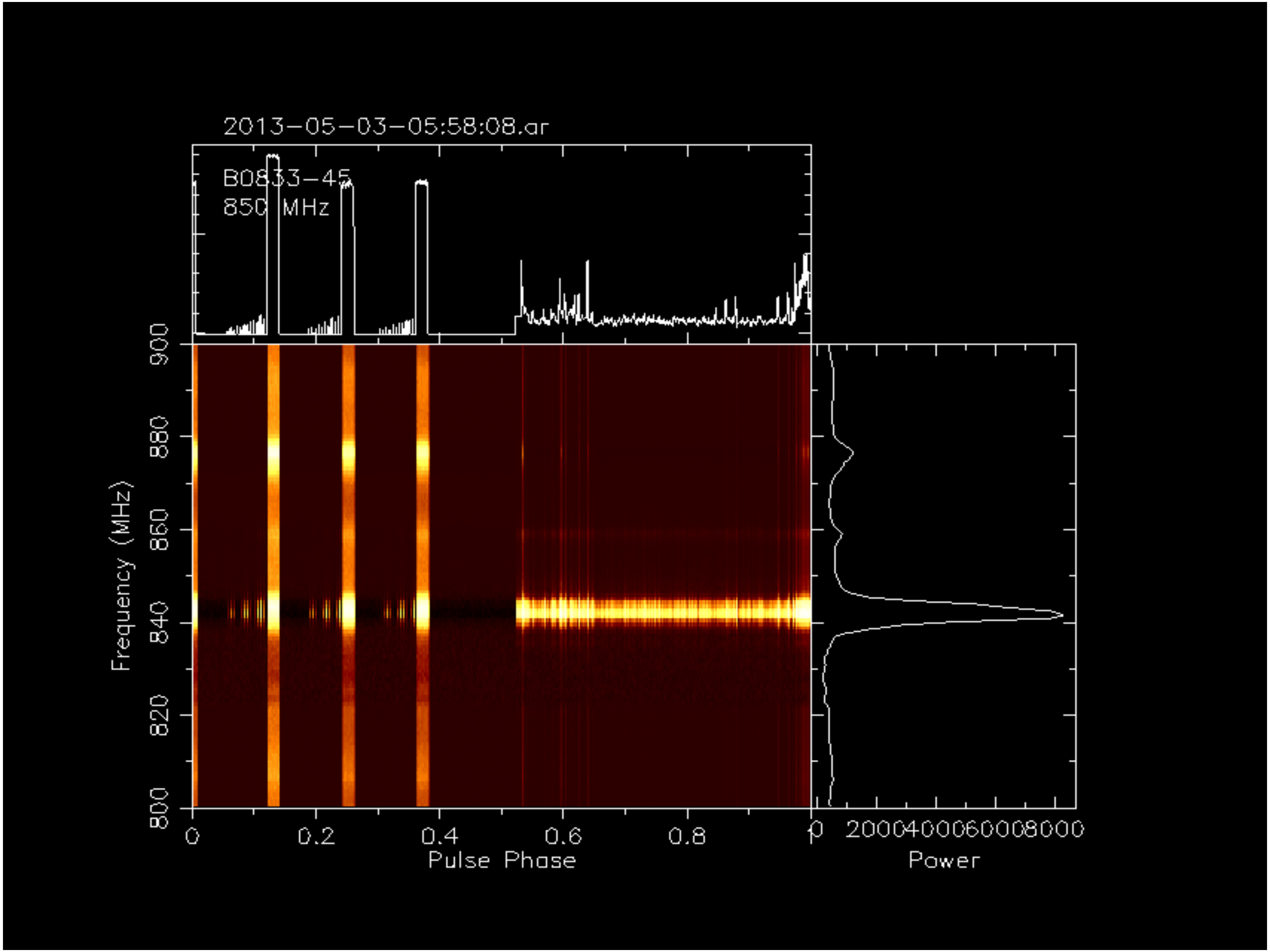

2013-05-03-05:58:08.ar
B0833-45
850 MHz
Frequency (MHz)
900
880
860
840
820
800
0
0.2
0.4
0.6
0.8
1
Pulse Phase
0 2000400060008000
Power

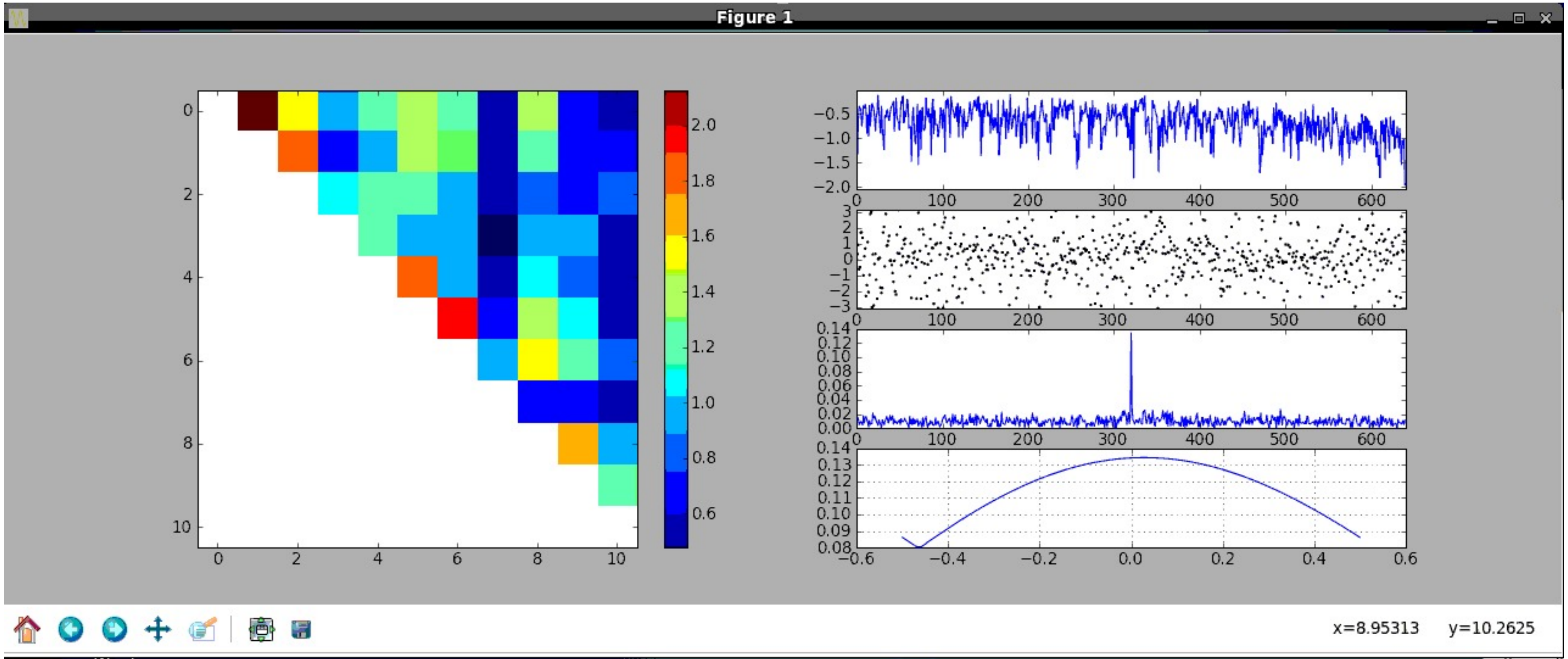


Figure 1
x=8.95313 y=10.2625

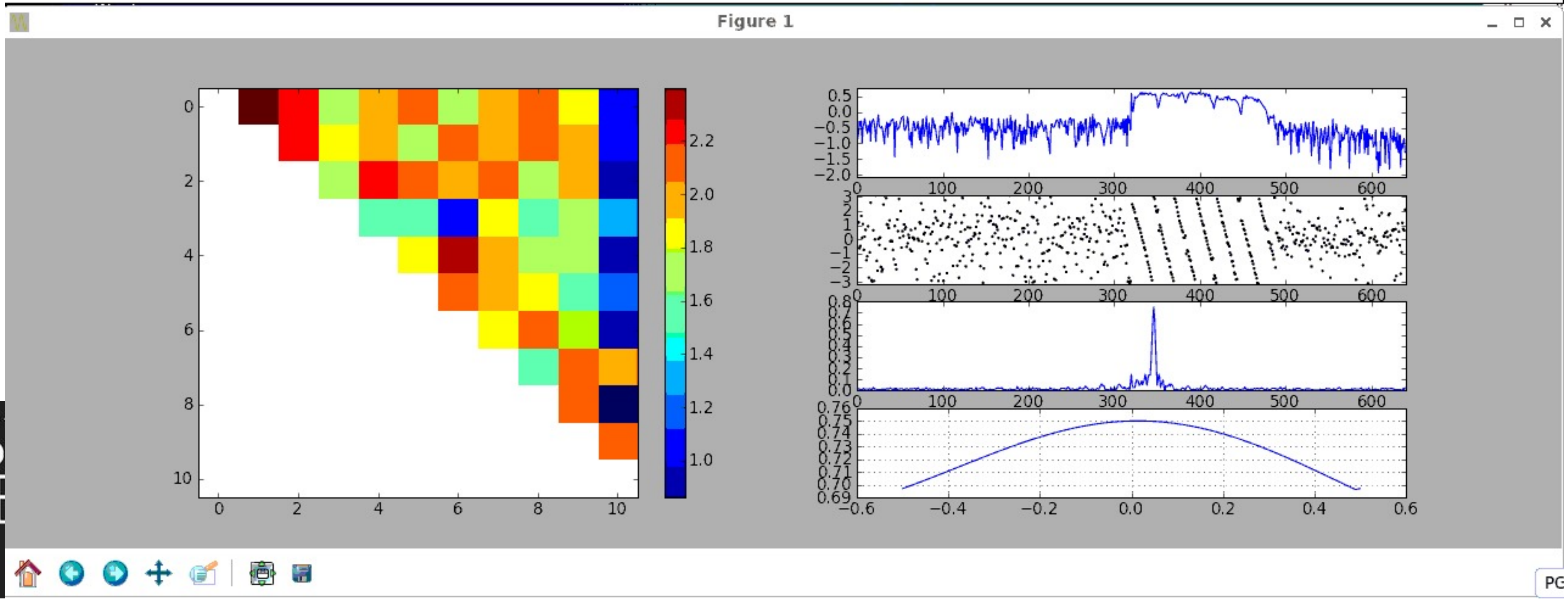
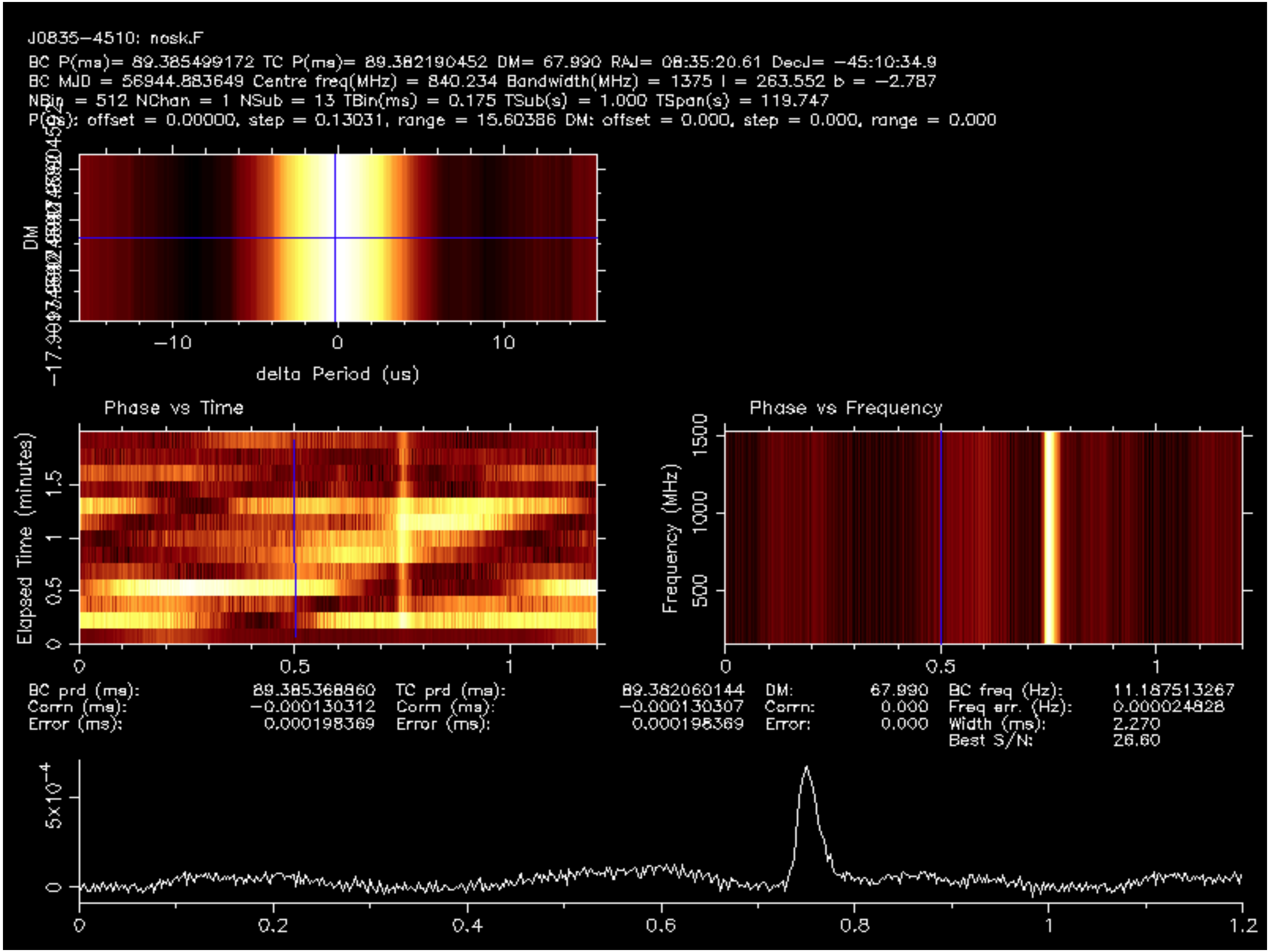
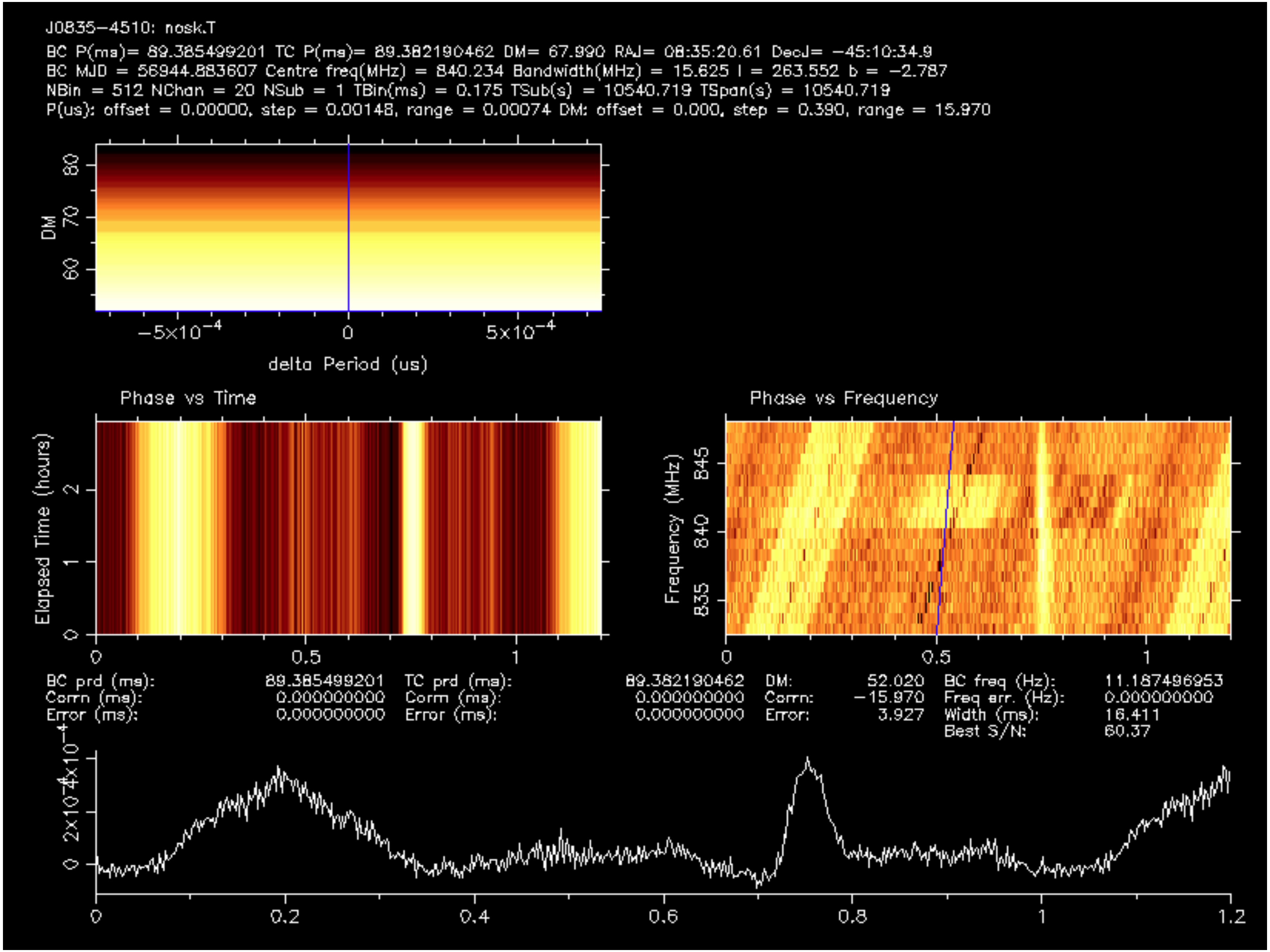
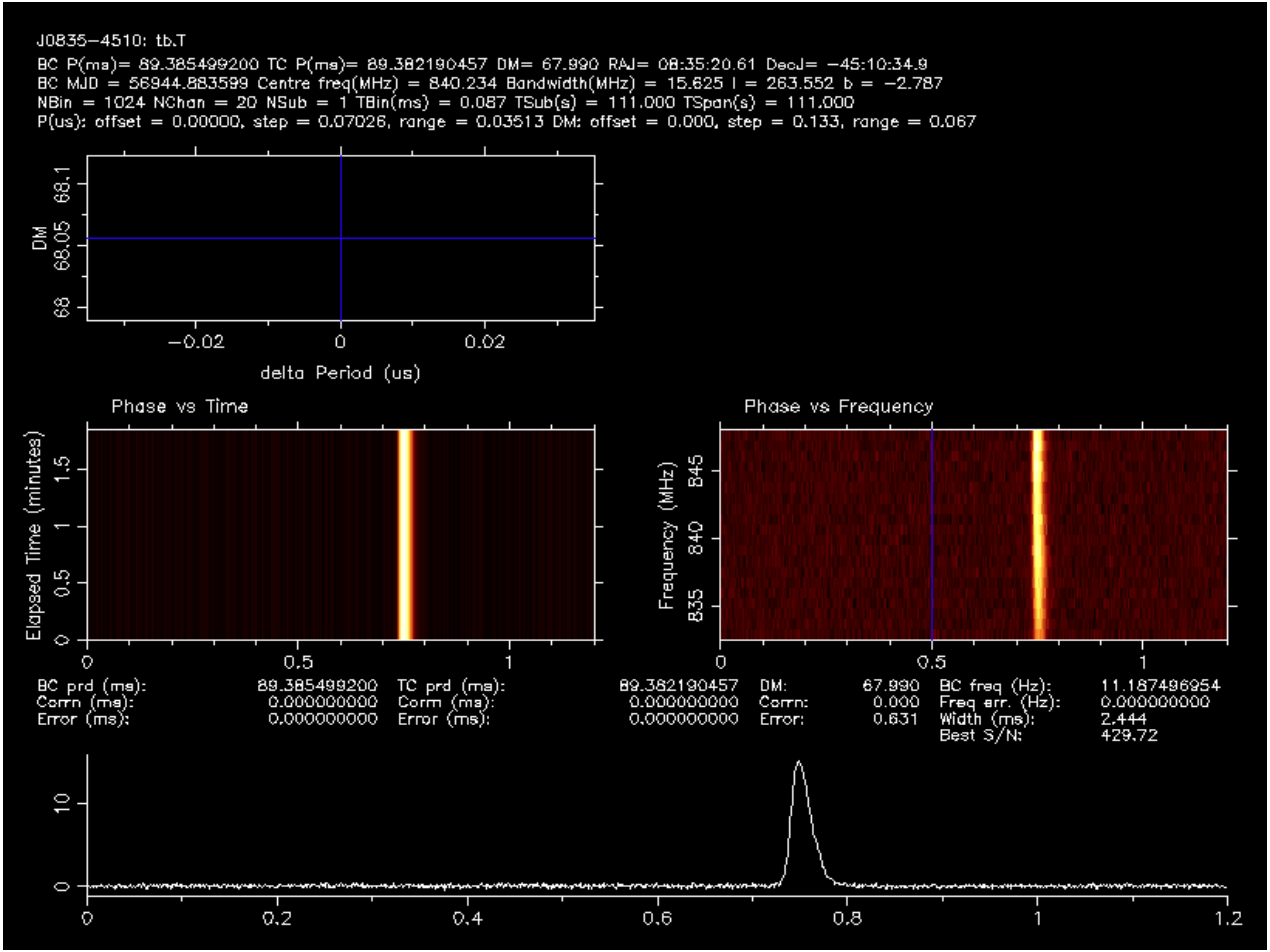
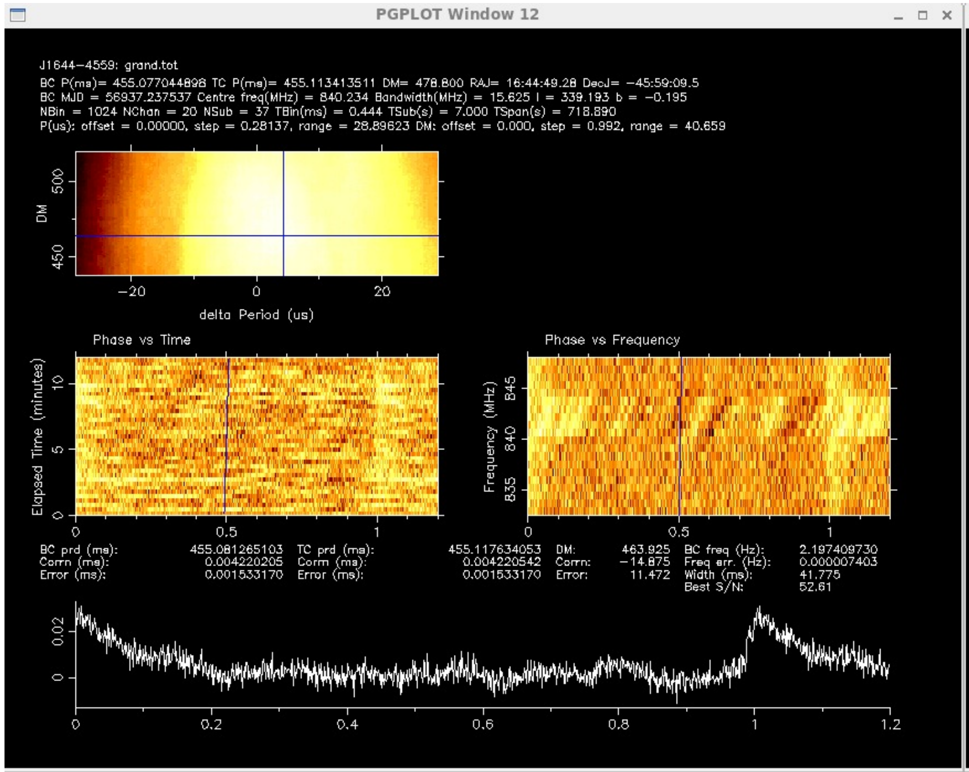


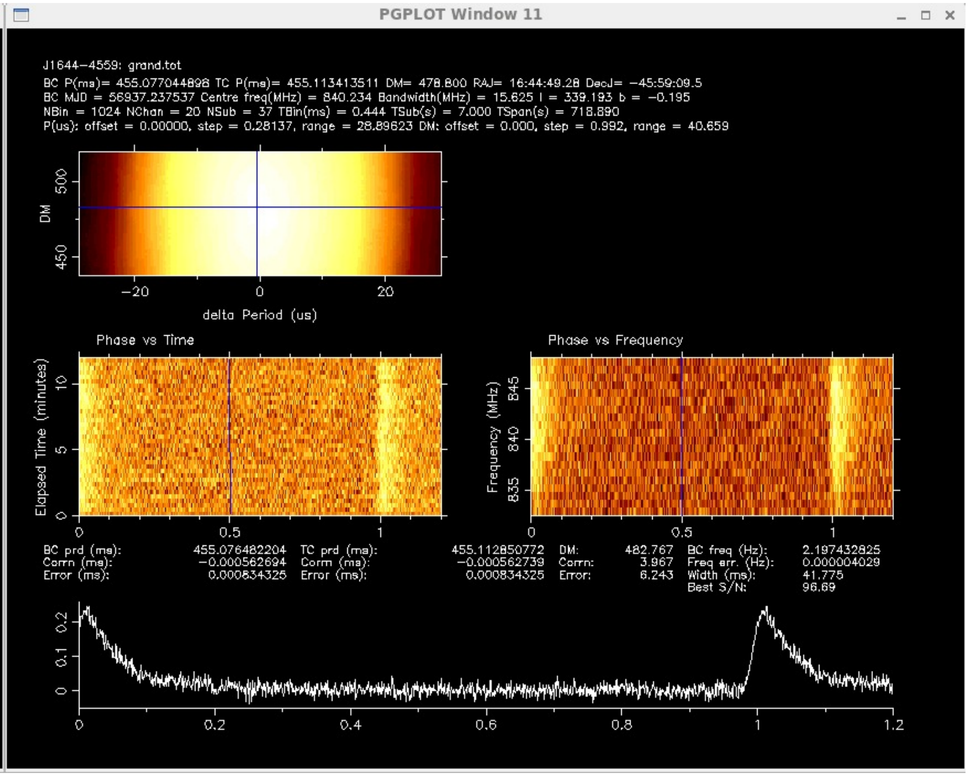
Figure 1

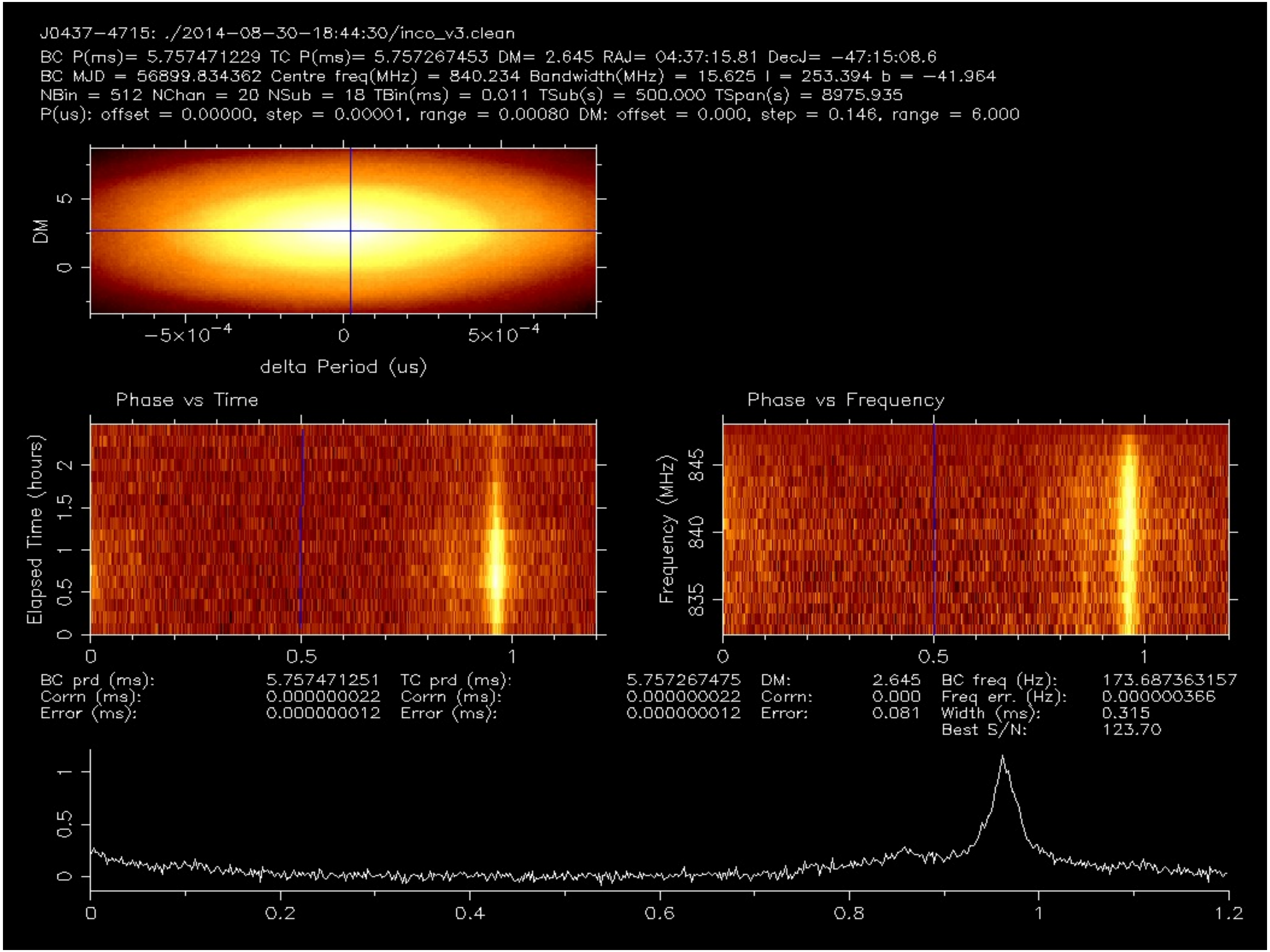

J0835−4510: nosk.F
BC P(ms)= 89.385499172 TC P(ms)= 89.382190452 DM= 67.990 RAJ= 08:35:20.61 DecJ= −45:10:34.9
BC MJD = 56944.883649 Centre freq(MHz) = 840.234 Bandwidth(MHz) = 1375 l = 263.552 b = −2.787
NBin = 512 NChan = 1 NSub = 13 TBin(ms) = 0.175 TSub(s) = 1.000 TSpan(s) = 119.747
P(us): offset = 0.00000, step = 0.13031, range = 15.60386 DM: offset = 0.000, step = 0.000, range = 0.000
DM
delta Period (us)
Phase vs Time
Elapsed Time (minutes)
Phase vs Frequency
Frequency (MHz)
BC prd (ms): 89.385368860
Corrn (ms): −0.000130312
Error (ms): 0.000198369
TC prd (ms): 89.382060144
Corrn (ms): −0.000130307
Error (ms): 0.000198369
DM: 67.990
Corrn: 0.000
Error: 0.000
BC freq (Hz): 11.187513267
Freq err. (Hz): 0.000024828
Width (ms): 2.270
Best S/N: 26.60
5x10^−4


J0835−4510: nosk.T
BC P(ms)= 89.385499201 TC P(ms)= 89.382190462 DM= 67.990 RAJ= 08:35:20.61 DecJ= −45:10:34.9
BC MJD = 56944.883607 Centre freq(MHz) = 840.234 Bandwidth(MHz) = 15.625 l = 263.552 b = −2.787
NBin = 512 NChan = 20 NSub = 1 TBin(ms) = 0.175 TSub(s) = 10540.719 TSpan(s) = 10540.719
P(us): offset = 0.00000, step = 0.00148, range = 0.00074 DM: offset = 0.000, step = 0.390, range = 15.970
DM
delta Period (us)
Phase vs Time
Elapsed Time (hours)
Phase vs Frequency
Frequency (MHz)
BC prd (ms): 89.385499201
Corrn (ms): 0.000000000
Error (ms): 0.000000000
TC prd (ms): 89.382190462
Corrn (ms): 0.000000000
Error (ms): 0.000000000
DM: 52.020
Corrn: −15.970
Error: 3.927
BC freq (Hz): 11.187496953
Freq err. (Hz): 0.000000000
Width (ms): 16.411
Best S/N: 60.37

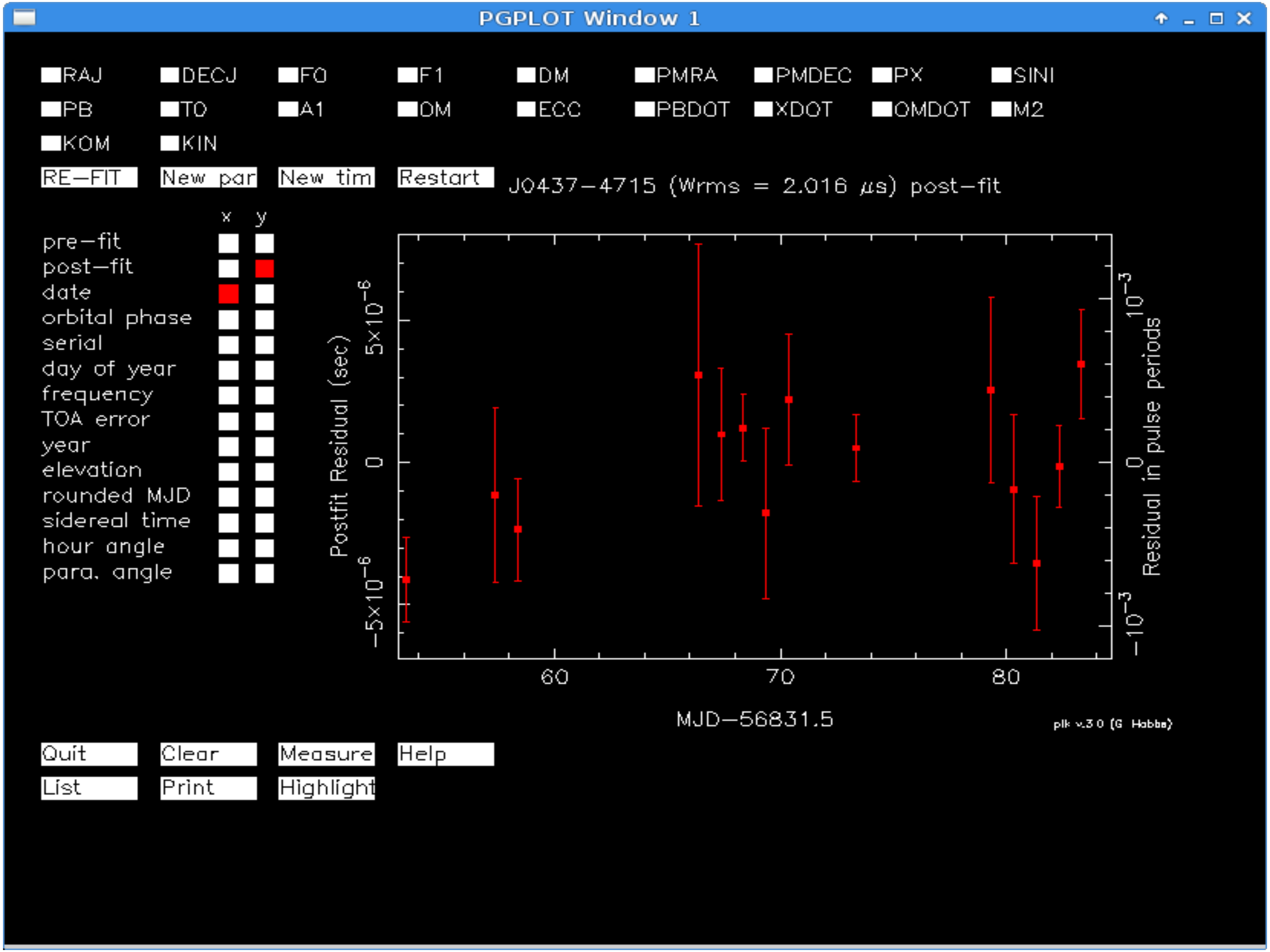

J0835−4510: tb.T
BC P(ms)= 89.385499200 TC P(ms)= 89.382190457 DM= 67.990 RAJ= 08:35:20.61 DecJ= −45:10:34.9
BC MJD = 56944.883599 Centre freq(MHz) = 840.234 Bandwidth(MHz) = 15.625 l = 263.552 b = −2.787
NBin = 1024 NChan = 20 NSub = 1 TBin(ms) = 0.087 TSub(s) = 111.000 TSpan(s) = 111.000
P(us): offset = 0.00000, step = 0.07026, range = 0.03513 DM: offset = 0.000, step = 0.133, range = 0.067
DM
delta Period (us)
Phase vs Time
Elapsed Time (minutes)
Phase vs Frequency
Frequency (MHz)
BC prd (ms): 89.385499200
Corrn (ms): 0.000000000
Error (ms): 0.000000000
TC prd (ms): 89.382190457
Corrn (ms): 0.000000000
Error (ms): 0.000000000
DM: 67.990
Corrn: 0.000
Error: 0.631
BC freq (Hz): 11.187496954
Freq err. (Hz): 0.000000000
Width (ms): 2.444
Best S/N: 429.72

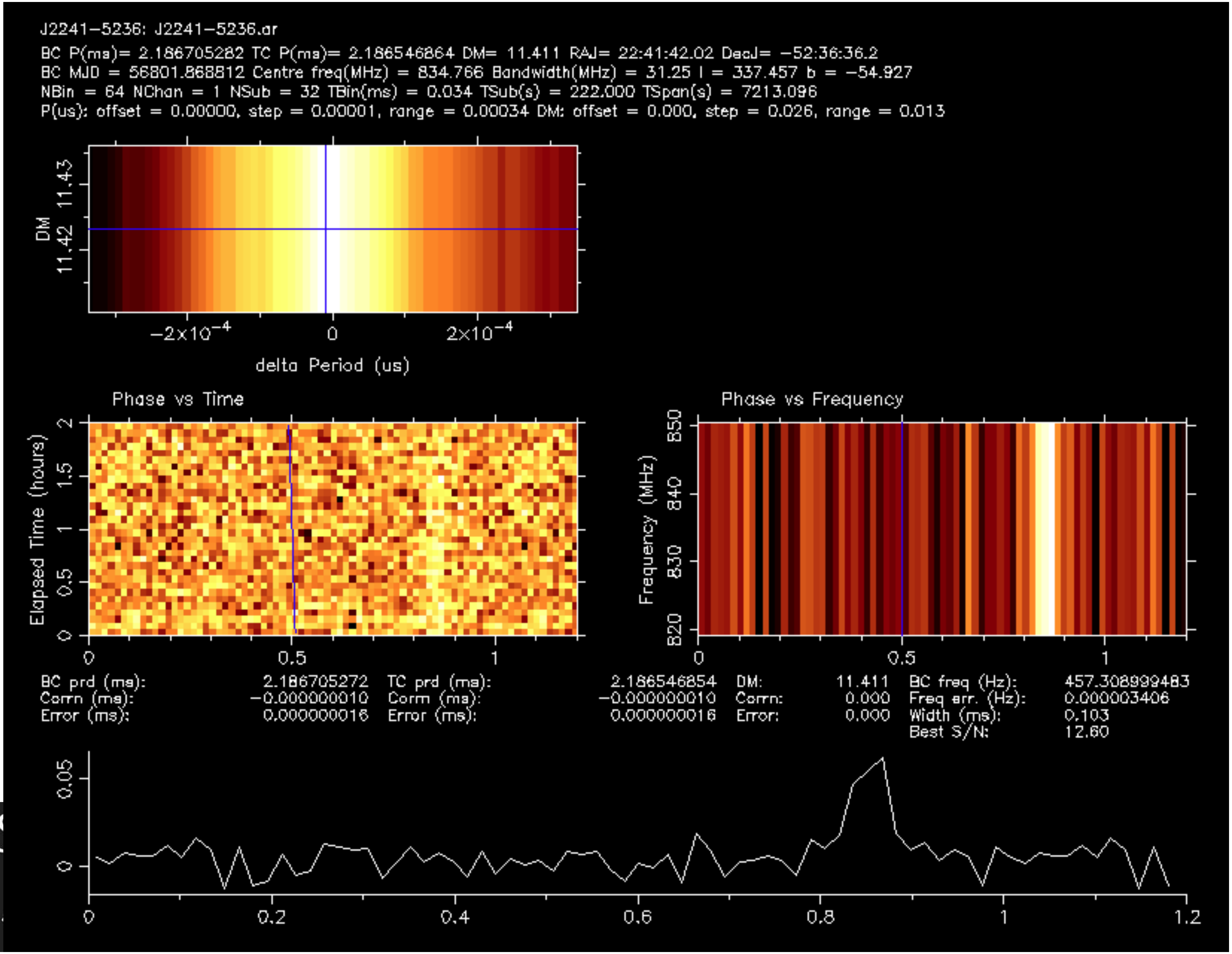

PGPLOT Window 12
J1644−4559: grand.tot
BC P(ms)= 455.077044898 TC P(ms)= 455.113413511 DM= 478.800 RAJ= 16:44:49.28 DecJ= −45:59:09.5
BC MJD = 56937.237537 Centre freq(MHz) = 840.234 Bandwidth(MHz) = 15.625 l = 339.193 b = −0.195
NBin = 1024 NChan = 20 NSub = 37 TBin(ms) = 0.444 TSub(s) = 7.000 TSpan(s) = 718.890
P(us): offset = 0.00000, step = 0.28137, range = 28.89623 DM: offset = 0.000, step = 0.992, range = 40.659
DM
delta Period (us)
Phase vs Time
Elapsed Time (minutes)
Phase vs Frequency
Frequency (MHz)
BC prd (ms): 455.081265103
Corrn (ms): 0.004220205
Error (ms): 0.001533170
TC prd (ms): 455.117634053
Corrn (ms): 0.004220542
Error (ms): 0.001533170
DM: 463.925
Corrn: −14.875
Error: 11.472
BC freq (Hz): 2.197409730
Freq err. (Hz): 0.000007403
Width (ms): 41.775
Best S/N: 52.61

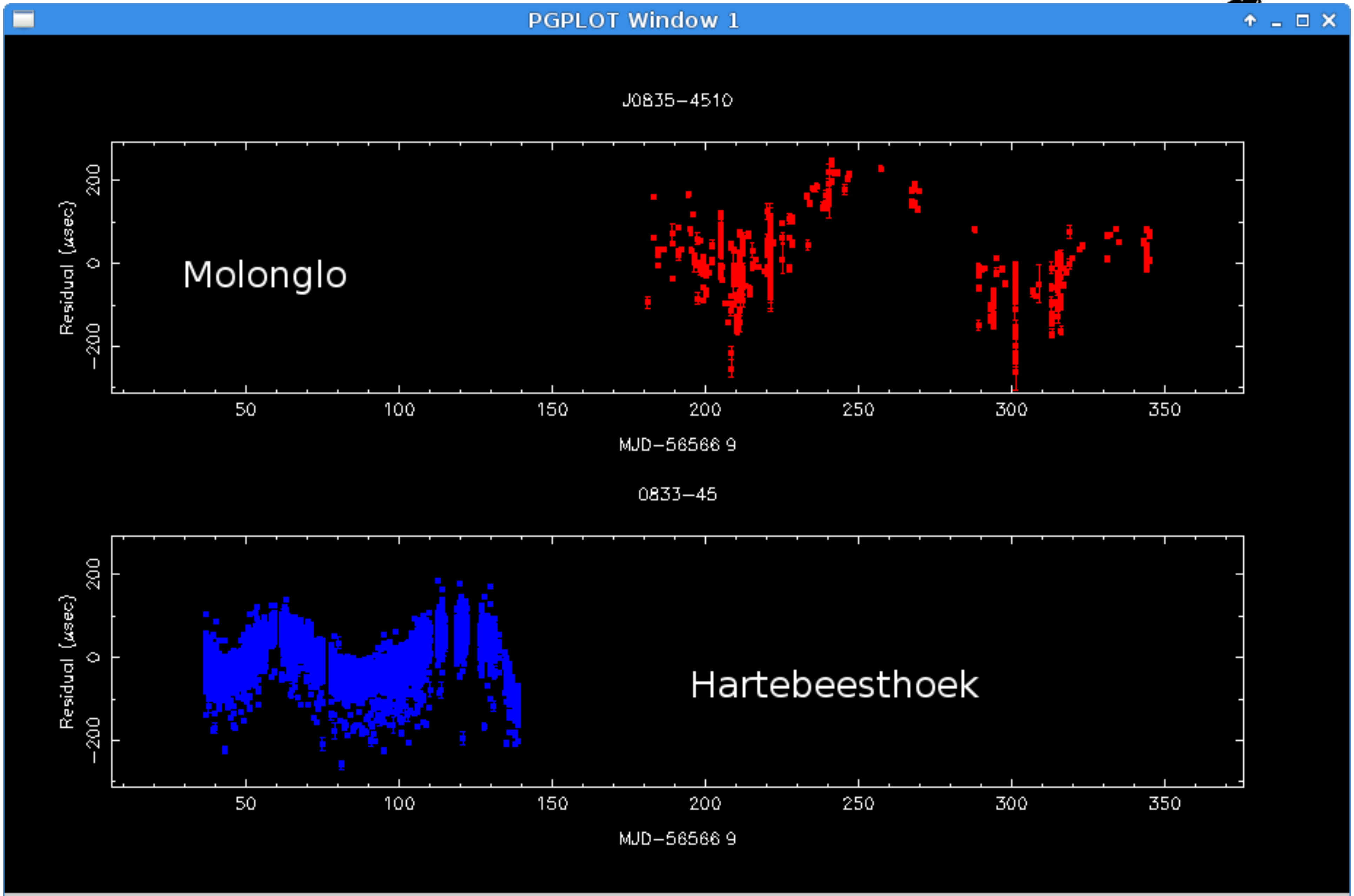

PGPLOT Window 11
J1644−4559: grand.tot
BC P(ms)= 455.077044898 TC P(ms)= 455.113413511 DM= 478.800 RAJ= 16:44:49.28 DecJ= −45:59:09.5
BC MJD = 56937.237537 Centre freq(MHz) = 840.234 Bandwidth(MHz) = 15.625 l = 339.193 b = −0.195
NBin = 1024 NChan = 20 NSub = 37 TBin(ms) = 0.444 TSub(s) = 7.000 TSpan(s) = 718.890
P(us): offset = 0.00000, step = 0.28137, range = 28.89623 DM: offset = 0.000, step = 0.992, range = 40.659
DM
delta Period (us)
Phase vs Time
Elapsed Time (minutes)
Phase vs Frequency
Frequency (MHz)
BC prd (ms): 455.076482204
Corrn (ms): −0.000562694
Error (ms): 0.000834325
TC prd (ms): 455.112850772
Corrn (ms): −0.000562739
Error (ms): 0.000834325
DM: 482.767
Corrn: 3.967
Error: 6.243
BC freq (Hz): 2.197432825
Freq err. (Hz): 0.000004029
Width (ms): 41.775
Best S/N: 96.69

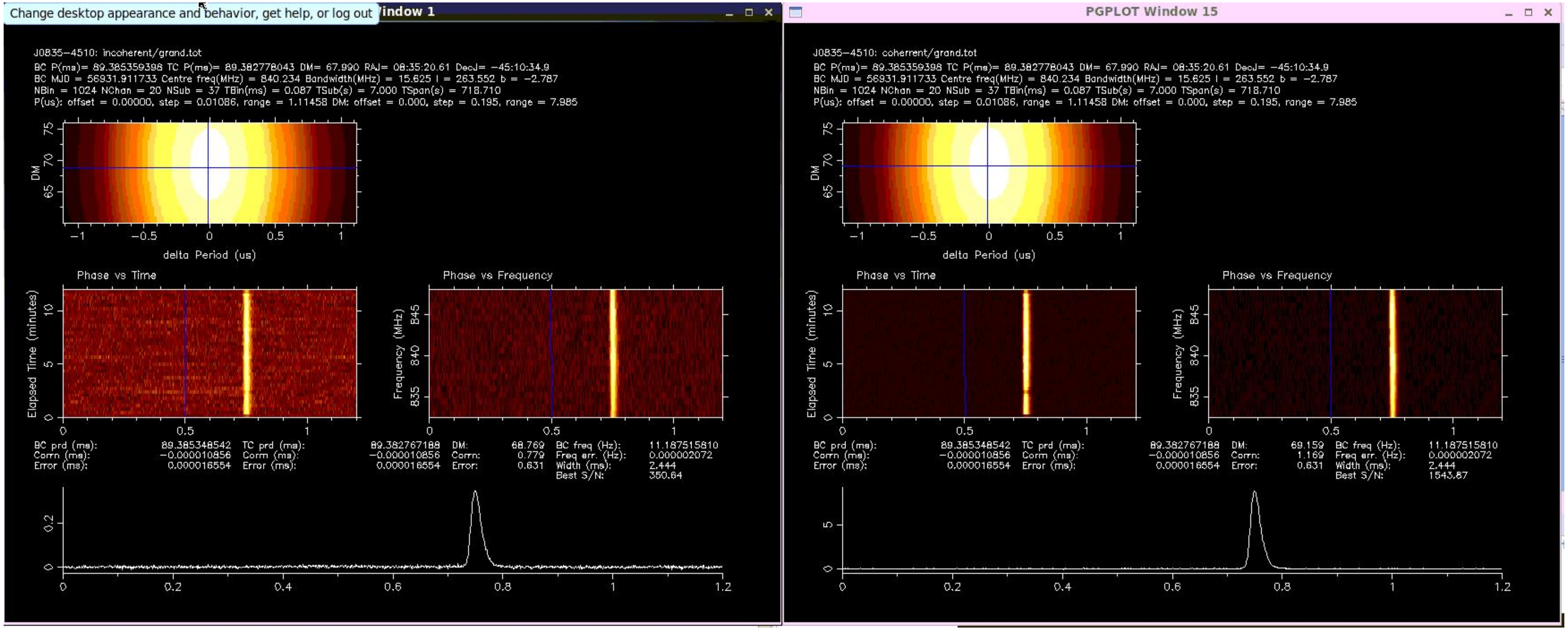


J0437-4715: ./2014-08-30-18:44:30/inco_v3.clean
BC P(ms)= 5.757471229 TC P(ms)= 5.757267453 DM= 2.645 RAJ= 04:37:15.81 DecJ= -47:15:08.6
BC MJD = 56899.834362 Centre freq(MHz) = 840.234 Bandwidth(MHz) = 15.625 l = 253.394 b = -41.964
NBin = 512 NChan = 20 NSub = 18 TBin(ms) = 0.011 TSub(s) = 500.000 TSpan(s) = 8975.935
P(us): offset = 0.00000, step = 0.00001, range = 0.00080 DM: offset = 0.000, step = 0.146, range = 6.000
DM
delta Period (us)
Phase vs Time
Elapsed Time (hours)
Phase vs Frequency
Frequency (MHz)
BC prd (ms): 5.757471251
Corrn (ms): 0.000000022
Error (ms): 0.000000012
TC prd (ms): 5.757267475
Corrn (ms): 0.000000022
Error (ms): 0.000000012
DM: 2.645
Corrn: 0.000
Error: 0.081
BC freq (Hz): 173.687363157
Freq err. (Hz): 0.000000366
Width (ms): 0.315
Best S/N: 123.70


PGPLOT Window 1
RAJ
DECJ
F0
F1
DM
PMRA
PMDEC
PX
SINI
PB
T0
A1
OM
ECC
PBDOT
XDOT
OMDOT
M2
KOM
KIN
RE-FIT
New par
New tim
Restart
J0437-4715 (Wrms = 2.016 μs) post-fit
x
y
pre-fit
post-fit
date
orbital phase
serial
day of year
frequency
TOA error
year
elevation
rounded MJD
sidereal time
hour angle
para. angle
Postfit Residual (sec)
5x10^-6
0
-5x10^-6
Residual in pulse periods
10^-3
0
-10^-3
60
70
80
MJD-56831.5
plk v.3.0 (G. Hobbs)
Quit
Clear
Measure
Help
List
Print
Highlight


J2241−5236: J2241−5236.ar
BC P(ms)= 2.186705282 TC P(ms)= 2.186546864 DM= 11.411 RAJ= 22:41:42.02 DecJ= −52:36:36.2
BC MJD = 56801.868812 Centre freq(MHz) = 834.766 Bandwidth(MHz) = 31.25 l = 337.457 b = −54.927
NBin = 64 NChan = 1 NSub = 32 TBin(ms) = 0.034 TSub(s) = 222.000 TSpan(s) = 7213.096
P(us): offset = 0.00000, step = 0.00001, range = 0.00034 DM: offset = 0.000, step = 0.026, range = 0.013
DM
delta Period (us)
Phase vs Time
Elapsed Time (hours)
Phase vs Frequency
Frequency (MHz)
BC prd (ms): 2.186705272
Corrn (ms): −0.000000010
Error (ms): 0.000000016
TC prd (ms): 2.186546854
Corrn (ms): −0.000000010
Error (ms): 0.000000016
DM: 11.411
Corrn: 0.000
Error: 0.000
BC freq (Hz): 457.308999483
Freq err. (Hz): 0.000003406
Width (ms): 0.103
Best S/N: 12.60

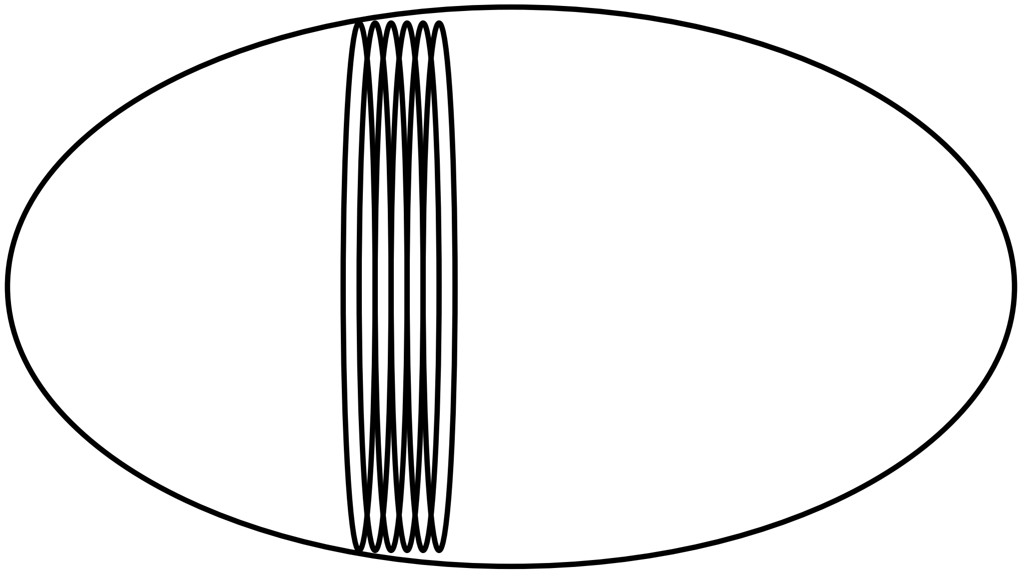

PGPLOT Window 1
J0835−4510
Residual (μsec)
Molonglo
MJD−56566.9
0833−45
Residual (μsec)
Hartebeesthoek
MJD−56566.9



Change desktop appearance and behavior, get help, or log out
/indow 1
J0835−4510: incoherent/grand.tot
BC P(ms)= 89.385359398 TC P(ms)= 89.382778043 DM= 67.990 RAJ= 08:35:20.61 DecJ= −45:10:34.9
BC MJD = 56931.911733 Centre freq(MHz) = 840.234 Bandwidth(MHz) = 15.625 l = 263.552 b = −2.787
NBin = 1024 NChan = 20 NSub = 37 TBin(ms) = 0.087 TSub(s) = 7.000 TSpan(s) = 718.710
P(us): offset = 0.00000, step = 0.01086, range = 1.11458 DM: offset = 0.000, step = 0.195, range = 7.985
DM
delta Period (us)
Phase vs Time
Elapsed Time (minutes)
Phase vs Frequency
Frequency (MHz)
BC prd (ms): 89.385348542 TC prd (ms): 89.382767188 DM: 68.769 BC freq (Hz): 11.187515810
Corrn (ms): −0.000010856 Corrn (ms): −0.000010856 Corrn: 0.779 Freq err. (Hz): 0.000002072
Error (ms): 0.000016554 Error (ms): 0.000016554 Error: 0.631 Width (ms): 2.444
Best S/N: 350.64
PGPLOT Window 15
J0835−4510: coherent/grand.tot
BC P(ms)= 89.385359398 TC P(ms)= 89.382778043 DM= 67.990 RAJ= 08:35:20.61 DecJ= −45:10:34.9
BC MJD = 56931.911733 Centre freq(MHz) = 840.234 Bandwidth(MHz) = 15.625 l = 263.552 b = −2.787
NBin = 1024 NChan = 20 NSub = 37 TBin(ms) = 0.087 TSub(s) = 7.000 TSpan(s) = 718.710
P(us): offset = 0.00000, step = 0.01086, range = 1.11458 DM: offset = 0.000, step = 0.195, range = 7.985
DM
delta Period (us)
Phase vs Time
Elapsed Time (minutes)
Phase vs Frequency
Frequency (MHz)
BC prd (ms): 89.385348542 TC prd (ms): 89.382767188 DM: 69.159 BC freq (Hz): 11.187515810
Corrn (ms): −0.000010856 Corrn (ms): −0.000010856 Corrn: 1.169 Freq err. (Hz): 0.000002072
Error (ms): 0.000016554 Error (ms): 0.000016554 Error: 0.631 Width (ms): 2.444
Best S/N: 1543.87

“Burst” mode

- Search fan beams for Lorimer bursts (FRBs)
- GPU dedisperser + “Heimdall”
  - Barsdell’s PhD thesis.
- Also find RRATs, single pulses from pulsars
- (Should) find 1 burst per 2 days > 10 sigma
- Real-time detector
- Raw dump from ring buffer
- Position 43”/SNR & 2 deg



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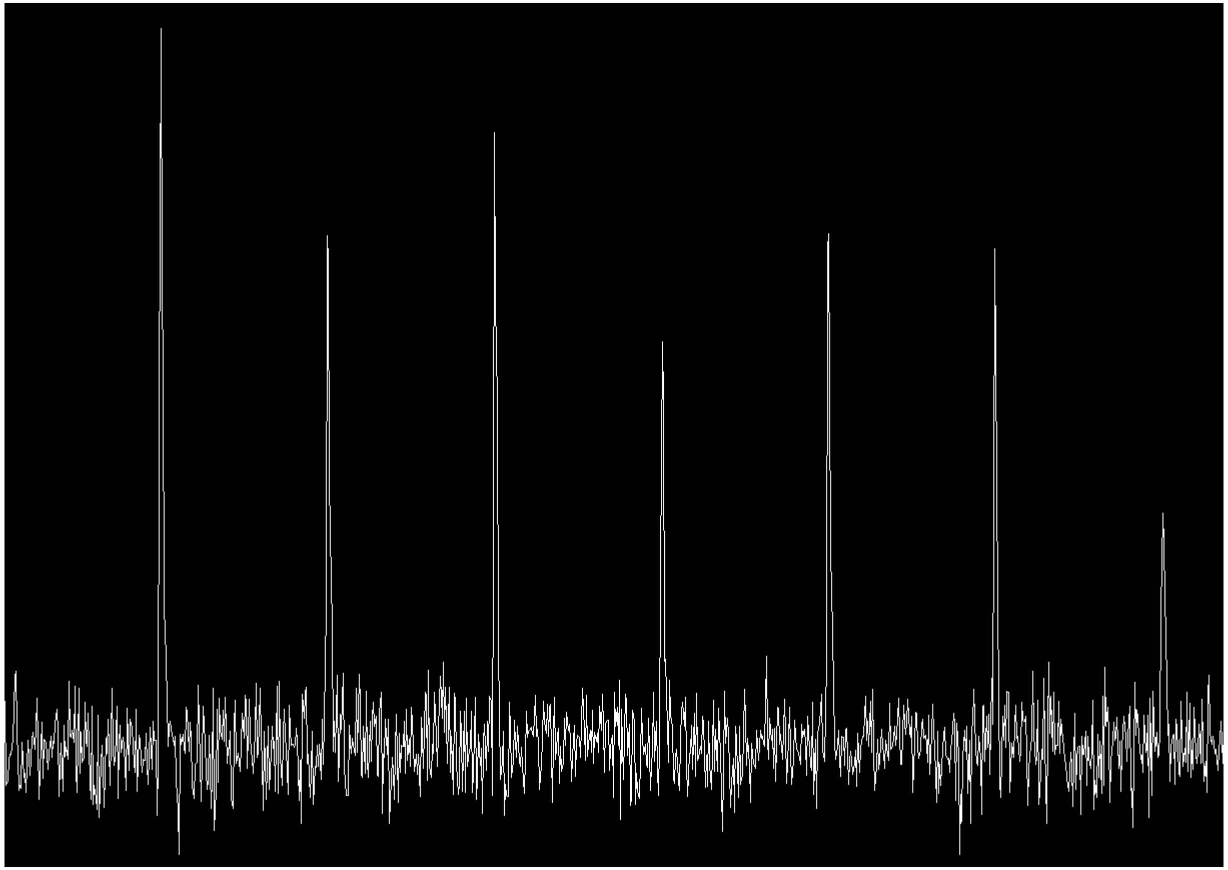
Single pulses



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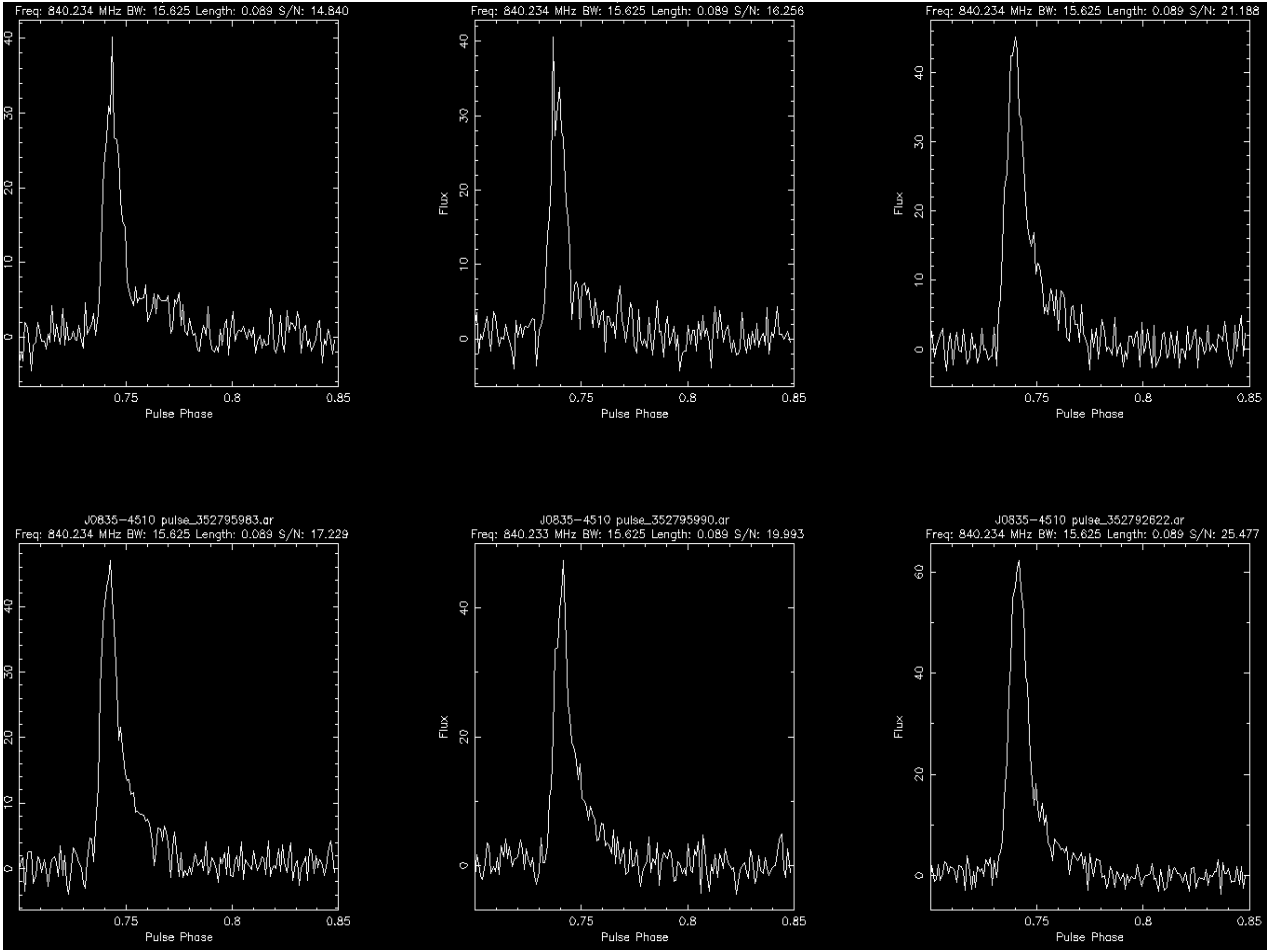
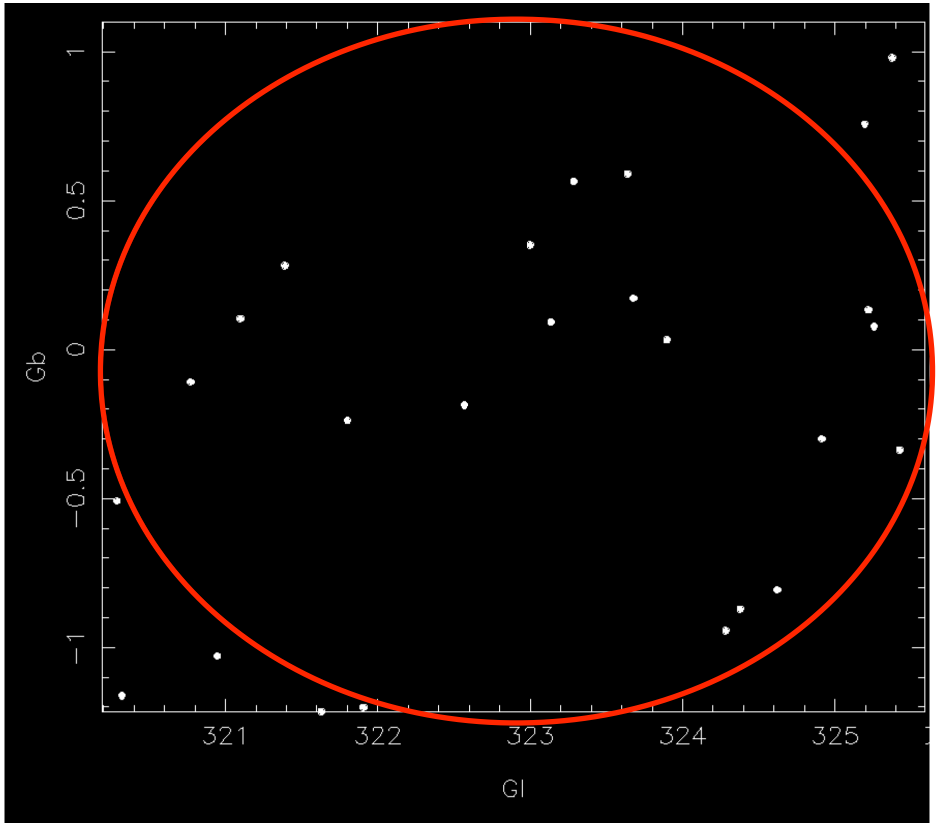

Freq: 840.234 MHz BW: 15.625 Length: 0.089 S/N: 14.840
Freq: 840.234 MHz BW: 15.625 Length: 0.089 S/N: 16.256
Freq: 840.234 MHz BW: 15.625 Length: 0.089 S/N: 21.188
J0835−4510 pulse_352795983.ar
Freq: 840.234 MHz BW: 15.625 Length: 0.089 S/N: 17.229
J0835−4510 pulse_352795990.ar
Freq: 840.233 MHz BW: 15.625 Length: 0.089 S/N: 19.993
J0835−4510 pulse_352792622.ar
Freq: 840.234 MHz BW: 15.625 Length: 0.089 S/N: 25.477
Flux
Pulse Phase

Fold fan-beam mode

- Coherently dedisperse any pulsar in the beam.
- Up to ~30 pulsars in one beam
- Time > 500 pulsars/day



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New system vs old MOST system

- 4 x FoV
- 10 x Bandwidth
- 256 us timescale RFI monitor & excision
- 512 fan beams/FX vs 64 fan beams
  - Redundancy for calibration.
- Multiple pulsar coherent dedispersion vs 1x3 MHz channel, one pulsar system
- *Simultaneous burst, mapping, pulsar mode, RFI excision modes using 11 DAQ GPUs + 8 FX/Burst/PSR nodes.*

Timeline

- Pulsar timing commenced
- Single pulse mode validated
- Computer build-out (Dec)
- Full science operations (Jan)

- Nasties:
- Telescope bends occasionally – self-RFI.

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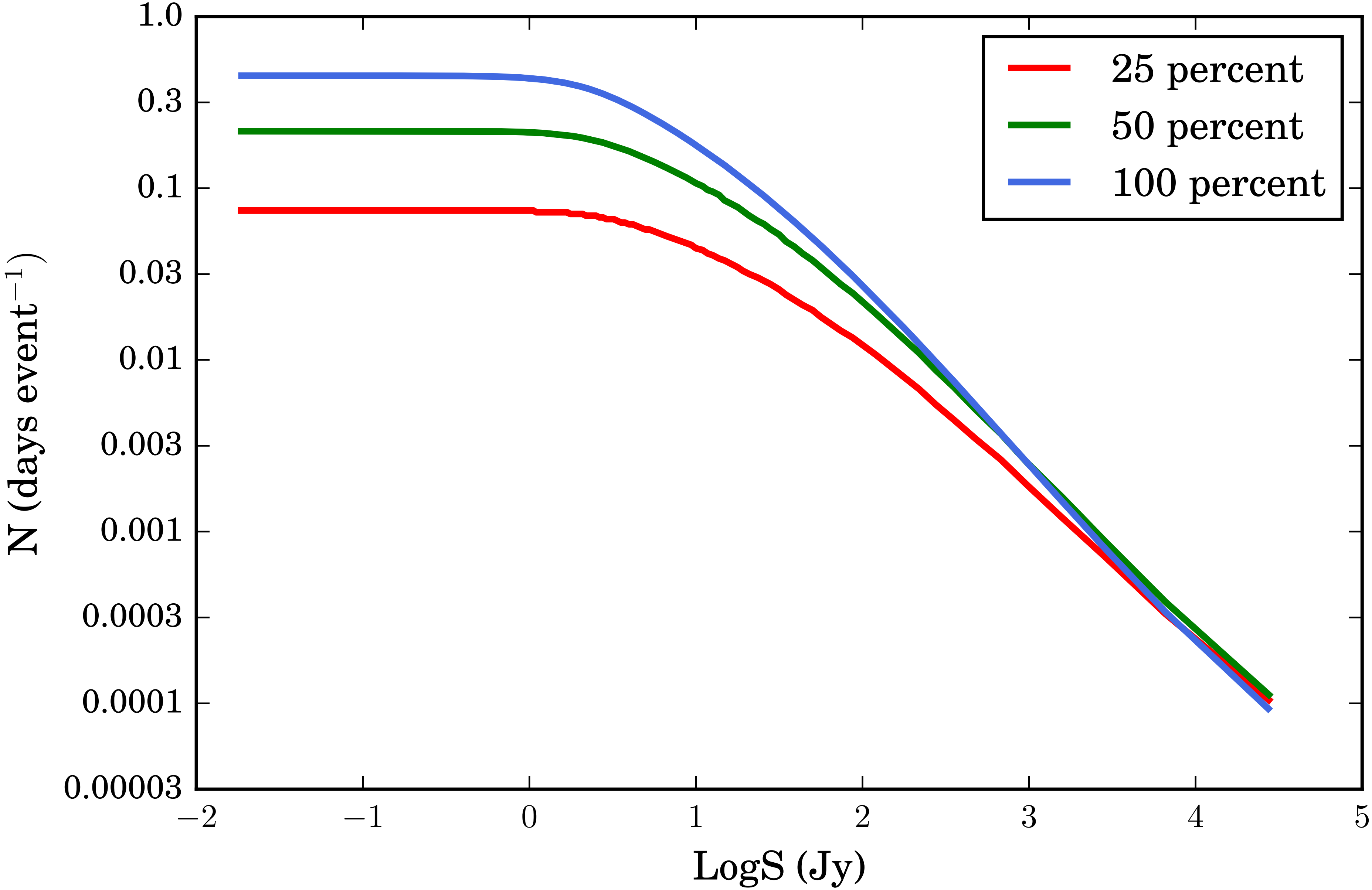
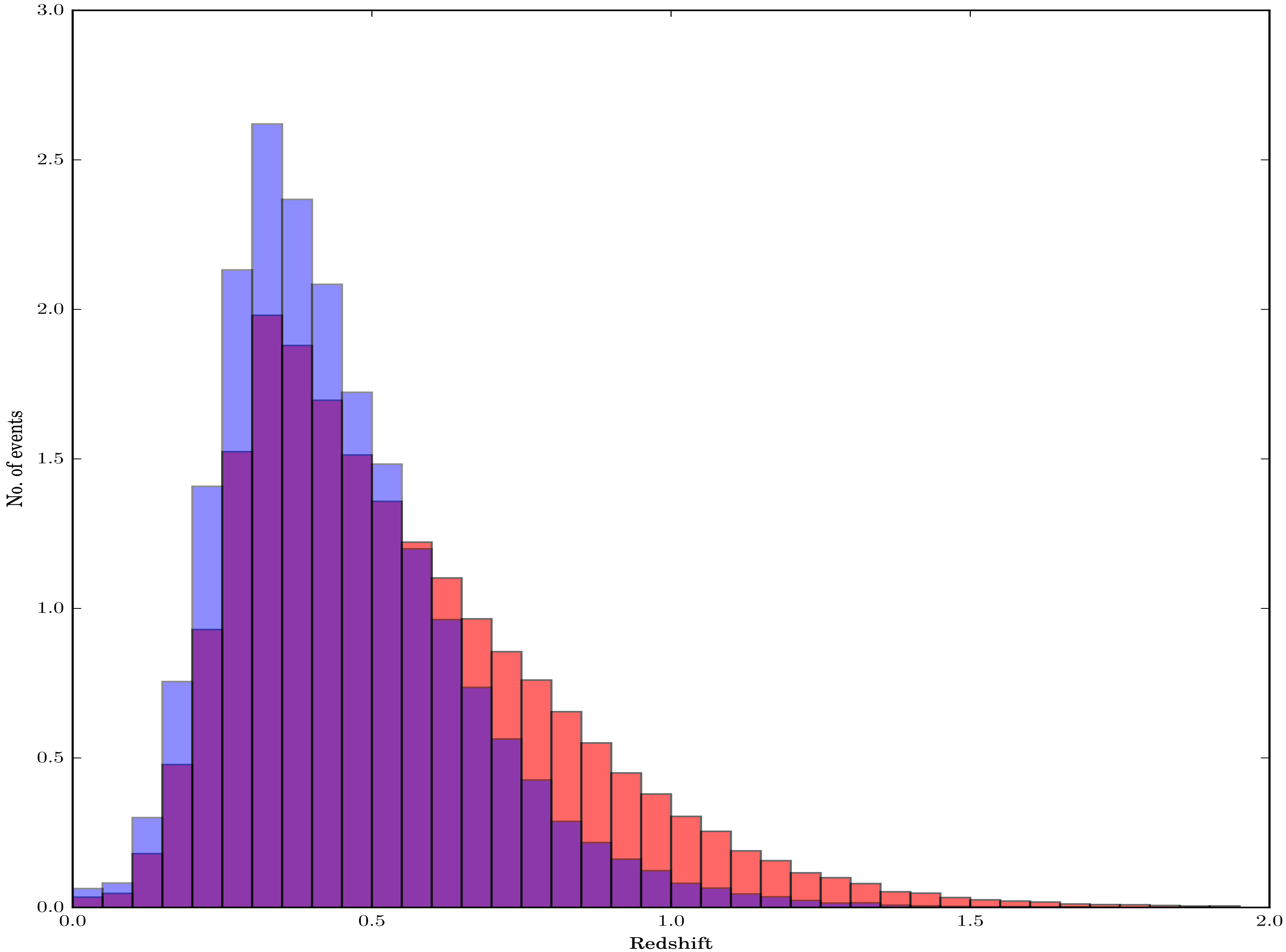
Data Release – Instantaneous!

- All events, pulsar timing, FRBs, immediately public.
- Time delay means MWA can “catch” events.



25 percent
50 percent
100 percent
N (days event^{-1})
LogS (Jy)
1.0
0.3
0.1
0.03
0.01
0.003
0.001
0.0003
0.0001
0.00003
−2
−1
0
1
2
3
4
5


3.0
2.5
2.0
1.5
1.0
0.5
0.0
No. of events
0.0
0.5
1.0
1.5
2.0
Redshift

MWA Upgrade?

- Change fine PFB to just flow-through mode
- Purchase 10Gb ethernet CX4 connectors
- Add new 56 Gb Infiniband for any corner turning.
- Upgrade GPUs
- Do “FX” correlation on coarse channels
- Use our correlator (no fine “notches”, delay tracking, pulsar modes)
- Change first PFB to one big fat PFB channel*
- Phase 2 – use CASPER hardware (40 GbE)

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Super-duper tile?

- 16 x 16 tiles, 2D FFT beamformer
  - Coherent pulsar, FRB searches.