

# Recent LOFAR Observations of Pulsar B0329+54:

HDF5, PRESTO, RFI, and **single pulse  
detections**

Jason Hessels

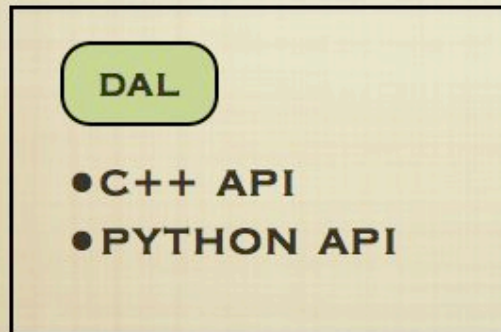
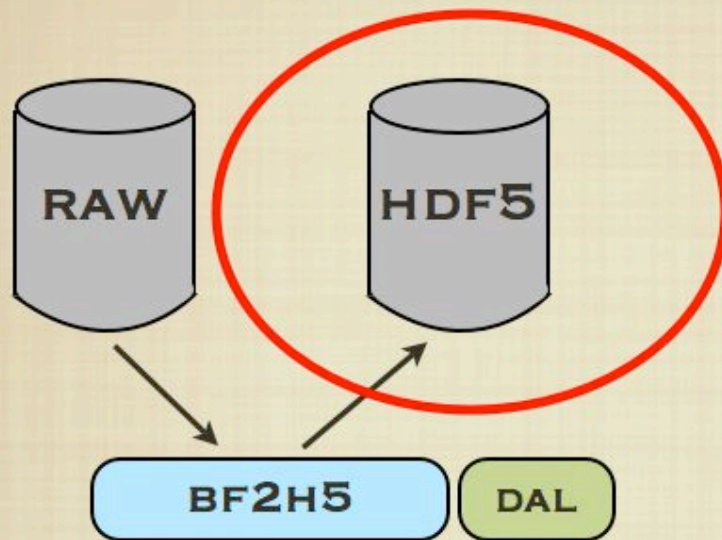
(Universiteit van Amsterdam)

LOFAR CS1 Meeting, April 23rd, 2008

# HDF5 format and PRESTO

- HDF5: flexible file format for raw beam-formed (and other?) data. Extensive LOFAR header structure defined.
- PRESTO: important, well-tested, suite of pulsar and single-pulse search and timing software (many MSPs and bursts discovered). No reinventing the wheel!
- pydal: **Joe Masters'** library of routines to read LOFAR HDF5 data (built from C++ DAL).

# CURRENT STATUS



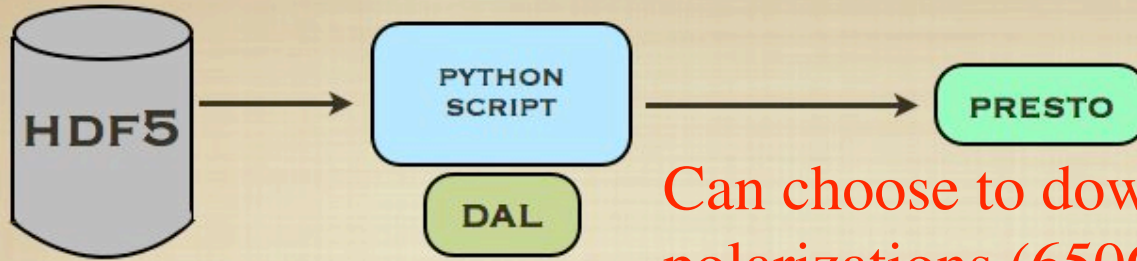
A screenshot of a file manager window titled 'File Window Tools Help'. The address bar shows the path '/home/jmasters/B0329.h5'. The main pane displays a directory tree for 'B0329.h5' containing a subdirectory 'beam000' and several files: 'SB000', 'SB001', 'SB002', 'SB003', 'SB004', and 'SB005'. To the right of the file list, there is a vertical column of 'Inf)' labels. Below the file list, a detailed view of the 'B0329.h5' file is shown, listing various attributes and their values.

```
B0329.h5
Group size = 1
Number of attributes = 29
FILENAME = /mnt/disk2/data/cs1/pulsar/B0329.h5
TELESCOPE = LOFAR
NUMBER_OF_STATIONS = 1
DATATYPE =
EMBAND =
SOURCE = Source A,Source B,Source C,Source D
OBSERVATION_ID =
PROJ_ID =
POINT_RA =
POINT_DEC =
OBSERVER =
EPOCH_MJD = 0.0
EPOCH_DATE =
EPOCH_UTC =
EPOCH_LST =
MAIN_BEAM_DIAM = 0
CENTER_FREQUENCY = 0
BANDWIDTH = 0
TOTAL_INTEGRATION_TIME = 0.0
```

# HDF5 QUICK LOOK

```
$ python
> from pydal import *
> file = BeamFormed("myfile.h5")
> file.summary()
> beam = file.getBeam(0)
> data = beam.getSubbandData_XY( 5, 0, 100 )
> file.number_of_beams()
> file.point_ra()
> file.number_of_samples()
```





Can choose to downsample and sum polarizations (650GB --> 3GB)

```

#!/usr/bin/env python

from pydal import *
from scipy import *
import sys
from pylab import *

def downsample(vector, factor):
    """
    downsample(vector, factor):
    Downsample (i.e. co-add consecutive numbers) a short
    of a vector by an integer factor.
    """
    if (len(vector) % factor):
        print "Length of 'vector' is not divisible by 'factor'=%d!" %
            factor
        return 0
    newvector = reshape(vector, (len(vector)/factor, factor))
    return add.reduce(newvector, 1)

# The BeamFormed object represents the file.
# The parameter is the name of the beam-formed file.
if (len(sys.argv) > 1):
    file = BeamFormed(sys.argv[1])
else:
    print "Please provide a beam-formed hdf5 file as input."
    sys.exit(1)

# get beam 0
beam = file.getBeam(0)

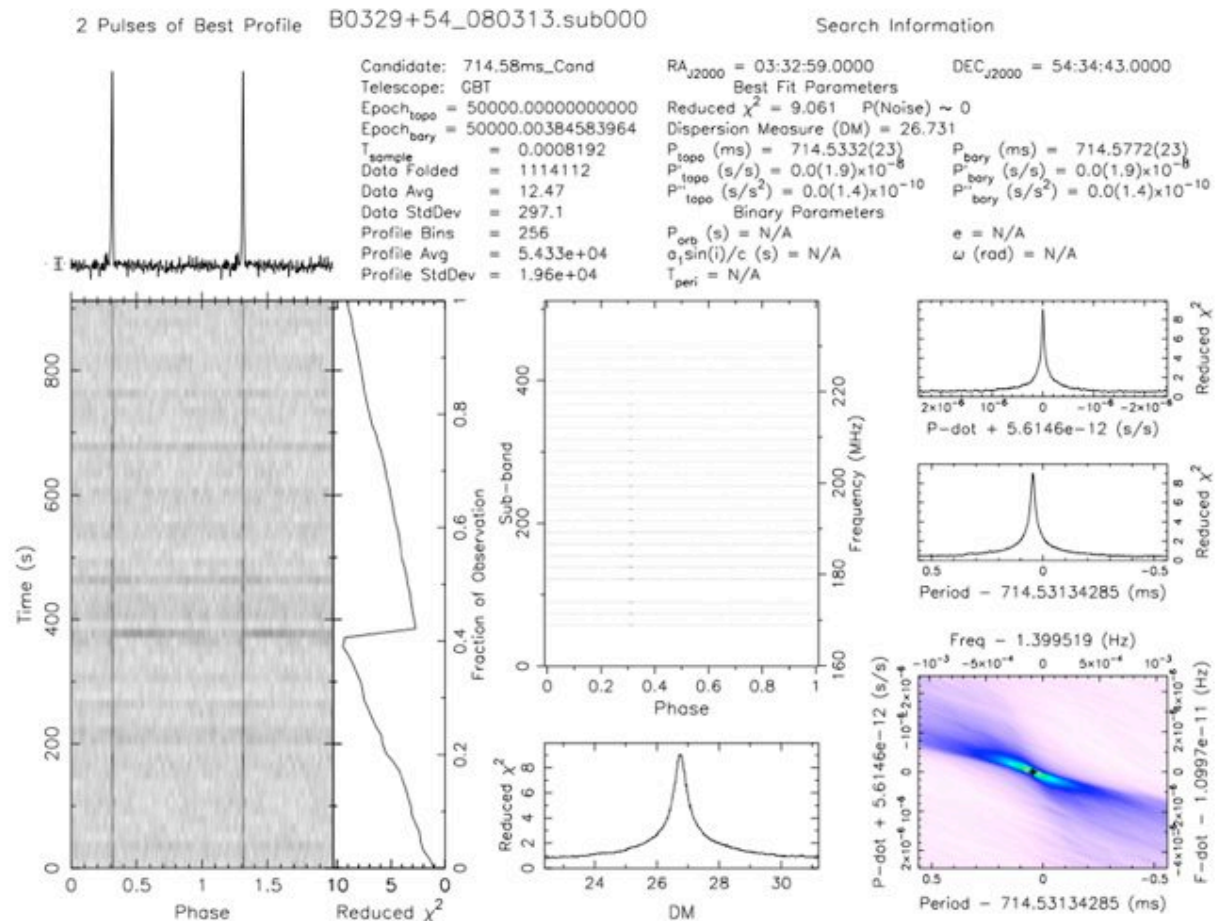
n_samples = 512 * 128

for subband in range(24):
    start = 0
    downsampled_data = array([], 'f')
    for count in range(2200):
        data = beam.getSubbandData_XY( subband, start,
            xx_intensity = abs(data[0])
            yy_intensity = abs(data[1])
            tot_intensity = sqrt(xx_intensity*xx_intensity + yy_

        data = downsample( tot_intensity, 128 )
        start += n_samples

    downsampled_data = concatenate( (downsampled_

    tmpfile = "B0329+54_080313_subband%02d" % subband
    fileobj = open(tmpfile, mode="wb")
    fileobj.write(downsampled_data)
    fileobj.close()
    print "Wrote ", tmpfile
  
```



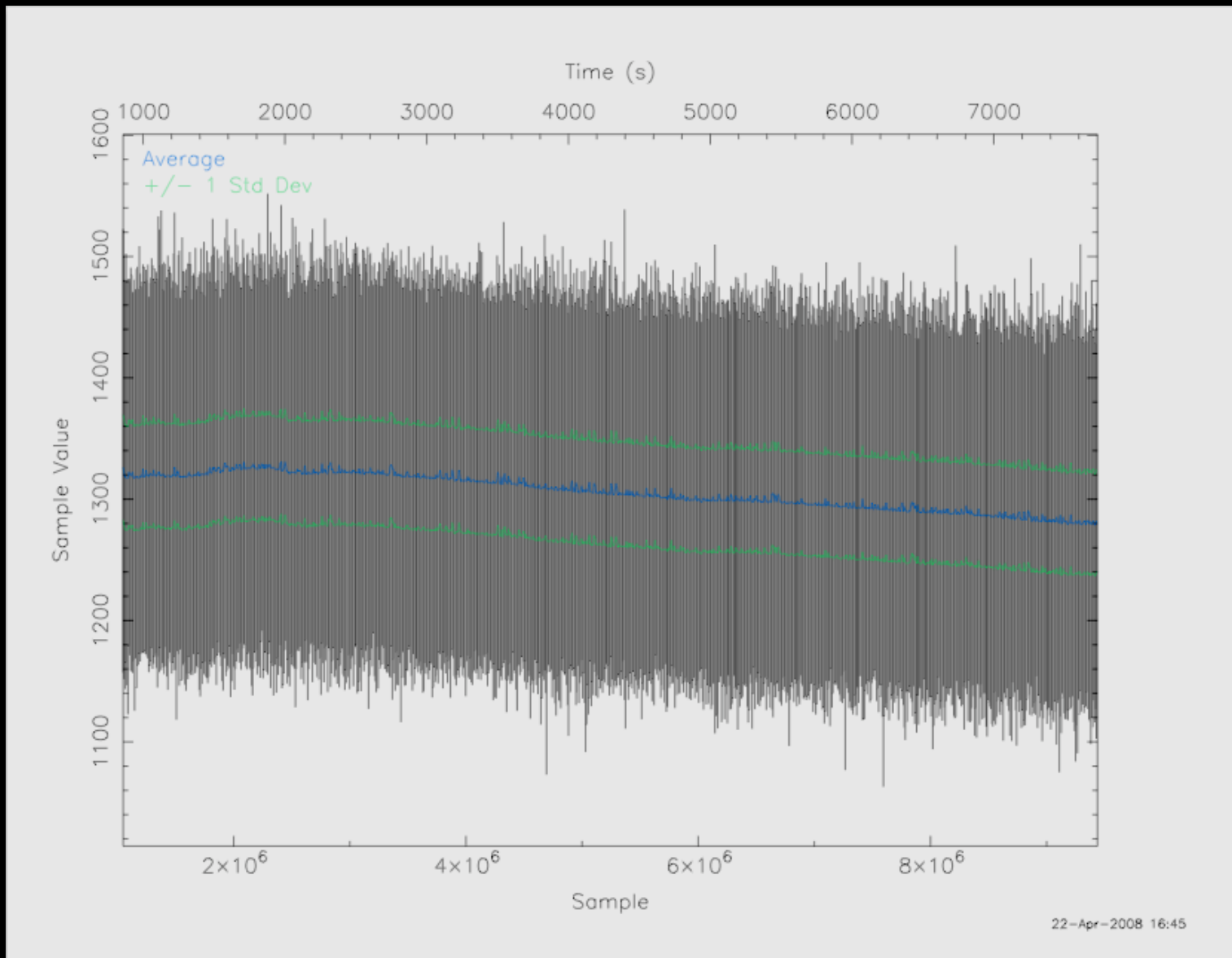
# Pulsars in the beam-formed “transit” data

Pulsar	Period (ms)	DM (pc/cm <sup>3</sup> )	S <sub>400</sub> (mJy)	Comments
B0329+54	714.5	26.8	1500	Single pulses!
B0355+54	156.4	57.1	46	Too weak?
B0450+55	340.7	14.5	59	Too weak?

6 HBA tiles, 48 subbands between 160-240MHz

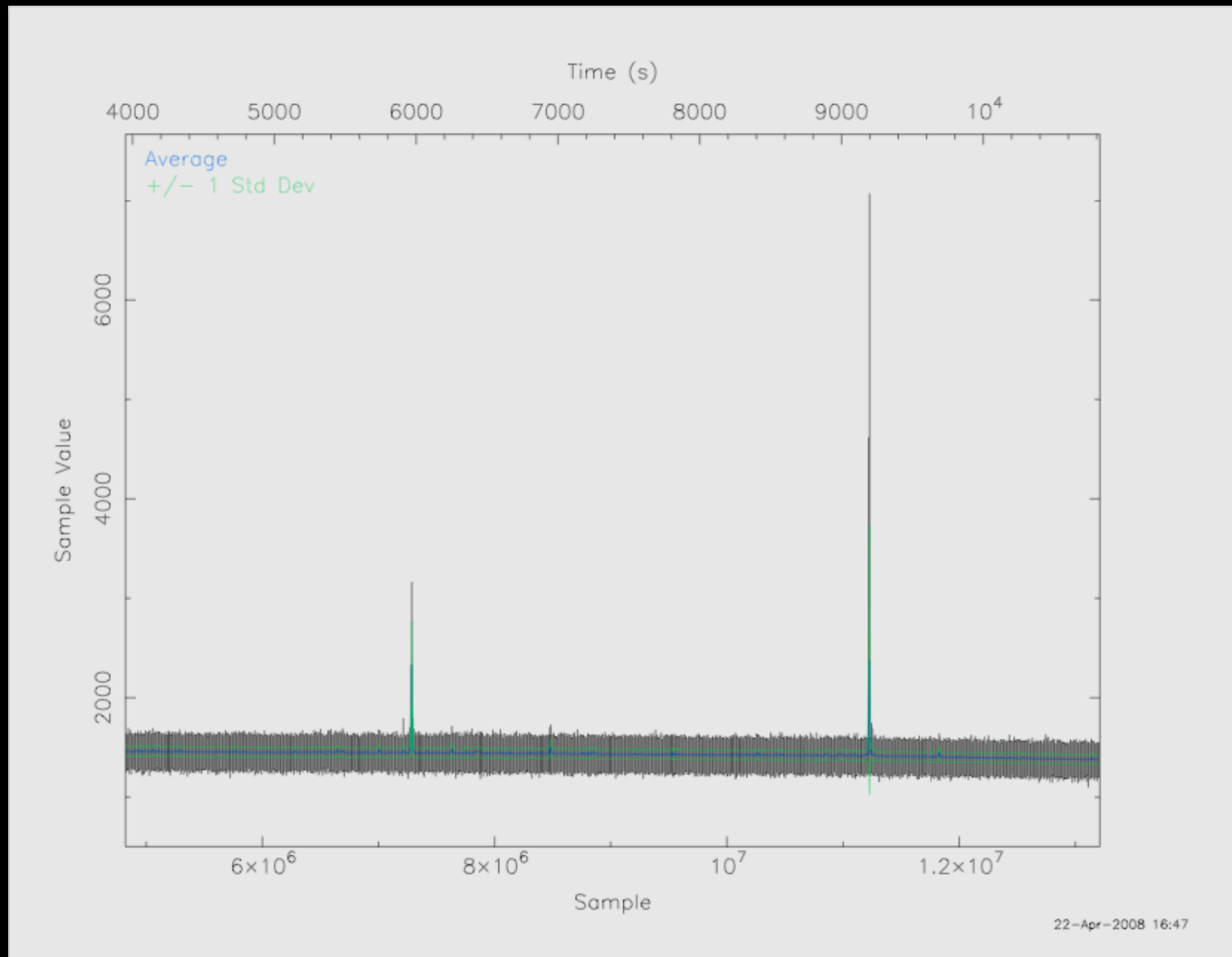
3hr on 080411 and 080417

# RFI situation



Relatively clean: e.g. subband 073

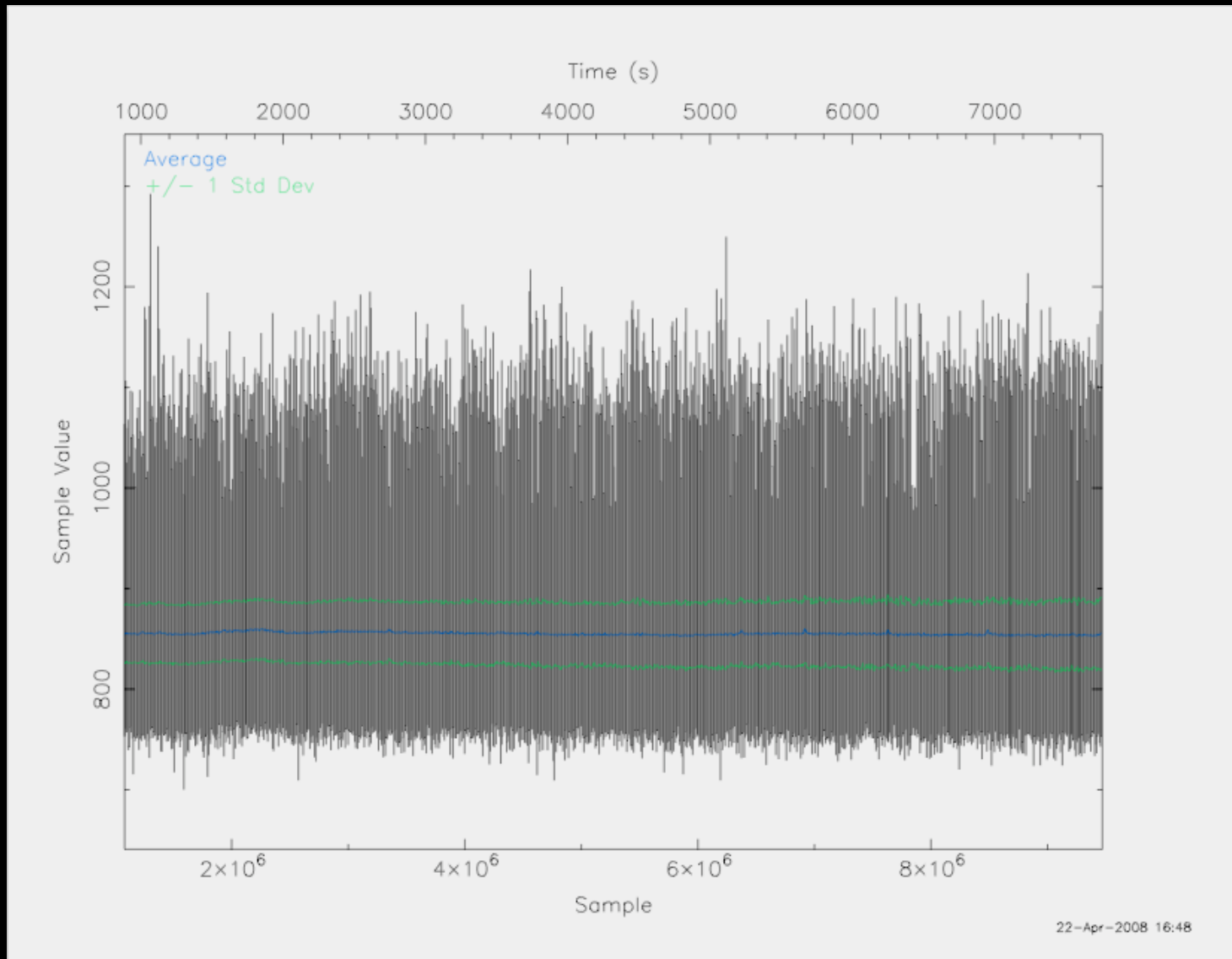
# RFI situation



Very bright RFI bursts: e.g. subband 097

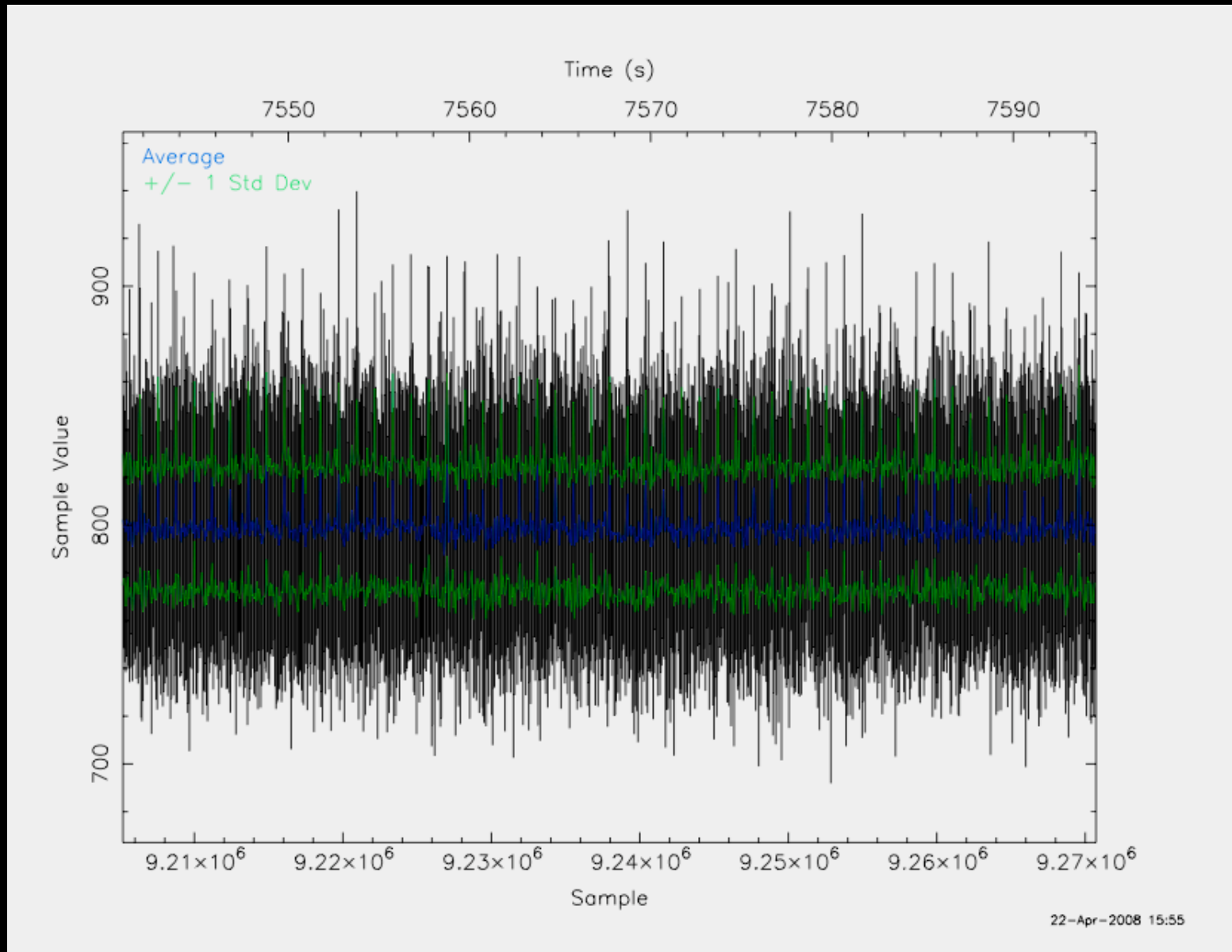


# RFI situation



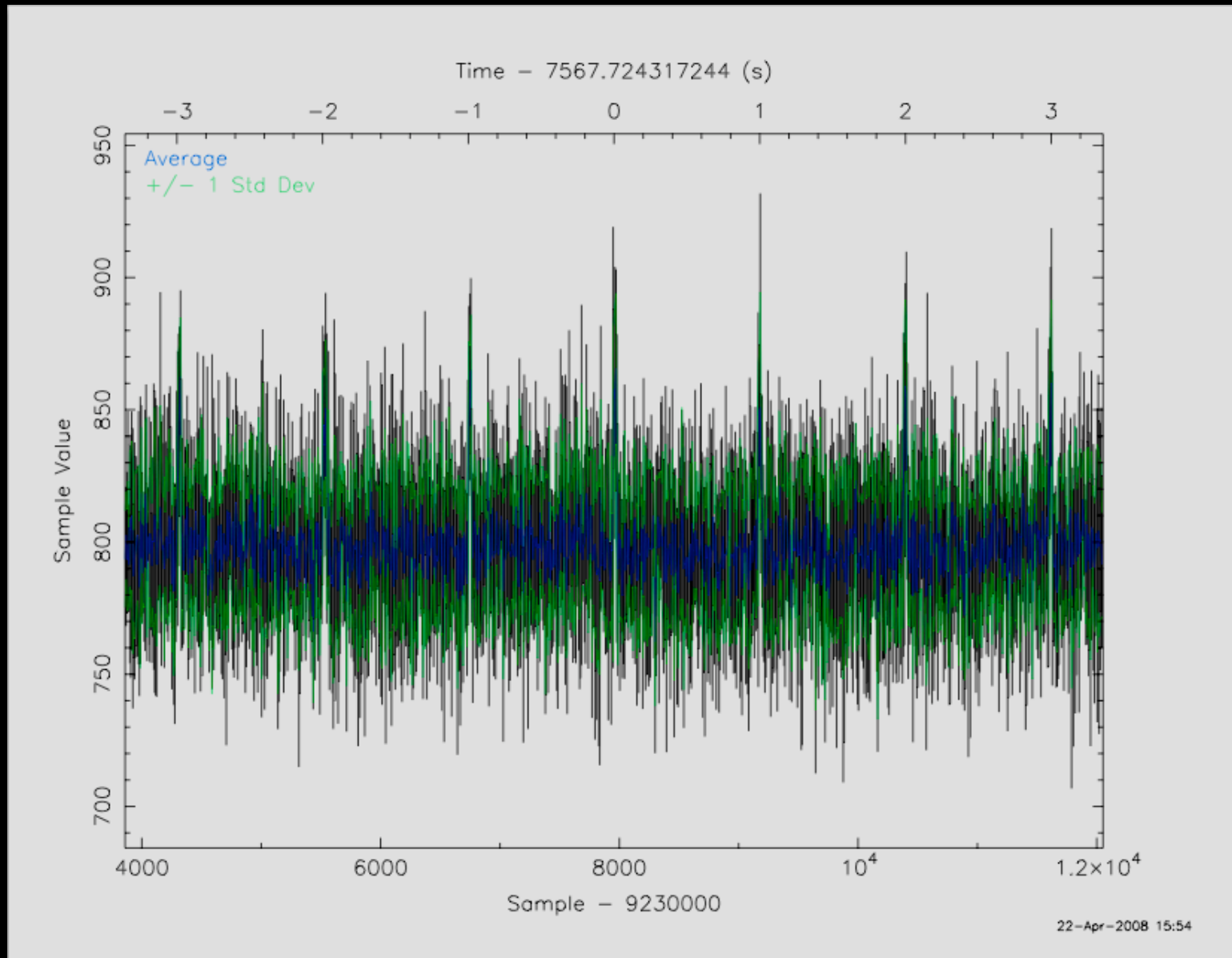
“Forest” of RFI bursts: e.g. subband 383

# 1-s Tick?



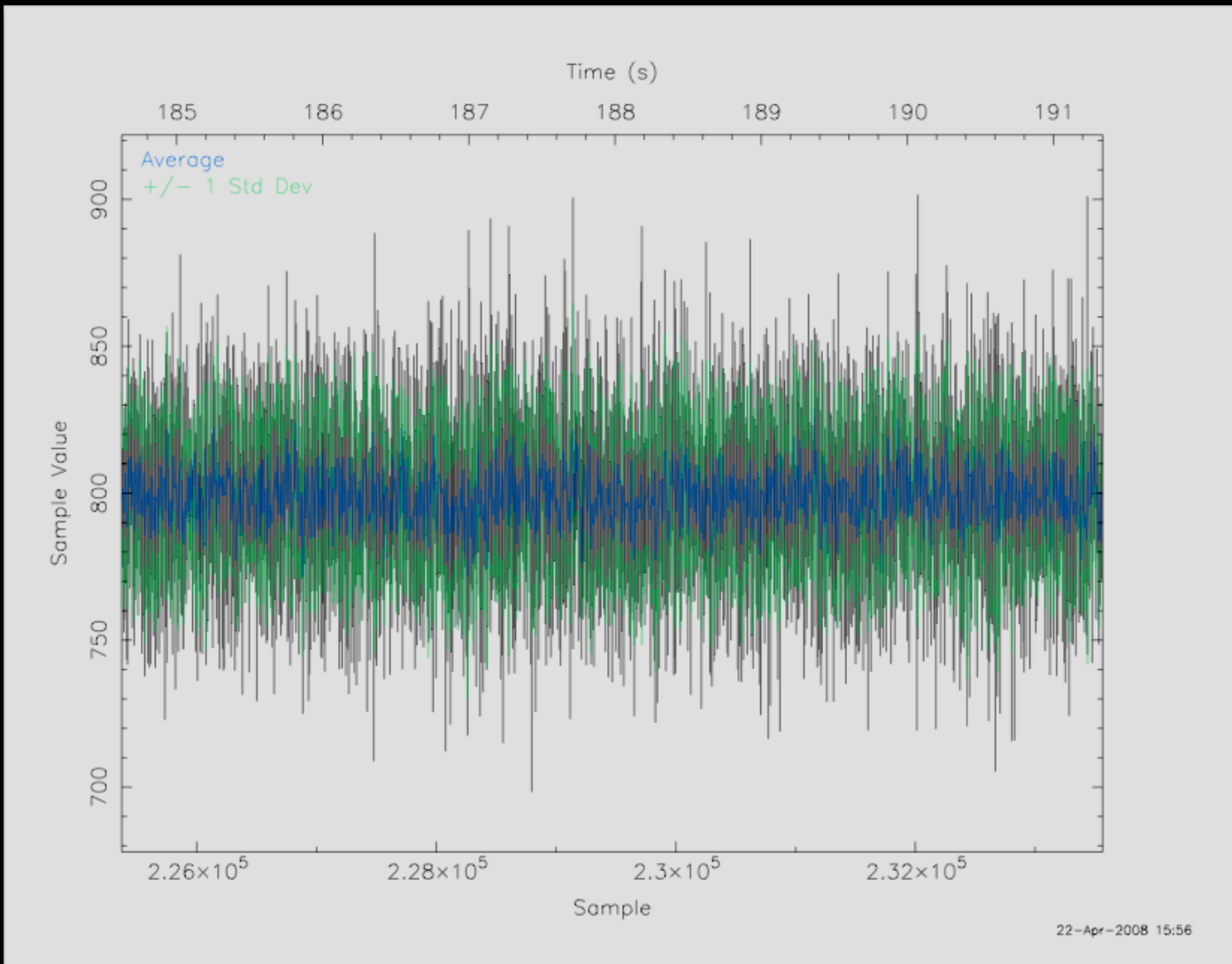
Can appear in otherwise “clean” subband

# 1-s Tick?



Related to size of data blocks?

# 1-s Tick?

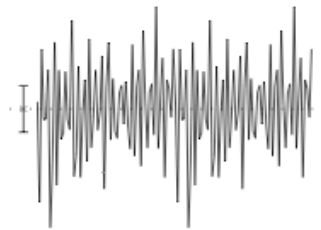


Comes and goes?! (same subband as previously)

# 1-s Tick?

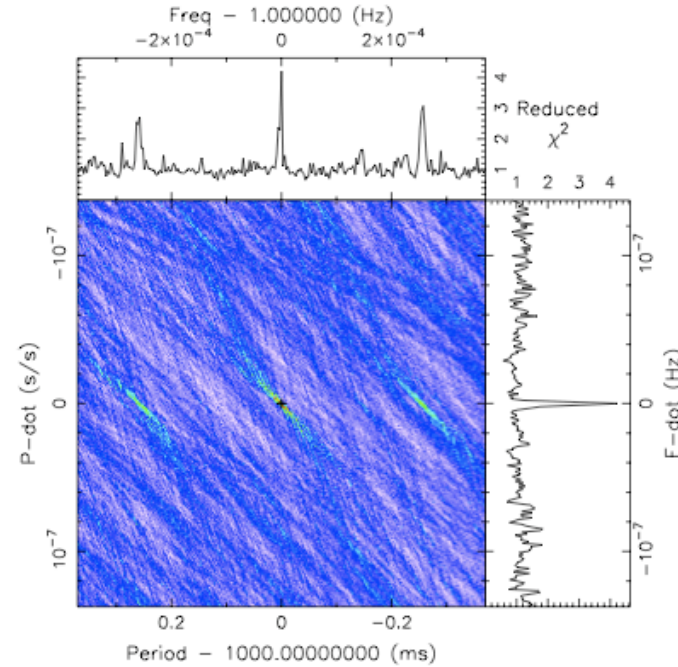
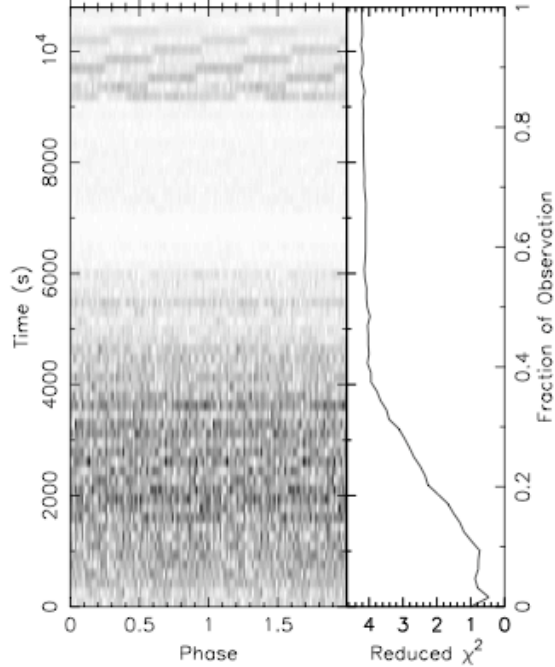
2 Pulses of Best Fit `B0329+54_080411_FULLRES_DM0.00.dat`

Search Information



Candidate: 1000.00ms\_Cand  
 Telescope: GBT  
 Epoch = N/A  
 Epoch<sub>topo</sub> = 50000.00386821383  
 Epoch<sub>bary</sub> = 50000.00386821383  
 T<sub>sample</sub> = 0.0008192  
 Data Folded = 13172736  
 Data Avg = 245  
 Data StdDev = 111.8  
 Profile Bins = 64  
 Profile Avg = 5.043e+07  
 Profile StdDev = 5.073e+04

RA<sub>J2000</sub> = 03:32:59.0000      DEC<sub>J2000</sub> = 54:34:43.0000  
 Best Fit Parameters  
 Reduced  $\chi^2$  = 4.212    P(Noise) < 1.17e-26 ( $\approx 10.6\sigma$ )  
 Dispersion Measure (DM) = N/A  
 P<sub>topo</sub> (ms) = N/A      P<sub>bary</sub> (ms) = 1000.00000(17)  
 P<sub>topo</sub> (s/s) = N/A      P<sub>bary</sub> (s/s) = 0.0(1.2) $\times 10^{-10}$   
 P<sub>topo</sub> (s/s<sup>2</sup>) = N/A      P<sub>bary</sub> (s/s<sup>2</sup>) = 0.0(7.3) $\times 10^{-14}$   
 Binary Parameters  
 P<sub>orb</sub> (s) = N/A      e = N/A  
 a<sub>1</sub>sin(i)/c (s) = N/A       $\omega$  (rad) = N/A  
 T<sub>peri</sub> = N/A



hessels 21-Apr-2008 10:19

Large variation in baseline



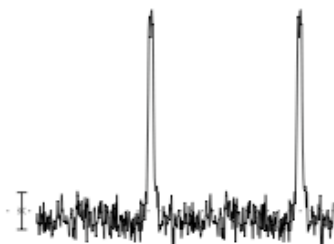
# RFI Excision

- Looked at each of 48 subbands by eye.
- Only used subbands that looked relatively “clean” (a little more than half).
- Much more sophisticated RFI excision will be done in future (remove narrow band, or short timescale RFI) using e.g. PRESTO routine “rfifind”.
- Important for all projects to characterize RFI background.

# B0329+54 Folded

2 Pulses of Best Profile B0329+54\_080411.sub000

Search Information



Candidate: 714.50ms\_Cand  
 Telescope: GBT  
 Epoch<sub>topo</sub> = 50000.000000000000  
 Epoch<sub>bary</sub> = 50000.00384567267  
 T<sub>sample</sub> = 0.0008192  
 Data Folded = 13172736  
 Data Avg = 29.47  
 Data StdDev = 457.2  
 Profile Bins = 256  
 Profile Avg = 1.52e+06  
 Profile StdDev = 1.037e+05

RA<sub>J2000</sub> = 03:32:59.0000 DEC<sub>J2000</sub> = 54:34:43.0000

Best Fit Parameters

Reduced  $\chi^2$  = 4.225 P(Noise) < 1.77e-101 ( $\approx 21.4\sigma$ )

Dispersion Measure (DM) = 26.759

P<sub>topo</sub> (ms) = 714.52499(51) P<sub>bary</sub> (ms) = 714.56905(51)

P<sub>dot\_topo</sub> (s/s) = -0.2(3.7)x10<sup>-10</sup> P<sub>dot\_bary</sub> (s/s) = -0.1(3.7)x10<sup>-10</sup>

P<sub>ddot\_topo</sub> (s/s<sup>2</sup>) = 0.0(2.2)x10<sup>-13</sup> P<sub>ddot\_bary</sub> (s/s<sup>2</sup>) = 0.0(2.2)x10<sup>-13</sup>

Binary Parameters

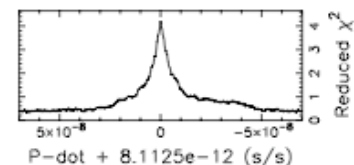
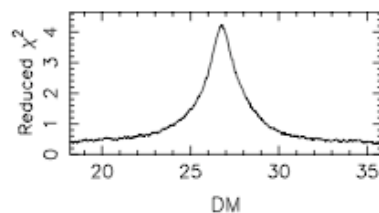
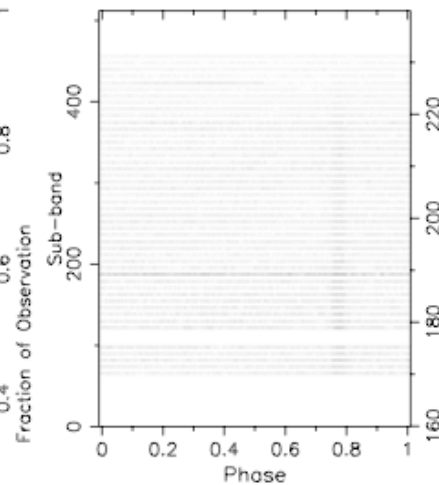
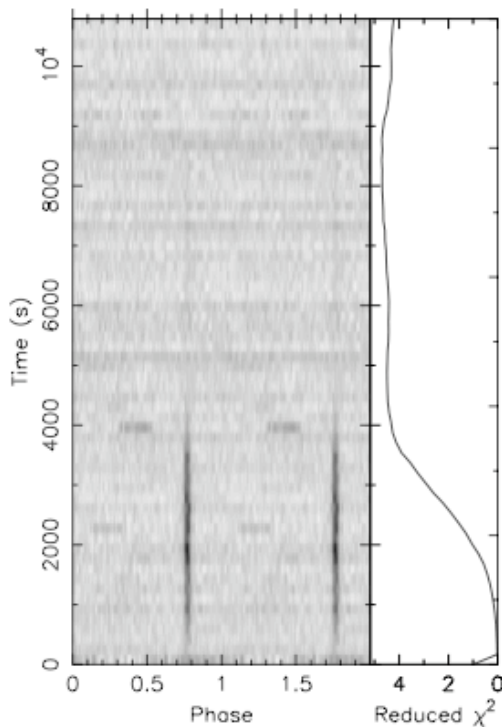
P<sub>orb</sub> (s) = N/A

a<sub>1</sub>sin(i)/c (s) = N/A

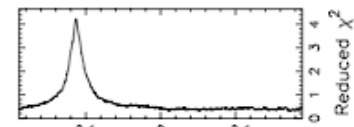
T<sub>peri</sub> = N/A

e = N/A

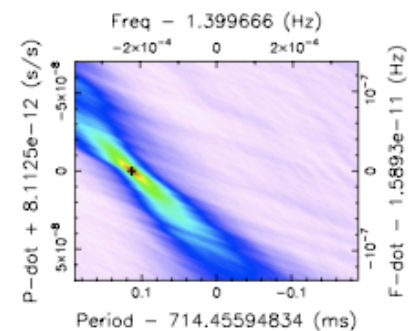
$\omega$  (rad) = N/A



P-dot + 8.1125e-12 (s/s)



Period - 714.45594834 (ms)



Freq - 1.399666 (Hz)

P-dot + 8.1125e-12 (s/s)

F-dot - 1.5893e-11 (Hz)

Period - 714.45594834 (ms)

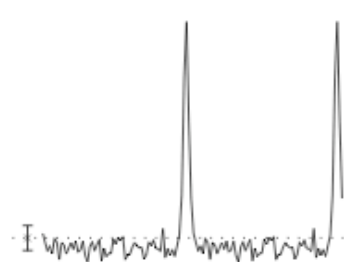
hessels 19-Apr-2008 03:38

All 48 subbands - 080411 - 160-240MHz

# B0329+54 Folded

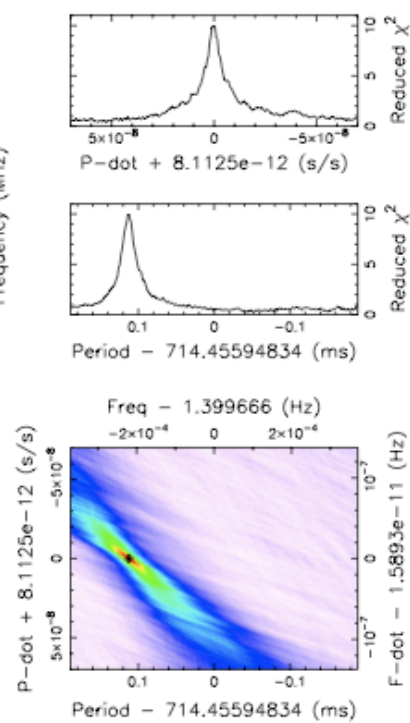
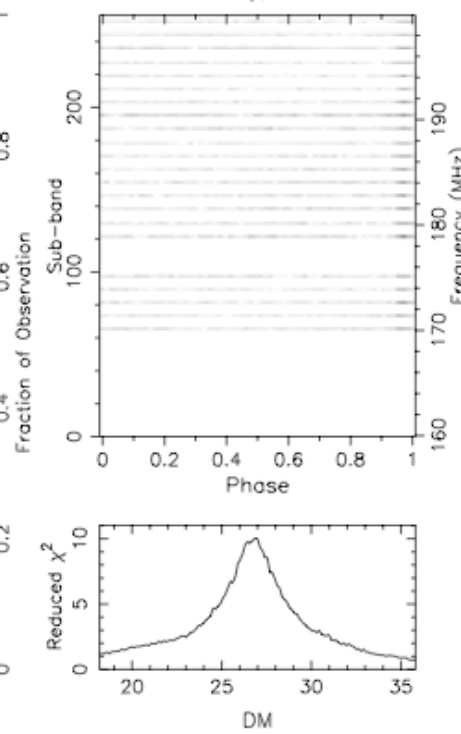
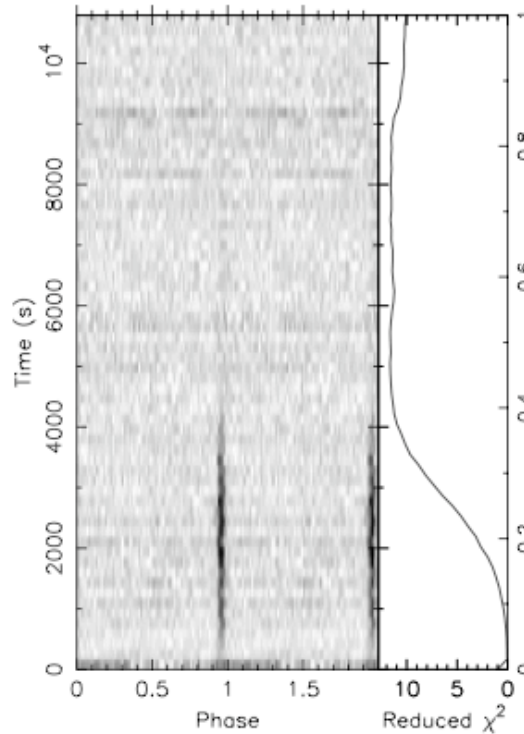
2 Pulses of Best Profile B0329+54\_080411.sub000

Search Information



Candidate: 714.50ms\_Cand  
 Telescope: GBT  
 Epoch<sub>topo</sub> = 50000.000000000000  
 Epoch<sub>bary</sub> = 50000.00383574610  
 T<sub>sample</sub> = 0.0008192  
 Data Folded = 13172736  
 Data Avg = 14.91  
 Data StdDev = 372.2  
 Profile Bins = 64  
 Profile Avg = 3.081e+06  
 Profile StdDev = 1.689e+05

RA<sub>J2000</sub> = 03:32:59.0000  
 DEC<sub>J2000</sub> = 54:34:43.0000  
 Best Fit Parameters  
 Reduced  $\chi^2$  = 10.025 P(Noise) < 9.06e-95 ( $\approx 20.6\sigma$ )  
 Dispersion Measure (DM) = 26.862  
 P<sub>topo</sub> (ms) = 714.52425(68)  
 P<sub>topo</sub> (s/s) =  $-0.2(4.9) \times 10^{-10}$   
 P<sub>topo</sub> (s/s<sup>2</sup>) =  $0.0(2.9) \times 10^{-13}$   
 P<sub>bary</sub> (ms) = 714.56831(68)  
 P<sub>bary</sub> (s/s) =  $-0.1(4.9) \times 10^{-10}$   
 P<sub>bary</sub> (s/s<sup>2</sup>) =  $0.0(2.9) \times 10^{-13}$   
 Binary Parameters  
 P<sub>orb</sub> (s) = N/A  
 a<sub>1</sub> sin(i)/c (s) = N/A  
 T<sub>peri</sub> = N/A  
 e = N/A  
 $\omega$  (rad) = N/A



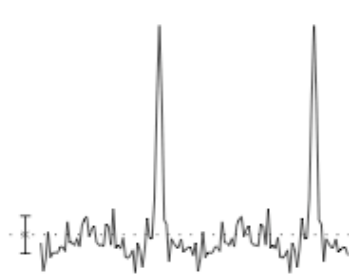
hessels 22-Apr-2008 09:35

Lower ~24 subbands - 080411 - 160-200MHz

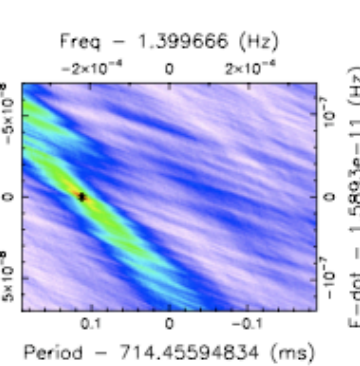
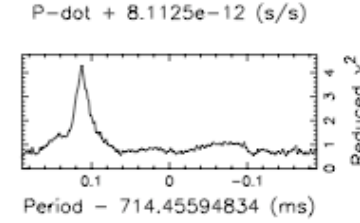
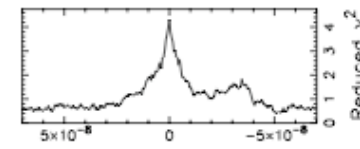
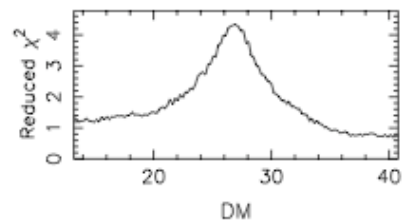
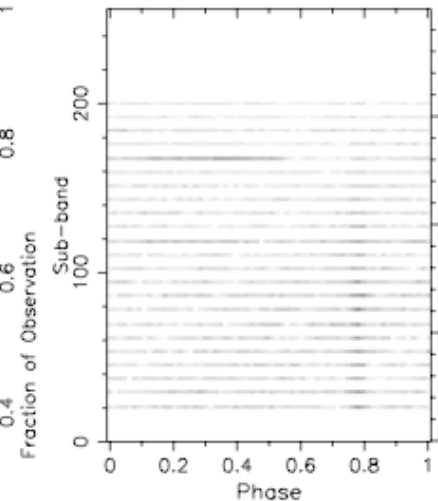
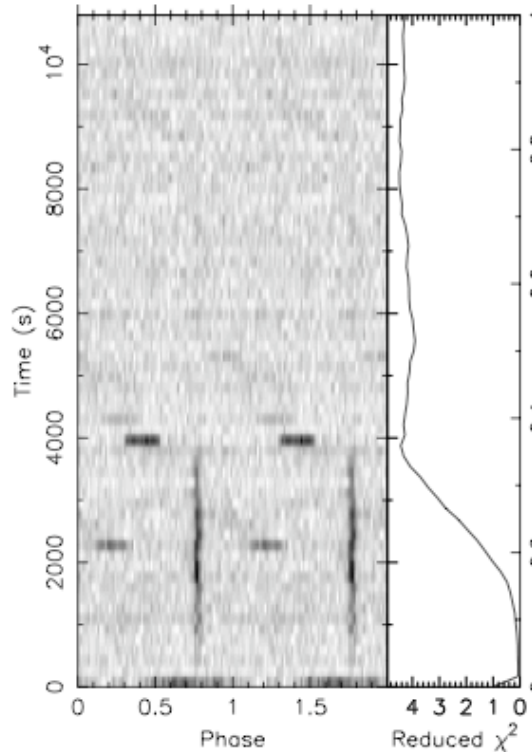
# B0329+54 Folded

2 Pulses of Best Profile B0329+54\_080411.sub000

Search Information



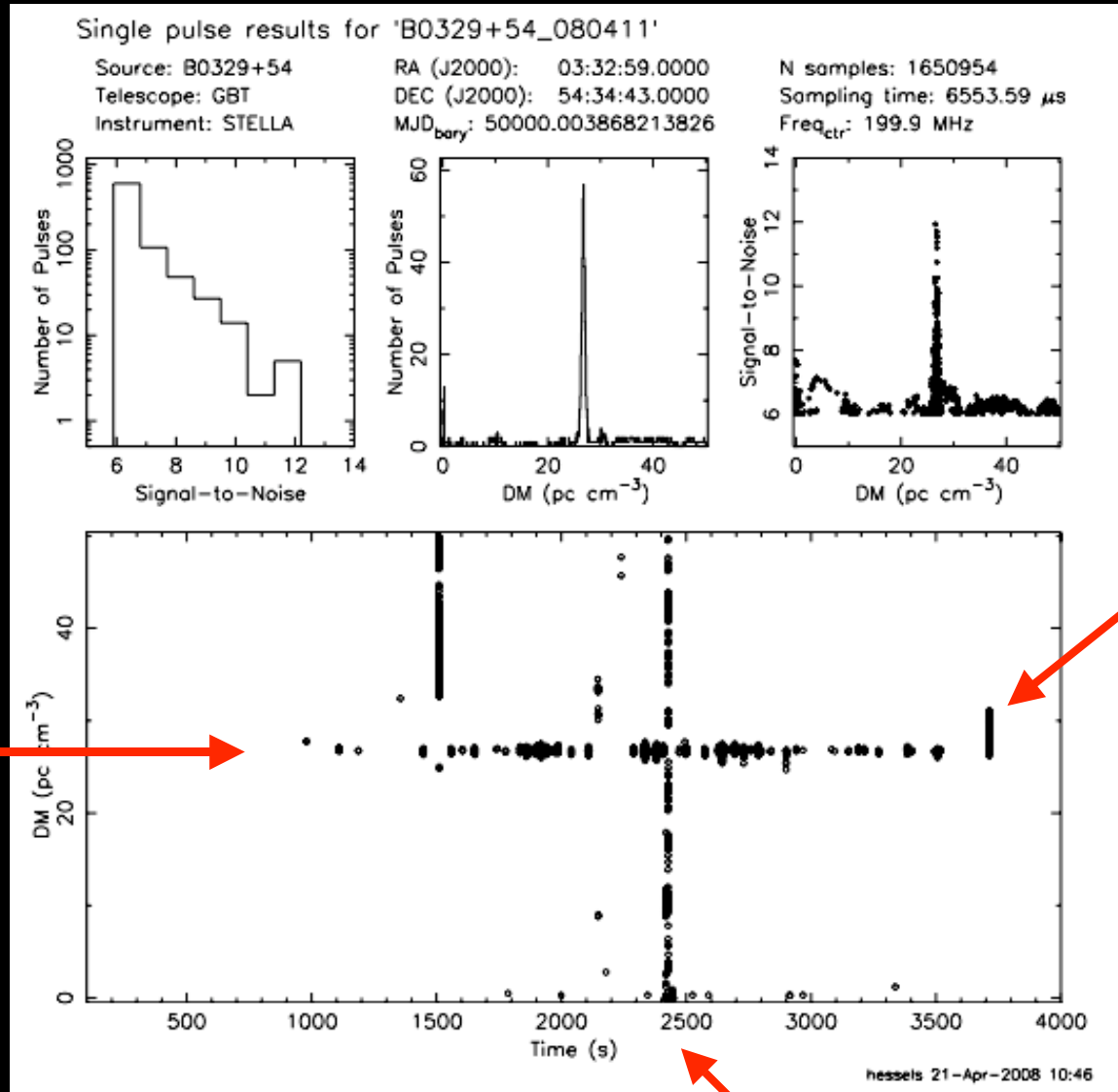
Candidate: 714.50ms_Cand	RA <sub>J2000</sub> = 03:32:59.0000	DEC <sub>J2000</sub> = 54:34:43.0000
Telescope: GBT	Best Fit Parameters	
Epoch <sub>topo</sub> = 50000.00000000000	Reduced $\chi^2$ = 4.318	P(Noise) < 8.72e-28 ( $\approx 10.9\sigma$ )
Epoch <sub>bary</sub> = 50000.00384567267	Dispersion Measure (DM) = 26.785	
T <sub>sample</sub> = 0.0008192	P <sub>topo</sub> (ms) = 714.5243(10)	P <sub>bary</sub> (ms) = 714.5683(10)
Data Folded = 13172736	P <sub>topo</sub> (s/s) = -0.2(7.5)x10 <sup>-10</sup>	P <sub>bary</sub> (s/s) = -0.1(7.5)x10 <sup>-10</sup>
Data Avg = 13.33	P <sub>topo</sub> (s/s <sup>2</sup> ) = 0.0(4.5)x10 <sup>-13</sup>	P <sub>bary</sub> (s/s <sup>2</sup> ) = 0.0(4.5)x10 <sup>-13</sup>
Data StdDev = 253.1	Binary Parameters	
Profile Bins = 64	P <sub>orb</sub> (s) = N/A	e = N/A
Profile Avg = 2.746e+06	a <sub>1</sub> sin(i)/c (s) = N/A	$\omega$ (rad) = N/A
Profile StdDev = 1.148e+05	T <sub>peri</sub> = N/A	



hessels 22-Apr-2008 10:00

Upper ~24 subbands - 080411 - 200-240MHz

# B0329+54 Single Pulses!



B0329+54  
DM =  
26.8 pc cm<sup>-3</sup>

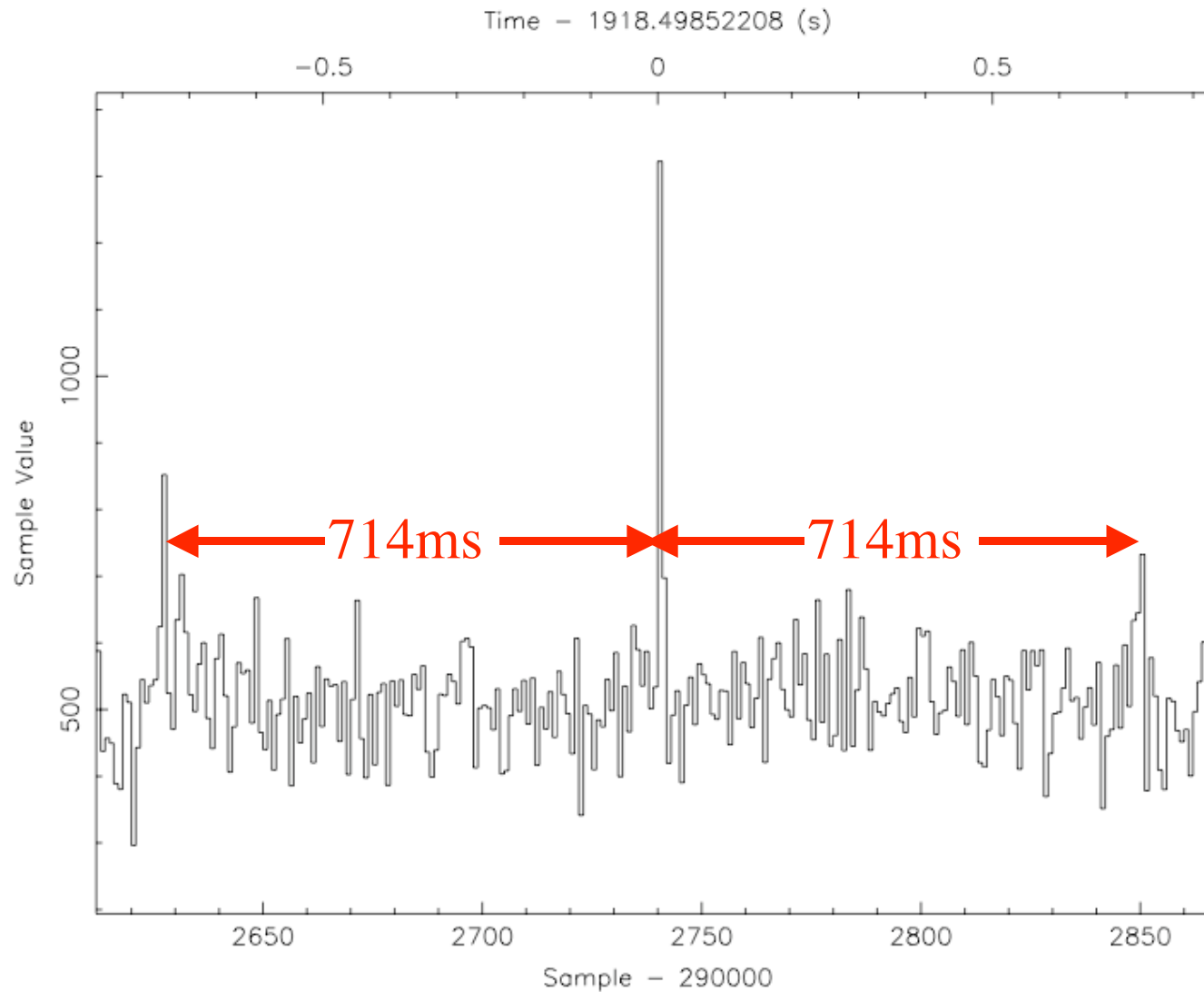
Puzzling  
DM =  
28.1 pc cm<sup>-3</sup>

500 trial DMs with 6.5ms time resolution

Interference



# B0329+54 Single Pulses!



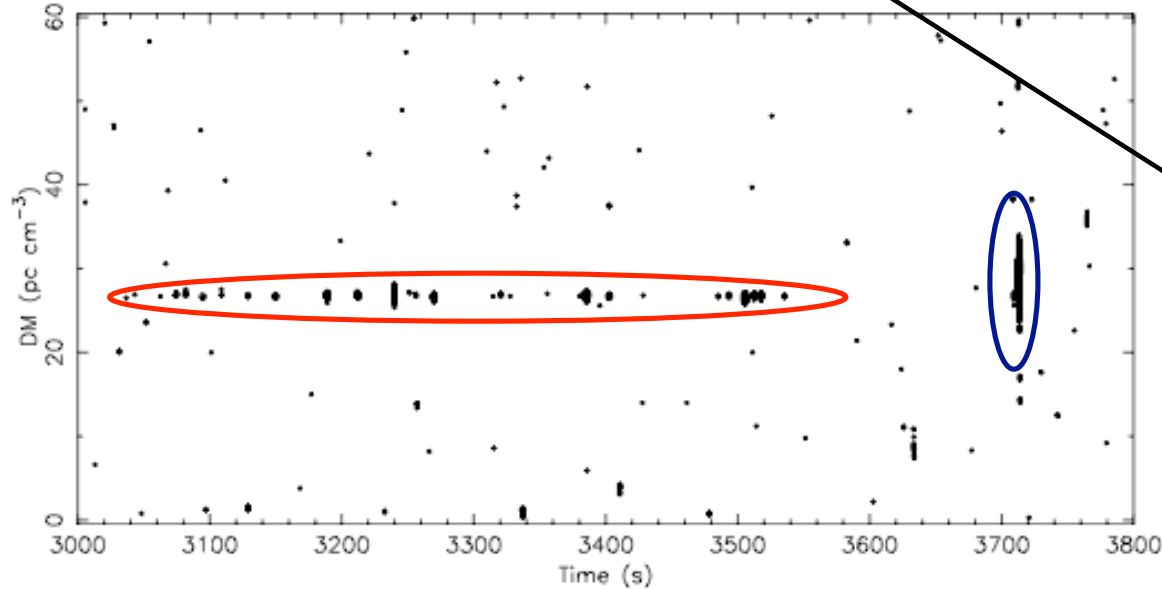
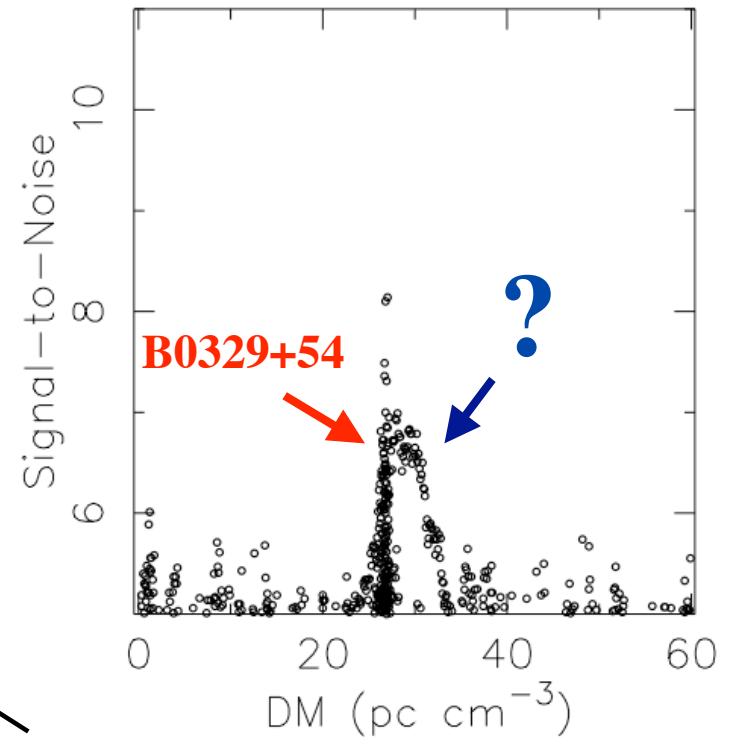
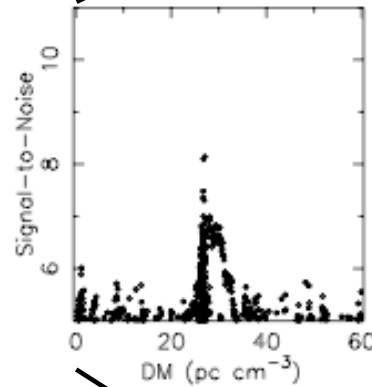
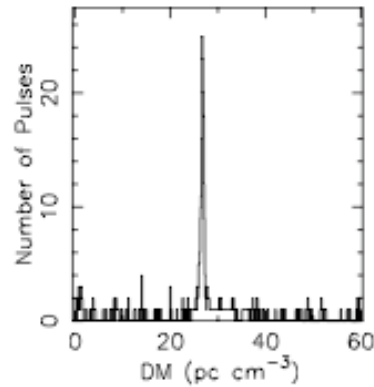
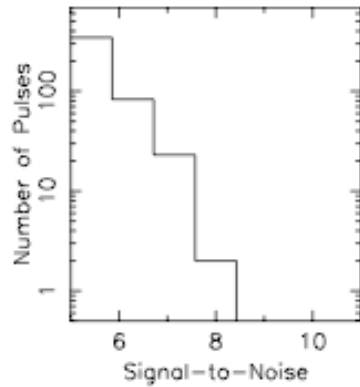
# B0329+54 Single Pulses

Single pulse results for 'B0329+54\_080411'

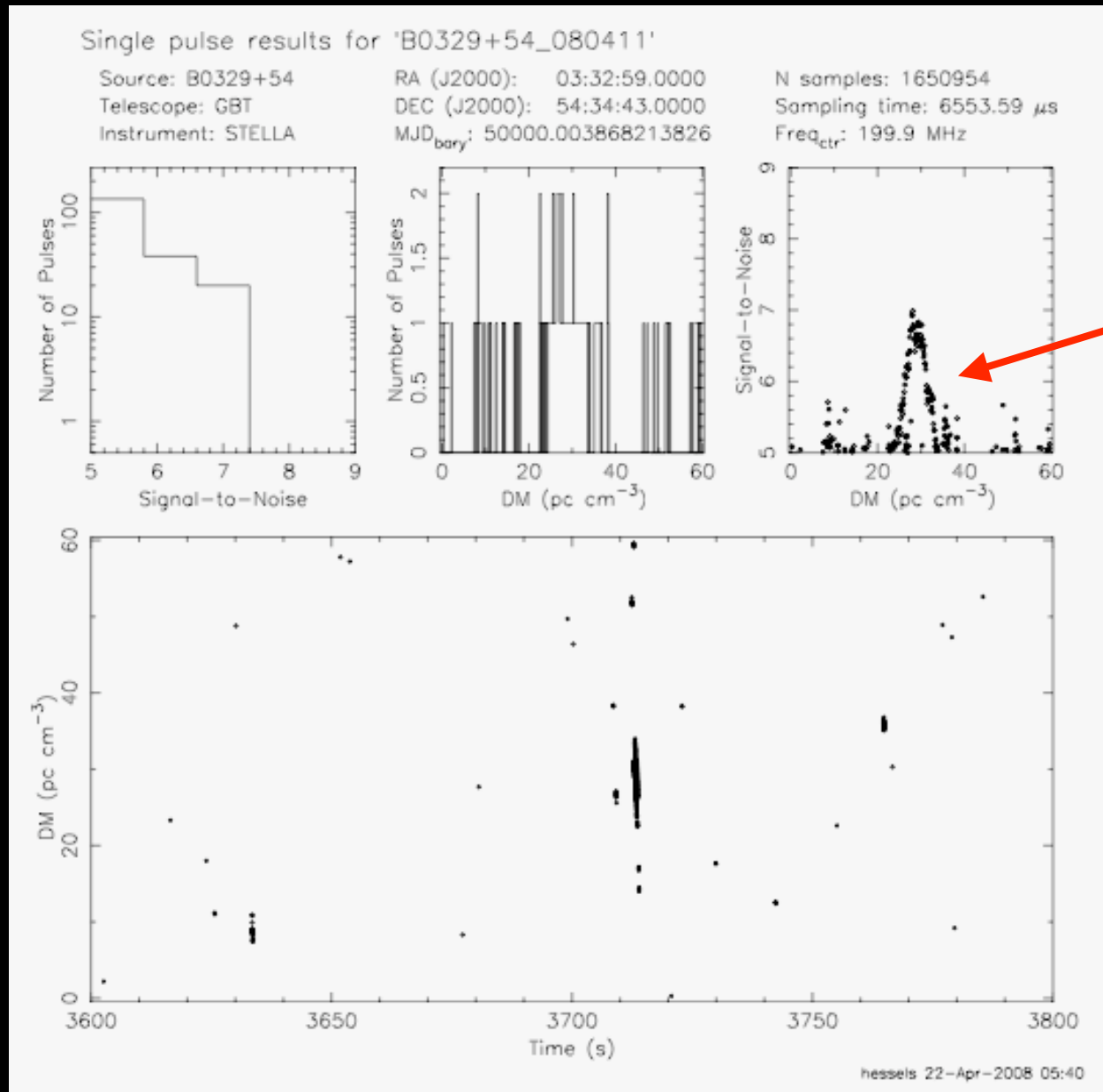
Source: B0329+54  
Telescope: GBT  
Instrument: STELLA

RA (J2000): 03:32:59.0000  
DEC (J2000): 54:34:43.0000  
MJD<sub>bary</sub>: 50000.003868213826

N samples: 1650954  
Sampling time: 6553.59  $\mu$ s  
Frequency: 199.9 MHz

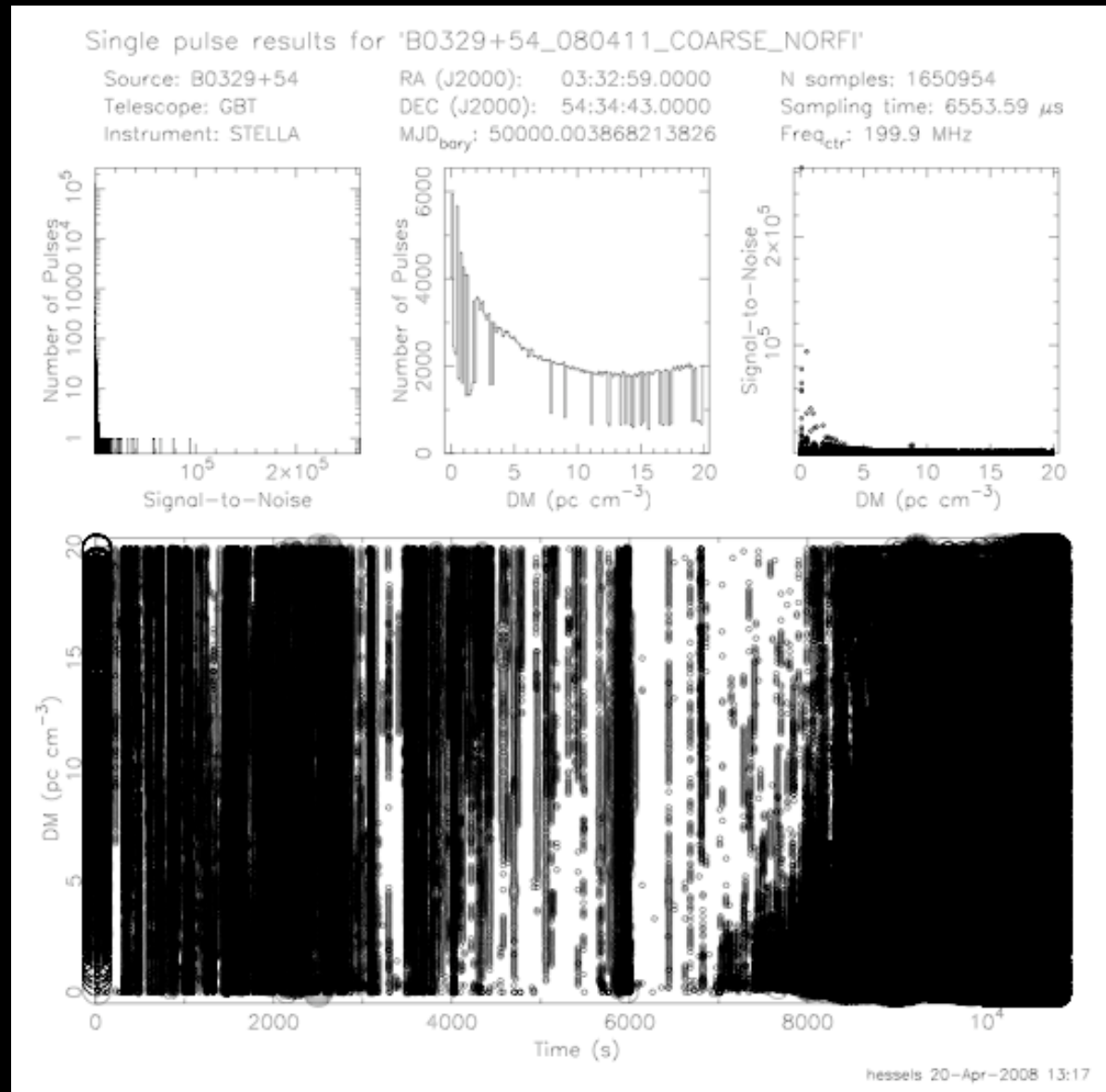


# B0329+54 Single Pulses



Looks dispersed

# B0329+54 Single Pulses



**Without** RFI excision (using all 48 subbands indiscriminantly)

# To Do:

- Figure out 1-s pulses
- Characterize RFI better
- Excise RFI better
- Characterize beam shape
- Vary timing and frequency stamps.
- Search for new bursts, at higher DMs and higher resolution.
- Determine nature of DM  $28.1 \text{ pc cm}^{-3}$  burst.