Timing pulsar B0329+54

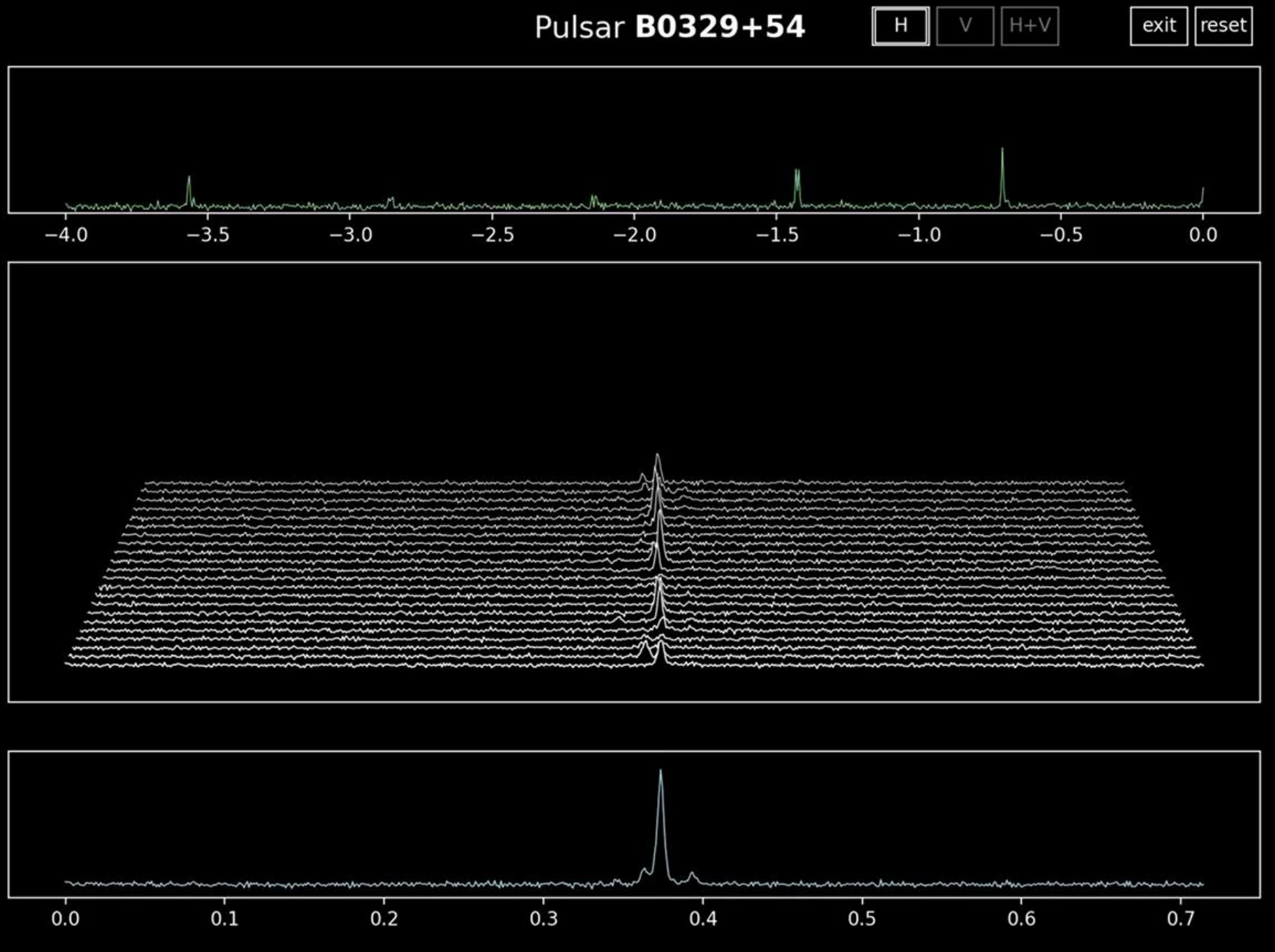
Dwingeloo Radio Telescope
EUCARA September 2025

Presented by Tammo Jan Dijkema
Contributions by all CAMRAS volunteers

1 july 1955

17 April 1956

Demo

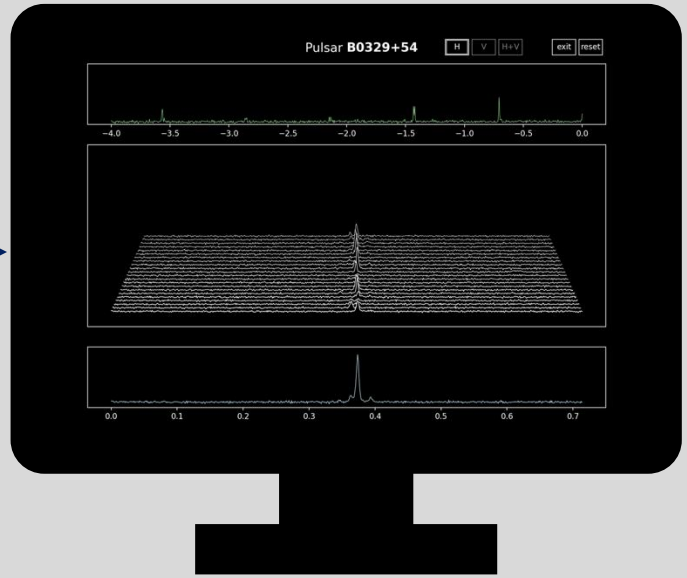

Pulsar **B0329+54**
H
V
H+V
exit
reset
−4.0
−3.5
−3.0
−2.5
−2.0
−1.5
−1.0
−0.5
0.0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7

Pipeline

Ettus USRP B210

usrp_to_vrt

vrt_pulsar



vrt_to_dada

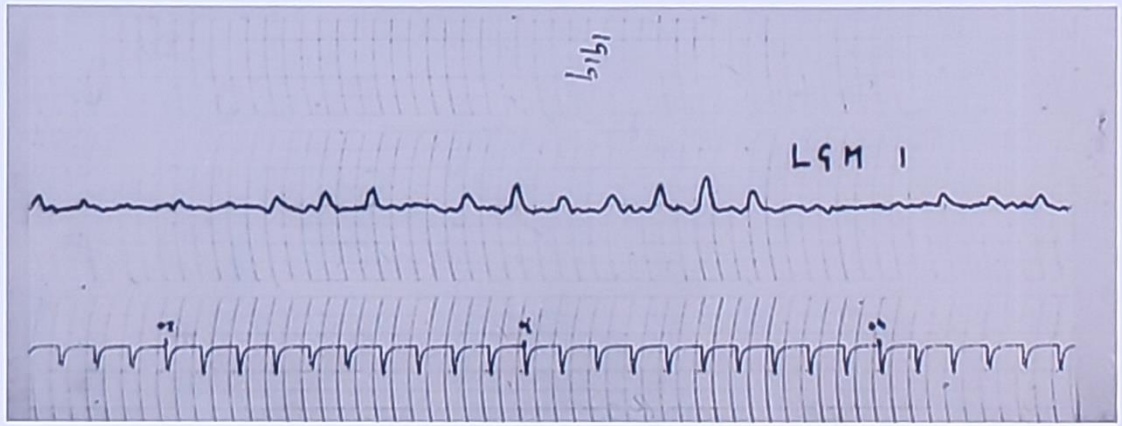
dspsr

*.ar

vrt_to_filterbank

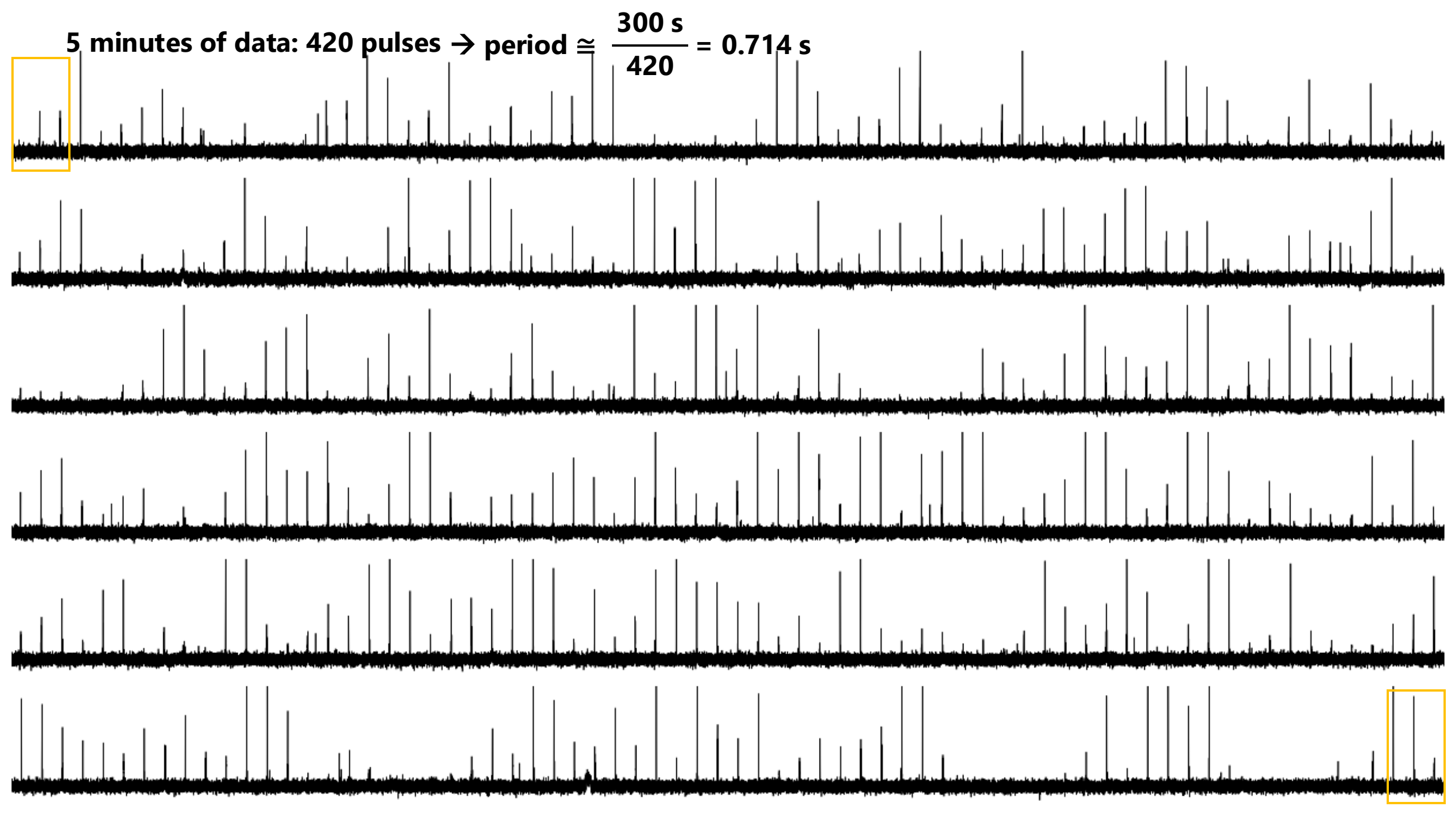
*.fil

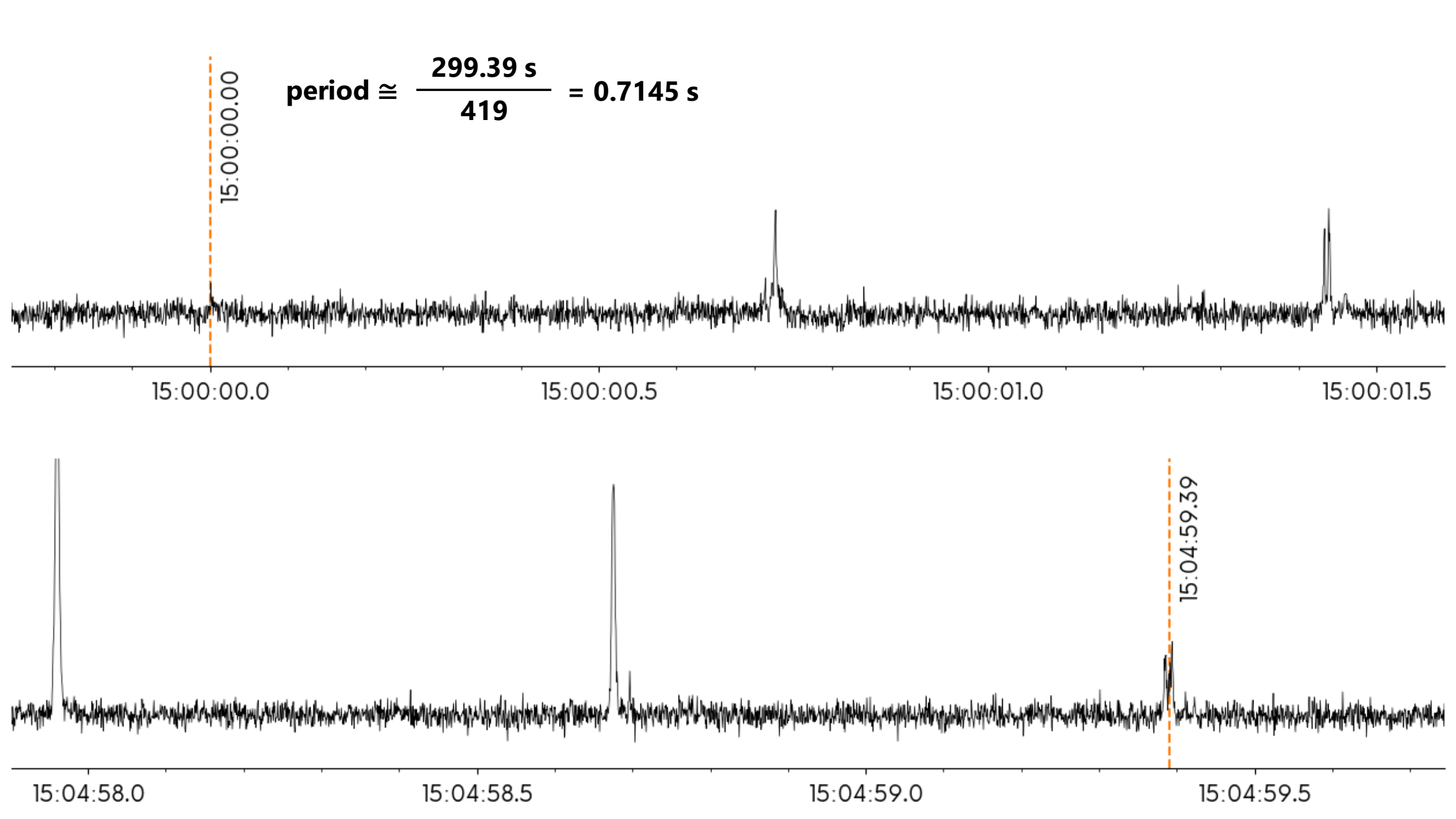
High-speed recording

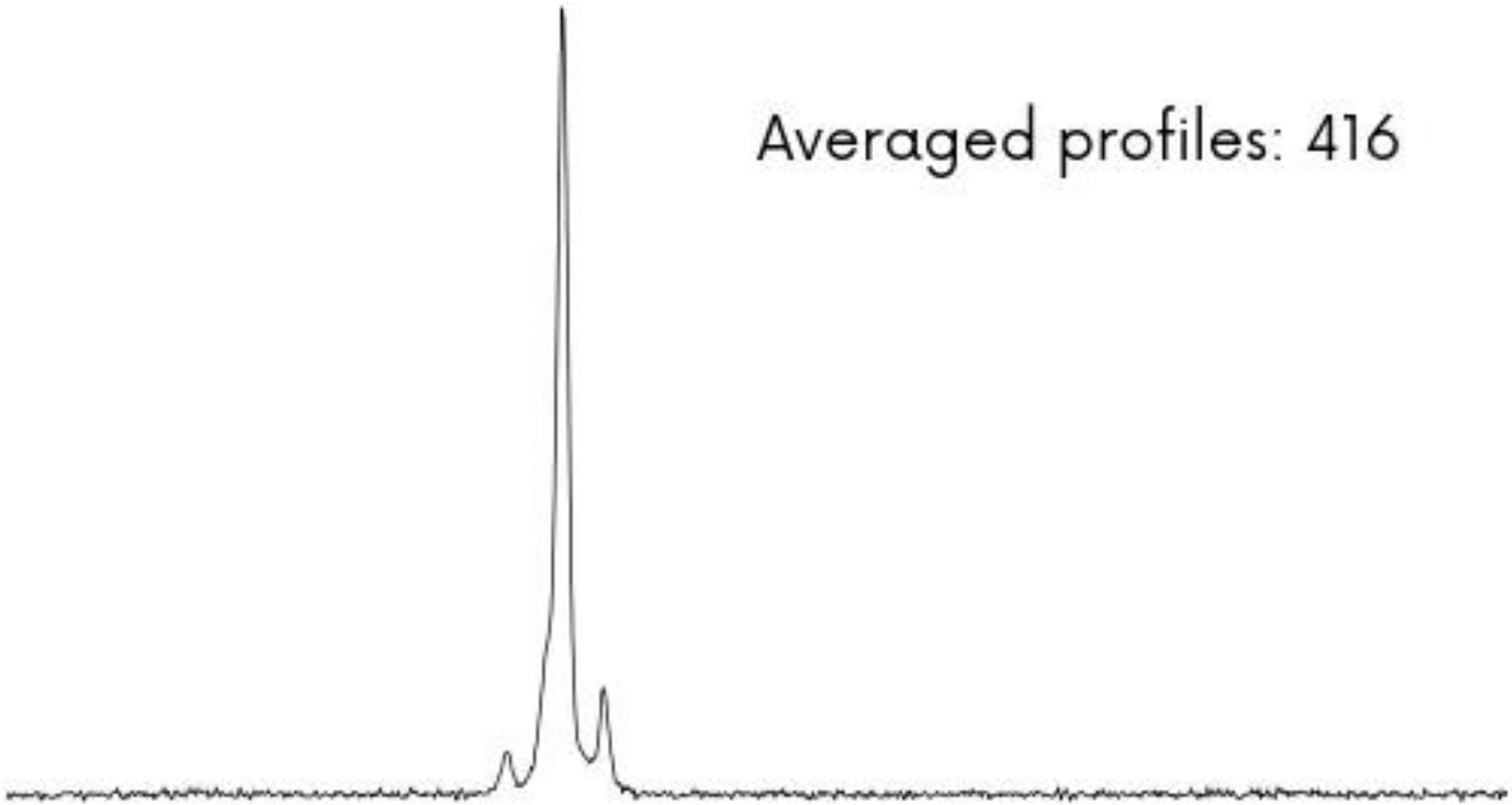


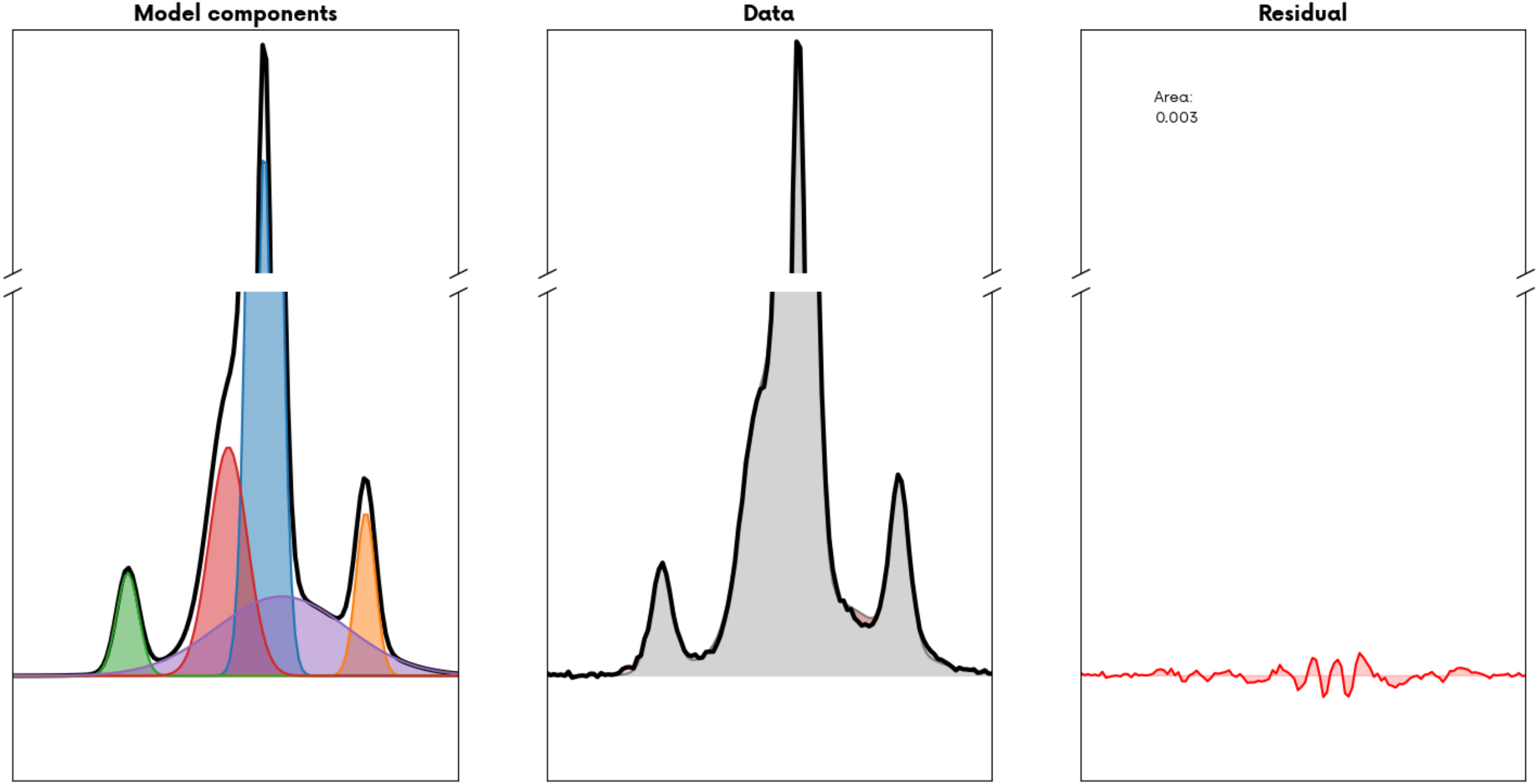
Top line - pulsed emission detected

Bottom line – one second time pulses


5 minutes of data: 420 pulses → period ≅ 300 s / 420 = 0.714 s


period ≅ 299.39 s / 419 = 0.7145 s
15:00:00.00
15:00:00.0
15:00:00.5
15:00:01.0
15:00:01.5
15:04:59.39
15:04:58.0
15:04:58.5
15:04:59.0
15:04:59.5


Averaged profiles: 416



Profile of Von Mises functions fitted to a 30-minute observation with PSArchive's paas

Calendar

2025

January

Mon	Tue	Wed	Thu	Fri	Sat	Sun
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	31		

February

Mon	Tue	Wed	Thu	Fri	Sat	Sun
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28		

March

Mon	Tue	Wed	Thu	Fri	Sat	Sun
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31						

April

Mon	Tue	Wed	Thu	Fri	Sat	Sun
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30				

May

Mon	Tue	Wed	Thu	Fri	Sat	Sun
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	

June

Mon	Tue	Wed	Thu	Fri	Sat	Sun
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30						

July

Mon	Tue	Wed	Thu	Fri	Sat	Sun
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			

August

Mon	Tue	Wed	Thu	Fri	Sat	Sun
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	31

November

Mon	Tue	Wed	Thu	Fri	Sat	Sun
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	

December

Mon	Tue	Wed	Thu	Fri	Sat	Sun
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	31					

Time of arrivals

60620.665841960925642
60620.672598303485125
60621.438596146737438
60621.565081341103054
60622.564401920593609
60622.660413344779826
60626.529644352905087
60627.423515605295119
60628.537860480945423
60629.566176356585336
60629.579978666893512
60631.640584404503709
60631.659638067634996
60634.499526545091439
60637.538755758677473
60638.586849886563079
60642.718234901700165
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60746.431015516139499
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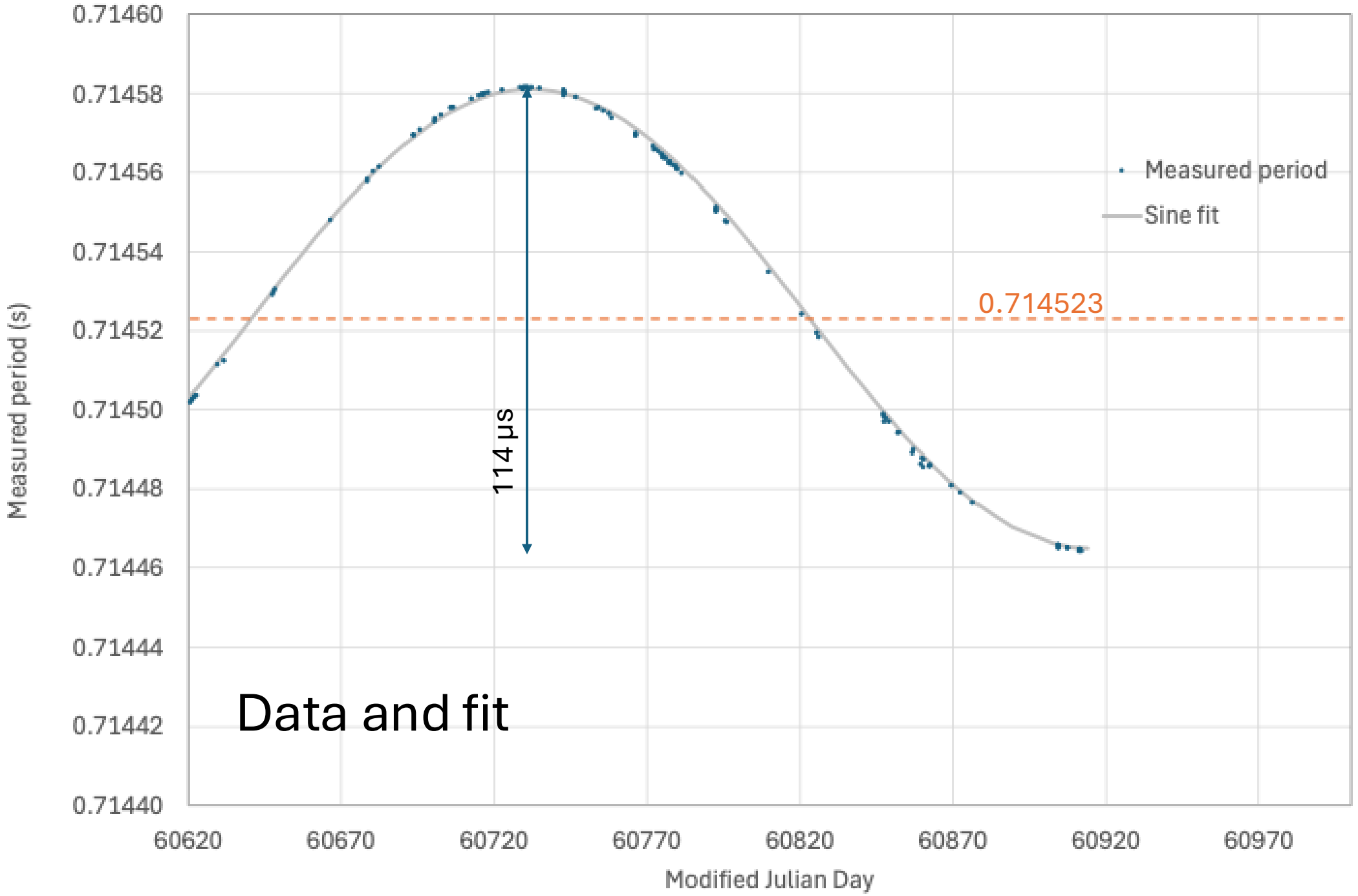
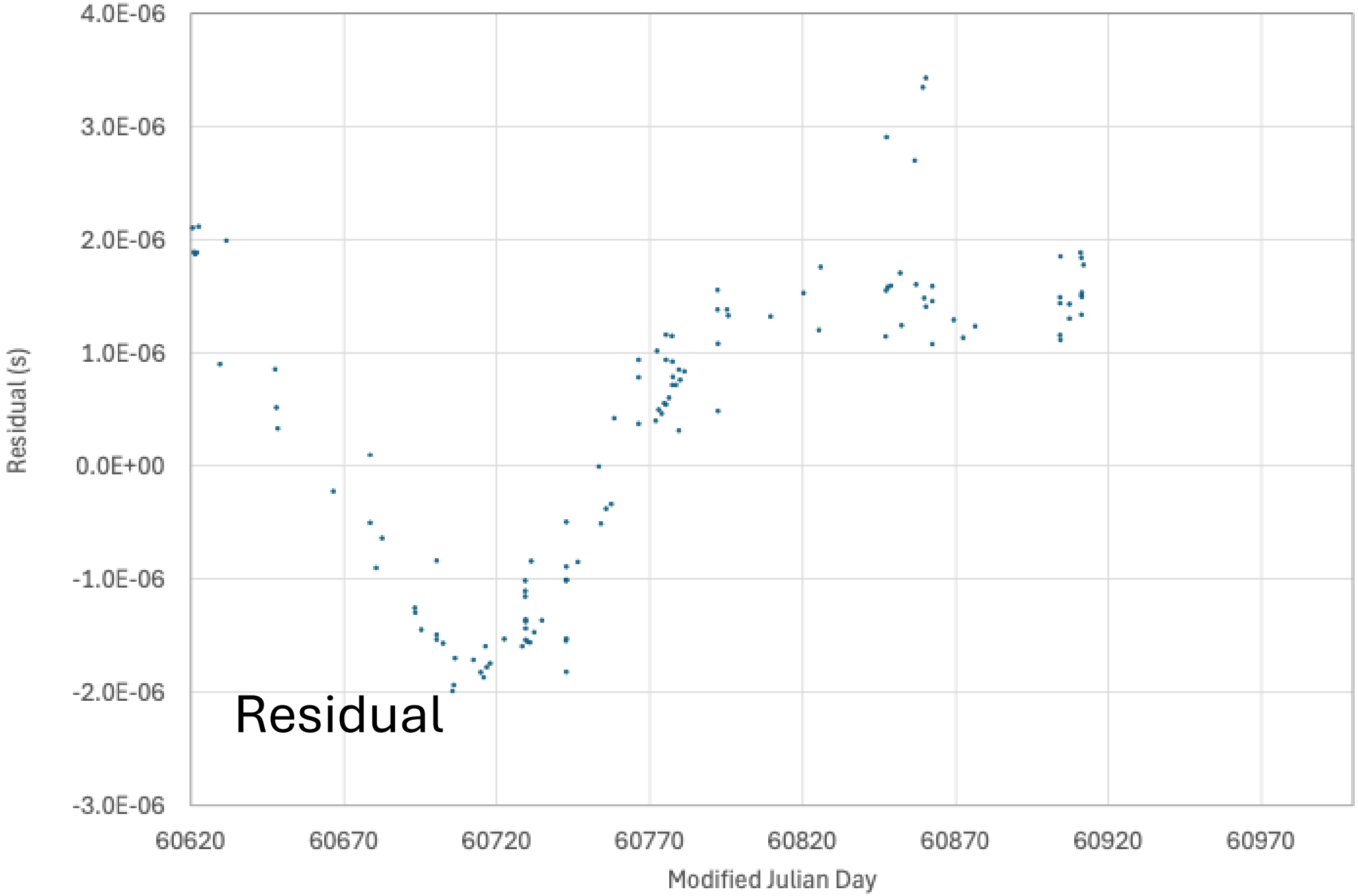
60911.392498551766270
60911.400982820596102
60911.449614372858850
60911.491217047783034
60911.520085055245991
60912.558018065249240
60915.453921621618785

MJD	Diff (s)	Period estimate	Rotations estimate	Fractional rotations	Use
60620.665842	#VALUE!	0.7145000	#VALUE!	#VALUE!	
60620.672598	583.748	0.7145000	817.00	0.00	TRUE
60621.438596	66182.214	0.7145018	92627.07	0.07	TRUE
60621.565081	10928.321	0.7145024	15295.01	0.01	TRUE
60622.564402	86341.298	0.7145028	120841.09	0.09	TRUE
60622.660413	8295.387	0.7145033	11610.00	0.00	TRUE
60626.529644	334301.559	0.7145036	467879.45	0.45	
60627.423516	77230.476	0.7145036	108089.69	-0.31	
60628.537860	96279.397	0.7145036	134750.05	0.05	
60629.566176	88846.492	0.7145036	124347.15	0.15	
60629.579979	1192.520	0.7145036	1669.02	0.02	TRUE
60631.640584	178036.336	0.7145114	249172.12	0.12	
60631.659638	1646.236	0.7145114	2304.00	0.00	TRUE
60634.499527	245366.364	0.7145124	343403.94	-0.06	
60637.538756	262589.404	0.7145124	367508.55	-0.45	
60638.586850	90555.333	0.7145124	126737.25	0.25	
60642.718235	356951.665	0.7145124	499573.81	-0.19	
60647.532252	415931.046	0.7145124	582118.75	-0.25	
60647.629904	8437.159	0.7145124	11808.28	0.28	TRUE
60648.409254	67335.863	0.7145291	94238.10	0.10	TRUE
60648.430996	1878.500	0.7145298	2629.00	0.00	TRUE
60651.758846	287526.207	0.7145304	402398.84	-0.16	
60653.655116	163837.787	0.7145304	229294.35	0.35	


0.71460
0.71458
0.71456
0.71454
0.71452
0.71450
0.71448
0.71446
0.71444
0.71442
0.71440
Measured period (s)
60620
60670
60720
60770
60820
60870
60920
60970
Modified Julian Day
Measured period
Sine fit
0.714523
114 µs
Data and fit


4.0E-06
3.0E-06
2.0E-06
1.0E-06
0.0E+00
-1.0E-06
-2.0E-06
-3.0E-06
Residual (s)
60620
60670
60720
60770
60820
60870
60920
60970
Modified Julian Day
Residual

$$f_{\text{observed}} = f_{\text{real}} \cdot \frac{c}{c - v}$$

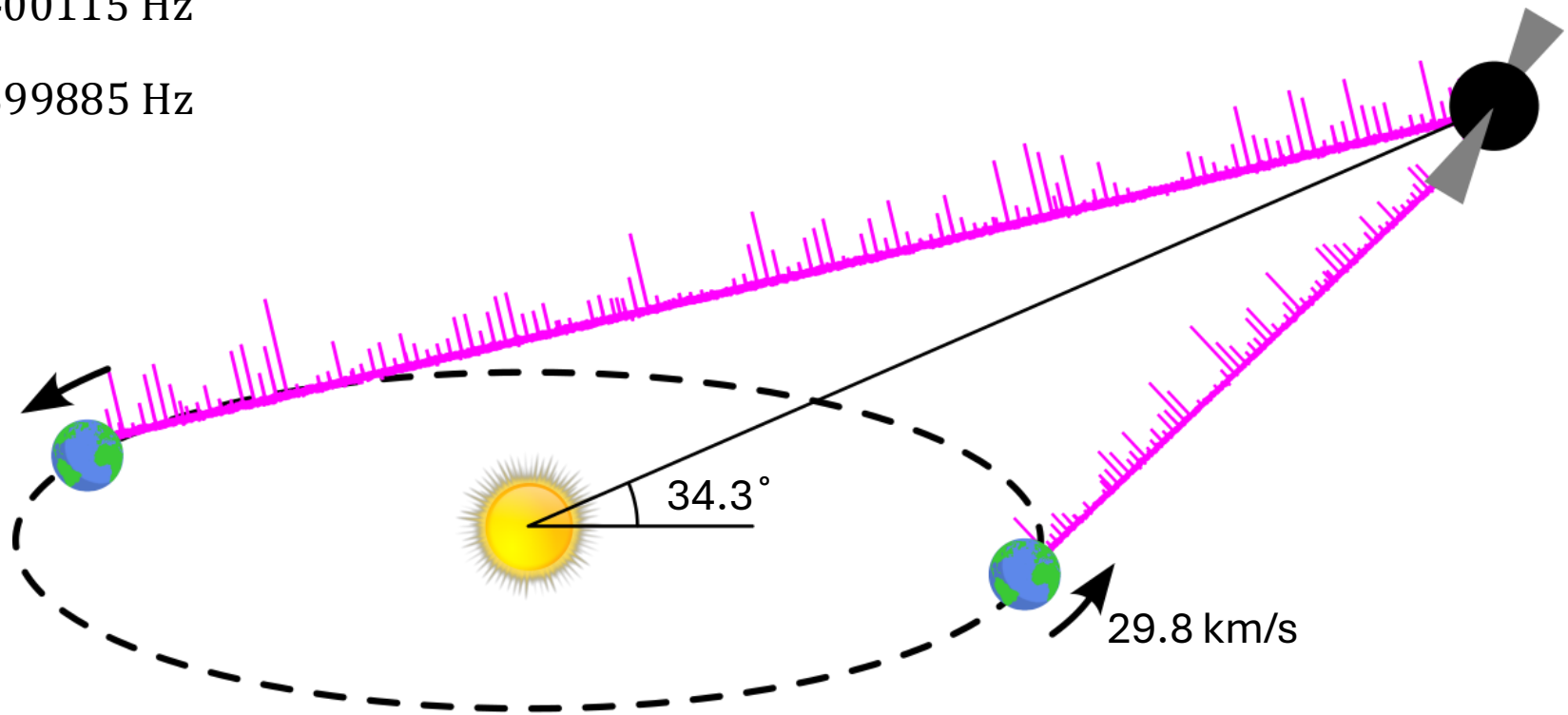
$$f_{\text{real}} = 1.400 \text{ Hz}$$

$$v_{\pm} = \cos 34.3^{\circ} \cdot \pm 29.8 \text{ km/s} = \pm 24.6 \text{ km/s}$$

$$f_{\text{max}} = 1.400 \cdot \frac{c}{c-24.6} = 1.400115 \text{ Hz}$$

$$f_{\text{min}} = 1.400 \cdot \frac{c}{c+24.6} = 1.399885 \text{ Hz}$$

$$p_{\text{max}} - p_{\text{min}} = 117 \text{ µs}$$

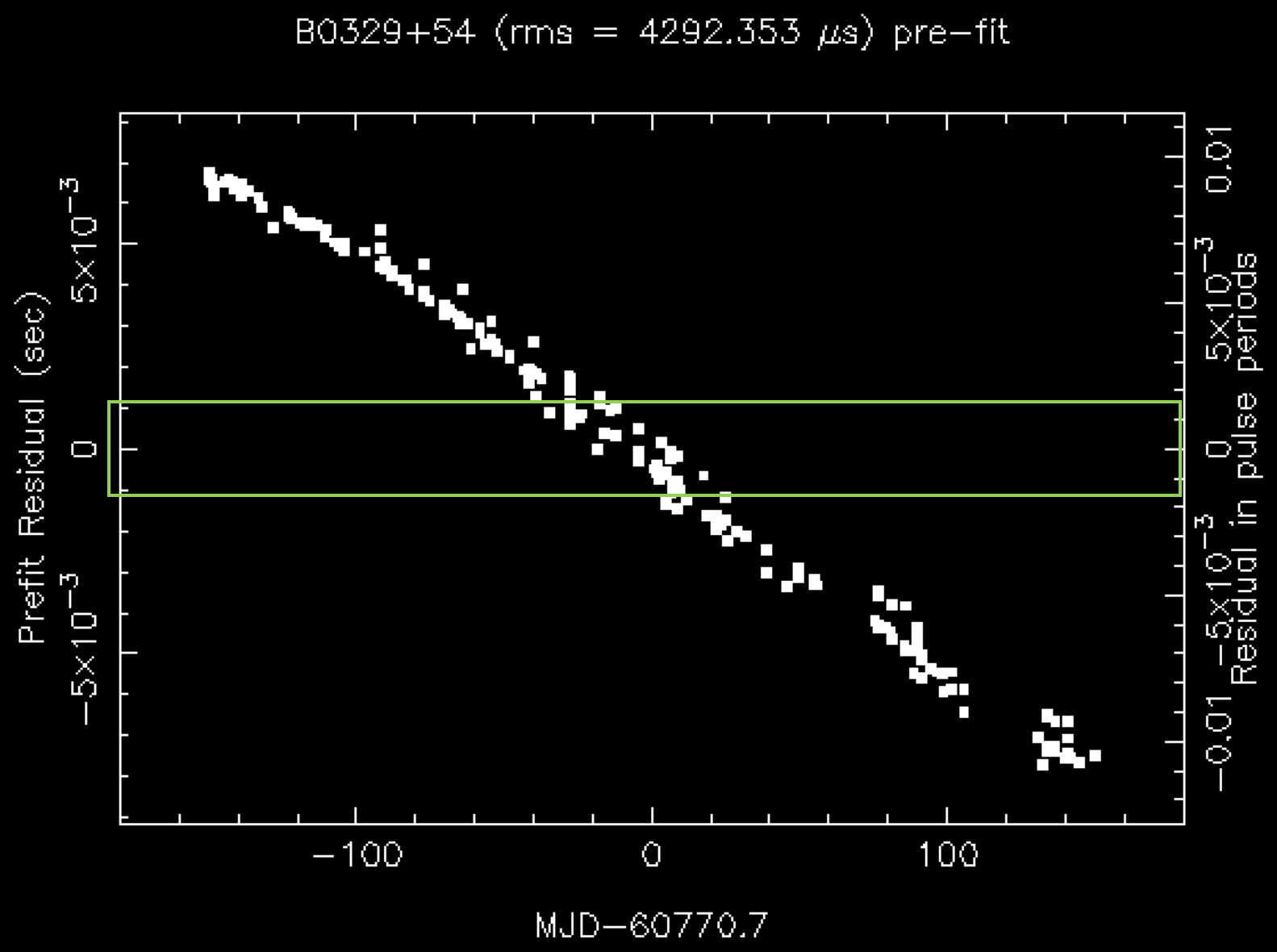


Effects I’m overlooking

- Elliptical Earth orbit
- Earth rotates around itself
- Clock drift
- Proper motion of pulsar

… so let’s use tempo2* for a proper model which incorporates all

* or PINT (Pint Is Not Tempo3), which produces same output



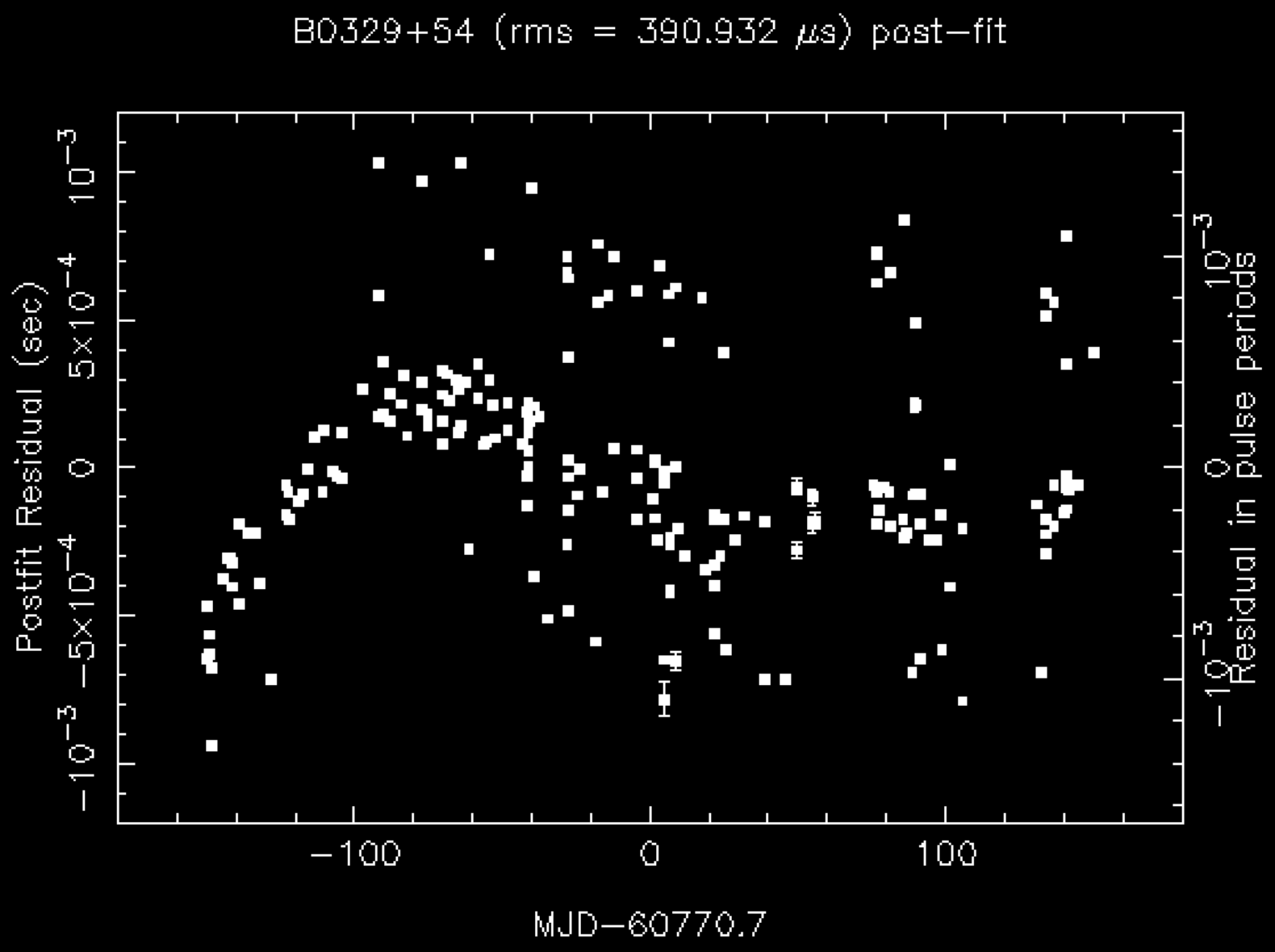
RAJ (hms) 03:32:59.444

DECJ (dms) +54:34:43.20

period (s) 0.714 522 228 061 1

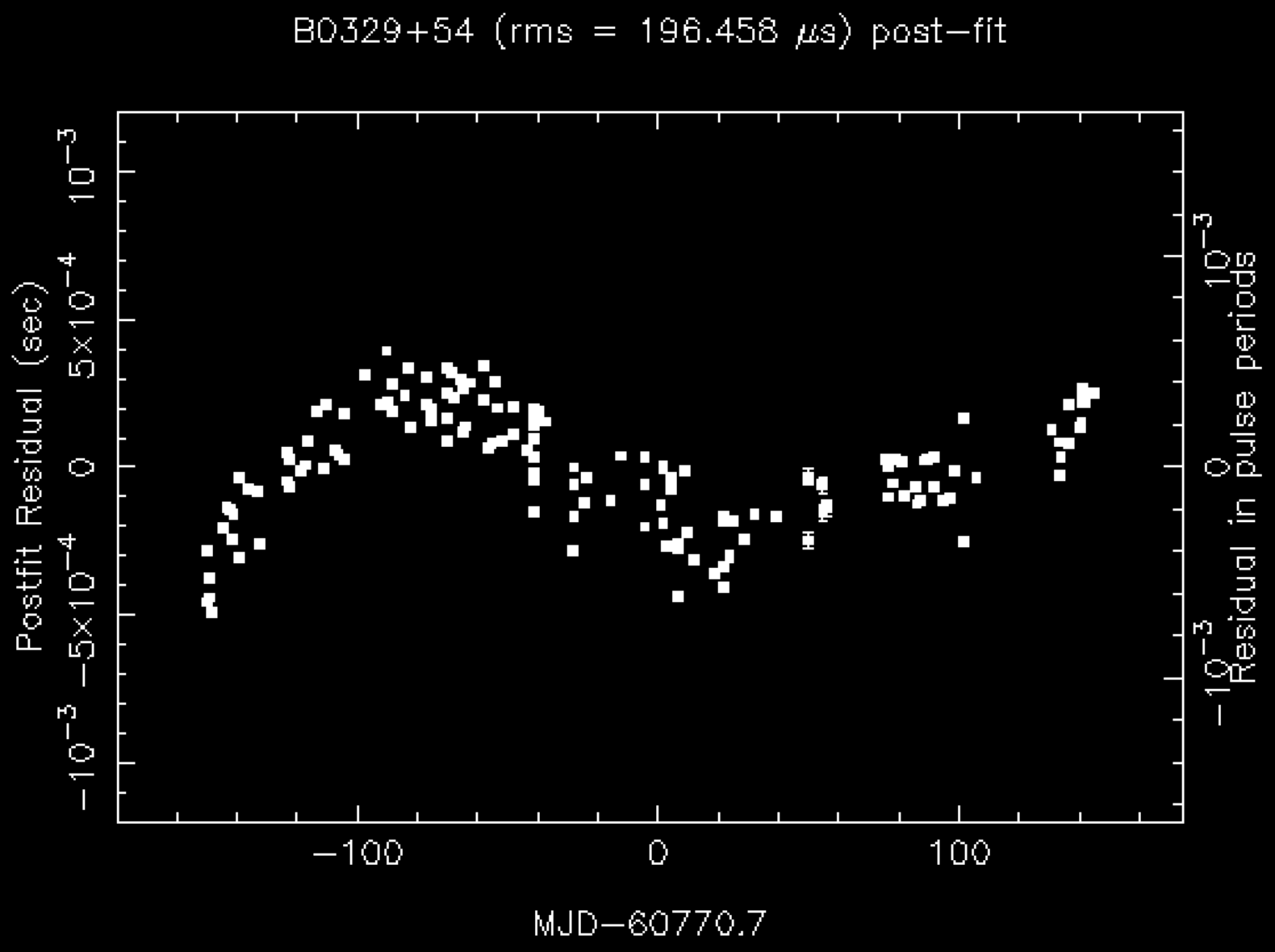
derivative 2.046 189 294 e-15

tempo2



RAJ (hms)	03:32:59.444
DECJ (dms)	+54:34:43.20
period (s)	0.714 522 227 644 8 ± 2.7 e-12
derivative	2.043 927 576 e-15 ± 7.4 e-19

tempo2



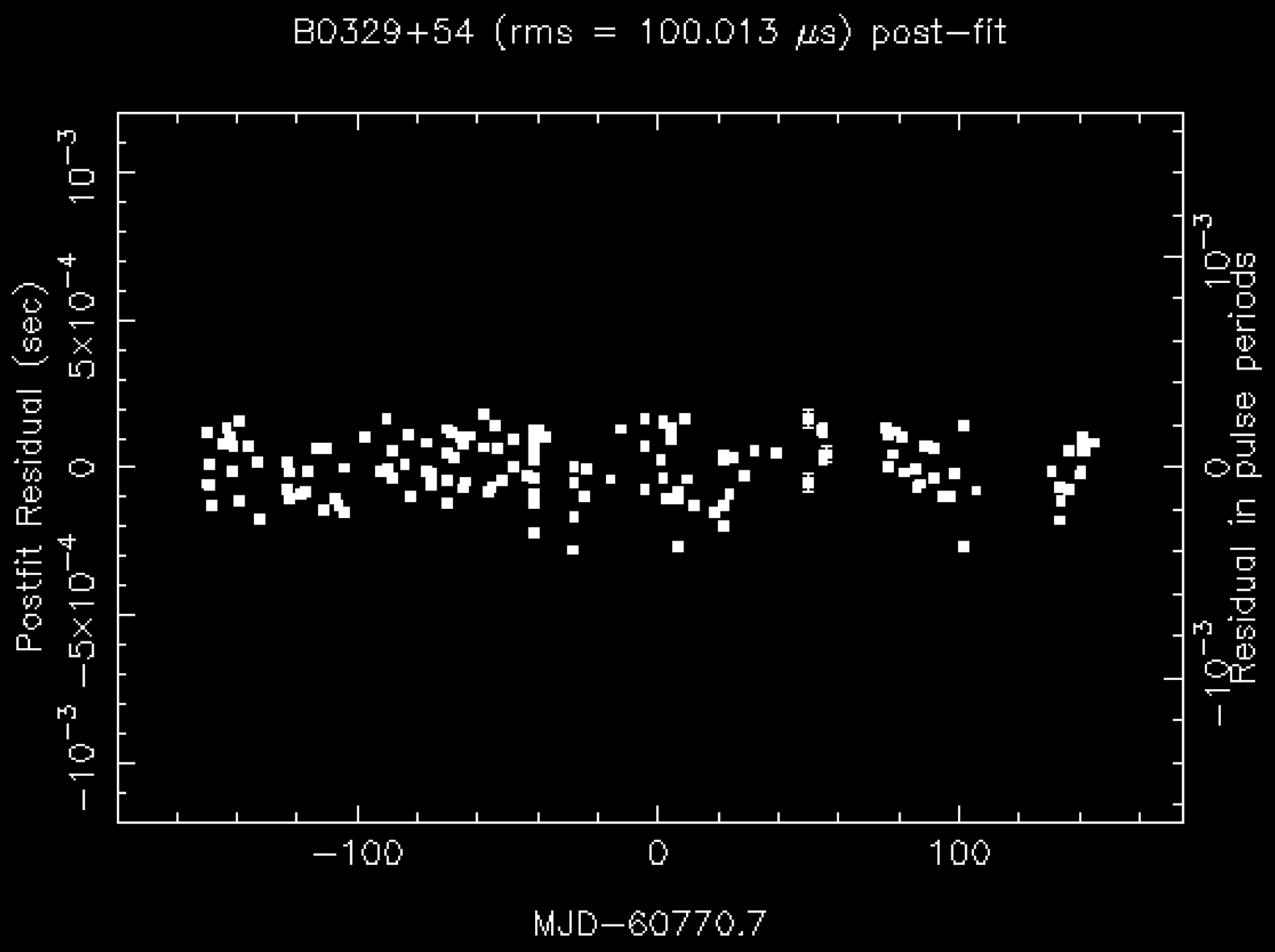
RAJ (hms) 03:32:59.444

DECJ (dms) +54:34:43.20

period (s) 0.714 522 227 641 7
± 1.6 e-12

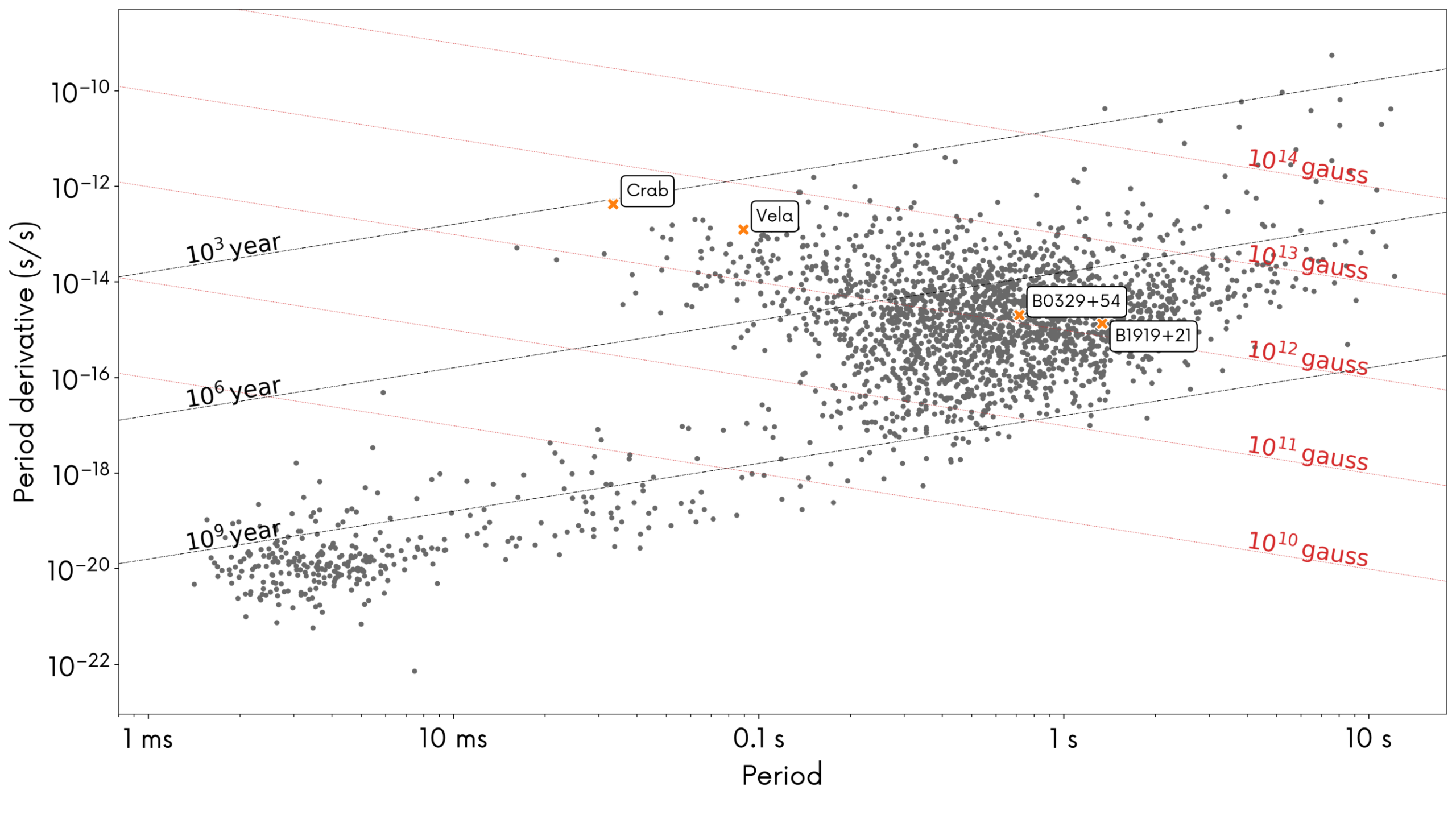
derivative 2.043 821 162 e-15
± 4.5 e-19

tempo2



RAJ (hms)	03:32:59.438
	± 0.002 139
DECJ (dms)	+54:34:43.80
	± 0.041 318
period (s)	0.714 522 227 673 2
	± 1.9 e-12
derivative	2.032 389 834 e-15
	± 1.3 e-18

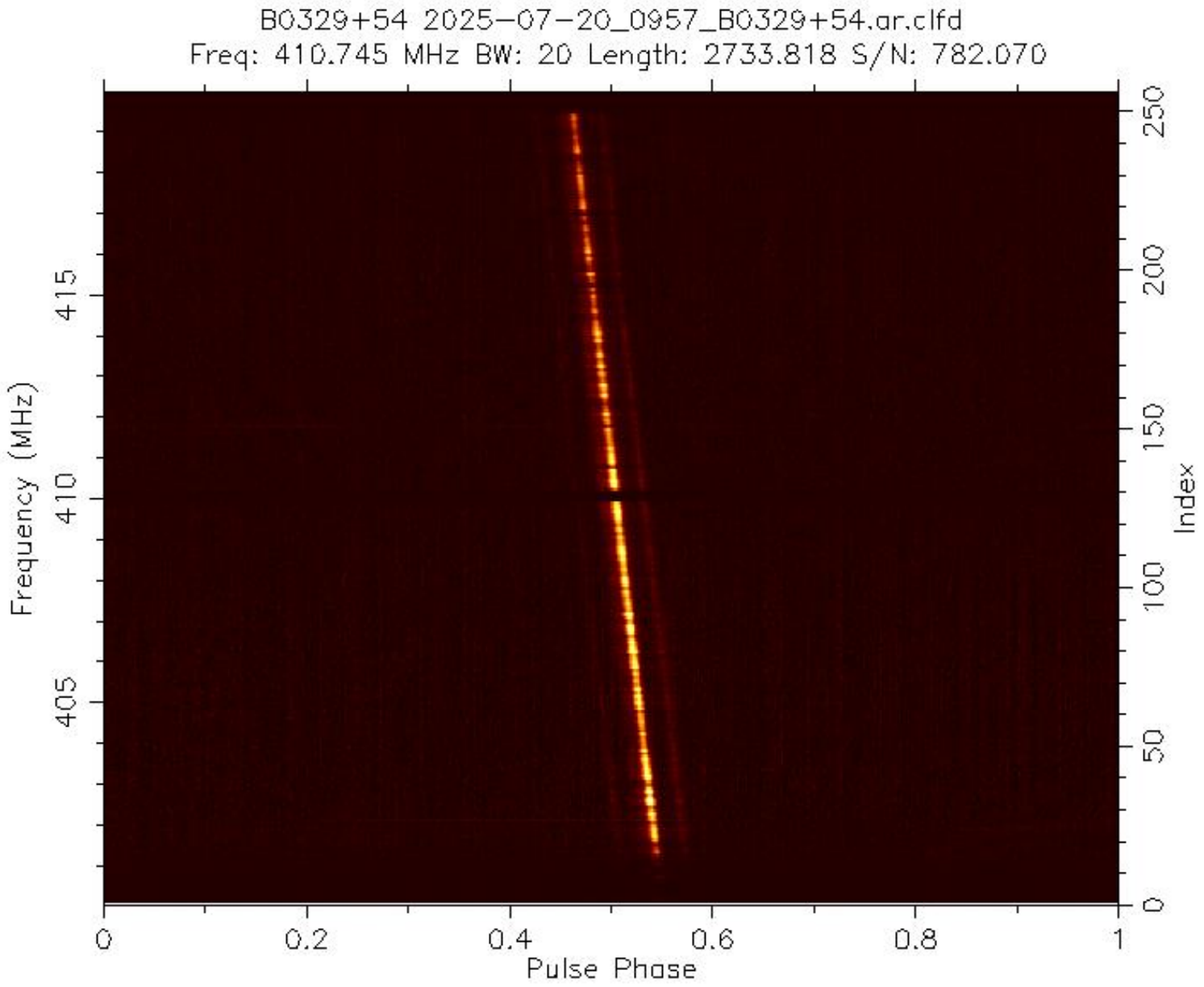
tempo2


Period derivative (s/s)
10^{-10}
10^{-12}
10^{-14}
10^{-16}
10^{-18}
10^{-20}
10^{-22}
10^{3} year
10^{6} year
10^{9} year
10^{14} gauss
10^{13} gauss
10^{12} gauss
10^{11} gauss
10^{10} gauss
Crab
Vela
B0329+54
B1919+21
1 ms
10 ms
0.1 s
1 s
10 s
Period

45 minutes of B0329

Some pulsar properties from
from Peter East's presentation

6. Dispersed in frequency
7. Scintillating amplitude / frequency

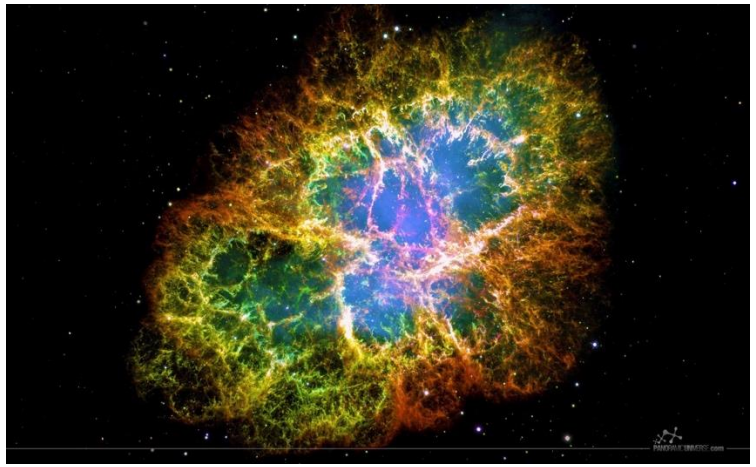


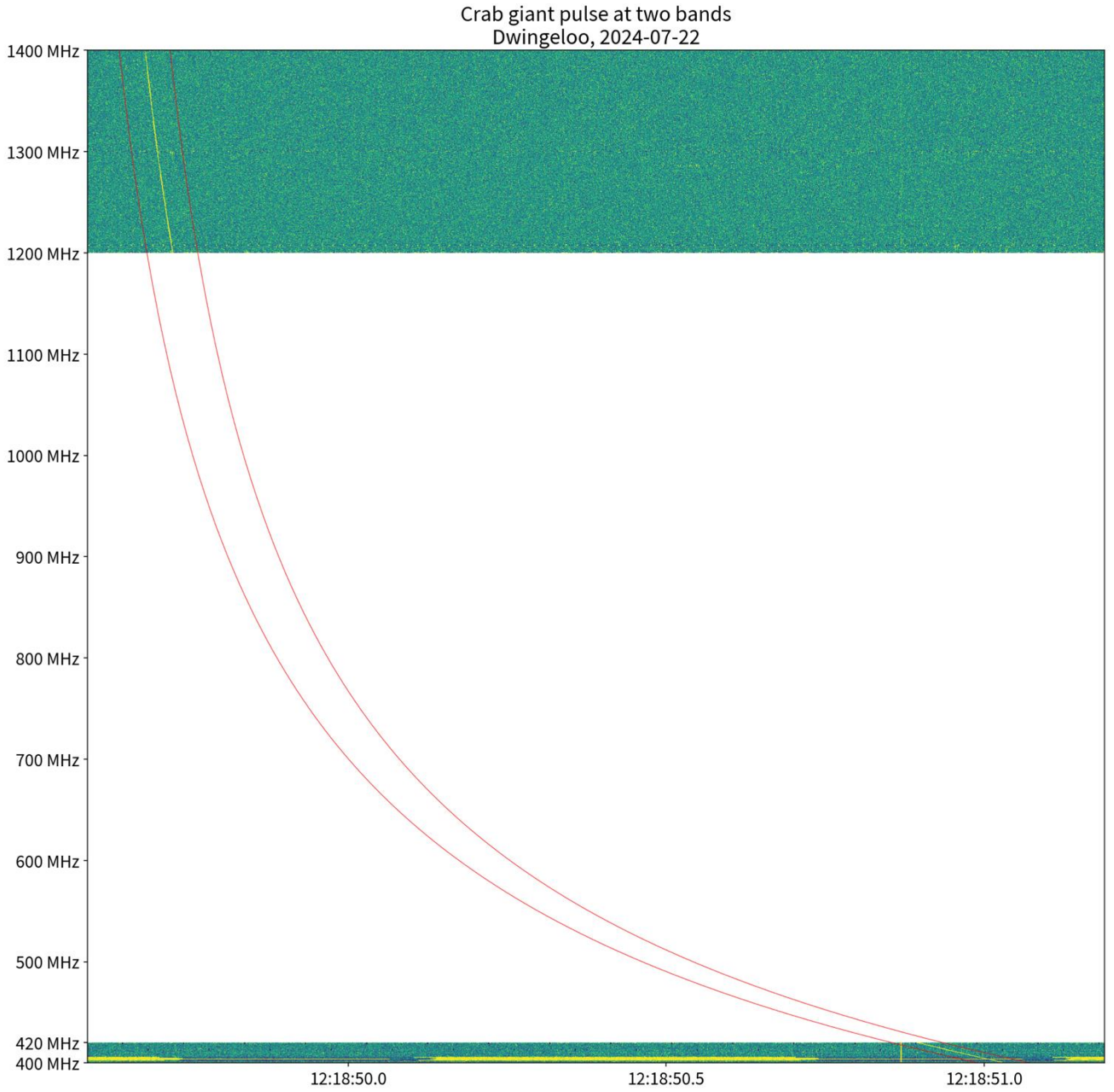
One single Crab giant pulse

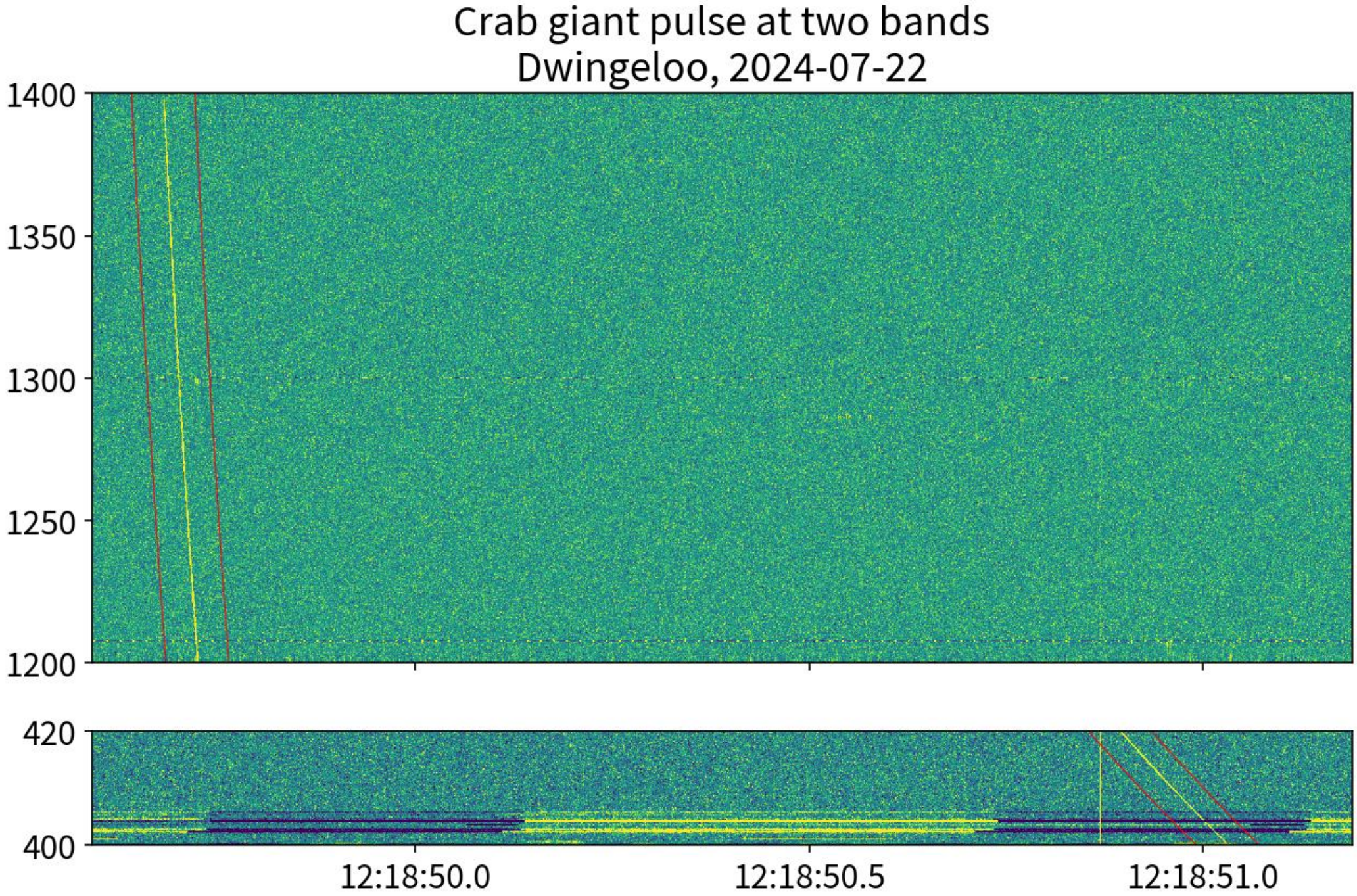
Some pulsar properties from
from Peter East's presentation

6. Dispersed in frequency

7. Scintillating amplitude / frequency



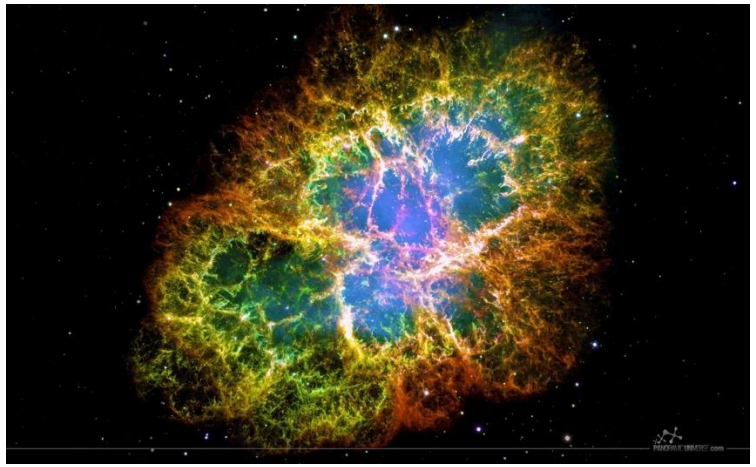


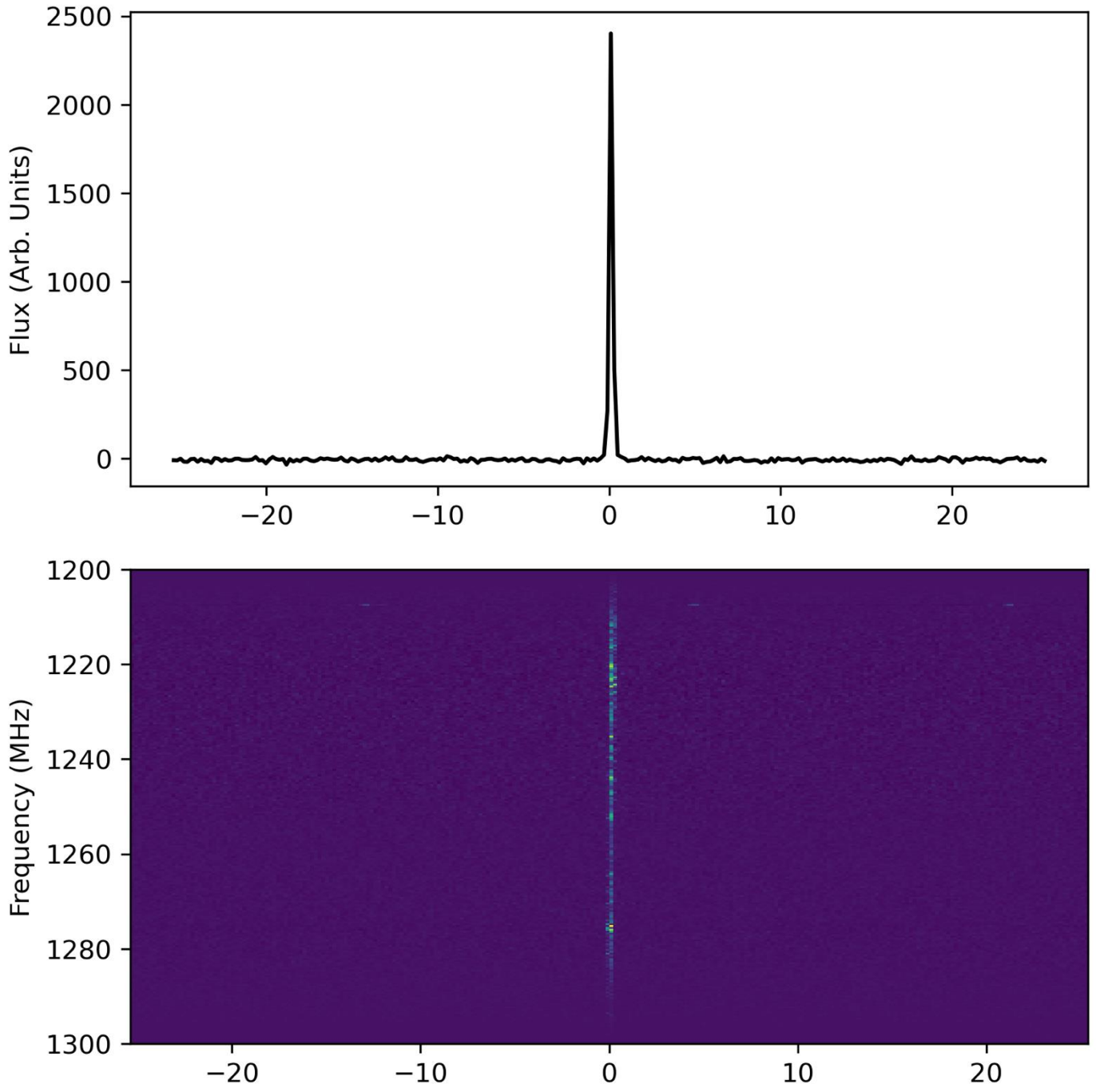

Crab giant pulse at two bands
Dwingeloo, 2024-07-22
1400
1350
1300
1250
1200
420
400
12:18:50.0
12:18:50.5
12:18:51.0

Crab giant pulses

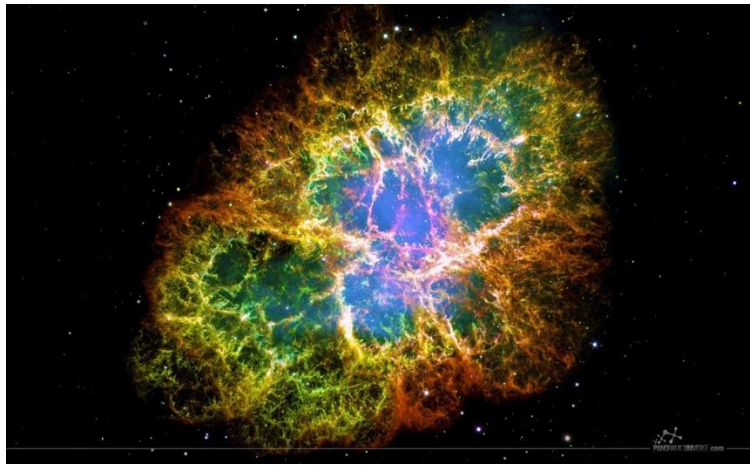
Filterbank files of very bright single Crab pulses:
https://data.camras.nl/giantpulses/bright_pulses

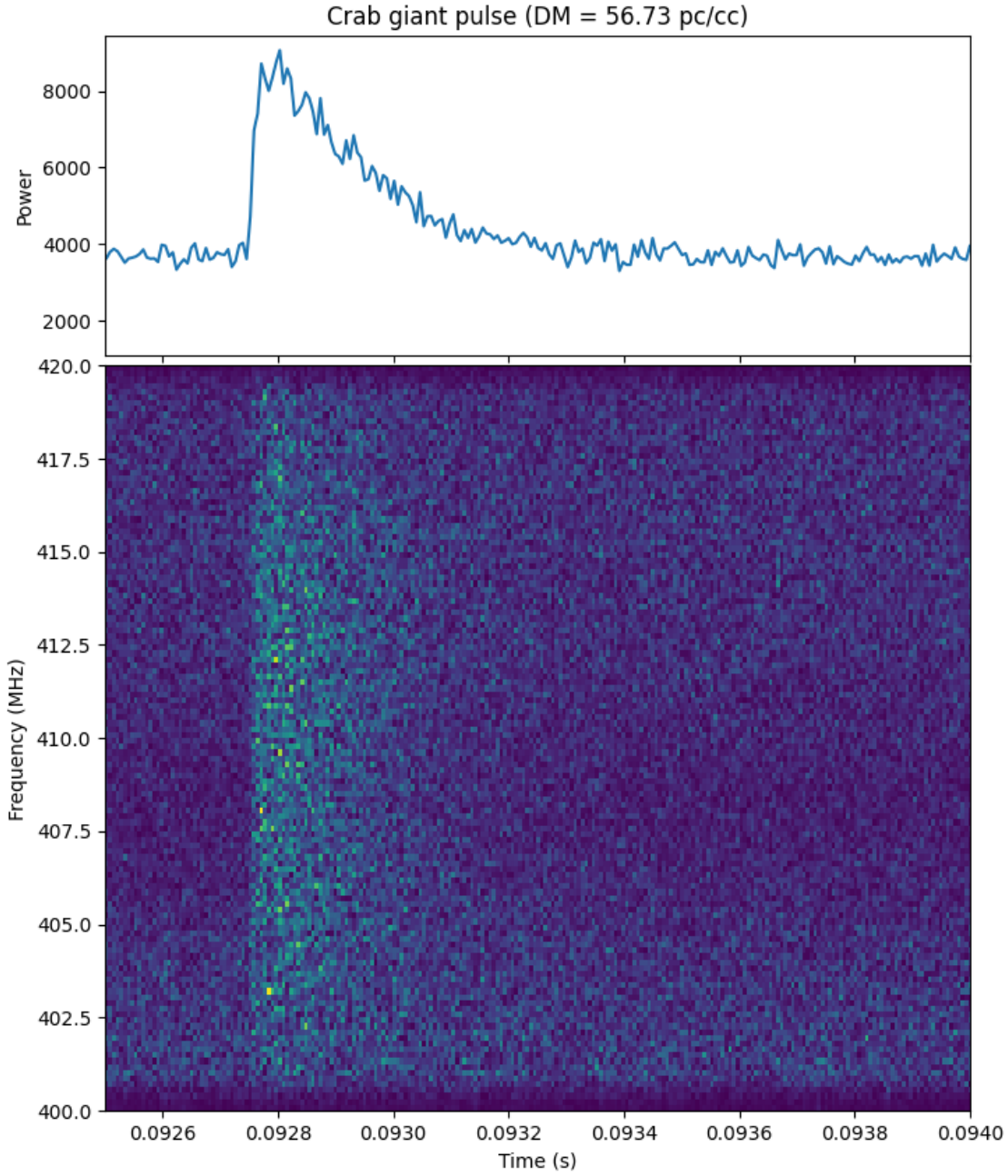
SNR	Number > SNR
6	10.202
10	4.812
15	1.979
50	191
100	44



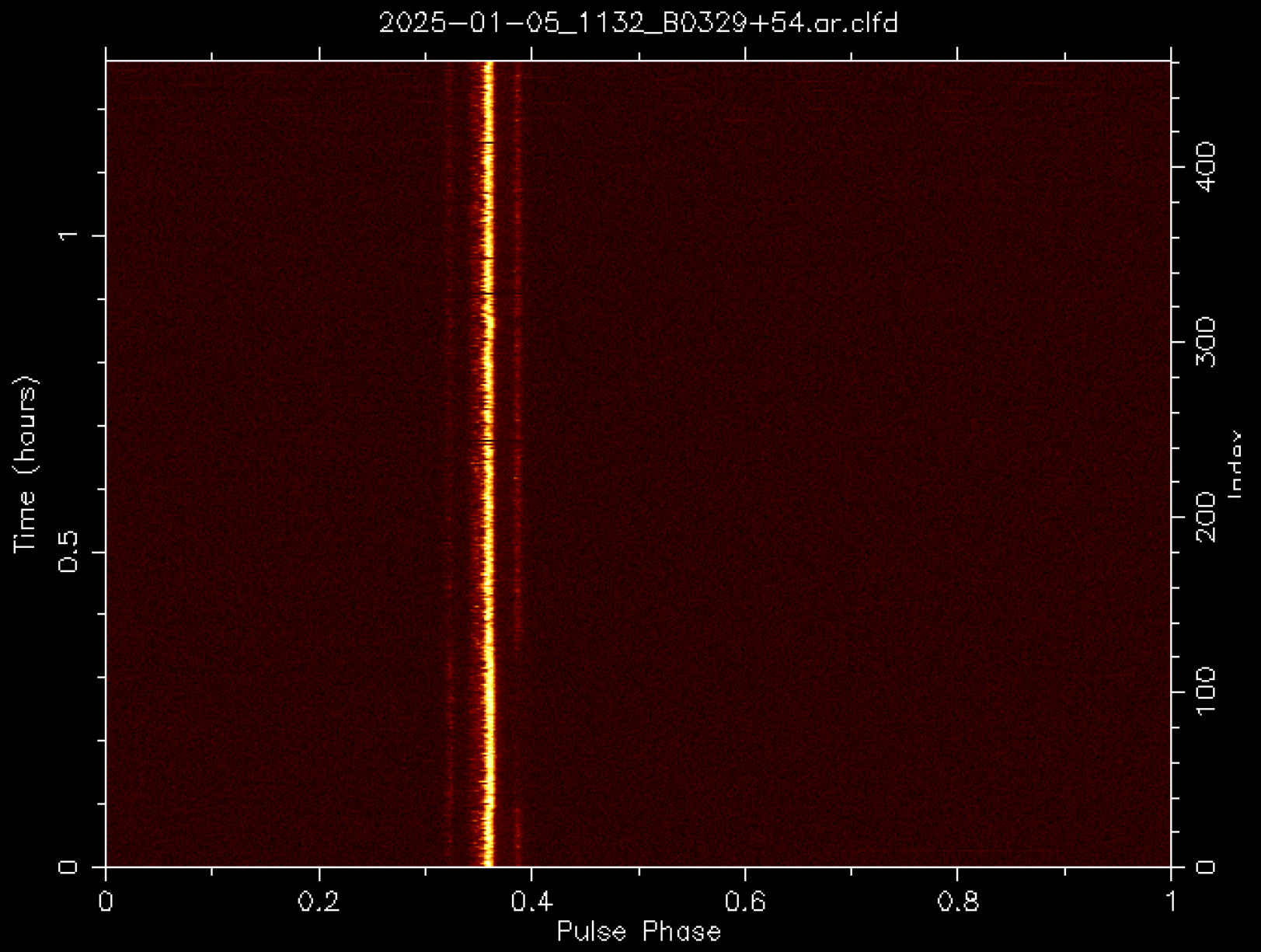


One single Crab giant pulse showing scattering

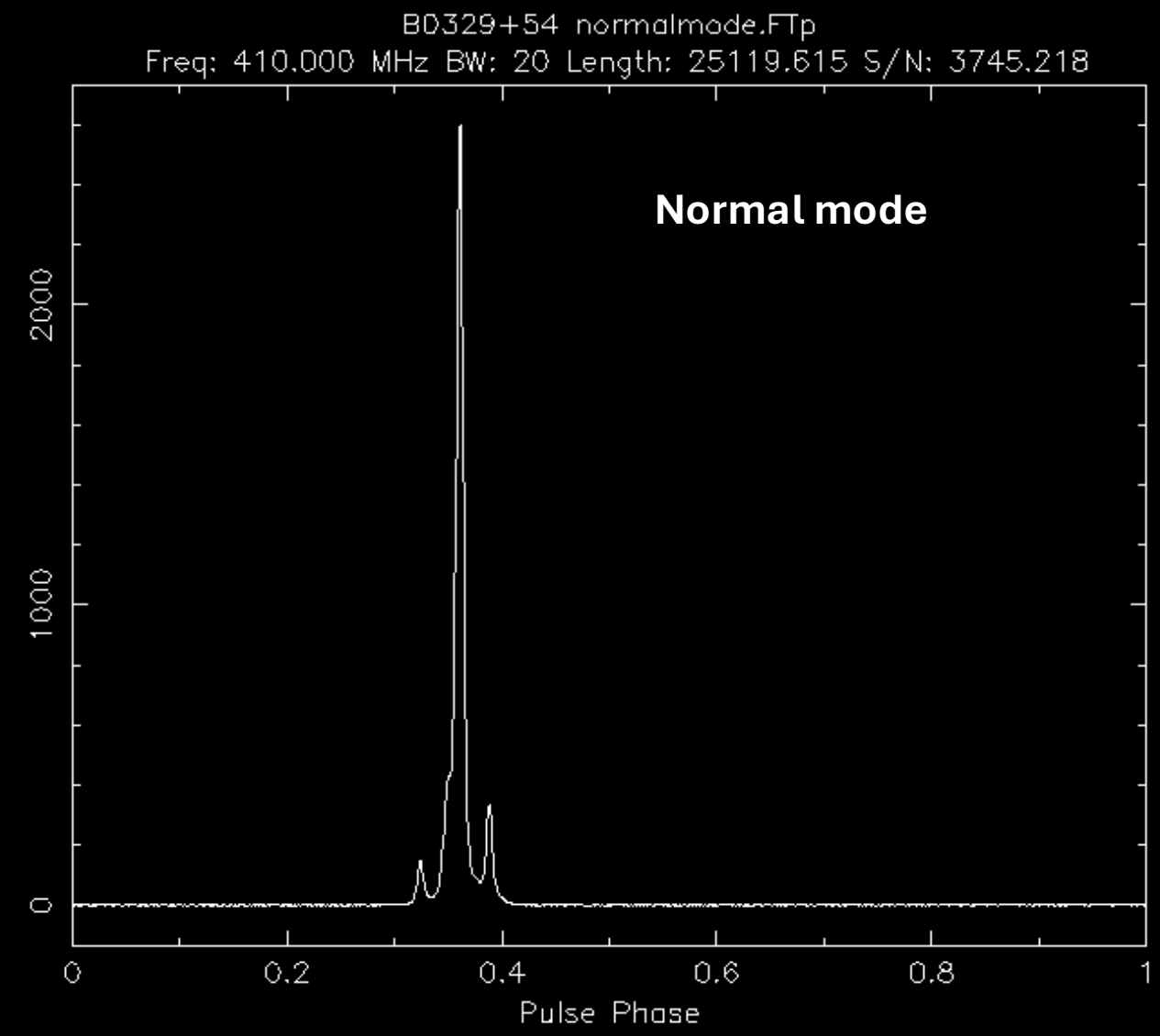


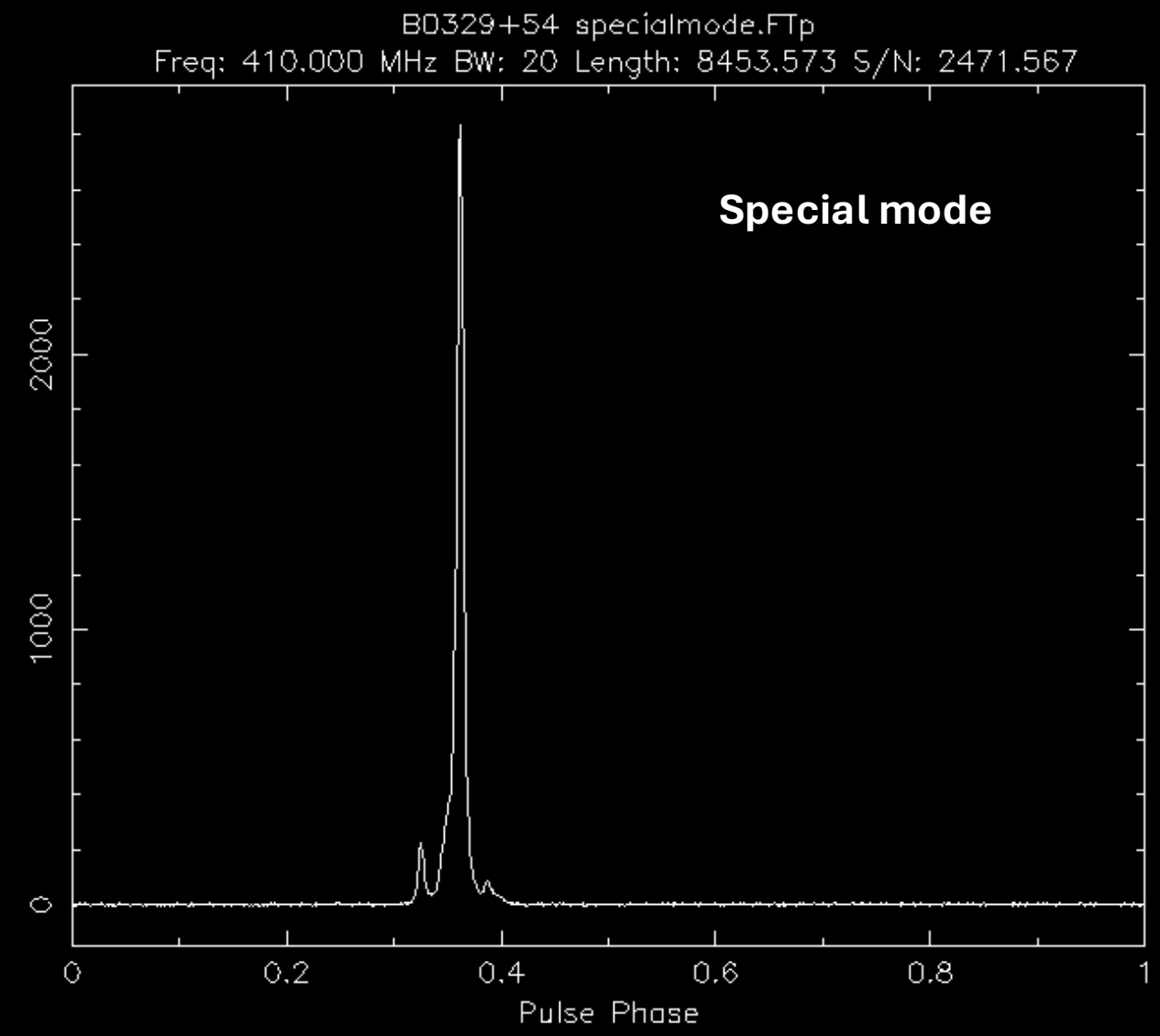


Mode switch

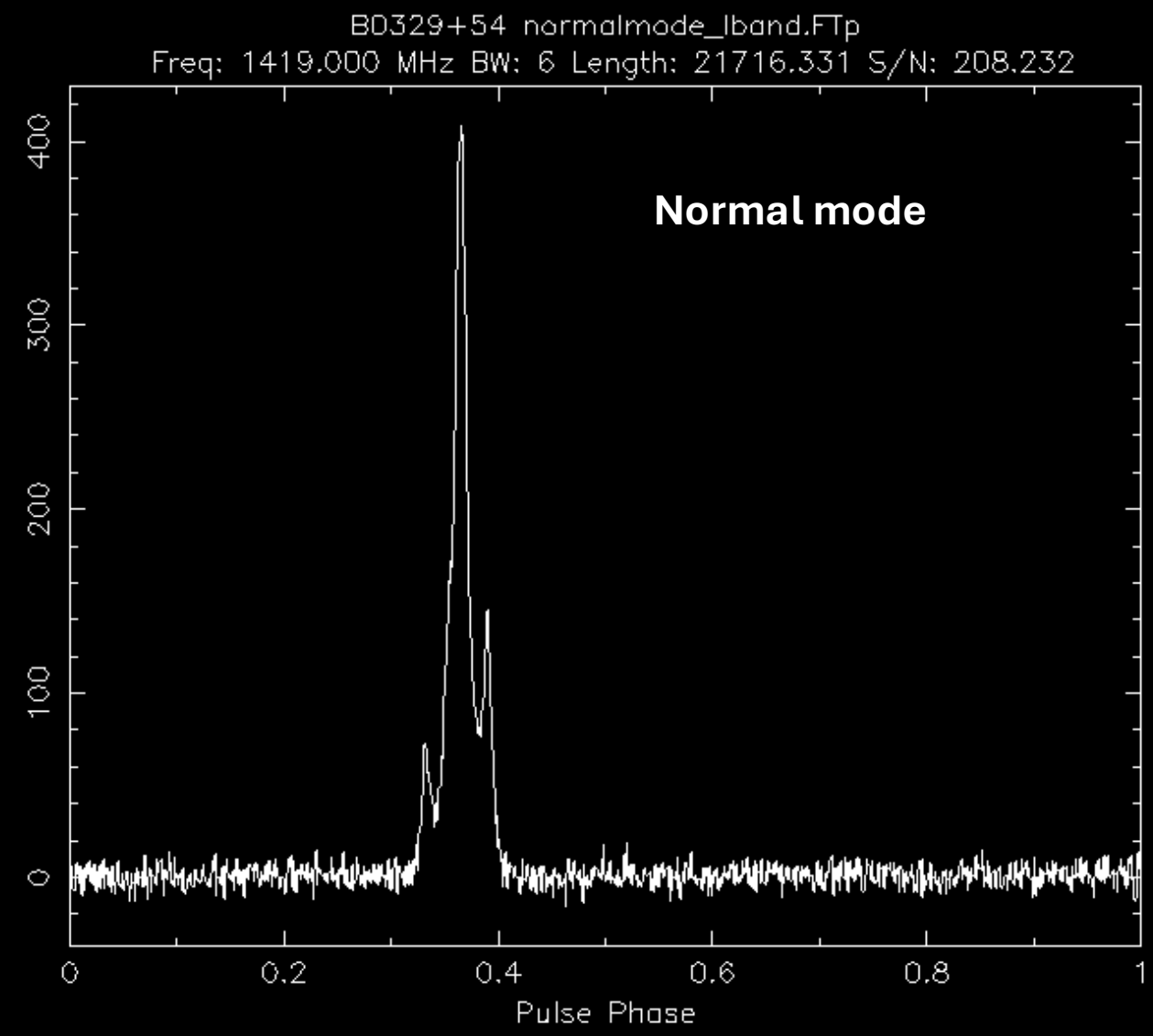

2025-01-05_1132_B0329+54.ar.clfd
Time (hours)
0
0.5
1
0
0.2
0.4
0.6
0.8
1
Pulse Phase
0
100
200
300
400
Index

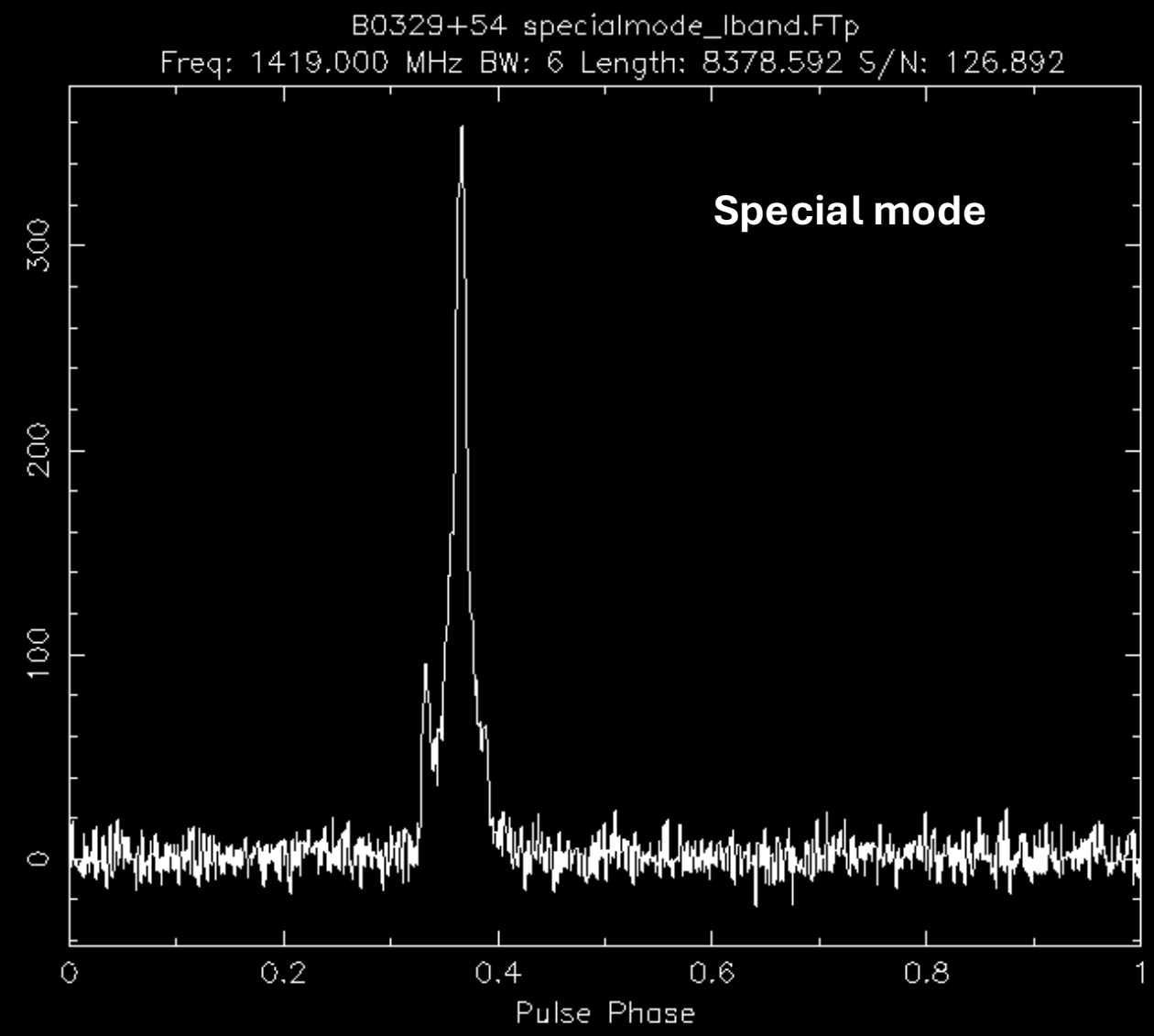
400 – 420 MHz


B0329+54 normalmode.FTp
Freq: 410.000 MHz BW: 20 Length: 25119.615 S/N: 3745.218
Normal mode
2000
1000
0
0
0.2
0.4
0.6
0.8
1
Pulse Phase

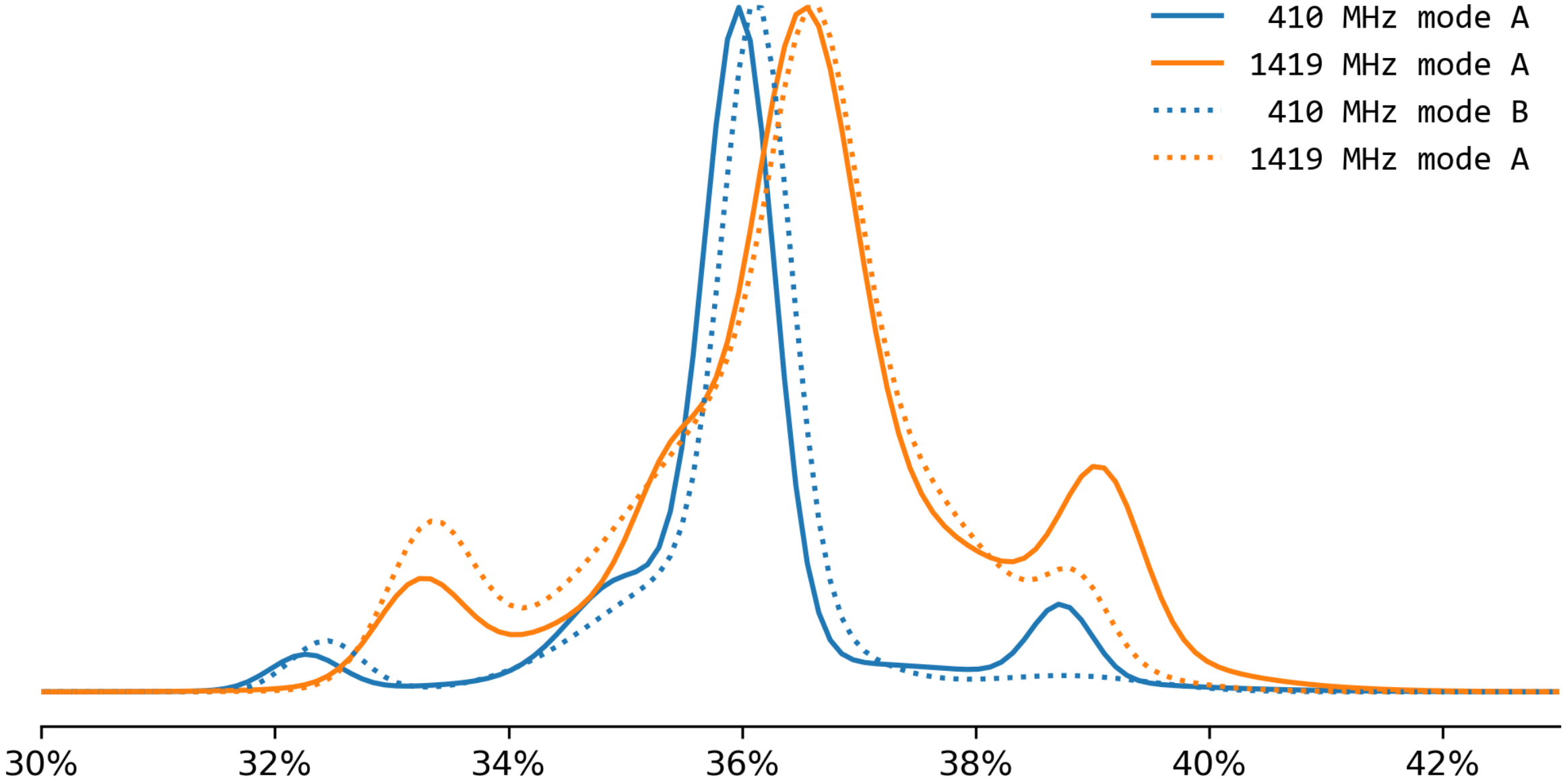

B0329+54 specialmode.FTp
Freq: 410.000 MHz BW: 20 Length: 8453.573 S/N: 2471.567
Special mode
2000
1000
0
0
0.2
0.4
0.6
0.8
1
Pulse Phase

1416 – 1422 MHz

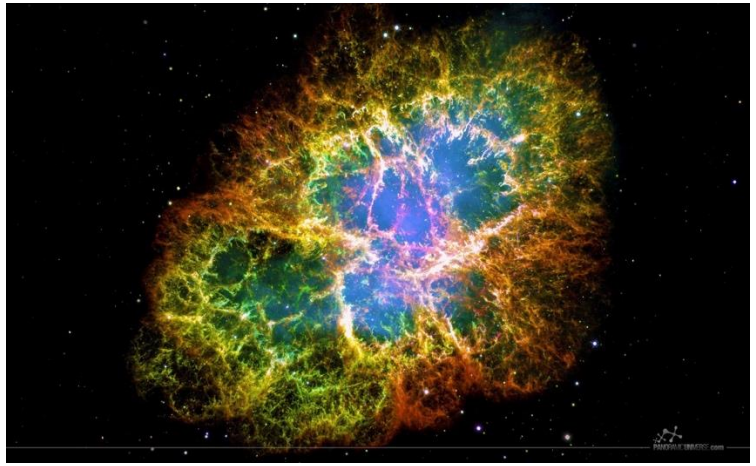


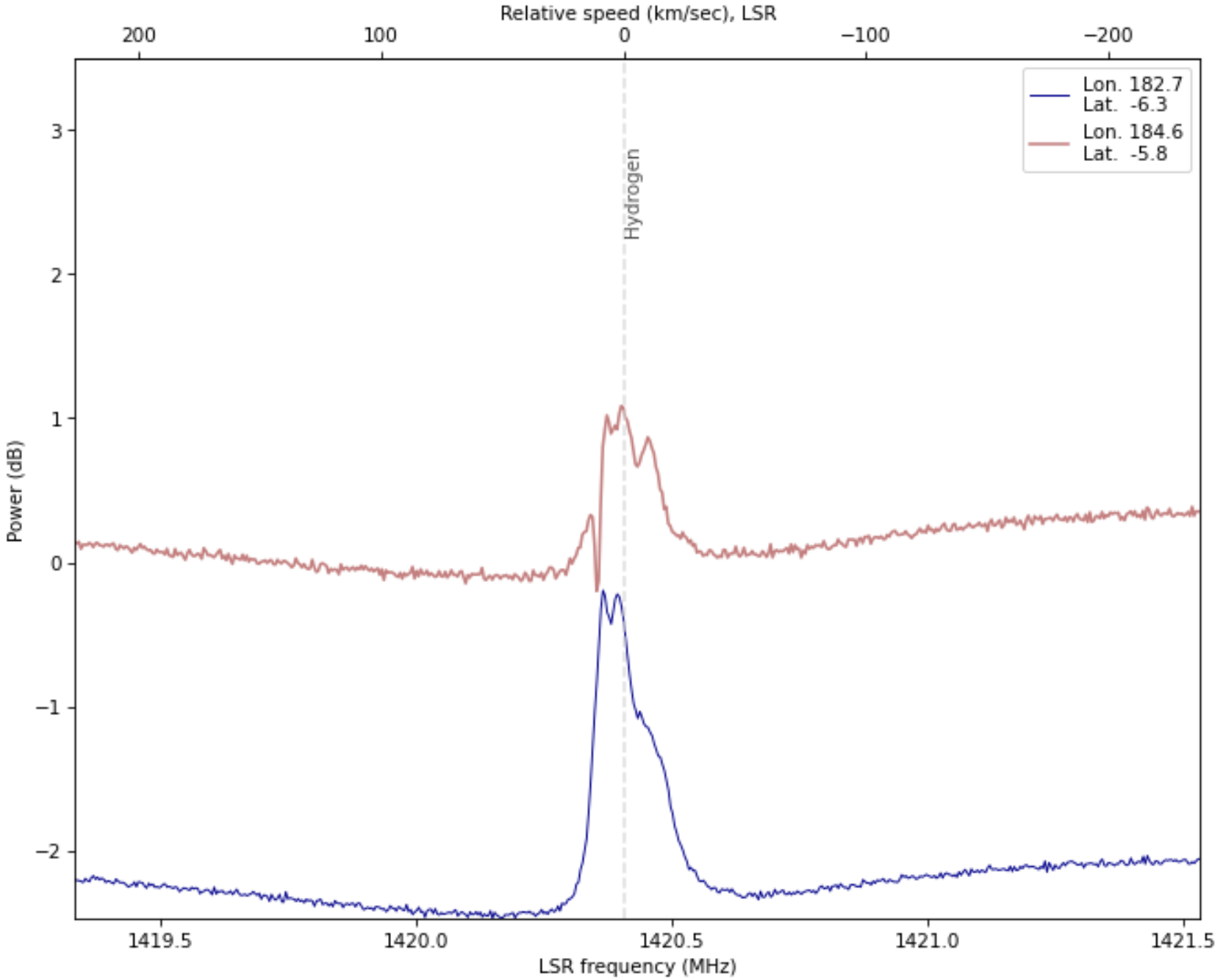


Two modes of pulsar B0329+54

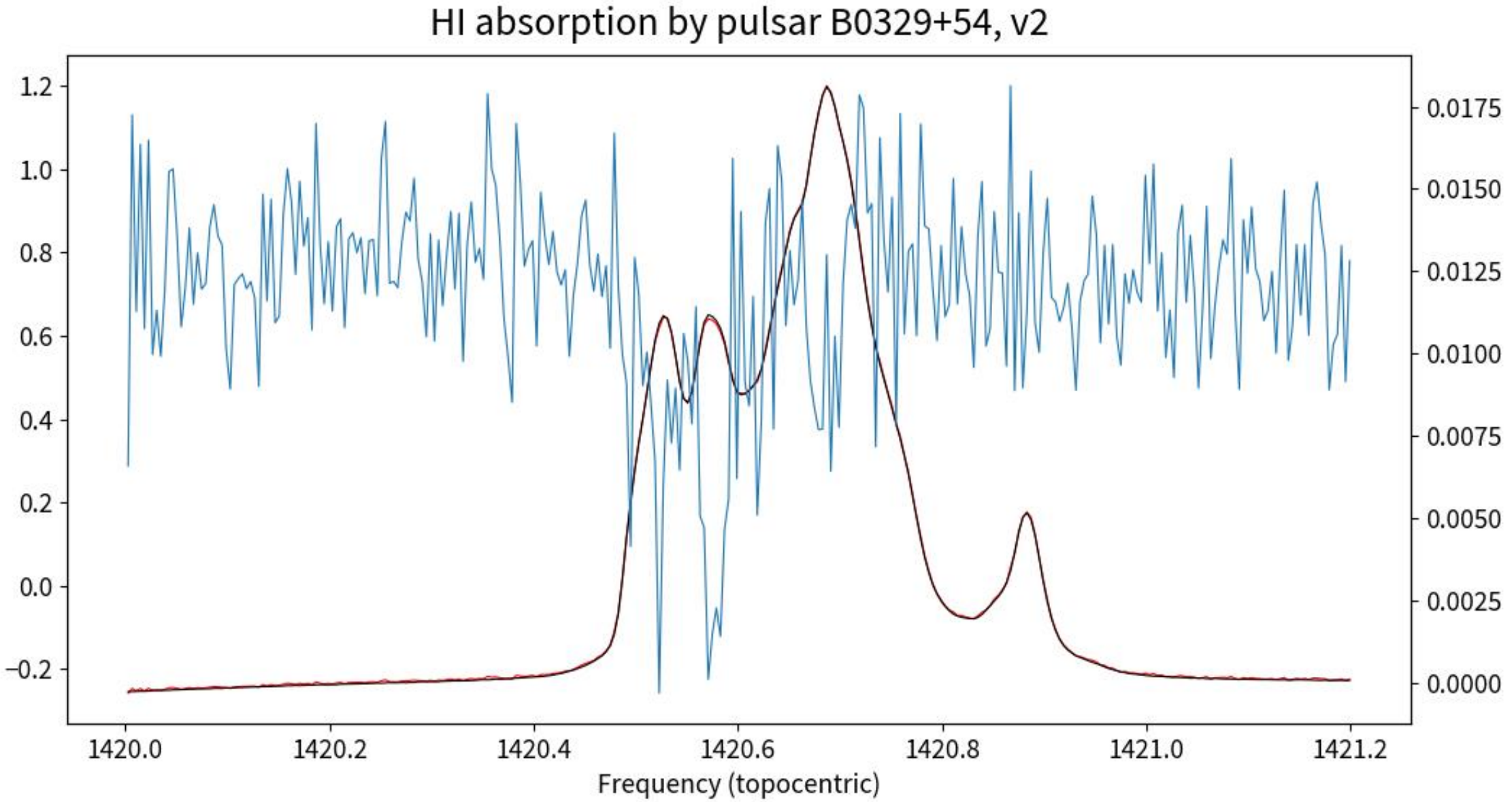


HI absorption
Crab nebula





HI absorption
B0329+54



Challenges

- Finding operators / tour guides
- Keeping the telescope operational
- Keeping the clock attached
- Not blowing up amplifiers
- Etc. etc.

Software used

vrt-iq-tools aquire data, fold real-time, write to data-buffer

pulsar-demo-gui visualize real-time

dspsr fold from dada, create ‘ar’ files

psrchive manipulate ‘ar’ files

clfd flag RFI in ‘ar’ files

tempo2 professional timing model

pint professional timing model, not tempo3

psrqpy create p-pdot diagram

astropy coordinate computations

scipy fit sine wave model

Future long-term pulsar observation plans

- Longer timeseries (keep going)
- Hydrogen line in pulsar
- Polarization
- Scintillation

- Millisecond pulsars?