Pulsars

The beginning of the story

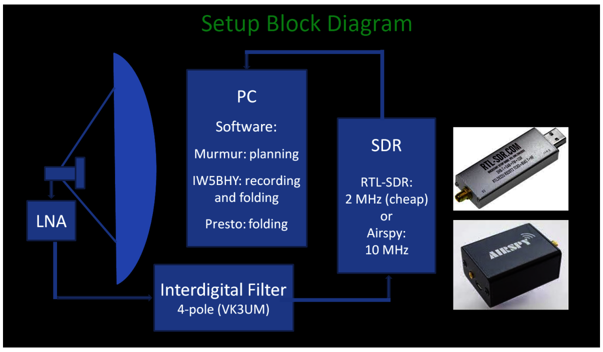
Back in 2013, I had completed my 7.3m homebuilt offset dish, and the 5m dish I had used before became obsolete. Mario, I0NAA, came to my QTH to pick it up. He mentioned that beside EME he plans to use the dish for radio astronomy, especially for receiving pulsars. That time I only knew that pulsars exist.
When I met Mario later from time to time, personally or on internet chat, pulsars were often a subject of our talks. He was insisting in a nice way that I should try to receive pulsars myself. He also sent me the software Murmur he has written, this is a very good tool for pulsar receives prediction, and I use it a lot now.
But I had no real idea how to start. Looking on internet, I came across the Neutron Star Group webpage, and was surprised about the reports of Andrea, IW5BHY, who regularly can receive the pulsar B0329+54 on 420 MHz with a corner reflector antenna, equivalent to a 2.5m dish. On occasion I had an EME QSO with Andrea, and decided to ask him by email about what I would additionally need, how to start and so on.
Andrea was (and is) extremely helpful, he told me what hardware to use and let me use the software he has written, which performs excellent. He guided me through the whole installation process, analyzed my first recordings and is still a helping hand for giving me hints for improvements. He spent many hours and wrote many emails. That way I learned a lot, and I am now able to do the measurements myself.

For people interested to try pulsar reception themselves, I wrote a step-by-step guide how to do it the (in my opinion) easiest way.

Download the PDF: Pulsars - How To Detect

Equipment

Antenna: 7.3m homemade offset dish, OE5JFL tracking system
Feeds: 70cm (424 MHz) dual-dipole with solid reflector, 23cm (1294 MHz) RA3AQ horn
Preamplifiers: 23cm cavity MGF4919, 70cm 2SK571 (30 years old!)
Line Amplifier: PGA103+
Interdigital filter: designed with VK3UM software, 70cm 4-pole, 23cm 3-pole
Receiver: RTL-SDR (error <1ppm), 2 MHz bandwidth
Software: IW5BHY, Presto, Tempo, Murmur



The following 23 pulsars were received with this setup (using the RTL-SDR) on 70cm until end of May 2017, 11 of them also on 23cm.
Signal/Noise ratio measured with IW5BHY software, S400 and S1400 values from ATNF catalogue.

Pulsar	70cm (424 MHz)	23cm (1294 MHz)
B0329+54	S400=1500 S/N=110	S1400=200 S/N=85
B0531+21 (Crab) *	S400=550 S/N=10	---
B0823+26	S400=73 S/N=18	S1400=10 S/N=9
B0834+06	S400=89 S/N=10	---
B0950+08	S400=400 S/N=32	S1400=84 S/N=14
B1133+16	S400=257 S/N=24	S1400=32 S/N=11
B1237+25	S400=110 S/N=6	---
B1508+55	S400=114 S/N=9	---
B1642-03	S400=393 S/N=26	S1400=21 S/N=9
B1749-28	S400=1100 S/N=21	---
B1818-04	S400=157 S/N=8	---
B1859+03**	S400=165 S/N=11	---
B1911-04	S400=118 S/N=12	---
B1919+21	S400=57 S/N=14	---
B1929+10	S400=303 S/N=33	S1400=36 S/N=9
B1933+16	S400=242 S/N=20	S1400=42 S/N=31
B1946+35	S400=145 S/N=6	---
B2016+28 ***	S400=314 S/N=14	S1400=30 S/N=12
B2020+28 ***	S400=71 S/N=9	S1400=38 S/N=6
B2021+51	S400=77 S/N=16	S1400=27 S/N=17
B2111+46	S400=230 S/N=6	---
B2217+47	S400=111 S/N=15	---
B2310+42	S400=89 S/N=11	S1400=15 S/N=6

note *: The Crab pulsar was a challenge, 30 rotations/sec and high dispersion. Received at the first attempt!

note **: The B1859+03 has a very high dispersion: DM=402!

note ***: The B2016+28 and the B2020+28 are only about 1deg apart from each other. 424 MHz profiles for both pulsars were obtained by analyzing the same recorded file.

In June 2017 the RTL-SDR was replaced by an Airspy SDR for receiving with 10MHz bandwidth.

It is difficult to find 10 MHz with an acceptable RFI situation, especially on 70cm.

The receiving software is based on Gnu-Radio, all developed by Andrea (IW5BHY) and his son.

A more detailed description can be found at the webpage of Nando, who is using the same system: I1NDP Pulsar II

He has big success detecting pulsars on 23cm, have a look!

Finding new pulsar candidates for observation is more a challenge now. Background noise from the sky is unfortunately high on 70cm for most pulsars. Also RFI at low elevation (declination) is an issue.

The following pulsars were additionally detected with the new setup:

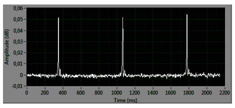
Pulsar	70cm (420 MHz)	23cm (1292 MHz)
B0031-07	S400=52	---
B0138+59	S400=49	---
B0320+39	S400=34	---
B0355+54	S400=46	---
B0525+21	S400=57	---
B0450-18	S400=82	---
B0450+55	S400=59	---
B0540+23	---	S1400=9
B0626+24	S400=31	---
B0628-28	---	S1400=23
B0740-28	S400=296	---
B0809+74	S400=79	---
B0818-13	S400=102	---
B0919+06	S400=52	---
B1540-06	S400=40	---
B1541+09	S400=78	---
B1604-00	S400=54	---
B1706-16	S400=47	---

B1804-08	---	S1400=15
B1822-09	---	S1400=12
B1831-03	S400=89	---
B1844-04	S400=75	---
B1845-01	---	S1400=8,6
B1900+01	S400=58	---
B1907+10	S400=50	---
B1915+13	S400=43	---
B2000+40	S400=53	---
B2045-16	S400=116	---
B2154+40	S400=105	---
B2255+58	---	S1400=9
B2319+60	---	S1400=12

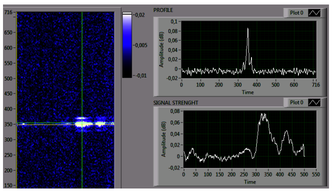
Status January 2018: 54 pulsars detected (47 on 420MHz, 18 on 1292MHz, 11 on both bands)

RECEPTIONS:

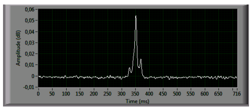
B0329+54



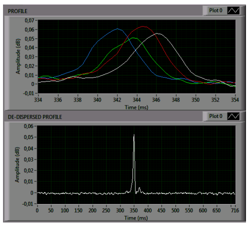
For receiving this strong pulsar on 424MHz, I need normally only one minute or even less. Sometimes it is even possible to get single pulses. With an integration time of several hours, the S/N of course improves a lot.



Scintillation can be a problem, especially on 23cm. Sometimes nothing for hours, then suddenly the pulsar is showing up. The whole plot is 5 hours.



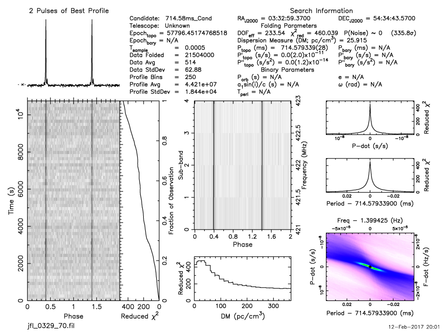
In this 23cm reception the pre-pulse and post-pulse of the B0329+54 normal mode can be seen very well.



These graphs of a 424MHz reception illustrate the effect of dispersion. The bandwidth of 2 MHz is divided into 4 subbands, 500 kHz each.

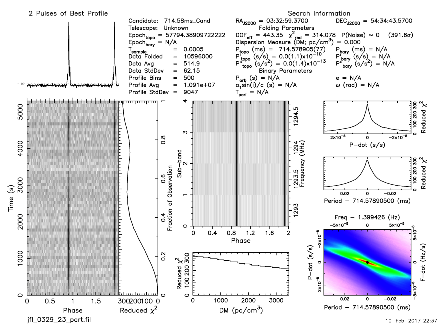
The upper graph shows the subbands separately and zoomed. The blue line is offset by slightly more than 4 ms from the white line. The difference of the center frequencies is 1.5MHz. This is a good coincidence to the 2.9ms/MHz dispersion of the pulsar on 420 Mhz.

The lower graph shows a beautiful pulse after de-dispersion.

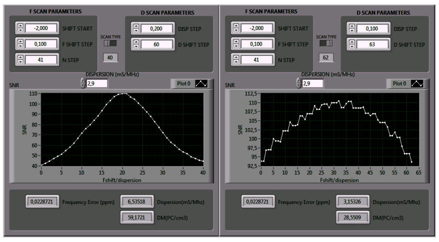


Another good software is Presto.

See the 424 MHz profile of B0329+54....



.....and the 1294 MHz profile of B0329+54



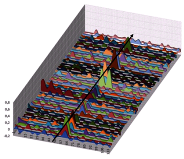
IW5BHY has programmed a nice tool to confirm if the pulses are likely to come really from a pulsar and not RFI. The folding time is shifted (useful on 70cm and 23cm) and the dispersion time (useful only on 70cm).

For an example I made these tests for the 424 MHz recording of the B0329+54. The left picture shows S/N depending on shifting the folding frequency, in the right picture the dispersion time is shifted.

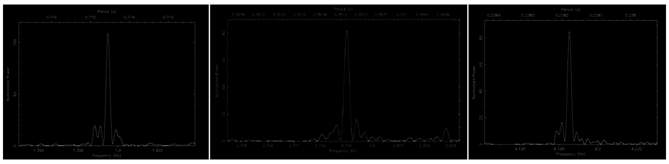
Andrea, IW5BHY, has found 50 single pulses in a one hour recording I made on 424 MHz. With a special written program he put the single pulses in a row, and generated an audio file from that. So you can even listen to the sound of the pulsar: **sound pulsar B0329+54** (The tone is very low frequency, it is good to use headphones and put level to maximum)

This 3D plot displays 50 consecutive periods at a peak of positive scintillation.

It is from one piece of observation of 36 seconds containing many single pulses.

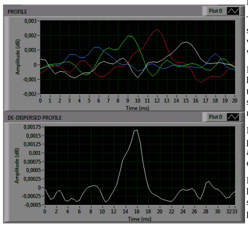


Also produced by IW5BHY, harmonic analysis of the dedispersed timeseries showing the fundamental and two harmonics:



.......other pulsars

B0531+21 (Crab pulsar)



424 MHz, S/N=10

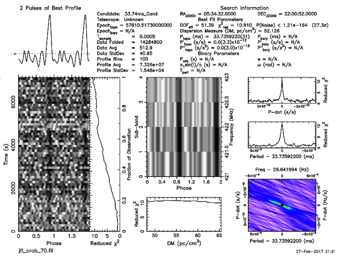
The reception of the Crab-pulsar B0531+21 was one of the highlights!

This young pulsar exists since a supernova explosion in 1054, which was observed on earth as a star even visible at daylight for about two years.

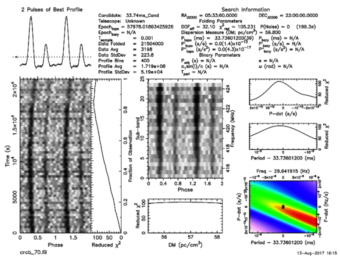
It rotates 30 times per second, is highly dispersed (3 ms per channel is the same as the pulse width) and its slowdown in rotation speed is remarkable.

Nevertheless, the pulsar reception was positive even on the very first attempt! The observation time in that case was two hours.

Beside the main pulse the Crab pulsar has an interpulse which is varying in strength. In this reception it is not present.



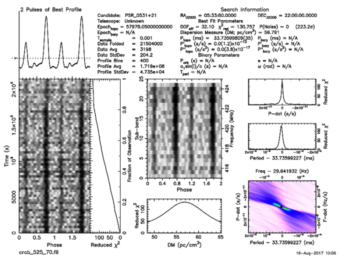
The following receptions of the Crab pulsar were made with my new setup: Airspy 10 MHz bandwidth



Crab main pulse and interpulse (no frequency tracking, curve bent)

After an 6 hours observation of the much weaker pulsar B0525+21 I was looking for the Crab pulsar in this file also, because their positions are close to each other.
There was low RFI during that time, so both pulsars signals came through nicely.
Because of the long observation time the Doppler effect was noticable and the curve was somewhat bent.
With the frequency tracking option of Presto the curve is straightened and S/N even better.

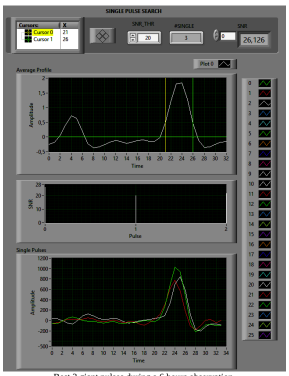
It was also nice to see the interpulse of the Crab on this occasion.



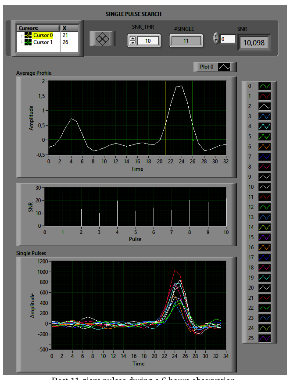
same as on the left side, but with frequency tracking, curve straight

Crab giant pulses

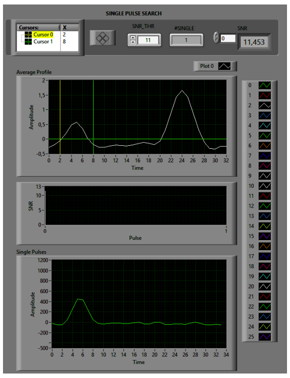
The Crab pulsar is known for its giant radio pulse emission. IW5BHY has written a very good software to search for giant pulses in the recorded files. I analyzed several observations, sometimes found nothing because separating the giant pulses from RFI spikes is not so easy. Sometimes found between 1...3 within 2 hours.
The 6 hours observation mentioned above was extremely good also in that respect. Depending on the threshold, up to more than 20 giant pulses are displayed with Andreas software.
Even one giant pulse at the phase of the interpulse was found, which is a very rare event.
I estimate the peak flux level of the best observed giant pulse (S/N=26) to be between 1000Jy and 2000Jy, means an increase of around 25dB above average!



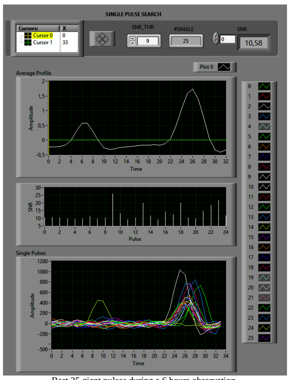
Best 3 giant pulses during a 6 hours observation.
Threshold for S/N=20, best S/N=26



Best 11 giant pulses during a 6 hours observation.
Threshold reduced to S/N=10

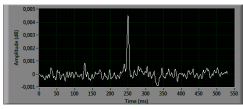
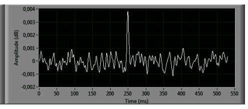


One giant pulse was found at the phase of the interpulse.
This is a very rare event!

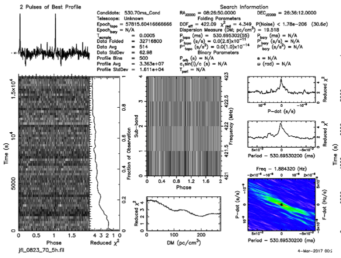


Best 25 giant pulses during a 6 hours observation.
Threshold reduced to S/N=9
The phase of the giant pulses is not constant, because during 6 hours of observation Doppler shift is significant.

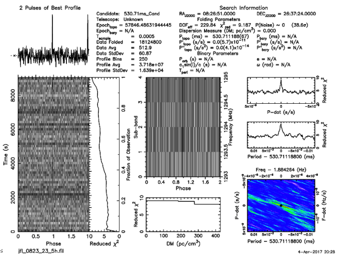
B0823+26

left side: 424 MHz, S/N=18 right side: 1294 MHz, S/N=9

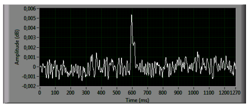


left side: 424 MHz

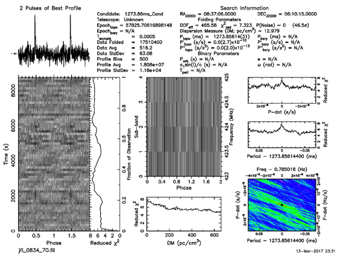


right side: 1294 MHz

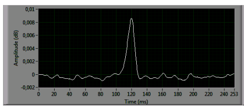
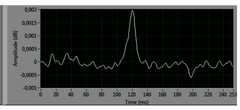
B0834+06



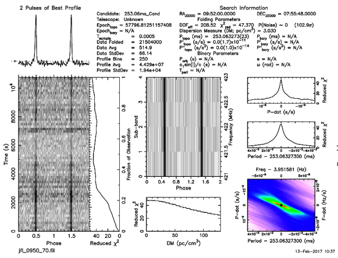
424 MHz, S/N=10



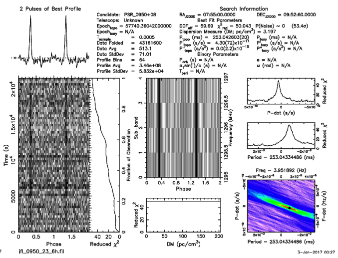
B0950+08

left side: 424 MHz, S/N=32 right side: 1294 MHz, S/N=14

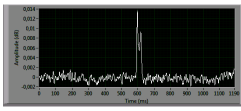
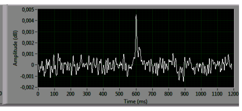


left side: 424 MHz



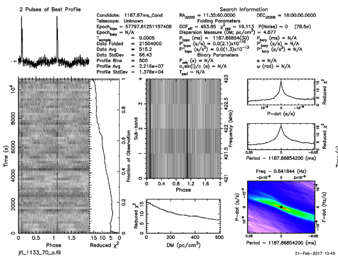
right side: 1294 MHz

B1133+16

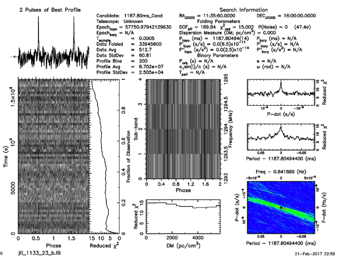



left side: 424 MHz, S/N=24 right side: 1294 MHz, S/N=11

especially on 70cm the typical double pulse can be seen nicely

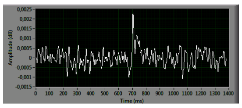


left side: 424 MHz

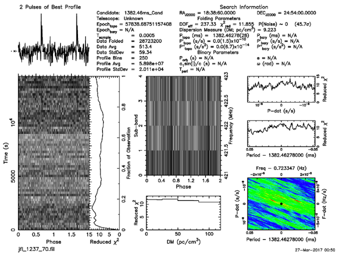


right side: 1294 MHz

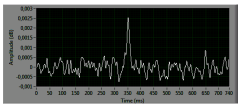
B1237+25



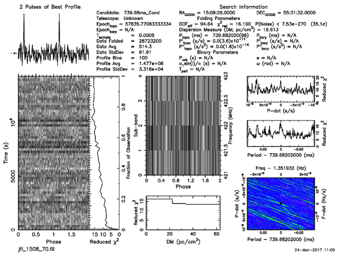
424 MHz, S/N=6



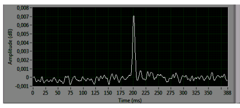
B1508+55

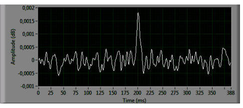


424 MHz, S/N=9



B1642-03

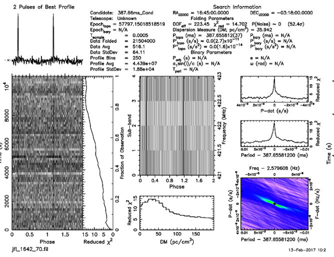




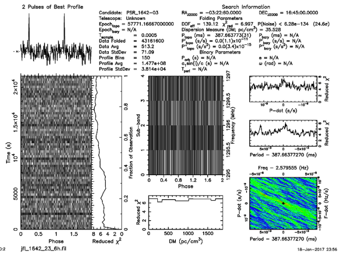
left side: 424 MHz, S/N=26 right side: 1294 MHz, S/N=9

Using my new system (Airspy SDR with 10 MHz bandwidth), I made drift scans on 41 consecutive days, each 30 minutes duration.

B1642-03 drift scans

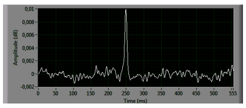


left side: 424 MHz



right side: 1294 MHz

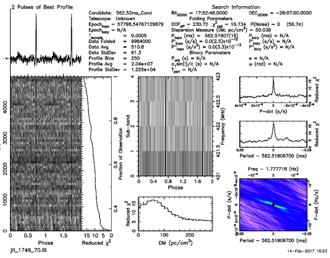
B1749-28



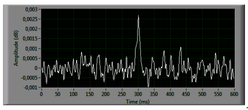
424 MHz, S/N=21

The declination of this pulsar is so low, that my antenna can 'see' it only for 2 hours just before culmination, maximum 2deg above a building. Because of the additional noise pickup the S/N is low.

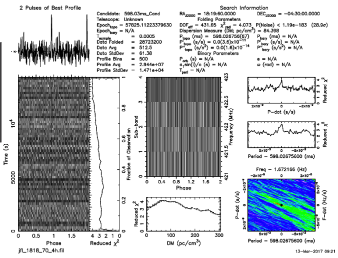
On 23cm I see no chance because of the much lower flux level.



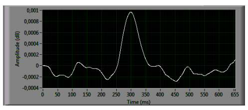
B1818-04



424 MHz, S/N=8



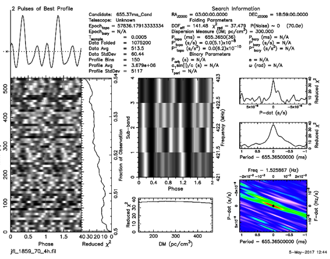
B1859+03



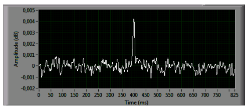
424 MHz, S/N=11

This pulsar has a very high dispersion: DM=402
Therefore the four 500kHz channels are separated by 22ms to each other, this is twice the W50 of 11ms! Because of the low pass filtering the pulse looks broader but became visible.

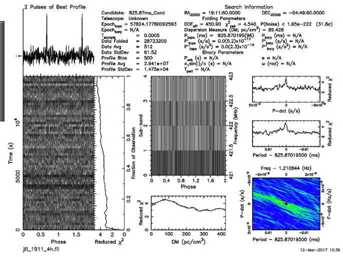
Thanks to Andrea IW5BHY for the extra analyzing work



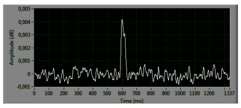
B1911-04



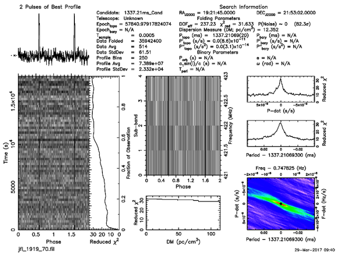
424 MHz, S/N=12



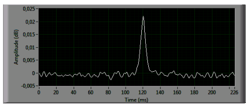
B1919+21



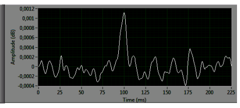
424 MHz, S/N=14



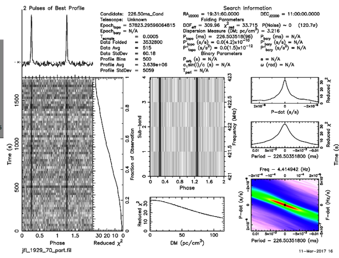
B1929+10



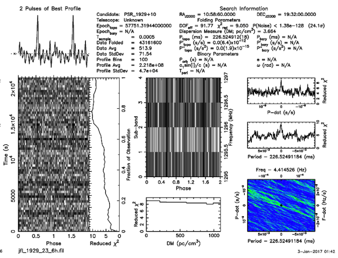
left side: 424 MHz, S/N=33



right side: 1294 MHz, S/N=9

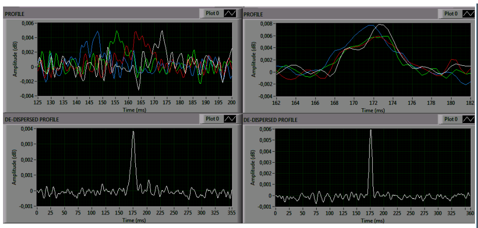


left side: 424 MHz



right side: 1294 MHz

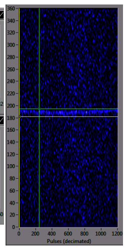
B1933+16



left side: 424 MHz, S/N=20 right side: 1294 MHz, S/N=31

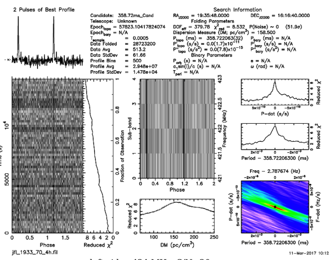
This pulsar has a very high dispersion, making things difficult on 424 MHz. The channels are separated by slightly more than 8ms to each other, this is nearly as much as the pulse width itself!

If you look carefully, the dispersion can be even seen on 23cm, but it is only in the range of 1ms over all channels.

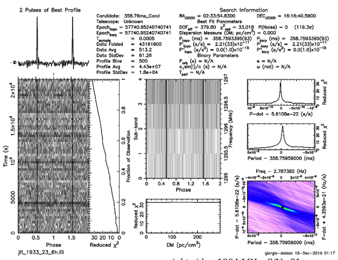


The waterfall graph of a 6 hours reception of the B1933+16 pulsar on 1294 MHz shows that the frequency is not constant over this long period.

This can result in a lower S/N when making long time observations without using special software.

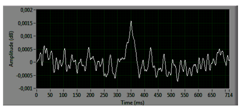


left side: 424 MHz, S/N=20

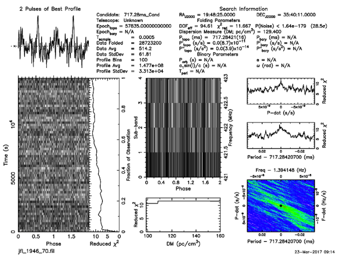


right side: 1294 MHz, S/N=31

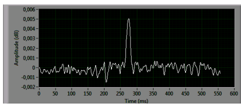
B1946+35



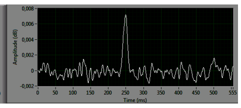
424 MHz, S/N=6



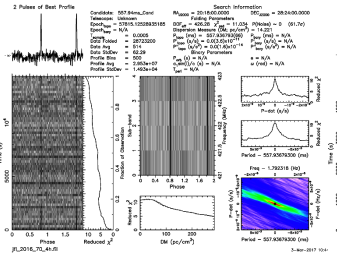
B2016+28



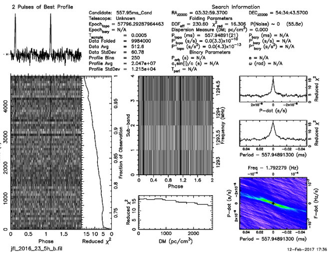
left side: 424 MHz, S/N=14



right side: 1294 MHz, S/N=12

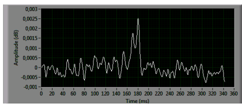


left side: 424 MHz

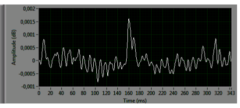


right side: 1294 MHz

B2020+28

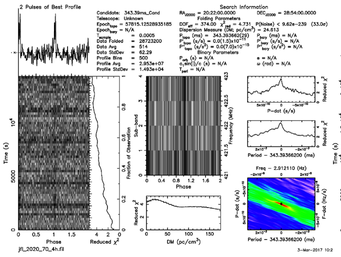


left side: 424 MHz, S/N=9

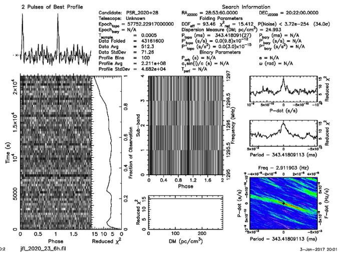


right side: 1294 MHz, S/N=6

especially with weak signals it is good to confirm the positive reception with a second software.

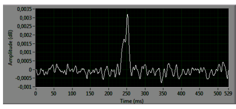


left side: 424 MHz

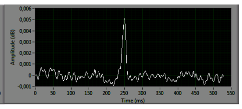


right side: 1294 MHz

B2021+51



left side: 424 MHz, S/N=16

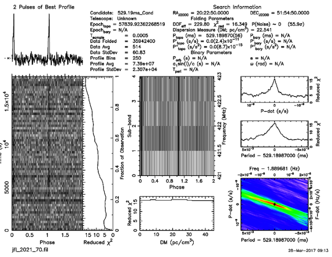


right side: 1294 MHz, S/N=17

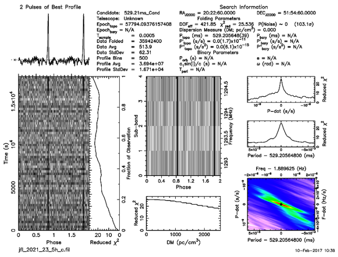
Reception of this pulsar showed me how important patience can be, especially on 23cm.

After 3 attempts, each 5 hours, with completely negative results, I decided to try a 4th (and last) time.

During the last 2 hours the signal came up. So 18 hours nothing, 2 hours signal….10%

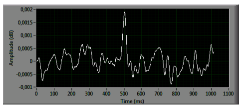


left side: 424 MHz

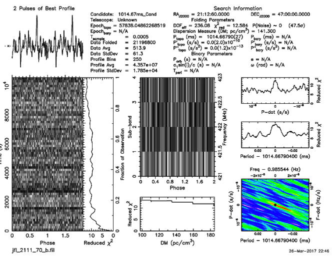


right side: 1294 MHz

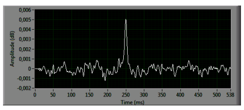
B2111+46



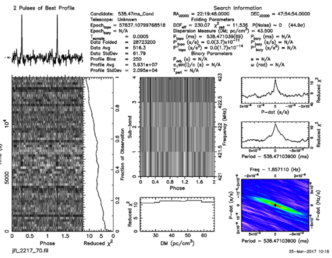
424 MHz, S/N=6



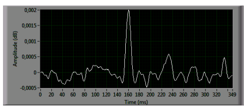
B2217+47



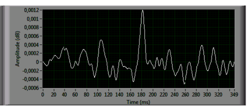
424 MHz, S/N=15



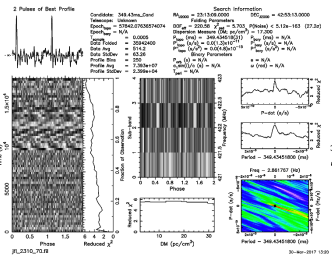
B2310+42



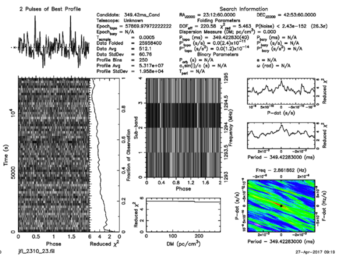
left side: 424 MHz, S/N=11



right side: 1294 MHz, S/N=6



left side: 424 MHz

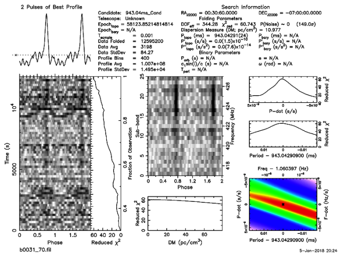


right side: 1294 MHz

The following pulsars were additionally detected with the new setup, Airspy 10MHz bandwidth

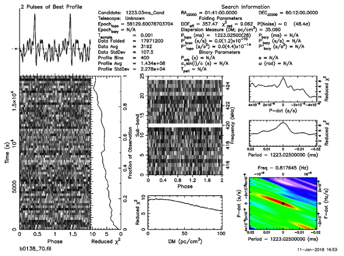
During some observations, especially for pulsars with low or negative declination resulting in low elevation, I suffered from extra RFI coming from buildings around.

B0031-07



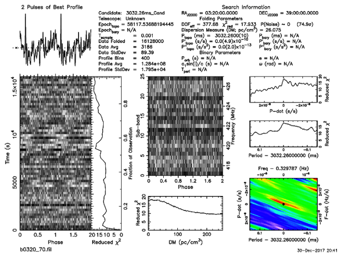
420 MHz

B0138+59



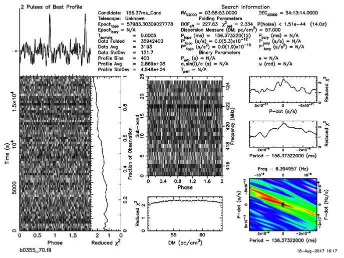
420 MHz

B0320+39



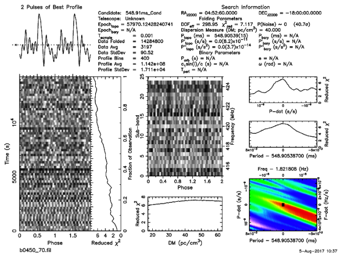
420 MHz

B0355+54



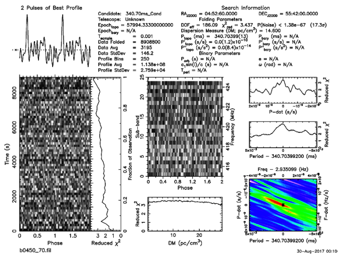
420 MHz

B0450-18



420 MHz

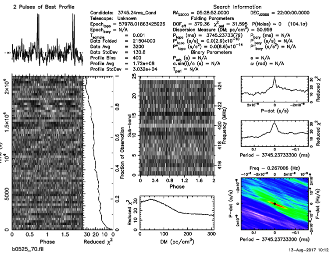
B0450+55



420 MHz

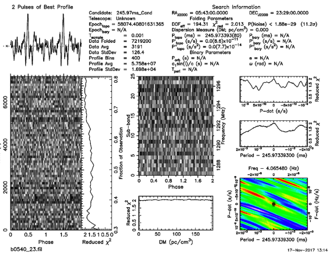
B0525+21

The pulse profile of this pulsar shows a double pulse. It was nice to see the coincidence with the EPN pulsar profile catalogue.



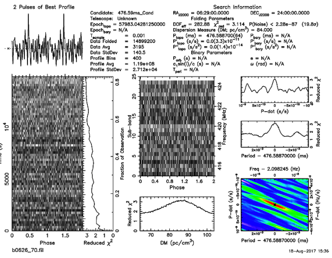
420 MHz

B0540+23



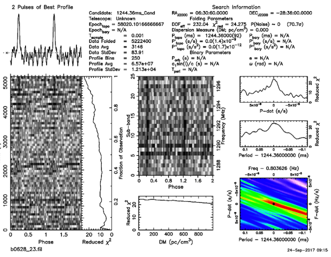
1292 MHz

B0626+24



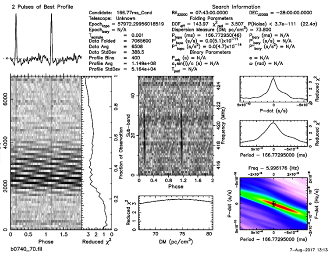
420 MHz

B0628-28



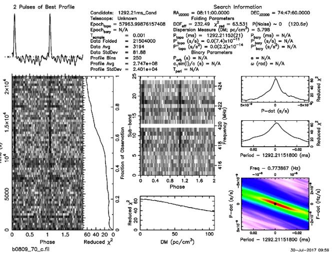
1292 MHz

B0740-28



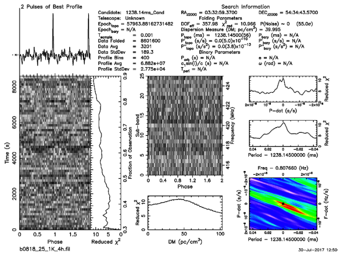
420 MHz

B0809+74



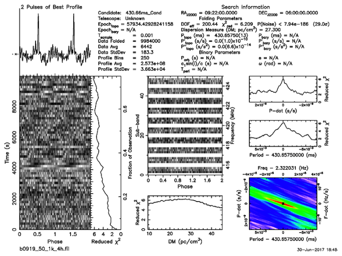
420 MHz

B0818-13



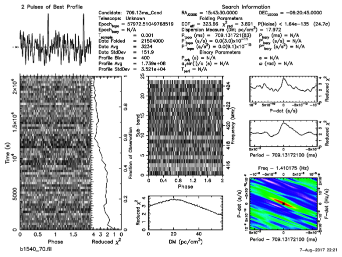
420 MHz

B0919+06



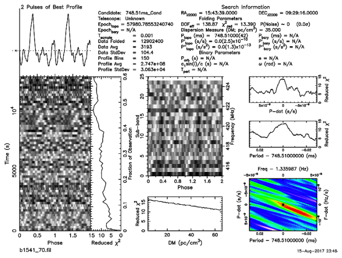
420 MHz

B1540-06



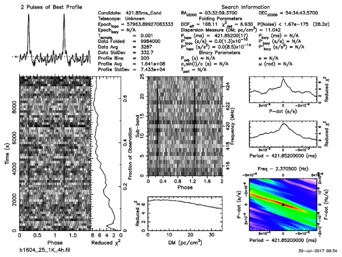
420 MHz

B1541+09



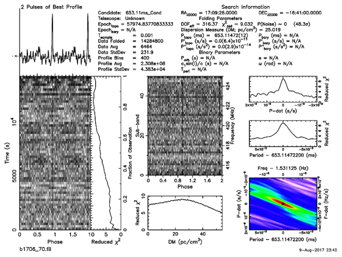
420 MHz

B1604-00



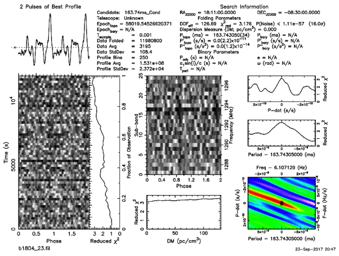
420 MHz

B1706-16



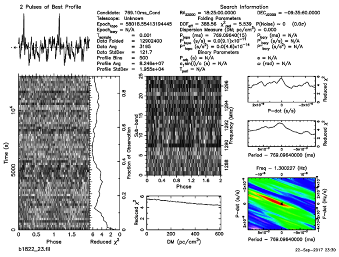
420 MHz

B1804-08



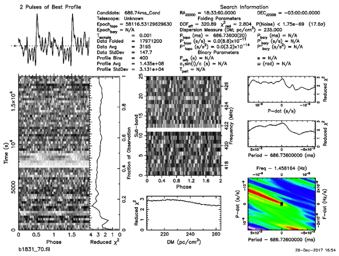
1292 MHz

B1822-09



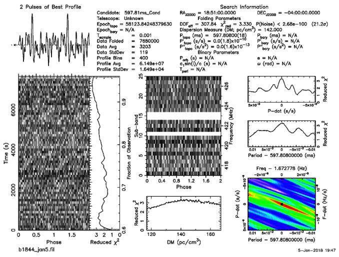
1292 MHz

B1831-03



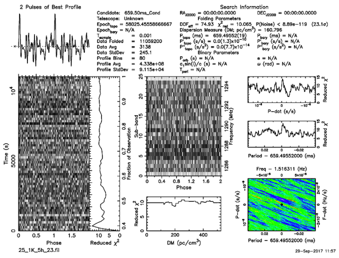
420 MHz

B1844-04



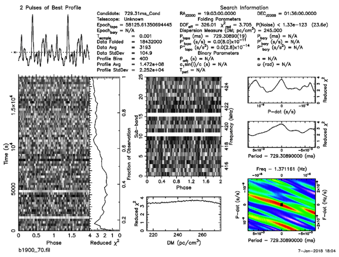
420 MHz

B1845-01



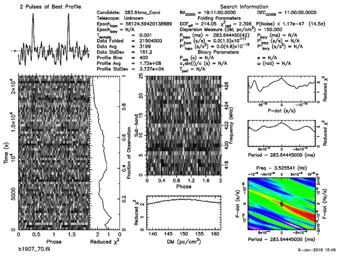
1292 MHz

B1900+01



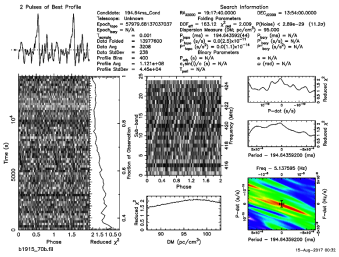
420 MHz

B1907+10



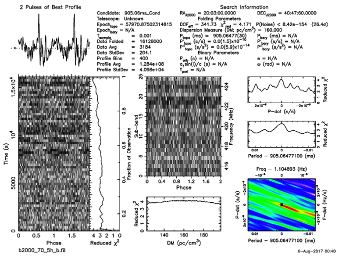
420 MHz

B1915+13



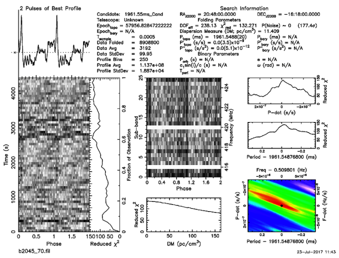
420 MHz

B2000+40



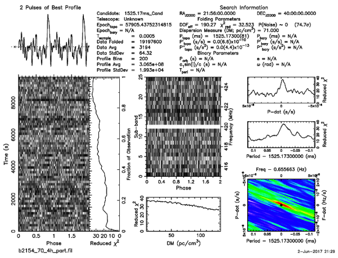
420 MHz

B2045-16



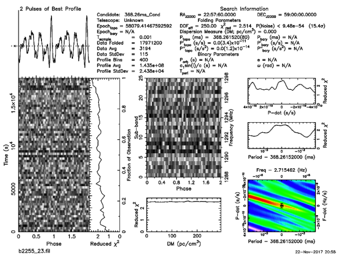
420 MHz

B2154+40



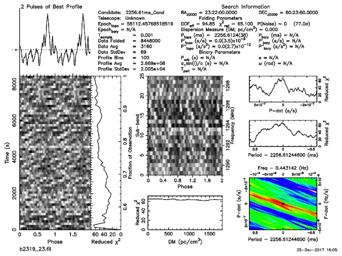
420 MHz

B2255+58



1292 MHz

B2319+60



1292 MHz

Succesful reception of some pulsars were also made with my 3m dish:

[Results with 3m dish]

.....and reception of B0329+54 with a single 23 element yagi on 70cm

[Result with 23 element yagi]

[return to radio astronomy]