

DSES 2026 Pulsar Observing Campaign

Deep Space Exploration Society (DSES), May 10, 2026

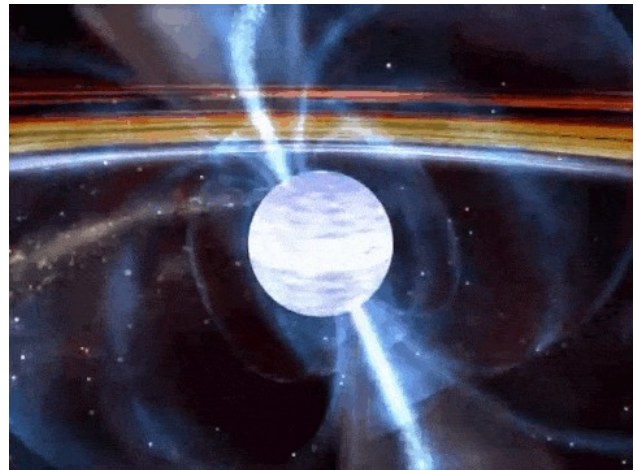
This memo outlines the 2026 DSES pulsar observing campaign. The intent of providing pulsar observing guidance is to encourage member participation and educational outreach. DSES owns and operates the 60 ft radio telescope near Haswell, Colorado. Besides the 60 ft dish, members have access to various antennas, feed horns and receivers that are well-suited for pulsar detection.

Planned experiments include:

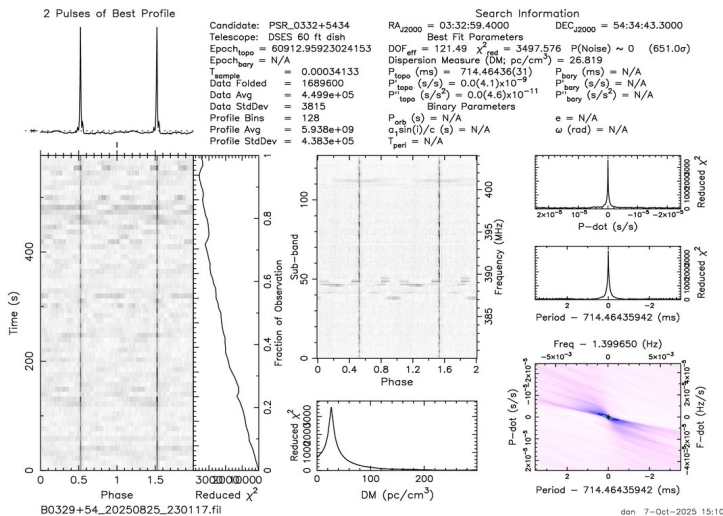
- Detecting new (for DSES) pulsars
- Pulsar scintillation studies
- Pulse time-of-arrival (TOA) analysis
- Pattern analysis of Crab pulsar giant pulses

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Artist's impression of magnetic fields around a pulsar.
(Credit: NASA GSFC)



Presto *prefold* plot for B0329+54

1. Pulsars

A. A pulsar is a highly magnetized, rapidly rotating neutron star that emits beams of electromagnetic radiation from its magnetic poles. These beams sweep through space like a cosmic lighthouse, and when they intersect with Earth, we can detect them as regular, precise pulses of radiation ranging from milliseconds to seconds. Pulsars are formed from the collapsed cores of massive stars after supernova explosions. They are not actually pulsating; rather the rotation of the star causes the radio beams to sweep past our line of sight, creating the observed flickering effect. Most pulsars are detected in the radio band, although some also emit X-rays and gamma-rays.

B. A few pulsars, such as the Crab pulsar, are visible in the optical (visible light) spectrum. The Crab pulsar, B0531+21, emits a main pulse with a period of 33 msec and a mean flux density of 550 mJy at 400 MHz. This pulsar is the visible neutron star in the center of the Crab supernova remnant, shown in the NASA image combining Hubble and Chandra imagery. For this pulsar, DSES has detected all three kinds of pulses: the main pulse, the interpulse and random, giant pulses.



2. Observing Strategy

- A. To improve observation sensitivity, pulsar astronomy seeks to optimize receiver/observing bandwidth, integration time and sampling clock quality, while minimizing system noise temperature (T_{sys}) and radio frequency interference (RFI). Each of these factors can contribute to the success, or failure, of an observing session.
- B. To avoid conflicts, coordinate with the DSES Board the desired observation period.
- C. Ensure that the desired feed will be available for the desired observation period. Coordinate and assist with the feed installation with Roger (W3MIX) and Ray (AAOL).
- D. Considering driving time, a typical observing session lasts ~ 7 hours, maybe from 10 am to 5 pm, or longer when members stay at the facility or in Eads. Plan on spending time at the beginning of a session to initialize the hardware, and at the end to shut everything down.
- E. A radio quiet zone should be enforced during data collection. Otherwise, RFI drowns out the pulsar signal. Power down all ham radio gear and non-essential equipment in the control room. Minimize vehicles with running engines near the dish (spillover). Minimize

use of control room appliances, including heater and air conditioner. Do not use the kitchen microwave or power tools during data collection. Disable Wi-Fi, Bluetooth, and cell phones. Use Ethernet cables for network access. Use clean, reliable power distribution. Avoid noisy switching power adapters (wall-warts), which cause low-frequency harmonic noise.

3. Planning

- A. Mission planning was covered in the April, 2026 presentation. See the DSES website, under Science-Training, or the supplemental document: "DSES_PulsarGuide_Planning_2026.pdf." The presentation includes IONAA Murmur, Stellarium and ATNF PSRCAT for planning.
- B. We expect to detect more, fainter and faster pulsars, thanks to 2025-26 system upgrades, including new coax feed line, new Software Defined Receiver (SDR B210), improved grounding and bonding in the control room, and new Rubidium reference clock.
- C. Use Murmur to predict which pulsars will be above the horizon during the observing period, and use the DSES Pulsar Catalog (in supplemental documents) to see which pulsars have already been detected. Select candidates and verify horizon rise and set times with Stellarium. Some suggested candidates are given below.
- D. Prepare GnuRadio data collection scripts for each candidate pulsar ahead of time. The scripts are described in the Software section.

4. 2026 Candidate Pulsars

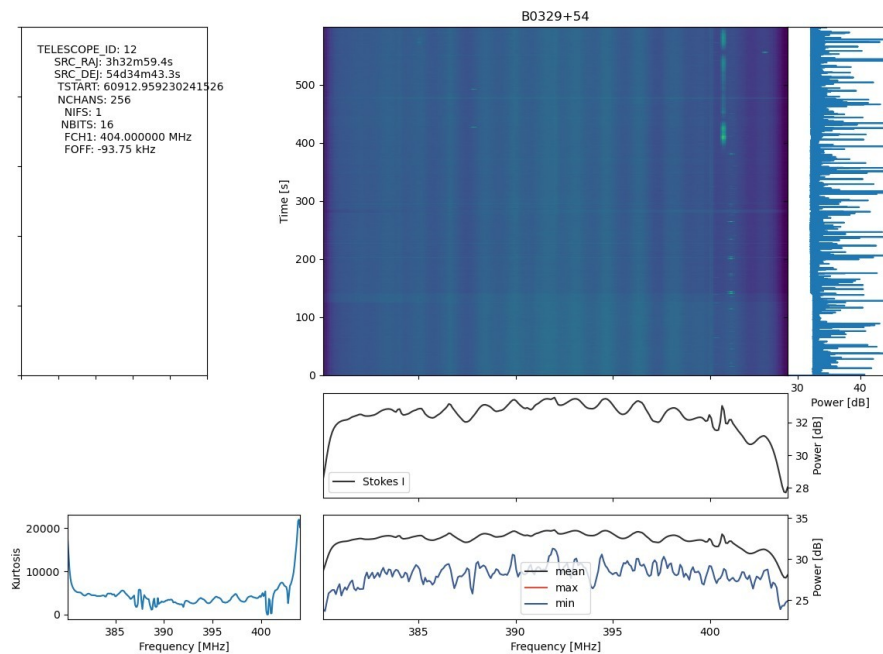
- A. Lacking flux calibration procedures, we use PSR B0329+54 as a reference pulsar to validate system performance. B0329+54 is the brightest pulsar in the northern hemisphere and is circumpolar (always above the horizon). "B0329+54_DSES_ObservationReport.pdf" in supplemental documents contains observing parameters and helpful comparisons.
- B. An observing session could start with three successive 10 minute collections of B0329+54, with the first gap between collections of a few seconds, and the second gap a few minutes. At the end of the day, collect another 10 minute run of B0329+54. This data will support our pulse Time of Arrival (TOA) experiments, where the goal is to phase-connect multiple observations of the same pulsar at the same frequency.
- C. Repeated observations of the Crab pulsar (B0531+21) provides data that can be used to search for patterns (if any) in the emission of giant pulses. Giant pulses do not always occur, so a 4 hour (240 minute) observation is recommended. The Crab pulsar is well above the horizon much of the day during the summer. Our 2025 observations of the Crab pulsar are presented in the supplemental document: "B0531+21_Crab_DSES-SARA_ObsReport.pdf."

- D. Vela (B0833-45) is the brightest pulsar and makes an exciting detection, as many individual pulses are easily visible in a time-series plot. Vela (-45° declination) will be low on the southern horizon for short periods in the early afternoons during June-August. A 20 minute collection should suffice.
- E. Some pulsars "scintillate" on the order of 10-30 minutes due to variations of electron density in the ionized interstellar medium (ISM) between the pulsar and the telescope. This scintillation can be seen in Presto plots and the data used as a probe to study the ISM. DSES has observed several pulsars with notable scintillation, including B0329+54 and B2020+28. Pulsar scintillation is distinguished from ionospheric scintillation (impacting GPS signals) and atmospheric scintillation (causing stars to twinkle).
- F. Pulsar B1919+21, discovered by Jocelyn Bell Burnell in 1967, is the first radio pulsar ever detected. It has a period of 1.3 seconds. DSES has tried, but not succeeded in detecting it. B1919+21 will be above the horizon late in the afternoons during August-September.
- G. Millisecond pulsars (MSP) have periods less than 10 milliseconds. They are generally older, stable pulsars. DSES has detected one MSP, J0437-4715, with a period of 5 milliseconds. There are several other MSP's DSES should be able to detect.
- H. There are many other pulsars that are detectable, but not previously detected by DSES. These "new" pulsars include B0823+26, B0834+6, B2154+40, B2217+47, and B2310+42.

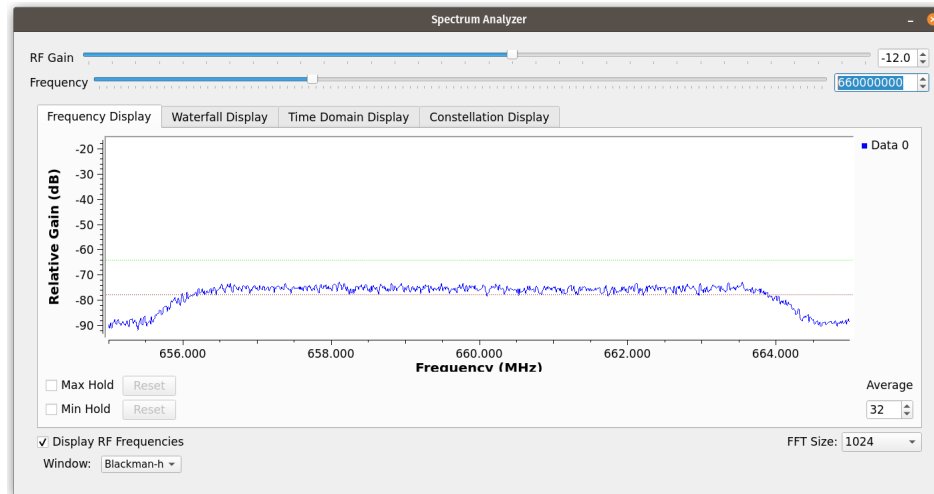
5. Instrument Hardware

- A. The 60 ft (18.3 m) dish may be equipped with various feeds, including 408, 1,296 and 1,420 MHz. Each feed has it's own low-noise amplifier (LNA) and filter. The bandwidth of the filter determines the maximum observing frequency. A coax feed line brings the RF signal to the receiver in the control room. We initially plan to use the 408 MHz dual dipole antenna, with a 90 MHz filter.
- B. We are exploring the old UHF TV broadcast band (663-698 MHz) which is now used for cell service. If there is not much RFI in this band at Haswell, then we may use it for pulsar detection. Pulsars are broadband emitters, many having highest flux density in the 300-800 MHz band.
- C. The primary receiver is the white Ettus USRP B210 with 56 MHz bandwidth. Pulsars have also been detected with the 60 ft dish and SDRPlay receivers (10 MHz bandwidth). During data collection, isolate the SDR away from other equipment. Connect the SDR to the feed line (channel 0, RX2), the reference clock and the data collection computer.

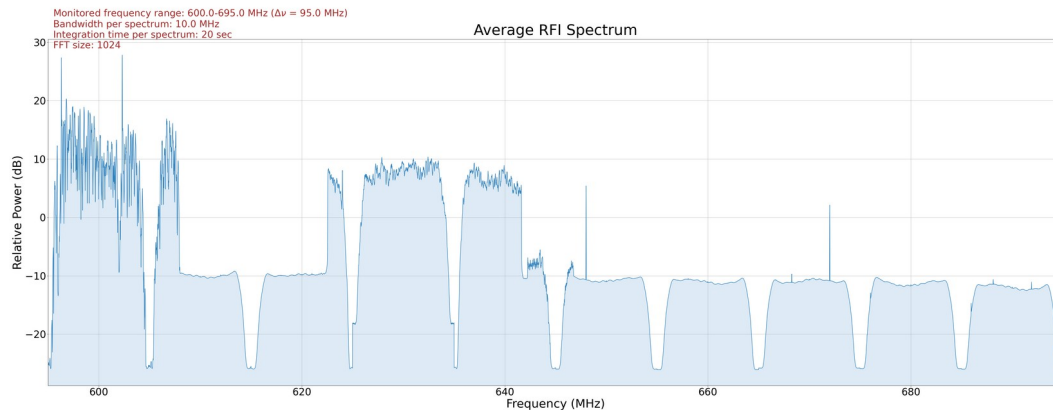
- D. The new rubidium reference clock is described on the DSES website under Projects- Precision Time and Frequency. This clock will support calculation of accurate, absolute pulse Time-of-Arrival (TOA), and also help us to phase-connect gaps between multiple data sets of the same pulsar. The data collection computer should access the network time server for reference. Questions on use of the clock should be directed to Rick (KOGD).
- E. Computer requirements include linux, GnuRadio and USB3. The data may be collected and processed on one computer, or two separate computers. In 2026 we plan to evaluate a Raspberry Pi 5 for data collection. The collected filterbank file would then be processed on the DSES pulsar workstation (32 CPU System76), or similar computer.
6. **Software** (Disclaimer: The tools below are just one approach. There are other methods.)
- A. Software installation is described in the supplemental document: "DSES Pulsar Software Installation and Operation," by Rick, KOGD. This memo focuses on using the software.
- B. Determine the optimal RF gain for the SDR. Using a beacon, or other signal, and a spectrum analyzer, adjust the gain for optimal dynamic range. You should see a > 20 dB jump in the noise floor when switching the LNA off/on. You can also check the dynamic spectrum (waterfall) for saturation by collecting filterbank data for 60 seconds, and then use *watutil* (from <https://github.com/UCBerkeleySETI/blimpy>). Some passband ripple is normal. Strong signals should appear, but pulsars are too faint to be seen in a waterfall display.
- i. > watutil -p a filterbank.fil



- C. Scan for RFI. The goal is to find a clean, wide bandwidth and center frequency for the observing session. Stray signals can later be removed (masked out).
- i. Use the Discone and SDRPlay (or similar SDR) and SDRConnect to scan the bands. You can also use SDRPlay with GnuRadio spectrum analyzer, setting average to high.



- ii. The Virgo RFIscan tool can be scripted to scan large frequency bands via SDRPlay <https://github.com/OxCoto/Virgo> or <https://github.com/OxCoto/CygnusRFI>



- iii. Repeat the spectrum analyzer scan with the B210 connected to the live dish feed.
 - iv. For the 408 MHz antenna, we have used the ham band (420-445 MHz), or in 2025 we successfully used 380-404 MHz.
- D. GnuRadio filterbank parameters are set in the data collection script (run_PSR.sh). Each pulsar to be collected needs a separate sub-directory, due to the large number of files generated during post-processing. Each pulsar sub-directory needs an ATNF parameter file (.par) and shell scripts to control data collection and processing.

- i. A filterbank file (.fil) is a 16-bit binary file with a SIGPROC ASCII header. The file stores radio frequency data in frequency channels instead of time data. The GnuRadio pulsar_filterbank application running on the B210 samples the analog RF signal and saves the channelized data in the filterbank file for (batch) pulsar detection.
- ii. When programming GnuRadio, use the visual tool, GnuRadio companion (GRC). You can then run the data collection from GRC, but it can be cumbersome to edit the parameters. Instead, we edit the parameters in a script, and then call the python filterbank code (generated by GRC) to execute the data collection.
- iii. Create the sub-directories and scripts prior to the observing session.
- iv. Use ATNF pulsar catalog to generate the ephemeris parameter file (.par)
 1. `> psrcat -e -psr psr.txt > psrName.par`
 2. Verify .par is EPHVER 2, TDB for Tempo
 3. A sample .par for B0329+54 is shown below

1 PSRJ	J0332+5434	
2 RAJ	03:32:59.4096	1.000e-04
3 DECJ	+54:34:43.329	1.000e-03
4 DM	26.7641	1.000e-04
5 PEPOCH	46473.00	
6 F0	1.399541538720	6.000e-12
7 F1	-4.011970E-15	1.400e-20
8 PMRA	16.97	3.000e-02
9 PMDEC	-10.37	5.000e-02
10 POSEPOCH	56000.00	
11 F2	5.3E-28	1.500e-28
12 RM	-64.33	6.000e-02
13 PX	0.59	2.000e-02
14 EPHVER	2	
15 UNITS	TDB	

- v. Copy an existing GnuRadio script and edit the parameters. Path names and four parameters from ATNF or Murmur may be set before the observing session: path, gnupath, pulsar name, RA-DEC, and W50. The other five parameters are set in the control room, after determining gain, center frequency and bandwidth at site.
 1. Fbsize is the number of frequency channels in the filterbank file, where channel width = bandwidth / fbsize. Optimal fbsize is described in the DSES Planning Guide, and in the reference book "The Handbook of Pulsar Astronomy," page 109. For most collections at 408 MHz we use fbsize of 256 or 512.
 2. Specify runtime in seconds. Runtime depends on pulsar flux density and collecting bandwidth. Compare with previous results of similar pulsars.
 3. The desired Tsamp is $\sim 0.1 * W50$, and is based on fbsize, bandwidth, W50, and FFT decimation rate. The calculated Tsamp and channel width are printed to the terminal at start-up for verification.
 4. The parameter section of a sample run_B0329+54.sh is shown below

```

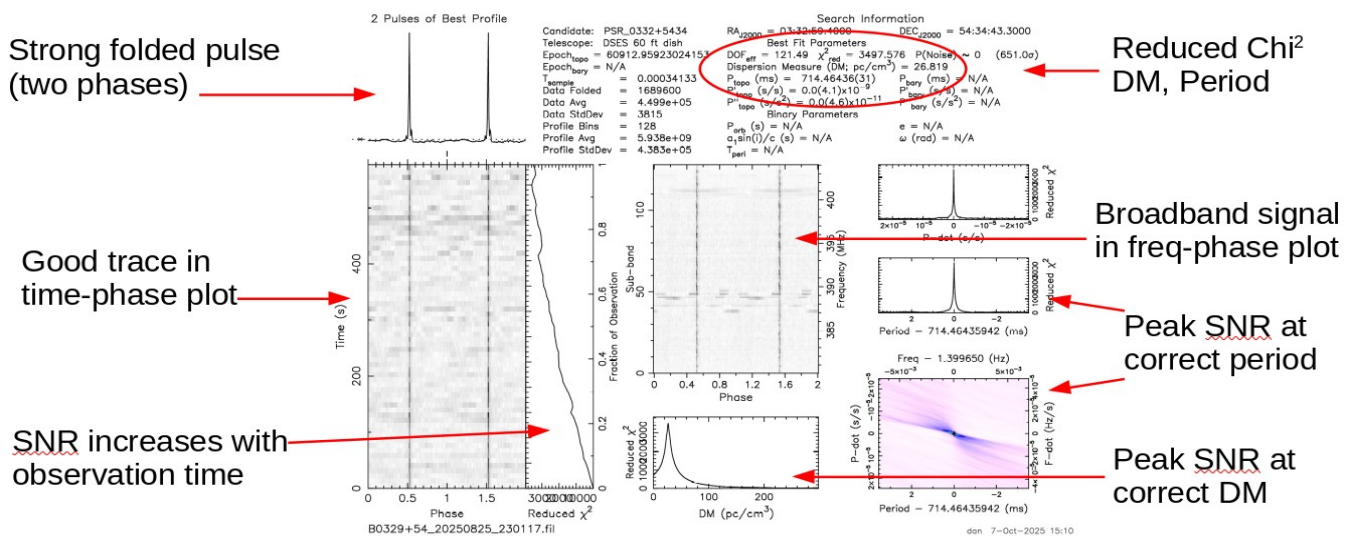
13
14 # path to pulsar_filterbank.py
15 gnuPath='/data1/Pulsar/gnuradio/autoRun/'
16
17 # Pulsar parameters, from ATNF or Murmur
18 # max 16 char for source. dec = hms. ra = dms.
19 path='/data1/Pulsar/data25/Aug26/B0329+54/'
20 sourceN='B0329+54'
21 ra=033259.40
22 dec=543443.30
23 pw50=0.0066
24
25 # filterbank parameters from site survey
26 rfgain=48
27 freq=392e06
28 samp_rate=24e06
29 fbsize=256
30 single_runtime=600
31

```

- E. System 1 is used for dish pointing and tracking. Observers need to be trained and approved to use System 1. For an observing session, follow the standard procedures to initialize the system. Once operational, select the target pulsar from System 1 Radio Source table, and start tracking. After System 1 has acquired and is tracking the target pulsar, then start data collection. Dish tracking and data collection are two independent processes.
- F. Data collection is performed by executing the run_PSR.sh, after System 1 is tracking the target pulsar. Monitor System 1 tracking during data collection.
- i. > bash run_PSR.sh
 - ii. If a single computer is used for collection and processing, then combine the run_PSR.sh and detect_PSR.sh scripts. If a separate computer is used for processing, then transfer the collected filterbank (.fil) file to a shared location for the processing computer.
- G. Pulsar detection uses the collected filterbank file in batch mode. All necessary parameters are contained in the header, or in the associated parameter (.par) file. Two key processes in pulsar detection are dedispersion, which depends on the pulsar's dispersion measure, and folding, which depends on the pulsar's period. See Chapter 7 "Observing Known Pulsars" in the "Handbook fo Pulsar Astronomy."
- i. Pulsar dedispersion corrects the frequency-dependent time delays caused by radio waves traveling through the ISM, which otherwise smears out sharp pulsar pulses and degrades timing precision. Dispersion is observed as a frequency-dependent delay in pulse arrival times, where lower radio frequencies are delayed more than higher frequencies due to interactions with the ISM. We use incoherent dedispersion, where the observing band is split into narrow frequency channels, and each channel's signal is

digitally delayed and summed. While computationally efficient, it leaves residual dispersion within each channel and limits time resolution based on channel width.

- ii. The Dispersion Measure (DM) is defined as the integrated column density of free electrons between the observer and the pulsar. DM units are parsecs per cubic cm.
- iii. Folding is a data analysis technique to increase the signal-to-noise ratio (SNR) of pulsar observations by stacking, or folding, time-series data based on the pulsar's precise, regular period. We are detecting known pulsars, not searching for unknown pulsars, so we constrain the search parameters. Folding converts noisy, raw data into a clear, averaged pulse profile, allowing for detection of faint pulsars.
- iv. Prepfold is the main tool in the *Presto* package that we use for dedispersion and folding. Detailed installation instructions for *Presto 4* are in: "DSES Pulsar Software Installation and Operation" by Rick, K0GD, April 11, 2025. *Presto* version 5 installation instructions are on github. These notes are based on version 5. *Prepfold* has many parameters to control dedispersion and folding. To learn more, do `> prepfold -h`, or follow the *Presto* tutorial available with *Presto* on github. The simplest way to use *prepfold* is with the .par file. Note that all time measurements are calculated as topocentric (time at the telescope), not barycentric (time at the barycenter of the solar system):
 1. `> prepfold -timing PSR_param.par -topo PSR_filterbank.fil`
- v. A "quick look" feature is seen by calling *prepfold* at the end of the data collection script. This automatically generates a *prepfold* plot from the new filterbank file for viewing in the control room. Due to the large number of variables, the quick look is not always optimal. Iterating *prepfold* manually during post-processing can improve results.
- vi. To check intermediate results during a long data collection, use *rsync* to copy the live filterbank file into another directory and manually run *prepfold*. A sample *prepfold* plot is shown below. A pulsar is confirmed when all areas in the plot are correct.

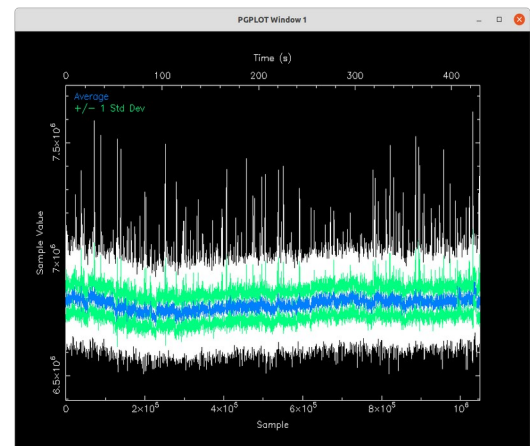
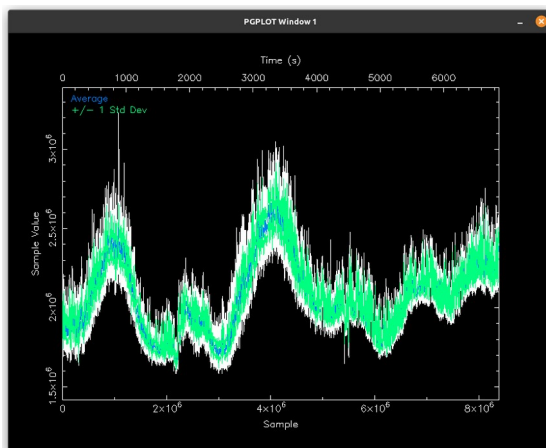


H. Post processing

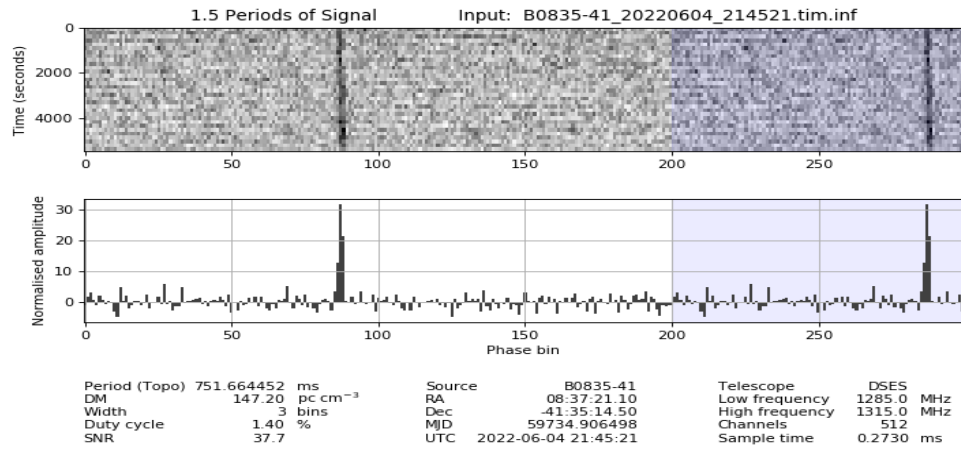
- i. Manual refinement (via command line) of the automatic *prepfold* plot is often required. Poor results can be due to the complexity of the algorithm and the presence of noise, or sometimes due to old ephemeris values in the .par file. ATNF maintains accurate values for pulsars used in active research, such as MSP's. However, ephemeris data for some pulsars can be a decade old, leading to inaccurate folding period or DM. Use feedback from the algorithm to specify period, DM and other parameters as you manually iterate. Enabling DM or period search can help.

- ii. RFI removal can be accomplished two ways.
 1. Strong RFI can often be seen in the time-frequency plot from *prepfold*. Or use *watutil* (described above) to view portions of the filterbank waterfall. Generally, *watutil* is not able to process large files, so break it into smaller portions, and check for significant RFI signals. Then use the `-ignorechan` option with *prepfold* to skip that frequency channel(s).
 2. A more analytical approach is to use the *Presto* tool *rfifind*, as described in the *Presto* tutorial. This tool was used to identify low-frequency (e.g., 120 Hz) harmonic noise in DSES pulsar data before we had eliminated ground loops. Low-frequency harmonic noise with a period similar to the pulsar severely degrades the folding results. Using many *rfifind* examples, an extended analysis of sample data from Green Bank 20m, Parkes 64m and DSES 18m is presented in the supplemental document "DSES_RFI_Jan-2025.pdf." *Rfifind* may be iterated to produce the best noise mask for *prepfold*.

- iii. Visualizing time-series data helps understand signal quality. While the filterbank data and the *prepfold* algorithm are in the frequency domain, the data can be converted to a time-domain signal via an inverse FFT. Use the *Presto* tool *prepdata* to make a dedispersed time series, and *exploredat* for visualization. A time-series with large jumps indicates noise distortion, impacting folding (a flat time-series is better).



- iv. Slow period pulsars, say with period between 1 and 3 seconds may be detected with the time-domain algorithm *riptide* (<https://github.com/v-morello/riptide>). Since *prepfold* was designed to search for new millisecond pulsars (MSP), it does not perform as well on slow pulsars, or pulsars with wide pulse (large W50). We have used *riptide* to detect slow pulsars where *prepfold* failed.



- v. Pulsar scintillation was introduced in section 4.E above. Strong scintillation may be observed in the *prepfold* time-phase plot as pulse traces fade in and out over periods of 10-30 minutes. A detailed analysis would require new tools, such as *scintools* (<https://github.com/danielreardon/scintools>) and the ability to convert from SIGPROC filterbank to PSRFITS. Scintillation is discussed in Chapter 4 "Effects of the Interstellar Medium" of the "Handbook of Pulsar Astronomy." The Green Bank 20m telescope is being used to research ISM effects and pulsar scintillation at 1420 MHz.
- vi. Crab pulsar giant pulses may be detected with single pulse techniques. The first Crab giant pulses detected by DSES are reviewed in the supplemental document "B0531+21_Crab_DSES-SARA_ObsReport.pdf." DSES used the Presto tool *single_pulse_search.py*. A statistical analysis of Crab giant pulses at 1420 MHz with the Green Bank 20 m telescope is an example of what can be accomplished. Single pulse searches are discussed in Chapter 6 of "Handbook of Pulsar Astronomy."
- vii. The pulse time-of-arrival (TOA) is the absolute time of the nearest pulse to the mid-point of the observation. The goal of pulsar timing is to account for every rotation of the pulsar over an extended period containing multiple observations. Combining accurate TOAs with high SNR allows multiple observations to be phase-connected. The supplemental document "DSES-Pulsar-TOA-Guide-2026.pdf" outlines processing steps and a recent DSES example, using the Presto tool *get_TOAs.py*. Also, see Chapter 8 "Pulsar Timing" of the "Handbook of Pulsar Astronomy."

7. Reference

- A. "Handbook of Pulsar Astronomy," Lorimer and Kramer, Cambridge, 2005

8. Referenced DSES Supplemental Documents

- A. B0329+54_DSES_ObservationReport.pdf
- B. B0531+21_Crab_DSES-SARA_ObsReport.pdf
- C. DSES_PulsarCatalog_Aug_2025.pdf
- D. DSES_PulsarGuide_Planning_2026.pdf
- E. DSES Pulsar Software Installation and Operation.pdf
- F. DSES-Pulsar-TOA-Guide-2026.pdf
- G. DSES_RFI_Jan-2025.pdf

9. Bibliography

- A. "Essential Radio Astronomy," Condon and Ransom, Princeton, 2016
- B. "Fundamentals of Radio Astronomy: Astrophysics" Snell, Kurtz, and Marr, CRC Press, 2020
- C. "Fundamentals of Radio Astronomy: Observational Methods," Marr, Snell, and Kurtz, CRC Press, 2020