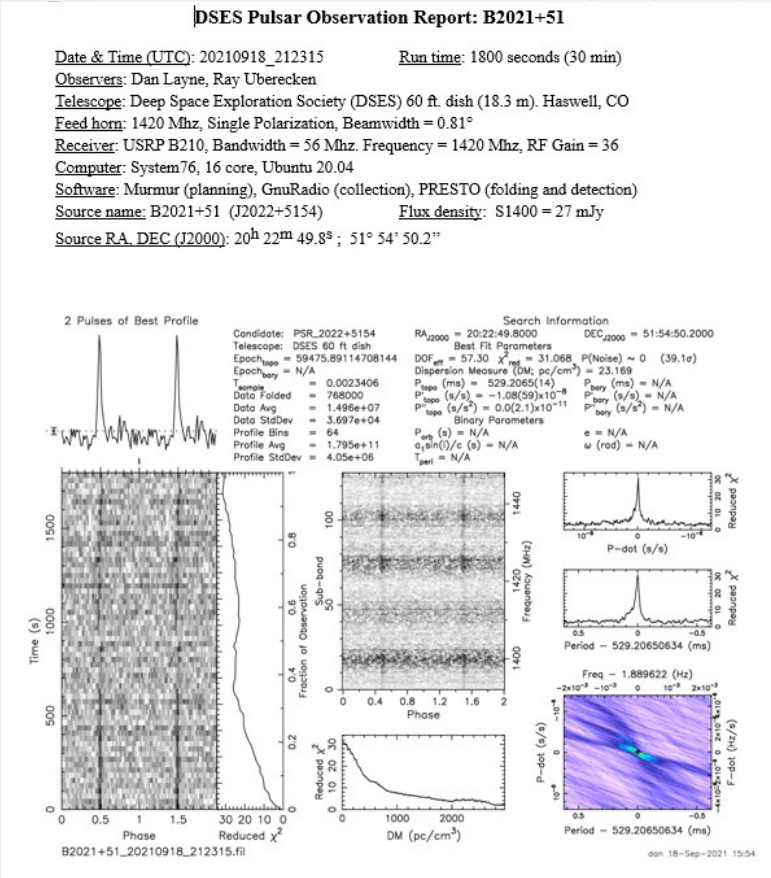
Deep Space Exploration Society Science Meeting



DSES Pulsar Observation Report: B2021+51

Date & Time (UTC): 20210918_212315 Run time: 1800 seconds (30 min)
Observers: Dan Layne, Ray Uberecken
Telescope: Deep Space Exploration Society (DSES) 60 ft. dish (18.3 m). Haswell, CO
Feed horn: 1420 Mhz, Single Polarization, Beamwidth = 0.81°
Receiver: USRP B210, Bandwidth = 56 Mhz. Frequency = 1420 Mhz, RF Gain = 36
Computer: System76, 16 core, Ubuntu 20.04
Software: Murmur (planning), GnuRadio (collection), PRESTO (folding and detection)
Source name: B2021+51 (J2022+5154) Flux density: S1400 = 27 mJy
Source RA, DEC (J2000): $20^h\ 22^m\ 49.8^s$; 51° 54' 50.2"

September 27, 2021

Dan Layne

DSES.science

NASA APOD

How did a round star create the
Red Square Nebula?

No one is quite sure. A star at the center, MWC 922, somehow expelled cones of gas.

Infrared exposures from Hale and Keck-2 telescopes

DSES Information (1/2)

- SARA Drake's Lounge 12 noon 3rd Sunday of every month
- Updated DSES Radio Astronomy Observation Guide available
- EdX "Radio Sky II: Observational Radio Astronomy" course 9/30 – 11/18
- Acquired absorber for 21 cm to measure T_{hot}
- 9 ft dish – Spectacyber running
  - Plan to add RTL-SDR; Conducting calibration runs on S7 for T_{sys}
- SuperSID – working and porting data to Stanford Solar Center
- Radio Jupiter – SDR and antenna ready. Just need to put it on internet

DSES Information (2/2)

- Interferometer project – next chart
- Tropospheric transmission – 1296 MHz feed available
- EME systems – 1296 MHz feed available
  - Moon orbit determination using EME equipment
- 60’ dish pointing and tracking updates – see Mount Cal presentation 9/13/21
- Pulsars
  - Detected 4 pulsars Aug. 7 (one new one)
  - Detected 2 pulsars Sep. 18 (one new one)
  - DSES is now credited with 14 pulsars (5th in world amateurs - 4th has 23 pulsars)

Haswell Two-Dish Interferometer Project

- 3.7 m ComTech dish from KRCC installed 9/18/2021
  - Installation time-lapse video (¼ speed) Dish Installation
- Interferometer requirements and design?
  - Prime focus feed horn (C band and/or Ku band)
  - Dish alignment, timing and cabling
  - 2nd dish location straight East: fixed or movable?
  - Dual channel coherent SDR (*e.g.*, N210, B210, Lime)

Pulsar Detection with AutoPoly

Deep Space Exploration Society

Current Process to Detect Known Pulsar

- Use Murmur to plan observation (PSR, flux, time above horizon)
- Configure System 1 controller to track pulsar (PSR, RA, Dec)
- Configure GnuRadio Companion filterbank collection parameters
  - Runtime, RF gain, fbsize, fbdecim, bandwidth, output directory, etc.
- Run GnuRadio Companion to collect filterbank file (SIGPROC .fil)
- Run Presto “prepfold” to process filterbank file
  - RFI mask not needed. Enter Period, DM, etc. on command line
  - Iterate the folding as needed (converge or diverge)

Two Problems with Current Process

- Predicting optimal runtime is difficult
  - Integration time might be estimated from the Radiometer equation, but it needs accurate Tsys
  - Some data collections do not yield pulses, so time is wasted
  - No need to continue long collection if pulse can already be detected
- Iterating prepfold on the command line can be tedious
  - Can improve results via Tempo polynomial coefficients (polycos) for ATNF pulse ephemeris, but it is a manual, multi-step process

AutoPoly Process to Detect Known Pulsar

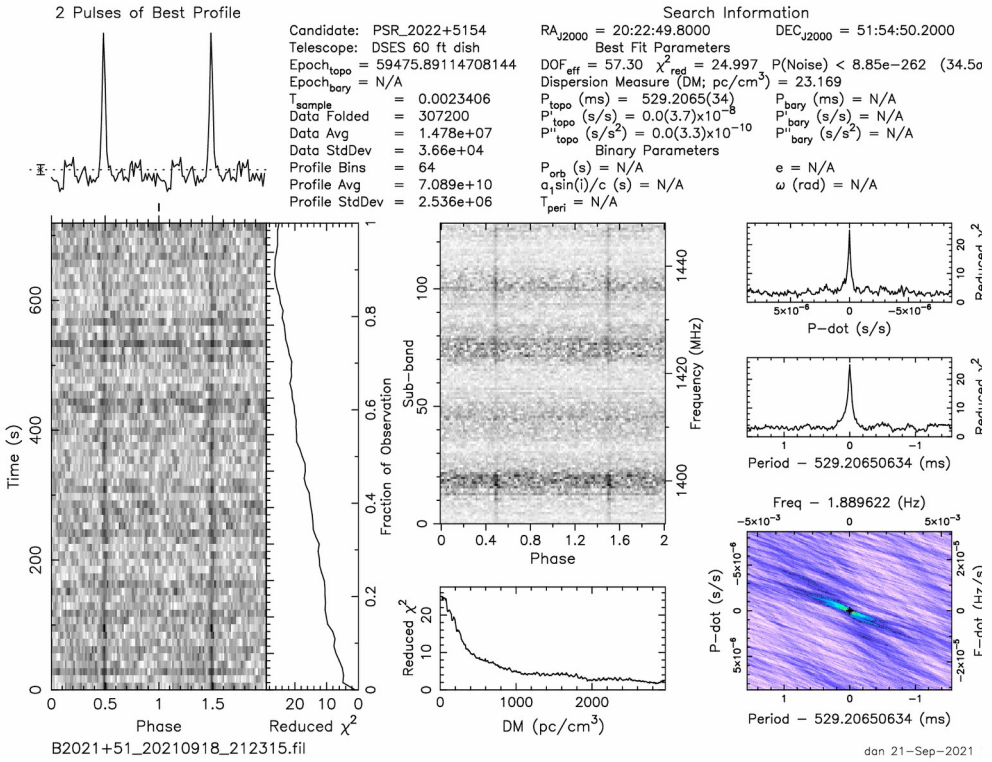
- (same) Use Murmur to plan observation (PSR, flux, time above horizon)
- (same) Configure System 1 controller to track pulsar (PSR, RA, DEC)
- (new) Configure GnuRadio and prepfold parameters in AutoPoly script
  - GR: Runtime, RF gain, fbsize, fbdecim, bandwidth, output directory, etc.
  - Configure each pulsar once (at home), then run repeatedly at Haswell
- (new) Run AutoPoly script to collect and process filterbank files
  - Script generates num_iter filterbank files, each for specified runtime
  - A time gap (a few seconds) occurs between files as GnuRadio restarts (Presto pads gaps)
  - Script calls prepfold on intermediate files and plots cumulative results
  - Using automatic polycos, Tempo calculates pulse times of arrival from timing model (.par)
  - No need to iterate on command line. Can kill script at any time

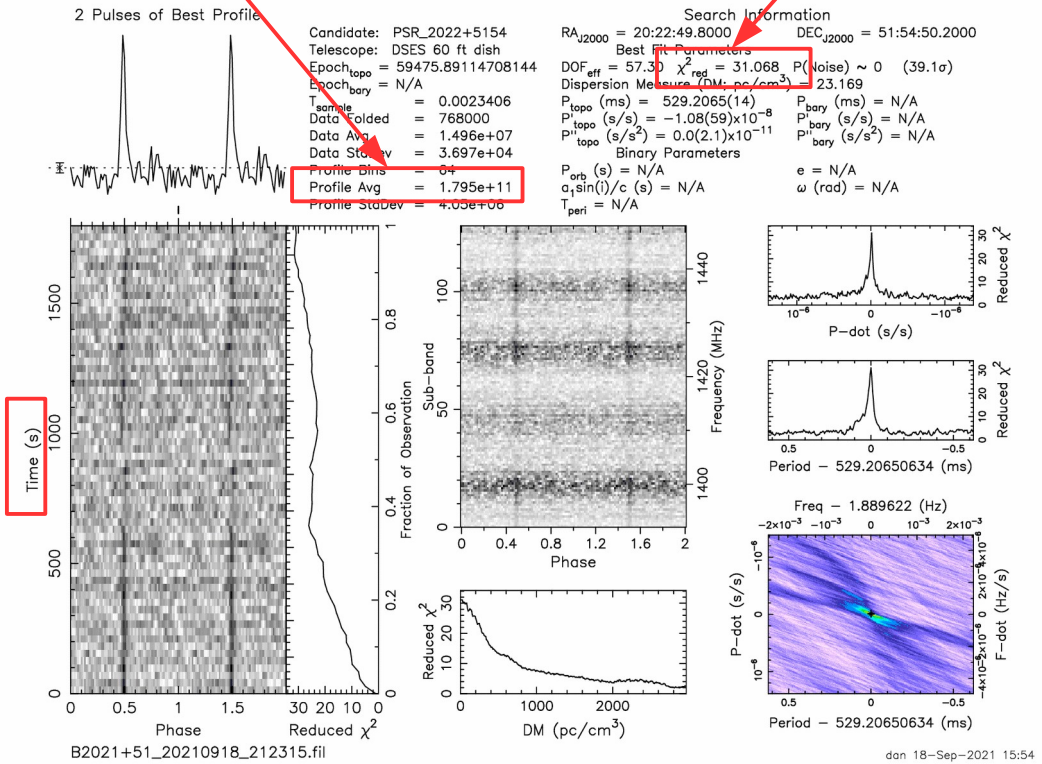
e.g.,B2021+51, 09/18/2021, S1400 = 27 mJy

First 15 minutes (900 sec) on left

Second 15 minutes (1800 sec total) on right

Look for improved pulse definition in phase plots, stronger pulse (better SNR), larger reduced Chi-squared.





Development Background 1/2

- Experimented with Skynet GBO 20m Crab pulsar data
  - Prepfold can ingest multiple PSRFITS files
  - Prepfold pads (zero fills) time gaps between files
  - Polycos ephemeris aligns pulse phase across all files
- 1st try for DSES: Transform DSES .fil to psrfits
  - Failure: psrfits needs extra parameters for applications, .fits from .fil is incomplete
- 2nd try for DSES: Fake it with simulated collections of multiple .fil
  - Tried to copy, clip filterbank files and edit headers for new times
  - Tried simulated data from hardware simulator and software simulator (SIGPROC Fake)
  - Failure: To align phase across multiple files, Tempo polycos requires real pulse train as defined by ATNF parameters

Development Background 2/2

- 3rd try for DSES: Transform GBO psrfits to .fil for testing
  - All files for each collection need the same freq and tsamp
  - Converted via Your_Writer psrfits2fil. Verified with watutil
  - Success: GBO .fil (Stokes I only) results almost as good as .fits (IQUV)
- GBO .fil files were used to develop and test AutoPoly
  - One pulsar data collection per sub-directory. Any number of .fil
  - Each pulsar has two config files: .par and AutoPoly.sh (next charts)
  - GBO Crab demo

Tempo .par File

- Tempo calculates pulse TOAs from input timing model (.par)
- Create .par from ATNF website “Get Ephemeris”
  - https://www.atnf.csiro.au/research/pulsar/psrcat/
  - Copy and paste PSR data into local PSR.par file
- Or, install ATNF DB “PSRCAT” and run
  - psrcat -e -psr psr.txt > PSR.par
- AutoPoly script calls prepfold with -par option for timing
  - .par provides period, DM, etc.

Example - 2022+5154.par File

Notes:

1. File name excludes B or J
2. Field names and values are directly from ATNF
3. EPHVER=2 and UNITS=TDB indicate Tempo
4. EPHVER=5 and UNITS=TCB indicate Tempo2

Open Save

2022+5154.par
/data/Pulsar/data/DSES-2021-Dan/Sep18/B...

```
PSRJ          J2022+5154
RAJ           20:22:49.8730                1.200e-03
DECJ          +51:54:50.233                1.100e-02
DM            22.54968                     5.600e-04
PEPOCH        46640.00
F0            1.88965575261                6.000e-11
F1            -1.093868E-14                1.500e-19
PMRA          -5.23                        1.700e-01
PMDEC         11.5                         3.000e-01
POSEPOCH      46640.00
DMEPOCH       56789
F2            -2.27E-26                    1.600e-27
RM            -6.73                        8.000e-02
PX            0.50                         7.000e-02
EPHVER        2
UNITS         TDB
```

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AutoPoly.sh

- Bash shell script
  - Edit parameters for current pulsar, if needed
  - Execute via > bash autoPoly.sh
  - GnuRadio and Presto output goes to terminal window
  - Script displays cumulative prepfold plot for each iteration
  - Run to completion, or kill via Ctl-C

Example - AutoPoly.sh

Notes:

1. Just showing parameter section
2. Lines 15-26 are GnuRadio params
3. Line 29 is prepfold param

autoPoly_J2022+5154.sh
/data/Pulsar/data/DSES-2021-Dan/Sep18/B2021+51

```
12
13 # Set pulsar filterbank parameters
14 # max 16 char for source. dec = hms. ra = dms.
15 numIter=6
16 single_runtime=900
17 path='/data1/Pulsar/data21/dan/Sep18/B2021+51/'
18 sourceN='B2021+51'
19 ra=202249.8
20 dec=515450.2
21 pw50=0.0021
22 rfgain=36
23 freq=1420e06
24 samp_rate=56e06
25 fbsize=2048
26 fbdecim=64
27
28 # prepfold param
29 parFile="${path}2022+5154.par"
30 nCPU=12
31 cd $path
32 if [ ! -s "$parFile" ]
33 then
34     echo "runPulsar error: $parFile not found."
35     exit 1
36 fi
37 outFile="${path}${sourceN}_all"
38 inFile="${path}${sourceN}"
39 gnuPath='/data1/Pulsar/gnuradio/autoRun/'
40
41
```

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Technical Detail

- Output prepfold plot identifies Telescope as “DSES 60’ dish”
- However, internally, Presto and Tempo use CHIME as geolocation
- Problem: Default AutoPoly ephemeris is too short (1 hour). Presto aborts.
  - In prediction mode, Tempo calculates ephemerides for several hours, or days
  - But max hour angle for CHIME = 1, while Haswell needs 12
- Solution:
  - Change tracklen to 12 for CHIME in presto/src/polycos.c
  - Only see tiny change in presto results for GBO, VLA, CHIME geolocations
  - Too complicated to create custom site for Haswell in Presto/Tempo

AutoPoly Things To Do

- More live testing at Haswell
  - ¾ B0329+54 failed, while B2021+51 worked fine on 09/18
- Pre-populate scripts for Haswell pulsars with S1400 > 5 mJy
- Some ATNF .par data in Tempo2 format. Can’t run it
- What if observations span more than 2-3 days?
  - Use PSRCHIVE – PSRADD to merge prepfold archives (.pfd)
  - Generates statistics and pulse plot, but no prepfold plot
  - Can span any time period, any time gap between obs

Misc. Topics

HI Drift Scan

- Use 60’ dish in stow position (near zenith) with 1420 feed
- Airspy SDR at 2.5 MHz or 10 MHz bandwidth
- Raspberry Pi 4B for data collection
  - Ubuntu 21.04, GnuRadio 3.8, Python 3.9.5
  - Remote access via TeamViewer (installation in progress)
  - Astro-virgo spectrometer and WVURAIL DSPIRA (+ cal)
  - Testing at home in progress (no dropouts at 10 MHz)
- Deploy to Haswell for 24x7 unattended drift scan
  - 30 samples per hour, ~15 seconds per sample, < 1 GB/day = 30 GB/month
  - DSL upload too slow (2 Mbps ~1 GB/hr). Use 64 GB flash drive. Retrieve data monthly
  - Use python scripts to analyze data, animate plots
- Can also characterize 3.7 m dish with meridian drift scans

2021 Observation / Feed Schedule

- September – December 2021
  - 1420 MHz feed for pulsar and HI observations
  - Potentially swap 1420 feeds in near future
  - 1296 MHz if EME team wants it

Questions?

Future Topics?