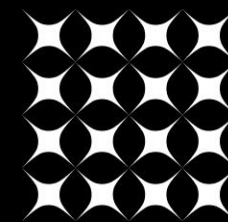




中国科学院国家天文台
NATIONAL ASTRONOMICAL OBSERVATORIES, CAS



中国科学院
计算机网络信息中心
Computer Network Information Center,
Chinese Academy of Sciences



MWA
MURCHISON
WIDEFIELD
ARRAY

Effectively processing SKA-low precursor pulsar survey data in China

Mengyao Xue¹, Qiuyang Fu¹, Weiwei Zhu¹, Kaichao Wu², Zihan Zhang², Yukai Zhou³, Ramesh Bhat⁴, Chia Min Tan⁴, Bradley Meyers^{5, 4} et al.

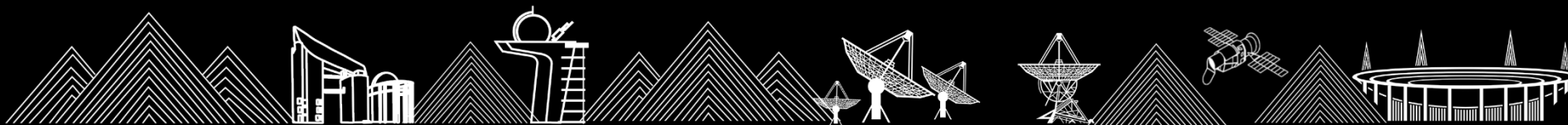
¹ National Astronomical Observatories, Chinese Academy of Sciences;

² Computer Network Information Center, Chinese Academy of Sciences;

³ Peking University;

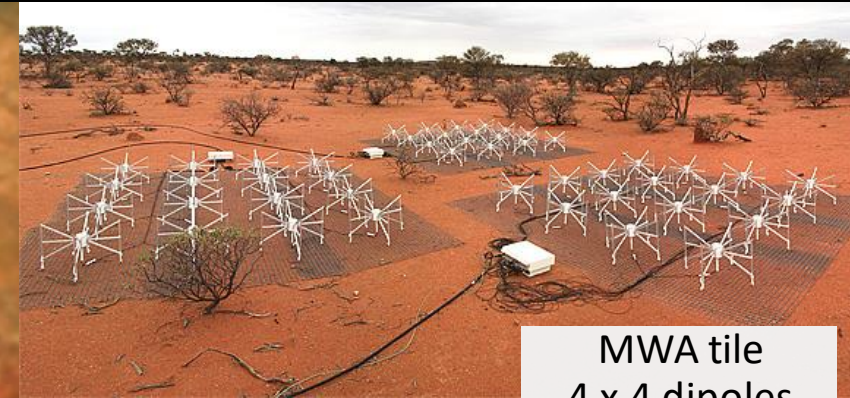
⁴ International Centre for Radio Astronomy Research (ICRAR), Curtin University;

⁵ Australian SKA Regional Centre (AusSRC), Curtin University



Murchison Widefield Array (MWA)

Precursor for the SKA-low at the same site



Compact configuration of the MWA:
128 tiles, 400m baseline

Observing pulsars with the MWA

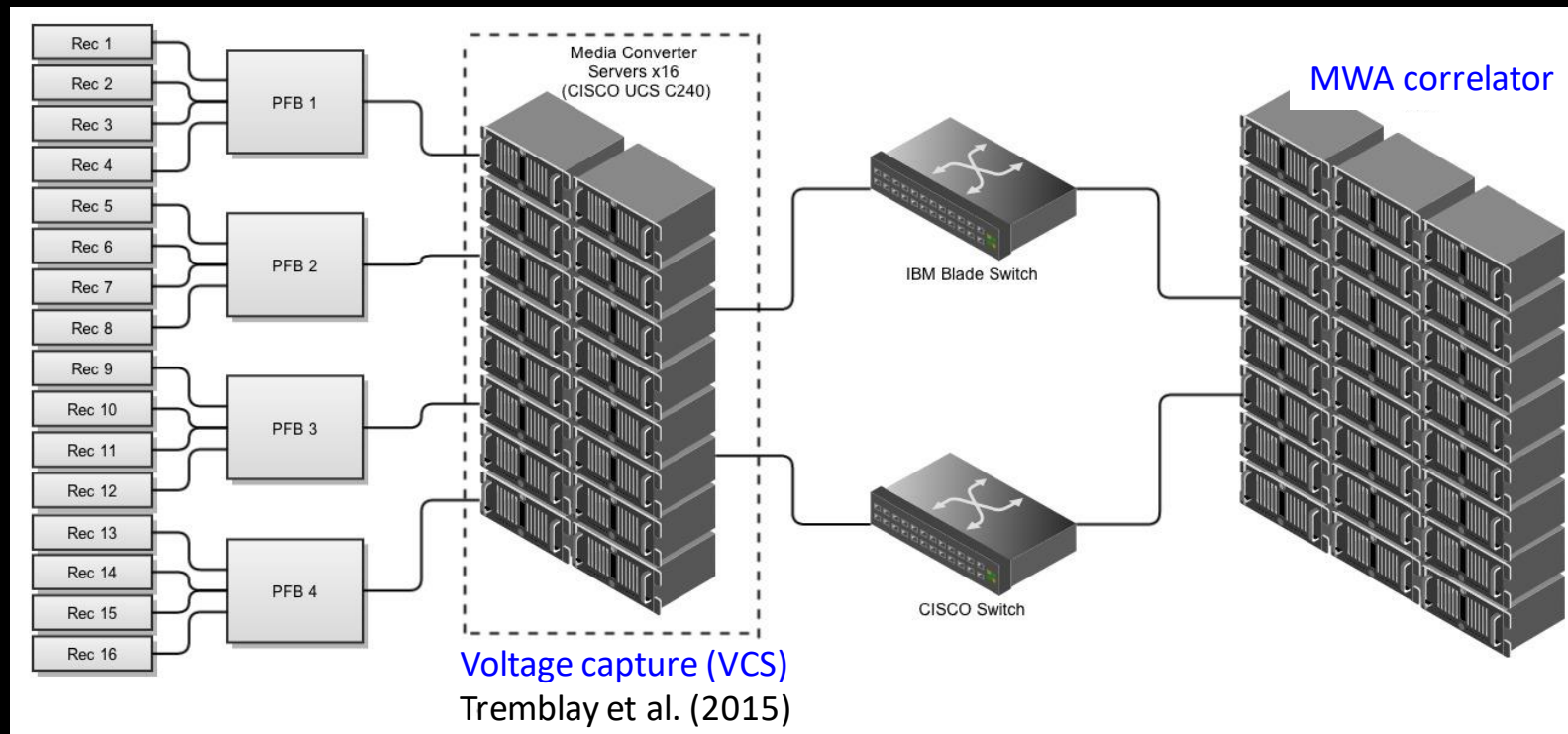
the “voltage capture” (VCS) way

Record all channelised voltage streams from each tile

Bandwidth: 30.72 MHz (24 coarse channels, 1.28 MHz each)

Time resolution: 100 μ s Frequency resolution: 10 kHz

Data rate: 28 TB per hour Maximum recording: 1.5 hour



Observing pulsars with the MWA

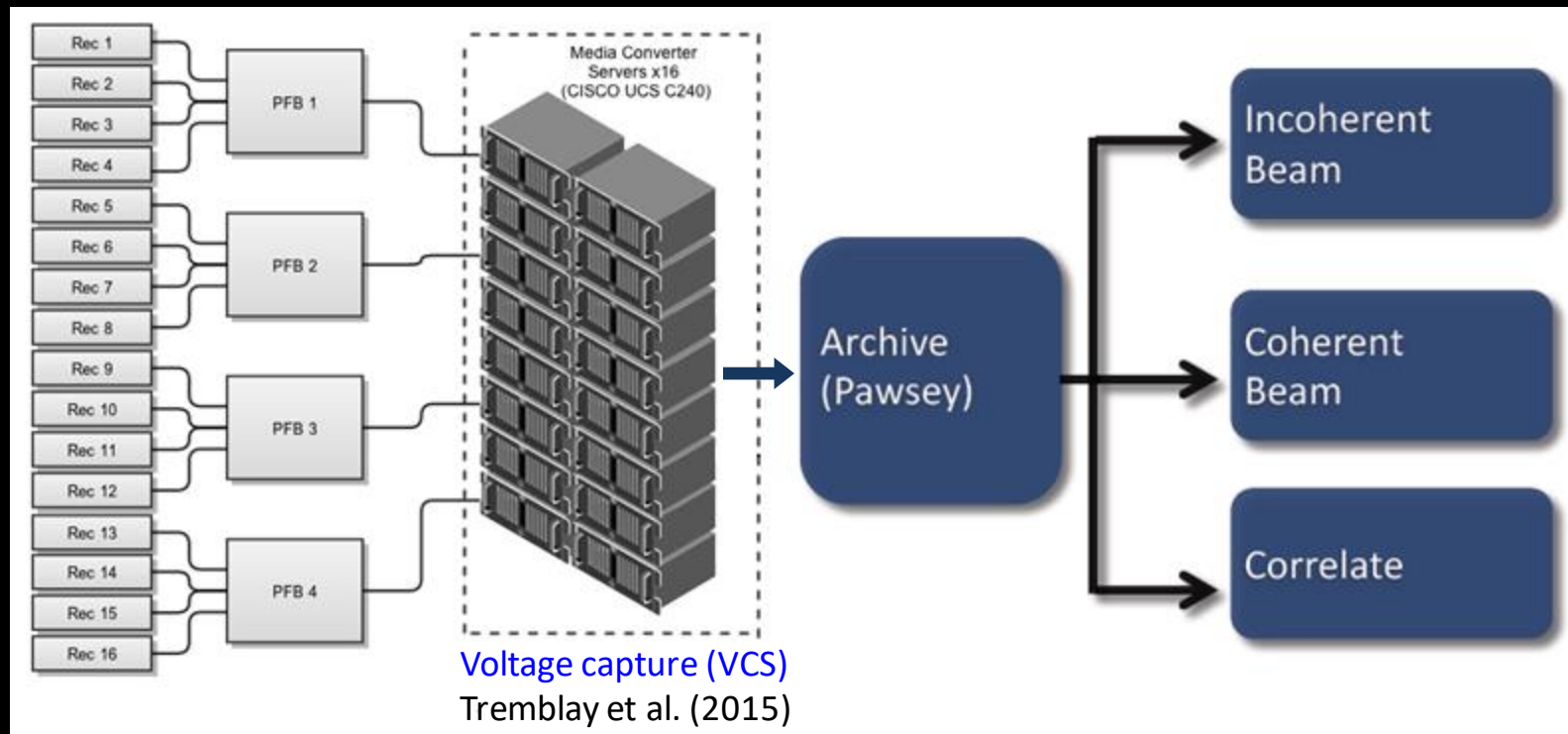
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Data rate: 28 TB per hour Maximum recording: 1.5 hour



The Southern-sky MWA Rapid Two-metre (SMART) Survey

PI: Ramesh Bhat

- Southern-all-sky pulsar survey, **4800** sec drift-scan for each observation
- An important demonstrator pulsar survey for SKA1-Low
 - provide info of pulsar population at low-frequency
 - helping optimise survey strategies

Uniqueness of the SMART Survey

- Record voltages instead of real-time beam forming
- Large field-of-view ($\sim 610 \text{ deg}^2$)

Cover entire observable sky with just 70 observations, 94 hrs

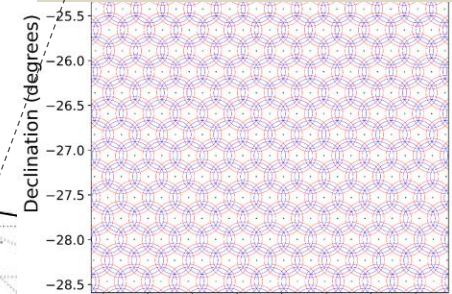
Pros of offline beamforming

- require less observation time
- flexibilities in subsequent data processing

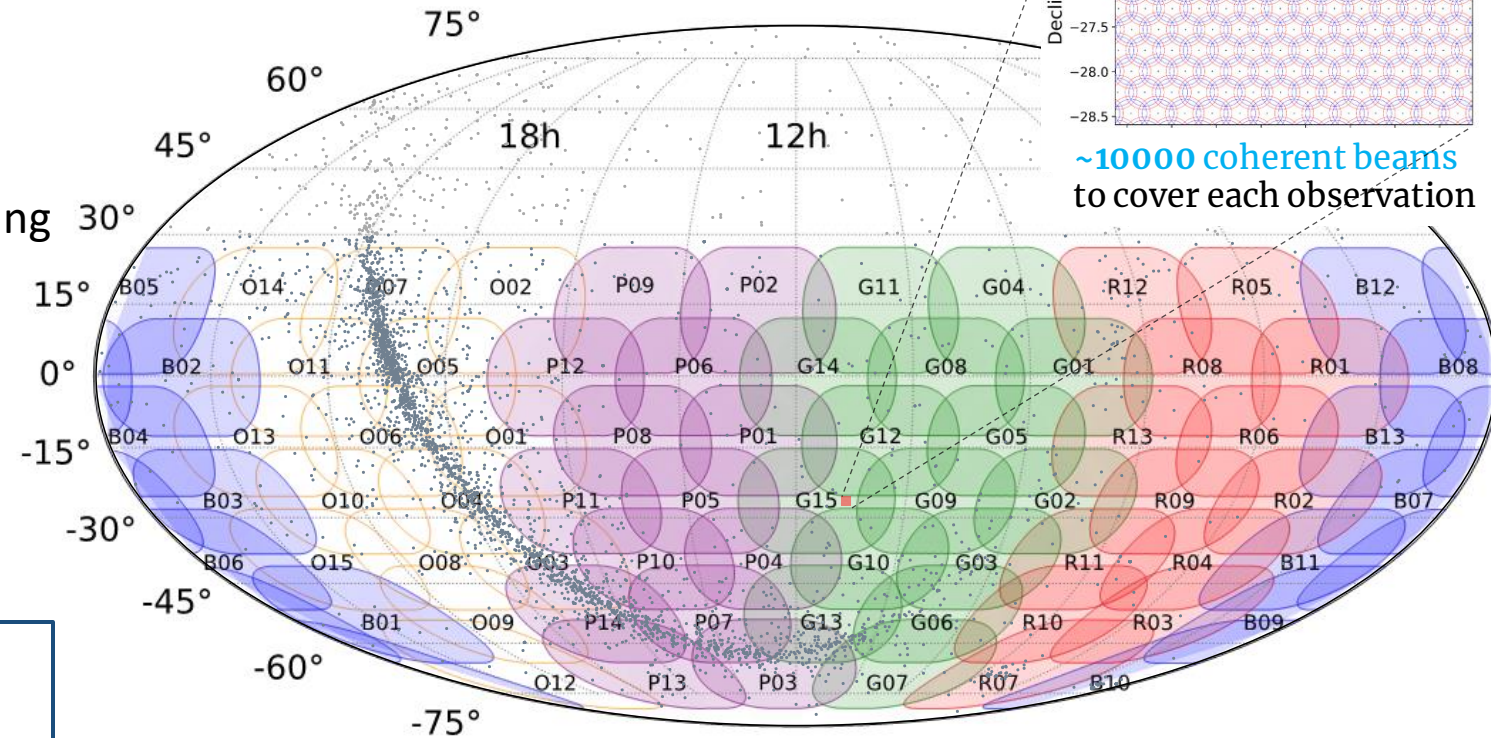
Cons of offline beamforming

- demands intensive computational resources
- poses significant I/O challenges

An example of the coherent tied-array beam tessellation



~ 10000 coherent beams to cover each observation



Sky coverage of 70 SMART observations

2018 2019 2020 2021 2023

requires > 10 years to complete the data processing with current processing software and available computing resources in Australia

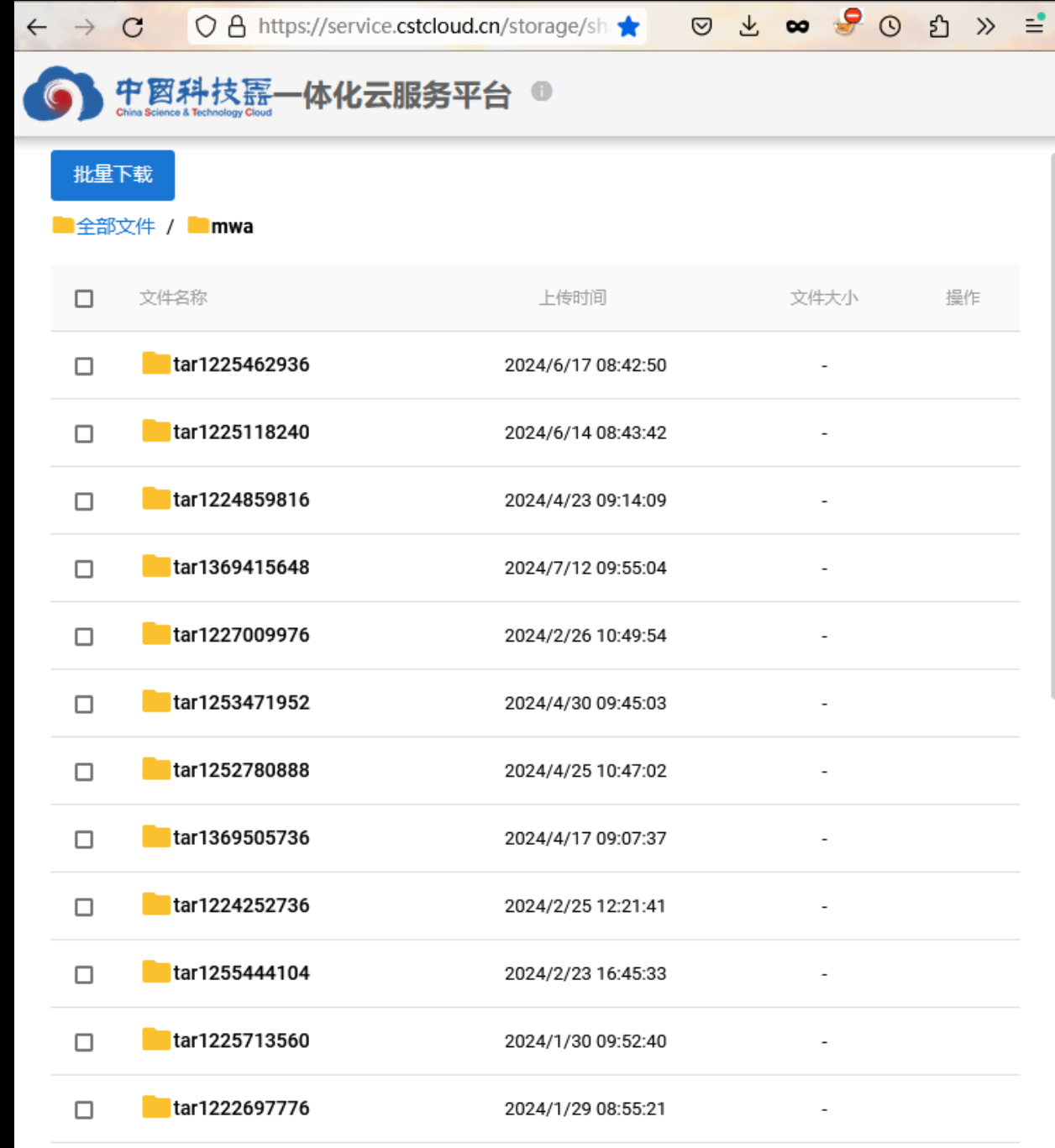
Transferring the voltage data to China

~120 MB/s from Perth to Beijing

So far have transferred **2.98 PB** (/3.28 PB)
MWA SMART survey data

51(/51) legacy observations (**1.78 PB**) &
15(/19) MWAX observations (**1.20 PB**)

Stored on cstcloud (object storage)



The screenshot shows the CSTCloud storage management interface. At the top, there's a navigation bar with the CSTCloud logo and the text '中国科技云一体化云服务平台'. Below this, there's a '批量下载' (Batch Download) button and a breadcrumb path '全部文件 / mwa'. The main content is a table listing files and folders. Each row has a checkbox, a file name (starting with 'tar'), an upload time, a file size (indicated by a dash), and an '操作' (Action) column.

☐	文件名称	上传时间	文件大小	操作
☐	tar1225462936	2024/6/17 08:42:50	-	
☐	tar1225118240	2024/6/14 08:43:42	-	
☐	tar1224859816	2024/4/23 09:14:09	-	
☐	tar1369415648	2024/7/12 09:55:04	-	
☐	tar1227009976	2024/2/26 10:49:54	-	
☐	tar1253471952	2024/4/30 09:45:03	-	
☐	tar1252780888	2024/4/25 10:47:02	-	
☐	tar1369505736	2024/4/17 09:07:37	-	
☐	tar1224252736	2024/2/25 12:21:41	-	
☐	tar1255444104	2024/2/23 16:45:33	-	
☐	tar1225713560	2024/1/30 09:52:40	-	
☐	tar1222697776	2024/1/29 08:55:21	-	

Beamforming and pulsar searching on CNIC ORISE cluster (东方超算)

7000 nodes in total

for each node:

- 1 CPU (32 cores), 4 DCU (FP32 13.41 TFLOPS + 16GB HBM2 Memory for each), 128GB Memory, 240GB SSD



Kaichao Wu, Zihan Zhang

Processing Pipeline

using the task control tool



scalebox
(CNIC)

github.com/kaichao/app-mwa

github.com/kaichao/scalebox

**Beamforming using
ROCm/HIP version vcstools**

github.com/fxzjshm/MWA-vcstools

Down-sample psrfits
by a factor of 4 in time

**FFT Pulsar search using
GPU version PRESTO**

Yukai Zhou



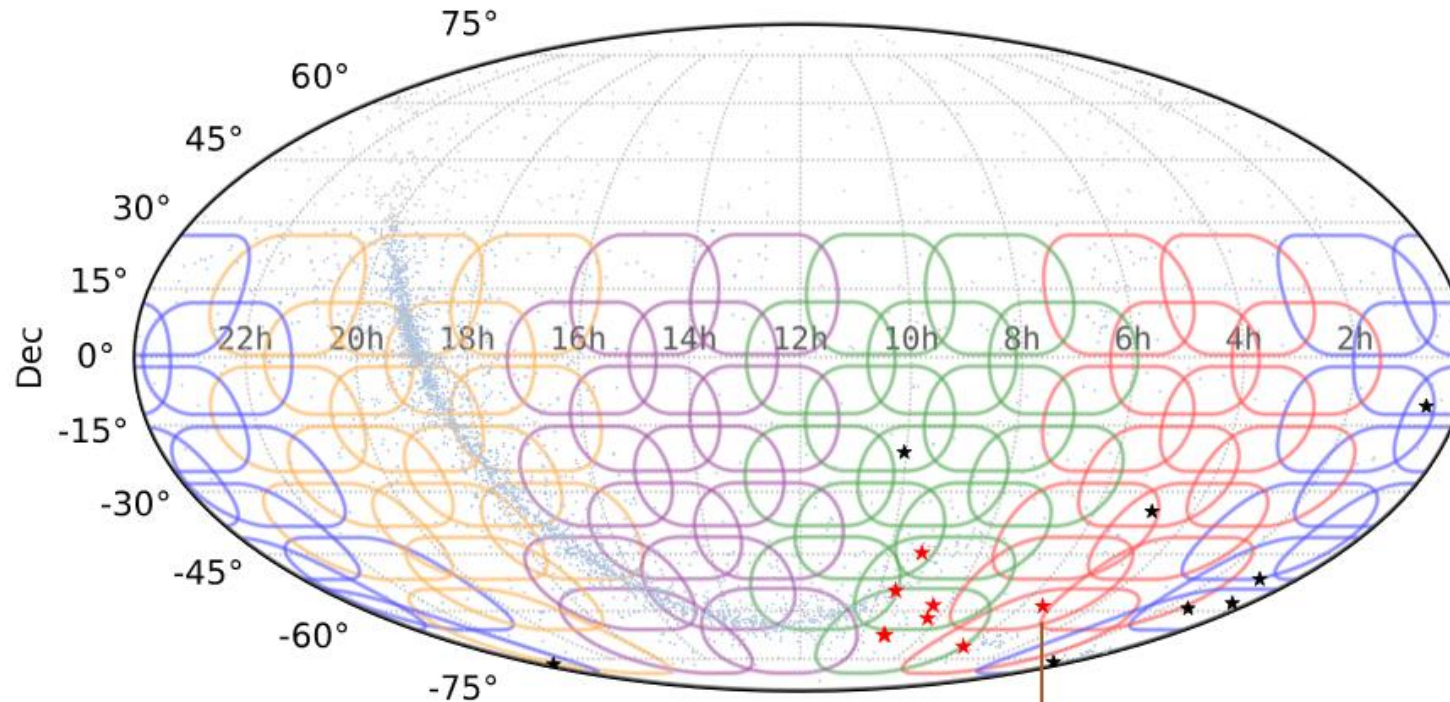
Original coherent beam-forming code
(NVIDIA CUDA)

AI tool to efficiently
sift candidates

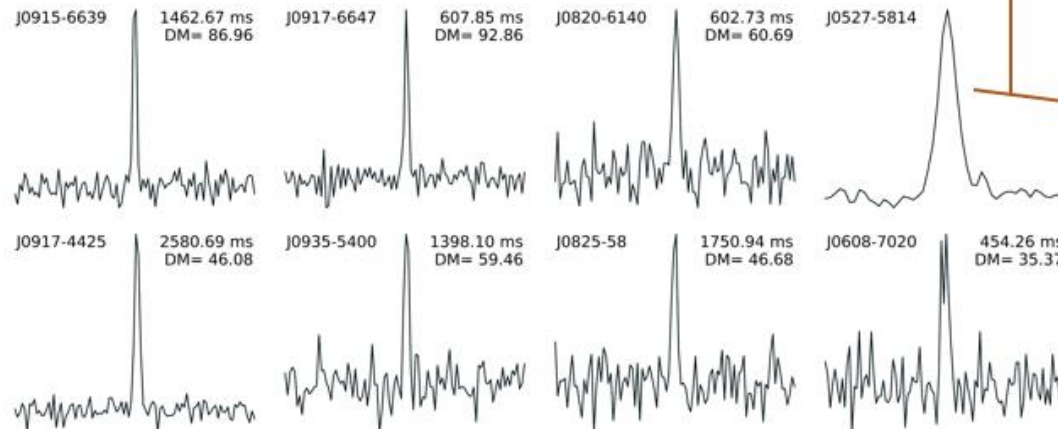
Qiuyang Fu



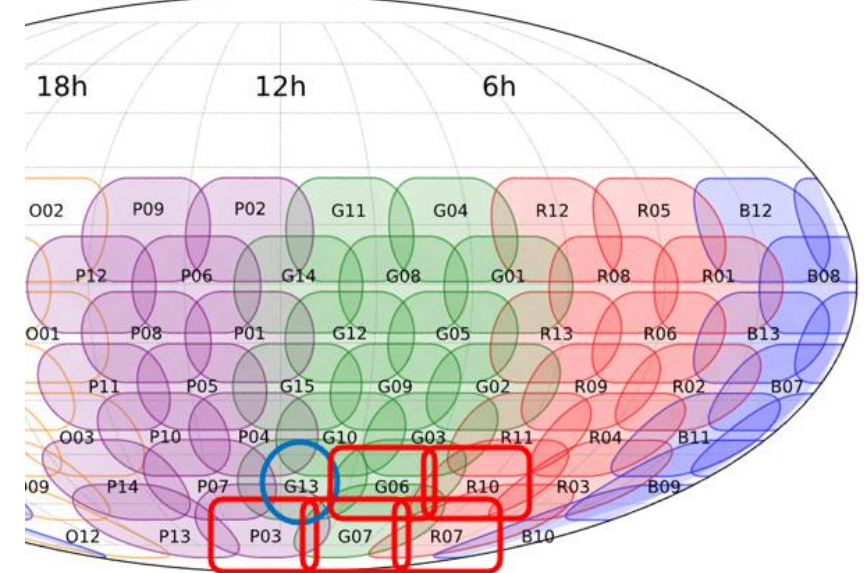
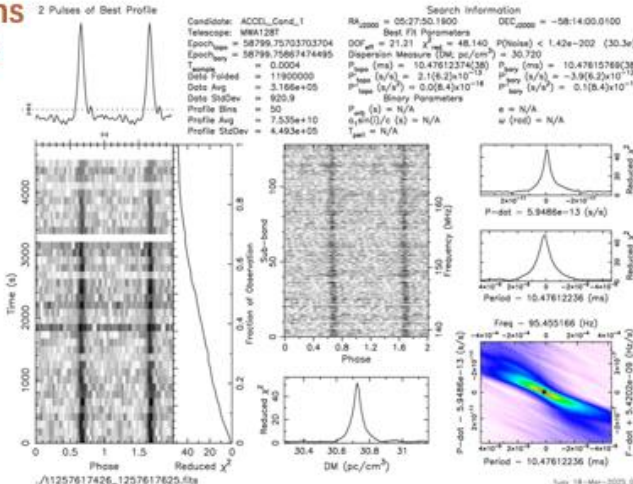
Results



- All cataloged pulsars (PSRCAT v2.61)
- ★ SMART new pulsars discovered using computing resources in Australia
- ★ SMART new pulsars discovered using computing resources in China



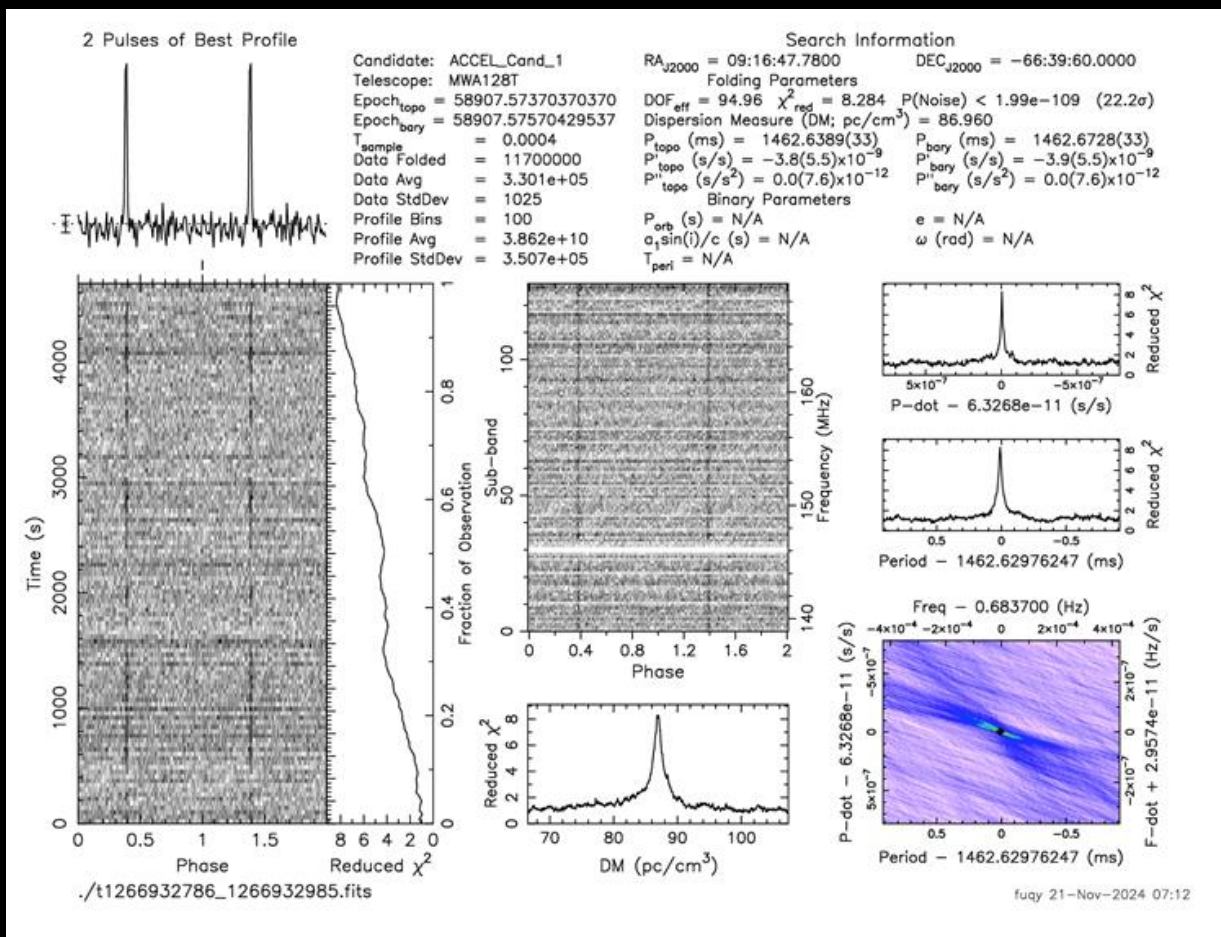
A new MSP
P0 10.48ms
DM 30.72



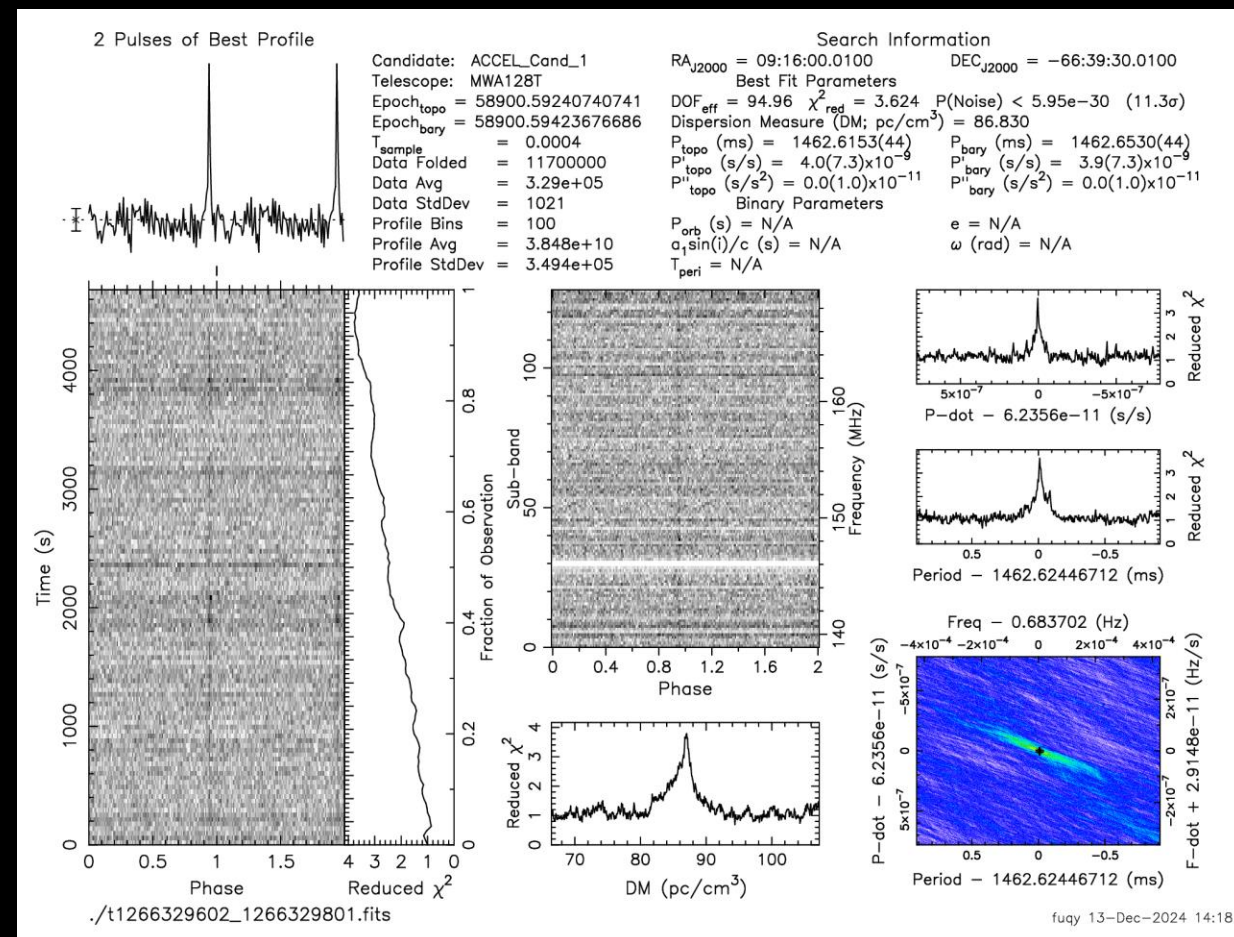
- 5 observations processed
- 1 observation currently processing

- **9** new pulsar discoveries (1 MSP)
- **102** known pulsars

Our new pulsar discoveries 01

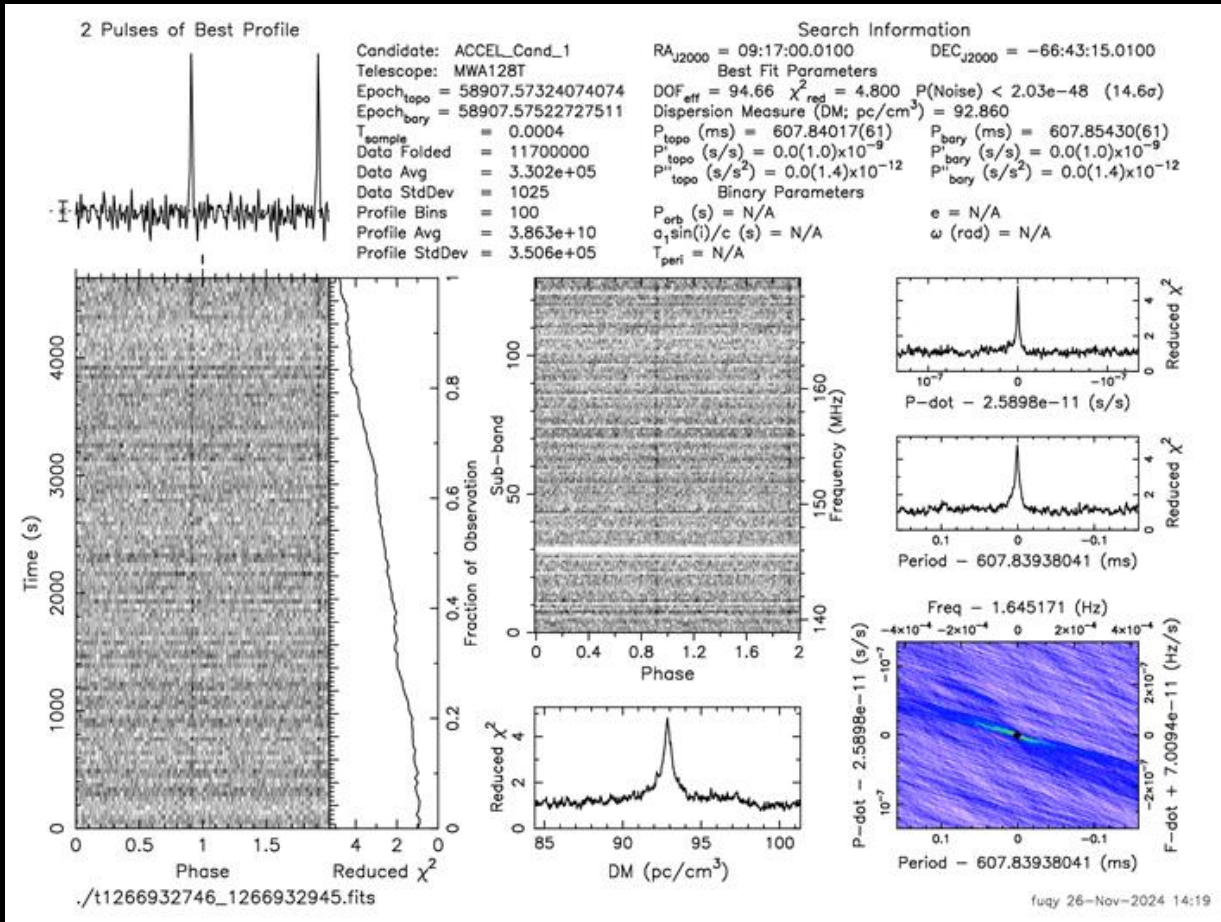


Obs: G07

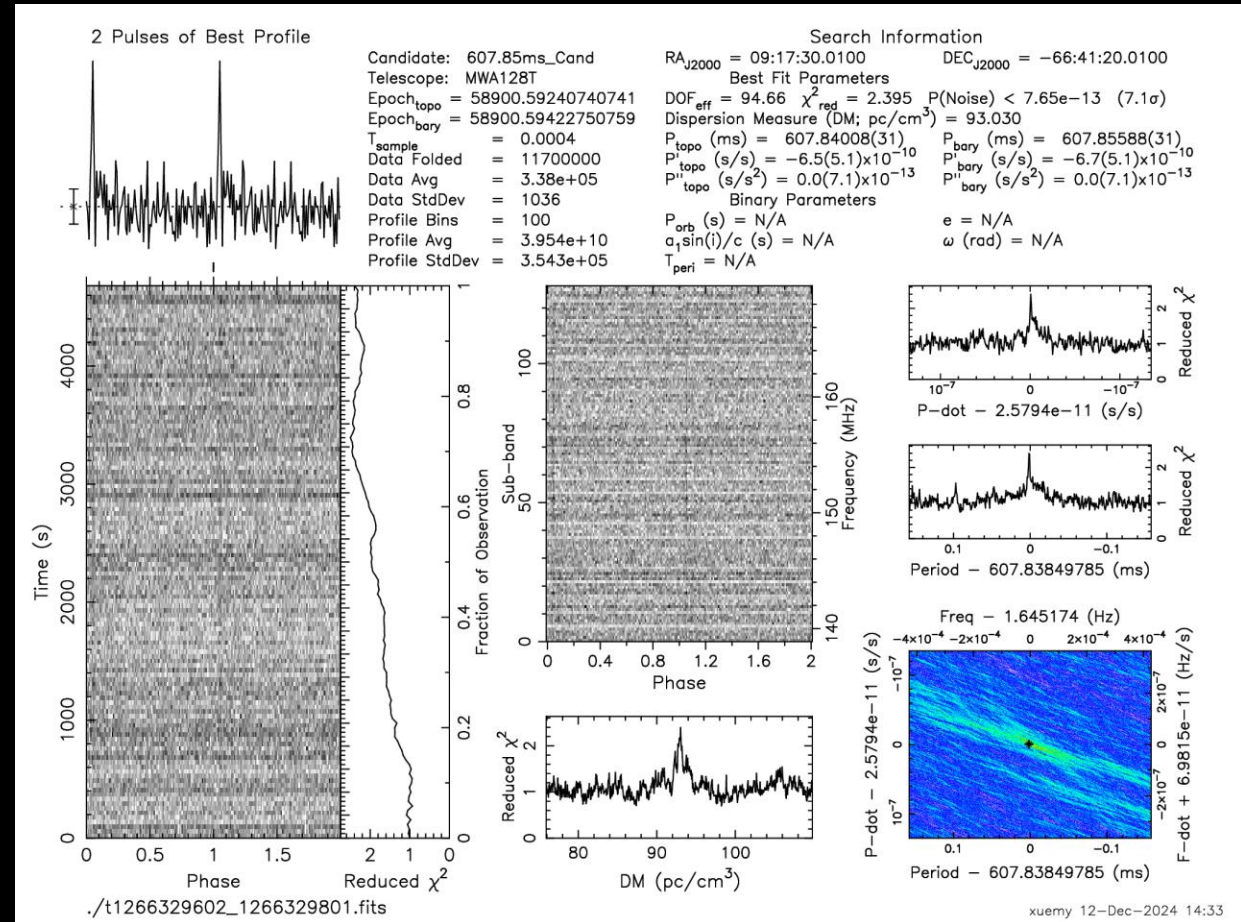


Obs: G06

Our new pulsar discoveries 02

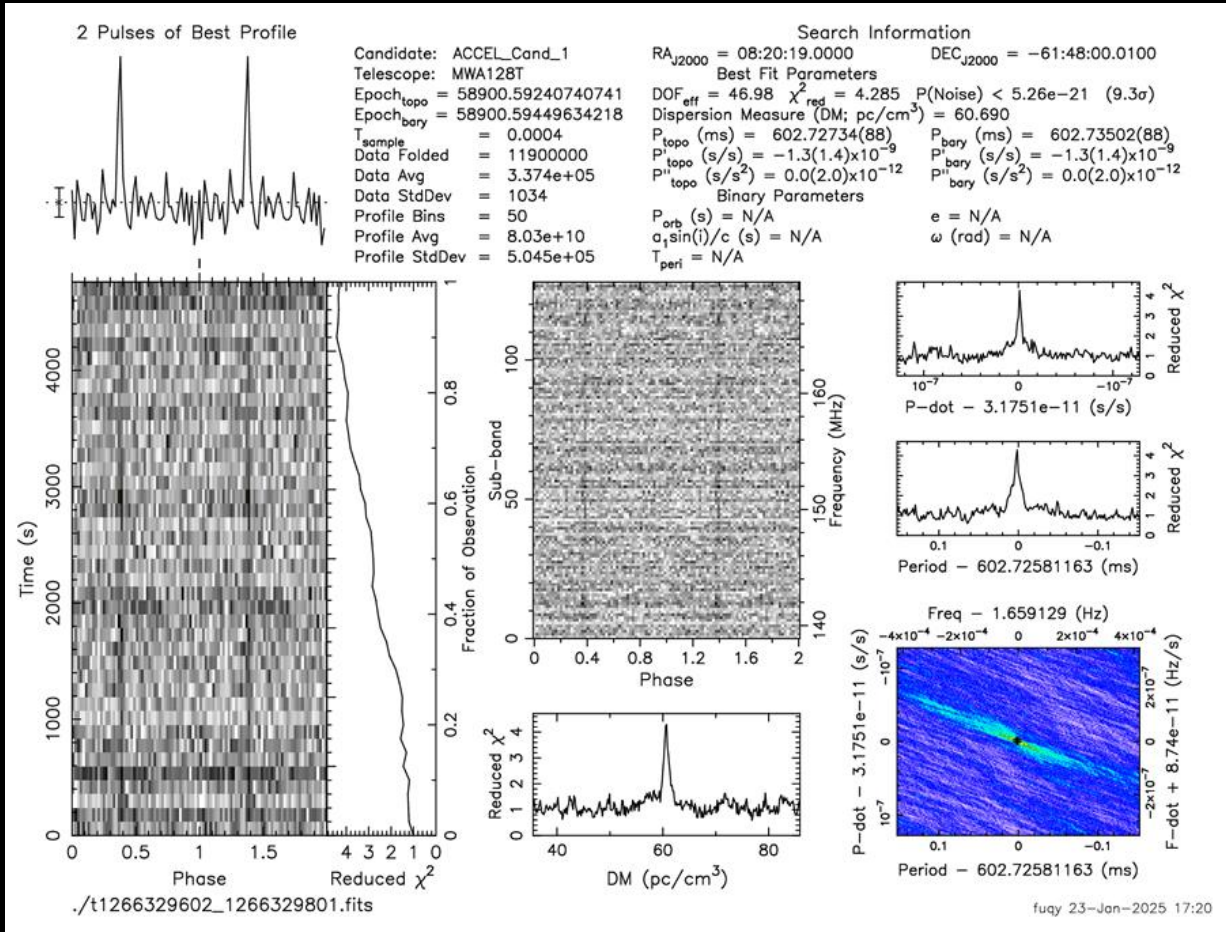


Obs: G07

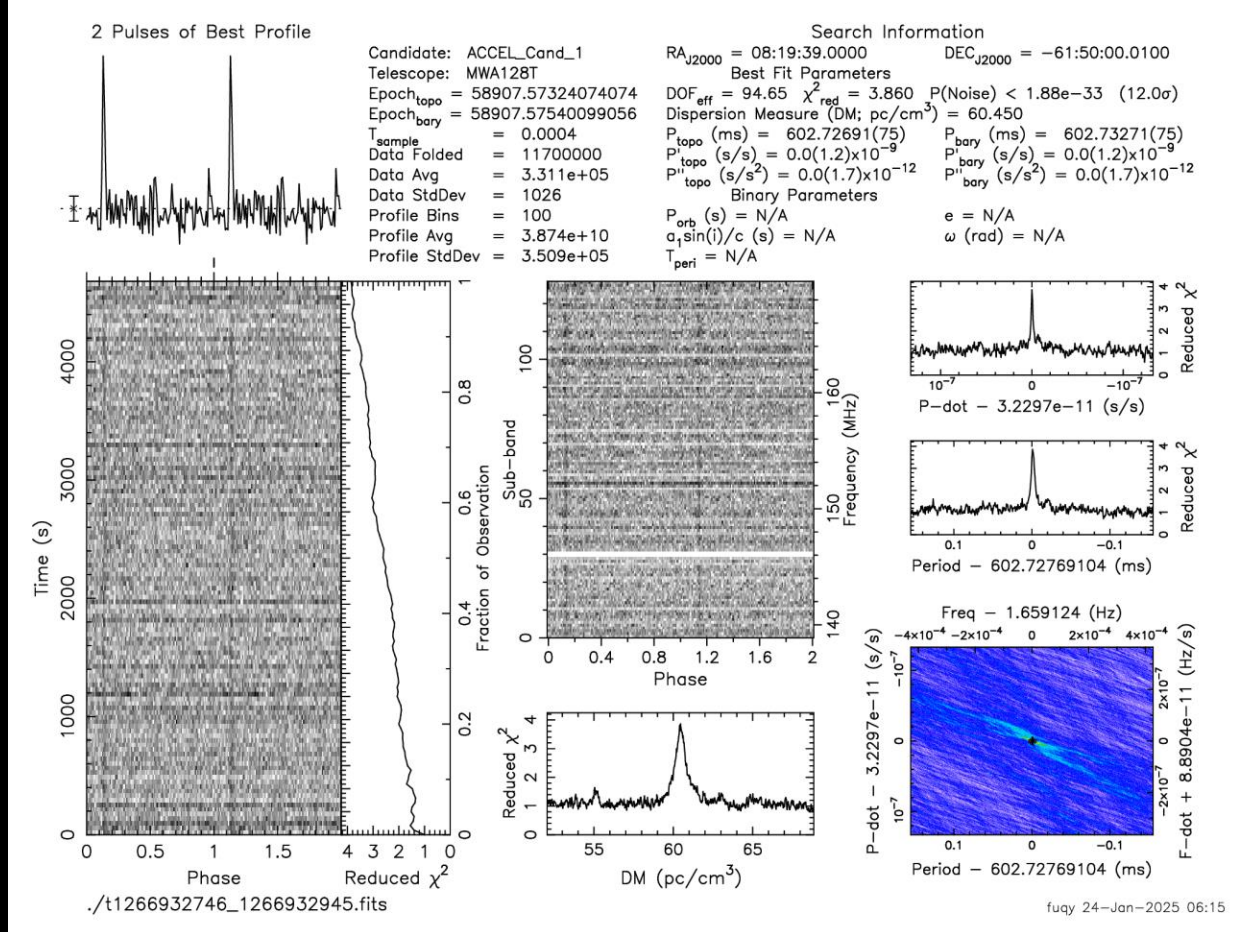


Obs: G06

Our new pulsar discoveries 03

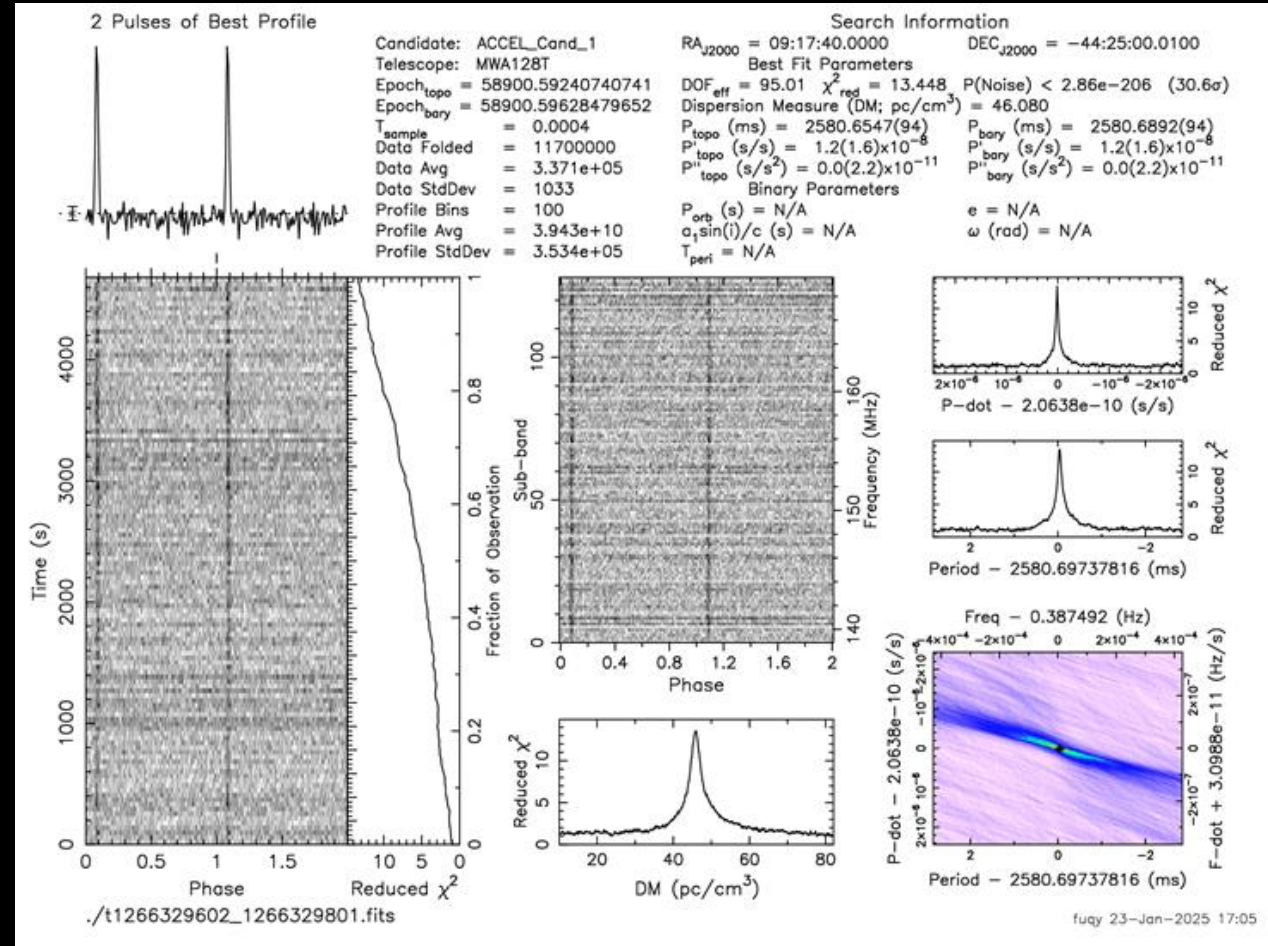


Obs: G06



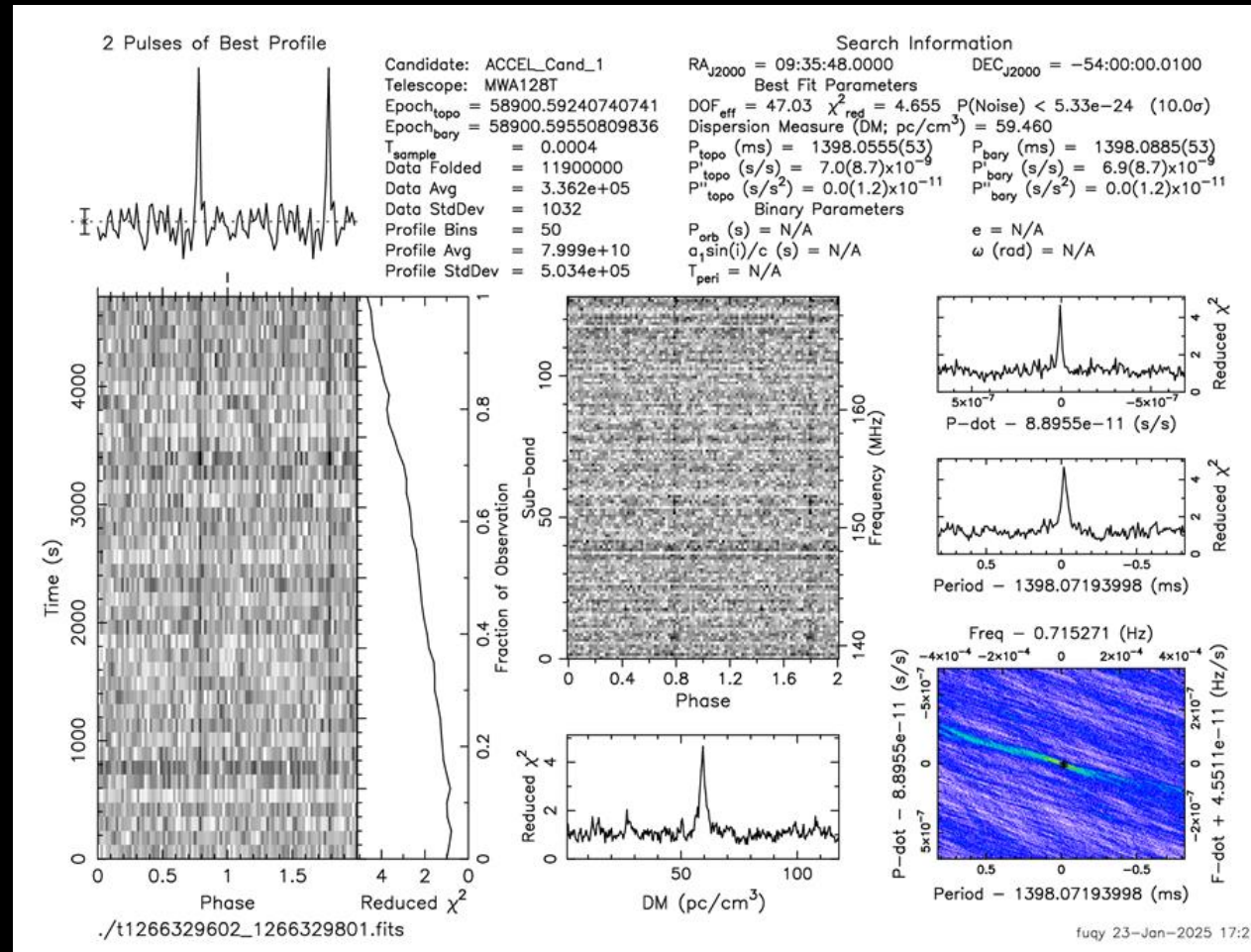
Obs: G07

Our new pulsar discoveries 04



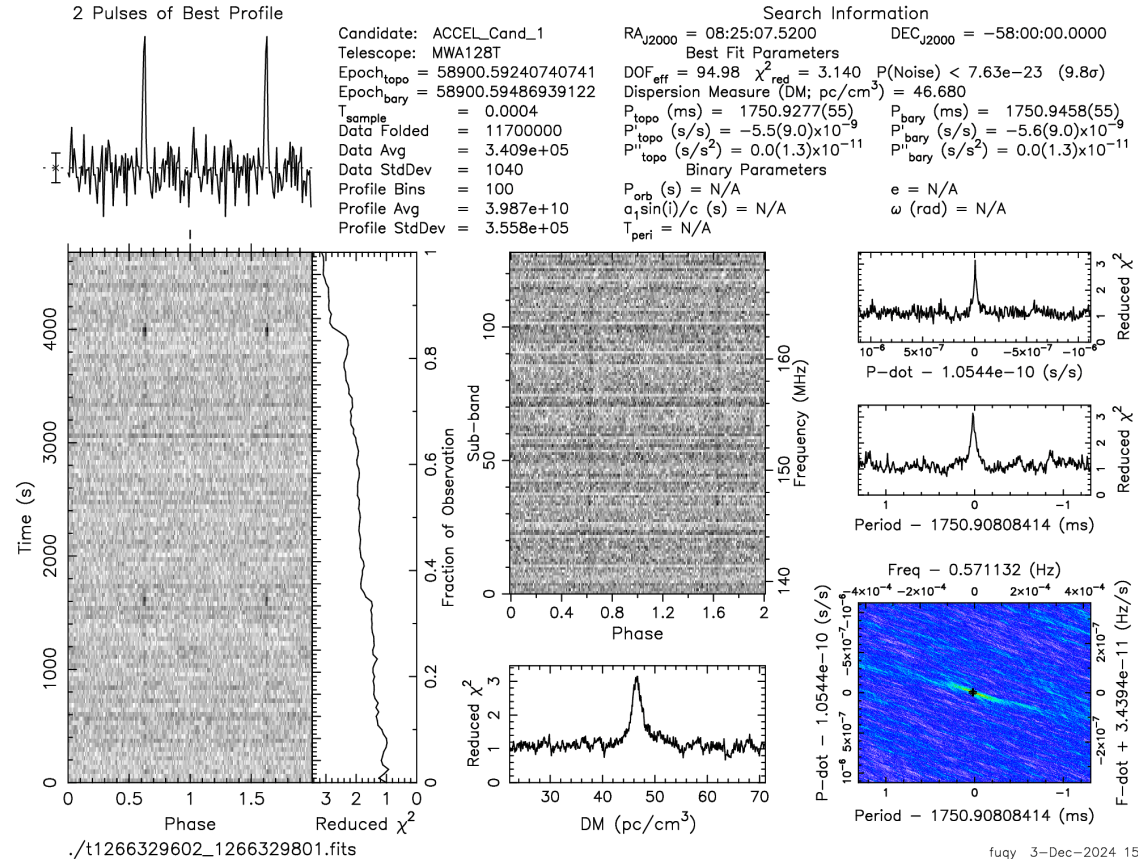
Obs: G06

Our new pulsar discoveries 05



Obs: G06

Our new pulsar discoveries 06

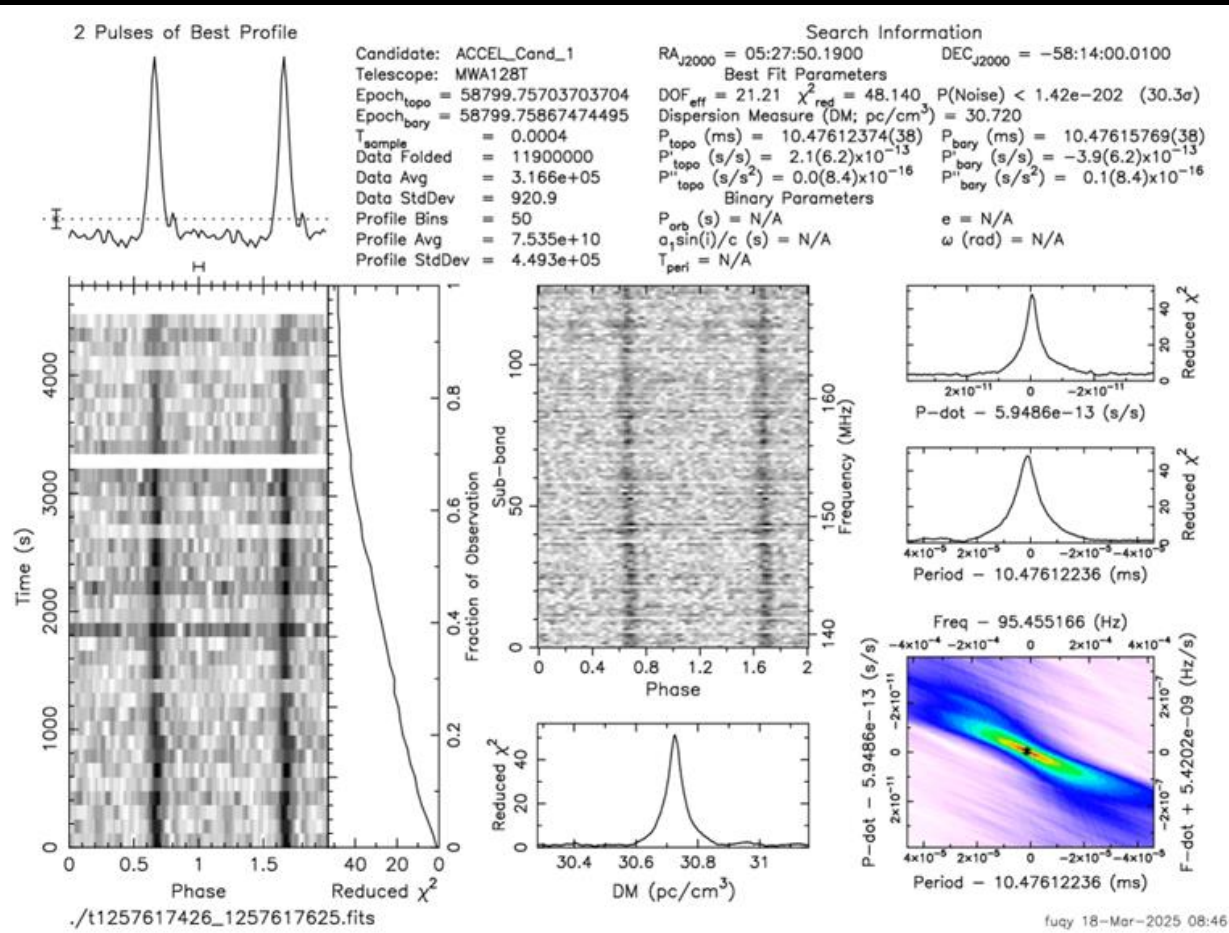


Obs: G06

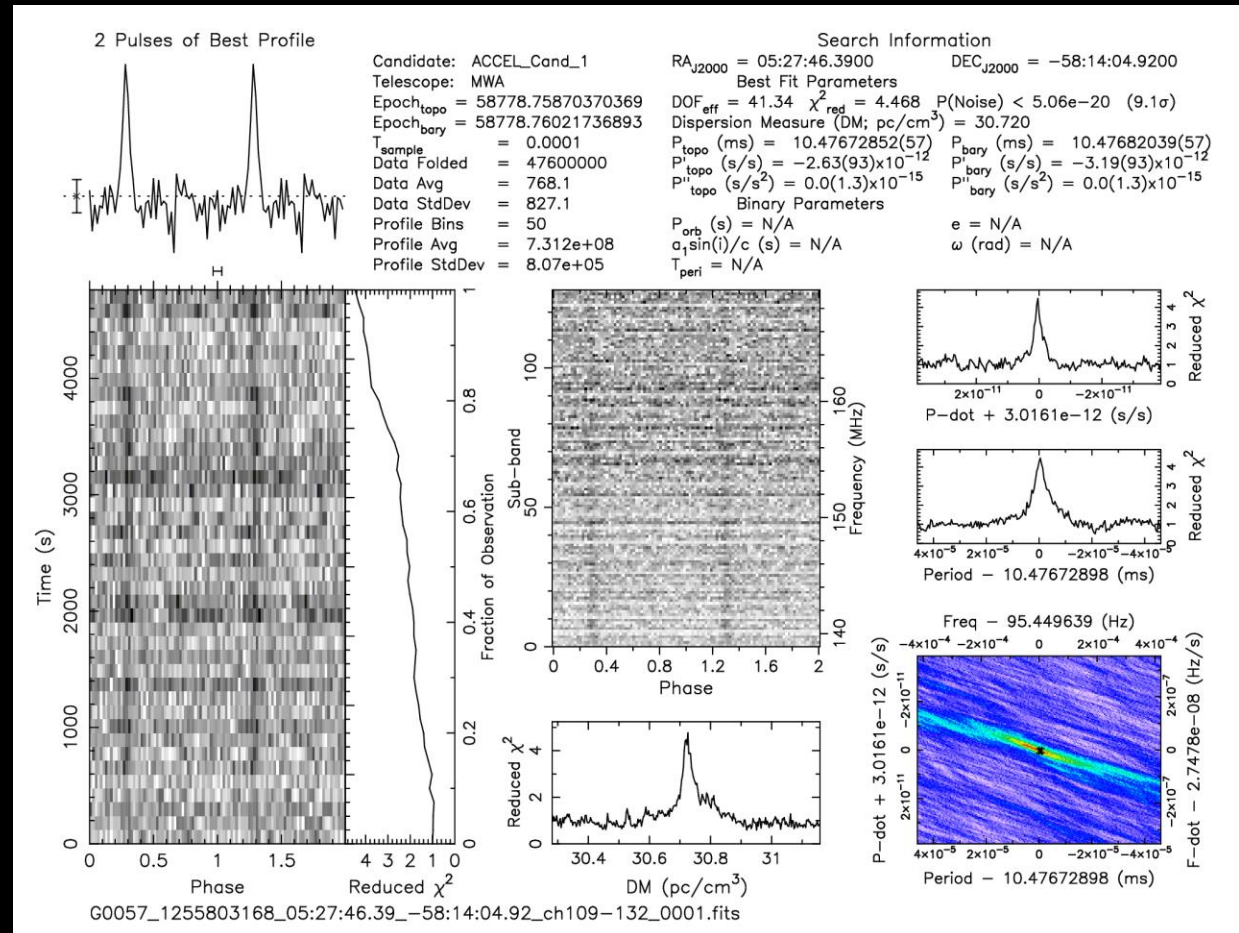
fuqy 3-Dec-2024 15:27

Our new pulsar discoveries 07

10.48ms MSP



Obs: R10



Obs: R07

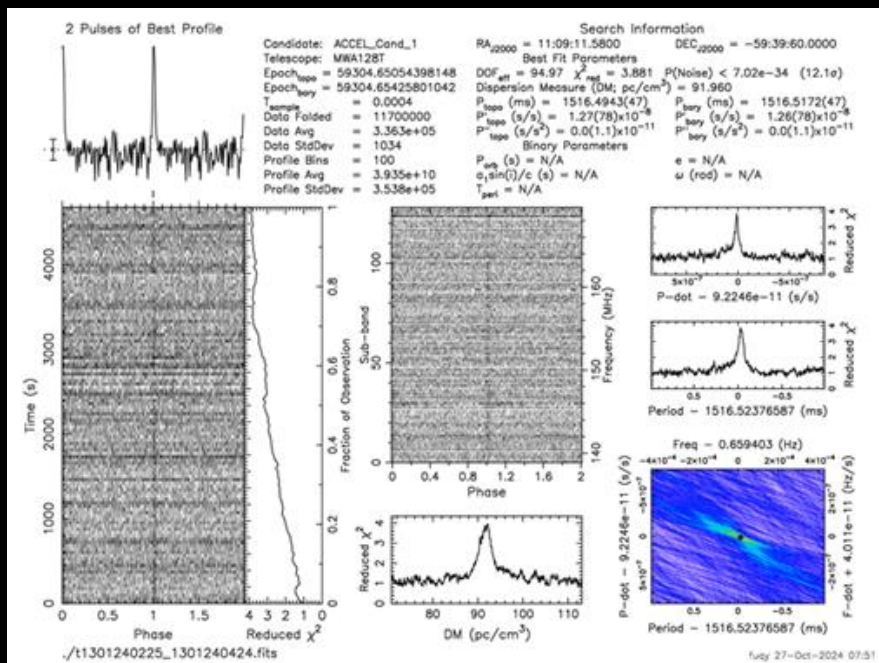
Figure 1 displays the search results for the three best candidates. Each panel includes the following information:

- Top Left:** Two pulses of the best profile.
- Top Right:** Search information for the candidate, including RA₂₀₀₀, DEC₂₀₀₀, epoch, and fit parameters.
- Bottom Left:** A 2D heatmap showing the distribution of $\dot{P}$ (y-axis) versus $\dot{F}$ (x-axis) for the candidate. The color scale represents the number of events, ranging from 0 to 4000. Marginal histograms are shown on the right and bottom.
- Bottom Right:** A 2D heatmap showing the distribution of Phase (y-axis) versus Time (x-axis) for the candidate. The color scale represents the number of events, ranging from 0 to 4000. Marginal histograms are shown on the right and bottom.

The three candidates are:

- ACCEL_Cand_2:** RA₂₀₀₀ = 14:55:59.9000, DEC₂₀₀₀ = -68:43:39.5000, Epoch₂₀₀₀ = 59304.65345392039, $\dot{P}$ (ms) = 0.0004, $\dot{F}$ (s/s) = 1.22(40) × 10⁻¹⁰, $\dot{P}$ (s/s) = 3.379e+05, $\dot{F}$ (s/s) = 0.0(5.5) × 10⁻¹⁴, $\dot{P}$ (s/s) = 1052, $\dot{F}$ (s/s) = 100, $\dot{P}$ (s/s) = 4.027e+10, $\dot{F}$ (s/s) = 6.332e+05.
- ACCEL_Cand_2:** RA₂₀₀₀ = 11:41:07.0000, DEC₂₀₀₀ = -65:45:19.1000, Epoch₂₀₀₀ = 59304.65383641365, $\dot{P}$ (ms) = 0.0016, $\dot{F}$ (s/s) = 1.22(40) × 10⁻¹⁰, $\dot{P}$ (s/s) = 3.381e+05, $\dot{F}$ (s/s) = 0.0(9.3) × 10⁻¹³, $\dot{P}$ (s/s) = 523.2, $\dot{F}$ (s/s) = 100, $\dot{P}$ (s/s) = 9.972e+09, $\dot{F}$ (s/s) = 8.956e+04.
- ACCEL_Cand_2:** RA₂₀₀₀ = 12:02:28.3000, DEC₂₀₀₀ = -58:20:33.6000, Epoch₂₀₀₀ = 59304.65445981452, $\dot{P}$ (ms) = 0.0016, $\dot{F}$ (s/s) = 1.22(40) × 10⁻¹⁰, $\dot{P}$ (s/s) = 3.381e+05, $\dot{F}$ (s/s) = 0.0(6.1) × 10⁻¹³, $\dot{P}$ (s/s) = 521.5, $\dot{F}$ (s/s) = 100, $\dot{P}$ (s/s) = 9.972e+09, $\dot{F}$ (s/s) = 8.956e+04.

PSRJ	RAJ (hms)	DECJ (dms)	P0 (s)	DM (cm ⁻³ pc)
J1107-5947	11:07:58.7	-59:47:04	1.516531	158.40



Summary & Future works

- Up till now, we discovered **9** new pulsars (include **1 MSP**) from MWA SMART survey data, more than half of the total 17 new pulsars discovered by the MWA
- A strong **showcase** of pulsar search in low-frequency array data
 - intercontinental voltage data **transfer**
 - efficient post hoc processing using **remote** computing facilities
- In the future, we will keep on processing MWA SMART data
 - apply single pulse search & FFA search
 - more new pulsar discoveries
 - reference data set for SKA-Low pulsar survey