Proceedings on Development of **PRESTO (GPU Jerksearch pipeline).**

PULSEJET (PULsar SEarching with Jerksearch using Efficient Template banking)

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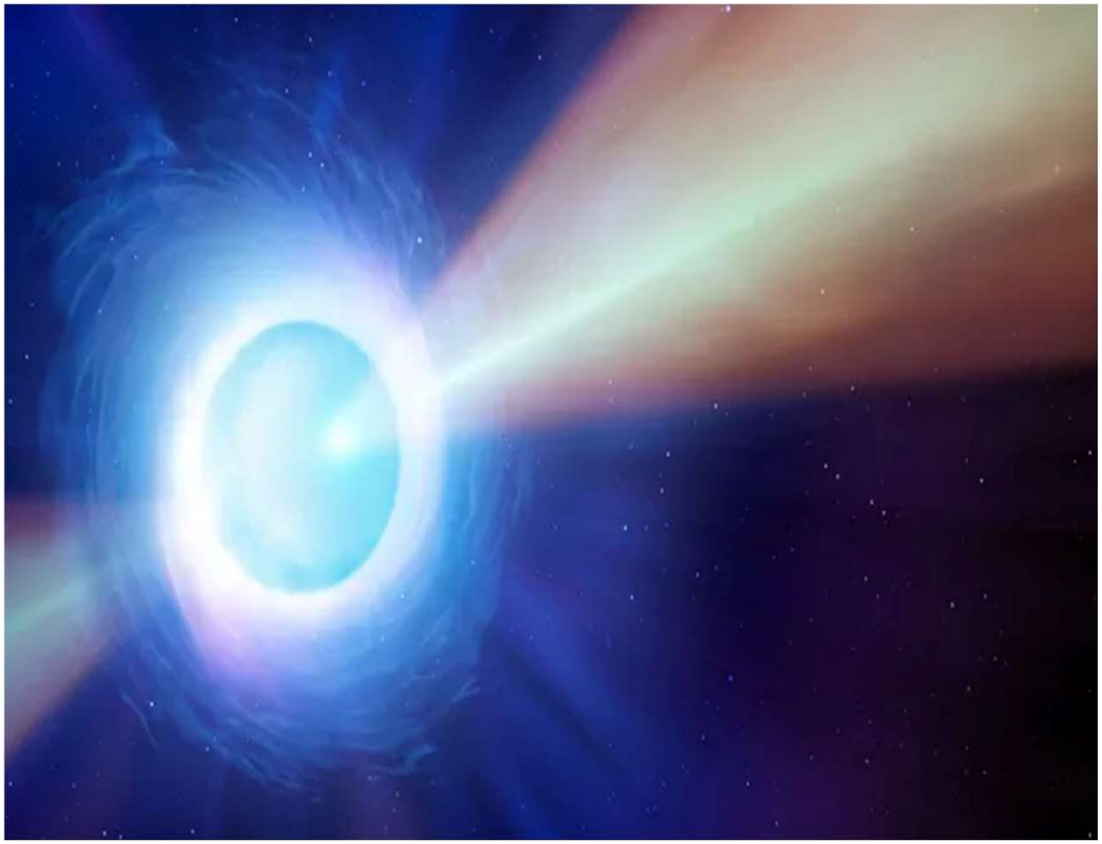
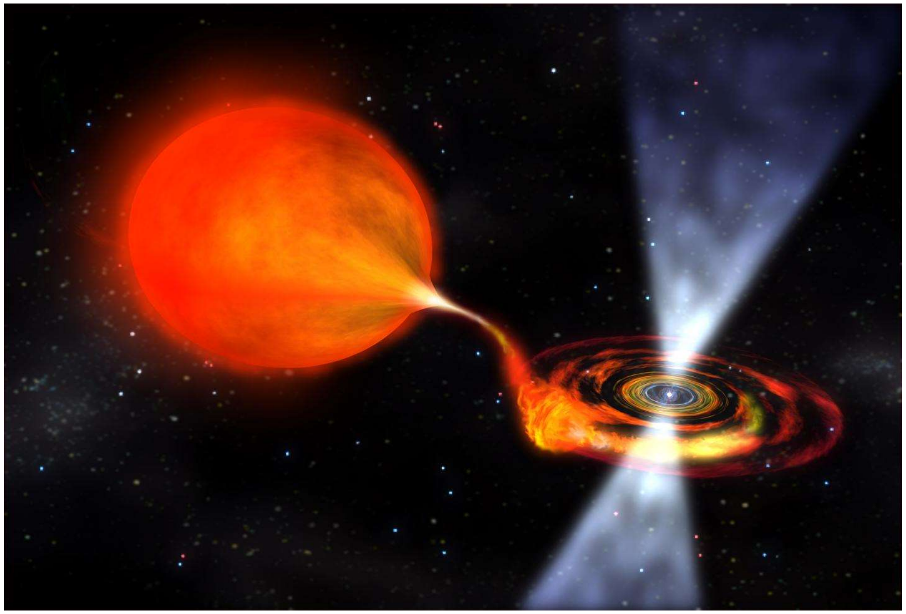
Pulsars

- Fast Rotating, highly magnetized neutron stars
- Cosmic "*Lighthouses*": Radio Emission from magnetic poles
- Misaligned magnetic and spin axis
- One pulse per rotation along line of sight towards either beam
- The time taken for one rotation i.e the interval between two pulses is called the spin period.



What makes pulsars interesting?

- Astrophysical Laboratories
  - Test of matter at ultra high densities.
  - Tests of relativity.
- Gravitational wave detection
  - pulsar timing arrays.
- Probing the interstellar medium
- Magnetospheres and particle acceleration.



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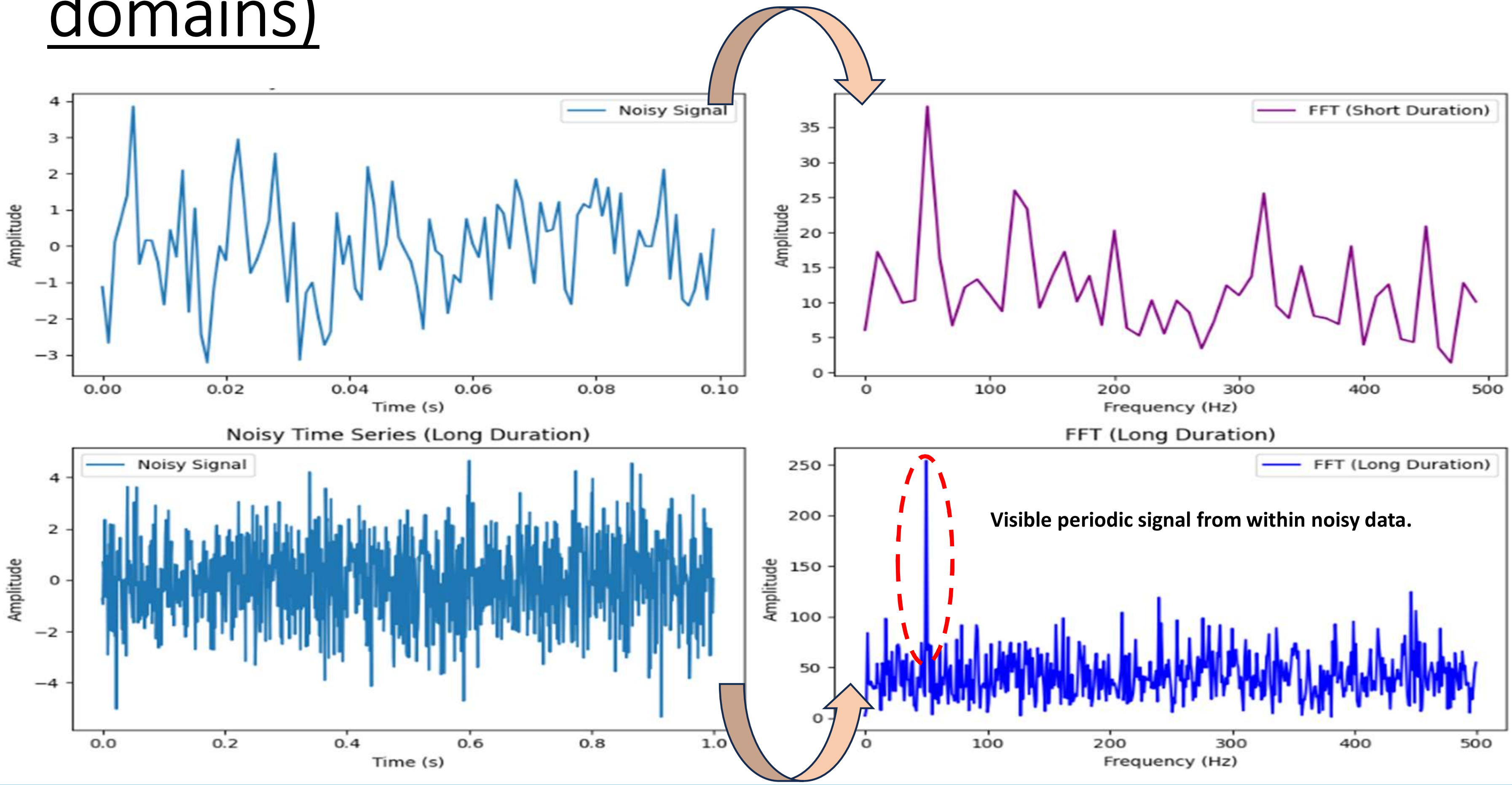
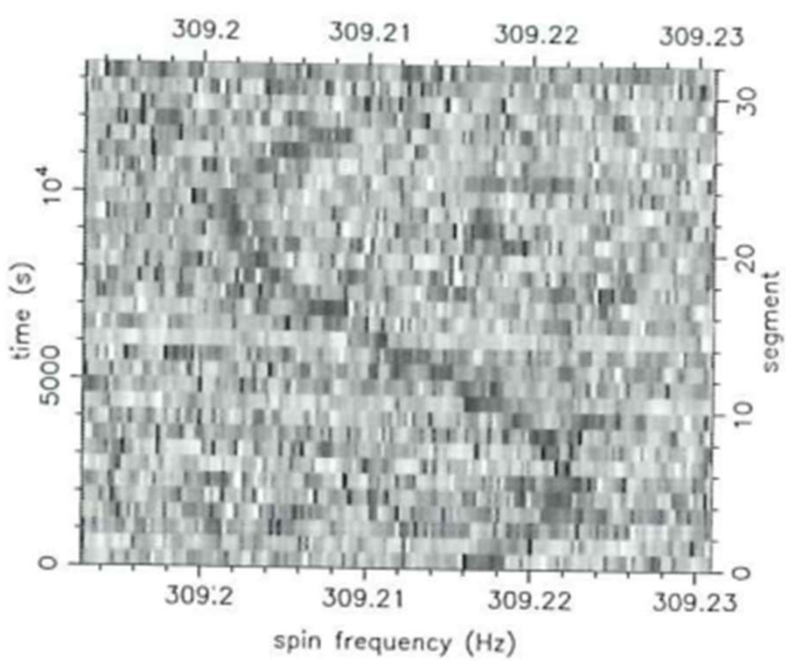
Pulsar Searches (The time domain and frequency domains)



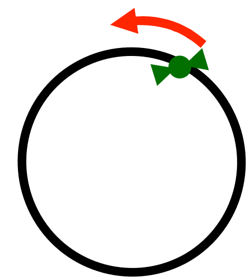
Binary systems

If the pulsar is in a binary the rotational period will change slightly during the course of the observation.

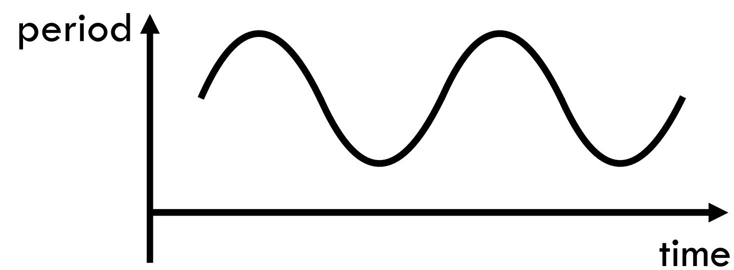


Equation for Doppler shift:

$$P'(t) = P_0(1 + v(t)/c)$$



Evolution of the period in a circular orbit:

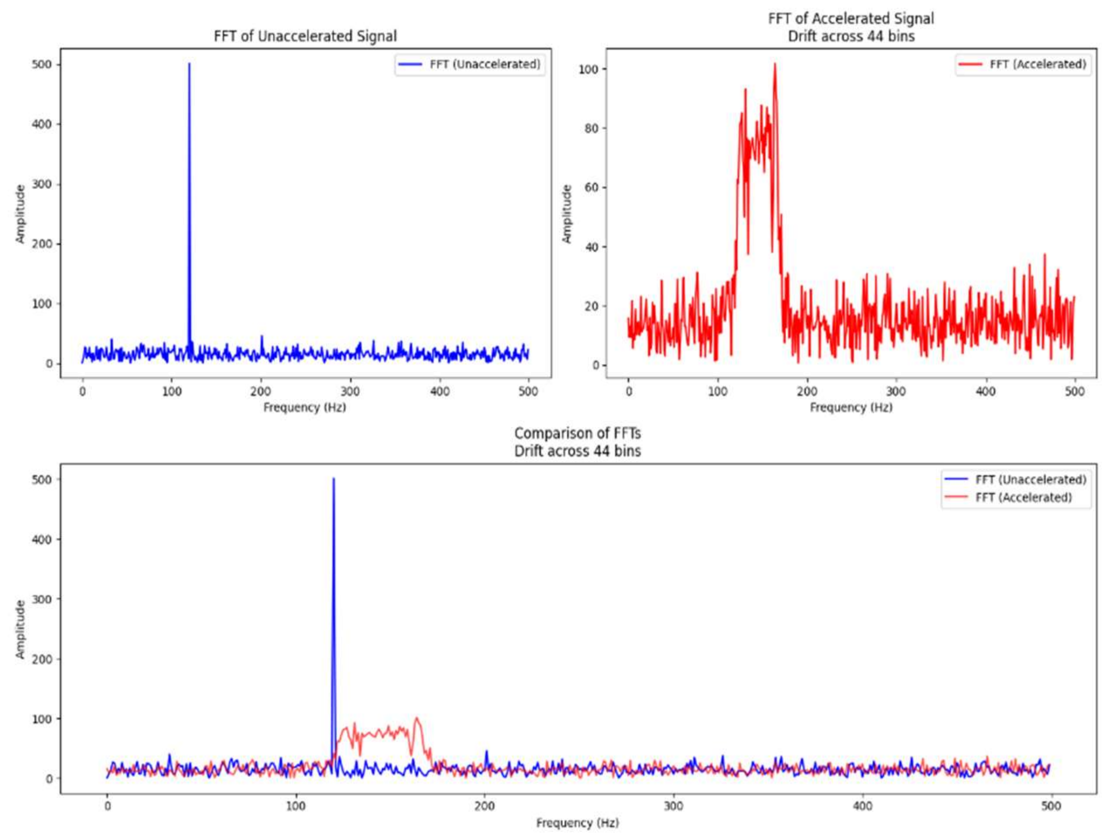


Acceleration Search (PRESTO implementation 2002)

- Designed to detect binary pulsars whose signals are affected by constant acceleration.
- If a is acceleration, f is spin frequency , h is the no. of harmonic, T is observation time and c is speed of light.
- Typically for observations where observing time $\boldsymbol{T_{obs} \leq P_{orb}/10}$

$$\mathbf{a} = \boldsymbol{zc/hfT^2}$$

Where ‘**z**’ is the number of Fourier bins in which the power has drifted during the course of the observation.



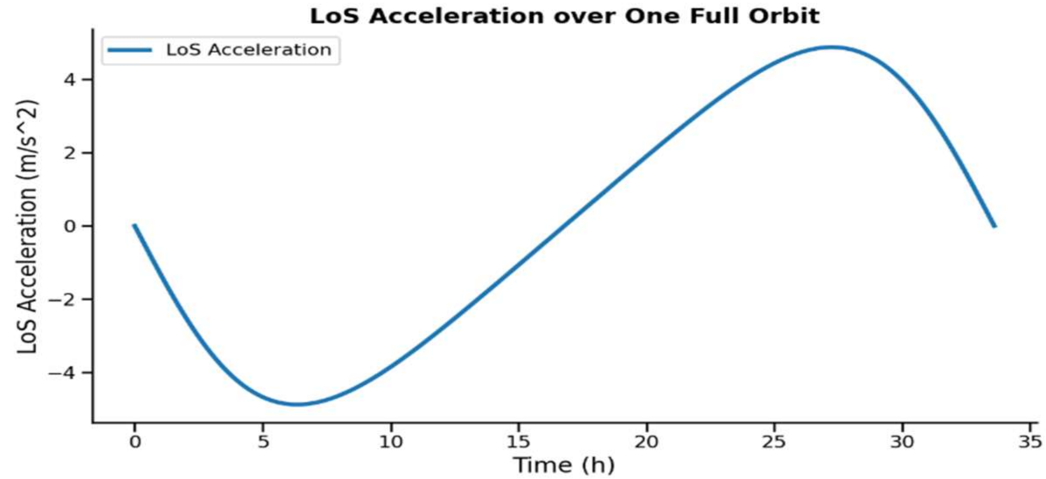
Jerk search (PRESTO implementation 2018)

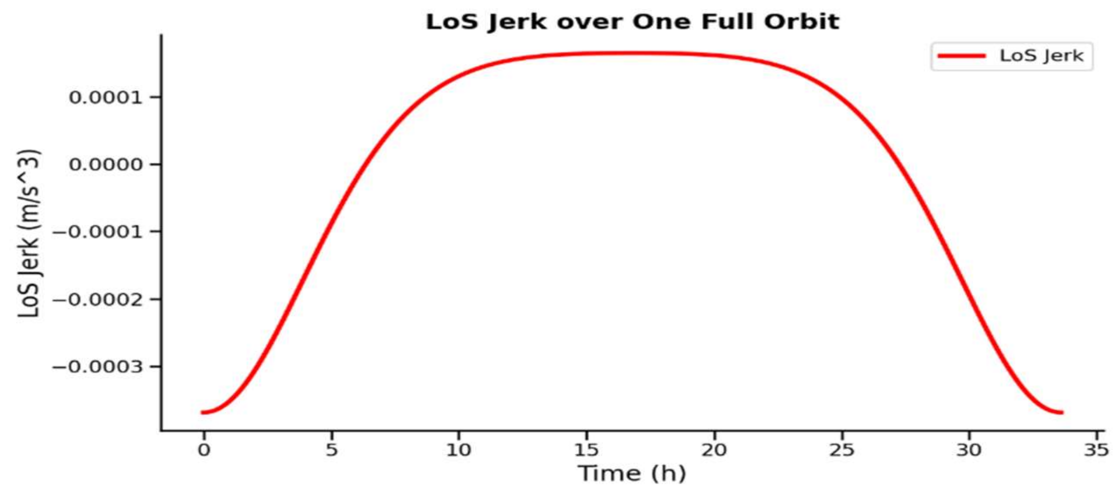
- Jerk search approximates a constant jerk with linearly varying acceleration.
- A constant jerk corresponds to a constant second time derivative of the frequency

$$w = z' = f''T^3$$

Where ‘w’ is the number of fourier bin derivatives which the power has scattered over.

- Significantly improves performance of binary searches for $T_{obs} \sim 0.05 - 0.15\, P_{orb}$





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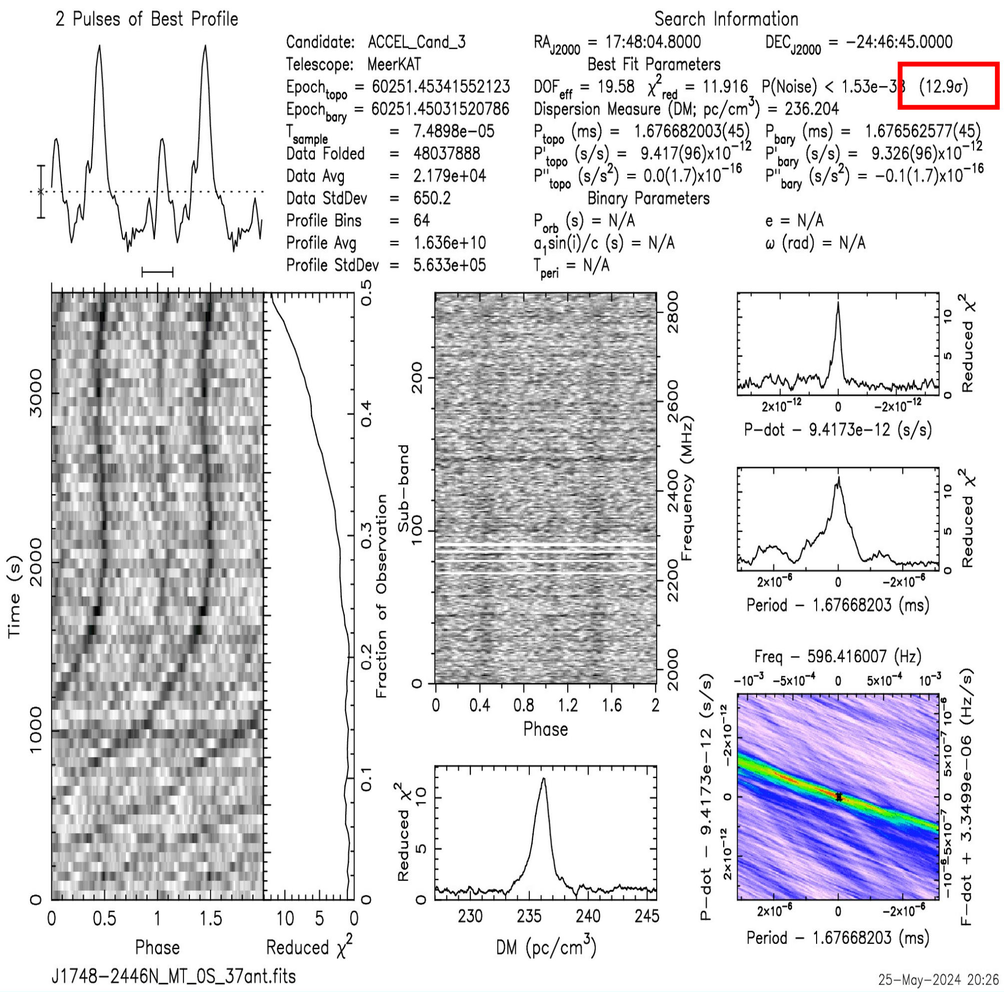
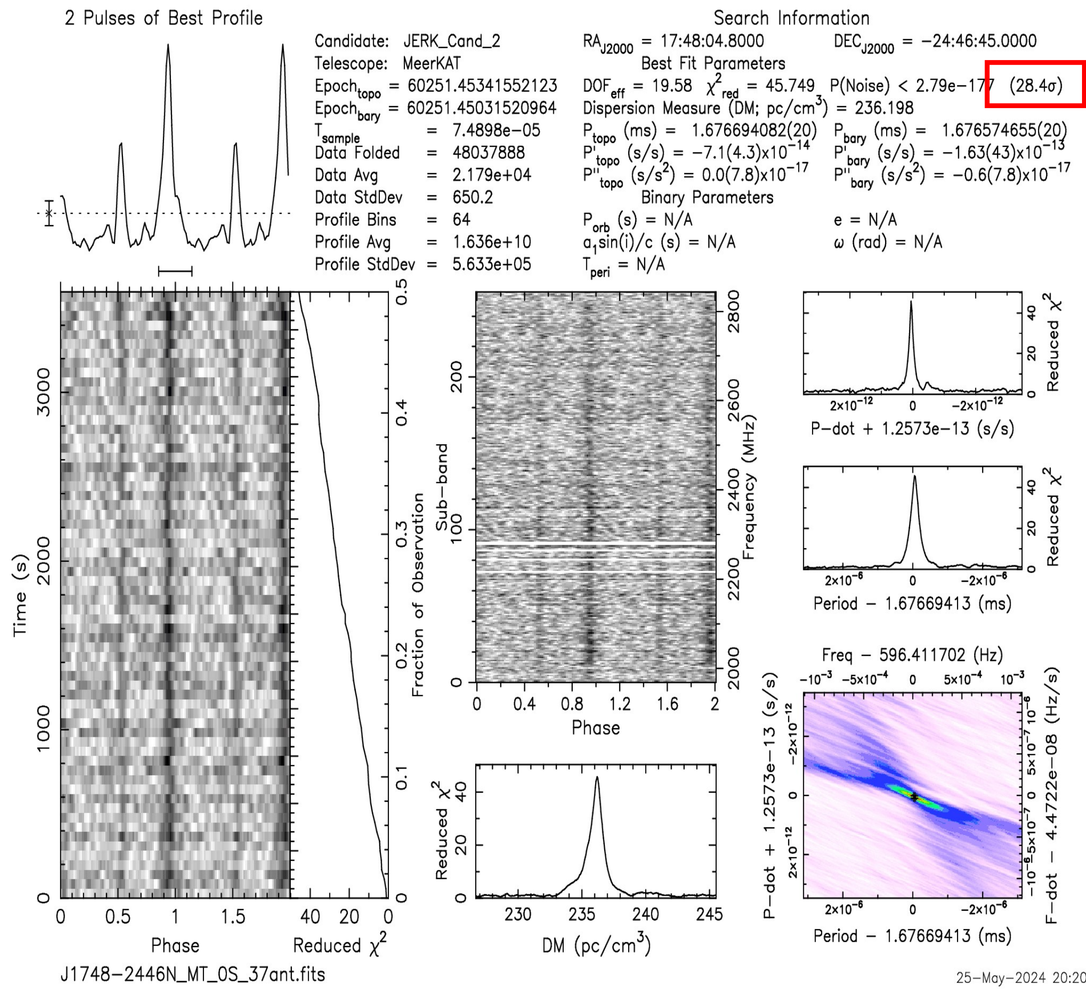
Profiles of J1748-2446 O

Accelsearch



Jerksearch



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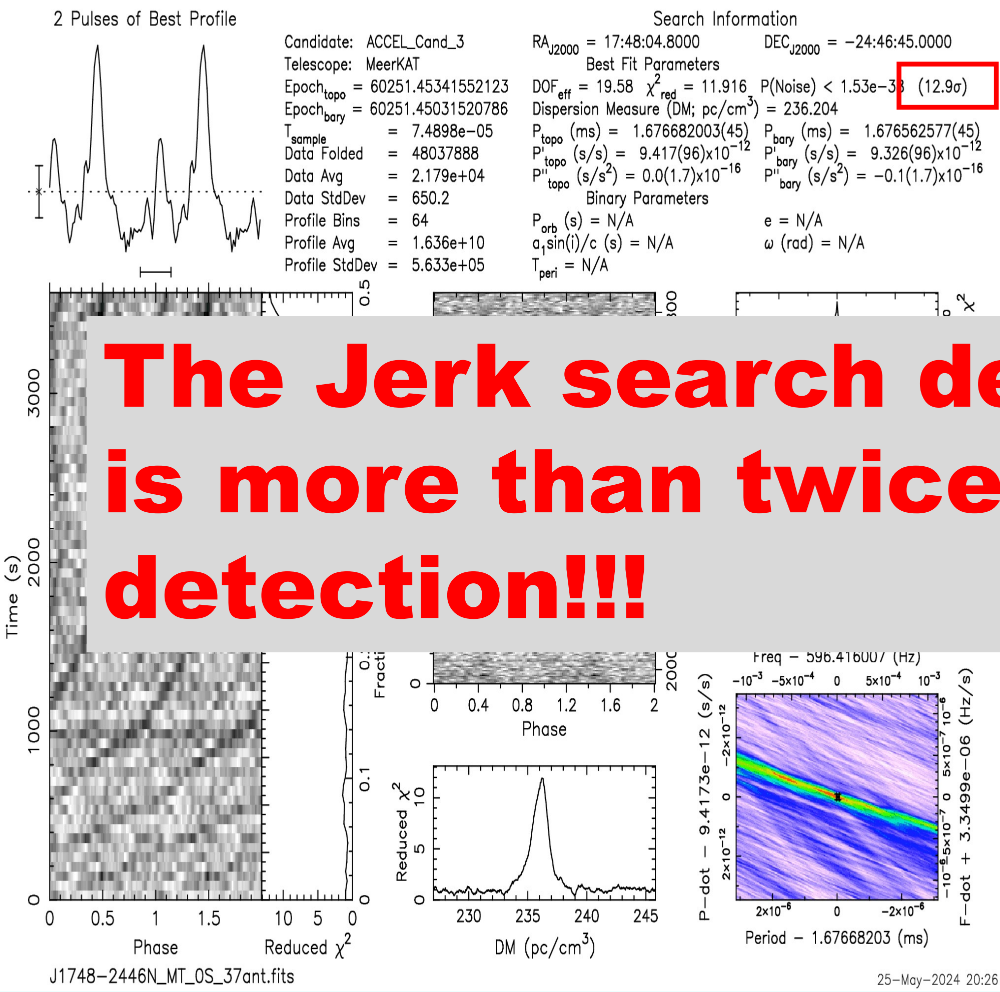
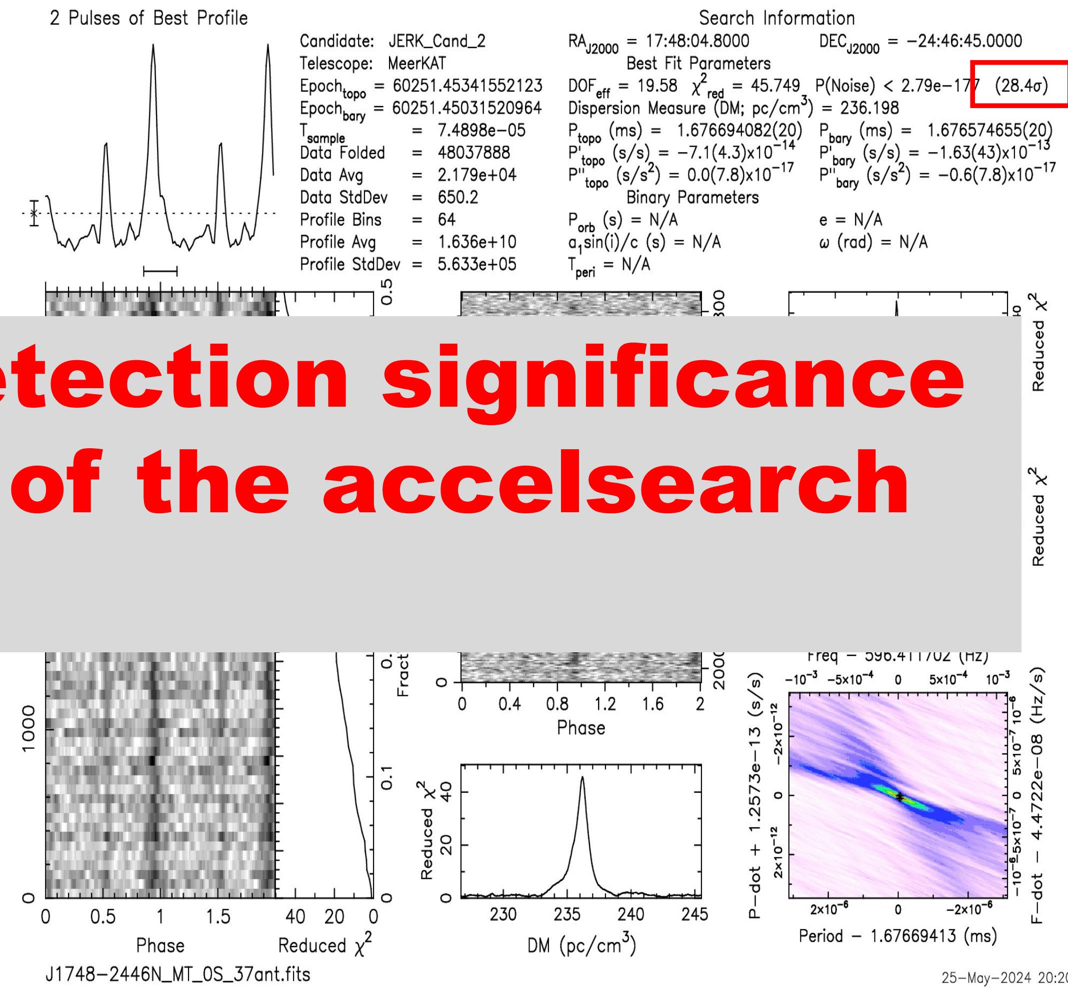


Jerksearch



The Jerk search detection significance is more than twice of the accelsearch detection!!!

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Motivation

- Pulsar searching is a super computationally intensive, highly iterative process.
- The magic of pulsar searching lies in the algorithms that perform periodicity searches in radio data.
- These Periodicity searches are highly iterative processes which are very well suited to be performed by GPU’s.
- I wanted to improve performance of existing Jerksearch codes by developing a GPU version of it and also improve basic performance of the algorithms itself.

Time domain searches vs Frequency domain searches

Frequency domain searches

- Recovers the power lost due to doppler effect by combing through nearby Fourier bins corresponding to the observed frequency of the signal.

  PRESTO implementation 2002 and 2018

  https://github.com/scottransom/presto.git

Time Domain searches

- Works on the principle of time domain resampling. Stretching or collapsing of the time series in different sections of the observation based on calculated frequency drift due to doppler effect.

  Peasoup implementation 2013

https://github.com/vishnubk/peasoup.git

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Runtime Benchmark tests (PRESTO 2018).

Computing resource used

- 14 computing nodes at our OAC computing cluster.
- 8 CPU nodes with 64 AMD Milan 7513 (16 core) each, 512 GB DDR4 3200 RAM ,960GB SSD and 4 x 1.92 TB SSD
- 6 GPU nodes with the same configuration and the addition of 2 GPU's (NVIDIA A40 48GB RAM DDR6 Pcle) per node

Computing time requirements

- An acceleration search run over **one MeerKAT S-band Globular Cluster** observation took me ~60 hours with **256 CPUs and 8 GPUs**. Within this, acceleration search alone takes **60-70%** of the computing time.
- With Jerk search enabled, these searches can take up to a week to finish.
- S –band data is one of the easiest data to search, Lower frequency bands are harder to search because of higher dispersion effect and greater radio frequency interference!!!

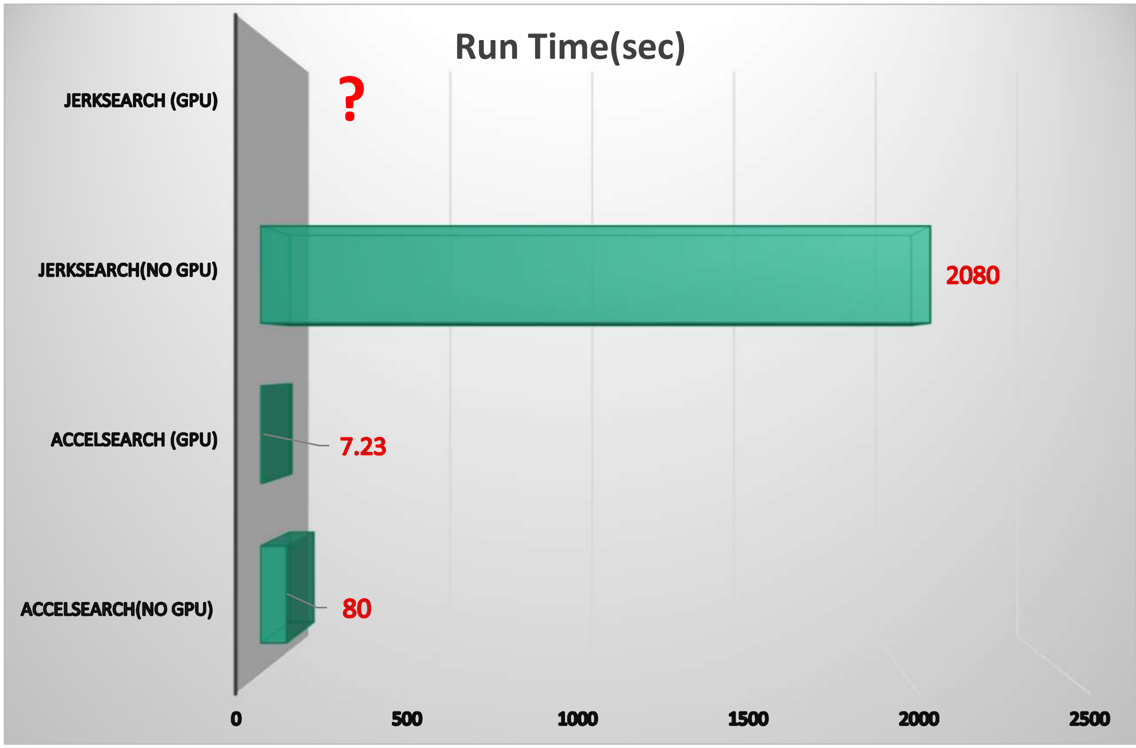

Fig (above): A runtime comparison of Acceleration search and Jerk search for the same data.

PRESTO vs Peasoup

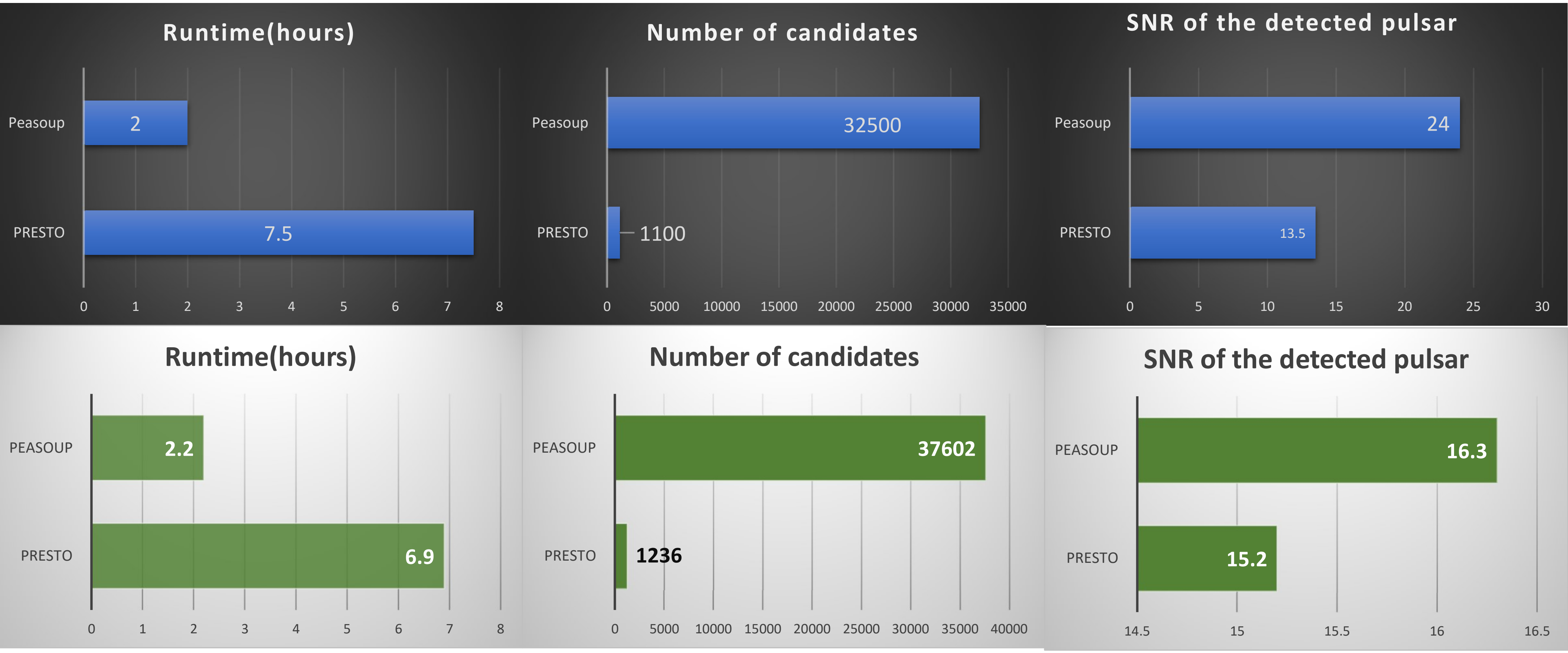

Figure above contains comparison plots of acceleration search runs for GPU versions of PRESTO and Peasoup for two pulsars A (black) and B (grey) for the exact same observation. Both the observations were 1 hour long and had only 1 pulsar in them.

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Looking even deeper. The template-bank method

- Acceleration and Jerk searches are essentially brute force methods. So, there is still a chance of missing pulsars which are not very bright or systems with extreme orbital parameters that are in an unfortunate orbital phase during the observation.

- We can go 1 step further in enhancing the sensitivity of our pulsar searches with a technique called the template bank method.

- We use the Template bank to model the characteristic features of a pulsar binary system like masses of the pulsar and the companion, the spin period of a pulsar, the eccentricity of the binary orbit, the orbital velocity etc and helps us create searches with higher sensitivity.

Work flow

Step 1

- Device a **<u>new Template bank model</u>** to minimize the number of dimensions of my parameter space while keeping sensitivity. Existing models had 3D parameter space. My model has 2D space.
- Test the **parameter space coverage of the new model** vs the existing model(s)

Step 2

- **Write the template bank Generation code and supporting codes that make it work and incorporate it into the search pipeline**
- Build a **new GPU based Time Domain Resampling code** that uses my template bank code to perform periodicity searches.

Step 3

- Test the code with **artificial data** from a pulsar injector software.

Step 4

- Test the code with real data and roll out the software for public use.

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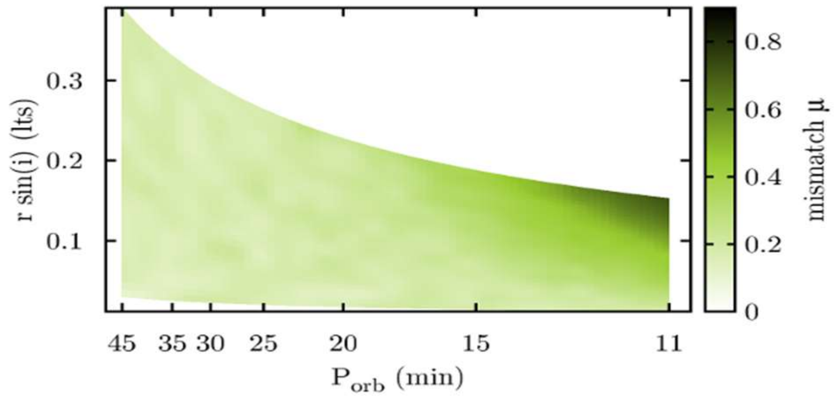
Generation of the new parameter space model, 4D to 3D space conversion

$$\phi_2 = 2\pi f \left[t - \left(\frac{a}{2c}\right) t^2 - \left(\frac{j}{6c}\right) t^3\right]$$

$$\phi_1 = 2\pi f \left(t + \tau \sin(\Omega t + \psi)\right) + \phi_0')$$

f = spin frequency
t = time
a = acceleration
j = jerk

f = spin frequency
t= time
Ω= orbital angular velocity
τ= projected orbital radius
ψ= initial orbital phase



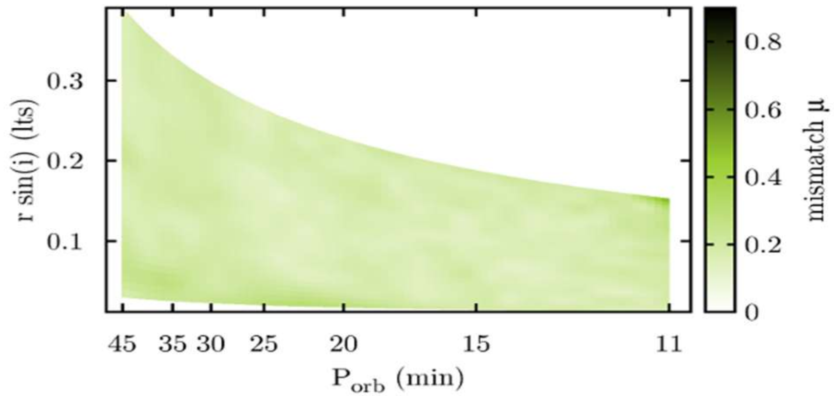


Fig (above) shows parameter space sensitivity models for 90% coverage of parameter space. My new phase model (left) vs the most robust phase model (right) that takes into account all possible parameters.

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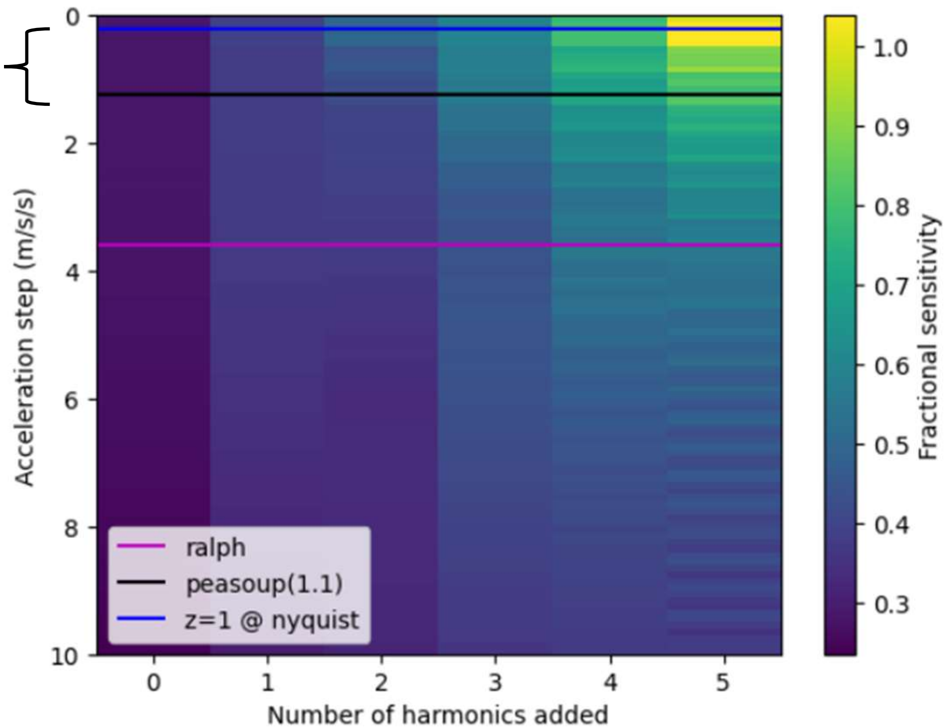
Search Sensitivity of different pulsar search algorithms in use.

Sensitivity of Template bank based Jerk searches.



The above figure shows the sensitivity of various pulsar searching algorithms based on the number of harmonics of the signal added to recover power and the minimum acceleration step size used to make the trial values.

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Conclusions

- GPU based Jerksearch pipeline almost ready.

- Currently one launch of the pipeline can only use 1 GPU. So, the data set or search parameter ranges can be broken down into subsets to exploit multiple GPU’s in HPC’s.

- Is more sensitive than both existing PRESTO and peasoup implementations in the parameter space I want to look into.

- Is less sensitive than the Template bank pulsar search code which exploits all 5 orbital parameters but should be significantly faster due to reduced dimension of parameter space. Exactly how much faster, remains to be tested.

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Future work.

Finish making the new distiller (pulsar candidate filtering and sorting code) for my pipeline.

Test the pipeline on real observations and perform benchmark tests

Roll out the code for public use and have possible publications

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You can find a beta version of my code at: **https://github.com/erc-compact/peasoupjerk.git**

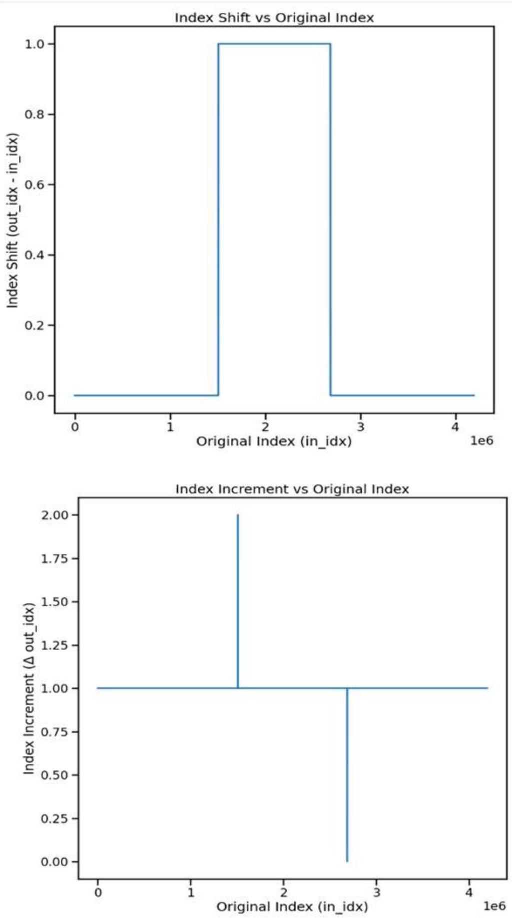
Special thanks to:

Dr. Vivek Venkatraman (MPIFR, Bonn)
Dr. Vishnu Balakrishnan (MPIFR, Bonn)
Dr. Alessandro Ridolfi (University of Bielefeld)

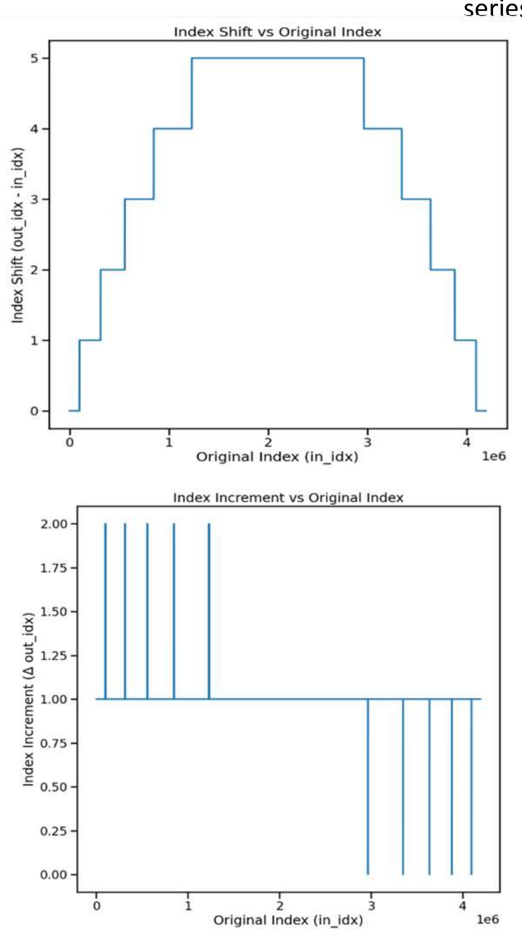
THANK YOU FOR LISTENING

HAVE A WONDERFUL DAY

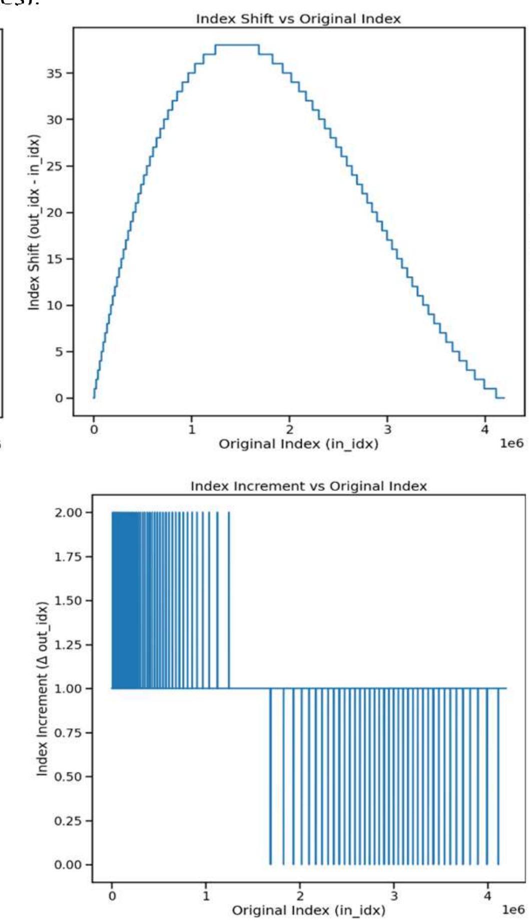
Computational complexity of Jerk searches: The graphs below show how many times a time series needs to be resampled to take into account the effect of the given acceleration and jerk values for a specific pulsar given the starting point of reference in the observation is at the centre of the x axis (Indicates number of samples in the time series).



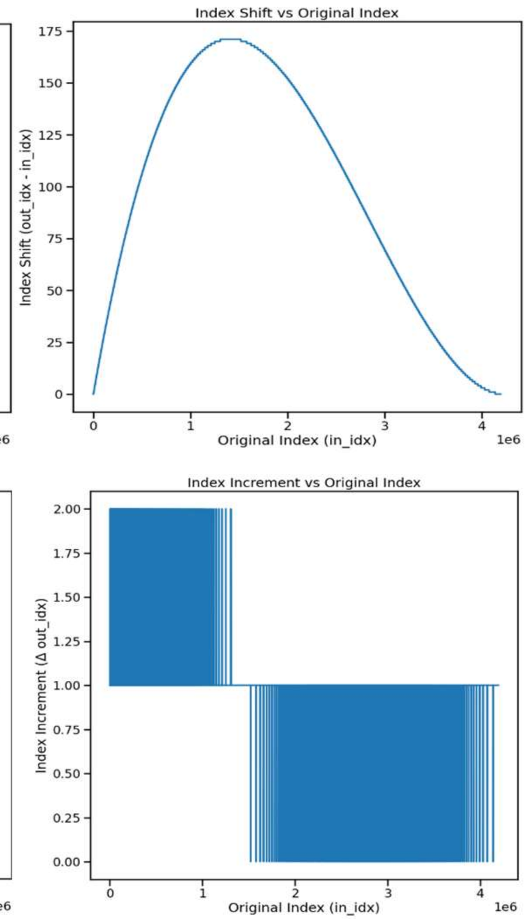
a= $-1 m/s^2$
j= $0 m/s^2$



a= $-10 m/s^2$
j= $0 m/s^2$



a= $-10 m/s^2$
j= $1 m/s^3$



a= $-10 m/s^2$
j= $5 m/s^3$

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