Crab Pulsar

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1. Introduction

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What is a Pulsar?

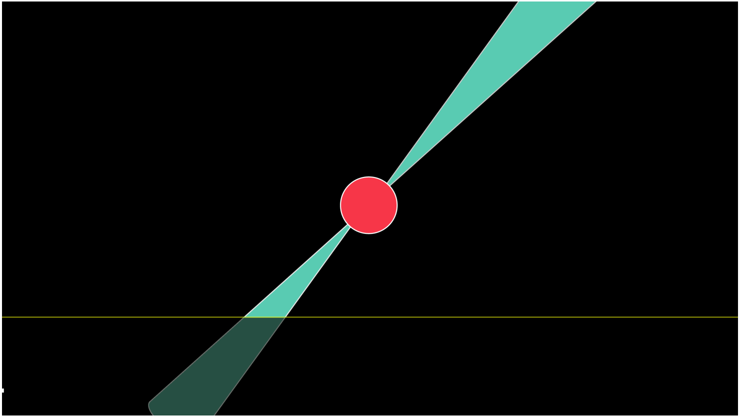

Figure 1: **`https://lilith.fisica.ufmg.br/~dsoares/extn/ogs/ogs-psr.htm`**

Aims and Goals of the Experiment

1. Measure dispersion measures (DMs) of multiple pulsars and find their distance from the earth.
2. Measure the period and identify pulsars by Fourier analysis of their data.
3. Measure the period of the Crab Pulsar a period of time using pulsar timing techniques to find its period derivative, and hence estimate its surface magnetic field and age.

2. Methodology

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Dispersion Measures

- Pulsar beams ”spread out” as they travel through the intergalactic medium.
  - Higher frequency signals arrive before low frequency ones.
- The delay caused due to dispersion is,

$$\Delta\tau = \tag{1}$$

where

$$DM = \tag{2}$$

in units of cm^{-3} pc.

- Distance to the pulsar may then be estimated by,

$$d = DM \cdot n_e \tag{3}$$

Dispersion Measures

- Pulse broadening decreases amplitude
  - No pulse broadening, maximum amplitude.
- Generate DM values and fit the data to a $-x^2$ graph to find DM
  - In reality, data is Lorentzian but interval of fitting chosen so that the first order Taylor expansion would be a valid choice.
- This method is limited in that it produces high error, but can identify a sensible DM for noisy data.

Searching for Pulsars via Fourier Analysis

- A Fourier transform takes a function as input in some basis, i.e., time, and outputs a new function which describes the extent to which frequencies are present in data.
- Discrete Fourier transforms exist alongside algorithms for performing them on computers, known as fast Fourier transforms (FFTs). This algorithm is defined by,

$$X_k = \sum_{m=0}^{n-1} x_m e^{-\frac{i2\pi km}{n}}, \quad k = 0, \ldots, n-1 \tag{4}$$

Searching for Pulsars via Fourier Analysis

- Feeding de-dispersed pulsar data into a real-FFT (RFFT), we can identify pulsar signals and their harmonics to determine the period.
- If a signal has N harmonics corresponding to an initial f_i and final f_f frequency, the frequency of the pulsar is,

$$f = \frac{f_f - f_i}{N}. \tag{5}$$

Pulsar Timing

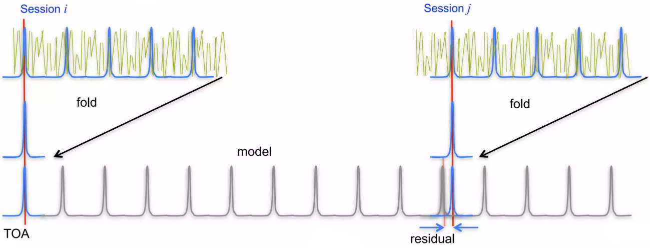

Figure 2: **`https://www.slideshare.net/slideshow/msp-masses/50521845`**

- If it is incorrect, the pulses will spread apart over time, before coming together again.

$$\frac{P}{t} = N + r \tag{6}$$

- r is the remainder corresponding to residual.
- Plotting r vs. t yields lines of gradient ν which is the true frequency of the pulsar.

Pulsar Timing - Delays

We wish to move into a more sensible frame of reference by applying delays.

- Assume pulsar is far away and at a constant position.

$$\Delta\tau_{\text{Roemer}} = \qquad\qquad \Delta\tau_{\text{Earth}} = \tag{7}$$

Pulsar Timing

- We can measure how the pulsar period changes over time via the period derivative $\dot{P}$.
- We estimate the surface magnetic field by,

$$B = \tag{8}$$

- Age is estimated by,

$$t = \tag{9}$$

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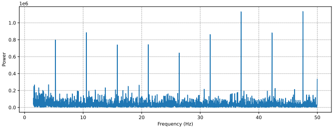
DM Values

Name	Obs. Date+Time	DM / cm^{-3} pc	d / pc
B0329+54	07/10/2025 @ 10:08	25.174±2.173	
B0950+08	07/10/2025 @ 11:04	7.389±2.361	
B1933+16	07/10/2025 @ 12:12	155.844±11.425	
B2021+51	07/10/2025 @ 13:46	15.846±7.668	

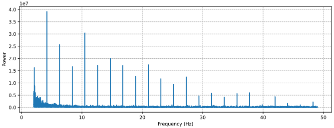
DM Values - Crab Pulsar

Name	Obs. Date+Time	DM / cm^{-3} pc	d / pc
B0531+21	21/10/2025 @ 07:12	55.675±5.249	
	21/10/2025 @ 08:33	55.401±15.757	
	11/11/2025 @ 05:49	55.355±7.196	
	19/11/2025 @ 18:45	55.192±4.468	

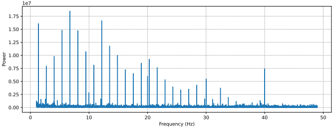
Fourier Analysis of Pulsar Data



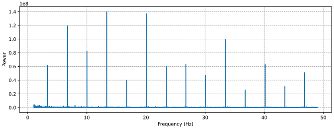
(a) first



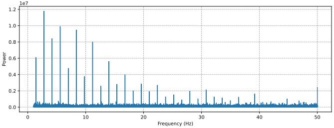
(b) second



(c) third



(d) fourth



(e) fifth

Fourier Analysis of Pulsar Data

Observation	ν/Hz	Possible Pulsars	
1		B$\cdots$	1σ, $x\%$
2			
3			
4			
5			

3. Results

3.1. Crab Pulsar Timing

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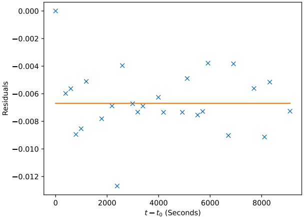
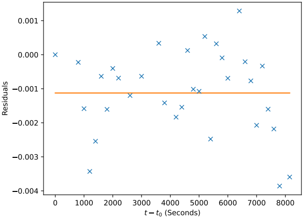
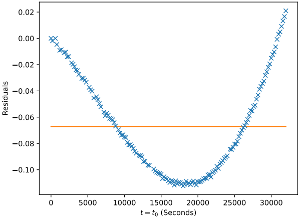


(a) dd/mm/yyyy, $P = (33.8472471 \pm 0.0000002)$ ms



(b) dd/mm/yyyy, $P = (33.8480021 \pm 0.0000001)$ ms



(c) dd/mm/yyyy, $P = (33.8483683 \pm 0.0000006)$ ms

Crab Pulsar Timing - Period Derivative

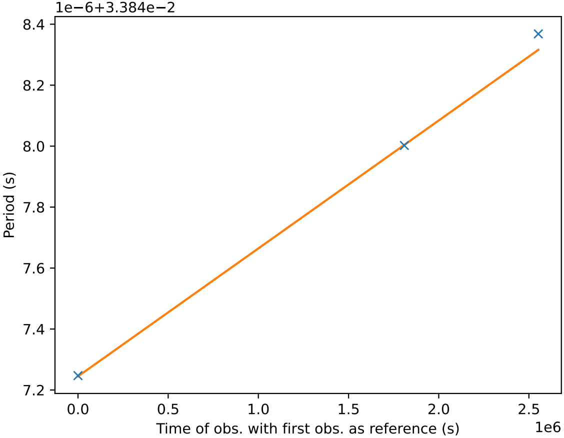


Figure 3: Measured $\dot{P} = (4.197 \pm 0.109) \times 10^{-13}$

Corresponding surface magnetic field and age:

$$B = \qquad\qquad t = \tag{10}$$

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Errors

- All values found to within 1σ of accepeted value.
- Errors could be improved in interpolation and other areas.

Thank you for listening!