Observing Pulsar Properties With The 42ft Telescope

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Using the 42ft telescope at Jodrell Bank the characteristic age of the Crab Pulsar was found to be (1239 ± 3) years. It's magnetic field was calculated to be $(4 \times 10^{12} \pm 0.1\%)$G. The dispersion measure for the pulsars B1933+16 and B0329+54 were calculated to be (157 ± 5) pccm^{-3} and (31 ± 2) pccm^{-3} respectively. This equated to distance measurements of (5233 ± 167) pc and (1033 ± 67) pc for the pulsars.

1. Introduction

A pulsar is a highly magnetised rotating neutron star. Through the rotation, charged particles are emitted along the magnetic field lines and this acceleration causes a characteristic beam of radiation to be emitted. The radiation beam is periodically viewed by an observer through the 'lighthouse effect' [1]. By measuring this regular period, a number of properties can be observed.

2. The Crab Pulsar Age and Magnetic Field

On the 1st September the time of arrival of the radio pulses from the Crab Pulsar were collected. Two corrections were applied to the data before analysis.

Firstly, the Earth observing the Crab Pulsar is not an inertial frame, therefore the raw data was shifted to the centre of mass of the Solar system (the barycentre). Secondly, the observations must be corrected for the elevation of the pulsar in the sky. These corrections produced the true temporal separation between pulse signals.

Two arrival times from the Crab Pulsar must be separated by an integer number of pulse periods. Therefore, an estimated period was used to calculate the expected arrival time of each pulse. The difference between the expected time of arrival and actual time of arrival is the residual.

By plotting the residual for each observation, a buzz saw shaped graph was produced. This showed that the period estimation was rapidly falling out of synchronisation with the true period of the Crab Pulsar. An improved estimation was obtained by using the gradient of the buzz-saw graph. The residuals were recalculated and plotted again using the revised period, this time producing a parabolic graph, Figure 1.

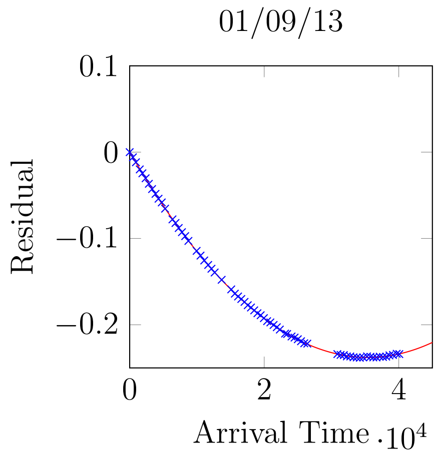

Figure 1: The residuals are in units of number of rotations. The arrival time is in units of seconds. Fitting a quadratic curve produced a coefficient $1.8978 \times 10^{-10} \pm 4.17 \times 10^{-13}$. It is unit-less. The period was estimated to be 0.03368648009 s.

Figure 1 show that the model is moving out of phase with the period estimate.

The period derivative, $\dot{P}$, (rate of change of the period, P) is proportional to the coefficient of the quadratic term. Thus the age, $A = \frac{P}{2\dot{P}}$ and magnetic field, $B = 3.2 \times 10^{19}\sqrt{P\dot{P}}$ (Gaussian units) can be calculated using the coefficient of the quadratic term of the fitted curve [1].

Date September	Age, A Years ± 3	Magnetic Field, B Gauss $\times 10^{12} \pm 0.1\%$
01	1239	4

Table 1: The calculated properties of the Crab Pulsar.

The Crab Pulsar is known to have an actual age of 940 years and magnetic field of 3.78×10^{12}G [3]. The calculated magnetic field, Table 1, agrees with the known value, however the age does not.

3. Dispersion Measurement for B1933+16 and B0359+64

As the radio signal from the pulsar travels to the Earth, it experiences a frequency dependent delay due to the refraction effects of the interstellar medium (ISM). The extend of this effect is characterised by the 'dispersion measure' quantity, DM.

It is the integrated column electron density, n_e, from the Earth to the pulsar;

$$\text{DM} = \int_{\text{Earth}}^{\text{Pulsar}} n_e \cdot dl. \tag{1}$$

By varying the frequency of the signal observed, ν, the subsequent delay in arrival time, t, was measured. They are related through the equation [2];

$$t = \frac{\text{DM}}{2.41 \times 10^{-4} \nu_{\text{MHz}}^2}. \tag{2}$$

The frequency was measured between 287.5 MHz and 292.5 MHz in 0.5 MHz increments.

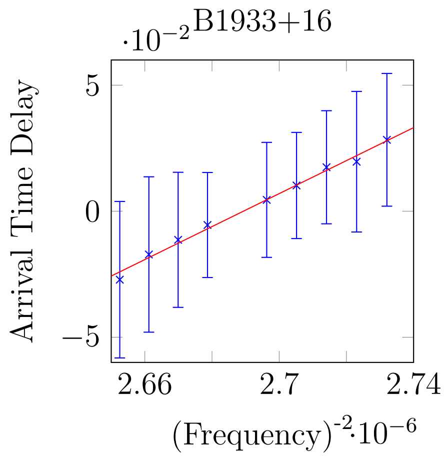

Figure 2: The errors arise from the uncertainty in the true arrival time of the signal. It has χ^2 value of 0.03. The fitted line has gradient shown in Table 2.

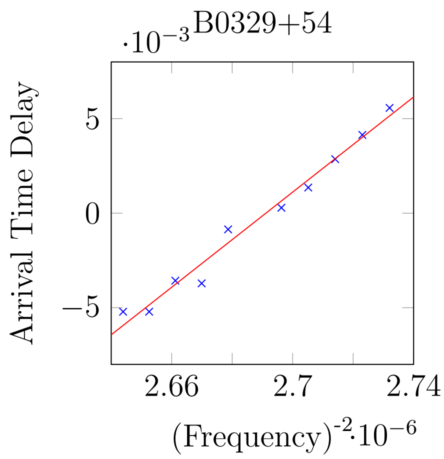

Figure 3: The error bars are too small to be visualised and a χ^2 value could not be calculated. As expected a linear graph was produced

For both Figure 2 and 3 the arrival time is in units of seconds and the x label has units of MHz^{-2}. By comparing the scale of the error bars on both Figures 2 and 3, it can be concluded that the errors given by the programme are not reliable. Therefore, the error on the gradient was obtained from the linear fit programme in MATLAB.

Using equation (2) and the gradients of the linear fits, a dispersion measure was calculated. Then by using an estimated value of n_e to be 0.03cm^{-3} a distance to the pulsar is calculated.

Pulsar	Gradient	DM	Distance
	$\times 10^5$ pccm^{-3}	pccm^{-3}	pc
B1933+16	6.54 ± 0.23	157 ± 5	5233 ± 167
B0329+54	1.30 ± 0.08	31 ± 2	1033 ± 67

Table 2: The results from applying equations (1) and (2). The errors in the gradient arise from the linear fit inaccuracies. The errors in the dispersion measurement and distance are propagated in the usual way.

The known values for B1933+16 are 159pc cm^{-3} at a distance of 7900pc [3]. For B0329+54 the dispersion measure is known to be 31pc cm^{-3} at a distance of 800pc. The calculated values, Table 2, for the dispersion measure agree with the known values, however the distances disagree.

4. Discussion and Conclusion

Overall in Section 2, the model used to calculate the age of the Crab Pulsar needs to be refined. It currently assumes that the current period of rotation is much smaller that the initial starting period. As the Crab Pulsar is young (the typical age of pulsars is 10 million years) this assumption is invalid, hence the discrepancy between the calculated and actual age. As the magnetic fields agree, we can conclude that the residual method is correct.

For Section 3, the true dispersion measures agree with the known values. From this it can be concluded that the method used and equation (2) are valid. The distances calculated do not agree with the known values due to the simplification in assuming that n_e is constant. In reality, the radio signal does not pass exclusively through the ISM, presence of ^{2}H regions can also disperse the signal. A more accurate calculation would take into account the variations of n_e along the line of sight of the pulsar.

References

[1] Lyne and Smith, *Pulsar Astronomy*. Cambridge University Press. 4th Edition.

[2] D. R. Lorimer and M. Kramer, *Handbook of Pulsar Astronomy*. Cambridge University Press.

[3] ATNF Pulsar Catalouge, Manchester, R. et al. 1993-2006 (2005).