Pulsars In Radio Wave

Zhongyuan Zhang

INTRODUCTION

This paper will utilize a methodological approach to determine the precise period of a pulsar and calculate the distance of the pulsar. Because the period of a pulsar changes depending on the time of year the observation is collected, a precise period needs to be calculated from the raw period. The distance of a pulsar can be calculated based on the signal's time delay due to the interstellar medium. Because the noise in the data is extremely strong compared to the signal, it is necessary to collect data using different channels; the signal from the pulsar can be determined by adding the signal in each every channel and calculating the average signal value.

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I. INTRODUCTION

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II. BACKGROUND INFORMATION

Pulsars are a kind of neutron star with radius about 10km and mass about 1.4 times of the sun. Pulsars are made of nuclear matter, which has an enormous density: one teaspoon of nuclear matter weighs about 3 billion tons. This density is explained by the fact that a nucleus occupies 99.9 percent of an atom's mass, but the radius of a nucleus is 100,000 times smaller than the radius of an atom. In the case of pulsars, the explosion of a supernova compresses the atom structure to the size of a nucleus, and as a result electrons and protons combine together and become neutrons.

Pulsars have extremely small rotating periods, which range from 12s to 0.0014s, because the explosion that created them decreases the radius of the supernova and reduces the inertia of momentum. Rotating periods are the amount of time a pulsar takes to complete a full rotation on its axis. Identify- ing a method to identify the precise period of a pulsar is critical for analyzing data related to pulsars. The collapse of a supernova also causes the surface magnetic field of pulsars to be between 108 and 1012T. Because of their strong magnetic field and large rotating velocity, pulsars emit radio waves that can be detected by telescopes, which can be used to measure the period of a pulsar.

The interstellar medium is a kind of matter in the universe that consists of hydrogen, helium, dust, and electrons. Negatively charged electrons in the interstellar medium act similarly to Earth's atmosphere and slow down the radio waves. Therefore, radio waves received on Earth will have an amount of interference. If two beams of a radio wave have constructive interference, the signal will be strong and clear, whereas if they are in destructive interference, the signal will be invisible. This phenomenon is known as scintillation, just like stars twinkle because of the Earth's atmosphere.

Relatedly, dispersion is an optics phenomenon caused by light waves being slowed down by the interstellar medium. For example, a beam of white light that passes through a prism will be dispersed into diff erent color because light with different frequencies travel at different speeds in the prism. In the context of pulsars, the radio waves emitted by pulsars are slowed down by interstellar medium, resulting in dispersion. Dispersion can be used to calculate the distance to pulsars. Dividing the dispersion measure by average plasma density, which is how much the radio wave slows down, and the result will be the distance.

III. ANALYSIS AND RESULTS

The goal of this analysis is to determine the distance of a pulsar from Earth. To accomplish this goal, a precise period of the pulsar must be identi ed. The example pulsar, J0332+5434, has a raw period of 0.71452s. Taken at dierent times in a year, the period of a pulsar will slightly change. The error is about 0.0001 times the raw period. In this lab, data on 10 trail periods was collected, and the most precise trail period will be used for later calculations. These trail periods were chosen by dividing the error range equally in 10 parts.

Each trail period was divided into 100 phase bins. In the program by python, this can be done by creating two 100-bin arrays, phaseCount and phase Power. The phase number, which indicates which bin is the power in, can be calculated by:

$$\phi = \frac{t}{P} \tag{1}$$

The corresponding bin can be calculated by:1

$$i = int(\phi \times nBins \tag{2}$$

The function int()converts the number into an integer, and n Bins refers to the number of bins. Each time in the data is put into these two equations to get the phase number. The corresponding bin in phase Count array will add one, and in phasePower array will add the power corresponding the time. Then the phasePower array was divided by the phaseCount array, and the result was plotted to a power vs. phase plot. This process was repeated for every trail period.

Using this data, I worked to identify the most accurate period, which corre- sponds to the plot with the sharpest peak. Because the pulsar's signal is periodic (i.e., its signal is sent at the same time interval), if the period is correct, as the signal repeats, the signal is always stored in the correct phase bin of the period. As a result, even though the signal is weak compared to the background noise, the average value for the signal is much stronger than the noise, and a sharp peak will appear, as shown in Figure 1. In contrast, if the period is largely di erent from the correct period, the signal will spread evenly throughout the phase bin, so the signal will remain weak and no peak will appear, as shown in Figure 2. If the period is slightly different from the correct period, the signal will be located in a few phase bins, so a peak will appear, but it will not be as sharp, as shown in Figure 3.

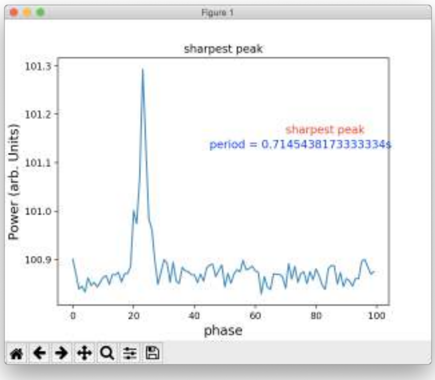

Figure 1: Sharpest peak and the most accurate period for the example pulsar

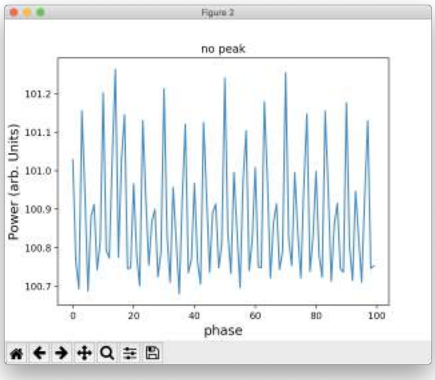

Figure 2: No peak appears when trial period is largely different from the correct period

After determining the period, the next step is to and the distance of the pulsar. A heat map of phase vs. frequency was used to accomplish this goal. From the heat map, we can directly identify the phase shift of different frequencies,

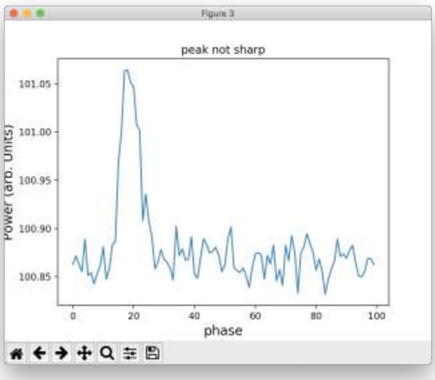

Figure 3: Peak that is not the sharpest when trial period is slight di erent from the correct period

which contributes to the time delay of signal in the data, as shown in equation 4; understanding the time delay is necessary determining the distance to the pulsar.

Figure 4 shows the signal of the pulsar. The signal is not continuous because of scintillation.

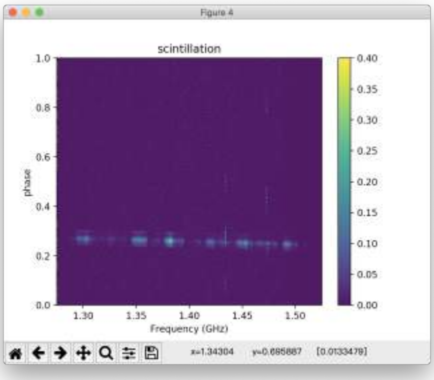

Figure 4: Phase vs. frequency plot

The phase decreases as the frequency increases because of the negatively charged electrons in the interstellar medium slow the radio waves down. The dispersion measure DM can be calculated by:

$$t2 - t1 = kDM\left[\frac{1}{f_1^2} + \frac{1}{f_2^2}\right] \tag{3}$$

where $t2 - t1$ is the time difference of the arrival of $f1$ and $f2$ and k =4:15 ms GHz2 cm3/pc.
The distance of the pulsar D can be calculated by this:

$$D = \frac{DM}{N} \tag{4}$$

where N ' –~0:03 e–=cm^3 is a constant.

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D is equal to 3179.5419960658774 light year
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Figure 5: Distance to the pulsar

IV. THEORY AND DISCUSSION

Results indicate that the time delay for the observed pulsar is that the time delay is about 17.15s and the frequency difference is about 0.19GHz. Based on the distance calculated by equations 3 and 4, the observed pulsar is about 3,180 light years from Earth. To illustrate this phenomenon, consider two people, A and B, who start running at the same time in the same location. For every 100 seconds, A will run 10 more meters than B. Therefore, if we know they have been running for 400 seconds, we can know A runs 40 more meters than B. Similarly, the electron density is known, which means we know the rate of radio wave slowing down in interstellar medium, so if we know how much time the radio wave slows, the distance to the pulsar can thus be calculated.

V. SUMMARY AND CONCLUSION

The described approach to calculate the precise period and the distance of a pulsar can be used to every pulsar, as long as there is available data. Researchers may thus find this approach valuable in work that aims to advance the field's understanding of pulsars.

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