The Timing of a “Melting-Pot” Pulsar J0941-39

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Abstract

Rotating Radio Transients (RRATs) are rotating neutron stars that emit pulses very sparsely at several to many times the rotational period of the star. PSR J0941-39 is a unique melting pot of multiple traits typically not observed to occur all in one pulsar. PSR J0941-39 sometimes appears with a sporadic RRAT-like emission and other times emits as a bright pulsar with strong pulse-to-pulse modulation. This thesis presents a general overview on timing PSR J0941-39 and unveils several other phenomena that appear in this pulsar. We discovered that PSR J0941-39 has a classic mode change and an abrupt period change, which we have yet to explain. Two theories that can explain this phenomenon are discused: PSR J0941-39 has a similar spin behavior to intermittent pulsars or has a glitch.

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1 Introduction

Pulsars are very dense, rotating neutron stars that emit beams of electromagnetic radiation that sweep the sky like a lighthouse. Radio telescopes allow us to observe the pulsar's beams. The first pulsar was observed on November 28, 1967, by Jocelyn Bell Burnell and Antony Hewish [1]. Pulsar searching, monitoring, and timing are three ways that we learn about pulsars. Pulsar searching is a conceptually simple process, being the detection of dispersed pulses in noisy data. Once a pulsar has been discovered, it is subjected to many different types of follow-up observations in order to characterize its basic properties and later analyze the newly-found pulsar. Pulsar timing is the measurement of the arrival times of photons emitted by the pulsar, which is a means of precisely monitoring the pulsar's rotational behavior. This allows us to study a variety of phenomena that affect the propagation of their pulses. The amount of useful information that can be extracted critically depends upon pulsar timing, giving us the in-depth characteristics of a pulsar through its timing solution. Pulsar researchers have made and are still making great progress towards learning and discovering many new things about pulsars. Pulsars have provided us with an abundance of information about neutron stars, physics, general relativity, the galactic gravitational potential, magnetic fields, and much more.

A regular pulsar emits continuously, but we only see it intermittently because its beam is not always facing towards us. The time in which the beam is facing towards us is called the "pulsed signal." According to Burke-Spolaor and Bailes [2], pulsars can be broken down into two main types of intrinsic variation. The first type is pulse-to-pulse modulation, in which the object emits continuously at an intrinsically modulated amplitude. Pulse-to-pulse variations include intrinsic fluctuations of one profile component, phase-drifting of a profile component, and/or mode changing, where the whole profile shape actually changes for multiple pulsar rotations. The second type is nulling, during which the pulsar beam does not emit detectable radiation for a length of time. During the time of non-emission, the pulsar is said to be switched off. The nulling behavior in a pulsar can be quantified by a nulling fraction (NF), where the number of sequential rotations with on and off pulses is given by N_{on} and N_{off}. The NF is computed by $N_{\text{off}}/(N_{\text{on}} + N_{\text{off}})$ which is the fraction of off pulses typically seen in an observation. Generally, regularly emitting pulsars have an indefinite "on state." For a nulling pulsar, its fraction can range anywhere from approximately zero to $> 95\%$ [3]. One case of extreme nulling phenomena is the "intermittent pulsar." Intermittent pulsars have a NF of 100% when in the off state, and when they are on they seem to be continuously emitting [4]. More about intermittent pulsars will be discussed in a later section. Even though timing has allowed us to learn a lot about pulsars, and we know that some pulsars null, it is not yet understood why nulling happens.

The Rotating Radio Transients (RRATs) class is not well-defined, but generally refers to sporadically-detectable pulsars such as those discovered in the re-analysis of the Multi-Beam Pulsar Survey reported by McLaughlin [5]. RRATs have an average detected on-pulse interval that falls between a few minutes to a few hours, and the pulses have a duration between 2 and 30 milliseconds. So far over 60 RRATs have been discovered (Hessels et al. 2008; Deneva et al. 2009; Keane et al. 2010; Burke-Spolaor and Bailes 2010; Keane et al. 2011; Burke-Spolaor et al. 2011), including the original 11 from McLaughlin [5]. The properties of individual RRATs vary considerably. Most of the RRATs emit single pulses, and a few show evidence for clustering of pulses. It is clear that there are periodicities in the pulse arrival times for all RRATs where multiple pulses have been detected. The periods and magnetic fields of RRATs are generally larger than those of normal pulsars. RRATs have a period P ranging from 0.1 to 8 seconds, with an average longer than that of normal radio pulsars. However, RRAT distributions of other spin-down properties, such as spin-down energy loss rate and characteristic age, are similar to those properties in normal pulsars [6].

Recent investigations show that RRATs likely represent a combination of several different neutron star source populations rather than a single class. The discussion of Burke-Spolaor and Bailes [2] on RRATs supports that there might be a direct link between pulsars and RRATs. It was hypothesized that a RRAT could possibly be a part of the evolutionary phase of pulsars before the pulsar advances beyond the radio pulsar death line. The pulsar death line is when a pulsar's spin period slows down sufficiently, so that the radio emission mechanism is believed to turn off. Some RRATs seem to be pulsars with high NF of $> 95\%$.

Although the line between pulsars and RRATs is still unclear to researchers, we hope that by studying many different types of pulsars that line will become clearer. Through studying/timing PSR J0941-39, which is an uniquely interesting pulsar, my collaborator S. Burke-Spolaor and I hope to be able to reveal some new characteristics of RRATs and pulsars that will clarify the line. This pulsar does not fit clearly into any of the currently-identified pulsar categories. This pulsar sometimes acts like a single-pulse-emitting RRAT, and sometimes acts like a nulling pulsar.

In Sec. 2 we give some background on the mold-breaking PSR J0941-39 and discuss the reason that PSR J0941-39 is an interesting pulsar to study.

Section 3 describes in detail the processes of timing PSR J0941-39. In Sec. 4, we give the results of timing PSR J0941-39. Section 5 summarizes the main conclusions of this thesis.

2 Background Information on PSR J0941-39

PSR J0941-39 is a pulsar that was discovered with the Parkes telescope, as reported in Burke-Spolaor and Bailes [2]. The discovery of this pulsar was made through five single pulses, for which there was no clear periodicity. After follow-up observations on this source spread over approximately one-and-a-half years, the pulsar revealed unusual overall behavior.

Similarly to the behavior of intermittent pulsars, this pulsar has two gapparently distinct nulling states. One is a pulsar-like state, which henceforth we will refer to as the "high-activity state." The other manifesting state is the RRAT state, which we will hereafter refer to as the "low-activity state." The high-activity state of this pulsar emits as a bright pulsar with a strong pulse-to-pulse modulation, only nulling $\sim 10\%$ of the time. The low-activity state of this pulsar emits very sporadic pulses (like a RRAT) and nulls $> 98\%$ of the time. Burke-Spolaor and Bailes [2] showed that PSR J0941-39 has a triple-peaked profile and broad duty cycle, with complex sub-pulse drift, state changes, and longitude-dependent modulation when in the high-activity state (see Fig. 1).

An pulsar similar to PSR J0941-39 is B0826-34 [7]. PSR B0826-34 is the second pulsar found which oscillates between a high-activity state and a low-activity state. PSR B0826-34 is a relatively old pulsar with a characteristic age of 3×10^7 years. Like PSR J0941-39 this pulsar has remarkable drifting behavior in the high-activity state, and strong sporadic pulses during the low-activity state.

PSR J0941-39 represents the first detection of an object oscillating from a bright pulsar with a low nulling faction to a single-bursting source. PSR J0941-39 appears to oscillate between a clear "nulling pulsar" and more intermittent low-activity state. We have given PSR J0941-39 the nickname the "Melting Pot" pulsar because PSR J0941-39 appears to have many different phenomena. In summary, these phenomena are:

•***RRAT*** This pulsar appears to act like a RRAT during its low-activity state.

•***Pulse-to-pulse modulation*** This pulsar has phase drifting that occurs in the profile components during the high-activity state.

•***Nulling state change*** This pulsar has different nulling states, which

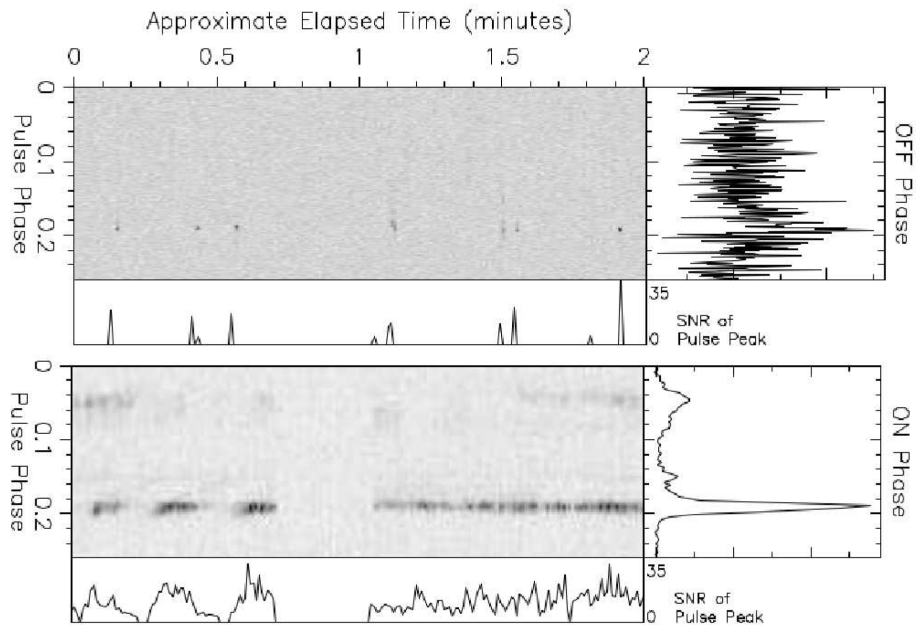

Figure 1: This figure is from Burke-Spolaor and Bailes (2009). Their caption for this figure was: Two-minute (205 rotation) pulse stacks exhibiting PSR J0941-39's RRAT [low-activity] and Pulsar [high-activity] states. The integrated profile shape is shown in the right panel. Tracks of the signal-to-noise ratio of the peak of each pulse with SNR > 3 are plotted below the pulse-to-pulse stacks. The brightest of the high-activity and low-activity phase are comparable, indicating that the low-activity state is not due to interstellar scintillation.

are the high-activity and the low-activity states.

•***Classic mode change*** This pulsar appears to be exhibiting a profile change, which we reveal in this thesis.

•***Intermittent pulsar*** Due to the two nulling states, it is possible that this pulsar is similar to intermittent pulsars. This possibility is discussed in a later section.

•***Glitches*** This pulsar appears to have undergone a possible glitch, which is discussed in a later section.

This "Melting Pot" of a pulsar is what makes this pulsar unique and by observing this pulsar's phenomena we hope to learn about the interplay between these usually disparate phenomena.

This pulsar superficially ties a close link between nulling phenomena and RRATs, possibly signifying a pulsar that is in some way transitioning from a high-activity state to a low-activity state. PSR J0941-39 may provide a link both between RRATs and pulsars as well as a link to older, non-radio-emitting neutron stars. This would help indicate that the RRAT phase represents a degradation of the radio emission mechanism before advancing beyond the radio pulsar death line, and indicating a possible evolutionary progression. By timing this pulsar, we might learn more about the magnetosphere and determine the origin of nulling pulsars. Finding a timing solution to this pulsar will give us a better understanding of whether this pulsar, like B0826-34, sits near the death line and therefore supports the previous discussion about RRATs as the evolutionary end of the pulsar life cycle.

3 Process of Timing PSR J0941-39

In order to time PSR J0941-39 we must examine each of its nulling states independently. There are several steps involved for timing both the high-activity state and the low-activity state. The first and most important step in timing is to obtain data. PSR J0941-39 pulsar archive data of the high-activity and low-activity state was obtained by S. Burke-Spolaor at the Parkes Radio Observatory in Parkes, NSW, Australia. Archive data is a single data file containing multiple rotations of the pulsar, which are averaged over the rotational period into "sub-integrations." These sub-integrations may be as short as one pulsar rotation or as long as the observation. In our data, sub-integration lengths were set at one rotation, and the observations are divided into 3 minute segments.

When timing PSR J0941-39, the software used was `PSRchive` and `tempo2`.

PSRchive software processes observational data stored as a three-dimensional array of pulse profiles: the polarization component, pulse phase and the frequency. Typically when analyzing observational data, it is necessary to discard data that have been corrupted by experimental error, instrumental distortion, and/or radio frequency interference. Through PSRchive I identified the radio frequency interference (RFI) and extracted (known as zapping) the RFI from the channels and sub-integrations in the high-activity state.

Many types of RFI are narrow band interference, so that the quality of an observation can be significantly improved by only discarding a small number of corrupted channels. RFI may also occur as broadband bursts of impulsive emission. When impulsive interference is persistent, it may not be possible to discard a subset of corrupted frequency channels or sub-integrations. The Parkes Telescope experiences varied local RFI, which makes it impossible to select a fixed set of frequency channels as an RFI filter. A good indicator of whether the zapped data is improved is the slight changes in signal-to-noise ratio (SNR is defined as the ratio of the signal power to the noise power) before zapping the data and after zapping the data. Usually after excising RFI from the data, the SNR will increase slightly, but if the pulse signal is zapped the SNR will begin to decrease.

Due to this pulsar's drifting in the high-activity state; there are ordered variations in the emission process. So it is necessary to 'scrunch' (the process in which the dispersion-corrected data is averaged over the frequency channels, over the time sub-integrations and over the phase bins) the data after all RFI is removed from the high-activity state. Scrunching the data increases the SNR of each observation in the high-activity state. I compressed the data with single-rotation sub-integration lengths, averaging the observations over a range of time segments. These segments were 30 seconds, 60 seconds, 120 seconds and the total amount of time in every observation ($\sim$ 15 minutes). By breaking the data up into these different segments we can see if there are any trends or correlations in the data as well as see if the RMS[1] of the residuals improves with greater integration lengths. The RMS of residuals gives us an idea of how far away our residuals are from our model. The RMS is determined from two sets of data; one set is the theoretical prediction, which is our pulsar model, and the other is the actual measurement, which is our TOAs. The RMS takes the difference between a TOA and our model and squares each difference and then takes the mean of

[1]Root Mean Square; which is a very common statistical measurement that is used when you want know how much something varies away from a prediction.

all squared differences, and finally takes the square root of that mean. The lower the RMS, the better the timing solution is.

The next step is to measure the pulse time of arrival (TOA) for each observation. TOAs can be determined accurately by a cross-correlation of the observed profile with a high signal-to-noise model profile obtained from the addition of many earlier observations at the particular observing frequency. We use `tempo2` to compare a model of the spin parameters, position, and orbital parameters of the pulsar with the actual observations of TOAs. The difference between the actual and predicted arrival times are known as the pulsar "timing residuals." After calculating these timing residuals, `tempo2` carries out a linear least squares fit to improve the parameters in the model. The standard parameters that are fitted in pulsar timing are right ascension (RAJ), and declination (DECJ), which give the position of the pulsar, pulse frequency (F0) and frequency derivative (F1), which are the basic spin parameters. These parameters get more refined as we add more data to timing residuals, giving a better timing solution for PSR J0941-39. The result of the timing solution for the high-activity state will be discussed in Sec. **??**.

Timing the low-activity state requires a slightly different approach than that of the high-activity state. The low-activity state timing is a little more tricky, because the low-activity state is nulling $> 98\%$ of the time. This means that during the observation, one may only see a few pulses emitted from the pulsar per observation. With only a few pulses being emitted, it is more difficult to distinguish the pulsed signal from RFI in the phase vs. time space.

The first thing to do after obtaining the data is to frequency-zap all the data in the phase vs. frequency plots. It is easier to identify RFI and zap out corrupted frequency channels in phase vs. frequency plots than in the phase vs. time plots because the pulsar is difficult to distinguish from impulsive RFI. By extracting the corrupted frequency channels from the low-activity state, the observation's noise level will decrease, resulting in better TOAs. After frequency zapping, the data signal-to-noise is increased; we are then able to go back through the data looking now at the phase vs. time space plots. We can now more easily distinguish and zap out the RFI from the pulse signal.

The next thing to do after all of the RFI has been removed from the low-activity state is to scrunch the data in time, frequency and bin scrunch the data to 512 bins. We then calculate the time of arrival by cross-correlating the pulse profile with a standard profile template. Finally, we use `tempo2` to compare the model of our parameters with the actual observations of TOAs, giving us a timing solution for the low-activity state; the results of which will be discussed in Sec. 4.

Due to the uniqueness of PSR J0941-39, we not only looked at the timing solution separately, but also with the combined nulling state's data. We took the TOAs from the low-activity and the high-activity state and used `tempo2` to compare the model of our parameters to the TOAs. When looking at the timing residuals we noted that a "jump" must be added to the data in order for the low-activity state and the high-activity state to line up. A jump is a parameter used in `tempo2` that is are often necessary to fit for an arbitrary constant offset between two different sets of arrival times. The jump between the states was suggestive of a phenomenon called a classical mode change. A classical mode change refers to an abrupt transition between two or more quasi-stable states of the different integrated profiles. Classical mode changes were first observed in PSR B1237+25, a five-component pulsar in which pulse power occasionally switches from the trailing two components to the central component [8]. Fitting a jump allowed us to notice two interesting phenomena that occurs between our high-activity and low-activity states. The first was a classic mode change that shifted the TOAs in the low-activity state slightly, and the second is that there also appears to be a glitch in the TOAs. Both of these discoveries will be discussed below.

4 Results

4.1 Timing characteristics

The tables below shows the final timed parameters of PSR J0941-39. Table 1 shows the best timed parameters of the low-activity state. Next, Table 2 shows the best timed parameter of the high-activity state. Table 3 gives the best timed parameters of both the high-activity state and the low-activity state residuals combined together.

Parameters	Measured
RAJ(hms)	09:41:31.08(11)
DECJ(dms)	-39:33:55.52(24)
F0(1/s)	1.70402078058(12)
F1(10^{-16} $1/s^2$)	-1.354(27)
P0(s)	0.586778433519(42)
P1(10^{-17} s/s)	4.662(93)

Table 1: Parameters of the low-activity state

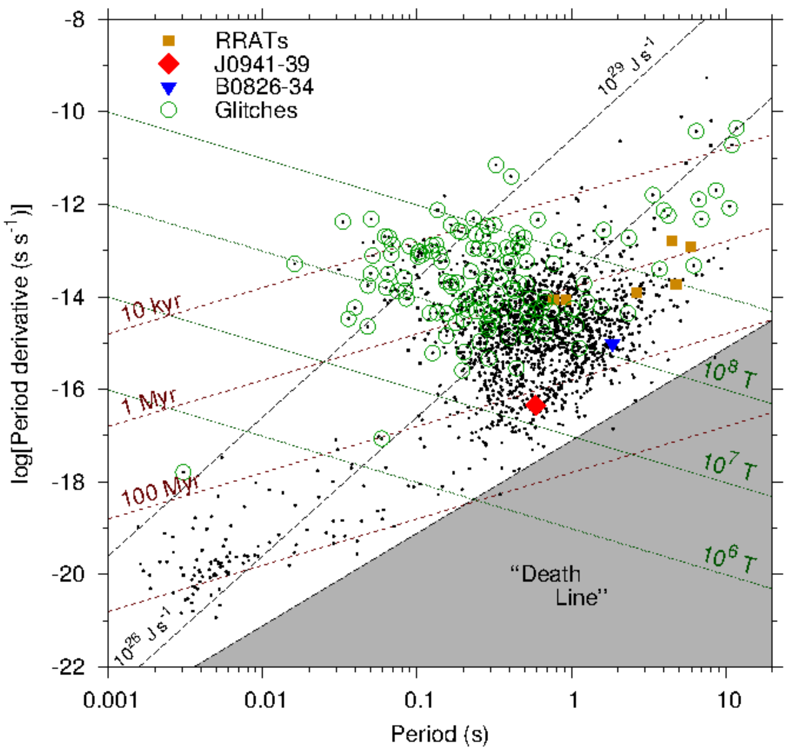

Figure 2: The period derivative vs. period diagram. Lines of constant τ, $B_{\rm surf}$, and $\dot{E}$ are indicated. Yellow squares indicate other RRATs that were discovered. Pulsars with glitches are indicated by the green circles. The blue triangle in this plot indicates the pulsar known as PSR B0826-34, which is the pulsar that is similar to PSR J0941-39. The red diamond shape indicates our pulsar J0941-39.

Parameters	Measured
RAJ(hms)	09:41:31.1706(52)
DECJ(dms)	-39:33:55.912(78)
F0(1/s)	1.704220780284(34)
F1(10^{-16} $1/s^2$)	-1.2923(78)
P0(s)	0.586778433621(12)
P1(10^{-17} s/s)	4.449(26)

Table 2: Parameters of the high-activity state

Parameters	Measured
RAJ(hms)	09:41:31.1869(90)
DECJ(dms)	-39:33:55.94(11)
F0(1/s)	1.704220780414(24)
F1(10^{-16} $1/s^2$)	-1.3212(46)
P0(s)	0.5867784335767(81)
P1(10^{-17} s/s)	4.549(16)
JUMP(s)	-0.00291(26)

Table 3: Parameters for both high-activity state and low-activity state

Figure 2 is a plot of the period vs. period-derivative for various pulsar populations. This plot show us the ages of different pulsars. On this plot the yellow squares indicate other RRATs that were discovered; and known pulsars with glitches are indicated by the green circles. The blue triangle in this plot indicates the pulsar known as PSR B0826-34, which is the pulsar that is similar to PSR J0941-39. The red diamond shape in this plot indicates our pulsar J0941-39; as we can see, our pulsar is very old because it is nearing the death line. The characteristic age (τ) of a pulsar is found by taking the ratio

$$\tau = \frac{P}{2\dot{P}.} \tag{1}$$

PSR J0941-39 is about 189.39 Myr old, which would make this a very old the pulsar. Another characteristic that can be calculated is the strength of magnetic field ($B_{\rm surf}$).

$$B_{\rm surf} = 3.2 \times 10^{19} G\sqrt{P\dot{P}}. \tag{2}$$

The strength of PSR J0941-39 is about 1.718×10^{11} G, meaning that it has a weak magnetic field compared to the general population of pulsars. We can also calculate the spin-down luminosity ($\dot{E}$),

$$\dot{E} = 4\pi I \dot{P} P^{-3}, \tag{3}$$

where I is the moment of inertia I=10^{45}g cm^2. The spin-down luminosity of PSR J0941-39 is approximiately 3.06×10^{30} erg/s, which makes PSRJ0941-39 a dim pulsar. The formulas of the age, magnetic field, and the spin-down luminosity were derived in Lorimer and Kramer [9].

4.2 Discovery of a classic mode change

While using `tempo2` to compare the combined low-activity and high-activity TOAs to the model, we inspected the graph of the pre-fit residuals phase vs. time. (We measure the time in Modified Julian Day, MJD.) We noticed that all of the high-activity TOAs were slightly above the low-activity TOAs. This indicated that a jump was needed to line up the two states. The next thing we wanted to know is what was happening between the high-activity state and the low-activity state for a jump to be needed, so we inspected the pulsar profiles of both the high-activity and low-activity states and overlaid the profiles (Fig. 5).

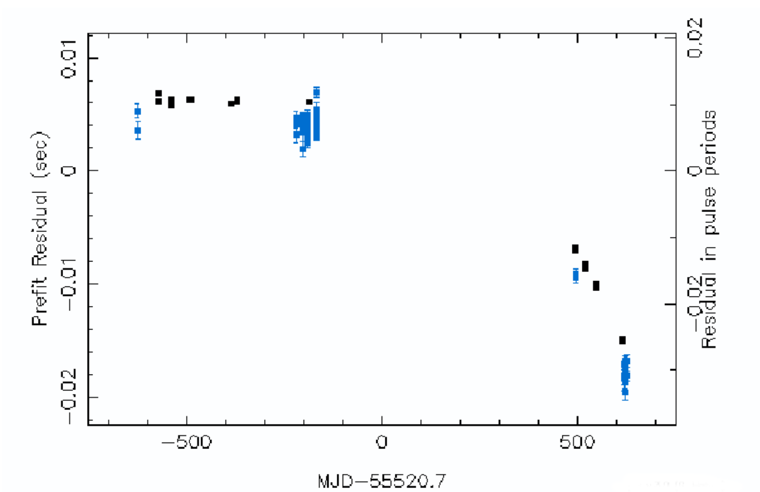

Figure 3: The residuals before the jump is added: high-activity state (black) and low-activity state (blue).

From Fig. 3 and 5 we are able to see that the low-activity state arrives slightly before the high-activity state. What this means is that PSR J0941-

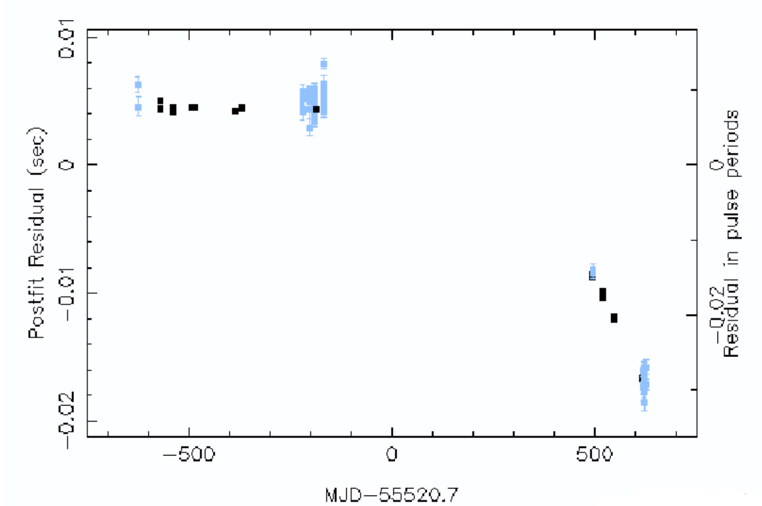

Figure 4: The residuals after the jump is added: high-activity state (black) and low-activity state (blue).

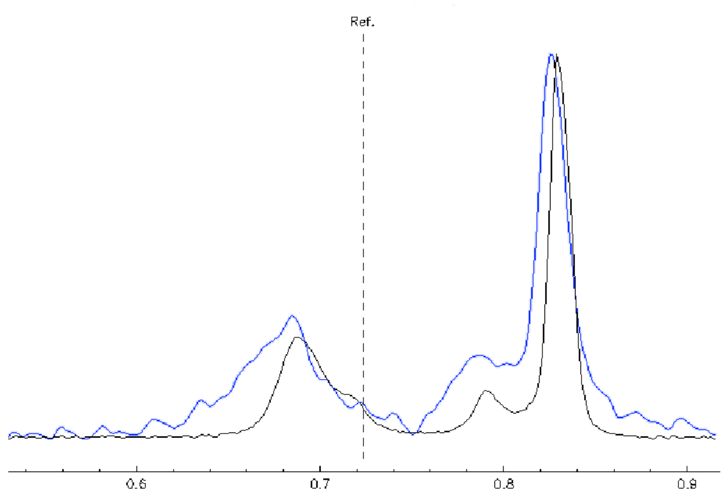

Figure 5: The phase shift of the profiles: high-activity state (black) and low-activity state (blue).

39 has a phase shift between the low-activity state and the high-activity state; it appears that the low-activity pulses are is arriving about 2.9 ms before the pulses of the high-activity state. We know that PSR J0941-39 has a nulling state change, but now after observing a phase shift we learn that PSR J0941-39 also has a classical mode change. A classical mode change usually favors one state for most of the time and then switches sporadically to the abnormal mode at other times. This is a different result than was discussed in Burke-Spolaor and Bailes, who suggested no significant profile component changing between the two states. The difference is attributed to the insufficient amount of data inspected by Burke-Spolaor and Bailes [2].

4.3 Discussion of a sudden change in period

The other result we obtained in the combined high-activity and low-activity state data was that there appears to be an abrupt change in the period. Why there is this abrupt change can be explained by two theories: The first theory is that our pulsar has spin behavior similar to intermittent pulsars, and the second theory is, that the abrupt change is due to a glitch.

As discussed in a previous Sec. 4.2 this pulsar has two nulling states. Due to this nulling state change, we presume PSR J0941-39 should have similar spin-down behavior to intermittent pulsars. Intermittent pulsars have an oscillating period derivative change. An intermittent pulsar will start off in an on state where it shows one value for the period derivative. Then the pulse signal will shut "off"suddenly, leaving either a weak pulse signal or no pulse signal at all. This sudden switching to an "off" state gives a different period derivative. But then at some point the pulsar turns back to an "on" state which then will increase the period derivative back to its original value. Therefore, we expect PSR J0941-39 to have a similar spin-down behavior as an intermittent pulsar since it switches from the high-activity state to the low-activity state. Unfortunately, we are still unable to prove that this is the case because we do not know the switching time scale between the high-activity state and low-activity state and we have not densely-sampled enough data to see a change occurring in the period derivative in each state. Therefore, further investigations are needed to determine whether or not this phenomenon is occurring, or whether the apparent period change is more likely be another phenomenon such as a glitch.

Glitches are characterized by a sudden increase of the pulsar rotation period (P0) accompanied by a change in spin-down rate of the period derivative (P1). The first model for this, proposed by Baym [10], explained glitches as the result of star quakes. Glitches give unique opportunities to study the internal structure of pulsars, due to these star quakes. These are caused by sudden and irregular transfer of angular momentum from the superfluid inner parts of the star to the more slowly rotating crust [12].

In particular, many young neutron stars exhibit (more or less) regular glitches, where the observed spin rate suddenly increases. These spin-up events tend to be followed by a slow relaxation towards the original spin-down rate. There are some cases though in which the glitch leads to a permanent change in the spin-down rate [11]. Glitches are rare and mostly observed for young pulsars around $10^4 - 10^5$ years old but can be found in older pulsars. Figure 2 show the spin-down properties of PSR J0941-39 compared to other glitches. In Fig. 2, there appears to be few other glitching pulsars in the proximity of PSR J0941-39, which indicates that this pulsar does not have typical spin parameters for glitching pulsars .

We examined all the residuals in the "pre-glitch" epoch (the TOAs before the period change) and all the residuals in the "post-glitch" epoch (the TOAs after the period change) and examined the periods and period derivative in a combination of high-activity / low-activity state; results are shown in the tables below.

Parameters	Measured
P0(s)	0.586778433489(18)
P1(10^{-17} s/s)	5.30(26)

Table 4: Pre-change spin parameters of the combined high-activity and low-activity states.

Parameters	Measured
P0(s)	0.586778343(59)
P1(10^{-15} s/s)	1.04(66)

Table 5: Post-change spin parameters of the combined high-activity and low-activity states.

As the tables show, there seems to be an abrupt change of the period, in which the period is increasing. Thus, PSR J0941-39 does have the sudden increase in period indicative of a glitch.

The size of a glitch can be measured by $\Delta\nu/\nu_{pre}$. In which $\Delta\nu$ is the change in frequency (post-glitch minus the pre-glitch) and ν_{pre} is the pre-glitch frequency. The size of our "glitch" is 154×10^{-9}. By measuring the

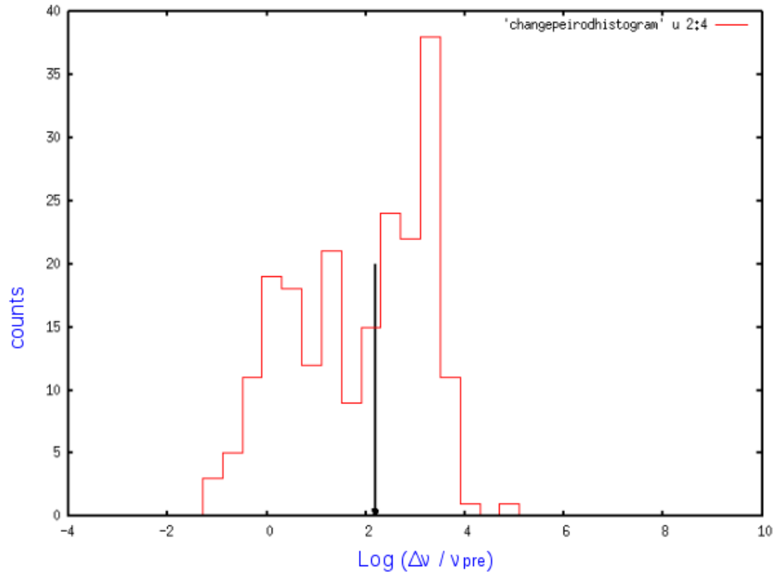

Figure 6: A histogram that shows the average sizes of all known glitches. The black arrow indicates where the size of PSR J0941-39 "glitch" lies in comparison to all known glitches.

size of our "glitch" we get a step closer in determining whether PSR J0941-39 has a glitch. Figure 6 indicates that our glitch does fall in the range of known glitch sizes, making it feasible that the observed change could very well be due to a glitch. Unfortunately further investigations are needed before we can prove or disprove our glitch theory.

5 Conclusions

We discussed the results of our timing solutions and the characteristics we learned from them. One of our discoveries was that PSR J0941-39 has two different types of change, a nulling state change and a classical mode change. The classical mode change was a new discovery that was not known previous to the work described here. Finally, we discussed two theories that could explain our other new discovery, which was an abrupt period change in our combined analysis of the high-activity and low-activity states. The first theory is that our pulsar has a similar spin behavior to intermittent pulsars. The second theory is that PSR J0941-39 has a glitch. We were not able to come to any conclusion about which theory is correct due to the fact that more investigations are needed to make a positive statement explaining why the abrupt period change is happening. However, we do see agreement of the magnitude and behavior of our pulsar's "glitch" with glitches measured in other pulsars.

In future work we hope to investigate both theories in depth. To investigate more on the intermittent theory we would need to obtain more densely-sampled data in order to determine the pulsar nulling state change time scale and we would need to observe more clearly multiple changes in the period derivative. The other theory we hope to investigate is the glitch, but to do this we need to obtain more data and to measure longer-term changing in the period derivative. If the period derivative remains stable throughout all of the nulling state changes, then it is relatively certain that this abrupt period change is a glitch.

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