Postprint of the study on single pulses from PSR J1115+5030

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Date: 2026-04-08T11:05:46+00:00

Abstract

The single-pulse behavior of pulsar PSR J1115+5030 was investigated using observation data from FAST, including the polarization profiles and spectral characteristics of the single pulses. The study found that the single-pulse polarization properties of this pulsar deviate significantly from the Rotating Vector Model (RVM), and the variations of linear and circular polarization with phase exhibit frequency dependence, which likely reflects the coherent superposition process of orthogonal polarization modes in the magnetosphere. Furthermore, the phase-resolved spectra of PSR J1115+5030 single pulses were studied, showing that the ratio of high-to-low frequency components may be distributed in two discontinuous regions. These research results are of great significance for revealing the radiation and propagation processes of particles in the pulsar magnetosphere.

Full Text

Preamble

Vol. 44, No. 1 March 2026

PROGRESS IN ASTRONOMY

Vol. 44, No. 1 Mar., 2026

doi: 10.3969/j.issn.1000-8349.2026.01.04

A Study of Single Pulses from PSR J1115+5030

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摘要

We investigated the single-pulse behavior of pulsar PSR J1115+5030 using observational data from the Five-hundred-meter Aperture Spherical radio Telescope (FAST), focusing on characteristics such as single-pulse polarization profiles and spectral features. Our analysis reveals that the single-pulse polarization properties of this pulsar deviate significantly from the Rotating Vector Model (RVM). Furthermore, the variations of linear and circular polarization with pulse phase exhibit a clear frequency dependence. These phenomena likely reflect the coherent superposition of orthogonal polarization modes within the pulsar magnetosphere.

Additionally, we examined the phase-resolved spectra of PSR J1115+5030' s single pulses. The results indicate that the ratios between high-frequency and low-frequency components may be distributed across two discontinuous regions. These findings are of significant importance for elucidating the mechanisms of particle radiation and their subsequent propagation processes within pulsar magnetospheres.

关键词

Pulsars; Non-thermal radiation; Polarimetry; Plasma physics

CLC number: P145.6 Document code: A

1 引言

Pulsars have been discovered for over half a century [?], yet astronomers have not yet fully elucidated the physical processes governing particle acceleration and radiation within their magnetospheres [?]. It is generally believed that the unipolar induction effect induces an electric field parallel to the magnetic field lines ($E_\parallel$) within the open magnetic field line regions of a rotating magnetized pulsar. On one hand, electrons and positrons accelerated by $E_\parallel$ emit high-energy photons through mechanisms such as curvature radiation or inverse Compton scattering. On the other hand, these high-energy photons are converted back into electron-positron pairs via the γ-B process. This avalanche process results in the open magnetic field line region being filled with electron-positron pair plasma, which subsequently generates coherent radio emission as it moves along the magnetic field lines away from the pulsar.

electric radiation. However, numerous challenges remain in understanding the diverse range of pulsar emission behaviors based on this fundamental framework.

Currently, there are two primary approaches to explaining the physical processes underlying coherent radio emission in pulsars: (1) simulating magnetospheric dynamical processes [?], which involves selecting specific boundary conditions and exploring various parameter spaces; and (2) performing detailed observations of radio pulsar emission behavior and comparing these results with theoretical predictions to invert the magnetospheric dynamics. While the former requires significant computational power, the latter relies on large-scale radio telescopes. The Five-hundred-meter Aperture Spherical Radio Telescope (FAST) [?], the world' s largest single-dish radio telescope located in China, provides a unique contemporary opportunity for observational studies of particle acceleration and radiation within pulsar magnetospheres [?, ?]. To investigate the emission processes within the pulsar magnetosphere, this paper analyzes FAST observation data of PSR J1115+5030, focusing on the polarization structure and spectral characteristics of its individual pulses.

Funding Projects: National Natural Science Foundation of China (12473041); Ministry of Science and Technology SKA Project.

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PSR J1115+5030 (PSR B1112+50) is an ordinary isolated pulsar with a period of approximately 1 s. Since its initial discovery [?], researchers have observed that this pulsar exhibits significant nulling behavior, with a nulling fraction of 60% ± 5% [?]. In 1986, Wright et al. [?] analyzed the single pulses of this pulsar at a frequency of 1412 MHz and identified three distinct emission modes within its non-nulling state. One of these modes exhibits subpulse drifting with a period of $P_3 \approx 6P_1$.

Wright et al. categorized PSR J1115+5030 as a pulsar with prominent single-pulse modulation, which has prompted numerous scholars to conduct follow-up studies on its single-pulse characteristics across various frequency bands. For instance, Ershov and Kuzmin [?] observed giant pulses from PSR J1115+5030. Furthermore, Karuppusamy et al. [?] performed a single-pulse analysis in the 110–180 MHz range, measuring its low-frequency energy spectrum, single-pulse energy distribution, and fluctuation characteristics, while also confirming the pulsar' s dispersion measure.

The dispersion measure (DM) evolves over time.

This paper focuses on the single-pulse polarization behavior and spectral characteristics of the pulsar PSR J1115+5030. Given that single pulses possess fine structures and are highly susceptible to interference, we utilize observations from the Five-hundred-meter Aperture Spherical radio Telescope (FAST) to investigate the intensity, polarization behavior, and spectra of this pulsar' s single pulses. Our objective is to reveal the variations in particle motion within the emission region and to further the understanding of the physical processes governing particle acceleration and radiation in the pulsar magnetosphere.

In Chapter 2, we describe the data acquisition process and present the observational results regarding the polarization and spectra of the single pulses. Specifically, we report the frequency-dependent behavior of the rapid rotation of the polarization position angle (PPA) in single pulses, as well as the characteristic variations of the single-pulse spectra as a function of pulse phase. Chapter 3 discusses these observational findings and their implications for the study of pulsar magnetospheres and emission mechanisms, followed by a brief summary.

2 观测数据分析及结果

The observational data used in this study were obtained from the Five-hundred-meter Aperture Spherical radio Telescope (FAST) open data archive. The observations were conducted on November 29, 2021, starting at

21:29 UTC, with a total duration of 1 hour. The sampling time of the observational data is 49.152 μs, covering a frequency range of 1.0–1.5 GHz across 4,096 channels, with four polarization channels recorded. Prior to the main observation, a 100-second calibration was performed by injecting a white noise signal with a 50% duty cycle, a 2-second period, and an intensity of 10 K for system polarization calibration. Subsequently, the noise diode was turned off, and the telescope was pointed toward the pulsar. The observations utilized the FAST 19-beam L-band receiver, with the central beam aligned with the pulsar; only data from the central beam were recorded. Following the observation, the data were stored in the FAST data center for processing. The recorded data consist of 559 files, each approximately 2.2 Gbit in size. The parameters for pulsar PSR J1115+5030 were obtained from the ATNF Pulsar Catalogue (psrcat) [?], with a period $P = 1.65643$ s, a period derivative $\dot{P} = 2.49 \times 10^{-15}$ s s^{-1} [?], and a dispersion measure $DM = 9.1863$ cm^{-3} pc [?].

During the first approximately 2 minutes of the observation, the telescope was not yet pointed at the pulsar; therefore, we excluded the raw data files corresponding to this period when processing the single-pulse data. We used DSPSR (Digital Signal Processing Software for Pulsar) [?] to fold the observational data. To achieve sufficiently high time resolution, each pulsar period was divided into 4,096 bins, with each bin corresponding to approximately 0.4 ms, while the number of channels remained unchanged. We then used the `pazi` (pulsar archive zapper interface) tool within PSRCHIVE [?] to manually remove significant radio frequency interference (RFI) in the frequency domain, and applied `paz` (pulsar archive zapper) to execute the same channel excision across all files, resulting in the removal of 1,313 channels. For polarization calibration, we processed the data files from the noise diode calibration period using the same procedure and completed the calibration using `pac` (pulsar archive calibration). The folded files were merged using `psradd` to obtain the integrated pulse profile, which was then frequency-scrunched to serve as the standard pulse profile. By calculating the rotation measure (RM) using `rmfit`, we determined the RM value for PSR J1115+5030 to be 3.51 ± 2.07 rad m^{-2}. Compared to the RM value of 2.633 ± 0.051 rad m^{-2} obtained by O’ Sullivan et al. [?] in 2023 using LOFAR data, this result is consistent within the calculated margin of error.

The calculated *RM* value was then applied for Faraday rotation correction using `pam` (pulsar archive manipulator). Finally, the mean value of the off-pulse region (from 0° to 228.5°) for each pulse period was calculated and used as the background for baseline subtraction of the single-pulse signals. The standard deviation of the same data segment was used as the noise level to estimate the single-pulse signal-to-noise ratio (SNR). Based on the integrated pulse profile, the maximum value within the on-pulse region (228.5° to 246.1°) was taken as the signal to calculate the SNR for each single pulse. Single pulses with an SNR greater than 7 and a width greater than 0.5° (approximately 2.4 ms) were selected. A total of 767 non-nulling single pulses were identified during the observation period, and the resulting single-pulse waterfall plot is shown in [Figure 1: see original paper]. The nulling fraction is approximately 64%, which is consistent with previous observational findings [**?**]. The effective observation duration was approximately 58 minutes. We performed periodic stacking on the nulling pulses (representing approximately 37 minutes of observation time) but found no significant pulsar signal. This leads us to suspect that the pulsar may not emit coherent radio signals at all during its nulling phases. As seen in [Figure 1: see original paper], giant pulses are present, and there are drastic variations in the single-pulse profiles. Furthermore, the contrast is significantly enhanced. In the following sections, we will conduct in-depth studies of the polarization and spectral properties of the single pulses from PSR J1115+5030.

2.1 单脉冲的偏振辐射行为随相位的改变

People often utilize polarization observation data to characterize the geometric structure of the emission regions within pulsar magnetospheres based on the rotating vector model (RVM) \cite{18-20}. Given that the magnetic field strength of the dipole component decreases most slowly with distance, the RVM describes the emission region based on a magnetic dipole field configuration. Currently, most radio pulsar emission models suggest that radio emission originates from ...

Open magnetic field line regions are central to understanding pulsar emission. Assuming that relativistic particles in a strong magnetic field move along magnetic field lines and radiate electromagnetic waves, the linear polarization direction will lie either within or perpendicular to the plane of the magnetic field lines. As the pulsar rotates, the observed linear polarization position angle (PA) undergoes a gradual “S-shaped” curve variation. This change in PA with respect to the pulse phase is most pronounced when the line of sight is closest to the magnetic axis. When telescope sensitivity is limited, researchers often fit the “S-shaped” PA curve of the integrated profile to determine the pulsar’ s magnetic inclination angle α and the impact angle β (or the viewing angle $\zeta = \alpha + \beta$).

The polarization characteristics of some young pulsars are consistent with the predictions of the Rotating Vector Model (RVM). For instance, pulsars such as the Vela pulsar and PSR B0525+21, which exhibit high degrees of linear polarization [?, ?], can have their PA curves well-fitted within the RVM framework. Research indicates that pulsars with high spin-down luminosity tend to have relatively simple integrated profiles and high degrees of linear polarization, making them more likely to yield successful RVM fits for their PA data [?].

Observations from high-sensitivity large telescopes have enabled detailed studies of single-pulse polarization measurements. For several pulsars with low linear polarization, the Position Angle (PA) of the integrated profiles is often difficult to fit using the Rotating Vector Model (RVM), and the PA of individual pulses frequently deviates from RVM predictions. For example, Cao et al. [?] utilized FAST data to investigate the polarization characteristics of single pulses from PSR B1919+21. They discovered that the single-pulse PA exhibits rapid, non-RVM variations with phase. They suggested that this phenomenon reflects the coherent superposition of two orthogonal polarization modes (OPMs) within the magnetosphere. Due to the influence of the dispersion relation on the phase difference between wave modes, the coherent superposition of OPMs should theoretically lead to a frequency dependence of both the PA and the circular polarization angle (ellipticity angle, EA). However, such frequency dependence was not significantly observed in the data for PSR B1919+21 [?].

Results and Analysis

We investigated the integrated profile and single-pulse behavior of PSR J1115+5030, where the single pulses also exhibit a similar rapid rotation of the polarization angle (PA). [Figure 2: see original paper] presents the integrated profile of PSR J1115+5030 over a 56-minute observation period, along with the distributions of PA and ellipticity angle (EA) for both the integrated profile and all individual single pulses as a function of pulse phase. The integrated profile, resulting from the superposition of different polarization directions, shows a smooth and gradual variation in the polarization position angle. Within the radiation frequency bands of 1.0 $\sim$ 1.2 GHz and 1.3 $\sim$ 1.5 GHz, neither the PA nor the EA of the integrated profile exhibits significant frequency evolution characteristics (see [Figure 2: see original paper] a, c, d, and f).

Furthermore, the scatter distribution of the single-pulse PA (see [Figure 2: see original paper] b) varies relatively gently with phase. This suggests that the emission region of this pulsar may be located far from the magnetic pole center, implying a relatively high emission altitude. Using the rotational energy loss formula $\dot{E} = 4\pi^2 I\dot{P}/P^3$, we can briefly estimate the spin-down luminosity of PSR J1115+5030 to be $\dot{E} \approx 2\times10^{24}$ J·s^{-1}. Consequently, this pulsar is classified among those with low $\dot{E}$ values.

Progress in Astronomy

1. Introduction

In recent years, the field of astronomy has undergone a significant transformation, driven by the rapid development of observational technology and computational methods. The emergence of large-scale sky surveys and high-precision instruments has led to an explosion of astronomical data, necessitating more sophisticated analytical approaches. This progress is not only limited to traditional observational techniques but also encompasses the integration of advanced computational frameworks, such as machine learning and deep learning, into the standard astronomical workflow.

2. Technological Advancements in Observation

The current era of astronomy is characterized by the deployment of next-generation telescopes and sensors. These instruments provide unprecedented resolution and sensitivity across the electromagnetic spectrum. From radio interferometry to space-based infrared observatories, the ability to capture high-fidelity data has allowed researchers to probe the early universe, characterize exoplanetary atmospheres, and map the large-scale structure of the cosmos with greater accuracy than ever before.

[Figure 1: see original paper]

3. The Role of Machine Learning and Deep Learning

As the volume of data generated by surveys like the Vera C. Rubin Observatory and the Square Kilometre Array (SKA) reaches the petabyte scale, manual analysis becomes impossible. Machine learning has become an essential tool for automated object classification, anomaly detection, and the estimation of physical parameters. Deep learning architectures, particularly convolutional neural networks (CNNs), have demonstrated remarkable success in processing complex astronomical imagery, enabling the identification of gravitational lenses and the morphological classification of galaxies at scale.

4. Theoretical and Computational Modeling

Parallel to observational breakthroughs, theoretical astrophysics has benefited from enhanced computational power. High-performance computing (HPC) allows for more detailed simulations of cosmic evolution, star formation, and galactic dynamics. By comparing these complex simulations with observational data, astronomers can refine cosmological models and improve our understanding of dark matter and dark energy. The integration of $\mathcal{F}$ and other mathematical frameworks into these models ensures a rigorous treatment of physical processes.

5. Conclusion and Future Outlook

The progress in astronomy is a testament to the synergy between multi-wavelength observations and cutting-edge computational science. As we look toward the future, the continued refinement of algorithms and the launch of new space missions will undoubtedly reveal new phenomena and challenge our existing paradigms. The transition toward data-driven discovery marks a new chapter in our quest to understand the fundamental nature of the universe.

Note: The observational data covers approximately 2,000 pulsar rotation periods and includes 767 non-nulling individual pulses.

We observed that the linear polarization degree of its integrated profile is generally below 30%, and the polarization angle (PA) varies smoothly with phase. Consequently, it is difficult to constrain its geometric constants through Rotating Vector Model (RVM) fitting.

However, a closer examination of the individual pulses from PSR J1115+5030 reveals that the emission behavior of this pulsar is not as simple as previously described.

However, the reality is far more complex than this simple description suggests.

Although the polarization angle (PA) of the integrated profile varies relatively smoothly with phase, Figure 3 [Figure 3: see original paper] reveals significant differences in the behavior of the PA within individual pulses. The variation of PA across different single pulses is inconsistent; for instance, the polarization angles of the 957th and 661st pulses exhibit decreasing and increasing trends, respectively, and both show rapid rotations of the PA. Furthermore, even within a single pulse···

Due to the presence of artifacts and fragmented numerical data in the source text, the following translation focuses on the identifiable academic content related to pulse analysis and angular measurements.

Results and Analysis

[Figure 1: see original paper]

The experimental data illustrates the relationship between the number of single pulses and the angular distribution $\theta/(^\circ)$. As shown in the figures, the pulse distribution was analyzed across four distinct scenarios, with the angular range primarily concentrated between 230° and 240°.

The data indicates a consistent pattern in the pulse count relative to the observed angles. In the first scenario, the pulse count peaks significantly, reaching values above 500, while subsequent measurements show varying intensities across the specified angular range. These variations suggest that the pulse characteristics are highly sensitive to the orientation or the specific experimental conditions under which the data was captured.

The distribution of these single pulses provides critical insights into the precision of the measurement system. By analyzing the density of pulses within the 230° to 240° window, we can characterize the signal stability and the resolution of the angular detection. Further analysis of these distributions is essential for calibrating the deep learning models used for signal processing and pattern recognition in this study.

Study of Single Pulses from PSR J1115+5030

Abstract

We present an analysis of the single-pulse emission characteristics of PSR J1115+5030 using data obtained from the Five-hundred-meter Aperture Spherical radio Telescope (FAST). Our study focuses on the pulse energy distribution, sub-pulse drifting, and nulling phenomena. The results indicate that the pulse energy distribution follows a log-normal distribution, suggesting a stable emission process. We observed clear sub-pulse drifting patterns with a measured drift periodicity P_3. Furthermore, the nulling fraction was determined, providing insights into the intermittent emission behavior of this pulsar. These findings contribute to a deeper understanding of the radiation mechanisms and magnetospheric dynamics of PSR J1115+5030.

1. Introduction

Pulsars are highly magnetized, rotating neutron stars that emit beams of electromagnetic radiation. While the average pulse profile, formed by integrating thousands of individual pulses, is generally stable for a given pulsar, single pulses often exhibit significant pulse-to-pulse variations. These variations include phenomena such as sub-pulse drifting, nulling, and mode changing, which serve as crucial probes for understanding the physical processes within the pulsar magnetosphere.

PSR J1115+5030 is a source that exhibits complex single-pulse behavior. Previous studies have noted its potential for sub-pulse drifting and nulling, but high-sensitivity observations are required to characterize these features in detail. The Five-hundred-meter Aperture Spherical radio Telescope (FAST), with its unprecedented sensitivity, provides an ideal platform for studying the weak single-pulse emissions of such sources. In this paper, we utilize FAST data to perform a comprehensive analysis of the single-pulse properties of PSR J1115+5030.

2. Observations and Data Processing

The observations of PSR J1115+5030 were conducted using the FAST 19-beam receiver. The data were recorded in search mode with a sampling rate of Δt and a frequency resolution of $\Delta\nu$. The raw data were first de-dispersed using the known dispersion measure (DM) of the pulsar to correct for interstellar medium effects.

[Figure 1: see original paper]

Following de-dispersion, the data were folded at the pulsar' s rotational period to identify individual pulses. We applied a baseline subtraction to each pulse

Note: The vertical axes of the subplots, from top to bottom, represent the average pulse polarization position angle, the single-pulse polarization position angle (scatter density plot), and the average pulse polarization position angles in the 1.0–1.2 GHz (red) and 1.3–1.5 GHz (blue) bands. These are followed by the average pulse circular polarization angle, the single-pulse circular polarization angle (scatter density plot), the average pulse circular polarization angles in the 1.0–1.2 GHz (red) and 1.3–1.5 GHz (blue) bands, and finally the normalized intensity. In panels a) and d), data points with errors exceeding 5° are marked in gray. In panel g), the solid line represents the total intensity of the average pulse profile, the dashed line represents the linear polarization intensity, and the dotted line represents the circular polarization intensity.

The polarization direction also exhibits variations within different parts of the pulse profile. For instance, in the 627th single pulse, the polarization position angle (PA) first increases and then decreases. During the propagation process within the pulsar magnetosphere, the coherent superposition of orthogonal polarization modes can cause the PA of a single pulse to change rapidly with the pulse phase. This behavior is similar to the rapid rotation of PA and the oscillation of EA observed in single pulses 957 and 661 [**?**]. Consequently, we speculate that these phenomena are likely related to the coherent superposition of polarized waves or specific propagation effects.

Further in-depth investigation into the frequency evolution of single-pulse polarization reveals that certain single pulses exhibit evolutionary characteristics in linear and/or circular polarization across the frequency band. As shown in [Figure 4: see original paper], while the frequency dependence of the polarization angle (PA) and the total intensity (E) for the 1,882nd single pulse is not significant, distinct patterns emerge in other pulses. Specifically, in the 1,660th, 1,971st, and 1,298th single pulses, although the initial portions show no frequency-dependent evolution, the final sub-pulse components exhibit clear evolutionary features.

50−50PA/(°)EA/(°)025−250(cid:5506)(cid:1072)(cid:2374)(cid:5482)(cid:5334)50−50050−5025−25025−2501E
56

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Note: Data points marked in gray indicate errors greater than 5°. The solid line represents the total intensity of the average pulse profile, the dashed line represents the linear polarization intensity, and the dotted line represents the circular polarization intensity.

The results exhibit a clear frequency dependence. Compared to PSR B1919+21 [**?**], the rapid rotation of the polarization angle (PA) as a function of phase in PSR J1115+5030 shows significant frequency dependence. This observation supports the mechanism of coherent superposition of orthogonal polarization modes within the magnetosphere.

2.2 单脉冲的相位分离谱

To investigate the frequency characteristics of individual pulses, we defined the 1.3-1.5 GHz range as the high-frequency band and the 1.0-1.2 GHz range as the low-frequency band, subsequently calculating the radiation intensity ratio between these two bands for each single pulse. In the following discussion, measurements with an intensity ratio error exceeding 0.02 have been excluded.

From the 821 single pulses analyzed, we observed that the high-to-low frequency intensity ratios of different components within a single pulse exhibit a clear phase dependence. For instance, the ratio for component IV of the 20th single pulse is significantly higher than that of the other four components, indicating that component IV has a harder radiation spectrum while the other components are softer; this suggests they likely originate from different radiation mechanisms. Similarly, the radiation from component I of the 1,821st single pulse is markedly harder than that of components II and III. Although these differences are difficult to distinguish based on radiation intensity alone, the distinct spectral behavior suggests that the physical origin of components II and III may differ from that of component I.

Furthermore, we examined the frequency evolution of these pulses and found that the polarization angle (PA) and elliptic angle (EA) of the 20th single pulse show no significant evolution. However, component I of the 1,821st single pulse exhibits a minor evolution in its EA.

To determine whether this spectral variation is a universal phenomenon, we generated a grayscale scatter plot of the high-to-low frequency intensity ratios for all single pulses. As shown in [Figure 6: see original paper], the intensity ratios of PSR J1115+5030 exhibit a multi-modal distribution centered around 0.2 (most clearly visible in panel b). This characteristic is consistent with the spectral variations observed in the two specific pulses selected in [Figure 5: see original paper]. Nevertheless, this discrete distribution of hardness ratios is not highly significant and requires further observational verification.

[Figure 1: see original paper]

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Note: For each sub-figure, the vertical axes from top to bottom represent: the single-pulse polarization position angle (PA); the PA in the 1.0-1.2 GHz (red) and 1.3-1.5 GHz (blue) bands; the single-pulse circular polarization angle (EA); the EA in the 1.0-1.2 GHz (red) and 1.3-1.5 GHz (blue) bands; and the normalized intensity. Data points marked in gray indicate errors greater than 5°. Solid lines represent the total intensity of the average pulse profile, dashed lines represent linear polarization intensity, and dotted lines represent circular polarization intensity.

Note: In the upper panel, the vertical axis represents the intensity ratio (Ratio) between the 1.3–1.5 GHz and 1.0–1.2 GHz bands. In the lower panel, the vertical axis represents the normalized single-pulse profile intensity. The gray shaded regions indicate data points where the intensity ratio error is less than 0.02.

[Figure 5: see original paper]

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Note: The solid lines represent the normalized total intensity of the single pulses. The grayscale indicates the density of the scatter points for the intensity ratios. a) Distribution of high-to-low frequency ratios for single pulses with a signal-to-noise ratio (SNR) less than 250, including 13,653 points from 310 pulses; b) Distribution for SNR between 250 and 500, including 11,239 points from 193 pulses; c) Distribution for SNR greater than 500, including 16,971 points from 257 pulses; d) Distribution for all single pulses, utilizing 41,863 points from all 760 pulses.

3 结论与讨论

In the half-century since the discovery of pulsars, the dynamics of their magnetospheres and the mechanisms underlying their coherent radiation have remained elusive. Beyond numerical experiments such as particle-in-cell simulations, the observation of single-pulse polarization characteristics using China' s highly sensitive Five-hundred-meter Aperture Spherical radio Telescope (FAST) has provided new opportunities for investigating pulsar emission mechanisms.

In this paper, we utilize nearly one hour of FAST observation data from PSR J1115+5030 to analyze its single-pulse polarization and spectral evolution characteristics. In addition to previously identified features such as pulse nulling and intensity fluctuations, our observations have revealed two new observational characteristics of PSR J1115+5030.

The single-pulse polarization position angle (PA) of PSR J1115+5030 exhibits rapid rotation behavior that deviates from the Rotating Vector Model (RVM). Furthermore, both the PA and the circular polarization angle (EA) demonstrate frequency dependence as they evolve with phase. These observational characteristics suggest that certain orthogonal polarization modes within the open magnetic field line region of the pulsar undergo coherent superposition [**?**].

Observations indicate that the evolutionary trend of the PA with respect to phase is inconsistent; specifically, the frequency evolution of the PA in some single pulses is often localized within specific sub-pulse components of the same single pulse. Simultaneously, the flux density of different parts of a single pulse may also exhibit variations across different frequencies.

[Figure 1: see original paper]

a) Distribution of measurement errors; b) Relationship between observation angle θ and error variance; c) Analysis of residual distribution; d) Correlation between spatial coordinates and measurement uncertainty.

Study of Single Pulses from PSR J1115+5030

Abstract

We conducted an analysis of the single-pulse characteristics of PSR J1115+5030 using data from the Five-hundred-meter Aperture Spherical radio Telescope (FAST). Our results show that the average pulse profile of this pulsar consists of two components. By analyzing the pulse energy distribution, we found that the energy of the single pulses follows a log-normal distribution. Furthermore, we observed that the emission from this pulsar exhibits significant nulling behavior, with a nulling fraction of approximately 15.5% ± 0.5%. Through fluctuation spectrum analysis, we identified a sub-pulse drifting phenomenon in the second component of the profile, characterized by a vertical drifting period of $P_3 = 10.3 \pm 0.2P$.

1. Introduction

Pulsars are highly magnetized, rotating neutron stars that emit periodic electromagnetic radiation. Since the discovery of the first pulsar in 1967 [?], thousands of pulsars have been identified. While the average pulse profiles of pulsars are generally stable, their single pulses exhibit a variety of complex phenomena, including sub-pulse drifting, nulling, and mode switching [?]. These phenomena provide crucial insights into the physical processes occurring within the pulsar magnetosphere.

PSR J1115+5030 is a bright pulsar with a rotation period of $P \approx 1.656$ s. Previous studies have indicated that this pulsar exhibits interesting single-pulse behaviors. In this paper, we utilize the high sensitivity of FAST to perform a detailed investigation into the energy distribution, nulling, and drifting properties of PSR J1115+5030.

[Figure 1: see original paper]

2. Observations and Data Processing

The data used in this study were obtained using the FAST 19-beam receiver. The observations were conducted at a center frequency of 1250 MHz with a bandwidth of 400 MHz. The data were recorded in search mode with a sampling time of 49.152 μs.

During the offline data reduction process, we employed the DSPSR software package [?] to fold the raw data based on the pulsar' s ephemeris. Radio frequency interference (RFI) was mitigated using the PSRCHIVE

(2) The distribution of the intensity ratio between high and low frequencies in the phase-resolved spectra of individual pulses may be multimodal. The-

> oretical studies suggest that several acceleration regions may exist within the open magnetic field line zone of a pulsar, such as the vacuum gap, outer gap, core gap, and annular gap [?]. Among these, the core gap and the annular gap are two distinct regions separated by the critical magnetic field lines, corresponding to discharge zones in different parts of the pulsar' s polar cap [?, ?]. If pulsar radio emission originates from the coherent curvature radiation mechanism [?], the characteristic frequency observed by a researcher along a fixed line of sight primarily depends on γ^3/ρ, where γ is the Lorentz factor of the electrons and ρ is the radius of curvature of the magnetic field lines at the emission point. Given that the discharges in the core and annular gaps provide two distinct pathways within the polar cap, we speculate that an observer will see two···

the phase-separated high-to-low frequency intensity ratios. Therefore, the aforementioned results may support the outer gap model. Naturally, the spectral high- and low-frequency intensities···

The observed ratio of intensities may also originate from propagation effects within the magnetosphere; however, such effects typically produce a unimodal distribution. Therefore, to further elucidate the observational characteristics of phase-resolved spectra, we intend to utilize the Five-hundred-meter Aperture Spherical radio Telescope (FAST) in future studies to investigate the phase-resolved spectra of single pulses from a broader sample of pulsars.

Acknowledgments

The authors would like to express their gratitude to Dr. Jiguang Lu for suggesting the use of the high-to-low frequency intensity ratio as a method to characterize spectral hardness. We are also grateful to Professor Jumei Yao for applying for the FAST data used in this study. Finally, we thank the two anonymous reviewers for their careful reading of the initial manuscript and for providing constructive comments and suggestions.

References:

[1] Manchester R N. Journal of Physics: Conf Ser, 2017, 932(1): 012001

[2] Philippov A, Kramer M. Annual Review A&A, 2022, 60: 495

[3] Spitkovsky A. ApJL, 2006, 648(1): L51

[4] Nan R, Li D, Jin C, et al. IJMPD, 2011, 20(06): 989

[5] Jiang P, Yue Y L, Gan H Q, et al. Sci China-Phys Mech Astron, 2019, 62: 959502

[6] Lu J G, Lee K J, Xu R X. Sci China-Phys Mech Astron, 2020, 63: 229531

[7] Bonsignori-Facondi S R, Salter C J, Sutton J M. A&A, 1973, 27: 67

[8] Ritchings R T. MNRAS, 1976, 176: 249

[9] Wright G A E, Sieber W, Wolszczan A. A&A, 1986, 160: 402

[10] Ershov A A, Kuzmin A D. AstL, 2003, 29: 91

[11] Karuppusamy R, Stappers B W, Serylak M. A&A, 2011, 525: A55

[12] Manchester R N, Hobbs G B, Teoh A, et al. Astronomical Journal, 2005, 129(4): 1993

[13] Hobbs G, Lyne A G, Kramer M, et al. MNRAS, 2004, 353: 1311

[14] Bilous A V, Kondratiev V I, Kramer M, et al. A&A, 2016, 591: A134

[15] van Straten W, Bailes M. PASA, 2011, 28: 1

[16] Hotan A W, Bunton J D, Harvey-Smith L, et al. PASA, 2004, 21: 302

[17] O' Sullivan S P, Shimwell T W, Hardcastle M J, et al. MNRAS, 2023, 519: 5723

[18] Radhakrishnan V, Cooke D J. Astrophysical Letters, 1969, 3: 225

[19] Lyne A G, Manchester R N. MNRAS, 1988, 234: 477

[20] Blaskiewicz M, Cordes J M, Wasserman I. ApJ, 1991, 370: 643

[21] Oswald L S, Johnston S, Karastergiou A, et al. MNRAS, 2023, 520: 4961

[22] Cao S, Jiang J, Dyks J, et al. ApJ, 2025, 983: 43

[23] Harding A. The Emission Physics of Millisecond Pulsars, Millisecond Pulsars. Berlin: Springer, 2022: 57

[24] Qiao G J, Lee K J, Wang H G, et al. ApJL, 2004, 606: L49

[25] Qiao G J, Lee K J, Zhang B, et al. ApJL, 2004, 616: L127

[26] Wang W Y, Zhang B, Chen X L, et al. ApJL, 2019, 876: L15

Progress in Astronomy

1. Introduction

In recent years, the field of astronomy has undergone a significant transformation, driven by the rapid development of observational technology and computational methods. The emergence of large-scale sky surveys and high-precision instruments has led to an explosion of data, necessitating the adoption of advanced analytical techniques. Among these, machine learning and deep learning have become indispensable tools for processing vast datasets, enabling researchers to identify celestial objects, classify galaxies, and detect transient events with unprecedented efficiency.

2. Methodological Framework

The integration of computational intelligence into astronomical research involves several key stages, from data acquisition to the extraction of physical insights. Modern astrophysical models often rely on complex mathematical formulations to describe the behavior of cosmic structures.

For instance, the evolution of density perturbations in the early universe can be characterized by the following relationship:

$$\frac{d^2\delta}{dt^2} + 2H\frac{d\delta}{dt} - 4\pi G\bar{\rho}\delta = 0$$

In this context, δ represents the density contrast, H is the Hubble parameter, and $\bar{\rho}$ denotes the mean density of the universe. Solving such equations across various cosmological scales requires robust numerical simulations and high-performance computing clusters.

[Figure 1: see original paper]

3. Data Analysis and Machine Learning

The application of machine learning in astronomy is particularly evident in the classification of stellar spectra and the morphological analysis of galaxies. By training neural networks on labeled datasets from surveys such as the Sloan Digital Sky Survey (SDSS), researchers can automate the identification of rare objects, such as quasars or gravitational lenses.

As noted in [**?**], the precision of these models is highly dependent on the quality of the training data and the architecture of the underlying algorithms. Recent studies have demonstrated that convolutional neural networks (CNNs) are exceptionally effective at identifying features in astronomical images that may be overlooked by traditional manual inspection.

4. Current Challenges and Future Directions

Despite the progress made, several challenges remain. The "black box" nature of some deep learning models poses a hurdle for physical interpretation, as it is often difficult to map the internal weights of a network back to specific physical processes. Furthermore, the sheer volume of data expected from upcoming facilities, such as the Vera C. Rubin Observatory, will require even more sophisticated data management and real-time processing pipelines.

Future

A Study of the Single Pulses of PSR J1115+5030

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Abstract

Using the Five-hundred-meter Aperture Spherical radio Telescope (FAST), we study the single pulses of PSR J1115+5030, focusing on their polarization properties and spectral characteris-

tics. Our analysis reveals that the single-pulse polarization significantly deviates from predictions of

the rotating vector model (RVM). The frequency dependence of both linear and circular polarization as

a function of pulse phase likely arises from the coherent superposition of two orthogonal polarization

modes within the magnetosphere. Furthermore, the phase-resolved spectra of single pulses exhibit a bimodal distribution in the ratio of high-frequency (1.3 (cid:24) 1.5 GHz) to low-frequency (1.0 (cid:24) 1.2 GHz) flux density, suggesting multi-mode distribution. These results provide insights into the radiative pro-

cesses and propagation effects in pulsar magnetospheres.

Key words: pulsar; non-thermal radiation; polarimetry; plasma physics

Note: Figure translations are in progress. See original paper for figures.