ВАК 2024 MODERN ASTRONOMY: FROM THE EARLY UNIVERSE TO EXOPLANETS AND BLACK HOLES
300 years Russian Academy of Sciences

Observations of giant pulses from B0531+21 at the Institute of Applied Astronomy

I. Bezrukov, I. Gayazov, A. Dyakov, D. Ivanov, A. Ipatov, S. Kurdyubov, D. Marshalov, A. Melnikov, A. Mikhaylov, V. Olifirov, and I. Rakhimov

Institute of Applied Astronomy of the Russian Academy of Sciences, Kutuzov emb. 10, Saint Petersburg, 191187 Russia

Abstract. This paper presents the results of observations of giant pulses from the pulsar B0531+21 (the Crab Nebula pulsar) conducted at the Institute of Applied Astronomy of the Russian Academy of Sciences (RAS). The primary aim of the study was to establish a domestic monitoring service and compute the ephemerides for this pulsar. Observations commenced in mid-2023 using the RT-13 telescopes of the Quasar-KVO network, operating in the S, X, and Ka bands. To achieve the research goals, we utilized the VLBI (Very-Long-Baseline Interferometry) registration system along with specially developed software and algorithms for data processing. A monitoring service for giant pulses was created, providing weekly ephemerides of the pulsar for over one and a half years. The period and its derivative were determined separately by timing the main pulses and interpulses. The obtained results demonstrate a high accuracy of period determination, consistent with the data from the Jodrell Bank Observatory, with a root mean square deviation of 7 picoseconds.

Keywords: pulsars: general, individual (B0531+21); radio astronomy; observational techniques

DOI: 10.26119/VAK2024.008

1 Introduction

The study of giant pulses from pulsars provides valuable insights into the emission mechanisms and the extreme physical conditions in pulsar magnetospheres. The Crab Pulsar (B0531+21) is a well-known (Hankins & Rickett 1975) source of giant pulses, making it an ideal target for such studies. This paper describes the observation setup, data processing techniques, and results of recent observational sessions at the Institute of Applied Astronomy of the Russian Academy of Sciences (IAA RAS).

2 First experiment

In our first experimental session (Kurdubov & Marshalov 2022), we conducted a 20-minute observation of the Crab pulsar to test the capabilities of our equipment. The observations were performed using the RT-32 and RT-13 radio telescopes at the Svetloe, Badary, and Zelenchukskaya observatories. The setups included L-band (Svetloe and Badary 32m) with a bandwidth of 128 MHz and frequency range from 1589.5 to 1717.5 MHz, and S and X-bands (Svetloe, Badary, Zelenchukskaya 13m) with a bandwidth of 512 MHz and frequency ranges from 2163.8 to 2675.8 MHz (S-band) and from 8591.6 to 9103.6 MHz (X-band). Data were recorded in the VDIF (VLBI Data Interchange Format) format with coherent de-dispersion for enhanced time resolution.

Key system performance metrics included an SEFD (System Effective Flux Density) of 280 Jy (RT-32, L-band), 1000 Jy (RT-13, S-band), and 800 Jy (RT-13, X-band), with 1-sigma sensitivities of 44 Jy at 8 μs (RT-32, L-band), 63 Jy at 1.6 μs (RT-13, S-band), and 60 Jy at 1.6 μs (RT-13, X-band).

Overall, 712 pulses were detected at Badary and 657 at Svetloe in the L-band, while 262 pulses were detected at Badary, 182 at Svetloe, and 51 at Zelenchuk in the S-band. Detection rates were 36 pulses per minute (L-band) and 12 pulses per minute (S-band). These detection rates are comparable to previous observations at Goldstone and Arecibo observatories (see, for example, Majid et al. 2011).

3 Regular observations

After success of experimental session, regular observations of B0531+21 were conducted 5–6 times per day over a period of 1.5 years. These observations were integrated into the standard observation programs R and RX. Each session consisted of one-minute scans in the X and S bands using the RT-13 radio telescopes at Svetloe, Badary, and Zelenchuk observatories. The observations covered a frequency range from 2163.8 to 2675.8 MHz (S-band) and from 8591.6 to 9103.6 MHz (X-band) with a bandwidth of 512 MHz. Only the right polarization was recorded using 2-bit quantization. For all detected pulses, fragments of the original data were saved for further analysis.

The regular observation data were analyzed using a thresholding algorithm to identify pulses with a signal-to-noise ratio (SNR) greater than 7. Maximum SNR for single pulse in S-band were 72, 78, 75 for 13m telescopes in Badary, Zelenchukskaya and Svetloe.

The dispersion measure (DM) for individual pulses was estimated, and the timing analysis was performed using the `tempo2` software. The pulsar ephemeris was constructed for the entire observation period, with determined parameters F0, F1, and F2. Pulses were divided into main pulses and interpulses, and weekly ephemerides were generated based on the arrival times of the main pulses. Monthly ephemerides were also generated based on the interpulse arrival times.

The timing residuals for the entire observation period were calculated and compared with the ephemerides from Jodrell Bank (Lyne et al. 1993). The results showed good agreement, with the added benefit of higher operational frequency and timeliness from the IAA RAS observations.

Our weekly ephemeris by main pulse, monthly ephemeris by interpulse and Jodrell ephemeris for comparison shown at Fig. 1. The common polynomial was calculated by our MP time series and substracted from all time series of pulsar period. The coefficients of polynomial are on the plot. Also, the RMS differences of period time series were calculated by interpolating it on the same epochs. The RMS differences of our values of epoch periods and Jodrell Bank ones were 7 ps.

4 Discussion

Our observational setup and data analysis techniques have proven effective in detecting giant pulses from the Crab Pulsar. The rates of detected pulses align well with those from other major observatories, demonstrating the capability of our instruments. Future work will focus on improving the sensitivity and timing accuracy, as well as expanding observations to other pulsar sources.

5 Conclusion

The successful detection of giant pulses from the Crab Pulsar using the IAA RAS facilities highlights the effectiveness of our observational and data processing methods. Continuous monitoring and improvements in our techniques will further enhance our understanding of pulsar emission mechanisms.

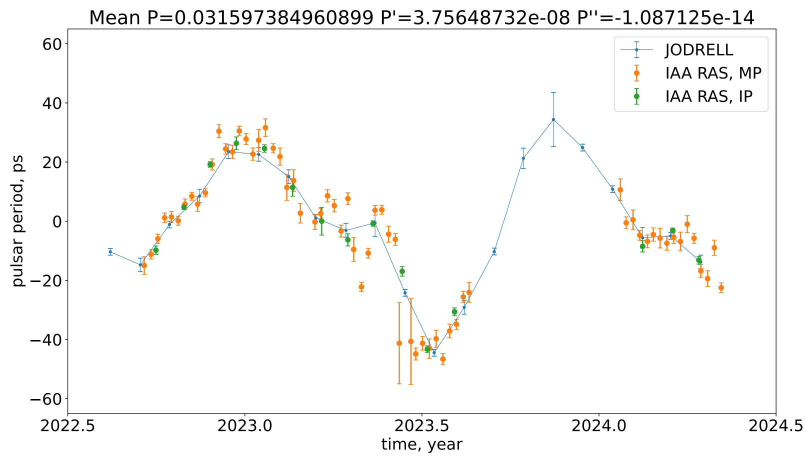

Fig. 1. Our results of the determination of Crab pulsar period by interpulses and main pulses, Jodrell monthly ephemeris. Mean polynomial was calculated using our MP results and excluded from all three period time series, parameters are presented in title.

The establishment of a monitoring service for the Crab Pulsar's pulses has enabled the IAA RAS to provide up-to-date ephemerides that align well with those from Jodrell Bank. The ability to detect and analyze giant pulses on a regular basis enhances the understanding of the pulsar's emission mechanisms and contributes valuable data for ongoing research. The results from these observations are available for immediate dissemination and can be published in real-time on the IAA RAS website.

Acknowledgements. The observations were carried out at the Badary, Svetloe, Zelenchukskaya radio observatories.

References

Hankins T. and Rickett B., 1975, Methods in Computational Physics: Advances in Research and Applications, 14, p. 55

Kurdubov S. and Marshalov D., 2022, Journal of Astronomical Instrumentation, 11, p. 2250015

Lyne A., Pritchard R., and Graham Smith F., 1993, Monthly Notices of the Royal Astronomical Society, 265, p. 1003

Majid W., Naudet C., Lowe S., and Kuiper T., 2011, The Astrophysical Journal, 741, p. 53