Observation of Pulsars Using a CMOS Camera and Evaluation of Temporal Accuracy During High-Speed Readout

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Abstract

We conducted observations in January and April. In these observation, I focused on **a rapidly variable pulsar** and conducted a total of approximately two hours of observations with 4 ms cadence.Based on the January observation data, I performed a time-series analysis and was able to derive **a light curve with two peaks**.Using this data, I measured the temporal precision and confirmed that data can be acquired with sufficient temporal precision even during fast readout.Furthermore, by comparing with the April data, I aim to measure **the spin-down of pulsar**.

Development of CMOS Cameras

We have developed a CMOS camera that utilizes six newly developed **CMOS sensors**, which are characterized by their wide field of view and high temporal resolution.

With full-frame readout at maximum speed, it can capture **10 frames per second**, and with 100-line partial readout, it can capture **1,000 frames per second,** making it possible to observe rapidly variable pulsars.

Our goal is to eventually operate this CMOS camera on the Subaru Telescope.The Subaru Telescope's high light-gathering power and high resolution, combined with the CMOS sensor's wide field of view and high temporal resolution, will open up **new frontiers in observational astronomy.**

Observations of the Crab Pulsar

- **Monitoring equipment**
  - Arizona University 2.3 m Bok Telescope

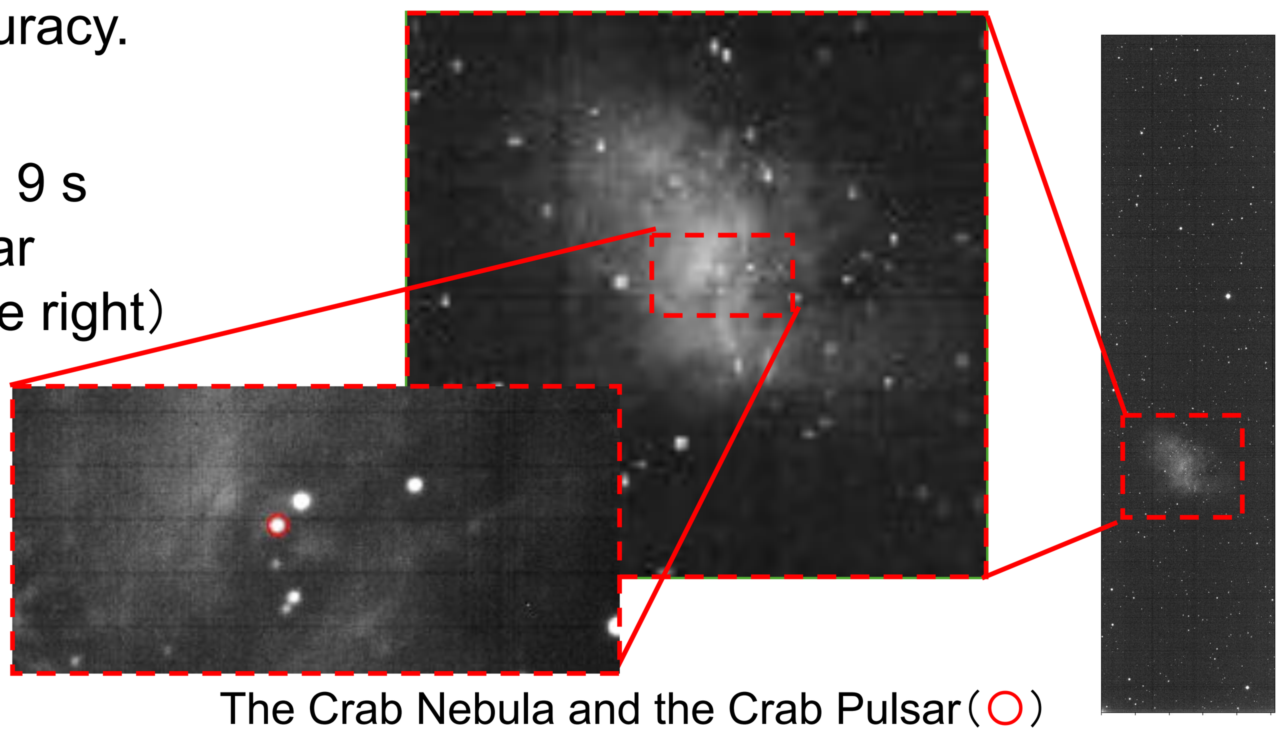
Arizona University 2.3 mBok Telescope

- **Filter**
  - OG-515
    Transmits wavelengths of 515 nm or longer

- **Observation data**
  - 200 Line, 4 ms, 120000 frames
    ⇒ It was used for periodic analysis.
  - 200 Line, 4 ms, 10000 frames
    ⇒ It was used to analyze time accuracy.

	Specifications
Frame rate	12bit 3fps、10bit 10fps Partial readout: 1000 fps
Read noise	5 e- or under (High gain) 30 e- or under (Low gain)
dark current	1000 e-/pixel/sec (Room temperature)
Quantum efficiency	50% or more @400 nm 40% or more@800 nm
Pixel scale	0.23 arcsec/pix

- Full Readout, 9 s
  ⇒ Crab Pulsar
  (Figure on the right)



The Crab Nebula and the Crab Pulsar（○）

Periodic Analysis

This is because the intervals become uneven during the process of converting time to the solar system's center of mass.

【Lomb-Scargle periodogram】

- A method suitable for non-equidistant time data

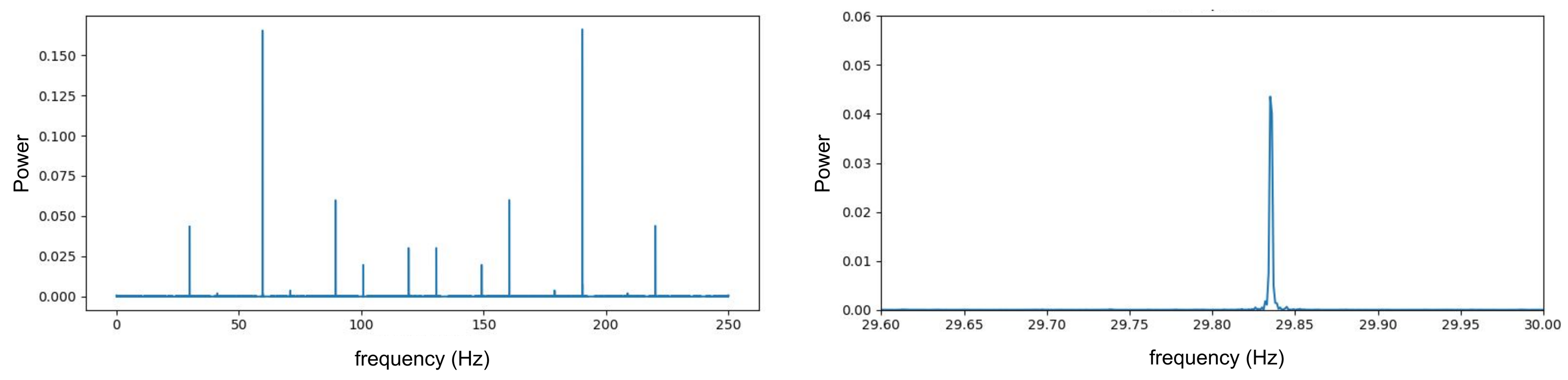


Fig1, Power Spectrum (1 data set)
(Figure on the right: Enlarged view of the 29.60–30.00 Hz range)

【Results】

- Data acquisition at approximately 4 ms intervals
  ⇒ Data acquisition rate: approximately 250 Hz
- High-frequency signals that are integer multiples of 30 Hz
  ⇒ Because it has two peaks
- False signals ⇒ The difference between the data acquisition rate and an integer multiple of the pulsar's frequency.
- From the figure on the right, the spectrum peaks at 29.835 Hz
  ⇒ **Period : 33.518 ms**

【Light Curve】

- I performed periodic folding on 120,000 frames of data.
- You can see that there are two peaks in one cycle.

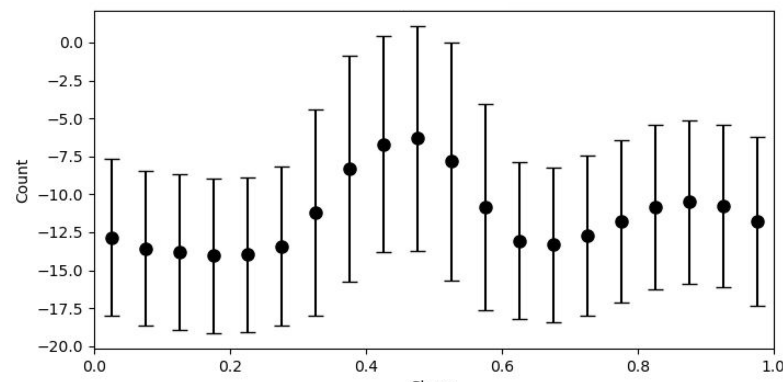


Fig2 Light Curve

Analyze Time Accuracy

It is known that the Crab Pulsar is **spinning down at a rate of 3.8 × 10^{-10} Hz/sec.**

To confirm that the change in the period is due to spin-down rather than an error, it is necessary to determine the time accuracy.

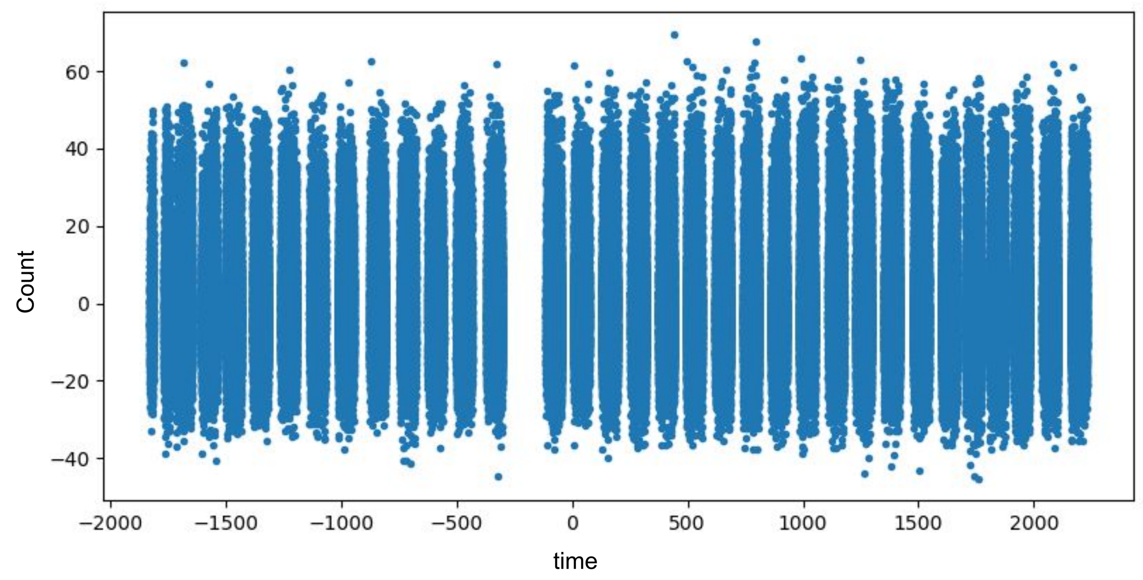
【Data Used】

- 2026/01/30 23:20 - 0:27 (Δt = 4020 s)
  4 ms, 10000 frames × 35 times

【Method】

- Assign the GPS timestamp to each individual frame of all the data.
- Combine 35 data points to plot a single light curve.

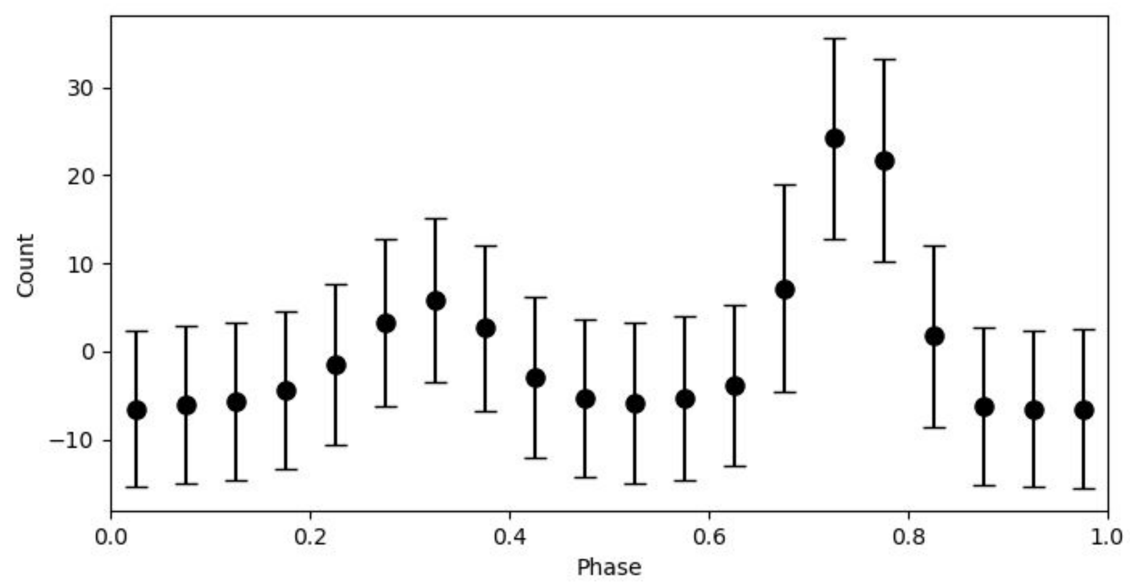
→ Since the 35 data points are not continuous and there are gaps between them, if we could plot a light curve using all the data together,
$\delta t / \Delta t = 0.004 / 4020 = 9.95\times10^{-7}$
this would indicate a time resolution of 9.95×10^{-7}.



Fig,3 Count value for time

【Results】

As in Figure 2, two peaks were observed in the light curve in Figure 4.
This indicates that the temporal resolution of this data is 9.95×10^{-7}.



Fig,4 Light Curve

【Future perspectives 】

We conduct observations of pulsars in January and April.
By comparing these data, we aim to measure spin-down.