Decoding the Nature of Giant Micro-Pulses from the Vela Pulsar

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Background

Pulsars are some of the most fascinating and enigmatic objects in the universe, and the Vela pulsar, J0835-4510, is no exception. Discovered in 1968, pulsars are rapidly rotating neutron stars that emit beams of electromagnetic radiation, which can be detected as pulses at regular intervals. These celestial objects are the core remnants of stars, 8-20 times more massive than the Sun that have undergone supernovae. Neutron stars usually have a mass 1.4 times of the sun and are compressed into a diameter of about 10 miles, making them the densest objects in the universe besides black holes. The Vela pulsar is in the Vela supernova remnant about 1,000 light-years from Earth, rotating at approximately 11 hertz with a magnetic field trillions of times stronger than Earth's. MJD, or the Modified Julian Date, is a calendar system used by scientists to utilize quantifiable number of days starting from November 17, 1858. S/N is signal-to-noise ratio, or the intensity of a signal compared to the background noise.

Objective

In this study, we aim to identify and characterize radio micro-giant pulses emitted by J0835-4510. Through our data analysis, we hope to gain insights into the physical processes that generate these pulses. Observations produced roughly 12 million raw data points. This raw data was analyzed and compressed to record over 570,000 individual pulses from Vela.

Fig. 1 The Green Bank 20-meter radio telescope. Photo taken by Ann Schmiedekamp

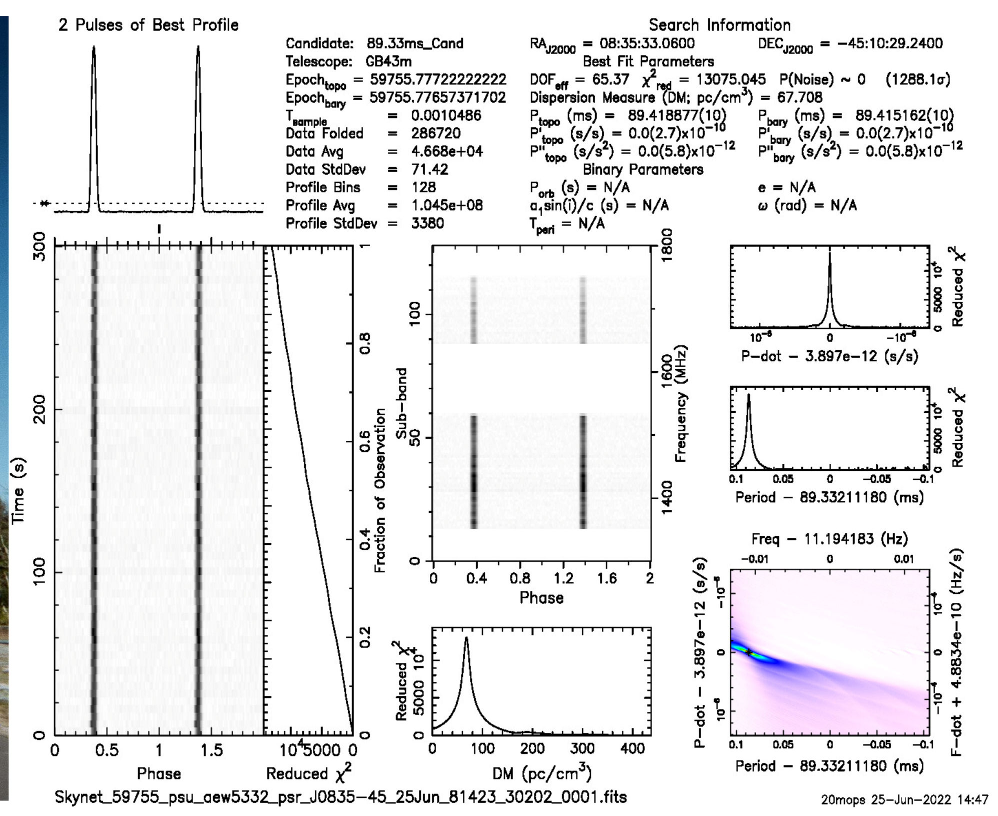

Fig. 2 This Prepfold Plot displays the periodicity of the observation signal. Once the pattern is processed, stacking of the data normalizes noise. Frequency dispersion is corrected for with a DM value from a timing model (par file) and broadband RF signals are observed in the L-Band.

Fig. 6 (Super Micro-Giant Pulse Activity)
This graph illustrates pulsar activity with giant pulses over 50 S/N. These pulse S/N values are at least 294% stronger than the ordinary pulses.

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- (Software)Ransom, Scott, PRESTO, https://www.cv.nrao.edu/~sransom/presto/

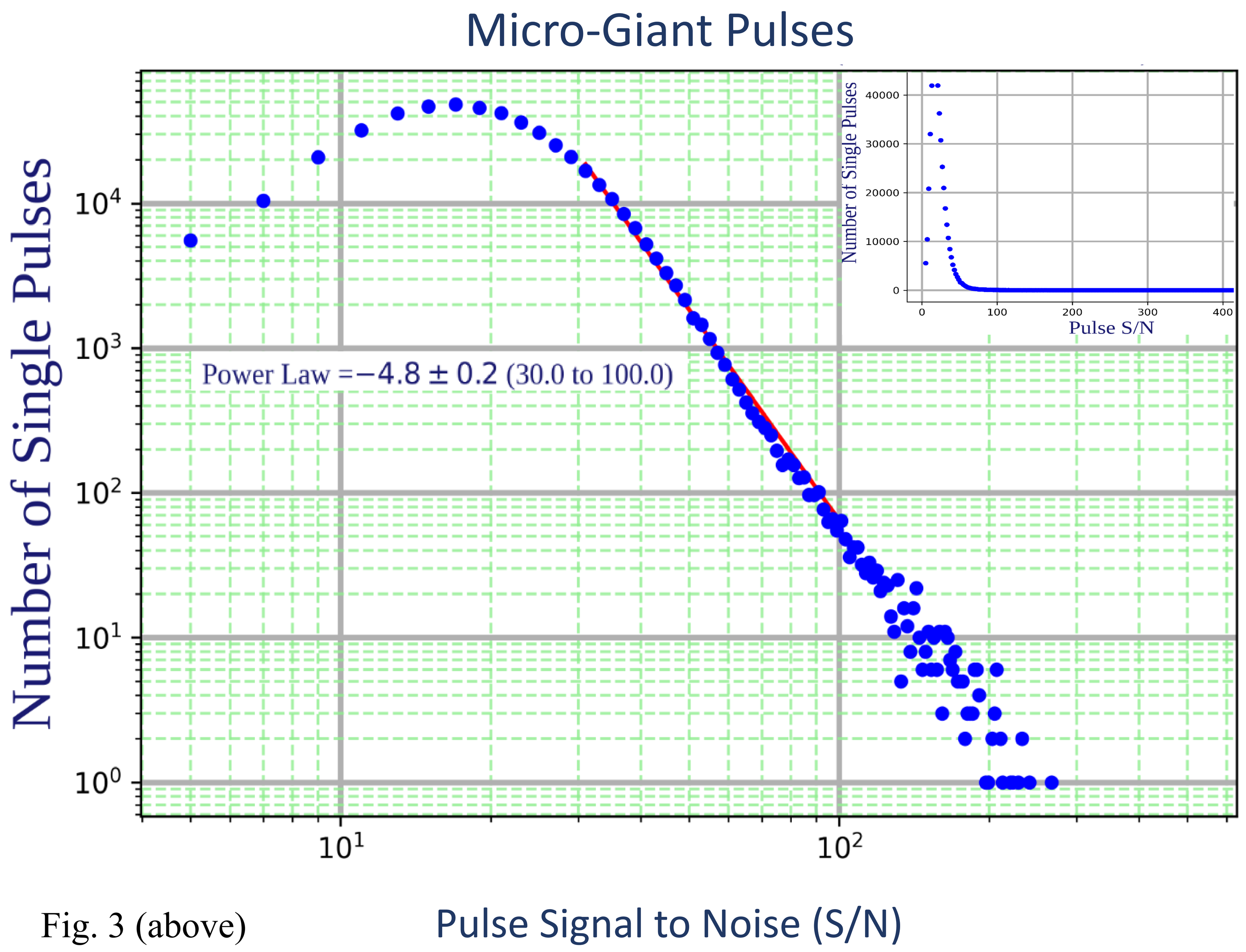
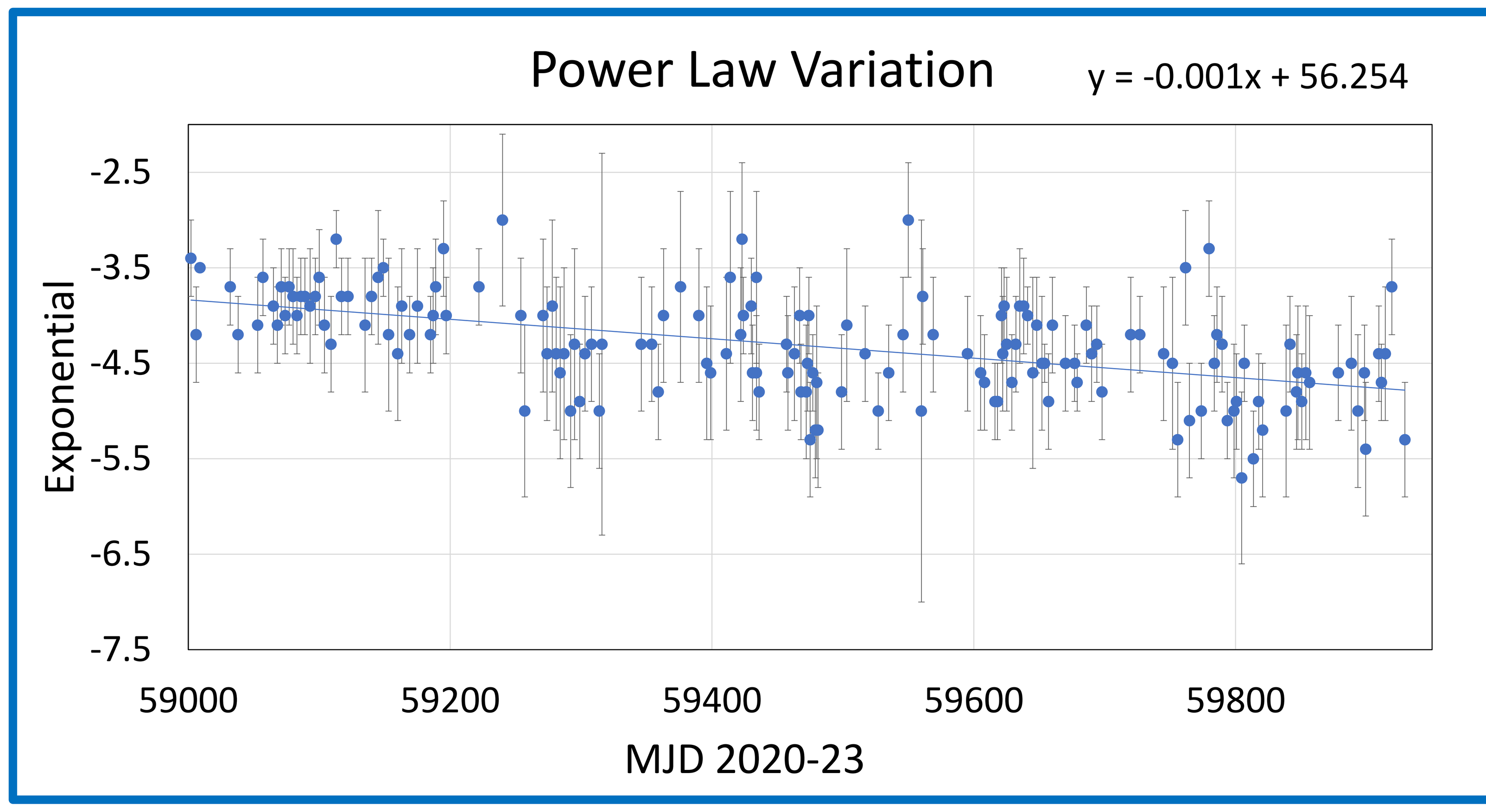
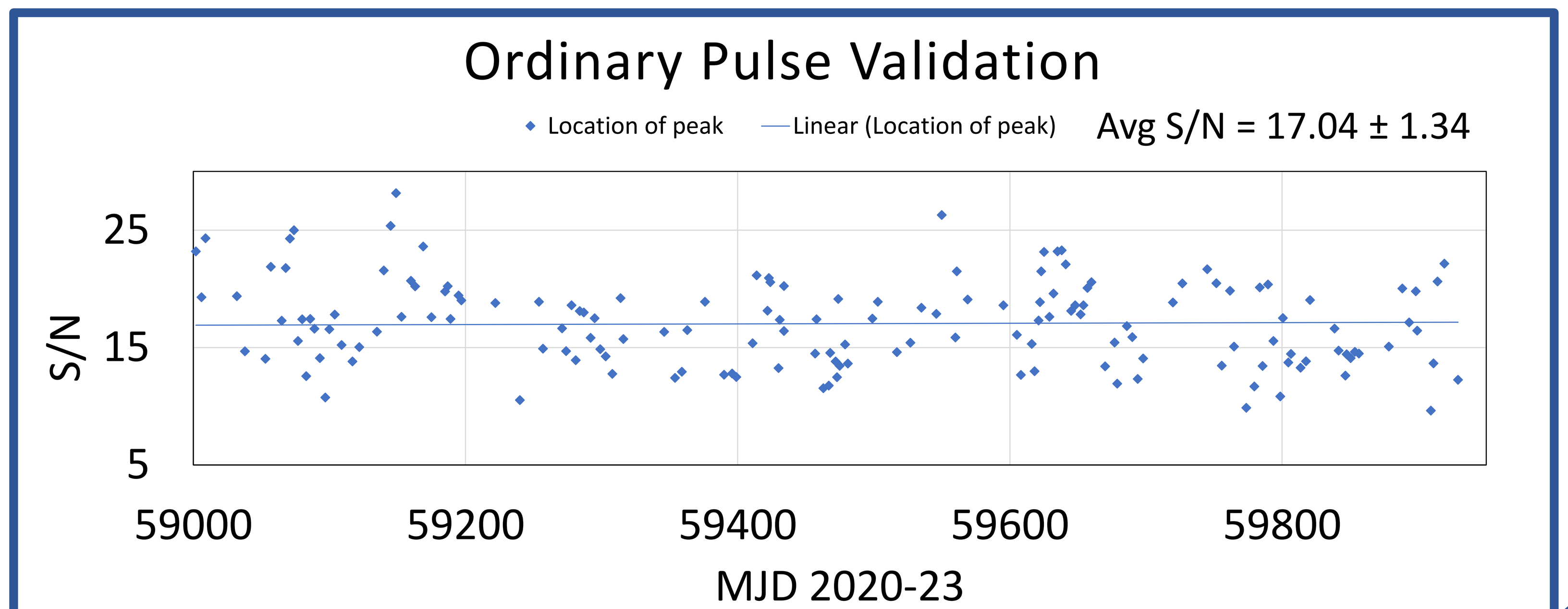
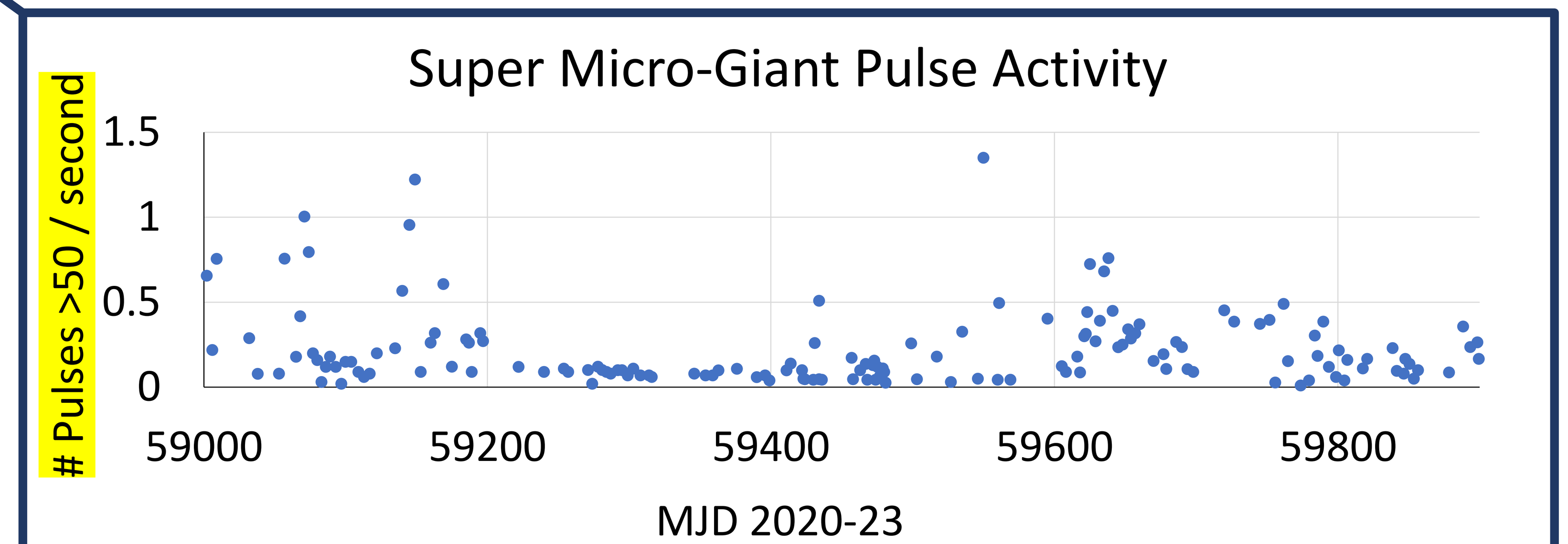


Fig. 3 (above)
This log scale graph displays the count rate of pulses, from 2020 to 2023, between thresholds in bins of every 2 S/N values. Although the signal is periodic, there are fluctuations in the strength of the detected pulses. Ordinary pulses can be observed at the vertex of the quadratic. The Power Law was determined by the fit.







Methods

- Students remotely operated the 20-meter radio telescope at the Green Bank Observatory in Green Bank, West Virginia through the Skynet web interface.
- Data consists of observations taken in the frequency range of 1350 MHz to 1750 MHz, with an integration time of 0.0001 seconds, and observation durations ranging from 100 seconds to 900 seconds during a 3-year period spanning 2020-2022. Utilized Jupyter Notebooks that consist of Python code to process the raw (.fits) files produced from the telescope. Programs from the PRESTO suite, such as "rfifind" and "prepfold", were used to clean and filter out bad data.
- Each observation's notebook provided graphical and textual data for user approval of the quality of the data.
- The output of the notebooks are text files listing each pulse detected with arrival time and strength information.
- In Excel, further data analysis was conducted using Excel functions, graphing on scatter plots, and analyzing the trendlines and their slopes.

Fig. 4 (Power Law Variation)
Plotted in this graph is the power law for each observation over the three-year time frame. There was an unexpected decreasing linear trend that suggests a decrease in the super micro-giant pulse activity.

Conclusions

- Our analysis of the multi-observation logarithmic graph found a power law exponent of -4.8 ± 0.2 and a S/N ratio ranging from 30-50. These signals were identified as micro-giant pulses and S/N ratios greater than 50 as super micro-giant pulses.
- The decreasing slope of the "Power Law Variation" graph may illustrate a weakening of super micro-giant pulses over time as the decreasing power law exponent would reach lower S/N values.
- We observed no trend in the average S/N ratio of about 17 from 2020 to 2023, signifying stable data collection.
- We note that there is heightened super micro-giant pulses activity on August 10, 2020, October 27, 2020, and December 2, 2021. There were no notable events in these time periods, and these spikes can be seen in the ordinary pulse validation.

Fig. 5 (Ordinary Pulse Validation)
Ordinary pulses from Vela were established over a three-year period where no significant slope was observed. Ordinary pulses were averaged at 17.04 S/N ± 1.34.

References

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