

CLOUDY WITH A CHANCE OF EXOMOONS

HUNTING FOR TRANSITING EXOMOONS AROUND A BROWN DWARF

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INTRODUCTION

This research project investigated the possibility of exomoons (moons orbiting planets outside our Solar System) around the free-floating brown dwarf 2MASS J10475385+2124234 (2M1047). Brown dwarfs are intermediate celestial bodies, more massive than planets (more than 75 Jupiter masses) but insufficient to sustain core hydrogen fusion like true stars. 2M1047 exhibits auroral emission (fig. 1). Unlike Earth, where aurorae are powered by the Sun, 2M1047 displays aurorae despite not having a parent star. One hypothesis is that these aurorae are driven by a nearby orbiting moon, in a similar way to how Jupiter's moon Io powers its aurorae. I used spectroscopic and photometric data from the James Webb Space Telescope (JWST). JWST's (Fig. 2) high sensitivity for infrared data let's us study brown dwarfs in detail providing the opportunity to search for exomoons. The JWST has completely revolutionized the field of Astronomy. By analysing light curves (Fig 3), we can see if there are any suggestions for transits. (Fig. 4)

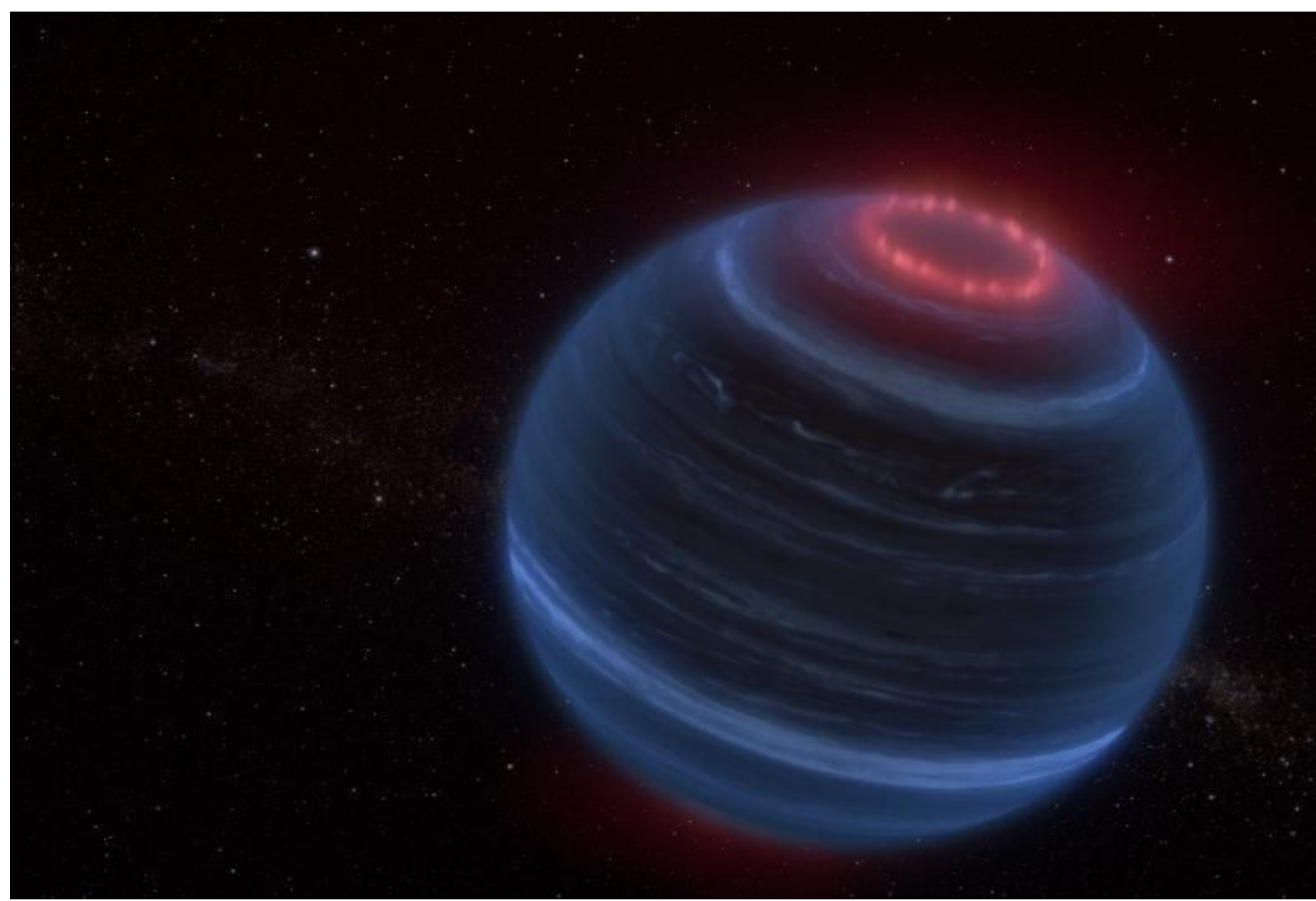


Figure 1: Artist's impression of a brown dwarf exhibiting aurorae

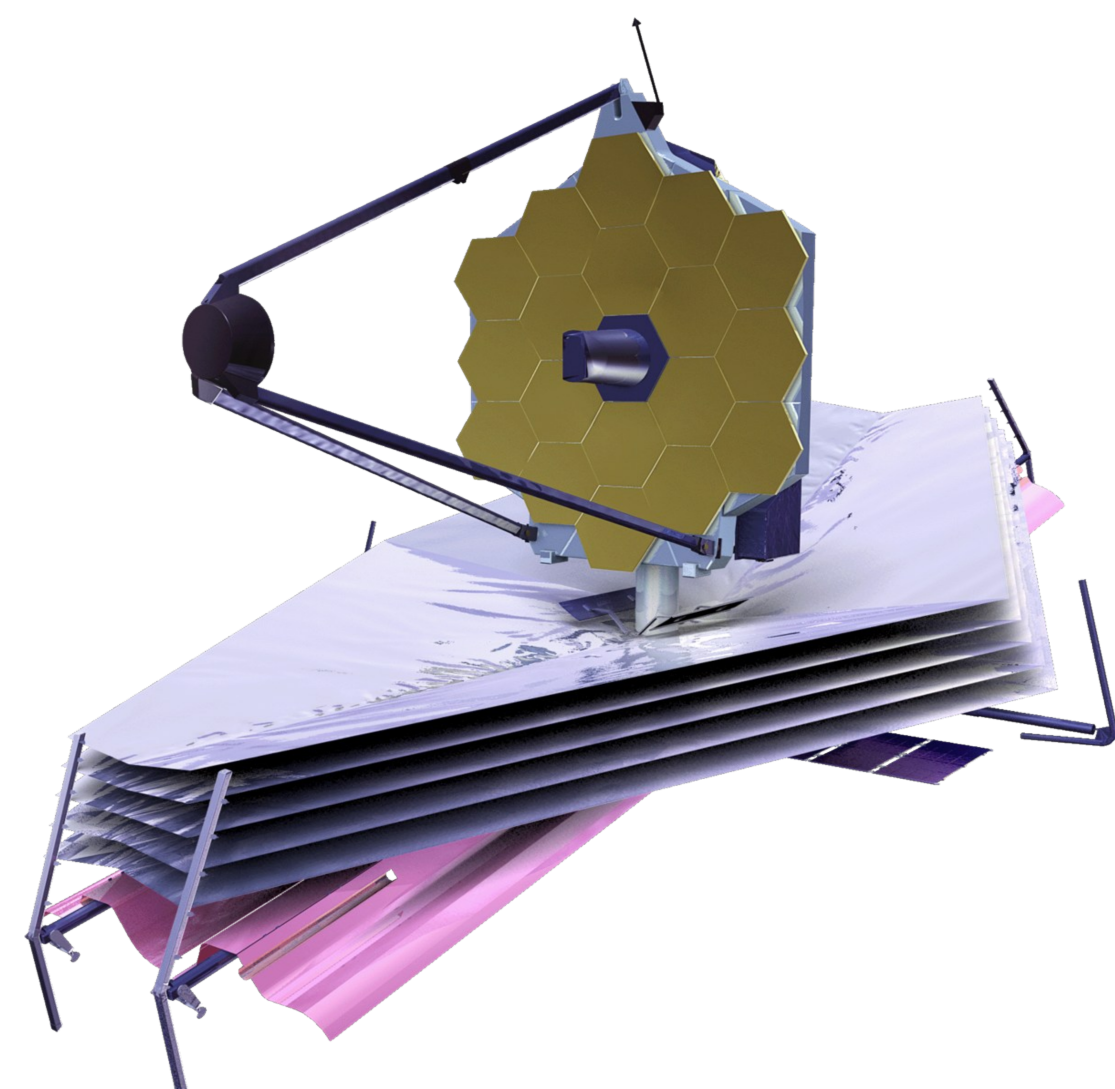


Figure 2: James Webb Space Telescope

METHODOLOGY

1. Data reduction: JWST data was processed through binning to improve signal-to-noise ratio. From this, I generated light curves and spectra.
2. Three light curves were selected at specific wavelengths (Fig. 3)
3. Modelling: Run the Gaussian Processing and transit model and the Gaussian Processing model only model on the three light curves
4. Using Dynesty, a nested sampling package, we determine the Bayesian evidence for each model represented by a logz value. The comparison of log z values allowed us to assess which model fits best.

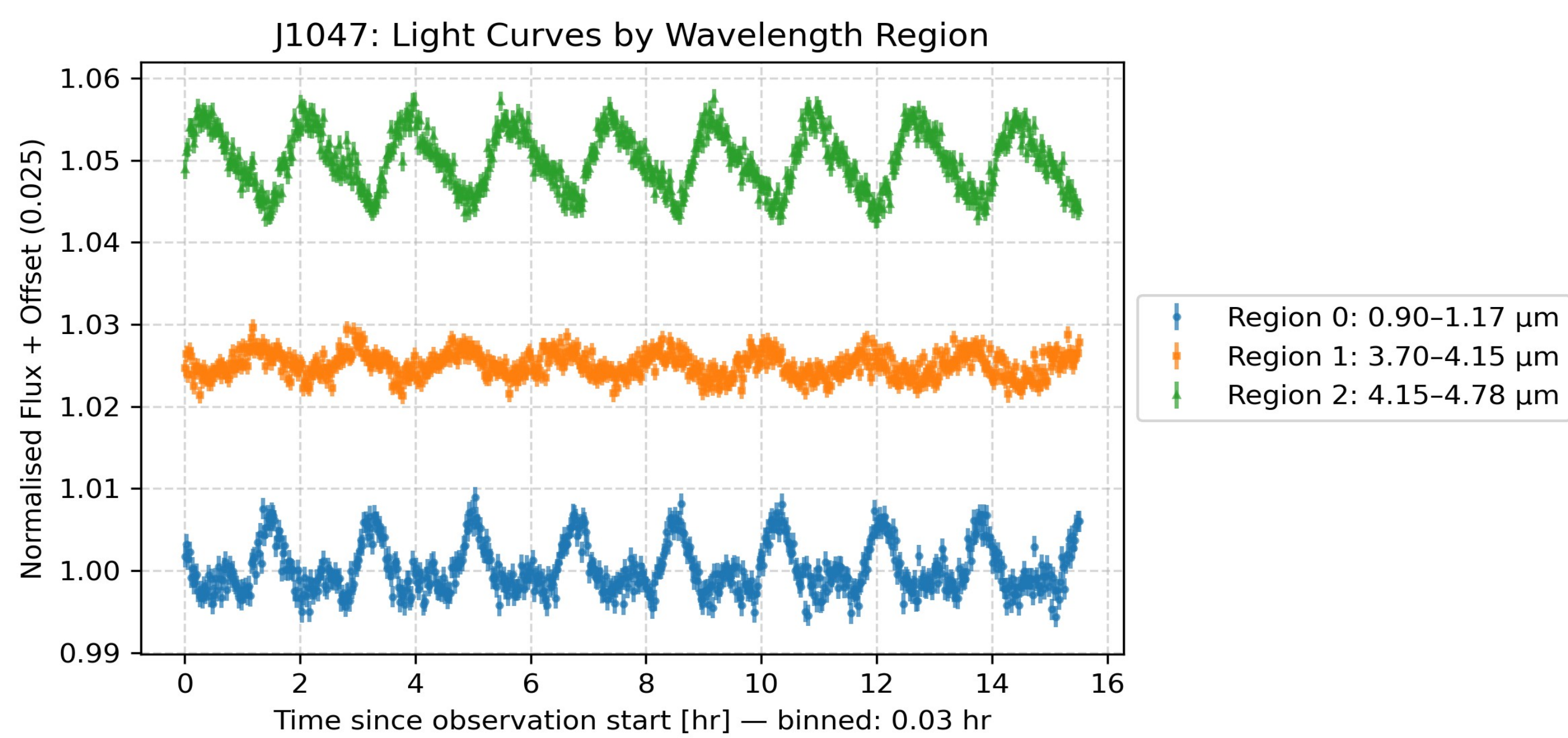


Figure 3: Light curves of selected wavelength regions

RESULTS

The three extracted light curves (Fig. 3) using two different models: Gaussian process variability model (GP) and combined Gaussian process and transit. The results are shown in Table 1. To reduce noise, the data is binned in different sizes. For example, a bin size of five corresponds to combining five minutes of data into a single point. Model performance was assessed using the log Z value, it refers to the logarithm of the marginal likelihood function, which is maximized to obtain the optimal set of hyperparameters in Gaussian Process Models¹. In Bayesian inference, the difference in log Z between models indicates which model is more strongly supported by the data. Across all the three datasets, the GP variability model is strongly favoured as it shoes higher $\Delta \log z$ is higher. However, this result does not rule out the possibility of satellites around 2M1047. Instead, it highlights the limitations of the current dataset and methodology, showing that with the models applied here, variability provides the more statistically significant explanation.

Log z values of different data binnings				
	GP	GP + transit model	Model Preferred	Significance
5 mins binning	3479.60±0.38	3478.61±0.361	GP	Not worth mention
10 mins binning	1633.46±0.36	1630.76±0.37	GP	Strong
20 mins binning	516.62±2.58	499.85±2.79	GP	Decisive

Table 1: Results of log z values

CONCLUSION

Although this project did not provide definitive evidence for an exomoon around 2M1047, it demonstrated several key achievements. I successfully conducted a three-band search (three light curves) on vast data set within six weeks. The analysis pipeline I developed can be used to search for other exomoons. If I had more time, I would simulate moon transits of varying masses and inject them to test detectability and identity the most suitable data reduction processes. With this I could evaluate the model performance. There are hundreds of hours of data publicly available on JWST which could be thoroughly inspected to find satellites. Beyond the scientific outcomes, this project also provided valuable experience in advanced coding, data analysis, and model comparison—skills that are directly applicable to ongoing research in astrophysics.

