

Photometric And Spectral Analysis of The Transiting Exoplanet HD 189733 B

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Abstract—HD 189733 b is a transiting hot-Jupiter exoplanet whose periodic pas-sage in front of its host star produces measurable variations in stellar flux. In this work, photometric observations of HD 189733 are analysed using Python-based astronomical and signal-processing techniques. The light curve is processed to identify the planetary transit and estimate the orbital period, transit depth, planet-to-star radius ratio, planetary radius, orbital distance, surface gravity, density, and equilibrium temperature.

Frequency-domain and time-frequency analyses are also applied to ex-amine the behaviour of the observed photometric signal. The derived parameters are compared with published values to evaluate the consistency of the analysis. In addition, previously published transmission-spectrum measurements are examined to discuss the atmospheric properties of HD 189733 b. This work demonstrates how astronomical observations and signal-processing methods can be combined to study the physical and orbital characteristics of an extrasolar planet.

I. INTRODUCTION

HD 189733 b is a well-studied transiting extrasolar planet orbiting the K-type star HD 189733. Because the orbital plane of the system is aligned close to our line of sight, the planet periodically passes in front of its host star. During this event, known as a transit, the observed stellar brightness decreases by a small but measurable amount. Analysis of these variations in stellar flux provides a powerful method for investigating the orbital and physical properties of exoplanets.

Transit photometry can be used to determine several important planetary parameters. The interval between successive transits provides an estimate of the orbital period, while the fractional reduction in stellar flux during transit is related approximately to the square of

the planet-to-star radius ratio. When combined with information about the host star, these measurements can be used to estimate the planetary radius and orbital distance. Additional physical quantities, including surface gravity, mean density, and equilibrium temperature, can then be examined using appropriate physical relations and literature values.

HD 189733 b is particularly interesting because it is a hot Jupiter located extremely close to its host star. Previous observations have also investigated its atmosphere using transmission spectroscopy. During a transit, a small fraction of the stellar radiation passes through the planetary atmosphere before reaching the observer. The wavelength-dependent transit signal can therefore contain information about atmospheric scattering, absorption, clouds, and haze.

In this work, photometric observations of the HD 189733 system are analysed using Python and astronomical data-analysis tools.

The light curve is cleaned, normalized, folded according to the detected orbital period, and binned to re-veal the transit profile. Signal-processing techniques are additionally used to examine the data in the frequency and time-frequency domains. From the processed observations, several orbital and physical parameters of HD 189733 b are estimated and compared with published values.

The purpose of this study is not to claim a new detection of HD 189733 b, but to independently reproduce and investigate measurable properties of this known exoplanet using publicly available astronomical observations and computational analysis. The project also demonstrates the connection between signal-processing methods and modern observational astronomy.

II. OBSERVATIONAL DATA AND METHODOLOGY

2.1. Photometric Data

Photometric observations of the HD 189733 system were obtained from publicly available space-based observations. The light-curve data were accessed and analysed in Python using astronomical data-analysis tools. The measurements consist primarily of observation time and normalized stellar flux, allowing variations in the apparent brightness of HD 189733 to be examined. Photometric observations from the Transiting Exoplanet Survey Satellite (TESS) [3] were used in this analysis. The light curve contains periodic decreases in stellar flux associated with the transit of HD 189733 b across its host star. Before performing the transit analysis, invalid measurements were removed and the light curve was normalized so that the out-of-transit stellar flux was approximately unity.

2.2. Transit Search

The periodic transit signal was investigated by searching the processed light curve for repeating reductions in stellar brightness. The Box Least Squares (BLS) algorithm [2] was applied to search for periodic transit signals. A Box Least Squares (BLS) period-search technique was used to identify periodic box-shaped signals characteristic of planetary transits. The strongest relevant periodic signal was used as the candidate orbital period. The resulting period was approximately 2.216 days, consistent with the expected short-period orbit of HD 189733 b.

2.3. Phase Folding and Binning

After determining the orbital period, the light curve was phase folded. Phase folding places observations from different orbital cycles onto a common time axis relative to the transit. This allows repeated transit events to be combined and makes the characteristic decrease in flux more clearly visible.

The folded observations were subsequently binned to reduce scatter and produce a clearer representation of the average transit profile. The resulting folded and binned light curves were used for subsequent estimation of the transit depth and planetary properties.

2.4. Computational Analysis

The analysis was performed in Python using

numerical, plotting, and astronomical data-analysis libraries. NumPy was used for numerical calculations, Matplotlib for visualization, and astronomical Python tools were used for processing the light-curve observations.

Additional signal-processing analysis was performed in the frequency domain and the time-frequency domain. These methods were used to investigate periodic structure and changes in signal power within the photometric time series.

III. TRANSIT ANALYSIS AND RESULTS

3.1. Orbital Period

The Box Least Squares analysis identified a strong periodic transit signal with an orbital period of approximately

$$P = 2.215993 \text{ days.} \quad (1)$$

For comparison, the published orbital period of HD 189733 b is approximately 2.218576 days. The percentage difference between the period recovered in this analysis and the published value was approximately 0.116 per cent.

The close agreement indicates that the periodic transit signal of the known planet was successfully recovered from the photometric data.

3.2. Transit Depth

The phase-folded light curve was binned to obtain a clearer representation of the average transit profile. The median normalized flux outside the deepest portion of the transit was close to unity, while the minimum binned flux was approximately 0.983.

A simple estimate of the transit depth was calculated as

$$\delta = F_{\text{baseline}} - F_{\text{minimum}}, \quad (2)$$

where δ represents the fractional transit depth.

The resulting value was approximately

$$\delta \approx 0.01718, \quad (3)$$

corresponding to a decrease in stellar brightness of approximately 1.72 per cent.

3.3. Planet-to-Star Radius Ratio

For a simplified transit geometry, the transit depth can be related to the planetary and stellar radii through

$$\delta \approx \left(\frac{R_p}{R_*}\right)^2 \quad (4)$$

Therefore,

$$\frac{R_p}{R_*} \approx \sqrt{\delta} \quad (5)$$

Using the transit depth obtained above produced a planet-to-star radius ratio of approximately 0.131. This value should be regarded as a simplified estimate rather than a precision measurement because the calculation uses the minimum binned flux instead of fitting a complete physical transit model. Effects such as stellar limb darkening, stellar activity, orbital geometry, and instrumental systematics are not explicitly modelled.

3.4. Estimated Planetary Radius

Using an adopted stellar radius of 0.78 solar radii together with the estimated planet-to-star radius ratio, the planetary radius was calculated from

$$R_p = \frac{R_p}{R_*} R_* \quad (6)$$

The resulting simplified estimate was approximately

$$R_p \approx 7.12 \times 10^4 \text{ km.} \quad (7)$$

Because this quantity depends directly on the simplified transit-depth estimate, it is also treated as an approximate result. A later comparison with published parameters is used to examine the limitations of this method.

3.5. Orbital Distance

The orbital distance was estimated using the recovered orbital period and an adopted stellar mass. For a planetary mass much smaller than the stellar mass, Kepler's third law can be written as

$$a = \frac{(GM_*P^2)^{1/3}}{4\pi^2} \quad (8)$$

where a is the orbital semi-major axis, G is the gravitational constant, M_* is the stellar mass, and P is the orbital period.

Using the recovered period and an adopted stellar mass of approximately 0.8 solar masses resulted in $a \approx 0.03088 \text{ AU.}$ (9)

The published orbital distance used for comparison was approximately 0.03126 AU, corresponding to a difference of approximately 1.21 per cent.

IV. ESTIMATED PHYSICAL PROPERTIES

4.1. Planetary Mass

The planetary mass was not determined directly from the TESS transit light curve. Instead, a literature value of approximately 1.13 Jupiter masses was adopted for subsequent calculations. Using a Jupiter mass of 1.898 1027 kg gives $M_p \approx 2.145 \times 10^{27} \text{ kg.}$ (10)

The distinction between quantities measured from the photometric data and parameters adopted from previous observations is maintained throughout this analysis.

4.2. Gravitational Acceleration

Using the adopted planetary mass and the simplified radius estimate, the gravitational acceleration at the reference planetary radius was calculated using

$$g = \frac{GM_p}{R_p^2} \quad (11)$$

The resulting value was approximately

$$g \approx 28.25 \text{ m s}^{-2}, \quad (12)$$

which is approximately 2.88 times the gravitational acceleration at the surface of the Earth.

HD 189733 b is a gas giant and therefore does not possess a solid surface comparable to that of the Earth.

The calculated value should therefore be interpreted as the gravitational acceleration at the adopted reference planetary radius.

4.3. Mean Density

Assuming an approximately spherical planet, its volume was estimated from

$$V = \frac{4}{3} \pi R_p^3 \quad (13)$$

The corresponding mean density was calculated using

$$\rho = \frac{M_p}{V} \quad (14)$$

Using the adopted mass and simplified radius estimate produced

$$\rho \approx 1.42 \text{ g cm}^{-3}. \quad (15)$$

This value inherits the uncertainty associated with

the simplified planetary-radius calculation and is therefore not treated as a precision determination of the density of HD 189733 b.

4.4. Equilibrium Temperature

The approximate equilibrium temperature of the planet was estimated using the stellar effective temperature, stellar radius, and calculated orbital distance. Under simplified assumptions, the equilibrium temperature can be expressed as

$$T_{eq} = T_{*} \sqrt{\frac{R_{*}}{2a}} \quad (16)$$

where T_{*} and R_{*} represent the effective temperature and radius of the host star, respectively.

Using an adopted stellar temperature of approximately 5050 K produced

$$T_{eq} \approx 1224 \text{ K}, \quad (17)$$

equivalent to approximately 951 °C.

This value represents a simplified equilibrium-temperature estimate rather than a direct measurement of atmospheric temperature.

4.5. Distance from Earth

The HD 189733 system is located at an adopted distance of approximately 19.8 pc from Earth. Using

$$1 \text{ pc} \approx 3.26156 \text{ ly}, \quad (18)$$

$$\text{the corresponding distance is approximately } d \approx 64.6 \text{ ly}. \quad (19)$$

This is equivalent to approximately

$$d \approx 6.11 \times 10^{14} \text{ km}. \quad (20)$$

Unlike the orbital period recovered from the light curve, the distance from Earth is an externally determined astronomical parameter used to provide physical context for the planetary system.

V. PHOTOMETRIC AND SIGNAL-PROCESSING RESULTS

5.1. Observed Light Curve

Figure 1 shows the photometric time series used for the analysis of the HD 189733 system. Variations in the measured stellar flux are visible throughout the observation interval, including repeated decreases associated with the planetary transit.

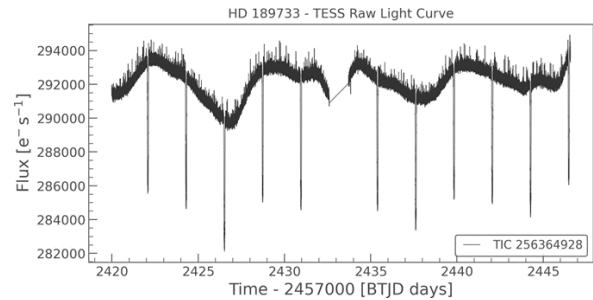


Figure 1: Photometric light curve of the HD 189733 system used in this analysis. The measured stellar flux varies with time, with repeated transit events producing decreases in brightness.

5.2. Cleaning and Normalization

Before searching for planetary transits, invalid measurements and significant outliers were removed from the light curve. The remaining flux measurements were then normalized so that the typical out-of-transit stellar brightness was approximately unity.

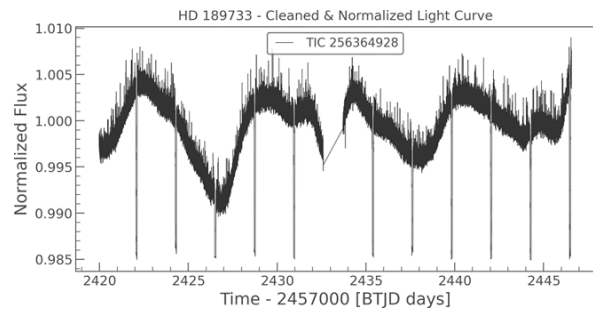


Figure 2 shows the resulting cleaned and normalized light curve.

Figure 2: Cleaned and normalized photometric light curve of HD 189733. Invalid measurements and significant outliers were removed, and the stellar flux was normalized around unity before further transit analysis.

5.3. Light-Curve Flattening

After cleaning and normalization, the light curve was flattened to reduce long-term variations in the measured stellar flux. These variations can arise from stellar activity, instrumental effects, and other slowly varying trends in the observations.

Flattening preserves the shorter-duration decreases in flux associated with planetary transits while reducing the influence of the slowly varying

baseline. The resulting flattened light curve was subsequently used for the transit-period analysis.

5.4. Box Least Squares Transit Search

The Box Least Squares (BLS) method was applied to the flattened light curve to search for periodic transit-like decreases in stellar flux.

BLS tests a range of trial orbital periods and measures how strongly a repeating box-shaped transit model matches the observations.

The strongest BLS peak was identified as the most likely orbital period of the transiting planet. From the present analysis, the recovered period was approximately

$$P \approx 2.216 \text{ days.} \quad (21)$$

Figure 3 shows the flattened light curve of HD 189733.

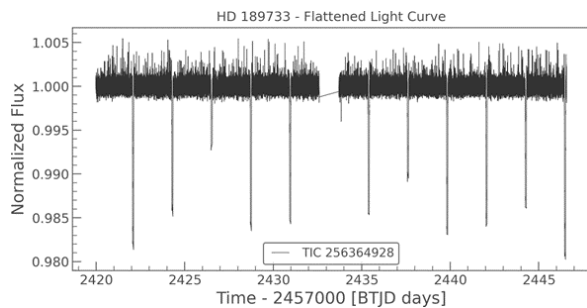


Figure 3: Flattened light curve of HD 189733 after removal of long-term flux variations. Repeated decreases in normalized flux correspond to candidate transit events.

This value is close to the published orbital period of HD 189733 b, approximately 2.219 days, supporting the successful recovery of the planetary transit signal from the photometric observations.

Figure 4 shows the BLS periodogram obtained from the processed light curve.

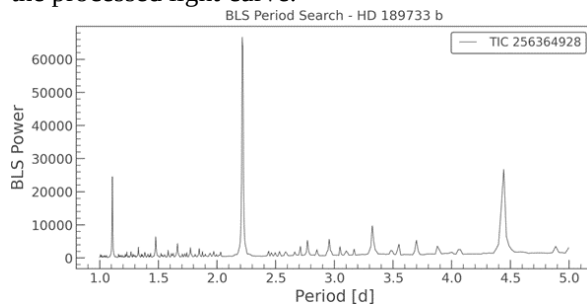


Figure 4: Box Least Squares periodogram of the HD 189733 light curve. The dominant peak corresponds to the recovered orbital period of approximately 2.216 days.

5.5. Phase-Folded Transit Light Curve

Using the orbital period recovered from the Box Least Squares analysis, the flattened light curve was phase folded so that observations from successive planetary orbits could be compared within a single orbital cycle.

Phase folding aligns the repeated transit events and provides a clearer representation of the characteristic decrease in stellar flux produced as HD 189733 b passes in front of its host star.

The phase-folded light curve therefore provides an additional visual confirmation of the periodic transit signal detected by the BLS analysis.

Figure 5 shows the resulting phase-folded light curve.

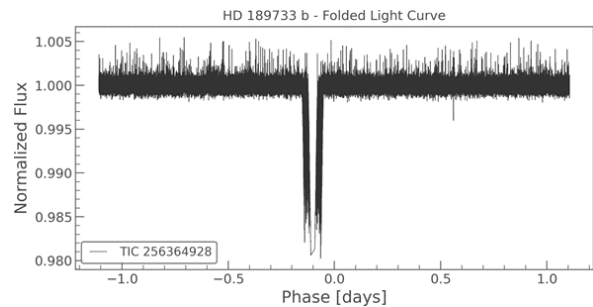


Figure 5: Phase-folded light curve of HD 189733 b using the recovered orbital period. Repeated transit observations are aligned in orbital phase, revealing the characteristic transit profile.

5.6. Binned Transit Light Curve

To reduce the scatter in the phase-folded observations and make the transit morphology easier to examine, the phase-folded measurements were grouped into phase bins. The normalized flux within each bin was then averaged to produce a smoother representation of the transit.

The resulting binned light curve preserves the characteristic decrease in stellar brightness during the planetary transit while suppressing much of the point-to-point scatter present in the individual measurements. This provides a clearer visualization of the transit profile of HD 189733 b.

5.7. Transit Depth Measurement

The transit depth was estimated from the binned and normalized phase-folded light curve. The median normalized flux was used as the out-of-transit baseline, while the minimum flux represented the deepest point of the observed transit.

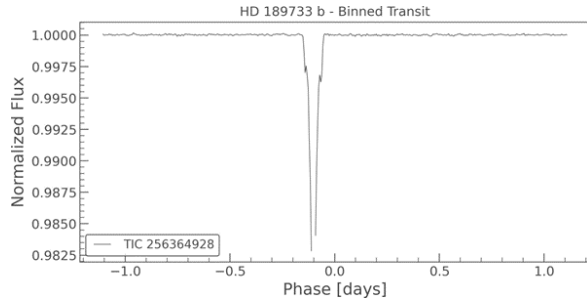


Figure 6: Binned phase-folded transit light curve of HD 189733 b. Averaging measurements within phase bins reduces observational scatter and reveals the transit profile more clearly.

The baseline flux obtained from the processed light curve was

$$F_{\text{baseline}} = 1.0000063, \quad (22)$$

while the minimum observed normalized flux was

$$F_{\text{min}} = 0.9828276. \quad (23)$$

The transit depth was calculated from the difference between these two quantities,

$$\delta = F_{\text{baseline}} - F_{\text{min}}. \quad (24)$$

This produced a transit depth of

$$\delta = 0.0171787, \quad (25)$$

corresponding to

$$\delta \times 100 \approx 1.71787\%. \quad (26)$$

Therefore, during the deepest part of the detected transit, the observed stellar flux decreased by approximately 1.72 per cent relative to the estimated baseline level.

5.8. Planet-to-Star Radius Ratio

The planet-to-star radius ratio was estimated from the measured transit depth. For a simple transit approximation, the transit depth is related to the radius ratio by

$$\delta \approx \frac{(R_p)^2}{R_s^2} \quad (27)$$

where δ is the measured transit depth, R_p is the planetary radius, and R_s is the stellar radius.

Therefore, the radius ratio was calculated as

$$\frac{R_p}{R_s} = \sqrt{\delta}. \quad (28)$$

Using the measured transit depth of 0.0171787, the

resulting planet-to-star radius ratio was

$$\frac{R_p}{R_s} \approx 0.13107. \quad (29)$$

This corresponds to a planetary radius approximately

$$13.11\% \quad (30)$$

of the radius of the host star.

5.9. Estimated Planetary Radius

The physical radius of HD 189733 b was estimated using the planet-to-star radius ratio derived from the transit depth.

A stellar radius of

$$R_s = 0.78 R_{\odot} \quad (31)$$

was adopted, where $R_{\odot}$ represents the solar radius.

Using a solar radius of approximately 696340 km, the planetary radius was calculated using

$$R_p = \frac{R_p}{R_s} R_s \quad (32)$$

Using the derived radius ratio of approximately 0.13107 and the adopted stellar radius, the estimated planetary radius was

$$R_p \approx 71188.7 \text{ km}. \quad (33)$$

This value represents the planetary radius estimated directly from the transit depth together with the adopted radius of the host star.

5.10. Orbital Period and Orbital Distance

The orbital period recovered from the Box Least Squares analysis was used to estimate the orbital distance of HD 189733 b from its host star. The recovered orbital period was

$$P = 2.215993 \text{ days}. \quad (34)$$

For the orbital-distance calculation, the period was converted from days to seconds. A stellar mass of $0.8 M_{\odot}$ was adopted, where $M_{\odot}$ is the solar mass.

The orbital semi-major axis was then estimated using Kepler's third law,

$$a = \frac{(GM_s P^2)^{1/3}}{4\pi^2} \quad (35)$$

where G is the gravitational constant, M_s is the adopted mass of the host star, and P is the recovered orbital period.

The resulting orbital distance was

$$a \approx 4.6200 \times 10^6 \text{ km}, \quad (36)$$

which corresponds to

$$a \approx 0.030883 \text{ AU}. \quad (37)$$

The result indicates that HD 189733 b orbits very close to its host star, consistent with its classification as a close-in giant exoplanet.

5.11. Planetary Mass

For the subsequent calculation of the physical properties of HD 189733 b, a planetary mass of 1.13 Jupiter masses was adopted.

Using a Jupiter mass of

$$M_J = 1.898 \times 10^{27} \text{ kg}, \quad (38)$$

the planetary mass in kilograms was calculated as

$$M_p = 1.13M_J. \quad (39)$$

This gives

$$M_p \approx 2.14474 \times 10^{27} \text{ kg}. \quad (40)$$

Thus, the adopted planetary mass corresponds to approximately 1.13 times the mass of Jupiter. This mass was subsequently used together with the estimated planetary radius to calculate the surface gravity and mean density of the planet.

5.12. Surface Gravity

The surface gravity of HD 189733 b was calculated using the adopted planetary mass and the planetary radius estimated from the transit analysis.

The surface gravitational acceleration was calculated using

$$g_p = \frac{GM_p}{R_p^2}, \quad (41)$$

where G is the gravitational constant, M_p is the planetary mass, and R_p is the estimated planetary radius.

Using the adopted planetary mass of approximately $2.14474 \times 10^{27} \text{ kg}$ and the estimated planetary radius of approximately 71188.7 km , the calculated surface gravity was

$$g_p \approx 28.25 \text{ m s}^{-2}. \quad (42)$$

For comparison with the standard gravitational acceleration at the Earth's surface, the calculated value was divided by 9.81 m s^{-2} , giving

$$\frac{g_p}{g_e} \approx 2.88.$$

(43)

Therefore, the calculated surface gravitational acceleration of HD 189733 b is approximately 2.88 times the standard gravitational acceleration at the Earth's surface.

5.13. Mean Planetary Density

The mean density of HD 189733 b was estimated using the planetary mass and radius obtained in the preceding calculations. Assuming the planet to be approximately spherical, its volume was calculated using

$$V_p = \frac{4}{3} \pi R_p^3. \quad (44)$$

The mean planetary density was then calculated from

$$\rho_p = \frac{M_p}{V_p}, \quad (45)$$

where M_p is the adopted planetary mass and R_p is the estimated planetary radius.

Using the values obtained in this analysis, the calculated mean density is

$$\rho_p \approx 1419.23 \text{ kg m}^{-3}, \quad (46)$$

which is equivalent to

$$\rho_p \approx 1.419 \text{ g cm}^{-3}. \quad (47)$$

This value provides an estimate of the bulk density of HD 189733 b based on the adopted mass and the radius derived from the transit depth.

5.14. Equilibrium Temperature

An approximate equilibrium temperature for HD 189733 b was estimated from the effective temperature and radius of its host star together with the calculated orbital distance.

Assuming uniform redistribution of the incident stellar radiation and zero Bond albedo, the equilibrium temperature was estimated using

$$T_{eq} = T_* \sqrt{\frac{R_*}{2a}} \quad (48)$$

where T_* is the stellar effective temperature, R_* is the stellar radius, and a is the orbital semi-major axis.

A stellar effective temperature of 5050 K and the stellar radius used in this analysis were adopted for HD 189733. Using the orbital distance calculated previously, the resulting equilibrium temperature is $T_{eq} \approx 1224.37$ K. (49)

For reference, this corresponds numerically to approximately

$$T_{eq} \approx 951.22 \text{ }^{\circ}\text{C}. \quad (50)$$

The equilibrium temperature represents a simplified estimate and depends on assumptions concerning the planetary albedo and redistribution of absorbed stellar radiation.

5.15. Distance from Earth

The distance to the HD 189733 planetary system was adopted as 19.8 parsecs. This value was converted into light-years and kilometers to provide the distance in more familiar units.

Using the conversion

$$1 \text{ pc} \approx 3.26156 \text{ ly}, \quad (51)$$

the corresponding distance is

$$d \approx 64.58 \text{ ly}. \quad (52)$$

The distance in kilometers was also calculated using the light-year conversion, giving

$$d \approx 6.11 \times 10^{14} \text{ km}. \quad (53)$$

Therefore, the HD 189733 system is located approximately 19.8 pc, or 64.58 light-years, from Earth. This distance is an externally adopted astronomical parameter rather than a quantity derived from the transit light curve in the present analysis.

5.16. Frequency-Domain Analysis

A frequency-domain analysis was performed on the flattened photometric light curve of HD 189733 using the Fast Fourier Transform (FFT). Before applying the transform, the mean flux was subtracted from the light curve in order to remove the zero-frequency component.

The median time interval between successive observations was used as the sampling interval. The corresponding positive Fourier frequencies were calculated using the real-valued FFT.

The amplitude spectrum was obtained from the magnitude of the Fourier coefficients. Figure 7 shows the resulting frequency spectrum of the photometric time series.

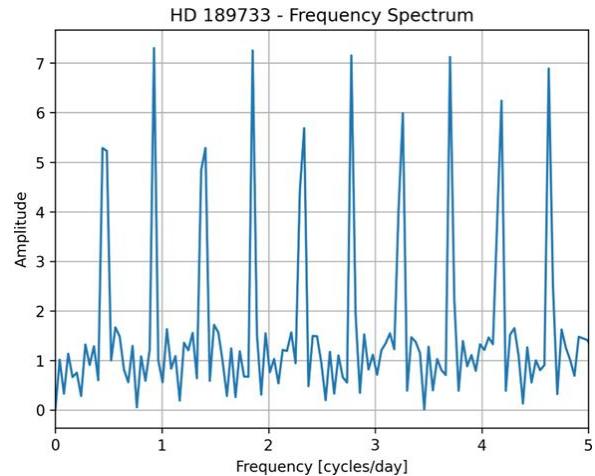


Figure 7: Frequency spectrum of the flattened HD 189733 photometric light curve obtained using the Fast Fourier Transform. Peaks in the spectrum represent periodic or quasi-periodic components present in the analysed time series.

5.16.1. Discrete Frequency-Spectrum Representation

To provide a clearer representation of the individual frequency components, the FFT spectrum was additionally visualized using a stem plot. Unlike the continuous line representation, the stem representation displays the calculated spectral amplitudes at individual frequency bins.

This representation makes the locations and relative amplitudes of prominent spectral components easier to distinguish within the analysed frequency range of 0–5 cycles per day.

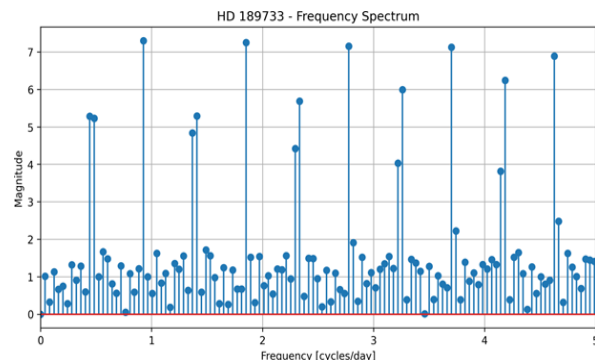


Figure 8: Stem representation of the FFT frequency spectrum obtained from the flattened HD 189733 photometric light curve. Each vertical stem represents the amplitude associated with an individual Fourier frequency bin within the displayed range.

5.17. Time–Frequency Spectrogram Analysis

To examine how the frequency content of the photometric signal varies with time, a time–frequency spectrogram was generated from the flattened HD 189733 light curve.

The median interval between consecutive observations was used to estimate the sampling frequency. Prior to the analysis, the mean flux was subtracted from the signal. The spectrogram was then calculated using segments of 256 samples.

Unlike the Fourier spectrum, which represents the frequency content of the complete time series, the spectrogram provides both temporal and frequency information. This makes it possible to examine whether spectral power remains stable or changes during the observation interval. Figure 9 shows the resulting time–frequency representation.

5.17.1. Logarithmic Time–Frequency Representation

The time–frequency power distribution was additionally represented on a logarithmic decibel scale in order to improve the visibility of weaker spectral components. The spectrogram power was converted according to

$$S_{dB} = 10 \log_{10}(S + 10^{-12}), \quad (54)$$

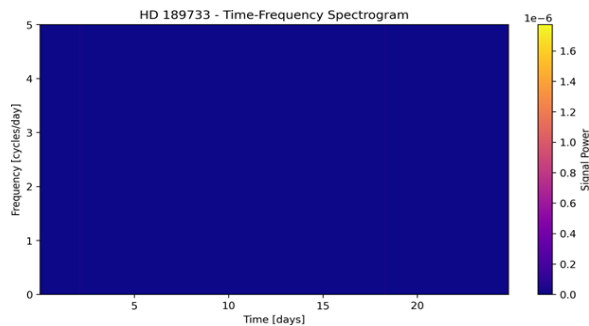


Figure 9: Time–frequency spectrogram of the flattened HD 189733 photometric light curve.

Time is shown along the horizontal axis, frequency in cycles per day along the vertical axis, and colour represents the relative signal power at each time–frequency location.

where S represents the spectrogram power. The small positive constant was included to avoid taking the logarithm of zero. The logarithmic representation compresses the large dynamic range of the spectrum, allowing weaker time–frequency structures to be visualized more clearly than in the

linear-power representation. Figure 10 shows the resulting logarithmic time frequency spectrogram.

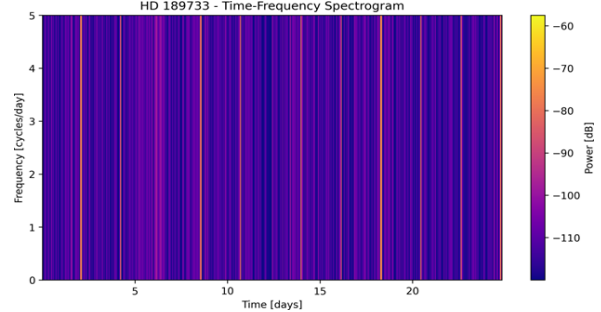


Figure 10: Time–frequency spectrogram of the flattened HD 189733 photometric light curve represented on a logarithmic decibel scale. Colour indicates spectral power in dB, while the horizontal and vertical axes represent time and frequency, respectively.

5.18. Three-Dimensional Visualization of the Planetary System

A three-dimensional visualization was constructed to provide a schematic representation of the orbital configuration of HD 189733 b around its host star. The orbital path was represented using the adopted orbital separation of approximately 0.03126 AU. The host star was positioned at the origin, while the planetary orbit was represented by a circular path in the orbital plane. HD 189733 b was placed along this path to illustrate its position relative to the host star.

The visualization is intended as a schematic representation of the system geometry and should not be interpreted as a fully scale-accurate reconstruction of the physical sizes and separation of the star and planet. Figure 11 shows the resulting three-dimensional representation.

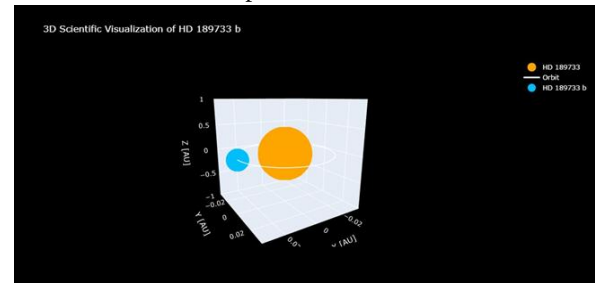


Figure 11: Schematic three-dimensional visualization of the HD 189733 planetary system.

The host star is shown at the centre, the orbital path represents the adopted orbital separation, and HD 189733 b is shown along the planetary orbit.

The orbital distance estimated using Kepler's third law was 0.03088 AU, compared with the adopted reference value of 0.03126 AU. This corresponds to a relative difference of approximately 1.2074%. These results show that the calculated orbital parameters are close to the adopted reference values.

In particular, the small difference in the recovered orbital period supports the consistency of the transit-search and period-detection procedure. The remaining differences may arise from the adopted stellar parameters, observational noise, light-curve processing, and simplifying assumptions used in the calculations

5.19. Hubble Transmission Spectrum

To complement the photometric analysis, previously published transmission-spectrum measurements of HD 189733 b were examined. The wavelength-dependent planet-to-star radius ratios used here were adopted from the published measurements attributed to Pont et al. (2008), rather than derived from the TESS light curve analysed in this work.

Published Hubble Space Telescope transmission-spectrum measurements from Pont et al. [1] were used for comparison with the photometric analysis. The measurements cover wavelengths from approximately 575 to 1025 nm. The planet-to-star radius ratio shows small variations with wavelength, representing changes in the apparent transit radius of the planet across the observed spectral range. The associated measurement uncertainties were included as error bars.

5.20. Comparison with Reference Values

The orbital parameters obtained from the present analysis were compared with adopted reference values for the HD 189733 planetary system in order to evaluate the consistency of the derived results.

The orbital period recovered from the Box Least Squares analysis was 2.21599 days, while the adopted reference value was 2.21858 days. The relative difference between these values was approximately 0.1164%. Figure 12 presents the adopted transmission spectrum.

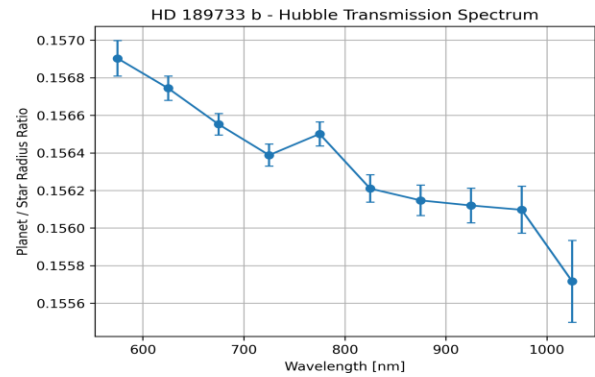


Figure 12: Transmission spectrum of HD 189733 b constructed from published wavelength-dependent planet-to-star radius-ratio measurements attributed to Pont et al. (2008). Error bars represent the corresponding published measurement uncertainties.

VI. DISCUSSION

The analysis of the HD 189733 system demonstrates how transit photometry and signal-processing techniques can be combined to extract important characteristics of an exoplanetary system. The processed light curve showed a clear decrease in normalized stellar flux during transit, providing evidence of the passage of HD 189733 b across its host star.

The Box Least Squares analysis identified a dominant periodic transit signal, and phase folding using the recovered period aligned the individual transit events into a well-defined transit profile. The derived orbital period of approximately 2.216 days was close to the adopted reference value of 2.21858 days, with a difference of approximately 0.1164%.

The estimated orbital distance of approximately 0.03088 AU was also close to the adopted reference value of 0.03126 AU, with a difference of approximately 1.2074%. This agreement indicates that the combination of transit analysis and Keplerian orbital calculations produced values consistent with the expected properties of the system.

The estimated planetary radius, mass, surface gravity, density, and equilibrium temperature further illustrate the physical properties of HD 189733 b. The results are consistent with the

interpretation of the planet as a large gas giant orbiting very close to its host star.

Frequency-spectrum and time-frequency analyses provided complementary views of periodic variations in the photometric observations.

These methods demonstrate how techniques commonly used in digital signal processing can also be applied to astronomical time-series data.

Overall, the analysis shows that publicly available astronomical observations, combined with Python-based photometric and signal processing methods, can be used to investigate and characterize a known exoplanetary system.

VII. LIMITATIONS

Several limitations should be considered when interpreting the results of this study. The analysis depends on the quality of the available photometric observations, which may contain instrumental noise, stellar variability, data gaps, and other systematic effects.

The calculated planetary properties also depend on adopted stellar and planetary parameters. Uncertainties in the stellar radius, stellar mass, and planetary mass can therefore propagate into the estimated planetary radius, orbital distance, surface gravity, density, and equilibrium temperature.

The equilibrium-temperature calculation represents a simplified estimate and does not include a complete treatment of atmospheric albedo, heat redistribution, atmospheric circulation, or spectral absorption. Similarly, the three-dimensional orbital representation is intended as a scientific visualization and should not be interpreted as a physically scaled representation of the actual sizes of the star and planet.

The FFT and spectrogram analyses provide complementary representations of the frequency content of the photometric signal. However, spectral features cannot by themselves be interpreted as independent astrophysical signals without additional statistical analysis.

The transmission spectrum presented in this study uses previously published wavelength-dependent measurements rather than a transmission spectrum independently extracted from the TESS observations used for the transit analysis.

Finally, HD 189733 b is an already known

exoplanet. Therefore, this work should be considered an independent educational analysis and characterization of a known planetary system rather than a claim of a new exoplanet discovery.

VIII. FUTURE WORK

Future work can extend this analysis by incorporating additional observations from multiple observing sectors and instruments. Combining a larger number of transit observations could improve the precision of the recovered orbital period and transit parameters.

More advanced transit models could be applied to estimate parameters such as orbital inclination, scaled semi-major axis, impact parameter, and limb-darkening coefficients. A complete uncertainty-propagation analysis could also provide confidence intervals for the derived planetary properties.

The signal-processing analysis could be extended using additional time-series techniques to distinguish stellar variability, instrumental effects, and potentially significant periodic features. Spectroscopic observations from space- and ground-based instruments could further improve atmospheric characterization. Future development of this work may also incorporate automated processing pipelines and machine-learning methods for identifying candidate transit signals in larger astronomical datasets. Such extensions would provide a natural progression from the analysis of a known exoplanet toward more advanced

astronomical signal-processing and exoplanet-search applications.

IX. CONCLUSION

This study presented a photometric and signal-processing analysis of the HD 189733 planetary system using observational light-curve data. The observations were cleaned, normalized, and flattened before the Box Least Squares method was applied to identify the periodic transit signal associated with HD 189733 b. The analysis recovered an orbital period of approximately 2.216 days. Phase folding revealed the repeated transit profile, allowing the transit depth and planet-to-

star radius ratio to be examined. These measurements, together with adopted stellar and planetary parameters, were used to estimate several physical properties of the system, including planetary radius, orbital distance, mass, surface gravity, density, and equilibrium temperature.

Digital signal-processing techniques were additionally applied through frequency-spectrum and time-frequency analyses. A three-dimensional orbital visualization and a published transmission-spectrum dataset were included to provide complementary representations of the planetary system.

The recovered orbital period differed from the adopted reference value by approximately 0.1164%, while the calculated orbital distance differed by approximately 1.2074%. The close agreement demonstrates that the implemented analysis workflow can reproduce important characteristics of this known exoplanetary system. Overall, this work demonstrates the application of Python-based astronomical data analysis, transit photometry, and digital signal processing to the characterization of a known exoplanet. It also provides a foundation for future studies involving more advanced transit modelling, uncertainty analysis, spectroscopic observations, and automated searches of astronomical time-series data.

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