PHOTOMETRIC OBSERVATION OF THE HIGH-AMPLITUDE δ SCUTI STAR GP ANDROMEDAE

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ABSTRACT

GP Andromedae [HIP 4322; $\alpha_{J2000} = 00^h55^m18.5^s$; $\delta_{J2000} = +23°09'49.37''$] is a high-amplitude δ Scuti star located in the constellation of Andromeda and has a short pulsation period of about 0.0787 days with a magnitude variation of ΔV = 0.6 mag. The aim of this research is to construct and analyze the light curve and deduce the period pulsation of GP Andromedae. Observation was carried out using the ITB-UNDANA Telescope with CCD QSI 616 on the V band. Aperture photometry was performed to measure the flux of GP Andromedae. The light curve was constructed using differential photometry method, and the determination of the period was carried out using the Lomb–Scargle method. The results of this study are the light curve of GP Andromedae in the V band magnitude $V = 10.319 - 10.900 \pm 0.004$ and a pulsation period value of 0.0773 days, which is lower than in previous studies. A hypothesis was formed regarding the existence of a low-mass star that has evolved to an advanced stage near GP Andromedae, causing its radius to expand and triggering a mass transfer process into GP Andromedae. This process will increase the density of GP Andromedae and causes its pulsation period to decrease. This opens up new discussions and encourages further research to verify the decreasing pulsation period of GP Andromedae.

Keywords: GP Andromedae — Delta Scuti variable stars(370) — Short period variable stars(1453) — Photometry(1234) — Light curve(918) — Lomb-Scargle periodogram(1959)

1. INTRODUCTION

Stars generally shine with a constant light, but many stars also exhibit variations in their brightness. Stars whose brightness changes are known as variable stars. Variable stars can be studied by measuring their brightness changes over time, which are then represented as a graph called a light curve. The GCVS (General Catalogue of Variable Stars) (Samus et al. 2017) records more than 50,000 variable stars, both extrinsic and intrinsic, which are then classified based on their physical characteristics. Photometry is one of the fundamental branches of astronomy that involves measuring the flux emitted by celestial objects as a function of wavelength. Ground-based photometric observations are often conducted on short-period variable stars because ground-based observations typically have relatively short observation windows (Djumari et al. 2024).

GP Andromedae is a high-amplitude δ Scuti star located in the Andromeda constellation. Like other δ Scuti stars, it demonstrates periodic brightness variations driven by both radial and non-radial pulsations of its outer layers. δ Scuti stars generally belong to spectral types A0 to F5 and are found near or on the main sequence, occupying the lower section of the instability strip on the Hertzsprung-Russell diagram. They are characterized by pulsation periods ranging from roughly 0.25 to 5 hours and magnitude variations between 0.003 and 0.9 in the V-band. These oscillations are attributed to complex internal stellar dynamics and evolutionary processes.

A high-amplitude δ Scuti star GP Andromedae exhibits significant magnitude variations with a magnitude in the V-band ranging from 10.43 to 11.03, according to the AAVSO, and a spectral class of A3 as recorded in the GCVS. Rodríguez et al. (2000) observed GP Andromedae and derived a period value of P = 0.0787 days. In particular, the pulsation period of GP Andromedae has exhibited notable variability over time, offering a unique opportunity for in-depth investigation. These changes may provide insights into the underlying mechanisms governing δ Scuti stars and their evolutionary trajectories.

A predicted period change (increase) due to stellar evolution exists for stars of δ Sct-type in the lower instability strip. Since the period is related to the structure of the star through the pulsation equation $P\sqrt{\rho} = Q$, the period change is therefore related to the radius change, if we assume that the star's mass does not vary. As a consequence, one may hope that the small changes in pulsation period have the potential to help reveal evolutionary changes in the stellar structure (Breger & Pamyatnykh 1998). Previous studies, Zhou & Jiang (2011) analyzed that the fundamental pulsation period of GP And is slowly increasing at a rate of $\dot{P}/P = (5.49 \pm 0.1) \times 10^{-8} yr^{-1}$ in accordance to the standard stellar evolution model.

In this study, we aim to construct the light curve of GP Andromedae and determine its pulsation period using observational data collected with the ITB-Undana telescope. This research utilizes differential photometry method, Fourier transform, and the Lomb-Scargle method to analyze the star's variability. By comparing this result with aforementioned measurements, we seek to contribute to the understanding of the evolving characteristics of δ Scuti stars, specifically GP Andromedae. Section 2 describes the observational methods and data reduction processes. Section 3 explains the data processing steps to construct the light curve and derive the pulsation period. Section 4 presents the analysis of the derived results and compares them with previous studies, and Section 5 concludes with a summary of the study and its implications.

2. OBSERVATION AND DATA REDUCTION

Data that used in this research is derived from observations in the Basic Astronomy Laboratory II course. The observation was conducted on November 9, 2024, at the Observatory of Nusa Cendana University in East Nusa Tenggara, Indonesia. ITB-UNDANA telescope (Celestron C-8) with f/10 focal ratio and 2032mm focal length was used for the observation. Equipped with a CCD camera QSI 616 with a resolution 1536x1024 pixels and 9 μm/pixel. The target of this observation is the high-amplitude δ Scuti star GP Andromedae [$\alpha_{J2000} = 00^h 55^m 18.5^s$; $\delta_{J2000} = +23°09'49.37''$]. The observation began at 20.14 local time (UTC+08) until 22.38 local time (UTC+08) and produced 81 sample data with 90 seconds of exposure time using a V filter. The observation also included bias, dark, and flat field.

Before the reduction, those 81 frames are plate solved using AstroImageJ. Thus, those frames will have the uniform coordination of the target star. This will ease the identification of every flux in the target star by only one specific uniform aperture area in every frame.

Every sample of those 81 samples of observed images is corrected using the method of data reduction to produce the clean flux of the star. The process of data reduction is done by AstroImageJ. The equation that use in the process is listed as below

$$clean = \frac{(raw - mbias) - (mdark - mbias)}{norm[(mflat - mbias) - (mdark - mbias)]} \quad (1)$$

where,
clean : calibrated image
raw : raw image
mbias : master bias frame (electronic bias in the CCD)
mdark : master dark frame (thermal noise)
mflat : master flat frame (non-uniform pixel sensitivity)
norm : normalization of flat field

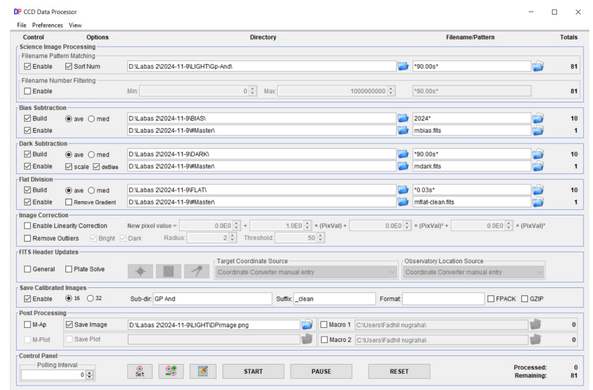

Figure 1: Data processing menu in AstroImageJ.

Dark images have been taken on the 10s exposure time, bias images have been taken on the 10s exposure time. Each of them is taken to 10 sample data. Nevertheless, those data had not been taken on the same day, rather on a day after the observation due to the unresolved trouble of the observation day. For the flat images, the data that is taken are 10 samples. Each image was taken with two exposure times, 0.03 seconds (2x2 binning) and 0.08 seconds (1x1 binning). However, the flat field images used were those taken with 0.03 seconds exposure time. It was chosen to match the binning of the raw images that used to increase the signal-to-noise ratio (SNR) of the target object, considering the presence of thin clouds that reduced the intensity of the starlight during the observation. Flat images are shot at 17.30 local time (UTC+8).

Every variable except the raw is responsible for data error because those variables define noise flux. Therefore, the raw images have to be reduced by those variables to produce the minimal error of clean images. In addition, normalization of corrected masterflat data in the denominator of the equation is responsible for weakening the strong flux and strengthening the weak flux due to the difference of flux distribution in corrected masterflat data. Thus, the clean images pixel counts can be reduced by the same common adjusted values.

Mean statistics is used for the normalization because the data distribution of all three flux data (dark, bias, and flat) follow the Gaussian distribution without any outlier. So the mode of data statistics is not significantly shifted. Thus, the majority of data is still in the center of the distribution.

Clean flux that is gathered from the process is limited at the visual range. This is because the shot of the images is taken at V filter. However, this will not affect the result of the periodicity because the energy distribution of the star peaks in the visual range and the variability of the star could be observed in visual range magnitude.

3. DATA ANALYSIS AND RESULT

Differential photometry method is used in constructing the light curve. Essentially, differential photometry involves the calculation of the differential flux from the target star relative to the comparison star. The light curve is constructed by plotting the differential magnitude as a function of time. TYC 1739-1584 [$\alpha_{J2000} = 00^h54^m57.85^s$; $\delta_{J2000} = +23°10'42.37''$] was selected as a comparison star because it is located relatively close to the target star in the image, making it reasonable to assume that both stars lie within the same column of air. Additionally, this star has a spectral class (G0) and apparent magnitude value that are nearly identical to those of the target star. The magnitude values in the standard V photometry system for GP Andromedae can be derived using the following method.

First, the extinction coefficient can be neglected because the target star and the comparison star are located in the same part of the sky, so the air mass of both stars is relatively the same. Second, if the target star and the comparison star have the same spectral class, then the color coefficient can be simplified because both have similar color indices. If both of these conditions are met, the difference in instrumental magnitude between the target star and the comparison star has the same value as the difference in apparent magnitude of the two objects. This allows for accurate calculations in the reduction of the star's brightness value using the differential photometry approach (Djumari et al. 2024).

The differential apparent magnitude of GP And, $m_{\rm star}$, is calculated using equation 2. Where m represents the V magnitude, and F represents the flux. The subscript *star* indicates the target star, and the subscript c indicates the comparison star, which is assumed to be a non-variable star.

$$m_{star} - m_c = -2.5 \times \log\left(\frac{F_{star}}{F_c}\right) \tag{2}$$

It is important to note that the measured flux from aperture photometry has a measurement error, which implies that the magnitude value of GP Andromedae derived from equation 2 will also include an error due to error propagation. The calculation of this error propagation is given by equation 3.

$$\Delta m_{star} = \sqrt{\left(\frac{\partial f}{\partial F_{star}}\Delta F_{star}\right)^2 + \left(\frac{\partial f}{\partial F_c}\Delta F_c\right)^2} \tag{3}$$

where

$$\frac{\partial f}{\partial F_{star}} = -2.5 \times \frac{1}{\ln(10)F_{star}} \tag{4}$$

and

$$\frac{\partial f}{\partial F_c} = -\left(-2.5 \times \frac{1}{\ln(10)F_c}\right) \tag{5}$$

Δ denotes the error and f refers to the function for calculating the differential apparent magnitude of the target star, which is equation 2. The differential apparent magnitude values of GP Andromedae derived through the differential photometry method are listed in Table 1.

The light curve is constructed by plotting the magnitude values as a function of time in *Heliocentric Julian Date* (HJD). Therefore, the *Julian Date* (JD) values obtained from the observations need to be converted to HJD first. In variable star research, time accuracy is very important. We need to consider the time it takes for light from the object to reach the observer. JD is the time when light reaches Earth, while remember that the Earth is moving around the Sun. The Earth's revolution causes differences in the distance between the Earth and the observed celestial object, so it is better to use the Sun as a more general reference position. The concept of time when light from a celestial object reaches the Sun is called *Heliocentric Julian Date* (HJD). The following is the equation to convert JD to HJD, where r is the Earth-Sun distance and c is the speed of light.

$$HJD = JD - \frac{r}{c}\left[\sin(\delta_\star)\sin(\delta_\odot) + \cos(\delta_\star)\cos(\delta_\odot)\cos(\alpha_\star - \alpha_\odot)\right] \tag{6}$$

A light curve can then be constructed, representing the V magnitude as a function of time in HJD. The resulting light curve is presented in Figure 2.

A Lomb-Scargle periodogram analysis was performed to derive the pulsation period of GP Andromedae from the magnitude variability data obtained in the previous stage. The results of the periodogram calculation are $P = 0.0773$ days and $f = 12.9315$ cycles/day, and are presented in Figure 3. This period is taken from the most dominant signal frequency in the light curve.

The period value obtained from the Lomb-Scargle periodogram analysis is then used to fold the time series in the light curve. This folding process aims to see how the light curve looks when presented in a 1-phase range, so that the HJD time function will change into phase.

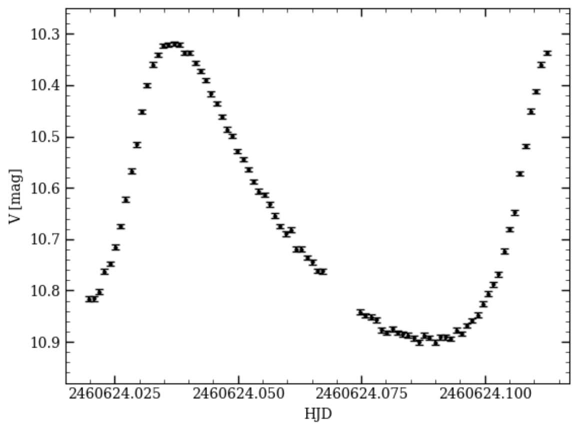

Figure 2: Light curve of GP Andromedae as a function of time in HJD.

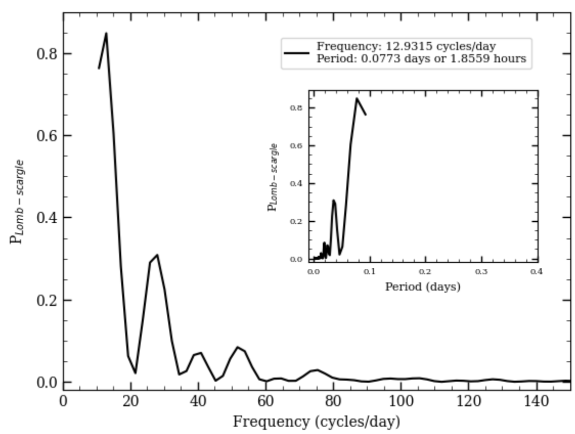

Figure 3: Analysis of the Lomb-Scargle periodogram for GP Andromedae.

The following is the equation used to convert HJD to phase.

$$Phase(\Phi) = \left(\frac{HJD - HJD_{\max}}{P}\right) mod(1) \tag{7}$$

where HJDmax is the time when a variable star has maximum brightness. Usually HJDmax is used as the Epoch or starting point of the phase of a variable star light curve. In this research, we used HJDmax from our own observations, which is at HJD 2460625.037. This selection is based on the fact that the period used is derived from our own observational data, so we can only ensure that this period value is constant around the time of our observations.

Then, a light curve of GP Andromedae is produced in Figure 4, showing the variability of V magnitude in the periodic phase domain. The red line represents a fitting model constructed using a 5-term Fourier series. The selection of the number of Fourier series terms used for fitting is based on the lowest Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) values among models with 3 to 10 terms. AIC and BIC are criteria for evaluating the quality of a fitting model by considering the model complexity. They are commonly used to find the model that best represents the data while avoiding overfitting. The smaller the AIC and BIC values, the better the fitting model. The fitting using a 5-term Fourier series has the lowest AIC and BIC values, so we chose this model to represent our observational data.

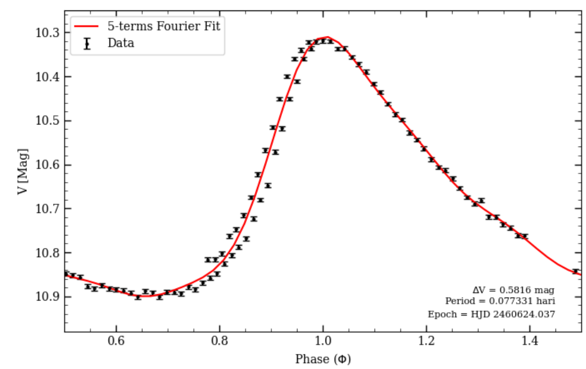

Figure 4: Light curve of GP Andromedae as a function of time in phase.

4. DISCUSSIONS

According to (Young 2012) the pulsating variable stars located in the unstable regions of the H-R diagram vary in brightness due to physical changes within the interior of the star, and their pulsations are due to the periodic expansion and contraction of the surface layers of the stars. The change of the variable stars' sizes can be explained with the usage of magnitude. The pulsation of variable stars happens when they are not in their hydrostatic equilibrium. In this case, the variable star system will act as an oscillator, and the prevalence and regularity of pulsating stars imply that the dissi- pated energy is replenished in some way. The variable stars are commonly distinguished by their period of pulsation and the shape of the light curve, which in turn act as a function of their mass and their evolutionary stage as well. Yet, the dynamic and the energy transformation of variable stars haven't been well understood until this moment.

In most δ Scuti stars, the $P_{Lomb-Scargle}$ versus *frequency* plot used to derive the pulsation period of the star will produce a graph with one or two dominant signals (observed from the peak power values of the signal). These dominant signals originate from the variability in brightness due to pulsation motion within the star. The same method was applied to derive the period of GP Andromedae, Figure 3 shows one dominant signal and several smaller signals. The frequency of the dominant signal was used to derive the pulsation period of GP Andromedae. Smaller signals might be caused by uneven gas clouds rotating around the star or possibly starspots on the surface of GP Andromedae. Additionally, noise from observations and instrumentation could also contribute to the appearance of these signals.

Another thing to consider is that the pulsation period of the GP Andromedae, at the time of this report, started to decrease. This was an interesting phenomenon, as the previous measurement Rodríguez et al. (2000) showed that the pulsation period was 0.0787 days or around 1.8888 hours, but in our recent measurement (2024), the period changed drastically to 0.0773 days.

The phenomenon of the decreasing pulsation period contrasts with the measurements from Rodríguez et al. (1993), Pop et al. (2003), Szeidl et al. (2006), and Zhou & Jiang (2011), which show an increase in the pulsation period of GP Andromedae at rates of $13 \times 10^{-8} yr^{-1}$, $6 \times 10^{-8} yr^{-1}$, $6.1 \times 10^{-8} yr^{-1}$, and $(5.48 \pm 0.1) \times 10^{-8} yr^{-1}$, respectively. Noise from the observations may be a contributing factor to the decrease in period, but it cannot be fully blamed, as there is a possibility that astrophysical processes are also responsible for the decrease in the pulsation period of GP Andromedae.

A predicted period change (increase) due to stellar evolution exists for stars of δ Sct-type in the lower instability strip. Since the period is related to the structure of the star through the pulsation equation $P\sqrt{\rho} = Q$, the period change is therefore related to the radius change, if we assume that the star's mass does not vary (Zhou & Jiang 2011). From this, it can be inferred that if the assumption of a constant stellar mass is not met, or meaning the stellar mass increase, it is plausible that the density of the star also increases. An increase in stellar density would lead to a shortening of the pulsation period. Considering that stellar evolution causes the radius star to expand, for the density to increase, the rate of mass increase must exceed the rate of radius expansion. Through this analysis, the most plausible astrophysical process to fulfill this condition is mass transfer from the surrounding into the star. Consequently, we propose the existence of a low-mass companion star near GP Andromedae, which being in its post main sequence evolutionary phase, causing its radius to expand and triggering a mass transfer process into GP Andromedae.

The results of this analysis open up new discussions and further research to verify the phenomenon of the decreasing pulsation period of GP Andromedae.

5. CONCLUSIONS

This study successfully determined the pulsation period of the variable star GP Andromedae, measured at 0.0773 days or approximately 1.856 hours. The light curve of this star was constructed in the phase domain using Lomb-Scargle periodogram analysis and fitted with a five-term Fourier series. The result revealed a decrease in the pulsation period compared to previous observation, sparking new discussions about the evolution of GP Andromedae.

The results of this study propose the hypothesis of a low-mass star that has evolved to an advanced stage near GP Andromedae, causing its radius to expand and triggering a mass transfer process into GP Andromedae. Where this mass transfer process increases the density of the GP Andromedae star and causes its pulsation period to decrease.

This research provides valuable insights into the characteristics of high-amplitude delta Scuti variable stars and highlights the need for further studies to verify the observed decrease in the pulsation period.

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APPENDIX

Table 1: Data differential magnitude [V] from the observation of GP Andromedae

JD	HJD	Phase	V [mag]
2460624.015	2460624.020	0.777	10.816 ± 0.004
2460624.016	2460624.021	0.791	10.815 ± 0.004
2460624.017	2460624.022	0.805	10.803 ± 0.004
2460624.019	2460624.023	0.819	10.763 ± 0.004
2460624.020	2460624.024	0.833	10.748 ± 0.004
2460624.021	2460624.025	0.847	10.715 ± 0.004
2460624.022	2460624.026	0.861	10.675 ± 0.004
2460624.023	2460624.027	0.875	10.623 ± 0.004
2460624.024	2460624.028	0.889	10.567 ± 0.004
2460624.025	2460624.029	0.902	10.516 ± 0.004
2460624.026	2460624.031	0.916	10.451 ± 0.004
2460624.027	2460624.032	0.930	10.400 ± 0.004
2460624.028	2460624.033	0.944	10.360 ± 0.004
2460624.029	2460624.034	0.958	10.340 ± 0.004
2460624.030	2460624.035	0.972	10.322 ± 0.004
2460624.031	2460624.036	0.986	10.321 ± 0.004
2460624.033	2460624.037	1.000	10.319 ± 0.004
2460624.034	2460624.038	1.014	10.321 ± 0.004
2460624.035	2460624.039	1.028	10.337 ± 0.004
2460624.036	2460624.040	1.042	10.336 ± 0.004
2460624.037	2460624.041	1.056	10.357 ± 0.004
2460624.038	2460624.042	1.070	10.372 ± 0.004
2460624.039	2460624.043	1.084	10.390 ± 0.004
2460624.040	2460624.045	1.098	10.417 ± 0.004
2460624.041	2460624.046	1.112	10.436 ± 0.004
2460624.042	2460624.047	1.126	10.462 ± 0.004
2460624.043	2460624.048	1.139	10.486 ± 0.004
2460624.044	2460624.049	1.153	10.498 ± 0.004
2460624.045	2460624.050	1.167	10.528 ± 0.004
2460624.046	2460624.051	1.181	10.544 ± 0.004
2460624.047	2460624.052	1.195	10.564 ± 0.004
2460624.048	2460624.053	1.209	10.588 ± 0.004
2460624.049	2460624.054	1.223	10.607 ± 0.004
2460624.050	2460624.055	1.237	10.613 ± 0.004
2460624.051	2460624.056	1.251	10.632 ± 0.004
2460624.052	2460624.058	1.265	10.654 ± 0.004
2460624.053	2460624.059	1.279	10.675 ± 0.004
2460624.054	2460624.060	1.293	10.689 ± 0.004
2460624.055	2460624.061	1.307	10.682 ± 0.004
2460624.056	2460624.062	1.321	10.719 ± 0.004
2460624.057	2460624.063	1.335	10.720 ± 0.004
2460624.058	2460624.064	1.349	10.736 ± 0.004
2460624.059	2460624.065	1.363	10.744 ± 0.004
2460624.060	2460624.066	1.377	10.762 ± 0.004
2460624.061	2460624.067	1.391	10.762 ± 0.004
2460624.062	2460624.075	1.489	10.842 ± 0.004
2460624.063	2460624.076	0.503	10.849 ± 0.004
2460624.064	2460624.077	0.517	10.852 ± 0.004
2460624.065	2460624.078	0.531	10.857 ± 0.004
2460624.066	2460624.079	0.544	10.877 ± 0.004
2460624.067	2460624.080	0.558	10.882 ± 0.004
2460624.068	2460624.081	0.572	10.875 ± 0.004
2460624.069	2460624.082	0.586	10.882 ± 0.004
2460624.070	2460624.083	0.600	10.884 ± 0.004
2460624.071	2460624.084	0.614	10.887 ± 0.004
2460624.072	2460624.085	0.628	10.893 ± 0.004
2460624.073	2460624.087	0.642	10.901 ± 0.004
2460624.074	2460624.088	0.656	10.887 ± 0.004
2460624.075	2460624.089	0.670	10.892 ± 0.004
2460624.076	2460624.090	0.684	10.901 ± 0.004
2460624.077	2460624.091	0.698	10.891 ± 0.004
2460624.078	2460624.092	0.712	10.891 ± 0.004
2460624.079	2460624.093	0.726	10.894 ± 0.004
2460624.080	2460624.094	0.740	10.878 ± 0.004
2460624.081	2460624.095	0.754	10.884 ± 0.004
2460624.082	2460624.096	0.768	10.868 ± 0.004
2460624.083	2460624.097	0.782	10.858 ± 0.004
2460624.084	2460624.098	0.796	10.848 ± 0.004
2460624.085	2460624.099	0.810	10.826 ± 0.004
2460624.086	2460624.101	0.823	10.806 ± 0.004
2460624.087	2460624.102	0.838	10.788 ± 0.004
2460624.088	2460624.103	0.851	10.768 ± 0.004
2460624.089	2460624.104	0.865	10.723 ± 0.004
2460624.090	2460624.105	0.879	10.681 ± 0.004
2460624.091	2460624.106	0.893	10.648 ± 0.004
2460624.092	2460624.107	0.907	10.572 ± 0.004
2460624.093	2460624.108	0.921	10.518 ± 0.004
2460624.094	2460624.109	0.935	10.451 ± 0.004
2460624.095	2460624.110	0.949	10.411 ± 0.004
2460624.096	2460624.111	0.963	10.360 ± 0.004
2460624.097	2460624.113	0.977	10.336 ± 0.004

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