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Further Evidence Found by TESS Is Confirming the Orbital Decay of Kepler-1568b

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Abstract: The orbital decay of Kepler-1658b remains a mystery to this day. Many previous authors have searched for this hot Jupiter using ground-based telescopes, with no secure results. Here, I present a search for Kepler-1658b with the data from NASA's Transiting Exoplanet Survey Satellite (TESS). By using the most recent TESS data, I have extended the time baseline of previous observations and was able to perform a more sensitive search. I evaluated the latest data and found further evidence to confirm the shrinking orbit of Kepler-1658b and predict the inspiral time of the system.

Keywords: exoplanets, Kepler 1658, TESS, transits, precise photometry.

1. Introduction

Kepler-1658 was the first planet candidate revealed by the Kepler mission, as KOI-1.01, KOI-2.01, and KOI-3.01 were known before launch [1]. Astronomers have been seeking evidence for the orbital decay Involving Kepler-1658 since at least the work of Vissapragada et al [2]. The authors showed that the orbit of Kepler-1598b should be shrinking constantly like WASP-12b [3] according to the analysis of the previous data from Kepler, WIRC, and TESS. Kepler-1658b is a hot Jupiter with an F-type host star [4]. Compared to some other systems, the data of Kepler-1658 is relatively unstable since its star is faint. As a result, we cannot guarantee the completeness of the study by Vissapragada et al. [2]. Recently, since more data detected by TESS came out, astronomers have further evidence to determine the future trend of changes in its orbit. Because the essay is a further evidence for proving the orbital decay, the introduction is relatively brief. For further introduction, please refer to Vissapragada et al [2].

2. Observations

2.1. Kepler

There are 12 quarters at a 30-minute cadence and three quarters at a 1-minute cadence observed by Kepler spacecraft. This is also a set of data that astronomers have previously studied, and it is mentioned again to be reused and combined with the latest data to find the result. By using **lightkurve** package [4], I downloaded the Kepler light curve and modeled the data sets by utilizing **exoplanet** package.

2.2. TESS

Although TESS data is not as high-quality as Kepler data, its database is relatively large. By doing so, errors can be reduced to a certain extent. All the data available is in Table 2.

To be more specific, there is an example from TESS Sector 41 with an orbit number from 1147 to 1153. In Figure 1, the transiting curves look relatively obvious. However, it is easy to notice that there is a breaking point in the middle of the whole curve. As a result, that data set cannot be useful for us to determine the transiting time, as shown in Figure 2.

3. Methods

Compared to Kepler's data, the individual data of TESS fluctuates significantly, but it still has reference value. By unifying the units of the two types of data and combining them with a plot and a residual plot, I found that the most suitable one for them is not linear regression, but quadratic regression. From Figure 1, we can easily see that on the left half of the figure (more precise data from Kepler), the residual plot shows an apparent pattern but not a random distribution. As a result, The data does not best fit with the linear regression line. Thus, a quadratic relationship needs to be needs to be considered. From Figure 2, the individuals are about randomly distributed alone x-axis, which means the quadratic regression fits the data sets. By using the Python program, the quadratic coefficient appears to be $(-7.23598 \pm 1.45176) \cdot 10^{-9}$. Because of its negative sign, the orbital decay of Kepler-1658b can be confirmed.

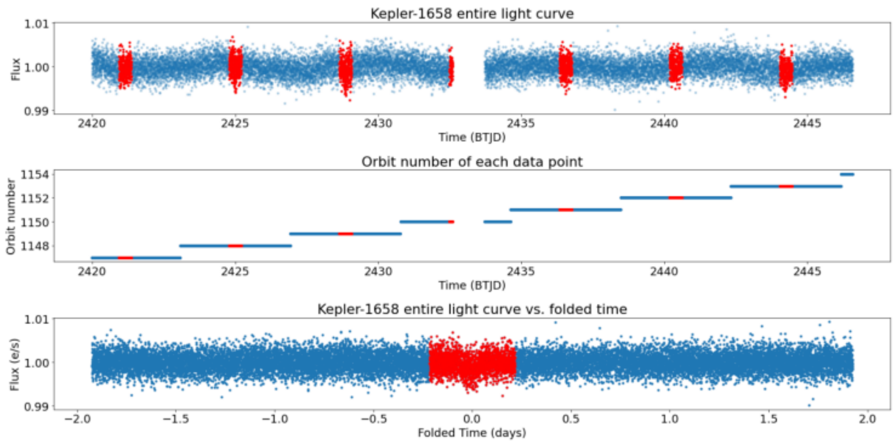

Figure 1: The overall light curve of Kepler-1658 (the red sign is where the transiting progress occur)

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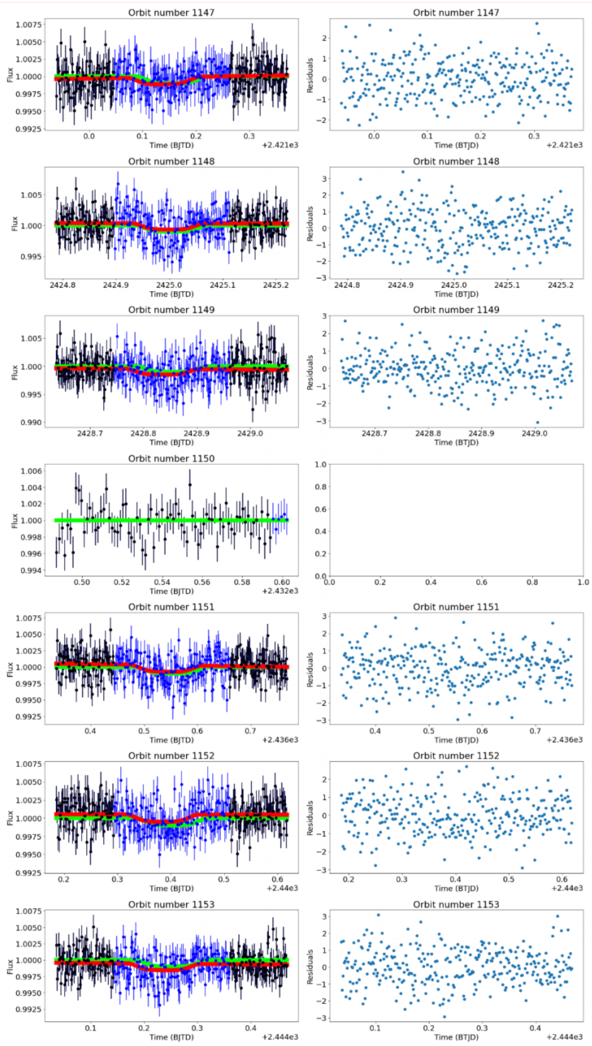

Figure 2: More specific steps for finding the transiting time interval

Table 1: For the Kepler data sets, LC and SC refer to long cadence (30-minute exposures) and short cadence (1-minute exposures), respectively. the data from the second column is the calculated results, for unifying the unit with TESS

Data Set	Orbit number (calculated result)	Transit Time (BJD)	
Kepler LC Quarter 0	-12	2454959.7314	+0.0014 -0.0015
Kepler LC Quarter 1	-6	2454982.82835	-0.00061 -0.00061
Kepler SC Quarter 2	11	2455048.26751	+000021 -0.00022
Kepler LC Quarter 3	35	2455140.65189	+0.00040 -0.00042
Kepler LC Quarter 4	59	2455233.03736	-0.00033 -0.00035
Kepler LC Quarter 5	83	2455325.42133	+0.00035 +0.00035

Table 1: (continued)

Kepler SC Quarter 7	131	2455510.19192	-0.00036 +0.00023
Kepler SC Quarter 8	155	2455602.57708	-0.00023 +0.00027
Kepler LC Quarter 9	178	2455691.11211	-0.00027 +.00033
Kepler LC Quarter 11	228	2455883.58121	-0.00031 +0.00032
Kepler LC Quarter 12	252	2455975.96583	-0.00033 -0.00036
Kepler LC Quarter 13	275	2456064.50087	+0.00036 -0.00036
Kepler LC Quarter 14	325	2456256.97026	-0.00037 -0.00035
Kepler LC Quarter 15	349	245634935438	+0.00038 -0.00039
Kepler LC Quarter 17	365	2456410.94385	+0.00065 +0.00064

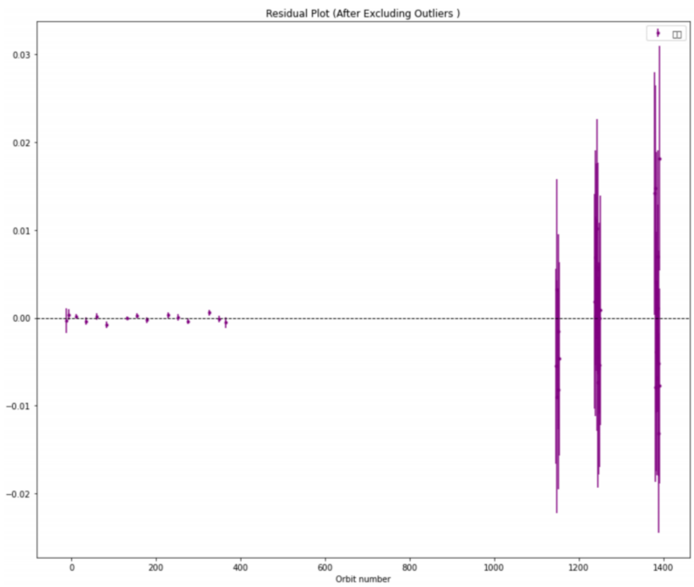

Figure 3: This is the residual plot of the quadratic regression, which contains the uncertainties of each individual.

4. Results

4.1. Calculation

In previous research [5], some constants have been measured. The quadratic coefficient:

$$C_2 = \left(\frac{P}{2}\right)\left(\frac{dP}{dt}\right) = (-7.23598 \pm 1.45176) \cdot 10^{-9} \tag{1}$$

Calculation for $\dot{P}$:

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$$\frac{\mathrm{dP}}{\mathrm{dt}} = \frac{2}{3.84937 \text{ days}} (-7.23598) \cdot 10^{-9} \text{ days} = 3.75956 \cdot 10^{-9} \quad (2)$$

Table 2: Outliers have been excluded

Orbit number (calculated result)	Transit Time (Days)
1147	2421.13999794±0.01107531
1148	2424.99813411+0.01252269
1149	2428.83521579+0.0132554
1151	2436.54138026±0.01111421
1152	2440.38408397+0.0112751
1153	2444.23698355+0.010986721
1238	2771.43875172+0.01222068
1239	2775.28636183±0.01134779
1240	2779.14246938±0.01221257
1242	2786.84010272±0.01180961
1243	2790.68282405±0.01203744
1244	2794.54313956±0.01247402
1245	2798.37506708±0.01198935
1246	2802.23733038±0.01202081
1247	2806.07532384+0.01212042
1249	2813.779754+0.01088812
1250	2817.62376733+0.01163627
1251	2821.47937701±0.01305526
1280	3318.05933387±0.01383833
1381	3321.90925122+0.01175709
1382	3325.7359887±0.01081116
1383	3329.59725668+0.0148565
1384	3333.43871939±0.01360349
1385	3337.285021521+0.01104347
1387	3344.99763735±0.01207266
1388	3348.84104345+0.01181232
1389	3352.67621157+0.0113846
1390	3356.53349542±0.01280488
1391	3360.40621754+0.01279
1392	3364.229641847+0.0111142

Unify the unit to msec/yr:

$$(2) = 3.75956 \cdot 10^{-9} \cdot \pi \cdot 10^{7} \cdot 1000 = 118.110 \pm 23.6966 \, \frac{\text{mec}}{\text{yr}} \quad (3)$$

Using data from Kepler, Palomar/WIRC, and TESS, we showed that Kepler-1658b's orbit appears to be shrinking at a rate of $\dot{P} = 118.11^{+23.697}_{-23.697} \frac{\text{mec}}{\text{yr}}$, coresponding to an inspiral timescale of P/P≈2.8 Myr. The inspiral timescale has increased compared to the previous research Vissapragada et al. [2].

5. Conclusion

Though the evidence so far points to the confirmation of the shrinking orbit of Kepler-1568b, we still cannot completely conclude that result since the database is still not enough. Astronomers may find

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different results in the future with the latest data. Following are three possible outcomes of Kepler-1658b. For one, it falls into its host star after about 2.8 million years. For another, its orbit will shrinking to a certain value, and then, it will always stay in that orbit. Last, the orbital decay does not appear.

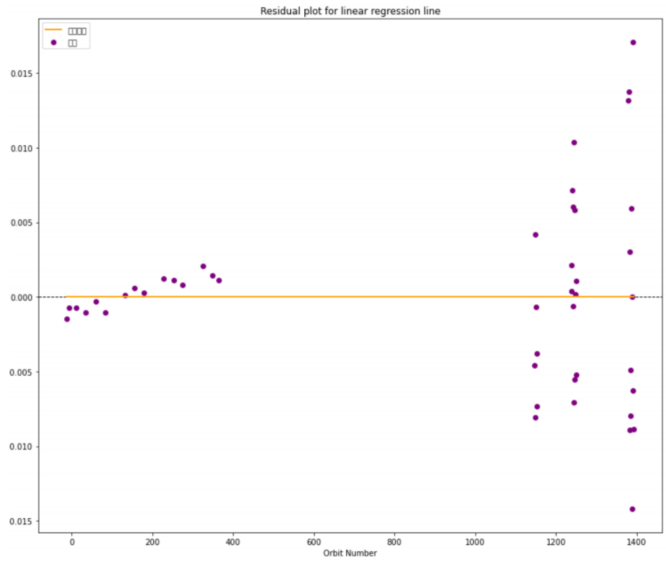

Figure 4: The yellow line is the linear regression result and each purple point is the individual data

References

[1] Borucki, W. J., Koch, D. G., Basri, G., et al. 2011, ApJ, 736, 19, doi: 10.1088/0004-637X/736/1/19

[2] Vissapragada, S., Chontos, A., Greklek-McKeon, M., et al. 2022, The Astrophysical Journal Letters, 941, L31, doi: 10.3847/2041-8213/aca47e

[3] Yee, S. W., Winn, J. N., Knutson, H. A., et al. 2019, The Astrophysical Journal Letters, 888, L5, doi: 10.3847/2041-8213/ab5c16

[4] Lightkurve Collaboration, Cardoso, J. V. d. M., Hedges, C., et al. 2018, Lightkurve: Kepler and TESS time series analysis in Python, Astrophysics Source Code Library. http://ascl.net/1812.013

[5] Chontos, A., Huber, D., Latham, D. W., et al. 2019, AJ, 157, 192, doi: 10.3847/1538-3881/ab0e8e