KIC 5768203: A δ Sct Pulsator Modulated by Rotation and Spots

Shuguo Ma1,2, Esamdin Ali1,2, Chenglong Lv1,2, Peng Wei1, TaoZhi Yang3, Hubiao Niu1, Jundan Nie4, Junhui Liu5, Peng Zong6, Guojie Feng1, and Mengfan Zhang6

1 Xinjiang Astronomical Observatory, Chinese Academy of Sciences, Urumqi, Xinjiang 830011, People’s Republic of China; mashuguo@xao.ac.cn
2 School of Astronomy and Space Science, University of Chinese Academy of Sciences, Beijing 100049, People’s Republic of China; aliyi@xao.ac.cn
3 School of Physics, Xi’an Jiaotong University, Xi’an 710049, People’s Republic Of China
4 CAS Key Laboratory of Optical Astronomy, National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100101, People’s Republic Of China
5 Astronomical Department, Xiamen University, Xiamen 361005, People’s Republic of China
6 Astronomical Department, Beijing Normal University, Beijing 100875, People’s Republic of China

Received 2021 December 28; revised 2022 May 10; accepted 2022 May 12; published 2022 June 28

Abstract

We perform a detailed analysis of the Kepler target KIC 5768203 based on the Kepler and Transiting Exoplanet Survey Satellite (TESS) data. Three independent frequencies are detected by Fourier analysis of the Kepler long-cadence data: two pulsation frequencies $f_{P0} = 7.807874(2)$ day$^{-1}$ and $f_{P1} = 9.970035(6)$ day$^{-1}$, which have amplitudes below 1.4 mmag in the Kepler band, and one modulation frequency $f_{rot} = 0.45813(1)$ day$^{-1}$. Based on a period ratio of 0.7803, $f_{P0}$ and $f_{P1}$ are supposed to be radial frequencies. However, further confirmation is needed. Based on the triplets and phase variations of the two pulsation frequencies, the star is possibly a δ Sct pulsator in a binary system. The modulation frequency $f_{rot}$ and its four harmonics could be attributed to the stellar rotation and surface spots. With the rotation frequency $f_{rot}$, the rotation velocity of the star is estimated to be 75(3) km s$^{-1}$. By analyzing the phase diagram without pulsations, it is inferred that there are starspots (or clusters of starspots) of large area on the surface of KIC 5768203. These starspots are slowly evolving in position and brightness over the course of the Kepler long-cadence observations. The finding of the rotation frequency in the TESS data implies the long-term presence of starspots on the surface of KIC 5768203.

Unified Astronomy Thesaurus concepts: Asteroseismology (73); Delta Scuti variable stars (370); Starspots (1572); Stellar rotation (1629)

1. Introduction

The δ Sct variables are typical A and early F stars with $T_{\text{eff}}$ in the range of 6300–8600 K and have intermediate masses from 1.5 to 2.5 $M_{\odot}$. δ Sct stars have a range of brightness variation less than 0.9 mag in the $V$ band. They pulsate in radial and nonradial modes, and usually have multiple frequencies in a range of 5–80 day$^{-1}$ (Breger 1979). A subclass called high-amplitude δ Sct stars (HADS) has a range of brightness variation larger than 0.3 mag in the $V$ band, and usually pulsates in one or two (or more) radial modes, accompanied by rotation velocities below 30 km s$^{-1}$ (Breger 2000; Niu et al. 2017; Yang et al. 2018). The γ Dor variables are usually F dwarfs and giants with the effective temperature range 6100–7500 K (Balona et al. 2011; Bradley et al. 2015). They usually pulsate in gravity (g) modes with a frequency range of 0.3–3 day$^{-1}$ (Kaye et al. 1999; Grigahcène et al. 2010). The two types of variables have different mechanisms of pulsation: the pulsation of δ Sct stars is driven by the $\kappa$ mechanism operating in the He II ionization zone (Baker & Kippenhahn 1965; Chevalier 1971; Breger 2000), while the pulsation of γ Doris is driven by the convective flux blocking mechanism (Dupret et al. 2005; Grigahcène et al. 2005).

In recent years, the Kepler space telescope (Borucki et al. 2010) and Transiting Exoplanet Survey Satellite (TESS; Balona et al. 2019) have provided a mass of high-precision photometric data, which have greatly facilitated the study of variable stars including of δ Scts and γ Doris (Balona et al. 2012; Handberg et al. 2021). The long time span of the Kepler mission has presented unprecedented frequency resolution, which allows us to detect new stellar features. The TESS mission covers the full sky and is capable of detecting stars closer and brighter than the typical Kepler targets (Stello et al. 2021). The sky overlapping between the Kepler and TESS mission is well suited for carrying out asteroseismology, as longer time-span data allows detection of more details, more frequencies, which potentially can be used to derive better constraints on the internal structure.

With high-precision photometry data, it is found that a majority of δ Scts display low frequencies that are compatible with the pulsating frequencies of γ Doris. (Grigahcène et al. 2010; Balona 2018). This phenomenon was first discovered by Handler et al. (2002), and these stars were called hybrid pulsators with just a few found by ground-based observations. Further researches show that the instability region where γ Doris are located is entirely within the region where δ Sct are located (Balona 2014, 2018). This implies that different driving and damping mechanisms may act simultaneously on a star (Xiong et al. 2015, 2016). Besides g-mode pulsations, the frequencies of δ Scts at the low frequency may originate from the orbital motion of the binary system (Murphy et al. 2018). Brightness variations due to rotation and starspots may also display low frequencies at a amplitude spectrum (Balona 2019a). Some studies present evidence of spots on the A- and B-type stars, suggesting that magnetic activity may exist on hot stars (Cantiello et al. 2009; Balona 2019b, 2021).
The Astronomical Journal, 164:22 (12pp), 2022 July

Ma et al.

Table 1
Parameters of KIC 5768203

| Parameters          | Value in Catalog      | References         |
|---------------------|-----------------------|--------------------|
| Kepler ID           | 5768203               |                    |
| TIC ID              | 377730260             |                    |
| RA                  | +18°51'56".4          |                    |
| Decl.               | −41°05'27".7          |                    |
| Kmags               | 10.08 mag             | a                  |
| Spectral Type       | F0                    | b                  |
| $T_{\text{eff}}$    | 6454 K                | a                  |
|                     | 6962(8) K             | b                  |
|                     | 6934(134) K           | c                  |
|                     | 6536(123) K           | d                  |
|                     | 6513(106) K           | e                  |
|                     | 6739(183) K           | f                  |
| [Fe/H]              | −0.62(1) dex          | b                  |
|                     | −0.62(2) dex          | b                  |
|                     | −0.3(2) g             | g                  |
| $M$                 | 1.5(3) $M_{\odot}$    | c                  |
| $R$                 | 3.2(2) $R_{\odot}$    | c                  |
| $\log g$            | 3.60(9) egs           | c                  |

Note. (a) KIC (Kepler Mission Team 2009). (b) Luo et al. (2019). (c) TIC (Stassun et al. 2019). (d) Ammons et al. 2006. (e) Gaia (Gaia Collaboration et al. 2018). (f) Breger et al. 2018. (g) Frasca et al. 2016.

The paper is structured as follows. The observation and data reduction of KIC 5768203 are presented in Section 2, and the frequency properties are analyzed in Section 3. We make some discussion for the features of KIC 5768203 in Section 4 and give a summary in Section 5.

2. Observations and Data Reduction

KIC 5768203 has short-cadence (SC) photometric observations in quarter two and long-cadence (LC) photometric observations in 14 quarters in the database of the Kepler Asteroseismic Science Operations Center (Kjeldsen et al. 2010). The SC data have a time span of 30 days with 43362 data points after removing some outliers, and the LC data have a time span of 1437.3 days in total with 50645 data points after removing some outliers. KIC 5768203 was observed by TESS in sectors 14 and 26 respectively with 2 minutes and 30 minutes exposure time. The TESS short and long-cadence data sets have the same time span of 51.8 days. Table 2 shows the time span of the Kepler and TESS data.

All the Kepler and TESS data of KIC 5768203 are downloaded from the Mikulski Archive for Space Telescopes (MAST) server. The Kepler data have been processed with NASA’s Kepler Data Processing Pipeline (Jenkins et al. 2010). The TESS data have been processed with the Science Processing Operations Center Pipeline (Jenkins et al. 2016). All the data sets contain two types of flux: the raw flux and the corrected flux. The raw flux is obtained with simple aperture photometry (SAP). The corrected flux is obtained with Pre-search Data Conditioning Simple Aperture Photometry (PDC_SAP), which corrects the SAP light curves for the systematics of the instrument. The corrected flux (PDC_SAP) is used in frequency analysis of KIC 5768203.

In the AAVSO international Variable Star Index and the SIMBAD database, KIC 5768203 is a δ Sct star with a pulsation period of 0.12807 day and a range of brightness variation of 0.003 mag. Murphy et al. (2018) proposed that KIC 5768203 was a δ Sct in a binary system with an orbital period of 183.73 days. Some statistical studies also involved KIC 5768203 (Huber et al. 2014; Stevens et al. 2017; Barcelò Forteza et al. 2018; Qian et al. 2018). Yutterhoeven et al. (2011) analyzed the star with the Kepler data and found three independent frequencies in the range 7.8–17.0 day$^{-1}$, but the detailed frequency analysis of the star has not yet been done.

Some parameters for KIC 5768203 are listed in Table 1, which are collected from the SIMBAD database. The multiple measurements of the effective temperature ($T_{\text{eff}}$) of KIC 5768203 have been displayed in Table 1, with the lowest $T_{\text{eff}}$ 6454 K in Kepler Input Catalog (KIC) and the highest $T_{\text{eff}}$ 6962 K provided by Qian et al. (2018). Several measurements of $T_{\text{eff}}$ obtained by using photometric indices in literature are in the range 6500–6900 K (Ammons et al. 2006; Berger et al. 2018; Gaia Collaboration et al. 2018). There are two LAMOST spectrum observations of KIC 5768203 with low resolutions. By using the two spectra, $T_{\text{eff}}$ and [Fe/H] are estimated to be 6922(15) K and 6913(24) K, −0.62(1) dex and −0.62(2) dex (Luo et al. 2019). The values in parentheses are the errors of measurements. The TESS Input Catalog (TIC) adopted a value of 6934(134) K as $T_{\text{eff}}$ of KIC 5768203 obtained from the LAMOST spectra (Stassun et al. 2019). Based on Gaia parallaxes and $T_{\text{eff}}$ from the LAMOST spectra, the radius, mass, and luminosity of KIC 5768203 are estimated to be 3.2(2) $R_{\odot}$, 1.5(3) $M_{\odot}$, and 22(1) $L_{\odot}$ by using empirical relations (Stassun et al. 2019). By using one of the LAMOST spectra, Frasca et al. (2016) measured [Fe/H] as −0.3(2) dex. The value of vsini did not be got with low resolutions of the LAMOST spectra.

The PYTHON package LightKurve is used to access and combine multiple quarters of data from MAST (LightKurve Collaboration et al. 2018). The LightKurve package is also used to inspect observation data, to remove outliers and normalize the flux. The relative magnitude of KIC 5768203 is calculated with the normalized flux. The samples of the SC and LC corrected light curves of the Kepler and TESS data of KIC 5768203 are shown in Figure 1. The strong pulsation and periodic modulation of KIC 5768203 can be seen in the top panel of the figure.

3. Frequency Analysis

The frequency analysis of KIC 5768203 is conducted by the software PERIOD04 (Lenz & Breger 2005). The light curve is fitted with the following formula:

$$m = m_0 + \sum_{i=1}^{N} A_i \sin(2\pi(f_it + \phi_i)),$$

where $m_0$, $A_i$, $f_i$, and $\phi_i$ are the zero point, amplitude, frequency, and phase of each peak, respectively.

In this paper, the corrected LC, SC light curves of the Kepler and TESS data (KLCD, KSCD, TLCD, and TSCD) are used to analyze the light features of KIC 5768203. The Nyquist frequencies of KLCD, KSCD, TLCD, and TSCD are 24.470 day$^{-1}$, 715.027 day$^{-1}$, 23.998 day$^{-1}$, and 348.051 day$^{-1}$ in sequence (Murphy et al. 2013). The frequency range of $0 < f < 80 \text{ day}^{-1}$ is chosen to detect all potential significant frequencies (Breger 1979; Kaye et al. 1999; Grigahcéne et al. 2010; Balona & Dziembowski 2011), and the frequency

http://www.aavso.org/vsx
resolution is used to distinguish close frequencies and filter out spurious frequencies. With the time span of observation data, the frequency resolutions, $f_{\text{res}} = 1.5/\Delta T$, of KLCD and KSCD, are calculated to be 0.001044 day$^{-1}$ and 0.05005 day$^{-1}$, respectively (Loumos & Deeming 1978). TLCD and TSCD have the same time span of 358.1 days from sector 14 to 26, and the frequency resolution of TLCD and TSCD is estimated to be 0.00426 day$^{-1}$. However, there are 300.1 days of no data between Section 14 and 26, which can lead to a significant overestimation of the frequency resolution. The frequency resolution of data in Section 14 and 26 is 0.06024 day$^{-1}$ and 0.05576 day$^{-1}$, which can be referred to identify suspicious frequencies. Because the Kepler data have signal-to-noise ratio and frequency resolution higher than the TESS data, the identification of frequencies should be based on the Kepler data. Each data set of Kepler and TESS is subjected to iterative
presh whitening, and modeled as a linear superposition of frequencies. During each iteration, a least-square fit of Equation (1) is applied to the corrected data, and the frequency, amplitude, and phase of the highest amplitude peak are determined. The resulting sinusoidal model constructed by using the above solutions is subtracted from the light curve. Then the next iteration uses the residual time series as input in the follow-up search. The periodograms of the significant prewhitening steps for each data set are showed in Appendix. The median amplitude in a window of 2 day$^{-1}$ centered on the extracted frequency at each iteration is calculated as noise. We adopt a criterion of signal-to-noise ratio ($S/N > 5.0$ suggested by Baran et al. (2015) to judge the significance of detected peaks, and calculate uncertainties of frequencies with a method suggested by Kallinger et al. (2008). All the significant frequencies extracted from the Kepler and TESS data are in the range of 0–24 day$^{-1}$. In order to show details more clearly, we only present the spectra in a range of 0–3 day$^{-1}$, excluding other frequencies with $S/N > 5.0$ are detected in KSCD and marked in Table 3. Retaining $f_{0}$, $f_{1}$, and $f_{2}$ in Tables 4, 5, and 6.

Figure 2. The amplitude spectra of KIC 5768203 in a range of 0–24 day$^{-1}$ and the partial enlarged detail in a range of 0–3 day$^{-1}$. The red dashed line in the partial enlarged detail marks the rotational frequency.

### 3.1. Frequencies in KSCD

Six frequencies with $S/N > 5.0$ are detected in KSCD and listed in Table 3. Among these frequencies, there are three independent frequencies and two harmonics. The two peaks $f_{01}$ and $f_{02}$ with the highest $S/N$ in the KSCD spectrum are in the δ Sct frequency range, and their period ratio ($P_{02}/P_{01}$) is 0.7803. According to Stellingwerf (1979), the period ratio of the fundamental mode and first overtone of δ Sct with radial pulsations can be in a range of 0.756–0.787; thus, we infer the two high frequencies might be the radial fundamental mode and first overtone. However, further confirmation is need to verify this. The two frequencies are also detected in KLCD, TLCD, and TSCD, marked as $f_{00}$ and $f_{01}$ in Tables 4, 5, and 6.

In the top panel of Figure 1, it can be seen that the light curve of KIC 5768203 in KSCD is modulated by a periodic signal. The signal has a period about two days. There are three significant frequencies at the low frequencies of KIC 5768203. The signal has a period about two days. There are three significant frequencies at the low frequencies of KIC 5768203. The rotation period of the star is need to be determined. The other two frequencies are harmonics of $f_{01}$ and $f_{02}$, and we mark them as $f_{01}$, $f_{02}$ in Table 3. Retaining $f_{0}$, $f_{01}$, $f_{02}$ and excluding other frequencies with $S/N$ higher than 5, we fold the residual light curve of KIC 5768203 by using a period of

### Table 3

Extracted Frequencies of KIC 5768203 in KSCD

| Number | Frequency (day$^{-1}$) | Amplitude (mmag) | S/N | Comment |
|--------|------------------------|-----------------|-----|---------|
| $f_{01}$ | 7.80787(2) | 1.380(2) | 262.2 | $f_{00}$ |
| $f_{02}$ | 9.97005(8) | 0.248(2) | 62.6 | $f_{01}$ |
| $f_{01}$ | 0.4576(1) | 0.361(2) | 31.1 | $f_{00}$ |
| $f_{01}$ | 0.9158(4) | 0.096(2) | 8.8 | $2f_{00}$ |
| $f_{01}$ | 0.4070(3) | 0.099(2) | 8.7 | alias |
| $f_{01}$ | 1.3778(6) | 0.057(2) | 5.0 | $3f_{00}$ |

Note. Among these frequencies, three peaks are independent frequencies, two are harmonics, one is an alias.
2.1853(5) days ($1/f_h$) in KSCD. The phase folded light curve is binned every 0.002 phase and showed in Figure 3. One frequency ($f_h$) adjacent to $f_2$ is detected in KSCD, not in KLCD. The separation between $f_h$ and $f_2$ is 0.0506 day$^{-1}$. With $f_{rms} = 0.05005$ day$^{-1}$ of KSCD, the frequency $f_h$ is identified as an alias.

### 3.2. Frequencies in KLCD

The observation time span of KLCD is much longer than that of KSCD, so more frequencies can be detected in KLCD than that in KSCD. Fifteen frequencies with S/N $> 5.0$ are detected in KLCD and listed in Table 4. Among these frequencies, there are three independent frequencies, two combinations, and four harmonics. The two frequencies $f_{h_1}$ and $f_{h_2}$ have the highest amplitudes in the KLCD spectrum. They have a period ratio of 0.7803 and are probably radial pulsations. The frequency of $f_{h_5}$ in Table 4 is twice as much as $f_{h_1}$, therefore it is a possible harmonic of $f_{h_1}$. The frequency of $f_{h_{10}}$ in Table 4 is equal to the sum of $f_{h_1}$ and $f_{h_2}$, and should be a combination. The frequencies $f_{h_3}$, $f_{h_4}$, $f_{h_6}$, $f_{h_7}$ form two triplets. There is an interval of 0.00543(7) day$^{-1}$ between the peaks of each triplet. The interval is marked as shift1 in Table 4. The frequencies $f_{h_8}$, $f_{h_9}$, $f_{h_{10}}$ form another triplet. There is an interval of 0.0108(1) day$^{-1}$ between each peak of the triplet, and the interval is marked as shift2 in Table 4. Shift1 is very close to the orbital frequency $f_{orb} = 0.00268$ day$^{-1}$ of the Kepler spacecraft in the error range. Shift2 is very close to the rotation frequency 0.011 day$^{-1}$ of the Kepler spacecraft in the error range. In frequency analysis of KIC 5768203, the PDC _ SAP flux is used. The PDC _ SAP flux has been corrected for the orbital and rotational effects of the Kepler spacecraft. No frequency or frequency interval of 0.00543(7) day$^{-1}$ has been found in other literature using the PDC _ SAP flux for frequency analysis. The shift1 of 0.00543(7) day$^{-1}$ for $f_{h_1}$ and $f_{h_2}$ may be attributed to the target itself. The shift2 is twice as much as shift1, and it is possibly caused by the same origin. This point is discussed in Section 4.1.

The frequency $f_2$ that may be due to periodic modulation is detected with four harmonics in KLCD. The first harmonic $f_1$ is the highest peak at the low frequency of KLCD. The double-humped wave of the phase diagram shown in Figure 3 may result in that the first harmonic has higher amplitude than the frequency $f_2$ has (Shi et al. 2021). The five related frequencies are marked as $f_{h_1}$, $f_{h_2}$, $f_{h_3}$, $f_{h_4}$, and $f_{h_5}$ in Table 4.

To observe details of brightness variation caused by the periodic modulation, we filter out the high frequencies (pulsation frequencies) with S/N higher than 5 and adopt the residuals of KLCD to analyze the periodic modulation. A modulation period is calculated as 2.18279(5) days by using the frequency $f_2$ in Table 4. We use the modulation period to fold the light curve of the residuals of KLCD, and show a phase evolution diagram over a time span of nearly four years in Figure 4. In the figure, each pixel presents one sampling point of the residuals of KLCD. Color, from blue to red, indicates the surface brightness of the star from bright to dark in each (time, phase) pixel, which is marked as the relative mag on the right Y-axis. For ease of visual clarity, the residuals of KLCD is folded with 2 times in phase. The time sequence is from left to right in the figure. The phase evolution diagram over a time span of nearly four years indicates the surface brightness of the star is uneven, and evolves gradually in time.

In Figure 4, there are three wide vertical white gaps and each gap corresponds to a time span of over 70 days without data in KLCD. We divide the residuals of KLCD into four segments

| Number | Frequency (day$^{-1}$) | Amplitude (mmag) | S/N | Comment |
|--------|------------------------|-----------------|-----|---------|
| $f_{h_1}$ | 7.807874(2) | 1.35(2) | 1152.3 | $f_{h_1}$ |
| $f_{h_2}$ | 9.970035(6) | 0.24(5) | 309.7 | $f_{h_2}$ |
| $f_{h_3}$ | 7.81324(1) | 0.062(2) | 51.0 | $f_{h_3}$ + shift1 |
| $f_{h_4}$ | 7.80237(7) | 0.03(2) | 51.4 | $f_{h_4}$ + shift1 |
| $f_{h_5}$ | 15.61559(6) | 0.013(2) | 20.9 | 2$f_{h_5}$ |
| $f_{h_6}$ | 9.96462(6) | 0.013(2) | 17.2 | $f_{h_6}$ + shift1 |
| $f_{h_7}$ | 9.97541(6) | 0.013(2) | 17.1 | $f_{h_7}$ + shift1 |
| $f_{h_8}$ | 7.79700(9) | 0.017(2) | 14.9 | $f_{h_8}$ + shift2 |
| $f_{h_9}$ | 7.8187(1) | 0.015(2) | 14.4 | $f_{h_9}$ + shift2 |
| $f_{h_{10}}$ | 17.7778(1) | 0.005(4) | 7.6 | 5$f_{h_5}$ |

**Note.** Among these frequencies, three are independent frequencies, two are combinations and four are harmonics. Shift1 is 0.00543(7) day$^{-1}$, and shift2 is 0.0108(1) day$^{-1}$.

| Number | Frequency (day$^{-1}$) | Amplitude (mmag) | S/N | Comment |
|--------|------------------------|-----------------|-----|---------|
| $f_{h_1}$ | 7.80785(3) | 1.11(1) | 54.2 | $f_{h_1}$ |
| $f_{h_2}$ | 9.970(2) | 0.23(8) | 11.3 | $f_{h_2}$ |
| $f_{h_3}$ | 0.464(4) | 0.09(1) | 5.8 | $f_{h_3}$ |
| $f_{h_4}$ | 0.419(8) | 0.06(4) | 5.1 | alias |

| Number | Frequency (day$^{-1}$) | Amplitude (mmag) | S/N | Comment |
|--------|------------------------|-----------------|-----|---------|
| $f_{h_1}$ | 7.80785(1) | 1.07(1) | 73.1 | $f_{h_1}$ |
| $f_{h_2}$ | 9.970(7) | 0.21(4) | 15.2 | $f_{h_2}$ |
| $f_{h_3}$ | 0.93(2) | 0.070(2) | 5.1 | 2$f_{h_3}$ |

Table 4. Extracted Frequencies of KIC 5768203 in KLCD

Table 5. Extracted frequencies of KIC 5768203 in TSCD

Table 6. Extracted frequencies of KIC 5768203 in TLCD
the period modulation, these frequencies order. In order to study variation of frequencies associated with 320 days, 263 days, 276 days, and 283 days in chronological based on the three gaps, and the time span of each segment is

![Figure 4](image_url)

**Figure 4.** The phase evolution diagram over a time span of nearly four years for the residuals of KLCD. Color, from blue to red, indicates the surface brightness of the star from bright to dark, which is marked as the relative mag on the right y-axis. Vertical white gaps correspond to time spans without Kepler data. Three yellow bands with lower brightness can be seen in one phase range of this diagram, which evolve gradually in time from left to right. The gray dashed lines are drawn to show the phase clearly.

Table 7

| Segment Number | Frequency (day^{-1}) | Amplitude (mmag) | Phase | S/N |
|----------------|----------------------|-----------------|-------|-----|
| 1              | 2_{rot}             | 0.91617(2)      | 0.118(2) | 0.180(6) | 30.8 |
|                | _f_{rot}            | 0.45809(5)      | 0.062(2) | 0.37(1)  | 16.6 |
|                | 3_{rot}             | 1.37427(6)      | 0.044(1) | 0.81(2)  | 10.6 |
|                | 5_{rot}             | 2.2897(2)       | 0.022(2) | 0.94(3)  | 6.97 |
|                | 4_{rot}             | 1.8336(2)       | 0.015(1) | 0.66(5)  | 4.02 |
| 2              | 2_{rot}             | 0.91603(3)      | 0.109(2) | 0.18(2)  | 28.5 |
|                | _f_{rot}            | 0.45801(6)      | 0.069(2) | 0.44(4)  | 19.3 |
|                | 3_{rot}             | 1.37423(9)      | 0.048(2) | 0.96(4)  | 11.0 |
|                | 4_{rot}             | 1.8332(1)       | 0.033(2) | 0.93(3)  | 8.15 |
| 3              | 2_{rot}             | 0.91639(3)      | 0.100(2) | 0.18(3)  | 25.9 |
|                | _f_{rot}            | 0.45811(5)      | 0.071(2) | 0.65(6)  | 19.2 |
|                | 3_{rot}             | 1.83303(2)      | 0.018(2) | 0.63(6)  | 4.71 |
| 4              | _f_{rot}            | 0.45825(6)      | 0.060(2) | 0.20(8)  | 16.5 |
|                | 2_{rot}             | 0.91667(9)      | 0.037(2) | 0.5(1)   | 9.53 |
|                | 4_{rot}             | 1.8323(2)       | 0.030(2) | 0.6(2)   | 7.48 |

The two pulsation frequencies detected in the Kepler data are also found in TSCD and TLCD, and the results of each data set are the same within the error range. The two other frequencies (f_2, f_0) at low frequency are detected in TSCD. They are consistent with the modulation frequency and the alias in KSCD within twice the margin of error. The separation of f_2 and f_0 in TSCD is 0.045 day^{-1}, which is much larger than the frequency resolution of TSCD. However, the frequency resolution of TSCD is dubious as discussed in Section 2. The identification for f_0 should be based on the result of KSCD. In TLCD, only the first harmonic of the periodic modulation is detected. The discovery of the modulation frequency in the TESS data infers that KIC 5768203 still has periodic motion and asymmetrical brightness.

### 4. Discussion

#### 4.1. A δ Sct Pulsator in a Binary System

By using KLCD to analyze the phase modulation of pulsations, Murphy et al. (2018) proposed that KIC 5768203 was a δ Sct pulsator in a binary system with an orbit period of 183.7(1) days. Subdividing KLCD into multiple 10 day segments as suggested by Murphy et al. (2018), we probe the phase variation of the two pulsation frequencies f_01 and f_02 in these segments. The result shows that phases of f_01 and f_02 have the same cyclic variation with an period of 184(2) days, as showed in Figure 6. In the amplitude spectrum of KLCD of KIC 5768203, there are two triplets with an interval of 0.00543 (7) day^{-1}. If the interval is due to the orbital period of the binary system, then the orbital period should be 184(2) days. The orbit period is consistent with that derived by Murphy et al. (2018) in the error ranges. KIC 5768203 could be a δ Sct pulsator in a binary system.

#### 4.2. The Periodic Modulation of the Light Curve of KIC 5768203

The light curve of KIC 5768203 is modulated by a periodic signal. Analyzing the amplitude spectrum of KIC 5768203, the frequency of the periodic signal and its several harmonics are found at the low frequency in KSCD and KLCD. As can be seen from the phase evolution diagram over a time span of nearly four years for the residuals of KLCD in Figure 4, the brightness of the star varies unevenly with phase and time after

3.3. Frequencies in TSCD and TLCD

The two pulsation frequencies detected in the Kepler data are also found in TSCD and TLCD, and the results of each data set
eliminating the effect of pulsations. The variation of the brightness is most likely caused by rotation and starspots. With a higher S/N in KLCD than KSCD, the frequency of $f_2$ in KLCD is adopted as the rotation frequency. Several harmonics should be blamed on stellar spots. The rotation period is derived as 2.18279 (5) days with the rotation frequency $f_{\text{rot}}$ in Table 4. With the rotation period and the radius $R = 3.2(2) R_\odot$, the rotation velocity of the star is estimated to be about 75(3) km s$^{-1}$. HADS usually pulsate in either one radial mode or two (or more) radial modes, along with a range of brightness variation larger than 300 mmag. KIC 5768203 has only two independent pulsation modes, which is similar to pulsation characteristics of HADS. However, the range of brightness of the light curve of KIC 5768203 is about 5 mmag, which is much smaller than the minimum brightness variation of 300 mmag of HADS. The relatively fast rotation speed of KIC 5768203 may be one of the reasons for its small pulsation amplitudes.

In addition to its own pulsations, the starspots on the surface are also one of the main causes of brightness variation for KIC 5768203. In four segments divided by three vertical white gaps, features of starspots can be seen from the phase evolution diagram in Figure 4 and the phase folded light curves Figure 5. The yellow bands in Figure 4 correspond to the dips in brightness. One band at Phase $\approx 0.1$ (or 1.1) extends throughout the whole time span of the Kepler long-cadence data. It is due to one long-term starspot. There seem to be other evolving starspots between Phase $\approx 0.4$ and 0.9 in Figure 4. The evolving spots are close in longitude.

In the first segment (segment1), two dips can be seen on the phase light curve in Figure 5, which are caused by one starspot at Phase $\approx 0.1$ (or 1.1) and another at Phase $\approx 0.5$ in Figure 4. The main hump on the phase light curve represents the surface brightness of the star without starspots. The two dips have almost the same depth. The brightness of the two dips is lower about 0.4 mmag than that of the main hump, and lower about 0.25 mmag than that of the secondary hump. The star at Phase $\approx 1.1$ is larger than the starspot at Phase $\approx 0.5$. There are some tiny dark regions between the two starspots in Figure 4. It is inferred that these regions are covered by small diffuse starspots, which cause slight decreases in brightness of the star.

In the second segment (segment2), there are three dips with unequal depths on the phase curve in Figure 5. The deepest dip
corresponds to the long-term starspot at \( \text{Phase} \approx 0.1 \) (or 1.1) in Figure 4, and has a brightness difference of about 0.43 mmag with the main hump. One significant starspot appears at \( \text{Phase} \approx 0.8 \) in Figure 4. The starspot at \( \text{Phase} \approx 0.5 \) becomes less prominent in segment 2 than in segment 1, and gradually merges with the starspot at \( \text{Phase} \approx 0.8 \) over time. The starspots at \( \text{Phase} \approx 0.5 \) and 0.8 in Figure 4 should be responsible for the two shallow dips on the phase curve in Figure 5, and the two shallow dipshave brightness differences of about 0.25 and 0.33 mmag with the main hump, respectively.

In the third segment (segment 3), there are two dips on the phase light curve in Figure 5, which are attributed to the two starspots at \( \text{Phase} \approx 0.1 \) and 0.7 in Figure 4. The two dips have almost equal depth, and their brightness is lower about 0.33 mmag than that of the main hump.

In the fourth segment (segment 4), there are still two significant dips on the phase light curve in Figure 5. The dip corresponding to the starspot at \( \text{Phase} \approx 0.1 \) has brightness lower about 0.25 mmag than the main hump. The other dip corresponding to the starspot at \( \text{Phase} \approx 0.7 \) has brightness lower about 0.2 mmag than the main hump. The two starspots seem to be getting closer and closer and have a tendency to merge in Figure 4.

The dips on the phase light curve of each segment appear at different phases. This indicates that the starspot corresponding to the dip has shifted its position on the surface of the star. The brightness difference between the dip at \( \text{Phase} \approx 0.1 \) and the main hump is estimated based on the phase light curve of each segment, and becomes smaller and smaller with time. It infers that the starspot at \( \text{Phase} \approx 0.1 \) is in the process of gradually becoming diffuse or disappearing. During the observing time span of KLCD, the starspot at \( \text{Phase} \approx 0.1 \) has always existed and will probably continue to exist for some time, and the starspot at \( \text{Phase} \approx 0.5 \) has existed for about 550 days and then merges with the starspot at \( \text{Phase} \approx 0.8 \) to form another starspot at \( \text{Phase} \approx 0.7 \). The merged starspot at \( \text{Phase} \approx 0.7 \) has existed for about 800 days, and might merge with the long-term starspot at \( \text{Phase} \approx 0.1 \) over time.

In addition to the prominent starspots discussed above, there are other small starspots which are obscure in Figure 4 and Figure 5. These small starspots correspond to harmonics of the rotation frequency of low S/N at the amplitude spectrum of each segment. Each prominent ‘starspot’ in Figure 4 might be a cluster of many small starspots on the stellar surface. The detailed geometries of these starspots (or clusters of starspots) could not be determined with the Kepler data.

In Figure 4, some blue points corresponding to very bright small areas can be seen. These bright points only appear in the residual data after eliminating the effect of pulsation. Ruling out the possibility for sampling outliers, these points should be attributed to the target itself. 162 flares had been detected on the surface of KIC 5768203 with the Kepler long-cadence data in the literature of Davenport (2016). These bright points may be due to the stellar flares.

The discovery of the rotation frequency and first harmonic in the TESS data infers that there are still spots on the surface of KIC 5768203. It is the first time that a \( \delta \) Sct pulsator is found to have starspots for a long time. The long-term existence of starspots may prove that KIC 5768203 has a relatively active magnetic field. A necessary condition forming the surface magnetic field is convection in the outer layer, which can generate the operation of the dynamic mechanism (Charbonneau 2014). KIC 5768203 with the effective temperature 6934 ± 134 K has a long-lived active magnetic field. It may be an example of possible convection on F stars, which is consistent with the latest studies about envelopes of A-F stars (Balona 2018, 2019b, 2021; Cantiello & Braithwaite 2019).

5. Summary

Based on high-precision photometric data from the Kepler Space Telescope and the TESS mission, KIC 5768203 is identified as a rotational \( \delta \) Sct star with large regions of spots. By using the Fourier analysis, three independent frequencies of KIC 5768203 are detected with two possible radial frequencies \( f_{r0} \) and \( f_{r1} \), and one rotational frequency \( f_{rot} \). The two radial frequencies have amplitudes lower than 1.4 mmag in the Kepler band. It is scarce that one \( \delta \) Sct pulsates only in radial modes of such low amplitudes. Thus, further verification is needed to explain the pulsations. By analyzing the triplets and phase variations of pulsations, KIC 5768203 is inferred to be a \( \delta \) Sct in a binary system. With the rotation frequency \( f_{rot} = 0.45813 \) (1 day\(^{-1}\)), the rotation velocity of the star is estimated to be 75(3) km/s. Harmonics of the rotation frequency are also detected and they are probably caused by large regions of starspots. Based on the phase plot without pulsations in KLCD (Figures 4 and 5), we discuss the features of these starspots. The discovery of the rotation frequency in the TESS data implies the long-term presence of starspots on the surface of KIC 5768203. It is rare that a \( \delta \) Sct star is found to have large-scale starspots for a long time. As a \( \delta \) Sct star with unusual properties, further study of KIC 5768203 is essential.

We thank the anonymous referee for the suggestive comments, which improved the manuscript. This research is supported by the National Natural Science Foundation of China (grant No. 12003060 and U2031209), the Natural Science Foundation of Xinjiang Uygur Autonomous Region (grant No. 2020D01B59), and the Chinese Academy of Sciences (CAS) “Light of West China” Program (grant No. 2021-XBQNXZ-029). We would like to thank the Kepler science team and the TESS mission for providing such excellent data. This research made use of Lightkurve, a Python package for Kepler and TESS data analysis. This work has made use of data products from the Guoshoujing Telescope (the Large Sky Area Multi-Object Fiber Spectroscopic Telescope; LAMOST). This research has made use of the International Variable Star Index (VSX) database, operated at AAVSO, Cambridge, Massachusetts, USA.

Appendix

Periodograms for Prewhitenning

We show Fourier amplitude spectra of the frequency prewhitenning process for the light curves of KIC 5768203 in KSCD (Figure 7), TSCD and TLCD (Figure 8), and KLCD (Figure 9). All the spectra in each database are showed in the same range of 0–24 day\(^{-1}\). We present all the amplitude spectra of the prewhitening steps in KSCD, TSCD and TLCD. In the prewhitening process in KLCD, there are many aliases of the pulsating frequencies and rotation frequency within the frequency resolution of 0.001044 day\(^{-1}\). So we only show some significant prewhitening amplitude spectra for KLCD.
Figure 7. Fourier amplitude spectra of the prewhitening process for the light curves of KIC 5768203 in KSCD. In order to see more details, the spectra are displayed in the range of 0–24 day$^{-1}$.
Figure 8. Fourier amplitude spectra of the prewhitening process in the range of 0–24 day$^{-1}$ for the light curves of KIC 5768203 in TSCD and TLCD. The left spectra are obtained from TSCD, and the right spectra are obtained from TLCD.
Figure 9. Fourier amplitude spectra of the prewhitening process in the range of 0–24 day$^{-1}$ for the light curves of KIC 5768203 in KLCD. The order of the spectra are from left to right and top to bottom.
ORCID iDs
Shuguo Ma https://orcid.org/0000-0001-5066-5682
Esamdin Ali https://orcid.org/0000-0003-1845-4900
Chenglong Lv https://orcid.org/0000-0001-6354-1646
Peng Wei https://orcid.org/0000-0002-5674-4223
TaoZhi Yang https://orcid.org/0000-0002-1859-4949
Hubiao Niu https://orcid.org/0000-0001-5796-8012
Junhui Liu https://orcid.org/0000-0002-7600-1670
Guojie Feng https://orcid.org/0000-0002-4788-8188

References
Ammons, S. M., Robinson, S. E., Strader, J., et al. 2006, ApJ, 638, 1004
Baker, N., & Kippenhahn, R. 1965, ApJ, 142, 868
Baran, A. S., Koen, C., & Pokrzywka, B. 2015, MNRAS, 448, L16
Barceló Forteza, S., Roca Cortés, T., & García, R. A. 2018, A&A, 614, A46
Balona, L. A., Guzik, J. A., Uytterhoeven, K., et al. 2011, MNRAS, 415, 3531
Balona, L. A., & Dziembowski, W. A. 2011, MNRAS, 417, 591
Balona, L. A. 2014, MNRAS, 437, 1476
Balona, L. A. 2018, MNRAS, 479, 183
Balona, L. A., Handler, G., Chowdhury, S., et al. 2019, MNRAS, 485, 3457
Balona, L. A. 2019a, IAU Symp. 339, Southern Horizons in Time-Domain Astronomy (Cambridge: Cambridge Univ. Press), 339, 77
Balona, L. A. 2019b, MNRAS, 490, 2112
Balona, L. A. 2021, FrASS, 8, 32
Balona, L. A., Lenz, P., Antoci, V., et al. 2012, MNRAS, 419, 3028
Berger, T. A., Huber, D., Gaidos, E., et al. 2018, ApJ, 866, 99
Borucki, W. J., Koch, D., Basri, G., et al. 2010, Sci, 327, 977
Bradley, P. A., Guzik, J. A., Miles, L. F., et al. 2015, AJ, 149, 68
Breger, M. 1979, PASP, 91, 5
Breger, M. 2000, ASP Conf. Ser. 210, Delta Scuti and Related Stars (San Francisco, CA: ASP), 3
Cantiello, M., Langer, N., Brott, I., et al. 2009, A&A, 499, 279
Cantiello, M., & Braithwaite, J. 2019, ApJ, 883, 106
Chevalier, C. 1971, A&A, 14, 24
Charbonneau, P. 2014, ARA&A, 52, 251
Davenport, J. R. A. 2016, ApJ, 829, 23
Dupret, M.-A., Grigahcène, A., Garrido, R., et al. 2005, A&A, 435, 927
Frasca, A., Molenda-Zakowicz, J., de Cat, P., et al. 2016, A&A, 594, A39
Gaia Collaboration, Brown, A. G. A., Vallenari, A., et al. 2018, A&A, 616, A11
Grigahcène, A., Dupret, M.-A., Gabriel, M., et al. 2005, A&A, 434, 1055
Grigahcène, A., Antoci, V., Balona, L., et al. 2010, ApJL, 713, L192
Grigahcène, A., Uytterhoeven, K., Antoci, V., et al. 2010, AN, 331, 989
Handler, G., Balona, L. A., Shobbrook, R. R., et al. 2002, MNRAS, 333, 262
Handberg, R., Lund, M. N., White, T. R., et al. 2021, AJ, 162, 170
Huber, D., Silva Aguirre, V., Matthews, J. M., et al. 2014, ApJS, 211, 2
Jenkins, J. M., Caldwell, D. A., Chandrasekaran, H., et al. 2010, ApJL, 713, L87
Jenkins, J. M., Twicken, J. D., McCauliff, S., et al. 2016, Proc. SPIE, 9913, 9913E
Kaye, A. B., Handler, G., Krisciunas, K., et al. 1999, PASP, 111, 840
Kepler Mission Team 2009, yCat, V/133
Kallinger, T., Reegen, P., & Weiss, W. W. 2008, A&A, 481, 571
Kjeldsen, H., Christensen-Dalsgaard, J., Handberg, R., et al. 2010, AN, 331, 966
Lenz, P., & Breger, M. 2005, CoAst, 146, 53
Loumos, G. G., & Deeming, T. J. 1978, ApSS, 56, 285
Luo, A.-L., Zhao, Y.-H., Zhao, G., et al. 2019, yCat, V/164
Lightkurve Collaboration, de Cardoso, J. V. M., Hedges, C., et al. 2018, ascl:1812.013
Murphy, S. J., Shibahashi, H., & Kurtz, D. W. 2013, MNRAS, 430, 2986
Murphy, S. J., Moe, M., Kurtz, D. W., et al. 2018, MNRAS, 474, 4322
Niu, J.-S., Fu, J.-N., Li, Y., et al. 2017, MNRAS, 467, 3122
Qian, S.-B., Li, J.-N., He, J.-J., et al. 2018, MNRAS, 475, 478
Shi, F., Kurtz, D. W., Holdsworth, D. L., et al. 2021, MNRAS, 506, 5629
Stassun, K. G., Oelkers, R. J., Paegert, M., et al. 2019, AJ, 158, 138
Stello, D., Saunders, N., Grunblatt, S., et al. 2021, MNRAS, 512, 1677
Stellingwerf, R. F. 1979, ApJ, 227, 955
Stevens, D. J., Stassun, K. G., & Gaudi, B. S. 2017, AJ, 154, 259
Uytterhoeven, K., Moya, A., Grigahcène, A., et al. 2011, A&A, 534, A125
Xiong, D. R., Deng, L., & Zhang, C. 2015, MNRAS, 451, 3354
Xiong, D. R., Deng, L., Zhang, C., et al. 2016, MNRAS, 457, 3163
Yang, T., Esamdin, A., Song, F., et al. 2018, ApJ, 863, 195