EXPLORING B4: A PULSATING sdB STAR, IN A BINARY, IN THE OPEN CLUSTER NGC 6791

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Received 2011 July 22; accepted 2011 September 16; published 2011 September 30

ABSTRACT

We report on Kepler photometry of the hot subdwarf B (sdB) star B4 in the open cluster NGC 6791. We confirm that B4 is a reflection effect binary with an sdB component and a low-mass main-sequence companion with a circular 0.3985 day orbit. The sdB star is a g-mode pulsator (a V1093 Her star) with periods ranging from 2384 s to 7643 s. Several of the pulsation modes show symmetric splitting by 0.62 μHz. Attributing this to rotational splitting, we conclude that the sdB component has a rotation period of approximately 9.63 days, indicating that tidal synchronization has not been achieved in this system. Comparison with theoretical synchronization time provides a discriminant between various theoretical models.

Key words: binaries: close – open clusters and associations: individual (NGC 6791) – stars: horizontal-branch – stars: oscillations

1. INTRODUCTION

Subdwarf B (sdB) stars are evolved low-mass stars that have helium cores surrounded by a thin hydrogen envelope (Saffer et al. 1994). Their effective temperatures range from 22,000 to 40,000 K; typical masses are approximately $M \approx 0.47 M_\odot$ (Heber et al. 1984; Heber 2009). Since these stars have survived the core helium flash, they provide an opportunity to study a rapid phase of stellar evolution (Kawaler 2010) and perhaps a direct probe of the post-flash helium core.

Many sdB stars are non-radial multiperiodic pulsators, which can be used in asteroseismic analysis (Charpinet et al. 2008a; Østensen 2010; and references therein). This analysis can allow us to determine the mass, internal rotation, compositional stratification, and other interior properties. There are two main classes of sdB pulsators. The first class to be discovered were the shorter period V361 Hya stars (O’Donoghue et al. 1997), which are primarily p-mode pulsators with periods typically between 2 and 4 minutes. The V1093 Her stars are g-mode pulsators with periods ranging from 0.75 to 2 hr with typical amplitudes of less than 0.1% (Green et al. 2003; Østensen 2010). Generally, the pulsation amplitude is higher in the V361 Hya stars (about 1%) than in the V1093 Her stars (Kilkenny 2007; Reed et al. 2007).

The formation of stars with such thin surface hydrogen layers (less than 0.1% of the stellar mass) is still not completely understood. There are several proposed formation channels. One channel that has significant observational support involves mass transfer to a companion and ejection of a common envelope (Han et al. 2002, 2003). Observationally, many of the known sdB stars are indeed in close binary systems, with orbital periods on the order of hours (Maxted et al. 2001; Morales-Rueda et al. 2003; Karl et al. 2004; Heber 2009).

Given the short orbital periods, these stars are generally thought to rotate synchronously as the result of tidal effects. However, two theoretical treatments of tidal synchronization provide a range of estimates for the timescale for synchronization (Tassoul 1987; Zahn 1975); for sdB binaries, they can differ by orders of magnitude. B4 provides a potential test of these scenarios. At these rotation velocities, it is not possible to measure rotational broadening in the H or He lines. The narrow metal lines can show broadening, but the lines are very weak, necessitating high resolution and high signal-to-noise (S/N) spectroscopy requiring large telescopes. Therefore, spectroscopic verification of tidal synchronization is difficult, though Geier et al. have addressed this issue with the sdB star PG 0101+039 (Geier et al. 2008). However, asteroseismology provides a possible way to test for synchronization by measuring rotational splitting of oscillation modes. In the few cases where this has succeeded, tidal synchronization seems to be verified: van Grootel et al. (2008) report that the sdB star Feige 48 appears to be in synchronous rotation. It is in a binary with a white dwarf companion, with an orbital and rotation period of 9 hr. Another sdB that shows evidence for rotational splitting at the orbital frequency is PG 1336-018 (Charpinet et al. 2008b), with an orbital period of 2.42 hr and a low-mass main-sequence companion.

These successes have been limited by the difficulty faced by ground-based photometry in resolving the pulsation spectra. Kepler provides long-term nearly continuous high-precision photometry, eliminating aliasing problems associated with ground-based data. Early results from Kepler observations of sdB stars (Østensen et al. 2010, Kawaler et al. 2010, Østensen et al. 2011, for example) show that Kepler provides exquisite time-series photometry of these stars. For single g-mode pulsators, the Kepler data have already allowed detailed seismic modeling of two sdB stars (van Grootel et al. 2010; Charpinet et al. 2011). These investigations have determined that the mass of the sdB g-mode pulsators is close to what is expected based on standard stellar evolution models. They also place tight constraints on the hydrogen layer thickness for these stars and indicate that the convective core may be significantly larger than current evolutionary models suggest.

A particularly interesting star that could shed light on the origins of sdB stars is the hot subdwarf B4 in the old open cluster NGC 6791 (Kaluzny & Udalski 1992). The broadband colors suggested that it was indeed hot enough to be an sdB star. Spectroscopy by Saffer et al. (1994) confirmed it was an sdB star, and that it was likely a member of NGC 6791 based on its spectroscopic distance. B4 was identified as a binary through a significant brightness modulation (Mocnik et al. 2003; de Marchi et al. 2007). However, since no eclipses were seen and the data points were sparse it was not possible to tell whether this was an ellipsoidal or a reflection effect variable.
The temperature determination by Saffer et al. (1994) placed B4 within the range of the V1093 Her stars, but it had not been observed with a high enough time resolution to detect pulsations. Photometric variations from binary effects and constraints given its membership in NGC 6791 would make it uniquely valuable asteroseismic target: a non-radially pulsating sdB star, in a close binary, in a cluster. Its presence within a cluster provides stringent constraints on its age (and metallicity) for comparison close binary, in a cluster. Its presence within a cluster provides stringent constraints on its age (and metallicity) for comparison.

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B4 was observed as part of the Kepler Guest Observer (GO) program during Cycle 2.

In this Letter, we report the discovery of multiperiodic g-mode pulsation in B4. We confirm that it shows a longer period variation associated with a reflection of light from a companion with a much lower temperature. This variation signals an orbital period for the binary system of 0.3985 days. Our analysis of the pulsations reveals that the sdB star is not in synchronous rotation. We also estimate the synchronization timescale using two prescriptions for tidal spin-up and show that the results favor that of Zahn (1975) but are dependent on the details of the structure of the sdB star.

2. OBSERVATIONS

While the primary mission of the Kepler spacecraft is the search for extrasolar planetary transits (Koch et al. 2010; Borucki et al. 2010), it is also very well suited for asteroseismic observations (Gilliland et al. 2010a). Observations of B4 were obtained in late 2010 and early 2011 by the Kepler spacecraft during Cycle 2 of the GO program. In this Letter, we analyze the first 6 months of data (Q6 and Q7) on this star. The data were taken at the short cadence mode, with individual integrations of 58.85 s. The data acquisition and pipeline reductions are as described in Gilliland et al. (2010b) and Jenkins et al. (2010). The data coverage is continuous except for short, monthly gaps for data retrieval and occasional brief safe mode events. The data pipeline produces both a raw and “corrected” flux value for each integration. Since the corrected value accounts for estimated background contamination (which may change with follow-up photometry in the future), we use the raw flux. For analysis of the photometric variations, we quote fractional variation from the mean flux.

We removed outliers beyond four times the rms deviation from the local mean (determined via a boxcar filter with a width larger than any expected pulsation but smaller than the timescale for binary variation). This filtering removed 225 points from the original data. B4 has a V magnitude of 17.87 (de Marchi et al. 2007) and a Kepler magnitude (Kp) of 18.27. The noise level is approximately 3.4 × 10^{-5} per integration; in six months of data, this reduces to a noise level of 6.7 × 10^{-5}.

3. ANALYSIS

3.1. Binary Variation

This star is quite faint even for Kepler, so to establish a binary ephemeris we use phased data to get a better sense of the overall light curve shape. We found each point of maximum, rather than keying on another phase, because the light curve shows more sharply peaked maxima and the time of each maximum could be defined more precisely than the flatter minimum. We assumed that the period did not change on timescales smaller than days. This allowed us to add several days of data together with a block-phasing procedure. We achieved the best results by averaging over 10 orbital cycles. Using this procedure, we found the period to be 0.3984944(35) days and T0 to be 55372.6002(9) (in BJD − 2,400,000).

If this modulation is caused by ellipsoidal variation, then the period of 0.3985 days would represent one-half of the orbital period, since in an ellipsoidal variable, there are two minima and two maxima per orbit. Furthermore, ellipsoidal variables often display minima of unequal depth (Hutchings 1974; Wilson & Sofia 1976; Bochkarov et al. 1979), producing a peak in the Fourier transform at the subharmonic of the highest-amplitude periodicity.

Figure 1 shows the light curve phased at twice the period determined above. This light curve shows minima of equal depth and maxima of equal height. There are no eclipses apparent. In the Fourier transform of the light curve, the largest amplitude peak corresponds to the 0.3985 day period and the next-highest frequency peak corresponds to the first harmonic of this orbital period. We note that the frequency of the first harmonic of the orbital period (in Table 1) is slightly more than 1σ away from exactly 2 × f orb. We do not think that this difference is significant. We see no significant peak at the subharmonic.

We conclude that the observed variation is caused by the reflection effect, with the light from the sdB star illuminating a cooler and fainter companion. Thus, the period of the binary is 0.3984944(35) days. A radial velocity curve for this star should therefore show a period of 0.39849 days. In addition, radial velocity observations would constrain the mass ratio of the system.

3.2. Pulsation

The Fourier transform of the g-mode region, with the peaks identified, is shown in Figure 2. B4 shows many periodicities in the frequency range from 120 to 420 μHz, which are characteristic of g-mode pulsation in V1093 Her stars. We followed the “standard” procedure of successive removal of periodicities by nonlinear least-squares fitting of sinusoidal signals at the frequency peaks (see Kawaler et al. 2010 and references therein). Each successive pre-whitening was performed in the time domain. We continued this process until no peaks remained at or above four times the rms noise level in the residuals. This 4σ limit was 0.29 parts per thousand (ppt). Above this we found 16 unique frequencies which are given in Table 1. There are three more frequencies near the detection threshold which await confirmation with further data, but we include them in Table 1 for reasons noted below.

The g-mode period distribution in B4 resembles, quite closely, that seen in non-binary sdB pulsators. In high-overtone g-mode pulsators (where n >> l), the periods of consecutive overtones should be equally spaced, with a period spacing that scales with 1/√(l(T+T)). Here, we use the standard labeling of non-radial modes, where n, l, and m are the radial, angular, and azimuthal quantum numbers. This behavior is seen in pulsating white dwarf stars (e.g., Winget et al. 1991, 1994) and in g-mode sdB pulsators (Reed et al. 2011). For the sdB stars observed by Kepler the period spacings range from 231 s to 272 s, with that spacing identified with l = 1 modes (Reed et al. 2011).

Figure 3 shows that B4 also follows this trend. This echelle diagram plots points associated with each periodicity; the vertical axis is the period and the horizontal axis is the period modulo the average period spacing of 240.7 s. For equally
spaced modes, the periodicities should line up vertically, with (small) departures to be expected as a result of mode trapping by composition gradients within the star. The “best” period spacing of 240.7 s is in very close accord with \( l = 1 \) pulsations in sDB stars (Reed et al. 2011). One periodicity, f1 (\( P = 7640 \) s), does not lie near the ridge (it would be at 226 s on the abscissa of Figure 3). Another lower amplitude mode, f19, also does not fall along the ridge.

As indicated in Figure 3, there are multiple periodicities for a given order in the diagram (i.e., three successive, nearly horizontal points). This multiplet structure results from rotational splitting: non-radial modes with the same values of \( n \) and \( l \)
can be split into equally spaced multiplets by rotation, with the frequency splitting proportional to the rotation frequency. The well-known relationship between frequency splittings and rotation (see, for example, Ledoux 1951) is

\[ f_{n,l,m} = f_{n,l,0} + m\Omega(1 - C_{n,l}), \]  

where \( \Omega \) is the (assumed solid-body) rotation frequency and \( C_{n,l} \) is the Ledoux constant. For B4, we adopt values for \( C_{n,l} \) from Kawaler et al. (2010) of 0.48 for \( l = 1 \) and 0.16 for \( l = 2 \) modes.

As can be seen in Figure 2 and in the table, there is one well-defined triplet in the data with an average spacing of 0.60 \( \mu \)Hz consisting of \( f_2, f_3, \) and \( f_4 \). Triplets are expected for rotational splitting of \( l = 1 \) modes. We also see many doublets with spacing of nearly twice that value (\( f_{10}, f_{11} \), \( f_{12}, f_{13} \), and \( f_{14}, f_{15} \)), along with two peaks separated by 0.59 \( \mu \)Hz (\( f_5, f_6 \)). Taken together, these multiplets, if \( l = 1 \), indicate a rotation...

Figure 2. \( g \)-mode region of B4. The arrows show all pre-whitened frequencies. The 4\( \sigma \) level above the noise is represented by the dotted line.

Figure 3. Echelle diagram of the periodicities \( f_2-f_{18} \) of B4 with a folding period is 240.7 s. Filled circles are suspected \( m = \pm 1 \) modes and open circles are \( m = 0 \) modes (or modes for which \( m \) cannot be determined). There is a clear ridge around 85 s.
frequency of 1.20 \mu Hz, (a rotation period of 9.63 days). The structure of the amplitude spectrum surrounding each of these frequencies is shown in Figure 4.

B4 is a close binary; if in synchronous rotation, we would expect to see splittings that are approximately 15.4 \mu Hz for \( l = 1 \) modes and 24.4 \mu Hz for \( l = 2 \) modes. The measured splittings are much smaller than this orbital frequency, leading to the surprising conclusion that the sdB component is most likely not in synchronous rotation. Though one might expect the system to be in complete spin–orbit resonance, with the sdB rotating at the orbital frequency, this does not seem to be the case.

The fifth column of Table 1 shows that some of the frequency spacings between periodicities approach the orbital frequency. Thus, some of the apparent frequency spacings that might match those expected for synchronous rotation arise instead as a consequence of equal period spacings for high-overtone \( g \)-modes.

### 3.3. Synchronization Timescales

Recent seismic studies of sdB binary systems with short periods suggest that they are in synchronous rotation; e.g., Charpinet et al. (2001) and van Groote et al. (2008) looked at systems with orbital periods of 2.42 hr and 9.02 hr, respectively. Geier et al. (2008, 2010) claim synchronous rotation in systems with orbital periods up to 14 hr. But B4, with an orbital period of 9.56 hr does not rotate synchronously.

There are two prescriptions to calculate the timescale for synchronization: Tassoul (1987, 1988) and Zahn (1975). Tassoul (1987, 1988) argue that large meridional currents driven by tidal effects can drive changes in the rotation rate in nonsynchronous systems. For stars with radiative envelopes, Claret et al. (1995) provides an estimate for the Tassoul (1988) synchronization time:

\[ \tau_{\text{syn}} = 2.13 \times 10^4 \text{ yr} \left( \frac{1 + q}{q} \right) \left( \frac{L}{L_\odot} \right)^{-1/4} \left( \frac{M}{M_\odot} \right)^{5/4} \left( \frac{R}{R_\odot} \right)^{-3} \left( \frac{P}{\text{days}} \right)^{11/4}, \]

where \( q \) is the mass ratio of the system (assumed to be close to 1) and \( P \) is the binary period. For parameters typical of sdB stars \((M = 0.48 M_\odot, R \approx 0.2 R_\odot, \text{ and } L \approx 30 L_\odot)\), \( \tau_{\text{syn}} \approx 2 \times 10^3 \text{ yr} \) for \( P = 0.4 \text{ days}, \) assuming a mass ratio of 1. We would thus expect B4 to be synchronous since it has an evolutionary timescale that is a factor of 500 times longer. While the Tassoul (1988) prescription is not easily extended to low-mass ratios, a mass ratio of 0.2 used in Equation (2) yields a synchronization time that is still short compared to the evolutionary timescale.

Zahn (1975) explores how tides couple to non-radial oscillations in the star. The oscillations propagate through the convective core and the radiative zone, and provide a torque. For stars with radiative envelopes, the resulting synchronization timescale, from Claret & Cunha (1997) can be written as

\[ \tau_{\text{syn}} = 3.43 \times 10^8 \text{ yr} \left( \frac{\beta}{0.13} \right)^2 \left( \frac{1 + q}{q} \right)^2 \left( \frac{M}{M_\odot} \right)^{7/3} \left( \frac{R}{R_\odot} \right)^{-7} \left( \frac{P}{\text{days}} \right)^{17/3} \left( \frac{E_2}{10^{-8}} \right)^{-1}, \]

where \( \beta \) is the “radius of gyration” (the moment of inertia, \( I \) scaled by \( MR^2 \)) and \( E_2 \) is a tidal constant for a given stellar
structure. $E_2$ depends sensitively on stellar structure, and in particular on the fractional size of the convective core. For large cores, $E_2$ can reach values of $10^{-5}$; for small convective cores, its value approaches zero (see Claret 2004).

Though we do not have values for $E_2$ calculated directly for sdB models, Claret (2004) provides $E_2$ for convective core burning main-sequence models with similar convective core mass fractions to the sdB stars (approximately 0.14). Though the sdB stars burn helium in the core, the presence or absence of convection is the most important factor for tidal coupling. Claret (2004) main-sequence models with that size core generally have values of $E_2$ between 5 \times 10^{-6} and 1.3 \times 10^{-8}, somewhat independent of mass. We choose $10^{-8}$ as a representative value. Using the same representative values for mass, radius, and orbital period, Equation (3) provides $t_{\text{syn}} \approx 10^9$ yr for $q = 1$. For a lower-mass companion (lower q), the timescale is even longer. We note that for Equation (3) to reduce to $10^9$ yr for B4, $E_2$ would need to be $\approx 10^{-7}$. For sdB stars with a comparable orbital period but more massive companion (i.e., Feige 48), synchronization should be swifter than for B4.

This leads us to the conclusion that the Zahn (1975) mechanism may be slow enough to allow the B4 binary to be out of spin–orbit synchronization. However, conclusive analysis requires direct calculation of $E_2$ for evolutionary stellar models at the correct $T_{\text{eff}}$ and $\log g$.

4. DISCUSSION

The hot blue sdB star, B4, in the old open cluster NGC 6791 is a pulsating member of a short-period reflection-effect binary with an orbital period of 0.3984944(35) days. Frequency splittings in the g-mode pulsation spectrum reveal that the sdB component rotates with a period of 9.63 days, and therefore is not in synchronous rotation. The nearly equal period spacings resemble the pattern seen in many other g-mode sdB pulsators observed with Kepler. Thus, the Kepler sdB pulsators form a homogenous class, independent of their binarity.

B4’s membership in NGC 6791 provides its (overall) age and metallicity; its initial main-sequence mass is close to the turnoff mass of 1.15 $M_\odot$. Further asteroseismic probing subject to these initial constraints should provide a new opportunity to address the riddle of the formation of sdB stars in general. Given that B4 is not in synchronous rotation, it will be important to compute the synchronization timescale for sdB stars in close binaries to evaluate the accuracy of current theoretical models of tidal synchronization. A spectroscopic determination of $T_{\text{eff}}$ and $\log g$ (as well as the mass ratio of the system) is essential for this.

We plan continued photometric monitoring of B4 with Kepler for as long as possible. In addition to refining the observed frequencies, increasing S/N could reveal lower-amplitude modes, allowing us to fill out the l = 1 pulsation spectrum and expose modes with higher values of l. In addition, extended photometry may allow us to measure the evolution of the sdB component through secular period changes as the star continues its nuclear evolution. If it is a newly formed sdB star that is experiencing tidal spin-up, we may also be able to measure the increasing rotational frequency through the pulsations.

We thank Andrzej Baran for helpful comments and discussions. Funding for this Discovery mission is provided by NASA’s Science Mission Directorate. The authors gratefully acknowledge the entire Kepler team, whose efforts have made these results possible. This material is based upon work supported by the National Aeronautics and Space Administration under grant No. NNX11AC74G issued through the Kepler Guest Observer Program-Cycle 2 (09-KEPLER-00-0056) to Iowa State University.

REFERENCES

Bochkarov, N. G., Kariskaia, E. A., & Shakura, N. I. 1979, SvA, 23, 8
Borucki, W. J., Koch, D., Basri, G., et al. 2010, Science, 327, 977
Charpinet, S., Fontaine, G., Brassard, P., & Chayer, P. 2008a, Commun. Asteroseismol., 157, 168
Charpinet, S., van Grootel, V., Fontaine, G., et al. 2011, A&A, 580, 3
Charpinet, S., van Grootel, V., Reese, D., et al. 2008b, A&A, 489, 377
Claret, A. 2004, A&A, 424, 919
Claret, A., & Cunha, N. C. S. 1997, A&A, 318, 187
Claret, A., Giménez, A., & Cunha, N. C. S. 1995, A&A, 299, 724
de Marchi, F., Poretti, E., Montalbò, M., et al. 2007, A&A, 471, 515
Geier, S., Heber, U., Podsiadlowski, Ph., et al. 2010, A&A, 519, A25
Geier, S., Nesslinger, S., Heber, U., et al. 2008, A&A, 477, L13
Gililand, R. L., Brown, T. M., Christensen-Dalsgaard, J., et al. 2010a, PASP, 122, 131
Gililand, R. L., Jenkins, J. M., Borkowski, W. J., et al. 2010b, ApJ, 713, L160
Green, E. M., Fontaine, G., Reed, M. D., et al. 2003, ApJ, 583, L31
Han, Z., Podsiadlowski, P., Maxted, P. F. L., & Marsh, T. R. 2003, MNRAS, 341, 669
Han, Z., Podsiadlowski, P., Maxted, P. F. L., Marsh, T. R., & Ivanova, N. 2002, MNRAS, 336, 449
Heber, U. 2009, ARA&A, 47, 211
Heber, U., Hunger, K., Jonas, G., & Kudritzki, R. P. 1984, A&A, 130, 119
Hutchings, J. B. 1974, ApJ, 188, 341
Jenkins, J. M., Caldwell, D. A., Chandrasekaran, H., et al. 2010, ApJ, 713, L87
Kaluzny, J., & Udalski, A. 1992, Acta Astron., 42, 29
Karl, C. A., Heber, U., Drechsel, H., et al. 2004, Ap&SS, 291, 283
Kawaler, S. D. 2010, Astron. Nachr., 331, 1020
Kawaler, S. D., Reed, M. D., Østensen, R. H., et al. 2010, MNRAS, 409, 1509
Kilkenny, D. 2007, Commun. Asteroseismol., 150, 234
Koch, D. G., Borucki, W. J., Basri, G., et al. 2010, ApJ, 713, 79
Ledoux, P. 1951, ApJ, 114, 373
Maxted, P. F. L., Heber, U., Marsh, T. R., & North, R. C. 2001, MNRAS, 326, 1391
Mochejska, B. J., Stanek, K. Z., & Kaluzny, J. 2003, AJ, 125, 3175
Morales-Rueda, L., Maxted, P. F. L., Marsh, T. R., North, R. C., & Heber, U. 2003, MNRAS, 338, 752
O’Donoghue, D., Lysen Gray, A. E., Kilkenny, D., Stobie, R. S., & Koen, C. 1997, MNRAS, 285, 657
Østensen, R. H. 2010, Astron. Nachr., 331, 1026
Østensen, R. H., Silvotti, R., Charpinet, S., et al. 2010, MNRAS, 409, 1470
Østensen, R. H., Silvotti, R., Charpinet, S., et al. 2011, MNRAS, 414, 2860
Reed, M. D., Baran, A. S., Quint, A. C., et al. 2011, MNRAS, 414, 2885
Reed, M. D., Tendulkar, D. M., Zhou, A.-Y., et al. 2007, MNRAS, 378, 1049
Saffer, R. A., Bergeron, P., Koester, D., & Liebert, J. 1994, ApJ, 432, 351
Tassoul, J.-L. 1987, ApJ, 322, 856
Tassoul, J.-L. 1988, ApJ, 324, L71
van Grootel, V., Charpinet, S., Fontaine, G., & Brassard, P. 2008, A&A, 483, 875
van Grootel, V., Charpinet, S., Fontaine, G., et al. 2010, ApJ, 718, L97
Wilson, R. E., & Sofia, S. 1976, ApJ, 203, 182
Winget, D. E., Nather, R. E., Clemens, J. C., et al. (The Whole Earth Telescope Collaboration) 1991, ApJ, 378, 326
Winget, D. E., Nather, R. E., Clemens, J. C., et al. (The Whole Earth Telescope Collaboration) 1994, ApJ, 430, 839
Zahn, J.-P. 1975, A&A, 41, 329
ERRATUM: “EXPLORING B4: A PULSATING sdB STAR, IN A BINARY, IN THE OPEN CLUSTER NGC 6791” (2011, ApJ, 740, L47)

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Received 2012 March 23; published 2012 April 17

The x-axis in Figure 1 of the original paper was incorrectly scaled. The range of the figure should go from 0 to 1.6 days. The correct Figure 1 is printed here. We have also changed the axis label and figure caption for clarity.

Figure 1. Photometric data on B4, phased on twice the suspected orbital period (2 × 0.3885 days). The equal-depth minima argue against an interpretation of the light curve as being caused by ellipsoidal variation.