PHOTOMETRIC AND SPECTROSCOPIC ANALYSIS OF THE SX Phe STAR BL Cam

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In the present paper, we report the photometric and spectroscopic observations of the pulsating star BL Cam obtained by the 1.88 m telescope at the Kottamia astronomical observatory (KAO). Fourier analysis of the light curves indicates one frequency, 25.14427 c/d, with harmonics 51.112 c/d, 33.388 c/d, and 17.72464 c/d. The frequency of 31-32 c/d reported in the literature is not detected in our data except for one close to 33.3882934 c/d. A total of 55 new times of maximum light have been presented. A new value of (1/P) dP/dt is estimated using the O-C diagram based on all newly obtained times of maximum light combined with those taken from the literature, assuming the periods are decreasing and changing smoothly. Using model atmosphere analysis, we computed the effective temperature and surface gravity as $T_{\text{eff}} = 7625 \pm 300$ K and $\log g = 4.30 \pm 0.37$. The bolometric magnitude $M_{\text{bol}} = 2.335$, radius $r = 1.69 R_\odot$, luminosity $L = 0.957 L_\odot$, the mass $M = 1.68 M_\odot$, and pulsation constant $Q = 0.025$ days. Locations of the star on the M-R and M-L diagrams indicate that it is close to the ZAMS track and is an unevolved star.

Keywords: stars: variables: SX Phe stars: frequency and pulsation analysis: model atmosphere analysis

1. Introduction

SX Phoenicis (SX Phe) stars are typically found in the galaxy's outer regions, known as the galactic halo. Their luminosity changes over 1-2 hours and have short periods (≤ 0.08 day) and large amplitudes (> 0.3 mag). In globular

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clusters, they are mostly found among blue stragglers [1]. These stars exhibit short-period pulsation behavior that varies on time scales ranging from 0.03 to 0.08 days (0.7 to 1.9 hours). SX Phe stars have spectral classifications in the A2-F5 range and magnitude differences of up to 0.7.

Giclas et al. [2] discovered BL Cam (= GD 428 in Simbad, 2MASS J03471987+6322422, Gaia DR2 487276688415703040), which was thought to be a candidate for a white dwarf. It is a pulsating star with a period of 0.039 days and an amplitude of 0.33 mag, according to Berg & Duthie [3]. McNamara [4] classified it as a Population II star with a metal abundance of [Fe/H] = -2.4. Previous researchers have investigated its multiperiodic character [5-7]. Hintz et al. [8] measured 32.679 c/d for the first overtone and 0.783 for the period ratio of the first overtone to the fundamental mode. Previous authors [9-12] had also discovered the first overtone at 31.6 c/d, resulting in a period ratio of 0.810. On the other hand, the first overtone did not detect [7]. In a multi-site photometric investigation of BL Cam, 21 distinct pulsation frequencies (excluding the fundamental mode) with amplitudes ranging from 1.6 to 7.4 mmag were discovered [6].

As demonstrated by [1], the period content of BL Cam is dominated by 25.5790 ± 3 c/d and its two harmonics and an independent frequency of 25.247 ± 2 c/d. An analysis of their times of maxima from the literature [13] determined a periodic change that made BL Cam a binary system and demonstrated that the evolution of the ephemerides of the different authors was natural and correct, given the shortness of the available data at their times. They showed that a binary system causes long-term variation with a longer time horizon.

In the present paper, we carried out photometric and spectroscopic observations for the star BL Cam. We will use a model atmosphere to determine the star's effective temperature and surface gravity at different phases. Frequency analysis, O-C curve, and period change of the star are investigated. The structure of the paper is as follows. The photometric analysis is presented in section 2. The spectral analysis is described in section 3. Section 4 is devoted to determining the star's physical parameters and evolution state, and the conclusion reached is presented in section 5.

2. Photometric analysis

2.1. Observation and data reduction. We present new photometric observations of BL Cam by using the 1.88m telescope of the Kottamia Astronomical Observatory (KAO), Egypt. We applied data reduction, bias subtraction, and flat-field correction to the raw CCD images without dark subtraction, which was already negligible. All observations were taken using an EEV 42-40 CCD camera with a format of 2048 x 2048 pixels, cooled by liquid nitrogen to -120 °C. Fig.1 shows the field BL Cam taken with the KAO. The variable star, the comparison star, and the check star are marked as V, C, and K, respectively. Fig.2 shows the KAO observations obtained in Johnson BVR filters and the SDSS in g, r, i, and z filters for the two nights, November 24 and November 26, 2021. All observations were analyzed using the MuniWin v.1.1.26 software [14], implementing the differential magnitudes method of aperture photometry.
2.2. Frequency and pulsation analysis. The frequency analysis of the BL Cam light curves was carried out with the help of two codes: Period04 [15] and Peranso V3.0.3.4 (www.cbabelgium.com/peranso). Both codes searched for significant peaks in the amplitude spectra using Fourier transformations of the light curves. Following the first frequency computation, we created the "periodogram" by fitting a sinusoid to the Period04 period and subtracting the sinusoid from the original magnitude (pre-whitening). Then we calculate the periodogram again, but the first frequency will not be presented, so the highest peak in the periodogram will be the subsequent frequency. We repeated this procedure many times if necessary to search for other peaks until no more peaks could be seen in the periodogram. Results of our analysis presented in the Table 1. The sigma of the residuals is 6.747 mmag

The V-band light curve analysis reveals one peak in the periodogram at 0.03977049 d (25.1442704±0.032979 c/d) (Fig.3).

We compared our results in Table 1 to that of [5], who used the data sets of [9,11] listed in Tables 5 and 6 together with the corresponding S/N values. Our results are in good agreement with those of [9]. The first impression from our results is; that we didn't find the secondary peak \( f_1 \) claimed by some authors in the region 31-32 c/d, [8] estimated \( f_1 \) as 32.6443 c/d, but we found the peak at 33.388 c/d. Also, we found a small difference between our \( f_0 \) (25.14427 c/d) and that of [7] (25.181 c/d) and [9] (25.5768 c/d). This difference may be attributed to our data being too short or not having enough data sets. In addition, independent frequencies \( f_2 \) and \( f_3 \) are detected together with the combinations \( f_2 + f_3 \sim f_0 \) and the amplitudes of \( f_1', f_2', \) and \( f_3' \) are larger than \( 3f_0' \). We do not detect at a significant level the linear combination \( f_0 + f_1 \) as reported by [9].

The sum of the squared residuals \( \chi^2 \) derived from a multi-parameter least-squares fit of sinusoidal functions was used to calculate the error for each value. Fig.3 depicts the frequency spectra; Fourier fits on the observational points for all sets of observations and the spectral window of each star.
2.3. **O-C curve and period change.** We used the Hertzsprung [16] method to construct the O-C curve to determine the time of brightness minima or maxima. We used all the data published in the literature to fill in the gaps in the O-C diagram. We use it if the scatter is the same as the raw data (about 0.2 mag.). Fig.4 depicts the maximum-light times used to investigate the period change. To derive the O-C differences for BL Cam from a computed linear ephemeris, we used the method described by [16]. We establish a reference time of maximum light from existing photoelectric observations. The adopted pulsation period is based on recent observations of the star from KAO data. The following relationship gives the least-square fit by the quadratic elements:

\[
\text{HJD}_{\text{max}} = M_0 + PE + QE^2.
\]  

Fig.2. The differential magnitude of BL Cam; SDSS $g$, $r$, $I$, and $z$ bands and VR bands.
where $M_0$ is a new epoch, $P$ is the new period, and $Q$ is used to measure the period change values ($dP/dt$) in seconds per year ($dP/dt = (2Q/P)365.25 \times 24 \times 60 \times 60$).

We employed a second-order polynomial least-squares approach to fit the O-C residuals. The revised ephemeris was evaluated using all available photometric observations from ASAS, KWS, and KAO to justify its validity throughout all observations. The linear ephemeris equation by [8] was used to calculate the light maximum.
The 55 new times of maximum light obtained for BL Cam are presented in Table 2. The least-squares fit for O-C with the root mean square $R = 0.954$ is

$$O-C = 7.994(14) \cdot 10^{-2} - 5.0349(15) \cdot 10^{-8} E - 3.2757(69) \cdot 10^{13} E^2 .$$

The quadratic trend in O-C data reflects a regular period decrease or increase. After constructing the O-C diagram, we found the decreasing period rate given by the equation

$$dp/dt = 0.17028E^{-02} \pm 0.14378E^{-05} s/yr .$$

The standard deviation of the residuals of a quadratic fit to the O-C values is $0^4.002$, with a correlation coefficient of 0.97.

3. Spectroscopic analysis

We observed BL Cam covering the spectral ranges 3360-5870 Å and 5300-9180 Å, with spectral resolutions of ~1000. The spectra were taken with the Kottamia Faint Imaging spectropolarimeter (KFISP) mounted on the 1.88 m telescope at Kottamia Astronomical Observatory (KAO) for a single night on November 25, 2021. The data were reduced using the Astropy-affiliated package CCDPROC [18]. We used the LACosmic routine [19] to remove cosmic rays from the images processed by Astro-SCRAPPY [20]. A particular Python routine was used to extract the spectra and calibrate the wavelength. Using IRAF, the spectra were flux calibrated. The signal-to-noise ratio was calculated with the specutils snr derived function [21]. Table 3 shows the log of the spectroscopic observations, and we plotted
TABLE 2. The New 55 Times of Maximum Light, a New Epoch, O-C, Number of Observations, and Data Source

| HJD-2450000 | Epoch | O-C (days) | No. of Obs. | Ref. | HJD-2450000 | Epoch | O-C (days) | No. of Obs. | Ref. |
|-------------|-------|------------|-------------|------|-------------|-------|------------|-------------|------|
| 3041.279    | 253607 | 0.04946    | 18          | 1    | 6186.419    | 334051| 0.02209    | 60          | 1    |
| 3293.459    | 260057 | 0.04926    | 249         | 1    | 6186.458    | 334052| 0.02170    | 56          | 1    |
| 3424.354    | 263405 | 0.04535    | 121         | 1    | 6280.259    | 336451| 0.02717    | 35          | 1    |
| 4031.848    | 278943 | 0.04164    | 22          | 1    | 6280.298    | 336452| 0.02776    | 40          | 1    |
| 4034.859    | 279020 | 0.04183    | 24          | 1    | 6623.336    | 345226| 0.02268    | 262         | 1    |
| 4064.612    | 279781 | 0.04144    | 325         | 1    | 6623.375    | 345227| 0.02287    | 220         | 1    |
| 4109.692    | 280934 | 0.04242    | 139         | 1    | 6623.416    | 345228| 0.02483    | 255         | 1    |
| 4419.462    | 288857 | 0.04164    | 82          | 1    | 6630.372    | 345406| 0.02189    | 201         | 1    |
| 4480.723    | 290424 | 0.03695    | 145         | 1    | 7034.402    | 355740| 0.01740    | 28          | 2    |
| 4499.528    | 290905 | 0.03597    | 40          | 1    | 7074.440    | 356764| 0.01935    | 44          | 1    |
| 4514.657    | 291292 | 0.03441    | 51          | 1    | 7314.652    | 362908| 0.01525    | 58          | 2    |
| 4793.737    | 298430 | 0.03558    | 152         | 1    | 7362.901    | 364142| 0.01779    | 48          | 1    |
| 4859.577    | 300114 | 0.03480    | 131         | 1    | 7370.719    | 364342| 0.01681    | 48          | 2    |
| 4863.604    | 300217 | 0.03538    | 288         | 1    | 7437.457    | 366049| 0.01466    | 37          | 2    |
| 4884.597    | 300754 | 0.03265    | 226         | 1    | 7651.398    | 371521| 0.01329    | 37          | 2    |
| 5261.299    | 310389 | 0.02913    | 35          | 1    | 7715.639    | 373164| 0.01701    | 133         | 1    |
| 5923.378    | 327323 | 0.02913    | 21          | 1    | 7745.935    | 373939| 0.01310    | 47          | 2    |
| 5942.414    | 327810 | 0.02502    | 93          | 1    | 7942.947    | 378978| 0.01173    | 41          | 2    |
| 5943.704    | 327843 | 0.02483    | 137         | 1    | 8077.636    | 382423| 0.00977    | 39          | 2    |
| 5977.484    | 328707 | 0.02405    | 120         | 1    | 8394.755    | 390534| 0.00762    | 35          | 2    |
| 5979.361    | 328755 | 0.02424    | 91          | 1    | 9168.884    | 410334| 0.00469    | 60          | 1    |
| 5980.416    | 328782 | 0.02365    | 50          | 1    | 9177.642    | 410558| 0.00450    | 93          | 1    |
| 5986.360    | 328934 | 0.02502    | 44          | 1    | 9543.434    | 419914| -0.00059   | 20          | 3    |
| 5993.357    | 329113 | 0.02326    | 42          | 1    | 9543.473    | 419915| -0.00039   | 17          | 3    |
| 5995.389    | 329165 | 0.02287    | 177         | 1    | 9543.512    | 419916| -0.00020   | 27          | 3    |
| 5996.367    | 329190 | 0.02346    | 156         | 1    | 9543.512    | 419916| -0.00020   | 7           | 3    |
| 6014.312    | 329649 | 0.02287    | 34          | 1    | 9544.529    | 419942| 0.00000    | 90          | 3    |
| 6186.380    | 334050 | 0.02209    | 63          | 1    |              |       |            |             |      |

1: AAVSO, 2: ASAS-SN, 3: KAO.
TABLE 3. Observation Log of the BL Cam Spectra

| Time (UT)   | HJD-2450000 | Phase | Exposure (s) | Standard Star | λ Range   | R    | Airmass | Average S/N |
|-------------|-------------|-------|--------------|---------------|-----------|------|---------|-------------|
| 21:29:32.96 | 9544.39554  | 0.376 | 900          | HR9087        | 3360-5870 | 1025 | 1.198   | 113.9       |
| 21:59:40.35 | 9544.41644  | 0.939 | 900          | HR9087        | 3360-5870 | 1025 | 1.206   | 113.3       |
| 22:25:30.52 | 9544.43438  | 0.406 | 900          | HR9087        | 3360-5870 | 1025 | 1.220   | 105.5       |
| 23:01:03.12 | 9544.45906  | 0.931 | 900          | HR9087        | 3360-5870 | 1025 | 1.252   | 108.0       |
| 21:17:03.84 | 9544.38687  | 0.598 | 600          | HR9087        | 5300-9180 | 1133 | 1.198   | 146.0       |
| 21:48:45.29 | 9544.40886  | 0.133 | 600          | HR9087        | 5300-9180 | 1133 | 1.202   | 166.2       |
| 22:15:05.11 | 9544.42714  | 0.592 | 600          | HR9087        | 5300-9180 | 1133 | 1.213   | 159.0       |
| 22:44:36.40 | 9544.44764  | 0.223 | 600          | HR9087        | 5300-9180 | 1133 | 1.235   | 189.6       |

Fig.5. The observed spectra of BL Cam in the blue (upper panel) and red (lower panel) bands at different phases.
the BL Cam spectra in Fig.5. The upper panel represents the blue region, while the lower panel represents the red region.

We created a small grid of synthetic spectra from LTE model atmospheres with the effective temperature range of $6000 \leq T_{\text{eff}} \leq 10000$ K. We adopted ATLAS9 grids [22] as input models for LTE computations, assuming solar
metallicity, a microturbulent velocity of 2 km/s, and a mixing length to scale height ratio of 1.25. The effective temperatures span the model grid’s temperature range of 250 K. The surface gravities of the models are of $1 \leq \log g \leq 5$. We used the SPECTRUM code [23,24] to synthesize the LTE spectra (for the range $\lambda \lambda 1500–8000 \AA$). SPECTRUM takes the depth points, temperatures, and total pressure and calculates them at each stage using a system of seven nonlinear equilibrium equations.

We developed a FORTRAN code that compares the flux values at each point on the observed and theoretical spectra. It then tabulates the differences to produce a single number that characterizes how good the fit is. The synthetic spectra are convolved with a Gaussian profile with FWHM = 5 Å. We adjusted the wavelength scale to begin comparing the observed and theoretical spectra. After that, we developed a code that minimizes the Euclidian distance between the observed and theoretical spectra to compare the grid with the observed spectra. The equivalent widths of the spectral lines are calculated numerically using the Runge-Kutta technique.

Following the above procedure, we calculated the star’s effective temperatures and surface gravities at different phases listed in Table 4. The mean effective temperature and surface gravity are adopted as $T_{\text{eff}} = 7625 \pm 300$ K and $\log g = 4.30 \pm 0.37$. Fig.6 shows the best fit of spectral lines $H_{\alpha}, H_{\beta}, H_{\gamma}, H_{\delta}$ at different phases in both the red and blue parts of the spectrum. In most cases, we obtained a good fit for the line centers, while the significant difference between the observed and the synthetic spectra occurs for the line wings.

### 4. Physical parameters and the evolution state

We computed the physical parameters of BL Cam using the mean photometric colors, effective temperature, and the parallax. Adopting the effective temperature as $T_{\text{eff}} = 7625 \pm 300$ K, we calculated the bolometric correction

| Phase | $T_{\text{eff}}$ (K) | log\(g\) |
|-------|---------------------|----------|
| 0.376 | 8000                | 4.0      |
| 0.406 | 8000                | 4.0      |
| 0.939 | 7750                | 4.0      |
| 0.931 | 7750                | 4.0      |
| 0.598 | 7250                | 4.5      |
| 0.592 | 7250                | 4.5      |
| 0.133 | 7500                | 4.5      |
| 0.233 | 7500                | 5.0      |
| Mean  | 7625±300            | 4.30±0.37|

TABLE 4. Effective Temperatures and Surface
Gravities at Different Phases of BL Cam
as \( BC = -0.089 \) [25]; the star's absolute magnitude and bolometric magnitude in the visible filter as \( M_V = 3.426 \pm 0.061 \) and \( M_{\text{bol}} = 3.337 \).

The stellar radius is calculated from a polynomial fit to the temperature-radius relation of [23] as \( R/R_\odot = 1.494 \pm 0.032 \). The masses \( M \) can be calculated from the equation by [26] \( \log M = 0.46 - 0.10 M_{\text{bol}} \) as \( M = 1.338 M_\odot \), and the luminosity is \( L/L_\odot = 3.642 \). The pulsational constant \( Q \) could be determined using the frequencies in the periodogram (Table 1) from the equation

\[
\log Q = 0.5 \log g + 0.1 M_{\text{bol}} + \log T_{\text{eff}} + \log P - 6.456.
\] (4)

Consequently, the \( Q \) value of \( f_1 \) is 0.025(17), which is within the theoretical range, 0.0096 < \( Q < 0.067 \), for the fundamental mode by [27]. The results are presented in Table 5; for the low-frequency pulsations (\( v \leq 25 \) c/d).

In Fig.7, we plotted the mass-luminosity relation \((M-L)\) and mass-radius relation \((M-R)\) for both zero-age main-sequence stars (ZAMS) and terminal-age main-sequence stars (TAMS) with metallicity \( Z = 0.014 \) from the grid of [28]. The locations of BL Cam on the two diagrams are close to the ZAMS track, indicating an unevolved star.

Also, Fig.7 (lower left panel) illustrates the position of BL Cam and six SX Phe variables on the \( \log T_{\text{eff}} \)-\( \log g \) diagrams for the masse tracks \( 1.4 M_\odot - 2 M_\odot \). The parameters of BL Cam agree well with those predicted for SX Phe candidates listed in Table 6 [29]. The tracks are plotted for the metallicity values \( Z = 0.019 \) ([Fe/H] = -1.61) and \( Z = 0.03 \) ([Fe/H] = -1.41). In the lower right panel of Fig.8, we plotted the isochrones appropriate for the effective

| Table 5. Physical Parameters of BL Cam |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| \( T_{\text{eff}} \) (K) | \( M/M_\odot \) | \( \log L/L_\odot \) | \( R/R_\odot \) | \( M_{\text{bol}} \) | \( \log g \) | \( \text{Age(yr)} \) | \( Q \) (days) |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| 7625            | 1.68            | 0.957           | 1.69            | 2.335           | 4.3             | 2.295 Gy        | 0.025          |

TABLE 6. Effective Temperatures and Surface Gravities of SIX SX Phe Stars

| Star name | \( T_{\text{eff}} \) (K) | \( \log g \) | Ref. |
|-----------|-----------------|-----------------|-----|
| SX Phe    | 7850            | 4.2             | 30  |
| KZ Hya    | 7650            | 4               | 31  |
| CY Aqr    | 7930            | 4.13            | 32  |
| BS Tuc    | 7250            | 3.75            | 33  |
| DY Peg    | 7800            | 4               | 32  |
| XX Cyg    | 7530            | 3.66            | 34  |
temperature and luminosity of BL Cam. In this figure, we can notice that the star crossed the instability strip's red edge (RE). From this diagram, the age of BL Cam could be determined as 2.295 GY.

5. Conclusion

We thoroughly analyzed the star BL Cam using photometric and spectroscopic observations obtained at the Kottamia observatory. According to the Fourier analysis of the light curves, the fundamental mode is independent pulsation mode at 25.14427 c/d and three harmonics, 51.112 c/d, 33.388 c/d, and 17.72464c/d. We combined the new times of maximum light with those provided by previous literature to perform an O-C analysis for the period change for BL Cam, yielding 55 times of maximum light. The variation rate of the fundamental period derived from the long-time scale of observations shows a negative period change ($dp/dt = 0.17028 \pm 0.14 \times 10^{-5}$ s/yr).
We used LTE model atmospheres to simulate the observed spectra. The effective temperatures and surface gravities at different phases are calculated by comparing the spectra to the appropriate synthetic spectra. We adopted the effective temperature and surface gravity of BL Cam as $T_{\text{eff}} = 7625 \pm 300$ K and $\log g = 4.30 \pm 0.37$, which is in good agreement with earlier studies. We located the star’s physical parameters on the evolutionary models to investigate its evolution state. The calculated mass ($1.68 M_\odot$) is in good agreement with mass tracks around $1.6 M_\odot$ and higher than the possible masses ($1.0 M_\odot - 1.4 M_\odot$) of the SX Phe stars predicted by [29].

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REFERENCES

1. P. Zong, A. Esamdin, J. N. Fu et al., Publ. Astron. Soc. Pacif., 131, 4202, 2019.
2. H. L. Giclas, R. Burnham, and N. G. Thomas, Lowell Observatory Bulletin, 7, 183, 1970.
3. R. A. Berg and J. G. Duthie, Astrophys. J. Lett., 215, L25, 1977.
4. D. McNamara, Publ. Astron. Soc. Pacif., 109, 1221, 1997.
5. S. Fauvaud, E. Rodríguez, A. Y. Zhou et al., Astron. Astrophys., 451, 999, 2006.
6. E. Rodríguez, S. Fauvaud, J. A. Farrell et al., Astron. Astrophys., 471, 255, 2007.
7. J. -N. Fu, C. Zhang, K. Marak et al., ChJAA, 8, 237, 2008.
8. E. G. Hintz, M. D. Joner, D. H. McNamara et al., Publ. Astron. Soc. Pacif., 109, 15, 1997.
9. A. -Y. Zhou, E. Rodriguez, S. -Y. Jiang et al., Mon. Not. Roy. Astron. Soc., 308, 631, 1999.
10. C. Kim and E. -J. Sim, JASS, 16, 241, 1999.
11. A. -Y. Zhou, B. -T. Du, X. -B. Zhang et al., IBVS, 5061, 1, 2001.
12. M. Wolf, M. Crilikova, M. Basta et al., IBVS, 5317, 1, 2002.
13. J. H. Pena, J. D. Paredes, D. S. Piña et al., Revista Mexicana de Astronomía y Astrofísica, 57, 419, 2021.
14. F. Hroch, Proceedings of the 29th Conference on Variable Star Research, 30, 1998.
15. P. Lenz and M. Breger, Communications in Asteroseismology, 146, 53, 2005.
16. E. Hertzsprung, BAN, 4, 178, 1928.
17. M. Abdel-Sabour, A. Shokry, and A. Ibrahim, Revista Mexicana de Astronomía y Astrofísica, 56, 287, 2020.
18. M. Craig, S. Crawford, M. Seifert et al., astropy/ccdproc: v1. 3. 0. post1, doi:10. 5281/zenodo. 1069648.
https://doi. org/10. 5281/zenodo. 1069648, 2017.
19. P. van Dokkum, Publ. Astron. Soc. Pacif., 113, 1420, 2001.
20. C. McCully, S. Crawford, G. Kovacs et al., astropy/astrosrappy: v1. 0. 5 Zenodo Release, https://zenodo. org/record/1482019, 2018.
21. N. Earl, E. Tollerud, C. Jones et al., astropy/specutils: V1. 5. 0, v1. 5. 0, Zenodo, doi: 10. 5281/zenodo. 5721652, 2021.
22. R. L. Kurucz, HiA, 10, 407, 1995.
23. R. O. Gray, Astron. Astrophys., 265, 704, 1992.
24. R. O. Gray, Astron. Astrophys., 273, 349, 1993.
25. C. B. Reed, Astrophys. J. Suppl. Ser., 115, 271, 1998.
26. A. N. Cox, Proceedings of IAU Colloq. 111, held in Lincoln, NE, 15-17 August 1988. Edited by E. G. Schmidt, Cambridge Univ. Press.; p. 1, 1989.
27. W. S. Fitch, Proceedings of the Workshop, Tucson, Ariz., March 12-16, 1979. (A81-21401 07-90) Berlin, Springer-Verlag.; p. 7-21, 1980.
28. L. Girardi, A. Bressan, G. Bretelli et al., Astrophys. J. Suppl. Ser., 141, 371, 2000.
29. J. Nemec, M. Mateo, in C. Cacciari, G. Clementini, eds, Astronomical Society of the Pacific Conference Series Vol. 11, Confrontation Between Stellar Pulsation and Evolution, p. 64-84, 1990.
30. M. S. Bessel, Astrophys. J. Suppl. Ser., 18, 195, 1969.
31. A. Przybylski and M. S. Bessell, Mon. Not. Roy. Astron. Soc., 189, 377, 1979.
32. D. H. McNamara and A. K. Feltz, Publ. Astron. Soc. Pacif., 90, 275, 1978.
33. A. W. Rodgers, Astrophys. J., 152, 109, 1968.
34. M. D. Joner, Publ. Astron. Soc. Pacif., 94, 289, 1982.