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B stars analysis from field 13 of the Kepler K2 mission

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Abstract. This paper reports a photometric, spectroscopic, evolutionary, and seismological analysis of 68 B stars from campaign 13 (C13) of the Kepler/K2 mission. Light curves were plotted using K2SC pipeline. The algorithms CLEANEST and IvS were used in the frequency analysis. We obtained optical spectra in the blue region for 27 targets. Astrophysical parameters were estimated with SME and MESA packages. A simplified seismic method was implemented in order to investigate average internal rotation frequency (ν_{rot}), and the buoyancy travel time (P_0). A colour-magnitude diagram helped us to better classify star variability.

Resumo. Este artigo relata uma análise fotométrica, espectroscópica, evolutiva e sismológica de 68 estrelas B da campanha 13 da missão Kepler/K2. As curvas de luz foram plotadas usando o código K2SC. Os algoritmos CLEANEST e IvS foram utilizados na análise de frequência. Obtivemos espectros ópticos na região do azul para 27 alvos. Os parâmetros astrofísicos foram estimados com os programas SME e MESA. Um método sísmico foi implementado a fim de investigar a frequência média de rotação interna (ν_{rot}), e o tempo de deslocamento do empuxo (P_0). Um diagrama de magnitude de cores nos auxiliou a classificar a variabilidade das estrelas.

Keywords. Stars: variables: general – stars: evolution – stars: fundamental parameters

1. Introduction

The K2 mission was developed with ∼ 80 days of observation per field. For C13, the photometric data were come by during 03/08/2017 to 05/27/2017. Example of variability as Slowly Pulsanting B-stars (SPB), hybrid (SPB/β Cep), MAIA, stars that presents low-frequency power excess, and stars showing binarity (BIN), rotation (ROT), or both are found in our sample. Using the Data Release 3 (DR3) of the GAIA, a colour-magnitude diagram can be plotted. The G-band absolute magnitude equation is described as follows:

$$M_G = G + 5 - 5\log_{10} r - A_{\mathrm{G}}, \quad (1)$$

with G-band the apparent magnitude, r is the distance, and A_{G} is the line-of-sight extinction in the G-band, see Torra et. al (2021). The spectrum sample in blue region (3900 to 4800 Å) were obtained from ground observations at Pico dos Dias/Laboratório Nacional de Astrofísica (OPD/LNA), with the 1.6m Perkin-Elmer Telescope and Cassegrain spectrograph. Others targets were acquired from LAMOST database.

The paper is organized as follows: in Section 2, we describe photometric diagnostic, and the GAIA colour-magnitude diagram too. In Section 3, we report about the Takata et. al (2020) method, and in Section 4 we demonstrated spectroscopic results.

2. Photometric analysis

The light curves are provided by NASA's Ames Research Center. The final product is the Pre-Search Data Conditioning (PDC) as the last step from Kepler Science Pipeline. Thereafter, we correct light curves for systematic and jitter errors using K2 Systematic Correction (K2SC) projected by Aigrain, Parviainen & Pope (2016).

Temporal analysis was performed by the CLEANEST algorithm, which detects signals in time series with irregular time sampling (more details in Foster (1995)). Then the temporal analysis is completed with prewhitening method applied on light curves, see Degroote (2010). This method fits a function to original signal in steps, saving a frequency and calculating the residuals. The model function that fits original signal is given by:

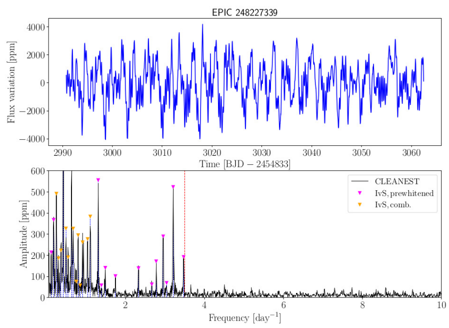

Figure 1. EPIC: 248227339, N_{tot}: 39, ν [days^{-1}]: 0.42, A_{max} [ppm]: 1104, Period [days]: 2.34, and Class: SPB/IGW (B9).

$$F(t_i) = \mu + C + \sum_{i=1}^{n_f} A_i \sin[2\pi(\nu_i t_i + \phi_i)] + \epsilon_i, \quad (2)$$

with ϵ_i the Gaussian noise, μ a median of observed flux, C a correction parameter in μ, and A_i, ν_i, and ϕ_i are the amplitude, frequency, and phase, respectively. The time of observed flux is t_i. A criterium is established to stop iteration in prewhitening method, i.e., when signal-to-noise ratio reach S/N < 5. In Fig. 1, a SPB/IGW light curve, and its periodogram is shown.

Fig. 2 illustrates a pie with variability determined of our sample of B stars. However, we can describe a colour-magnitude diagram with Gaia data in order to better classify the star variability types. Fig. 3 is an example for the difference between the stellar

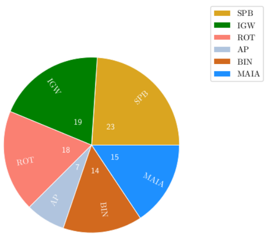

Figure 2. Pie distribution in variability for B stars from C13.

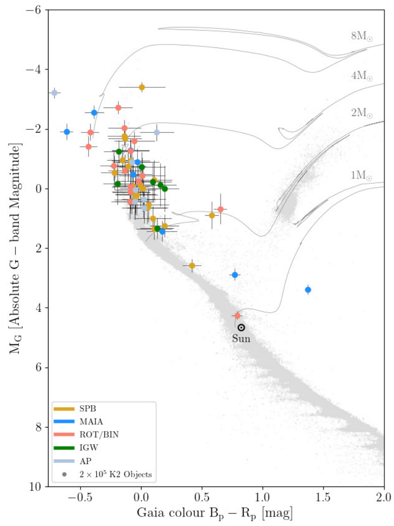

Figure 3. HR Gaia color-magnitude diagram of B stars from C13. In the inset are indicated the stars' variability type.

magnitudes measured in the Gaia blue and red passbands plotted against the G-band absolute magnitude.

3. Seismic diagnosis

In work of Takata et. al (2020), they report a asteroseismic simplified iterative method for identification of rotation frequency (ν_{rot}), and its associated g-modes period (P_0). The method is only valid for stars which present g-modes, for example SPB stars. Using the equations:

$$f_k(\nu_{rot})\sqrt{\frac{\Delta_k \nu}{m\Delta_k n}} = \sqrt{P_0}\left(\frac{\nu_{k+\frac{1}{2}}}{m} - \nu_{rot}\right),$$

$$f_k(\nu_{rot}) = \left[\frac{-1}{(m\Delta_k \nu)\Delta_k}\left(\frac{\sqrt{\lambda_{m,m}(s)}}{\nu_{co}}\right)\right]^{\frac{1}{2}} (\nu_{k+\frac{1}{2}} - m\nu_{rot}), \quad (3)$$

we conclude that this process converges when $[\nu_{rot}^{(i)} - \nu_{rot}^{(i+1)}]$ and $[\,P_0{}^{(i)}$ - $P_0{}^{(i+1)}]$ are small enough. More details are outlined in Takata et. al (2020), and in Fig. 4, we have an example of plot.

4. Spectroscopic results

The spectroscopy analysis was driven using the Spectroscopy Made Easy package (SME, Valenti & Piskunov (1996)) with Vienna Atomic Line DataBase (VALD) support. Stellar parameters as T_{eff}, $\log g$, and vsin i are obtained by interpolated atmospheric models. The uncertainties upon parameters are acquired

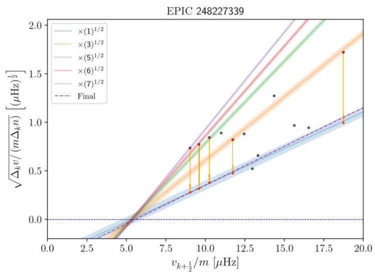

Figure 4. EPIC 248227339: $\nu_{rot} = 5.6\,\mu$Hz and $P_0 = 6.4 \cdot 10^3$ s.

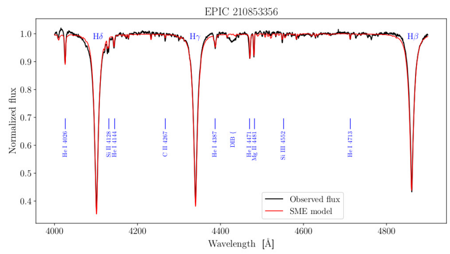

Figure 5. EPIC 210853356 (SPB): Spectra in blue region. Values: $T_{eff} = 12622^{+103}_{-103}$, $\log g = 3.8^{+0.1}_{-0.1}$, and vsin $i = 114^{+30}_{-30}$.

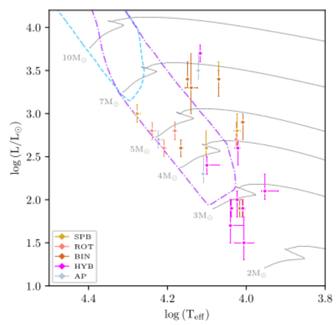

Figure 6. H-R diagram for B stars in C13. The instability strips of β Cep (light blue) and SPB (purple) stars are indicated.

by Monte Carlo method, and yields minimization in χ^2 to obtain 1σ of confidence interval. We show one of our spectra in Fig. 5.

We use Modules for Experiments in Stellar Astrophysics (MESA) evolutionary code assembled by Paxton et. al (2011). The conservative model was adopted, and it is schematized with hydrogen burning in the stellar core, with no perturbations due to star rotation. Furthermore, we employed the stellar parameters as T_{eff} and $\log g$ estimated by SME as input values to calculate luminosities, mass, radius, and age for some stars. For example, for EPIC 248227339 seen in Fig. 5, we figure out values: log $(L/L_\odot) = 2.6^{+0.2}_{-0.1}$, $M/M_\odot = 4.2^{+0.4}_{-0.3}$, $R/R_\odot = 4.8^{+0.8}_{-0.1}$, and Age $= 114.1^{+10.9}_{-46.1} \times 10^6$ years. Thus, a HR-diagram in Fig. 6 is plotted.

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