BRITE and Ground-based Photometry and Spectroscopy of the β Cephei Star ϵ Persei

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ϵ Persei was observed for a second time by the BRITE satellites from 9th September 2016 to 6th March 2017. We organized a ground-based spectroscopic campaign in order to determine the modes of pulsation and properties of the star simultaneously with the space photometry. The goal of our study is to find pulsation frequencies and amplitudes, to identify pulsation modes, to verify the orbital period and to find properties of ϵ Persei, i.e. core and envelope rotation, angular speed and exact evolution phase. First results are presented.

1 ϵ Persei (HD24760)

ϵ Persei (HD24760) is a triple star system. The main component ϵ Persei A is a β Cephei type star. Its spectral type is B1.5III (Abt & Cardona, 1983). The second component ϵ Persei B is a star of spectral type A6 or B9 IV(Abt & Cardona, 1983). The spectral type of the third component ϵ Persei C is not well established. The orbital period of the second component is equal to 14.069 days, the orbital period of the third component is around 25.8 years (Libich et al., 2005). ϵ Persei A (hereafter referred to as ϵ Persei) is a fast rotating star (projected rotational velocity $v \sin i$ between 130–153 km/s, Abt et al., 2002; De Cat et al., 2000) with multiple pulsation modes. It is also a run-away star (Toalá et al., 2017). Its variability has been the subject of several studies. The most recent work devoted to close binary orbital period determination was done by Libich et al. (2005). In that paper all references, information and a summary concerning former spectroscopic research of the star by Gies & Kullavanijaya (1988), Tarasov et al. (1995), and by De Cat et al. (2000) can be found. ϵ Per was used to understand line profile variations in hot stars by Gies & Kullavanijaya (1988).

ϵ Persei was observed for the second time by the BRITE satellites (Weiss et al., 2014; Pablo et al., 2016) from 9th September 2016 to 6th March 2017. We organized a ground-based spectroscopic campaign in order to determine the pulsation modes and properties of the star simultaneously with the space photometry.

ϵ Per A is a supernova type II progenitor. We intend to determine the core and envelope rotation (long-period gravity modes excited in the star carry information about the stellar core, acoustic oscillation modes about the stellar envelope), angular speed and exact evolution phase.

2 Spectroscopic observations

In 2016 ϵ Persei was re-observed by both professional and amateur astronomers using ground-based spectrographs as well as in 2014. In 2016, we obtained additional data from McDonald Observatory. The full list of spectroscopic observations is as follows:

- GATS - Krzysztof Kamiński, Wojciech Dimitrov, Monika Kamińska, Magdalena Polińska (Polińska et al., 2014)
- AAVSO:
  - Austria, Germany - Berthold Stober, Manfred Schwarz, Siegfried Hold, Ulrich Waldschläger
  - China - Dong Li
  - France (La Tourbiere) - Olivier Garde
  - USA (Baltimore)
- Lithuania (Moletai) - Erika Pakštienė, Šarūnas Mikolaitis
- Slovakia (Stara Lesna Observatory) - Ernst Paunzen
- USA (McDonald Observatory) - Elżbieta Zocłońska

2.1 Spectroscopic observations at McDonald Observatory

McDonald Observatory is located in Texas in the USA. The 2.1-m Otto Struve Telescope was used for 12 nights of observations from 12 Nov 2016 to 23 Nov 2016 (UTC) but only 10 were usable for science observations. The Sandiford Cassegrain Echelle Spectrometer was used to gather spectra in the range of 4341–4861Å with a resolution of R=60,000. All spectra were reduced and normalized with IRAF[1]. The Si III λ4553 line Å was studied so far. An example spectrum is shown in Fig. 1.

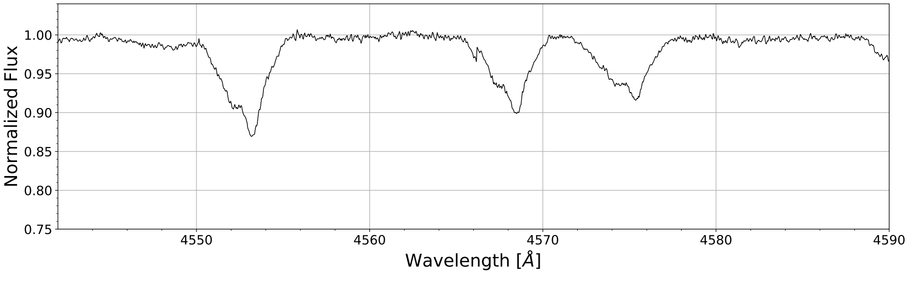

Fig. 1: Spectrum of HD24760 from McDonald Observatory taken on 2457706.86357745 JD, exposure time = 48 s. The three spectral lines are due to doubly ionized silicon (Si III at λ4553, 4568, 4574 Å).

We obtained 1210 high quality spectra of HD24760 during 10 consecutive nights starting on 14 Nov 2016. This high resolution time series spectroscopy is being used for mode identification. The variation of the flux profile of Si III spectral lines will be used to identify the modes. Line profile variations measured during the night of 16

[1]IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy (AURA) under cooperative agreement with the National Science Foundation

November 2016 are shown in Fig. 2. Consecutive spectra are shifted in the vertical direction according to time. We can see that the line profile shape and depth change with time due to stellar oscillations.

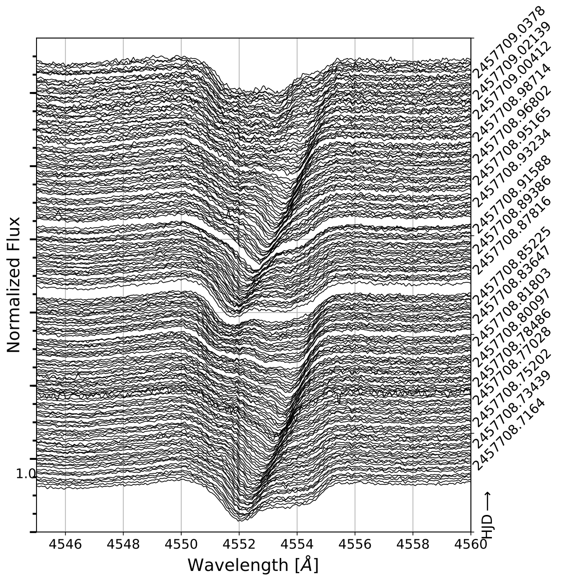

Fig. 2: Variation of the Si III 4553 Å line profile in the spectrum of HD 24760 on HJD 2 457 708/709

Using FAMIAS (Zima, 2008) we converted the wavelength scale to Doppler velocity and calculated radial velocities. Fig. 3 shows an example. One can again see that the effect of the pulsations is visible in the line profile.

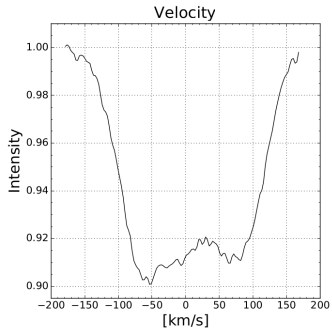

Fig. 3: Line profile of HD24760 in heliocentric velocity space

To find periodicities we performed a time series analysis of the line profile variations. The radial velocity curve from all 10 nights of data is shown in Fig. 4. The radial velocity curve from our data phased with the orbital period equal to 14.069 days found by Libich et al. (2005) is presented in Fig. 5. The FAMIAS software will

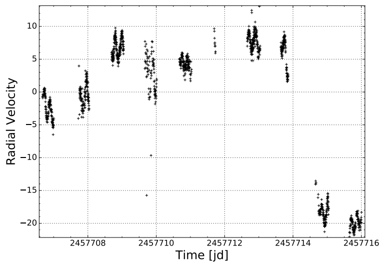

Fig. 4: Radial velocity curve of ϵ Per

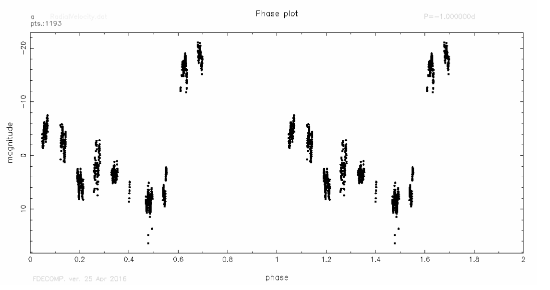

Fig. 5: Radial velocity of ϵ Per phased with the orbital period of 14.069 days

be used to identify the pulsation modes as well.

3 Photometric observations by BRITE

In 2014, during 168 days, four BRITE Constellation satellites observed ϵ Persei from a low earth orbit: BRITE-Austria, UniBRITE, BRITE Lem and BRITE Toronto. In 2016, during 179 days, only BRITE Lem and BRITE Toronto were observing the field with ϵ Per. Analysis of the 2016 data is still in progress. Preliminary results from BRITE-Toronto 2016 observations are shown in Fig. 6. Frequencies in bold frames are the ones found in both our photometry and spectroscopy. We used the fdecomp software (R. Smolec, priv. comm.) for finding frequencies.

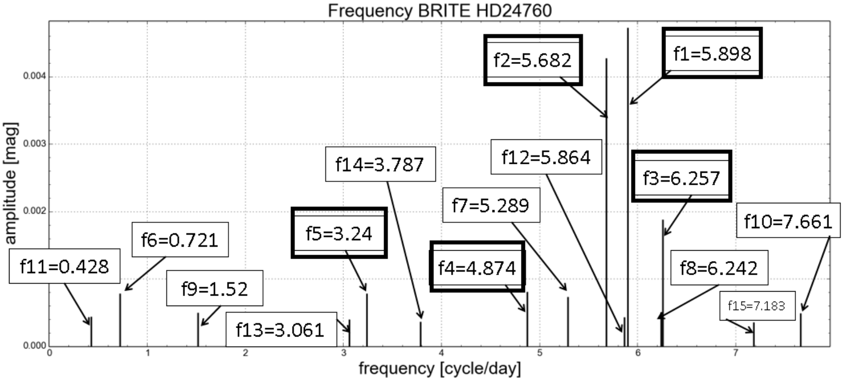

Fig. 6: Preliminary frequency spectrum of HD24760

Some additional decorrelation of the BRITE data still needs to be done. We are planning to recalculate all frequencies with a new approach and then identify the pulsation modes using FAMIAS.

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