A BRITE view on δ Scuti and γ Doradus stars

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BRITE-Constellation has obtained data for a few δ Scuti and γ Doradus type stars. A short overview of the pulsational content found in five stars – β Cassiopeiae, ϵ Cephei, M Velorum, β Pictoris and QW Puppis – is given and the potential of BRITE-Constellation observations of δ Scuti and γ Doradus pulsators is discussed.

1 Introduction

δ Scuti stars have spectral types A to early F, masses between $\sim$1.5 and 4.0 solar masses and pulsation periods between 18 minutes and 6 hours. They typically show multiple radial and non-radial pressure (p) mode frequencies of low degree ℓ which are excited by the κ-mechanism acting in the second helium ionization zone (e.g., Aerts et al., 2010). Although δ Scuti stars are one of the first groups of stars discovered to pulsate, they are still one of the least understood. Open questions include for example observed changes in pulsation amplitudes (e.g., Bowman et al., 2016), hybrid pulsators showing gravity (g) and pressure (p) modes (e.g., Kurtz et al., 2014), spots on the stellar surface, the presence of magnetic fields (e.g., Neiner & Lampens, 2015; Escorza et al., 2016), differential rotation of core versus envelope (e.g., Kurtz et al., 2014), or the influence of the sometimes rapid rotation on the pulsation frequencies (e.g., Reese et al., 2009). In only few cases, δ Scuti stars show characteristic spacings and splittings that can be used for an asteroseismic interpretation (e.g., Zwintz et al., 2011, 2013).

δ Scuti pulsation has also been observed in several pre-main sequence (pre-MS) objects (e.g., Zwintz et al., 2014) that gain their energy mainly from gravitational contraction on their way from the birthline to the zero-age main sequence (ZAMS). For pre-MS δ Scuti stars a relation between their pulsational properties and the relative stage in their pre-MS evolution was discovered: The least evolved stars that are still close to the birthline and, hence, have the largest radii, show the slowest pulsations. The further the pre-MS pulsators have progressed in their evolution to the ZAMS, and, hence, the more compact they have become, the faster they oscillate (Zwintz et al., 2014).

γ Doradus type stars have spectral types from late A to early F and show g-mode oscillations driven by the convective flux blocking mechanism (Guzik et al., 2000). Their pulsation periods range from $\sim$0.3 to 3 days (e.g., Kaye et al., 1999) where modes with same spherical degree ℓ and different radial orders n show equidistant spacings in period (Tassoul, 1980). If a chemical gradient is present at the edge of the convective core, the g-mode resonance cavity is modified, hence, resulting in periodic dips in the period spacing pattern (Miglio et al., 2008). Using four-year high-precision space-based photometric time series obtained by the Kepler (Koch et al.,

2010) satellite, period spacing patterns were recently detected (Van Reeth et al., 2015a,b) and subsequently used to determine the rotation rates and to identify mainly prograde dipole gravity and gravito-inertial modes from the pulsation frequencies (Van Reeth et al., 2016).

With masses between $\sim$1.4 and 2.5 solar masses, γ Doradus stars are the perfect test-beds to study the transition range from low-mass stars with radiative cores and convective envelopes to high-mass stars with convective cores and radiative envelopes. Hence, asteroseismology of γ Doradus pulsators allows to calibrate and improve upon our existing theories of stellar structure and evolution in the mass range of $\sim$1 to 2 solar masses.

2 BRITE observations of δ Scuti and γ Doradus stars

The main observational focus of BRITE-Constellation lies on the most massive O and B type stars. Only $\sim$6% of the targets have spectral types A and only $\sim$12% are of spectral types F, and not all of them have BRITE-Constellation data of sufficient quality for a pulsational analysis, e.g., because the data set length is too short for a thorough analysis.

As of August 2016, BRITE-Constellation has obtained data for seven δ Scuti stars and two γ Doradus stars for which I am the contact-PI. The data sets for the two δ Scuti pulsators 16 Persei and 44 Tauri were insufficient for a pulsational analysis and, hence, had to be omitted. The analysis of the γ Doradus star 43 Cygni is described separately by S. Gössl in these proceedings. Here I will describe the latest findings of four stars classified as δ Scuti type (i.e., β Cassiopeiae, ϵ Cephei, M Velorum, β Pictoris) and one as γ Doradus pulsator (i.e., QW Puppis) using BRITE-Constellation data (see Table 1).

Data reduction was performed using the tool developed by M. Kondrak (described in these proceedings) including decorrelations with CCD temperature, and the X and Y positions of the point-spread function on the CCD. For the frequency analyses, we used the software package Period04 (Lenz & Breger, 2005) that combines Fourier and least-squares algorithms. Frequencies were then prewhitened and considered to be significant if their amplitudes exceeded four times the local noise level in the amplitude spectrum (Breger et al., 1993; Kuschnig et al., 1997). We verified the analysis using the SigSpec software (Reegen, 2007). SigSpec computes significance levels for amplitude spectra of time series with arbitrary time sampling. The probability density function of a given amplitude level is solved analytically and the solution includes dependences on the frequency and phase of the signal.

2.1 β Cassiopeiae (HR 21, HD 432)

The F2 star β Cassiopeiae is reported to be a radial δ Scuti pulsator with a single pulsation period of 2.5 hours that has already evolved towards the Terminal Age Main Sequence (TAMS; Riboni et al., 1994). Che et al. (2011) determined a rotation period of 1.12 $\pm$ 0.04 d from interferometry. Together with a projected rotational velocity, $v \sin i$, of 70 $\pm$ 1 kms^{-1}, the authors conclude that the star rotates with 92% of its critical velocity and must be seen close to pole-on. Hence, β Cas radius is $\sim$24% greater at the equator than at the poles and its effective temperature, T_{eff}, is $\sim$1000 K higher on the poles than at the equator (Che et al., 2011).

BRITE-Constellation obtained data with different time bases during the CasCep I

Table 1: Overview of the BRITE-Constellation observations of the δ Scuti and γ Doradus stars discussed here: time bases (T) in days obtained by BRITE-Austria (BAb), Lem (BLb), Uni-BRITE (UBr), Heweliusz (BHr) and/or BRITE-Toronto (BTr). Data sets of insufficient quality for a pulsational analysis are marked with an asterisk (*).

Star	BAb	BLb	UBr	BHr	BTr
	T [d]	T [d]	T [d]	T [d]	T [d]
β Cassiopeiae	58	6	-	47	44
ϵ Cephei	-	$18^{\star}$	-	$24^{\star}$	48
M Velorum	$37^{\star}$	-	-	-	52
QW Puppis	-	-	-	78	-
β Pictoris	-	-	-	78	-

field observations in 2015 using BRITE-Austria, Lem, Heweliusz and BRITE-Toronto (see Table 1.) Figure 1 shows 5-day subsets of the photometric time series obtained by BRITE-Toronto in the red filter (upper panel) and by Lem in the blue filter (lower panel). The frequency analysis yielded two close frequencies at $9.897\,\mathrm{d}^{-1}$ and $9.043\,\mathrm{d}^{-1}$ whose difference amounts to $0.860\,\mathrm{d}^{-1}$ or a period of 1.16 d. This coincides well with the rotation period found from interferometry (as mentioned above; Che et al., 2011). Further analysis is ongoing and will be subject of a future publication.

2.2 ϵ Cephei (HR 8494, HD 211336)

Using photometric time series obtained from space with the WIRE satellite, Bruntt et al. (2007) identified 26 δ Scuti pulsation frequencies for ϵ Cephei in the frequency range between 12.7 and $34\,\mathrm{d}^{-1}$. The observed regular spacings found in the data were attributed to successive radial orders (Breger et al., 2009).

ϵ Cephei was included in the BRITE-Constellation CasCep I field (2015) and observed with Lem, Heweliusz and BRITE-Toronto. Unfortunately, the quality of the data obtained by Lem and Heweliusz is insufficient for an analysis of the star's pulsations. BRITE-Toronto observed ϵ Cephei for $\sim$48 days. From this data set we identified 24 frequencies in the range from 5 to $30\,\mathrm{d}^{-1}$ and four frequencies between 0 and $1.5\,\mathrm{d}^{-1}$. The seismic interpretation and comparison to previous works is ongoing and will include a detailed analysis of the spectroscopic time series observations obtained from the ground.

2.3 M Velorum (HD 83446)

No information about the variability of M Velorum can be found in the literature.

BRITE-Toronto observed M Velorum for $\sim$52 days during the VelaPuppis II field observing run from December 2014 to May 2015. The data obtained by BRITE-Austria during the same time are unfortunately insufficient for an asteroseismic analysis and had to be omitted. The BRITE-Toronto data allowed us to identify M Velorum as a δ Scuti type pulsating star with two pulsation frequencies: f_1 at $31.0806\,\mathrm{d}^{-1}$ with an amplitude of 1.6 mmag and f_2 at $34.2908\,\mathrm{d}^{-1}$ with an amplitude of 1.5 mmag. The amplitude specrum of M Velorum is shown in Fig. 2. Note that the peak around $29\,\mathrm{d}^{-1}$ corresponds to twice the orbital frequency of the satellite.

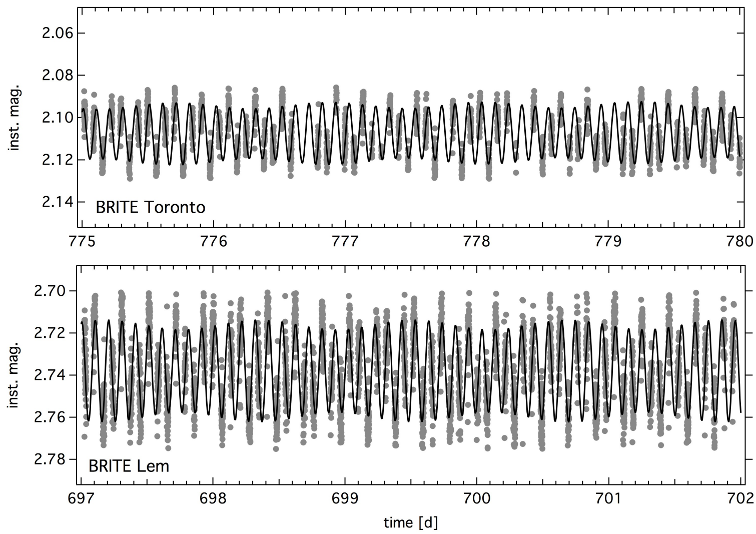

Fig. 1: β Cas: 5-day subsets of the red filter BRITE-Toronto (upper panel) and the blue filter Lem (lower panel) light curves and the corresponding multi-sine fit using the two frequencies at $9.897\,\mathrm{d}^{-1}$ and $9.043\,\mathrm{d}^{-1}$ (black lines).

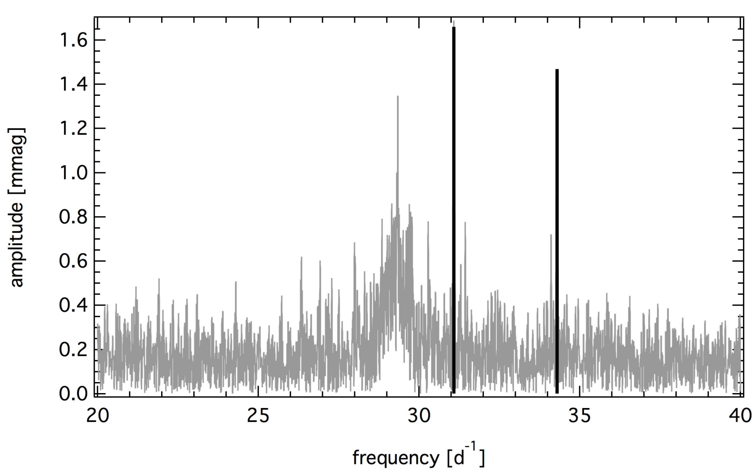

Fig. 2: Amplitude spectrum of the BRITE-Toronto data for M Velorum (grey), where the discovered two pulsational frequencies are marked in black.

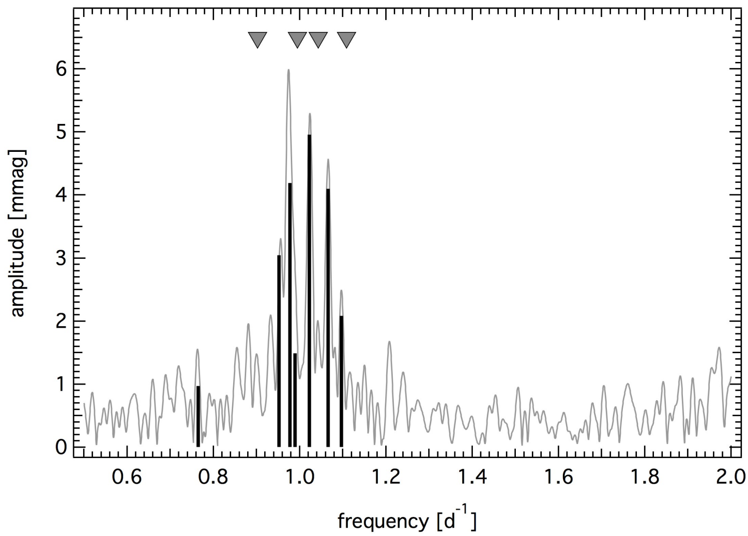

Fig. 3: Amplitude spectrum of the Heweliusz data for QW Pup (grey), where the seven pulsational frequencies detected in the BRITE-Constellation data are marked in black and the triangles show the frequencies found by Poretti et al. (1997).

2.4 QW Puppis (HD 55892)

With a V magnitude of 4.49 mag, QW Puppis is the third brightest known γ Doradus type pulsator. Poretti et al. (1997) reported four frequencies at $1.0434\,\mathrm{d}^{-1}$, $0.9951\,\mathrm{d}^{-1}$, $1.1088\,\mathrm{d}^{-1}$ and $0.9019\,\mathrm{d}^{-1}$ in this F0 star with T_{eff} of 6850 K.

The star was included in the VelaPictor I field in 2015 and observed by Heweliusz for ∼78 days. From these data we identified seven pulsation frequencies in the range between 0.7 and $1.2\,\mathrm{d}^{-1}$ (see Fig. 3) basically confirming the previous findings. Additional BRITE-Constellation observations of QW Puppis are planned for the period November 2016 to April 2017. A detailed asteroseismic investigation and a search for g-mode period spacing patterns will be conducted with the future, significantly longer data sets in both colors.

2.5 β Pictoris (HR 2020, HD 39060)

The young and nearby (distance ∼20 pc) A-type star β Pictoris has been studied frequently in the past and at multiple wavelengths. The star hosts a wide, edge-on, dense circumstellar disk that has been subject of many studies for the last three decades (for an overview see e.g., Lagrange et al., 2010), because its structure was theoretically linked to the presence of one or more massive planets. As a final confirmation of the theoretical predictions, Lagrange et al. (2010) discovered a giant planet (β Pictoris b) through direct imaging using NaCo at the ESO VLT.

The age of the β Pictoris system has been inferred using various methods (e.g., Mamajek & Bell, 2014) and is estimated to lie between 11.5 and 26 million years. The full formation of a planetary system from a disk around a young star needs about 10 million years (Mamajek & Bell, 2014). As such, the β Pictoris system can be used as a clock to test planet formation processes, but the lower limit of its age range appears to be on the lower side to have a fully developed planet. Given the system's youth and close distance, therefore its importance in exoplanetology, the rather large age spread is unsatisfactory and has a profound impact on our understanding of planet formation and early evolution.

β Pictoris is known to be a δ Scuti pulsator (Koen, 2003). Therefore, asteroseismology can be used to better characterize the star and provide an independent estimate of its age. Pulsations in β Pictoris were first discovered using photometric measurements obtained with the SAAO 0.5-m and 0.75-m telescopes (Koen, 2003). Using data collected in only four observing nights, three pulsation frequencies were discovered at $47.055\,\mathrm{d}^{-1}$, $38.081\ \mathrm{d}^{-1}$ and $52.724\,\mathrm{d}^{-1}$ with amplitudes of 1.63, 1.50 and 1.07 mmag, respectively. On the basis of this discovery, Koen et al. (2003) obtained 697 high-dispersion spectra with GIRAFFE at the SAAO 1.9-m telescope over a period of two weeks and found 18 pulsation frequencies from the line profile variations. Koen et al. (2003) tried to identify ℓ and m for β Pictoris reporting the detection of two modes of low degree ℓ and 16 other modes that they could not identify. At that time the theoretical models for δ Scuti pulsations did not distinguish between the pre- and post-MS evolutionary stages. The discovery of pulsations in such a presumably young object was important by itself, and the pulsation frequencies were interpreted as coming from a more evolved post-MS star.

A first trial run with BRITE-Constellation on β Pictoris was conducted between March and May 2015 using the satellite Heweliusz operating with a red filter. The reduced BRITE-Constellation data from that first trial run revealed already several additional pulsation modes that were previously unknown and confirmed some of the findings from 2003. The upcoming BRITE-Constellation campaign on β Pictoris between November 2016 and April 2017 will deliver photometric time series in two colors measured by at least two of the five nano-satellites simultaneously.

3 Conclusions

BRITE-Constellation observations of δ Scuti and γ Doradus stars have been quite successful in the past. As δ Scuti pulsations are easier to measure from the ground due to their shorter periods, new space data from BRITE-Constellation tend to confirm previous findings and sometimes increase the numbers of detected frequencies.

For γ Doradus type pulsators, BRITE-Constellation can contribute significantly to the advances in that research field due to the long observational time bases of up to 180 days. Currently, only space photometry obtained by the Kepler satellite (Koch et al., 2010) allows to detect period spacing patterns and conduct an asteroseismic mode identification for γ Doradus stars. But we found first evidence that we can detect and analyze similar g-mode period spacing patterns using BRITE-Constellation data (e.g., for 43 Cygni, see S. Gössl's contribution to these proceedings).

For both groups of pulsators, the color information from the BRITE-Constellation nano-satellites is a new addition that still has great potential in case of simultaneous observations of a given target in both filters with sufficient precision.

BRITE-Constellation will also be able to expand our knowledge about the young star β Pictoris, its pulsations, evolutionary stage and planetary system in particular with the upcoming observing run in 2016/2017 which will cover the time during the transit of the planet's Hill sphere (see also M. Kenworthy's contribution to these proceedings).

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