Stars and their variability observed from space
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BRITE-CONSTELLATION OPERATIONS AND DATA COLLECTION

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Abstract. BRITE-Constellation (BRight Target Explorer) consists of six nano-satellites aiming to study the variability of the brightest stars in the sky. Austria, Poland, and Canada contribute two spacecraft each all launched into low earth orbits. The satellites have the same structure: they are 20 cm cubes, 7kg mass, with a CCD photometer fed by 3 cm aperture telescopes. The main difference between pairs of satellites is the instrument passband which is set to blue (400-450nm) or red (550-700nm). The core scientific objective is to obtain high-precision two-color photometry, with a time base of up to 180 days, of stars brighter than 4.5 mag in order to study stellar pulsations, spots, and granulation, eclipsing binaries, search for planets and more. Since the launch of the first two BRITE satellites in February 2013 more than 6 and a half years of experiences in space have been gathered to run the mission and a summary of lessons learned is presented. By now more than 30 peer-reviewed scientific articles have been published based on data collected by BRITE-Constellation satellites in space and most results presented therein benefited greatly from supplementary spectroscopy obtained by meter-size ground-based telescopes. In addition the synergy potential with the 2018 launched NASA TESS mission is outlined.

Keywords: Techniques: photometric, Methods: observational

1 BRITE-Constellation overview

The acronym BRITE stands for BRIght Target Explorer. BRITE-Constellation is a fleet of six nano-satellites with each of three pairs funded and built in Austria, Canada and Poland. The primary goal of the BRITE mission is to collect high precision photometry from selected very bright stars in the sky with limiting magnitude of 4.5. Measurements are collected over a time span of up to 6 months and for most objects in two colors. Exposure times are typically set between 0.1 and 5 seconds. Three images of 16-30 stars in the instant field of view per minute are collected during 15-30 minutes of each satellite orbit. The aim is to achieve milli-magnitude precison photometry on orbital means. A comprehensive overview of the technical design of the satellites was provided by (Weiss et al. 2014) and of the BRITE mission operations by (Kuschnig 2017). This article is focused on developments and updates during the past two years.

Even after more than six-and-a-half years of operations of the two Austrian satellites and more than five years of the other spacecraft, five of the six units of BRITE-Constellation are collecting scientifically useful data. Table 1 comprises the main properties of the BRITE satellites.

Table 1. BRITE-Constellation satellites.

Country	Name	ID	Launch Date	Period [min]	Filter
Austria	UniBRITE	UBr	25-02-2013	100.37	RED
	BRITE-Austria	BAb	25-02-2013	100.36	BLUE
Poland	BRITE-Heweliusz	BHr	19-08-2014	97.10	RED
	BRITE-Lem	BLb	21-11-2013	99.57	BLUE
Canada	BRITE-Toronto	BAb	19-06-2014	98.24	RED
	$BRITE-Montreal$	BMb	19-06-2014	n/a	$BLUE$

While BRITE-Montreal did not separate from the launch vehicle and hence was never operational, all other BRITE satellites which where designed for a nominal productive lifetime of two years are still working very well three times longer then base-lined. Therefore, the BRITE satellites are perfect examples for nano-satellites that can be utilized for front-edge science extending over several years of productive lifetime, something often critized of such small platforms in space.

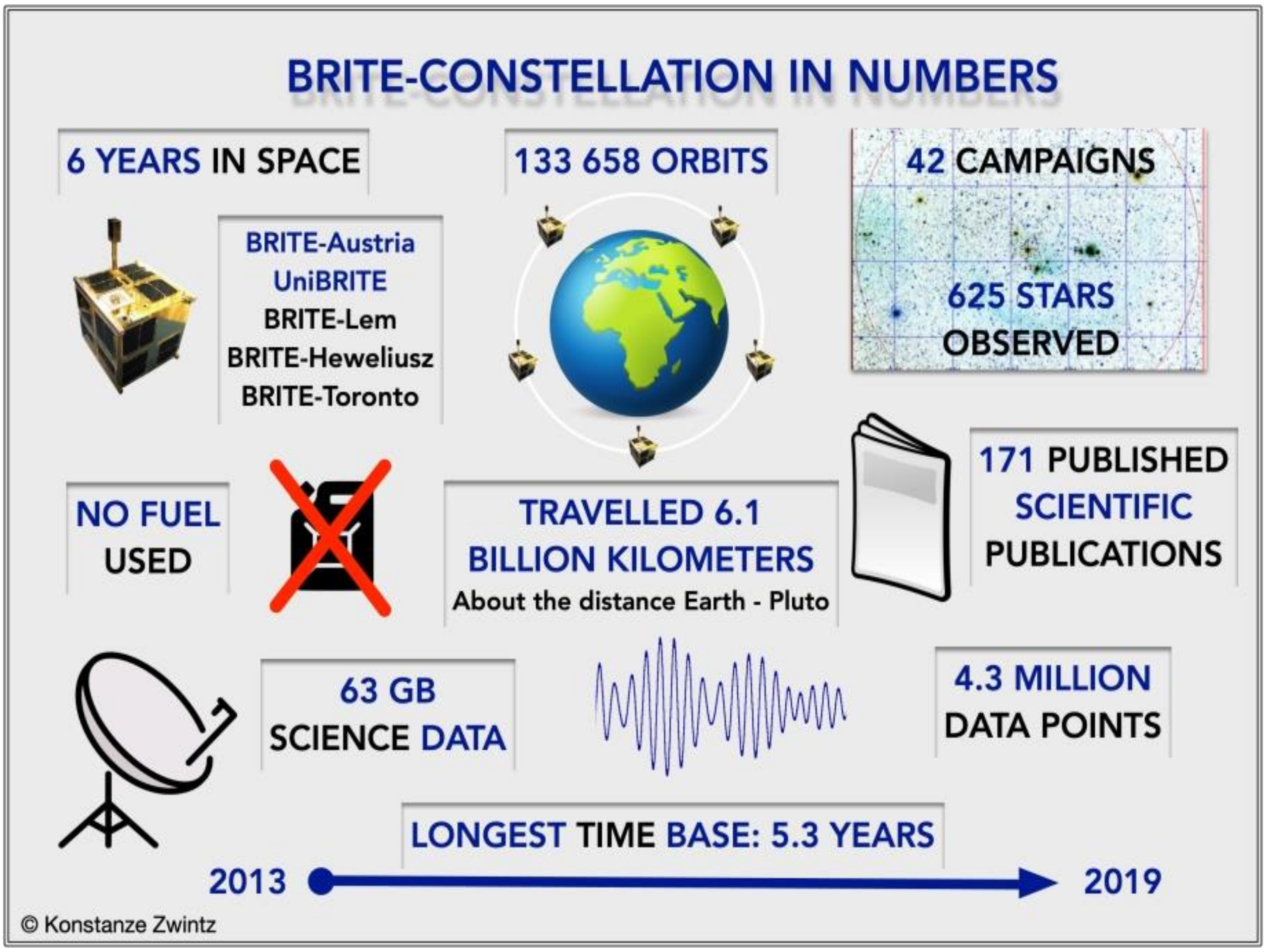

Fig. 1. BRITE-Constellation in numbers.

In total at the time of the conference, BRITE-Constellation satellites have observed 625 individual stars during 42 campaigns. More numbers and stats are shown in Figure 1 .

The observation fields and selected target stars within are shown in Figure 2 Apparently most observed fields were placed at or close to the Galactic plane due to the fact that many bright stars are found there on the sky. In particular many primary targets like bright O, B and Be stars can be placed in the 24 deg wide focal plane when selecting those orientations.

Many of the 625 stars were observed multiple times during the past six-and-a-half years since December 2013 when the first two BRITE satellites began regular science observations. Most notably, the brightest stars in the Orion field have essentially been measured during 5 campaigns even in two colors.

2 Performance over time

As reported in the past, the BRITE CCDs (Kodak,KAI 11002-M) are subject to radiation degradation where pixels and even whole columns had elevated dark (thermal) signals, 'hot pixels' and 'warm columns'. These defects emerge across the whole detector and progressively increase over time. The cause is bombardment of the CCD chip with high energy protons and electrons mainly during passages through the SAA (South Atlantic Anomaly), which occur every day in low earth orbit. While 'warm columns' have only modest effects on the quality of BRITE photometry, the number of 'hot pixels' which are generated at a rate of 1.7 percent per year (at 20C CCD operating temperature) and which merge with the stellar PSFs are a substantial source of noise.

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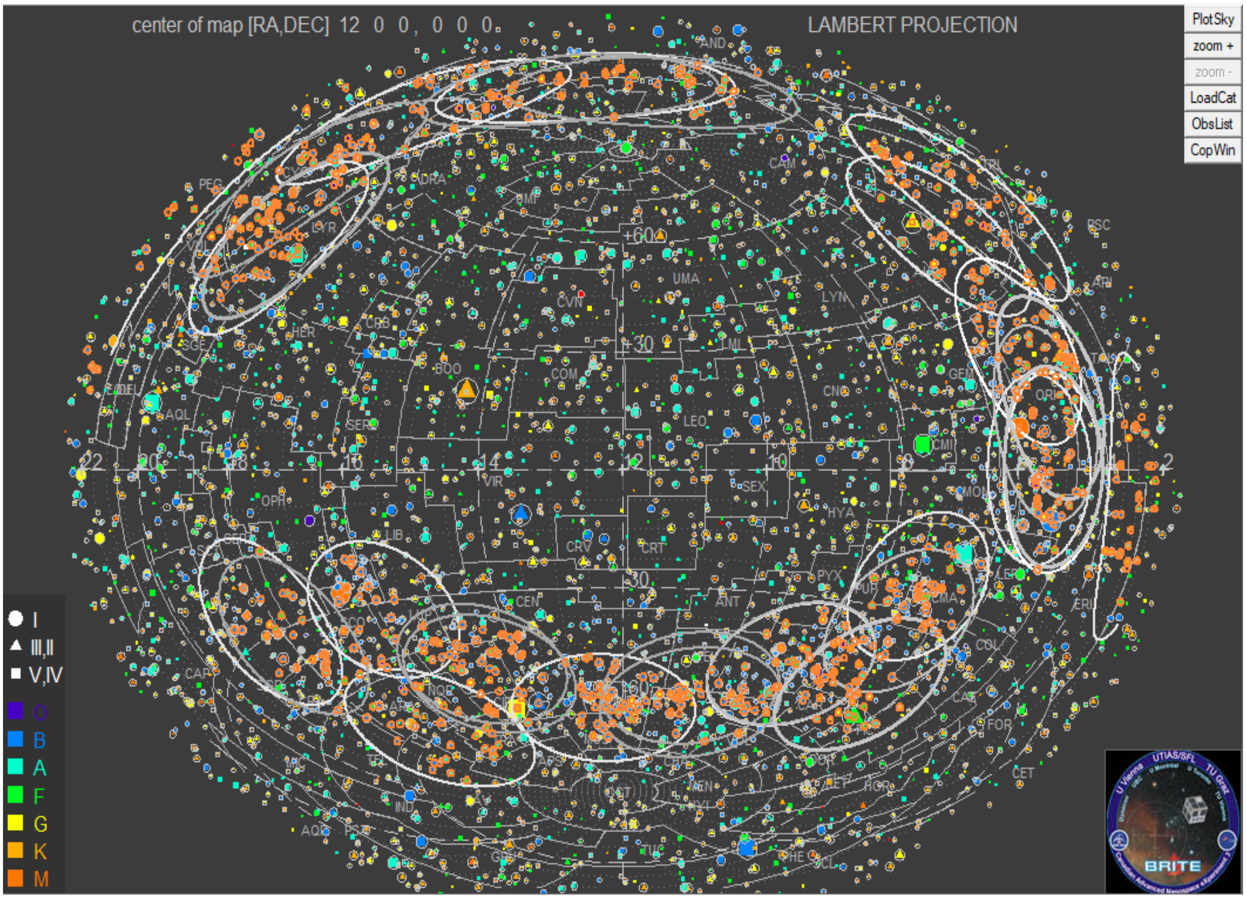

Fig. 2. BRITE-Constellation stars and observation fields

To compensate for that the operating scheme was changed in the fall of 2014 such that the position of the stars between each exposure changed from a position A to B and back to A and so forth by about 30 pixels along CCD rows. Subtracting images obtained from subsequent exposures for a star removes to a large degree the signal offsets of hot pixels when applying aperture photometric reduction to the collected data ((Popowicz et al. 2017)).

Up to the present four of the five BRITE satellites reveal a fraction of 'hot pixels' in excess of 12 percent. Only BRITE-Heweliusz (BHr) the second Polish satellite, which has a slightly different instrument design including specifically introduced radiation shielding of the detector housing has a significantly lower damage by a factor of four due to that foresight.

To evaluate the photometric performance over time during the past six years, the photometric scatter of stars can be calculated as shown in Figure 3

The photometric noise obtained based on BAb from ϵ and σ Orionis over the past six years shows in both cases only a modest increase. The past current and in the future projected 'hot pixel' fraction of the BRITE-Austria CCD has also been determined as shown in Figure 3. The residual 'problem pixel' fraction after applying the reduction pipeline is also drawn as solid bars. The photometric performance development over time here presented just for one satellite (BAb) is in fact consistent with UBr, BTr and BLb. BHr which is less affected by radiation damage reveals thus far no significant loss of data quality since launch in August 2014.

3 BRITE and TESS

TESS (https://tess.gsfc.nasa.gov/) is a NASA mission launched in April 2018 to search for planets around nearby stars across almost the full sky. While TESS photometry is more precise than BRITE photometry, about 90 percent of TESS targets will only be observed for 27 days. BRITE, however, can observe up to 180

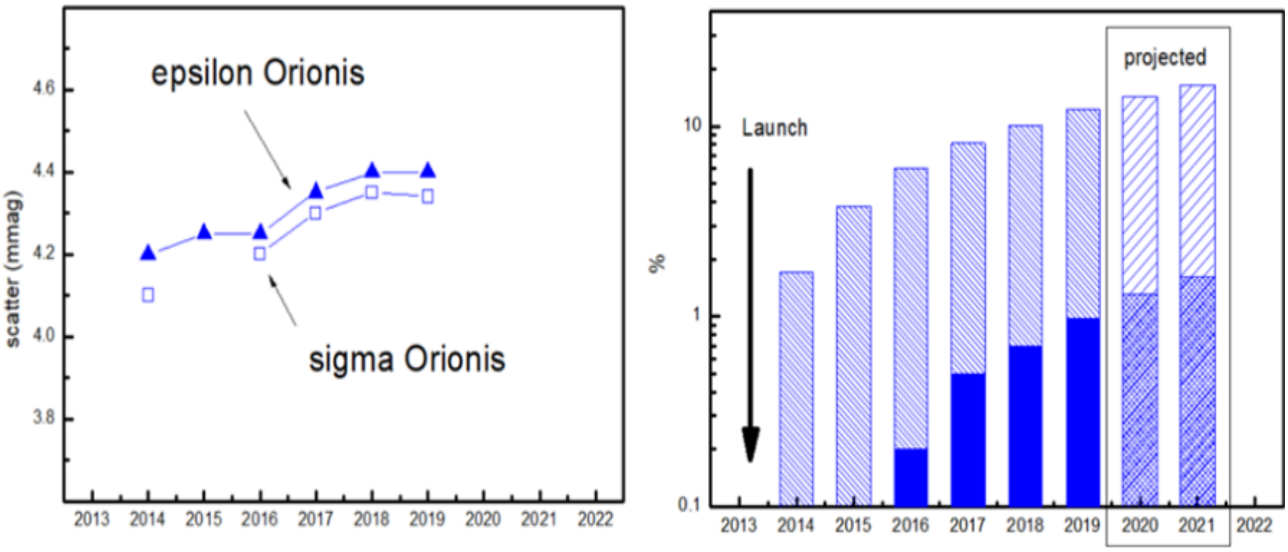

Fig. 3. (Left panel) BRITE-Austria photometric scatter (noise) values plotted over the past 6 observing campaigns of ϵ Ori and σ Ori. (Right panel) BRITE-Austria percentage of hot pixels in the past, current and projected till 2021. The solid blue bars indicate the residual pixel percentage when applying the chopping scheme.

days in a single observing campaign and additionally in two colours. Almost all stars in the BRITE program will be also observed by TESS, often even contemporaneously. Combining data sets from both missions opens up unique scientific opportunities.

TESS science data gathering started in July 2018. The observing plan started in the southern hemisphere split up in 13 segments each observed by four cameras for about 28 days. In parallel the BRITE observing plan also included southern fields and in December 2018 it started to overlap in time. As an example the contemporaneous photometric data collection of η Orionis is portrayed in Figure 4.

From the comparison of just that one case it is evident that combining both data sets for that one star collected in a blue passband (BLb) and the red range of TESS can be of particular value for the analysis of this complex multiple star system. The ultra-high precision of TESS data can reveal much more spurious variations which may be present in the BRITE data at very low signal-to-noise levels. However, the much longer time base of the BRITE data be used for much better frequency resolution in the Fourier analysis.

From December 2018 onwards, BRITE and TESS were observing more than 60 stars in common at least during 28 days contemporaneously. Among these were many different types of variable stars from hot massive O and B stars to cool Red Giants. Some of those were observed by two BRITE satellites in red and blue bands and in one band with TESS.

4 Summary and Outlook

The BRITE-Constellation satellites are still working well. Despite being six years in space, three times longer than the anticipated lifetime, high-precision photometric data from selected bright stars are still collected on a daily basis. Based on the current condition and performance of the hardware, despite significant radiation degradation of the CCD detectors, the mission can continue at least until the end of 2021 without severely compromised quality.

Many outstanding results based on BRITE data have furthered the understanding of physical processes acting in many different types of stars. Furthermore, a rare Nova eruption was recently monitored by BRITE satellites with unprecedented quality and time coverage. The overall scientific analysis has currently led to 31 refereed articles in highly-ranked journals, along with three international science conferences and their proceedings, adding up to a total of more than 170 publications to date. A recent highlight was this international conference Stars and their Variability, Observed from Space Celebrating BRITEConstellation with more than 260 scientist from across the globe coming together in Vienna.

The future activities of BRITEConstellation will focus, among various priorities, on the synergy of BRITE and TESS space photometry with ground based spectroscopy, collected contemporaneously by instruments such as SONG.

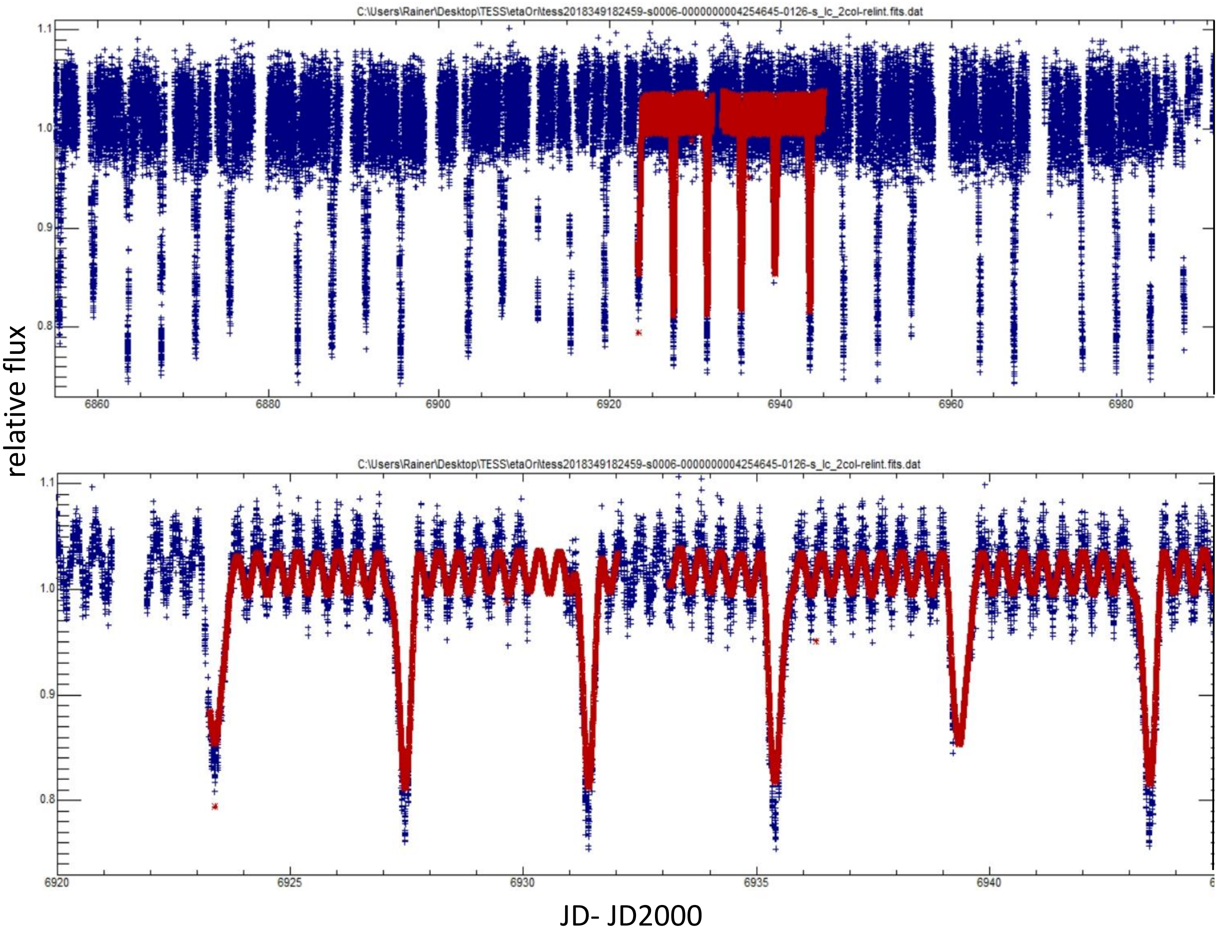

Fig. 4. top: complete 137-day long η Orionis light-curves obtained by BRITE-LEM (BLb) in blue and by TESS in red (21 days). bottom: closeup look at the period of contemporaneous observations

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