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The first Austrian nanosatellite BRITE-Austria/TUGSAT-1—a success story

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Abstract In February 2013, the first Austrian nanosatellite BRITE-Austria/TUGSAT-1 was launched into orbit to observe the brightness variations of massive luminous stars. Although the mission was originally planned to last only two years, BRITE-Austria has been providing scientific data at a high quality standard for more than eight years. The natural degradation of the systems on board over time as well as the impact of radiation, especially on the light-sensitive detectors, led to a decrease in efficiency and data quality. To ensure the continuous operation and a high level of data quality, several countermeasures were successfully introduced over the years, some of which are highlighted in this paper.
The BRITE mission has shown impressively that, with the help of small and inexpensive satellites, even highly demanding scientific objectives can be achieved. The BRITE satellites have delivered new insights into the physical nature of stars, their pulsations, and "heartbeats", as described in numerous publications, and even observed the complete development of a nova in the Carina field.

Keywords BRITE · Satellite · Nanosatellite · Constellation · Radiation · Asteroseismology

Österreichs erster Nanosatellit BRITE-Austria/TUGSAT-1 – eine Erfolgsgeschichte

Zusammenfassung Im Februar 2013 startete der erste österreichische Nanosatellit BRITE-Austria/TUGSAT-1 ins All, mit dem Ziel, die Helligkeitsschwankungen von massereichen hellen Sternen aufzuzeichnen. Trotz der ursprünglichen Missionsdauer von lediglich zwei Jahren liefert BRITE-Austria bereits seit über acht Jahren wissenschaftliche Daten auf sehr hohem Qualitätsniveau. Der altersbedingte Verschleiß und der kontinuierliche Einfluss von Strahlung auf die Satellitensysteme, speziell auf die optischen Sensoren, hat zu einem Einbruch der Effektivität und Datenqualität geführt. Um diesem Einbruch entgegenzuwirken und die Datenqualität über die Jahre zu gewährleisten, wurden mehrere Maßnahmen erfolgreich umgesetzt, von denen einige in diesem Artikel beschrieben werden.
Die BRITE-Mission hat eindrucksvoll bewiesen, dass selbst mit Kleinsatelliten unter den typischen Einschränkungen hinsichtlich Gewicht, Volumen und Budget herausragende Beiträge und Daten zur Wissenschaft geliefert werden können. Die BRITE-Satelliten haben wertvolle Erkenntnisse im Bereich des Sternenaufbaus und der Asteroseismologie gebracht, welche sich in zahlreichen Publikationen widerspiegeln. Ein besonderes Highlight war die Beobachtung des gesamten Entwicklungszyklus einer Nova im Sternenfeld Carina.

Schlüsselwörter BRITE · Satellit · Nanosatellit · Konstellation · Strahlung · Asteroseismologie

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Abbreviations

ADCS	Attitude Determination and Control System
ASAP	Austrian Space Applications Programme
BEST	BRITE Executive Science Team
BPSK	Binary Phase Shift Keying
BRITE	BRIght Target Explorer
CCD	Charge Coupled Device
GNB	Generic Nanosatellite Bus
PSLV	Polar Satellite Launch Vehicle
QPSK	Quadrature Phase Shift Keying
RMS	Random Mean Square
TUG	Graz University of Technology
UHF	Ultra High Frequency
UTIAS/SFL	University of Toronto Institute of Aerospace Studies/Spaceflight Laboratory
UV/IfA	University of Vienna/Institute of Astrophysics

1 Introduction

The BRITE mission was initiated in 2005, with the goal to build nanosatellites to fulfil highly scientific astronomical tasks. In 2006, the BRITE-Austria project was started at the Graz University of Technology (TUG). In cooperation with the Spaceflight Laboratory of the University of Toronto/Canada (UTIAS/SFL) and the Institute of Astrophysics of the University of Vienna (UV/IfA), the ambitious mission goal was to design, build, test, launch, and operate the first Austrian satellite BRITE-Austria/TUGSAT-1 [1].

The design and low cost of such nanosatellites, combined with the prospect of high scientific output, also attracted other countries. This led to the creation of the BRITE-Constellation, as national space programs in Austria, Canada, and Poland supported the construction of in total six nanosatellites, two per country, to pursue a common goal of investigating the brightness oscillations of massive, luminous stars by the use of differential photometry up to 100 days per campaign [2]. In February 2013, BRITE-Austria was launched from Sriharikota/India on-board a Polar Satellite Launch Vehicle (PSLV) next to its sister satellite UniBRITE. In the upcoming 1.5 years, the other four satellites of the constellation followed; however, only three (BRITE-LEM, BRITE-Heweliusz and BRITE-Toronto) made it to their final orbit (BRITE-Montreal was unfortunately not released from the rocket's upper stage).

2 The BRITE mission and spacecraft design

BRITE stands for BRIght Target Explorer, and its scientific objective is the observation of brightness variations of massive, luminous stars, with a visual magnitude up to 3.5. Such observations cannot be performed from the ground due to atmospheric turbulences. A custom-made 5-lens-telescope with a field of view of 24 degrees and a Charge Coupled Device (CCD) as a detector is used on-board the spacecraft to fulfil the scientific objective [3].

All BRITE satellites share the same design and are based on the Generic Nanosatellite Bus (GNB) developed by UTIAS/SFL. The only difference between the satellites is the filter used in front of the scientific telescope. While three satellites (including BRITE-Austria) are equipped with a filter sensitive in the blue spectrum (390–460 nm), the other three use a filter sensitive in the red spectrum (550–700 nm). The parallel observation of a specific field in the blue and red spectrum provides new insights in asteroseismology (Fig. 1).

The BRITE satellite has a cubic shape with an edge length of 20 cm and a total mass of 6.8 kg. It is mainly made of two aluminium trays hosting the subsystems and completed by six faces with body-mounted solar cells for power generation. For power storage, the spacecraft is equipped with two batteries in cold-re-

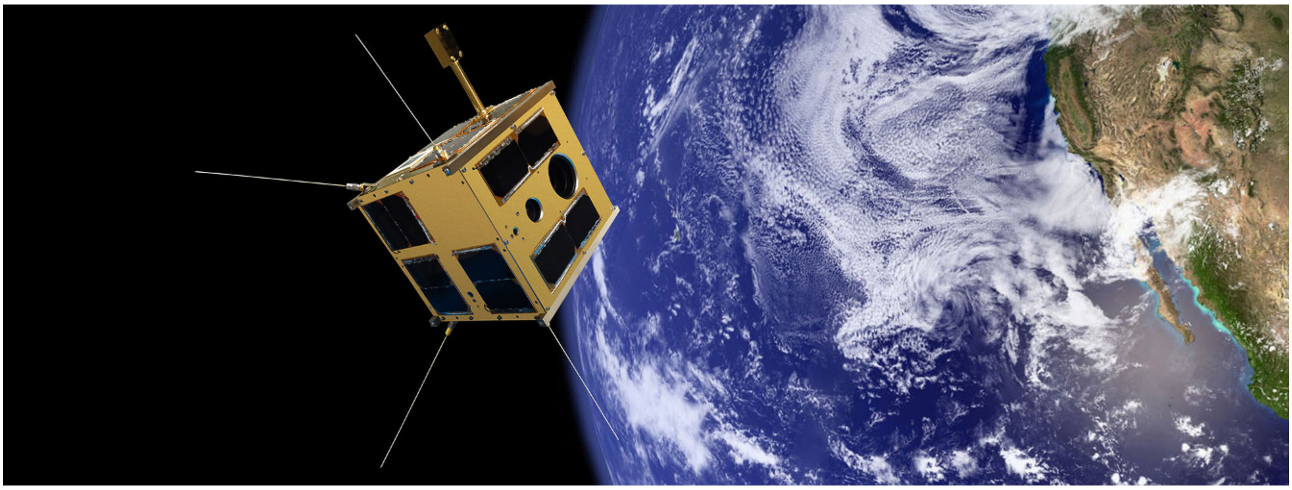

Fig. 1 The first Austrian nanosatellite BRITE-Austria/TUGSAT-1 is already in its ninth year in orbit (Artist's impression, image courtesy: TU Graz)

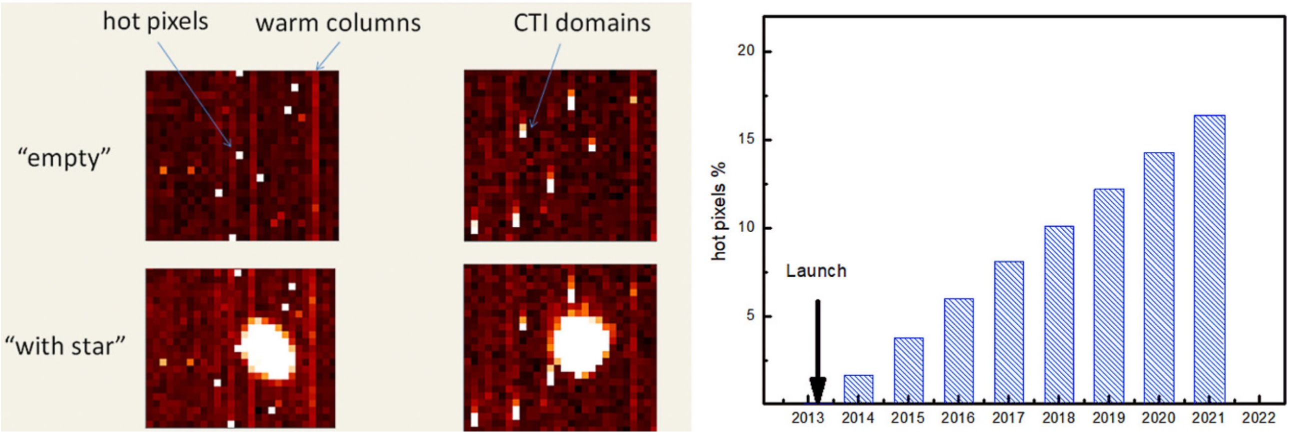

Fig. 2 Due to the radiation, various pixel effects are present on the CCD and impact the quality of the scientific data

dundancy. Three on-board computers are used for data handling, one dedicated for housekeeping, one for attitude determination and control (ADCS), and one for processing the scientific exposures. The communication system consists of an ultra-high frequency (UHF) receiver unit (4 monopole rod antennas) and an S-band transmitter (2 patch antennas placed on opposing faces).

Astronomical observations are very challenging and state high demands on the ADCS. In the case of BRITE, the satellites are equipped with a suite of sensors and actuators to be able to meet the stability requirement of 90 arcseconds random mean square (RMS) during observations. The sensors suite consists of a magnetometer (to measure the Earth's magnetic field), six sun sensors on each of the satellite's faces (to detect the incidence angle of the Sun), and a star-tracker, which is aligned with the telescope and provides the exact coordinates of the star field currently in view. For attitude control, three magnetorquers (for coarse pointing and desaturation of the wheels) as well as three reaction wheels (for fine pointing) are used.

3 Technical challenges and performance evaluation

BRITE-Austria is already in its ninth year in a low earth, sun-synchronous orbit at 780 km altitude. Like any other spacecraft in orbit, BRITE-Austria is subject to a harsh environment; especially the radiation is the main reason for hardware degradation. During its daily passage through the South Atlantic Anomaly (SAA), the spacecraft is exposed to a bombardment of high energetic electrons and protons due to the low magnetic shielding of the Earth in that area. Although the radiation affects all subsystems on-board, some key components are more sensitive to the radiation impact and degrade faster, leading to a decrease in quality and performance:

- *Solar cells*, due to the radiation, the generation capability decreases, leading to a lower output power
- *Light sensitive detectors*, like the CCD or photodiodes/sensors: the dark current, as well as the read noise, is increased, leading to pixel/area defects

On BRITE-Austria, the effects on the CCD were already seen during the first months after launch. Pixels and even entire columns showed elevated dark/thermal signals (so-called hot pixels and warm columns). In addition, vertical trails appeared in specific regions and revealed Charge Transfer Inefficiency (CTI) domains (Fig. 2).

Once detected, concepts were immediately developed to remove the signals caused by radiation damage. Next to avoiding observations during the SAA, the warm columns were compensated by calculating the median signal value of a column and subtracting these for each column in the raster of interest. The charge transfer time from pixel to pixel was reduced to diminish the CTI effect [4]. Regarding the hot pixels, an operational method, the so-called chopping mode, was introduced. Between two consecutive exposures, a small change in attitude is performed to "place" the star on a different area on the CCD, allowing the subtraction of both images to retrieve the signal values of the star of interest only.

Next to the radiation issue, the high duty cycles in orbit took a toll on the subsystems. As there are no refurbishment or replacement opportunities, the degradation of the subsystems over time led to lower efficiency and, hence, affected the overall mission performance. The elements, which suffered the most, are:

- the *batteries*: due to rapid temperature variations and the high number of recharge cycles, the storage efficiency degraded over the years
- the *attitude control system*: the quality of the bearings of the reaction wheels decreases, and hence the power demand increases

To give an example, a comparison of the battery behaviour of BRITE-Austria on a day in December 2013

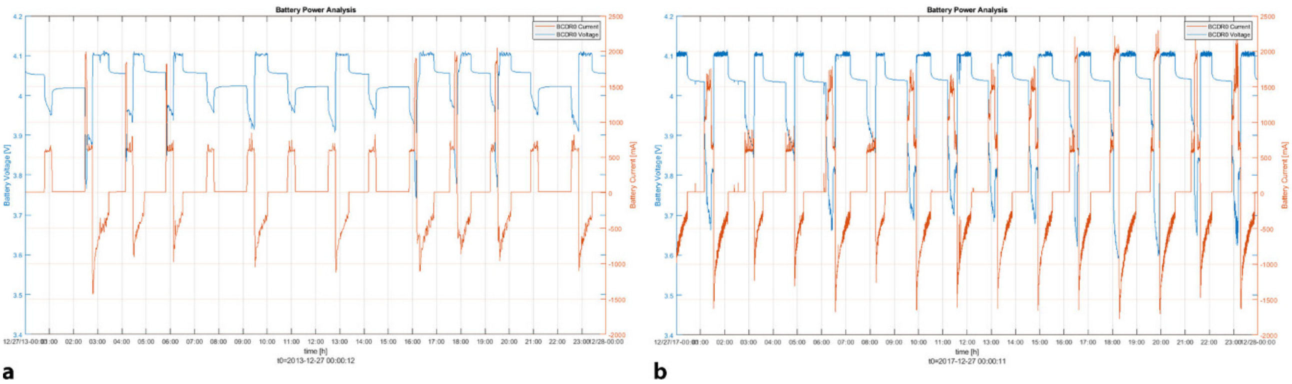

Fig. 3 The battery behaviour during eclipse from December 27th 2013 (**a**) and 2017 (**b**) is shown; the red line indicates the battery current, the blue line depicts the respective battery voltage

(left) versus 2017 (right) is shown in Fig. 3. When comparing the two plots, it can clearly be seen that the battery loses its capacity (red line) faster during eclipse, and, in addition, its regeneration time is significantly longer. To overcome the effect of degradation of the battery, several mitigation strategies were introduced. In the early years of operation, the scientific operations during eclipse were shortened or even avoided to minimize the capacity drop. Since winter 2020, however, the secondary battery, which is used as an emergency backup battery on-board the spacecraft, is used during operations, as the degradation of the primary battery was too severe to ensure even nominal operations without performing scientific observations.

These and other effects have been monitored and investigated thoroughly during the last years. Several functional and operational optimizations were already introduced, and mitigation strategies were elaborated to ensure the continuous scientific quality of the provided observations.

4 The BRITE-Constellation and its scientific highlights

Despite the challenges BRITE-Austria and its sister satellites faced over their lifetime, significant and outstanding results were produced. The most comprehensive summary of what the BRITE-Constellation achieved scientifically can be found in Weiss et al. [6]. Some highlights include:

- *Pulsations*: One key aspect of the BRITE observing program was to study various types of pulsating stars such as Be, β Ceph, γ Dor and δ Scuti stars. By measuring a multitude of pulsation frequencies, the internal structure of the star, its age, mass and composition can be modelled via asteroseismology methods. This resulted in more than 20 peer-reviewed papers on that matter.
- *Stars and exoplanets*: Even though not in the core science program, BRITE collected photometry from the very bright young star β Pictoris with at least one confirmed planet at an early stage of formation. This led to new insights into the physical nature of that system [7].
- *The "heartbeat" phenomenon:* BRITE-Constellation was first to detect tidal distortions via the presence of a "heartbeat" signal at periastron of ι Orionis [8], and it is the most massive heartbeat system known to date.
- *Nova Carinae 2018*: The BRITE satellites luckily observed a complete development of a Nova in the Carina field, including the original outbreak, the brightness maximum, as well as the final phases in unprecedented temporal resolution and precision [9].

Overall information about the BRITE-Constellation scientific program, data collection, and publications can be found at the WIKI site: http://brite-wiki.astro.uni.wroc.pl/bwiki/doku.php?id=lstars.

5 Conclusion

The BRITE-Austria mission showed impressively that, with the help of small and inexpensive nanosatellites, even highly demanding scientific tasks can be performed. Although BRITE-Austria is in its ninth year in orbit, and probably one of the longest operative nanosatellites in space, it still performs continuous scientific operations at a high-quality standard.

To highlight not only the scientific achievements, BRITE-Austria has, in addition, exceeded many mission requirements; a comparison of some system re-

Table 1 A comparison of some mission requirements and the actual achievements: a direct connection to the mission success can be drawn [5]

	Requirements	Achievements
Pointing accuracy	90 arcsec RMS	70 arcsec RMS
Instrument sensitivity (= #targets)	Visual magnitude: +3.5	Visual magnitude: +4.5
Science data return	2 MB/day	15 MB/day (+1.3 MB telemetry)
Downlink data rate	32 kbit/s (BPSK)	256 kbit/s (QPSK)
Mission lifetime	2 years	8 years and on-going

quirements with the actual achievements is given in Table 1.

By the end of September 2021, BRITE-Austria/TUGSAT-1 will have

- completed 45,000 orbits around Earth
- travelled about 2000 million kilometres (which is about 13.5 times the distance between Earth and Sun)
- observed more than 245 stars in 32 campaigns and has produced more than 141 GB of raw science data
- the longest time series of a star field, observing the Orion field for already 8 times

Together with its sister satellites, BRITE-Constellation has observed 704 stars and generated more than one million data points. Based on BRITE data, many outstanding results have fostered the understanding of physical processes in a variety of different types of stars. In addition, a rare Nova eruption in the Carina field has been monitored 2018 by the BRITE satellites with unprecedented time coverage and quality. The analysis of the provided scientific data has led to an impressive scientific statistic: to date, more than 219 publications, including 96 refereed journal articles and four international science conferences and their proceedings, were issued.

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Rainer Kuschnig, received a PhD degree in Astrophysics from the University of Vienna, Austria. He acts as the BRITE Mission Scientist since 2007 right after the conceptual phase was completed. Together with the BRITE Executive Science Team his role was to guide the technical development phase. After launch in February 2013, and still to date he manages the scientific aspects of the mission such as observation planning, instrument setup generation, data quality assessment, reduction and distribution, currently at the Institute for Physics at the University of Graz.