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TUGSAT-1 / BRITE-AUSTRIA- THE FIRST AUSTRIAN NANOSATELLITE

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ABSTRACT

A nanosatellite to investigate the brightness oscillations of massive luminous stars by differential photometry is currently developed by a Canadian/Austrian team within the BRITE (Bright Target Explorer) project. The first Austrian satellite funded by the Austrian Space Program, called TUGSAT-1/BRITE-AUSTRIA, builds upon the technologies of the Canadian CanX-2 nanosatellite and experience from the highly successful MOST mission. The satellite makes use of recent advances in miniaturized attitude determination and control systems. Precision three-axis stabilization by small reaction wheels and a star tracker provides the necessary accuracy for the photometer telescope to the arcminute level. This will provide to the astronomers photometric data of the most massive stars with unprecedented precision which cannot be obtained from the ground due to limitations imposed by the terrestrial atmosphere. The paper describes the spacecraft characteristics and the ground infrastructure being established in support of the BRITE mission which will consist of a constellation of up to four nearly identical satellites allowing to carry out long-term observation of stars (magnitude +3.5) not only with respect to brightness variations, but also in different spectrum ranges.

Keywords: Bright Target Explorer, nanosatellite, differential photometry

1. INTRODUCTION

In the past, two attempts have been made to develop an Austrian small satellite project. In 1991, within the framework of the AUSTROMIR project (flight of the first Austrian cosmonaut to the space station MIR), it was investigated whether a small subsatellite could be developed and ejected from the MIR space station. Due to the extremely tight time schedule (14 scientific experiments had to be developed), the project could not be realised.

In the 1990ies a second opportunity emerged in the framework of a cooperation between Switzerland and Austria. ALPSAT was a very challenging project with the aim was to develop a scientific satellite positioned at the L1 Lagrange point. This project could finally not be realised due to cost reasons.

In 2004/05 the Austrian Aeronautics and Space Agency (ALR) indicated that there would be possibilities for a small satellite project. Graz University of Technology (TU Graz) as prime contractor, University of Vienna and Technical University Vienna submitted a proposal for the third call of the Austrian Space Program. In February 2006 ALR awarded the contract.
Close cooperation had already been established with the University of Toronto, Space Flight

Laboratory (SFL), providing significant expertise in building and operating of small satellites. The BRITE project is based on the successful Canadian CanX and MOST satellites. TU Graz, University of Vienna and TU Vienna cooperate in this project together with SFL to design, build and test the first Austrian satellite, called TUGSAT-1 with the mission name BRITE-AUSTRIA (Bright Target Explorer).

The duration of the development project is approximately 2 years. Launch is planned for 2008. The project will rely to a significant extent on students at the universities involved. This will enable students to get hands-on experience in the design, manufacturing, testing and operations of a spacecraft as well as management of space projects. The students will be supported by space experts in Graz, Vienna and Toronto. The project management and key developments will by carried out by faculty and staff of the universities to ensure timeliness and sustainability after the project for future missions. It is the clear aim to develop a nanonsatellite platform which may be used for a variety of technological and science missions in the future.

2. THE BRITE-AUSTRIA MISSION

The satellite is in the nanosatellite class with a mass of about 5 kg. The scientific purpose is an astronomy experiment (star camera) flown on a three-axis stabilised nanosatellite. The goal is to observe the variations of the brightness of massive stars (magnitude: +3.5) with high accuracy. These massive luminous stars are among the least understood, because of their rapid rotation, strong radiation pressure and stellar wind. Using differential photometry brightness oscillations can be investigated. Astronomers expect to develop better models based on the long-term observations.

The nanosatellite utilizes recent improvements in 3-axis stability control to the level of 1 arc-minute, opening up for astronomy and future high-precision space missions a new domain of miniature, low-cost spacecraft.

The satellite will survey the sky, measuring the brightness and temperature variations of the brightest stars on timescales ranging from hours to months. The photometric data of luminous stars will provide time series with unprecedented precision which cannot be obtained from the ground due to limitations imposed by the terrestrial atmosphere. BRITE-Austria will investigate the role stellar winds play in setting up future stellar life cycles, and reveal pulsations that will allow astronomers to probe luminous star histories and ages through astroseismology.

TUGSAT-1/BRITE-Austria will carry a telescope (with no moving parts, only one optical bandpass filter) and a detector with a large field of view (~25 degrees across) that can monitor multiple target stars, so that differential photometry can be obtained both in brightness and color with precision better than 0.1% for a single observation. Only sub-rasters of the entire image will be downloaded for analysis.

Another nearly identical satellite (UniBRITE) is funded within the 3rd Investment Program of the University of Vienna. It is built by the Space Flight Laboratory of University of Toronto. The main difference between both satellites is the spectral range used for the optical telescopes which is defined by filters. A blue filter, ranging from about 380 nm to 550 nm, and a red filter, ranging from about 550 nm to 850 nm, will be implemented in respectively one of the BRITEs. This arrangement generates a pair of nanosatellites without any moving part, but which allow obtaining simultaneously information on temperature and geometric variations of pulsating luminous stars. The choice of these filter settings is hence dictated by astrophysical arguments, derived from astro-seismological needs.

The basic idea is to have this pair of BRITEs orbiting in similar orbits, so that both nanosatellites can observe the same star field closely at the same time, but in different colors. The only shortcoming of such a setup is the expected gap in the light curves due to occultation of the target field by the earth. The obvious remedy of this problem is to launch a second pair of BRITEs identical to the first pair, funded already by Austria, but launched in orbits which allow observing the target field in two colors at a time when the field is invisible for the other pair. Such a group of two pairs of nanosatellites will solve observational problems inherent to astroseismology of bright stars. The configuration mentioned is called BRITE-Constellation [2].

3. THE SATELLITE

The satellite consists of a cubic aluminum structure with a size of 20 x 20 x 20 cm. Fig.1 shows a mock-up of the satellite. Power is generated by multiple body-mounted strings of triple- junction solar cells. The available power is about 6 W on average. Energy is stored in a 5.3 Ah lithium-ion battery. The power subsystem has been designed for direct energy transfer.

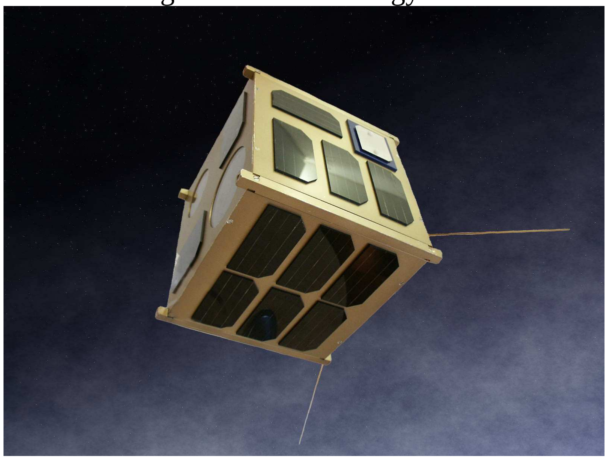

Fig.1: Mock-up of the Nanosatellite

Since the science instrument is a photometer with stringent requirements for pointing accuracy, a sophisticated attitude determination and control system (ADCS) for three-axis stabilization is necessary. This ADCS system is designed and built by SFL and Dynacon Inc. in Canada, with Dynacon providing reaction wheel and star tracker technology. It comprises coarse and fine sun sensors and a magnetometer for initial attitude determination with an accuracy of +/- 2 degrees. The target mission requirement for attitude accuracy is 1.5 arcminutes. To achieve this, a small star tracker camera is incorporated in the ADCS. Further key components of the ADCS system are miniaturized reaction wheels providing the required attitude stability. Three magnetic coils (magnetotorquers) in all axis are used for momentum damping.

Passive thermal control techniques are utilized to minimize the complexity and cost of the spacecraft. It is necessary to keep the photometer below a temperature of 20° C. Initial analyses show that this target can be achieved with passive methods.

The photometer consists of special optics (developed by Ceravolo Optics Ltd. in Canada) and a CMOS detector with 4560 x 3048 pixels. CMOS was selected instead of CCD because of lower power consumption. Details of this science instrument can be found in [2].

Three computers using an ARM-7 processor are on board of the satellite:

The main on-board computer (Main OBC) enables communications with the ground, as well as telemetry collection and mass-data storage. 2 MB of memory with EDAC (error detection and correction) are available for storing program variables and data. In addition, 256 MB of flash memory for long-term storage of measurement data are forseen.

The Attitude Determination and Control System computer (ADCS) controls the sun sensors, magnetometer, 3-axis magnetorquers and three reaction wheels to provide arc-minute-level pointing. The third computer is used for controlling the photometer. All computers communicate via serial links using a simple reliable protocol.

Telemetry

Data from the satellite are transmitted in S-Band. Binary phase shift keying (BPSK) has been chosen for the modulation format. Nominally a data downlink rate of 32 kbit/s will be used, although higher bit rates are possible depending on the figure of merit of the ground stations. Modulation is carried out at the carrier frequency which is generated by two PLL synthesizers in a mixing process to minimize EMC. A Field Programmable Array (FPGA) is used to format

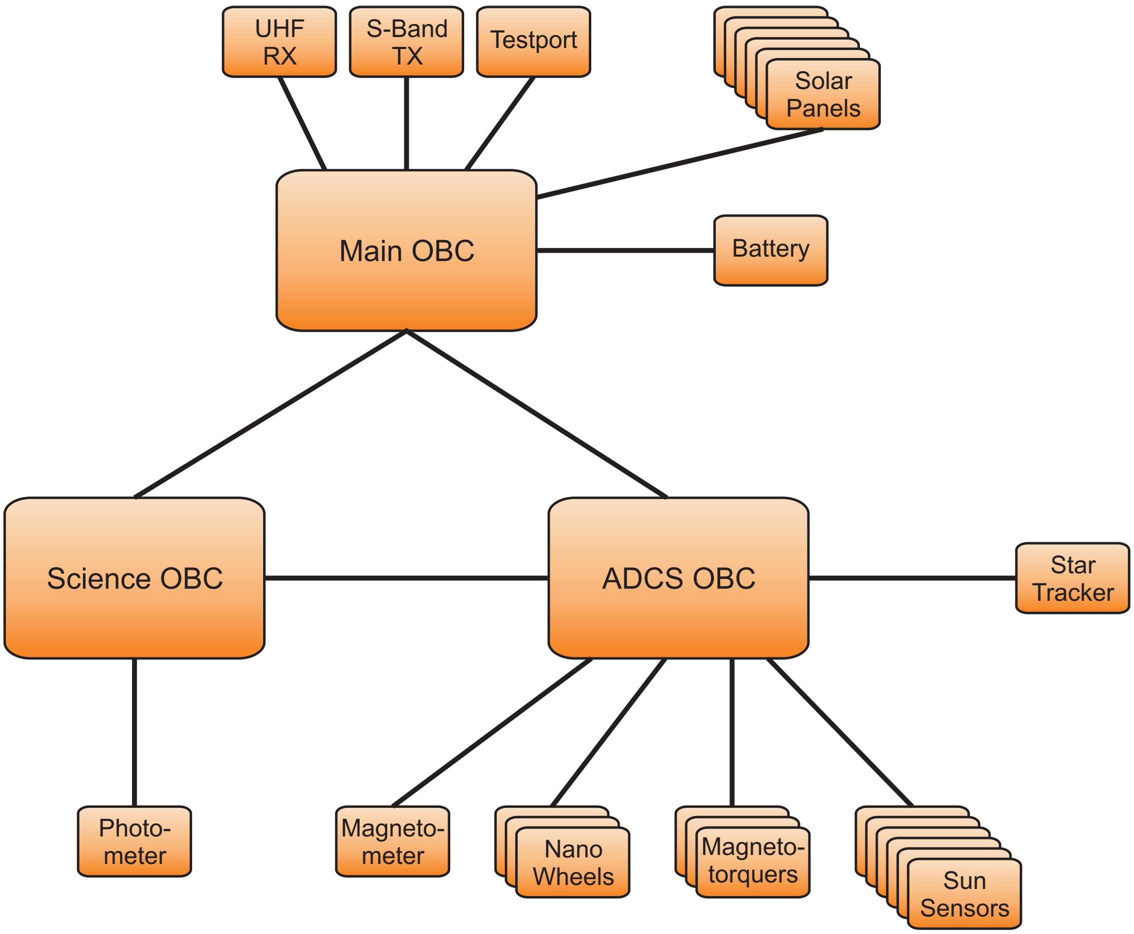

Fig.2: Block Diagram of the Nanosatellite

data, carry out the necessary scrambling, convolutional encoding, pulse shaping and constellation mapping.

The uplink from the ground station to the spacecraft operates in the UHF band. Gaussian Minimum Shift Keying (GMSK) is used for the modulation scheme. The data rate is nominally 4 kbit/s.

Two patch antennas are mounted on opposite sides of the satellite which are fed in phase with equal magnitude signals by the output stage of the power amplifier. The chosen configuration provides a near omnidirectional pattern. The polarisation is circular.

Four pre-deployed rod antennas are provided for the UHF radio.

The minimum telemetry transfer for science data is 180 kbyte per day.

The main subsystems of the satellite can be seen in Fig.2.

4. GROUND INFRASTRUCTURE IN AUSTRIA

For the mission period following the launch at least three ground stations will be in operations: Toronto, Graz and Vienna.
Continuous observation of each satellite pass is required for the operation of the nanosatellites.

The housekeeping data of the satellites have to be monitored to assess the status of the various spacecraft. Each ground station will be connected to the BRITE Constellation Management. Commands to the satellites are generated by this management system. The stations are designed to operate automatically. The BRITE Constellation Management however needs manual interaction when adapting new mission profiles.

For TUGSAT-1/BRITE-Austria and the other BRITE satellites a distributed ground station approach is planned. In case of failure at the master ground station the BRITE Constellation Management can pass the role of the master to any other ground station. There are already three ground stations operated for the Canadian MOST satellite which will be adapted as well for the BRITE Constellation.

The BRITE Constellation Management will have the following functions:

* Collect target fields from long-term planning Team

* Verify target feasibility

* Prepare commmands for observation campaign

* Manage uplink commands over the distributed Scenario

* Provide transparent management and data Interface

* Collect downlink data

* Forward verified data to science preprocessing

The current design allows the ground station network to be operated with any number of satellites and any number of ground stations. One constraint for the BRITE satellites is that there will be only one set of frequencies for all the satellites.

4.1 Graz Ground Station

In Graz two options exist for the establishment of the ground station infrastructure [3]. TU Graz has developed for ESA some years ago a versatile satellite ground station with a 2.4 m precision tracking antenna. The S-Band front-end (LNA/downconverter and SSPA) can be easily integrated in the fairly large front-feed box of the antenna. Modem, terminal node controller (TNC) and station computers are located in the shelter which is fully air-conditioned (Fig. 3).

This station was originally designed for Ka-Band experiments and could be converted for operations at S-Band. The shelter also contains auxiliary and test equipment such as spectrum analyser, bit error test set, frequency counter and RF power meter. All devices are controlled by the ground station PC. A software developed by TU Graz allows to fully monitor and control the station from a remote computer and facilitates automatic operations. Program tracking is utilised. Based on the orbital parameters the antenna is steered by the tracking software. Regular update of the orbital parameters is mandatory.

Fig.3: Graz Ground Station

A second option which is currently under investigation is the conversion of a 3.7 m antenna. The parabolic dish is mounted on a precision pedestal. This system was originally used as a C-band weather radar. A major advantage is the location of the antenna. It is installed on top of an observation tower from where there is an unobstructed 360° view of the sky from 0° elevation upwards. The existing C-band feed needs to be replaced by an S-band feed. The low-noise amplifier and downconverter to 70 MHz are small enough to be installed in the focal point of the antenna. Tests of the antenna controller have been made recently and showed good performance. The program track software has been designed such that it can be easily used with the antenna controllers of both the 2.4 and 3.7 m dishes.

An additional VHF/UHF ground station system with cross-Yagi antennas is available in Graz. This one has been built for the AUSTROMIR mission and will be used for the UHF uplink.

4.2 Vienna Ground Station

This ground station was designed and built by TU Vienna. It is installed at the Institute for Astronomy of the University of Vienna. It is used to issue commands in the S-band for operating the Canadian MOST satellite payload, the attitude control subsystem, and other housekeeping functions, and to download the observed data. The station was set up using high-end semi-professional equipment. It is operating autonomously with the data download from the satellite being controlled via Internet.

The ground station consists of two directional antennas (a 3m dish and a group of four long yagi antennas) on an azimuth-elevation mount and is shown in Fig.4.

This ground station is presently being adapted to support communication with BRITE-Austria/TUGSAT-1. A parabolic antenna which receives two orthogonally polarized waves picks up the signal from the satellite. The weak signal is filtered by S-Band filters, amplified by low noise amplifiers (LNA) and converted to the intermediate frequency by downconverters with a common local oscillator. To increase the selectivity, filters are introduced between LNAs and downconverters. The two-stage amplification by low noise amplifiers and low noise converters is necessary to guarantee that the signal input to the demodulator will be sufficiently strong. A polarization recovery unit optimally combines the output of the two downconverters. The demodulator recovers the data signal and feeds the terminal node controller (TNC) handling the communications protocol. The data collected from the satellite are stored on the hard disk of a personal computer. The Vienna ground station is working fully autonomously since January 2004.

For the operation of TUGSAT-1 the downlink of the Vienna ground station can be used without modifications. The uplink of the station is presently being adapted to support the operation of TUGSAT-1. Additionally a new communication control software is necessary which supports the simultaneous operation of MOST and the BRITE satellites.
Since the uplink of TUGSAT-1 is in a different frequency band than MOST an additional uplink chain is necessary. The chain consists of transmitter, power amplifier and an uplink antenna. Also a switch is needed which connects the desired uplink to the terminal node controller. Further a redesign of the uplink control sequence is necessary.

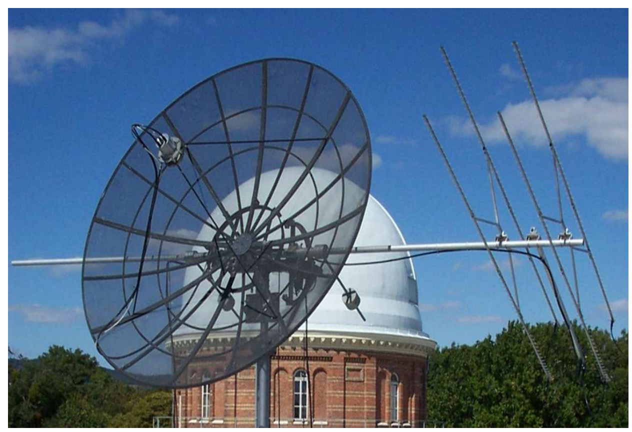

Fig.4: Ground Station in Vienna

5. DATA PROCESSING

The establishment of a science data centre is a very important task prior to the operational phase (after launch). Preparations are already under way [4].

The science data pre-processing mainly deals with data conversion, data storage and data assessment.
The raw error-free data coming from the BRITE Constellation Management has to be assessed for

proper performance of the instrument. This task is assisted by a series of tools:

BRITE-Job: data conversion to the FITS (Flexible Image Transport System) format, the most commonly used file format in astronomy, maintained by Goddard Space Flight Centre takes place. The raw FITS files will contain each a set of subrasters of the CMOS frame (windows) and each FITS file corresponds to a certain observing time of a target field.

BRITE-Preview provides quick-look analysis of data for quality assessment to identify potential problems of the instrument at the level of individual frames. The raw photometric data of the target stars have to be determined by point spread function (PSF) fitting and aperture photometry.

BRITE-History is used for quick-look analysis of the evolution of the target star photometry over time (Fourier transform and related techniques) as well as monitoring of characteristic parameters like count rates, temperature, subsatellite coordinates, power consumption, magnetic field, etc.

BRITE-Ok gives feedback to the BRITE Constellation Management if the mission profiles need corrections. The goal is that measures to improve the instrument's performance will then be applied within the next orbit.

6. SUMMARY

Within the BRITE (Bright Target Explorer) project the first Austrian satellite is realised in a cooperation between the Space Flight Laboratory (SFL) of University of Toronto, TU Graz, University of Vienna and TU Vienna. The nanosatellite platform is based on a design by SFL. It carries a small telescope with CMOS detector to investigate the brightness variations of massive luminous stars by differential photometry. A highly innovative aspect is the provision of a miniaturized attitude control system with nano reaction wheels and a star tracker. This system will allow precise pointing of the telescope with an accuracy down to 1 arcminute.

The ground infrastructure in Austria (satellite ground stations in Graz and Vienna) and the science data processing centre are prepared for the mission. SFL will use its existing ground infrastructure.

Another goal for the project is to provide the environment needed to operate an ensemble of nearly identical nanosatellites called BRITE Constellation, ideally grouped in pairs. This arrangement allows for dual-broadband, high precision, many months' long photometric time-series from space and with a maximum duty cycle. Such data sets cannot be obtained from ground, but are indispensable for astroseismology of luminous stars.

An important aspect of the project is the educational one. Highly motivated students and post-docs at the cooperating universities are involved in simulations, system studies and analyses of the various subsystems of the satellite. Several master theses on the topics of nanosatellites have been already carried out, diploma theses and projects in ground station technology are under way.

From the Austrian perspective, it is the clear goal to build up the expertise for developing a low-cost satellite platform for future scientific and technological missions.

7.ACKNOWLEDGEMENTS

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