Conference summary

S. Rucinski[1] and W. W. Weiss[2]

1. Department of Astronomy and Astrophysics, University of Toronto
50 St. George Street, Toronto, Ontario, M5S 3H4, Canada
2. Department of Astrophysics, University of Vienna
Türkenschanzstr. 17, 1180 Vienna, Austria

It is highly appropriate that the Second BRITE Conference has taken place three years after their launches which led to creation of the BRITE Constellation and 11 years after the first of the BRITEs were funded by Austria. In this time, particularly in the two years since the launches of the Polish and Canadian satellites, the Constellation reached its full maturity passing the point of over two million individual observations from the five operating satellites. With the high level of performance of its satellites, the BRITE Constellation currently enjoys a peak of its efficiency and scientific productivity which is fully expected to last for the next several years.

1 The current state of the Constellation

It is a great pleasure for both of us to summarize the Second Conference of the BRITE Constellation which is now concluding after four very useful and productive days. Both of us have been involved in the project from its beginning (Weiss et al., 2014) or even in its very infancy[1]. Thus, for us, it is unbelievably nice to see the project to be in its scientifically most productive stage: the data are flowing as required and the combined effort of very many people is now paying great scientific profit. These are the best years in the history of the BRITE Constellation.

The BRITE satellites are very likely the most complex of many nanosatellites so far launched. When the BRITE satellites were conceived, nanosatellites were mostly "technology demonstrators", mostly used for student training. The BRITE satellite concept was one of the forefront designs bypassing in its complexity the majority of its contemporaries. It is thanks to the vision of the Space Flight Laboratory of UTIAS in Toronto, particularly to Dr. Robert Zee, that our satellites determine the high-end level of performance and reliability among nanosatellite projects.

Many launches of nanosatellites take place nowadays: we learned during the conference that on average one new nanosatellite is launched every three days and more than 480 are currently in orbit. But the overall success rate is not that impressive (about 50%) so that our very sad and strongly felt loss of one satellite "Montréal" still implies a relatively high rate of technological success of 5/6 or 83% and fully confirms the excellent design and workmanship of all parties of our teams from three nations. This mishap, however, was due to the malfunction of the launcher, not to a fault of our engineers. We can be proud of the **technological and managerial achievements**, particularly in Austria and Poland where no experience with launches of research satellites existed prior to the BRITE Project.

[1]For notes on pre-historical stages of the project, extending as far back as 2002, see: http://www.astro.utoronto.ca/∼rucinski/BRITE/Early_history_of_BRITE.pdf

We have now reached the next stage of the project and are stepping beyond the stage of technology demonstration, which has been fully achieved. Now, we are migrating to the stage that the scientists want to achieve: a fully functional instrument performing top-notch science within an international collaboration. The invested funds can now lead to solid **scientific achievements**. We are happy to state at this very moment at the end of the Second BRITE Constellation Conference that this is exactly what is currently happening.

The best argument to support the sentiments expressed above is to compare the current situation with the general mood and feelings after the First BRITE Conference which took place in Gdańsk in September 2015. At that time, after the first months of the joint operation of all satellites, we were confronted with many problems, annoying rather than serious, but still very concerning. Such problems always surface in practically all space missions (there are too many quite famous ones to mention here, so we do not attempt to list them again) and they are very hard to avoid even with the best planning and management. An important point should be strongly stressed: the "selling point" for nanosatellites is their low budget. Consequently, this does not allow for extensive ground-based tests which are routinely done for e.g. NASA and ESA missions. Basically, the underlying nanosat philosophy is their "testing by flying".

In our case, the most serious technical problems have been related to the cosmic ray damage to detectors on board of the satellites at a rate higher than expected and to the entirely unexpected radio interference caused by unidentified radar operations over Central-Eastern Europe.

We learned during the conference that the solar cells do not show any signs of deterioration and that the on-board data-train does not produce any measurable nonlinearities. Loss of power is a death knell for any space mission while nonlinearities are known to occur in high-precision photometric systems, but are particularly hard to cure in space missions. We can sigh with relief: our satellites have several further years of reliable operations ahead and we are very happy about the quality of data produced by them.

We are obligated and committed to make the best use of these data by performing excellent research and educating highly qualified personnel!

2 Theory versus observations

It is a truism that modern astrophysics is an observation-driven science. The *Second BRITE Conference* certainly showed to us that there is an abundance of very interesting scientific problems requiring the unique data from BRITE Constellation. We could see ample indications that our theoreticians work on very many extremely interesting and timely topics which the BRITE Constellation may help to resolve observationally. There exists not only an abundance of ideas, but there are also many great expectations concerning BRITE Constellation, all this thanks to the uniqueness of the BRITE data. With observations sampled at a few times per minute and at the same time spanning continuously up to half a year, with the option to return the following year, the BRITE satellites give an unprecedented look at many time scales of variability of bright stars. And all of this is performed in blue and red colours! The wide range of timescales accessible to studies, extending from minutes to weeks and months, is an absolutely unique property of our Constellation.

A quick scan through theoretical problems presented at the conference leads us to a very wide range of theoretical subjects where the BRITE data are expected to be of relevance:

- Large discrepancies for global parameters between classical stellar models and observations, e.g., for mass, radius, relevance of magnetic fields and plausible field configurations.
- Discrepancies in predicted complex evolutionary effects and actually observed quantities, like mass-radius-age relations for stars in the field and in clusters, metallicity and its gradients.
- Advances in modelling of complex internal processes which seem to be contradicted by observations, e.g., internal rotation, mixing and overshooting, pulsation stability, frequency spectra which barely can be interpreted. In particular, massive stars pose serious problems in modelling.
- Interaction of a star with the environment, e.g. in binary systems, circumstellar disks and/or winds.

The strong theoretical context of BRITE Constellation is thus unquestionable as there is a great need for new data to constrain the large freedom in model parameters which the existent data is permitting. But, as everybody understands, the mission provides only precise time-domain photometry and this calls for complementary spectroscopic — or even better spectropolarimetric — investigations for the majority of our target stars. We note that, so far, there has not been an effort to launch a satellite enabling precise *spectro-photo-polarimetric* observations; the current technology already permits realisation of such a mission.

Interaction between BRITE observations and theory is an important subject because we should set proper expectation levels for future programs. It is true that theory needs observational data of the highest quality; for example we heard opinions that:

- "[theoretical] ... uncertainties [are] everywhere!!" (Georgy);
- "[there is] no lack of hypotheses — [but] lack of hard facts" (Rivinius);
- "[we have] ... lots of free parameters with sub-optimal modelling, hence observational checks are extremely important!" (Przybilla).

When the specifics of our mission are strictly followed then the BRITE contributions — even at this early stage of the mission — appear to be truly essential. During the conference we heard very encouraging statements which are also echoed in these proceedings:

- "Observations with BRITE-Constellation have established that at least two types of combination of discrete NRP modes can power mass-loss outbursts ... BRITE has enabled the most detailed description to date of these processes." (Baade et al.)
- "Furthermore we have shown the impact the BRITE-Constellation project has on our knowledge of massive stars. For the first time we are able to explore the asteroseismic effects of binarity in massive stars and in a system that was quite literally hidden in plain sight." (Pablo et al.)

- “ ... the prospects for detailed seismic studies of rapidly rotating B-type stars with B-C observations are promising.” (Cugier et al.)
- “BRITE photometry ... [provides] a new possibility of verifying the hypothesis of [pulsation] damping effects in close binaries ...” (Pigulski et al.)
- “This exciting new BRITE result is consistent with rotationally split dipole modes and indicates a non-rigid internal rotation profile of the star — a very rare insight into a hot star.” (Kallinger et al.)
- “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 .” (and even beyond..., Zwintz et al.)
- “These results illustrate the potential of BRITE-Constellation observations for γ Doradus stars” (Gössl et al.)

And this last quotation is a perfect summary:

- “While BRITE-constellation does not outshine these missions in any particular single property, in the combination of the observational properties it is the best possible compromise: it is more precise than SMEI, provides longer time bases than MOST, and its targets are much better known Be stars than those observed by Kepler or CoRoT will ever be. The latter is a key point.” (Rivinius et al.)

3 From raw data to science

Excellent research through the best use of the BRITE data is the performance goal of BRITE Constellation. It is not surprising therefore that a significant fraction of our conference was devoted to extracting the most useful data out from the hundreds of GBytes transmitted to ground from the satellites.

Early in the active life of the BRITE Constellation, a task force was formed, the Photometry Tiger Team (PHOTT). The Team is currently chaired by Bert Pablo and its main activities are summarized by Pablo et al. (2016), Pigulski et al. (2016), Popowicz (2016), and Popowicz et al. (2017). Several talks during this conference were devoted to this area and a very valuable half-day workshop on data management and data reduction was organized on Friday, right after the Conference.

Delivery of “ready to use” data to the BRITE community is in fact the second crucial element in the data flow chain from the satellites to science papers. As it was convincingly explained on the first day of the Conference by the BRITE Constellation manager, Rainer Kuschnig, it is a very challenging task to translate the observing program developed by the BRITE Executive Science Team (BEST) primarily on scientific grounds to commands which control the pointing and data acquisition details to be sent to the satellites, which each of them have their own characteristics and technical issues.

As we discussed in the previous section, a proper scientific interpretation of the BRITE data requires supplementary observations beyond precision photometry. Fortunately, a very good ground-based spectroscopic support for our program exists through the efforts of our Ground-Based Observing Team (GBOT), which presently is chaired by Konstanze Zwintz. With the provided spectroscopic support, BRITE observations gain an important “second leg” for proper theoretical analyses and interpretations.

4 Room for improvement?

We can only express the big sigh of relief that many problems that seemed to pile up during the first two years of BRITE Constellation operations have been satisfactorily resolved. Please remember that BRITE Constellation was built in collaboration of three countries with differences in culture and experience. Three different space agencies have been involved with their own funding, management rules and timelines. More than ten different institutions had to collaborate, with more than 40 scientists and engineers involved in Canada, several countries of Europe and in the United States. In particular the technical teams maintained excellent mutual contacts and openness in resolving inevitable hiccups in the development and operations.

The broader community of the BRITE Constellation currently includes 78 members of the BRITE International Advisory Science Team (BIAST) which is the group of scientists directly interested in BRITE data. Information about BRITE Constellation is distributed with a Newsletter typically every second week.

We should remember the characteristic of nanosatellites and what is their basic philosophy: they have been called into existence to be inexpensive, partly through avoidance of space qualification tests, giving them a flavour of experimental — if not slightly risky — undertakings. As a result, some inevitable indirect costs had to be paid:

- CCD detectors proved to be unexpectedly radiation sensitive when not cooled, leading to speedy accumulation of warm and hot pixels as well as charge transfer imperfections,
- Lack of any thermal regulation of the detectors, even of a passive one, prevented mitigation of these problems.
- Since the BRITE Constellation is only a secondary frequency user of the chosen uplink frequency, passes over Europe are subject to severe interferences from a strong ground-based emitter somewhere in Europe. Allocation of a dedicated frequency would have avoided these transmission difficulties.

In the past eleven months these problems have been successfully circumvented. Thanks to ingenious data processing, the effective CCD deterioration rate has dropped in terms of unusable pixels from the level of 6% per year to a manageable 0.2% per year. In the same time, newly developed techniques of data transmission have substantially limited the data losses due to the parasitic radio interference.

Let us return to the current BRITE Constellation and to the issues of immediate relevance: successful realization of the Constellation could have happened in such a short time and with such a success only thanks to a deep commitment and consensus of the international partners to optimize the final outcome of the “big science”. The mission of our five nanosatellites is currently in excellent shape as a single, well maintained instrument. It is no longer a technology demonstrator — the technology is serving to do frontline research! But do any remaining problems exist which can be fixed right now? Obviously, they do. Some can be resolved by our teams, but some are external.

Let’s start with the less hard and difficult: the data processing pipeline developed by the Photometry Team works very well, but it is a single pipeline and thus is — as any such product — subject to deficiencies and also improvements. It would be profitable to have a parallel pipeline for the crucial first stages of data processing to augment and verify the current pipeline.

The main and darkest cloud over our horizon is the matter of funding of continuing operations of the BRITE satellites in the three countries. As perceived by scientists, funding seems to be arranged for short time spans and with considerable reluctance. We see that this is a common problem and that **funding for science is much harder to achieve than funding for technology demonstration**. The three national teams constantly monitor their relative positions in this respect and for each team the best moments come when we get news of continuing support from any of our partners. The uncertainties with the funding lead to a lack of assurance for the smooth operation over the critical current period when the whole Constellation works at its peak capacity. These feelings are not imaginary or nebulously general: a really dark era of BRITE Constellation took place relatively recently, during the five months of no funding for the BRITE Constellation Manager position. This happened because of administrative time shifts in the funding agency proposal submission deadlines, coupled with approval and money transfer delays. Without the hard and dedicated work of the Manager (RK), who continued working even without employment, operations of BRITE Constellation would have had to be put on hold. Such a situation should never occur again.

5 The future

For us, the immediate future is to obtain as much data as possible and to publish as much as possible during the next years when the Constellation works so well. This will occupy the minds of most of us. But this should not prevent us from attempting to build up on the BRITE success. The undersigned are extremely happy to see new concepts for BRITE-size satellites being developed by members of our team.

The drivers for possibly more ambitious projects come from two directions: On one hand **technological progress** continues and can lead to elegant designs even for such instrumentally difficult areas as availability of UV detectors or efficiency of dispersing elements for spectroscopic applications. The current Constellation could also grow by “acquiring” more BRITEs, perhaps funded and built by other international partners, but utilizing the technological experience of the currently flying satellites. For example, the currently possible downlink rates of up to tens of MB/day could entirely change the data flow design of the mission. An obvious direction for crucial **research progress** is to build BRITE-class satellites working in the UV spectral band. Duplication of the BRITE success in this spectral region would be one of the greatest achievements in contemporary stellar astrophysics.

The current BRITE Constellation can be considered as an important stepping stone for further most profitable, international research endeavours. The invested funds act as a seed to profit development of entirely new directions for science in the three countries. The BRITE Constellation is a great achievement and we can all be proud of it.

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