When BRITE was a solely Canadian project: The distant prehistory...

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The Conference: "BRITE Side of Stars", Vienna, August 20-23, 2024
Session I: "The BRITE Story"

Motto: *BRITE is a child of MOST, and MOST is a child of an idea...*

The prehistory of MOST

I will discuss the BRITE project, specifically focusing on its very early stages when it was conceived as a single Canadian nano-satellite - several years before it evolved into a constellation. The satellite had different names at that time: CanX-3, BSP, and finally BRITE. To delve into those early stages, I must rewind over a quarter of a century, back to the inception of the MOST satellite project.

The concept of MOST originated in 1996 through a series of discussions between Kieran Carroll, a space-science engineering expert, and myself, an astronomer. The idea gradually took shape during our weekly meetings, with one of us delving into the observational requirements of stellar astrophysics, while the other absorbing the intricacies of artificial satellites: their orbits, launches, stabilization systems, natural constraints, and communications.

For a comprehensive understanding, I must take you back over half a century, to the mid-1950s. This was when my fledgling ideas about a small telescope on a small satellite first emerged. It coincided with my intense involvement in amateur astronomy during high school. More precisely, it was in 1957 that we learned the unexpected news about Sputnik-1. This ignited the initial sparks of the idea for a small telescope in orbit.

As time passed, I transitioned into a professional astronomer, utilizing telescopes large and small atop mountaintops and aboard astronomical satellites - a typical pursuit for a practicing astrophysicist of that time. However, the notion of a small telescope on a satellite persisted. It began to seem attainable in the years after 1987, when I joined the Institute for Space and Terrestrial Science (ISTS), a Provincial Centre of Excellence in Ontario. My responsibilities, alongside active astronomical research, included engaging with Ontario's extensive space-engineering industry.

I seized every opportunity to discuss the possibility of a small telescope on a satellite, albeit met with skepticism and perhaps a hint of pity from many knowledgeable individuals - a familiar reaction to me, given my encounters as an astronomer. This time, I was questioning two basic, well-established principles of satellite astronomy of that time: (1) for world-class astronomy, one must use big telescopes, while (2) small satellites are harder to build, stabilize and operate than the large ones.

There were good reasons for these principles: Of course, as for ground-based telescopes, large dimensions are needed for catching more photons and improving angular resolution - unless one is ready to observe bright objects. But, on an orbit, there was something more specific: An increased moment of inertia helps stabilize large spacecraft and give more useful volume for computers, electronics, and the like... And small satellites are indeed shakier. These principles were well-established; there was no way to question them. The idea of a small telescope on a small satellite became quite distant. Then I met Kieran Carroll...

In 1996, the Canadian Space Agency (CSA) announced a competition for funds for small orbital and sub-orbital payloads. Kieran and I met during a small-payloads workshop organized by the CSA. He was trying to get scientists interested in solar sailing technology but was also involved in micro-sat sized reaction wheel development. At that time, Kieran ran the space division of Dynacon, a small engineering company in Toronto; he was also affiliated with the University of Toronto Institute for Aerospace Studies (UTIAS), later becoming an adjunct professor there, teaching micro-satellite systems engineering. While at Dynacon, Kieran partnered with researchers at UTIAS on the development of a micro-sat-sized free-flyer called DICE, intended to operate inside the Space Shuttle's crew cabin to test dynamics and control methods. Although DICE did not end up flying, it laid the groundwork for the subsequent Dynacon/UTIAS partnership for the MOST micro-sat.

Meeting weekly to outline a general description of a small satellite for astronomy, we drafted an application for CSA funds together: I contributed expertise in general stellar astrophysics and experience with various astronomical satellites, both American (OAO-2, OAO-3, IRAS, EUVE) and European (ANS, IUE), while Kieran provided practical insights and oversight of the concept. The culmination of our efforts was a 45-page application submitted to the Canadian Space Agency in January 1997. Institute for Space and Terrestrial Science (ISTS), my employer at that time, contributed professional budgeting, management expertise, workflow calculations, and publication support. Despite formidable competition from the auroral research and sounding rockets community, we received the great news in the spring of 1998 that our proposal for a micro-satellite for astronomy had been successful—a remarkable achievement, particularly against the backdrop of ISTS's impending closure due to provincial-level political and financial shifts.

Fig.1: The micro-satellite MOST, an important milestone in the development of Canadian small astronomical satellites

The application described a 15cm telescope feeding a CCD detector system. The astronomical goal was accurate (better than 10 parts per million) photometry of stars to study their minuscule radial and non-radial oscillations (i.e., similar to seismic). Our ideas were formulated at first quite generally; in the end, the satellite took the shape of a box having a weight of 52kg and dimensions of 60x60x24cm. The planned orbit was a very special one and was treated as a special feature of the project: From among many already-special Sun-synchronous orbits (i.e., precessing slowly with a period of exactly one year), this one would be oriented to follow the dusk-dawn line on the Earth globe. This was to assure a constant visibility of the selected target for the longest time possible [up to two months], all the time probing the stellar signal frequently and regularly a few times per minute. One side of the satellite would be illuminated by the Sun, while the other would be directed towards space for observations and for cooling of the detector.

With the demise of ISTS, my circumstances underwent a drastic change, prompting me to reassess my situation. Fortunately, Kieran remained unaffected by these developments, and the core Canadian component of the Science Team remained intact. The original team, comprising Jaymie Matthews, Anthony F.J. Moffat, Dimitar Sasselov, and myself (as Principal Investigator), transitioned leadership to Prof. Jaymie Matthews (Vancouver) upon the approval of the MOST project. Jaymie invented the catchy bilingual name for the satellite, MOST for Micro-variability and Oscillations of STars/Microvariabilité et Oscillations STellaire. Under Jaymie's guidance, the project expanded, incorporating additional Canadian astronomers from coast to coast (David Guenther in Halifax, Gordon Walker, and later Jason Rowe in Vancouver/Victoria) and welcoming two Austrian astronomers from Vienna - Reiner Kuschnig and Werner Weiss, whose involvement later proved crucial for the BRITE Constellation project.

MOST was constructed between 1998 and 2003 at the newly established Space Flights Laboratory (SFL) within UTIAS. It marked Canada's first fully domestically-built satellite and the world's first micro-satellite dedicated to astronomy. MOST's design capitalized on advancements in component miniaturization and computer processing speeds, areas where Dynacon and UTIAS engineers possessed extensive expertise. Notably, stars served as ideal targets for stabilization devices, appearing as point-like objects against the backdrop of outer space.

MOST enjoyed a fruitful operational lifespan from 2003 to 2014, yielding a wealth of significant publications [2] and serving as a blueprint for subsequent small-satellite ventures. With this, we conclude the prelude to the BRITE project, transitioning seamlessly from the MOST era to the BRITE prehistory.

The (early) BRITE prehistory

A small personal remark: I began working at the David Dunlap Observatory in 1999 as a site director. It marked a shift for me into a new administrative-managerial role, alongside a parallel desire to make the most of the 1.9m telescope before the observatory would close. In July 2002, Dr. Robert (Rob) Zee, the Director of SFL, called me at the DDO and posed a question that sounded something like: "Can useful astronomy be done with a nano-satellite?" We can assume that this call marked the beginning of the BRITE project...

This is a suitable point to clarify the generally accepted convention: MOST, weighing less than 100 kg, was classified as a micro-satellite, whereas, a nano-satellite is assumed to weigh less than 10 kg. Hence, from the outset, the scale of the project was reduced by a factor of about 10 compared with MOST. The SFL's focus was shifting towards the new directions, striving to carve out its own engineering niche as a provider of modern orbital payloads.

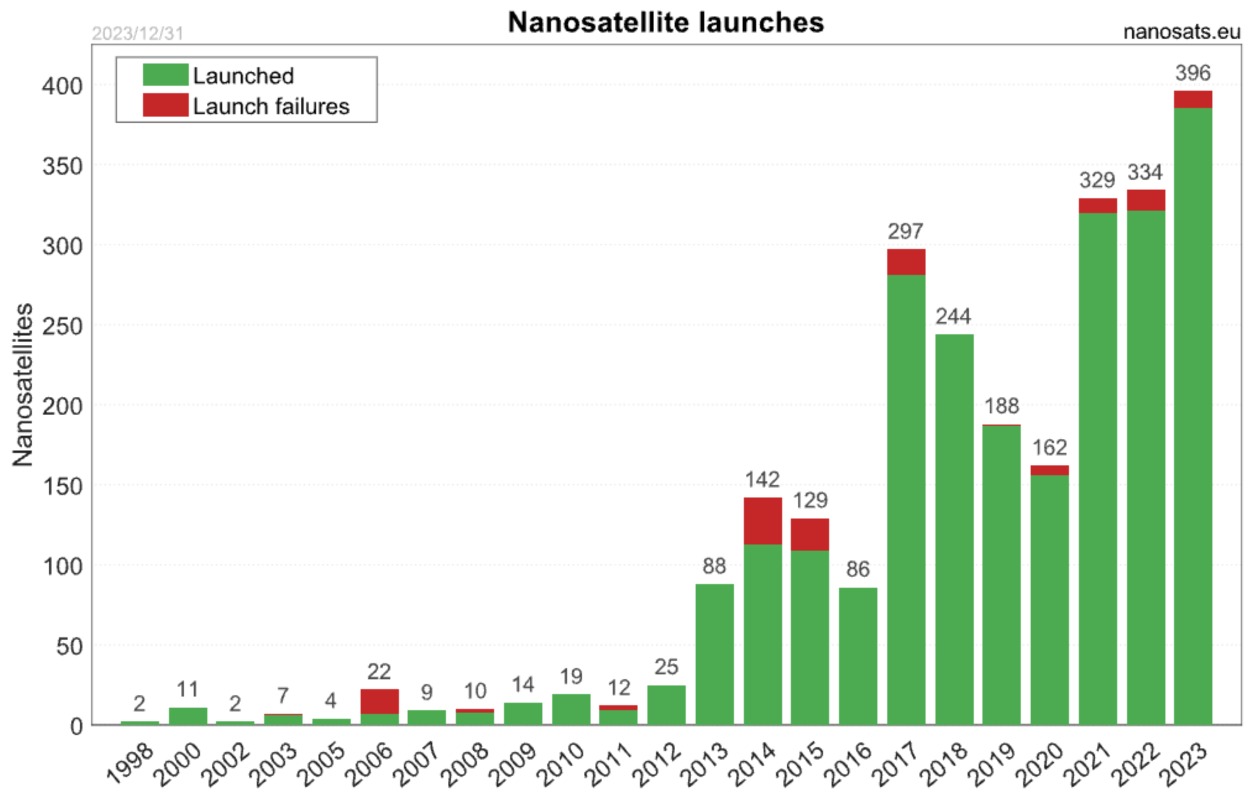

Fig.2: The number of nano-satellite launches. The UTIAS-SFL became an important player in this field very early as the BRITE precursor was conceived in 2002 (Source: nanosat.eu)

Returning to Rob Zee's question: I knew the answer to it. The matter of possible downscaling the MOST mission already surfaced during its planning, and for obvious reasons: The accessibility of targets for small astronomical instruments is always an issue and must be a subject of optimization.

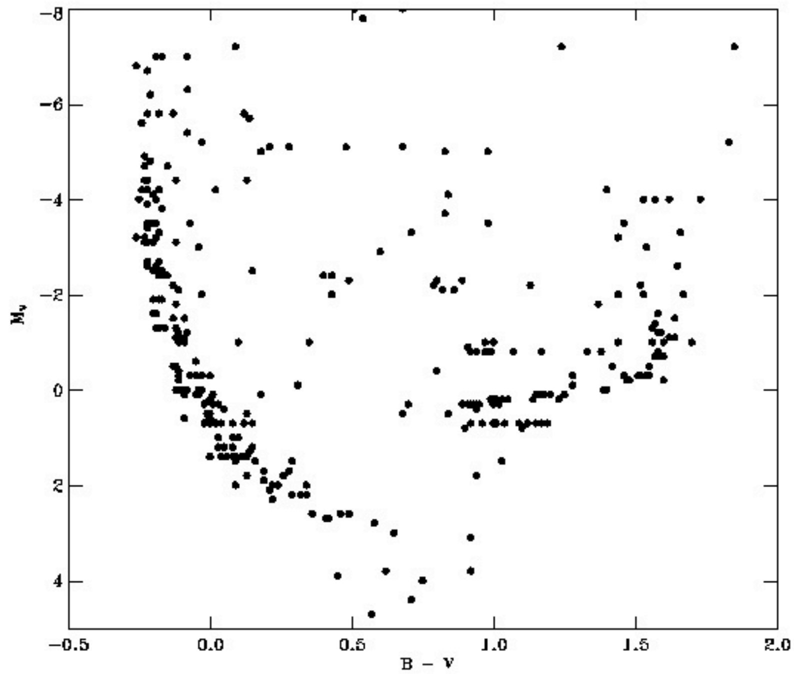

Fig.3: The colour-magnitude diagram for stars visible to +3.5 apparent magnitude predicted that we will see predominantly most luminous stars. The Sun is close to the lower margin at the centre. (Source: The BRITE Proposal)

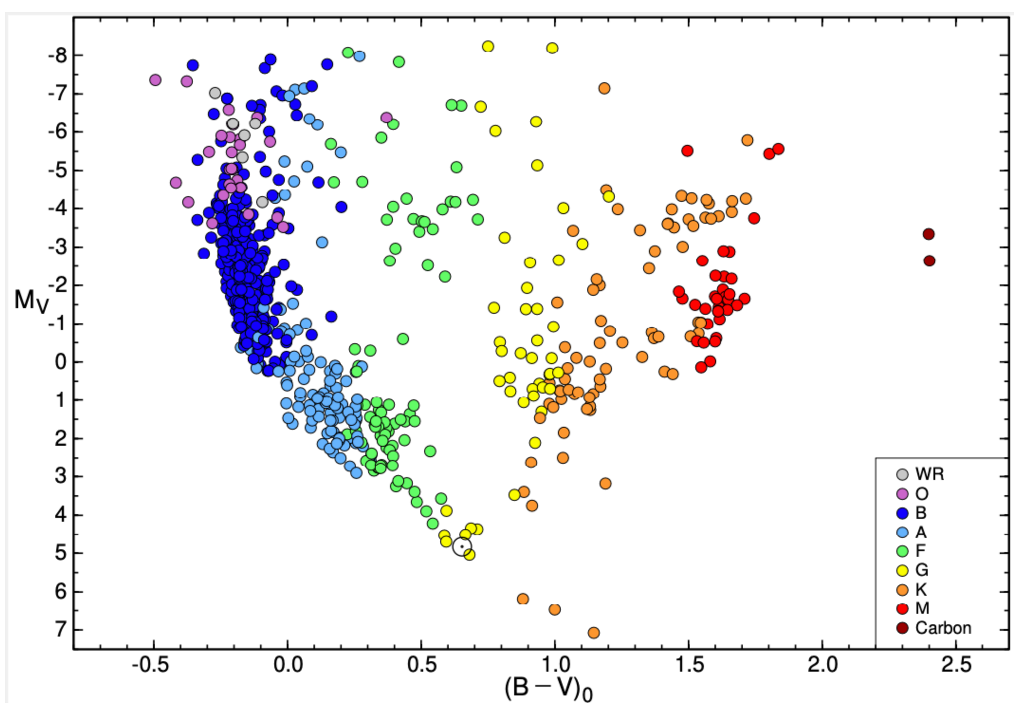

Fig.4: The same as in Fig.3, but for stars <u>actually observed</u> by BRITE to 2024 (Source: Andrzej Pigulski: BRITE-Wiki).

In the case of a nano-satellite, we would have smaller optical elements compared to the MOST satellite, which had a 15 cm mirror. A reasonable estimate was that an optical system with 3 cm diameter lenses would be the maximum feasible. With the detectors of that time, this would set a faint limit for accessible objects at about +3.5 apparent magnitude or slightly fainter. The difference of 5 magnitudes between the brightest stars and the +3.5 magnitude limit corresponds to a modest dynamic range in brightness of about 100 times. However, a property of stars significantly widens that range thanks to the large range in intrinsic luminosities, easily beating the $1/r^2$ geometric Euclidian dilution: the intrinsically brightest stars are visible and can be studied at very large distances!

When the actual bright stars of our sky are plotted on a diagram showing their intrinsic luminosities (Fig.3), the magnitude range increases to as much as 12.5 magnitudes, or a factor of 10^5 in luminosities. This convenient selection effect opens up a window to not only the most luminous, but also very rare, most massive stars. These stars are particularly important because (1) in their short lives, through successive cycles of star death and birth, they produce most of surrounding us elements, but (2) they still require intense research.

There are other convenient aspects of nano-satellites: launches of nano-satellites are much less costly than for larger satellites. However, the launches usually provide orbits with parameters and orientations on a "whatever-available" basis, which cannot assure long visibility periods like the MOST orbit. Nevertheless, this deficiency would be easier to tolerate for massive stars, where variation timescales are expected to be longer than for smaller, solar-type stars. Finally, as mentioned above, smaller satellite dimensions would force us to accept poorer satellite stabilization and more difficulties with data processing.

Proposal after proposal...

In 2002, one year before the launch of MOST, the SFL was preparing for the nano-satellite era by readying its first two non-astronomical nano-satellites. They were built according to a new CubeSat standard based on a box measuring 10x10x10cm and weighing less than 1.33kg, considered as a single unit. A typical nano-satellite would be assembled into a configuration of two or three such boxes. The first SFL satellites were named CanX-1 and CanX-2; they were relatively simple and definitely not suitable for astronomical use, as we required 3-axis stabilization.

Our astronomical plans necessitated meeting stringent requirements that were challenging to accommodate in the CubeSat format. While this represented a departure from prevailing trends, our needs drove the development of a general design, eventually taking the shape of a cube measuring 20x20x20cm, equivalent to 8 CubeSat units in an equilateral box. The stabilization requirements were initially set at better than 0.5 angular minutes, while the data acquisition system needed to take measurements of stellar brightness moderately frequently, at a rate of about one sampling per minute.

Due to these goals dominating our thinking at that time, the satellite was placed relatively early in the SFL numbering queue, receiving the designation CanX-3. While simpler subsequent satellites were assigned higher numbers in the internal SFL numbering (CanX-4, CanX-5, etc.) and several satellites were built and flown before it, CanX-3 remained an important reference point for a considerable period. It also had other names; initially called the Bright Star Photometer (BSP), it was later named "BRITE" (BRIght Target Explorer), a name coined by Tony Moffat.

The history of applications to the Canadian Space Agency was somewhat protracted, partly due to the reorganization occurring at the CSA, and partly due to hesitant support from the Canadian astronomy community, which was eager to see first results from the MOST satellite. Consequently, although the phone call from Rob Zee to me took place in 2002, not much progress occurred during that year. The evolution of the nano-sat program at the SFL over time is well described at https://www.utias-sfl.net/satellite-platforms/nanosatellites/.

The first BRITE Science Team was formed in 2003, consisting mainly of astronomers from the Department of Astronomy and Astrophysics at the University of Toronto: Slavek Rucinski (PI), C. T. Bolton, Marten van Kerkwijk, Stefan Mochnacki, and John Percy. The two external participants were Tony Moffat from Université de Montréal and Doug Welch from McMaster University. The Engineering Team comprised of Kieran Carroll and Daniel Faber from Dynacon Inc., and Robert Zee from UTIAS. The combined team submitted an Unsolicited Proposal to the CSA in July 2004 for a single satellite. This proposal described a satellite very similar to the final design, with crucial details, such as the selection of a detector, left for later decisions.

The subsequent proposal in 2004 was again unsuccessful, as were the similar proposals submitted by the same team in the following years. However, the time spent was not wasted, and some activities are noteworthy:

- A study of CMOS detectors for astronomical applications was contracted by the CSA and conducted in 2005. The study involved the Science Team, as mentioned above, along with Ceravolo Optical Systems, a company specializing in the design and manufacture of small optical systems for astronomy. The final Double-Gauss, telecentric system of the BRITE optics was created during this time and was actually used in the satellites. The CMOS study focused on the properties of such detectors with space and high-precision photometry in mind. CMOS detectors were not as well-known as CCDs, which were generally the preferred and best-understood astronomical devices, several weaknesses of CMOS detectors were noted and described in the study.

- The international character of a multi-satellite BRITE Constellation began to take shape. The 2005 application explicitly considered collaboration with Vienna astronomers as providers of the ground-based station for data downlinking.

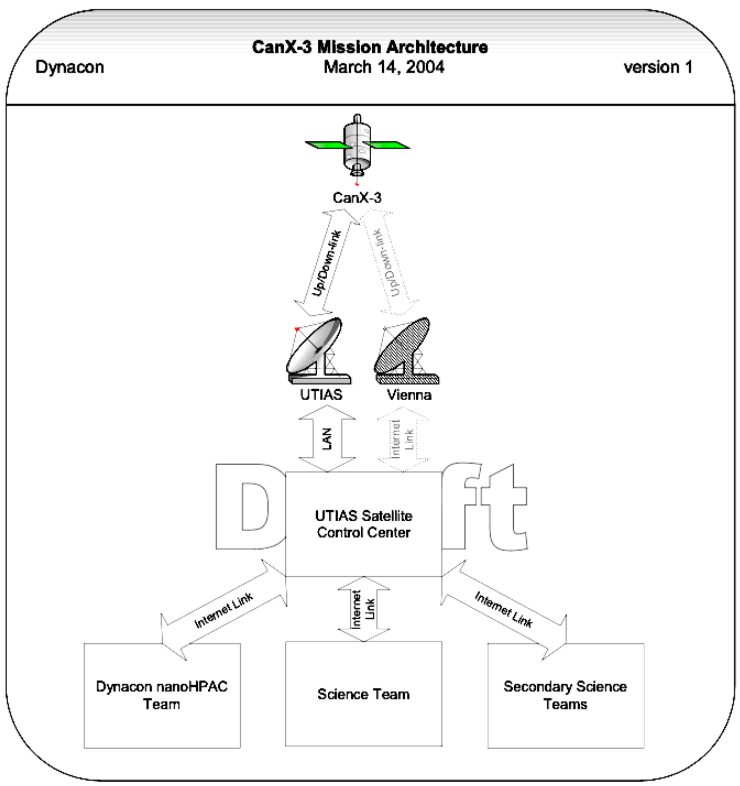

Fig.5: An early concept of the BRITE data flow involving the Vienna MOST station.

BRITE goes international: End of the prehistory

The early, 2005 proposal to the Canadian Space Agency explicitly mentions the initiative of the Austrian team led by Prof. Werner Weiss to utilize the MOST telemetry station in Vienna for data downloads from the planned satellite. The years 2003 to 2014 were a time when the MOST satellite was in full operating mode, and MOST engineers and users were learning important lessons for any further micro- and nano-satellite activities. Professor Werner Weiss (in Vienna) and Dr. Rainer Kusching (in Vancouver) formed a very strong component of the MOST team and were naturally very much aware of the BRITE project developments in Canada.

An Austrian application for funds to build two BRITE satellites, each for a separate spectral band, was successful in the spring of 2006. This application included a component of the Graz University of Technology (PI: Otto Koudelka). This success marked the first signs of life for the BRITE Constellation.

Independently of the Austrian and Canadian developments, I endeavoured to convince my former students and colleagues in Poland that they should consider joining the BRITE Constellation. However, I noticed a certain hesitation and disbelief. Possibly, it was easier for me to see - from Canada - the rapid economic progress of the country, but most of my Polish colleagues were skeptical and doubted any chances of procuring funding for what would then be the first Polish research satellites. To me, the positive aspects of joining were obvious and numerous. The best route seemed to be following the collaboration with the SFL exactly as already opened up by the Austrian team. The Polish team, led by Alex Schwarzenberg-Czerny, with Wojtek Dziembowski, Piotr Orleański, and Andrzej Pigulski, applied for funds in 2008 and were successful one year later.

In 2009, it appeared that four satellites would form the BRITE Constellation, but paradoxically, without the Canadian component. Fortunately, an application from the same team as before, but driven mostly by the SFL technical team, was successful in 2011. By that time, the Canadian Science Team underwent some rearrangements, with some members leaving while others became more active. Of note is the strong participation of Stefan Mochnacki in the technical aspects of the mission, particularly in the selection of the CCD detector, which was used in all six satellites. The CCD selection was a crucial component of the actual technical design, and through its extensive use, we learned both positives and negatives of the selected types.

From 2011 onwards, BRITE has become a truly international project.The Science Team is no longer limited to the three founding countries but now includes specialists from several countries. Construction activities remain centred on the Space Flight Laboratory in Toronto, where the main control station is located. The SFL shares technical know-how with Austrian and Polish engineers, and new ground-based stations have been built in those respective countries. The period of BRITE's pre-history has ended.

Notes

[1] We realized during the MOST mission that the sun-synchronous dawn-dusk orbit required more extensive baffling of the telescope aperture than was actually provided. Such an orbit implies continuous visibility of the bright Earth shining from below over half of the field of view. Fortunately, it was possible to account for this effect during the data processing stage.

[2] Publications in years 2003 - 2018 listed in the NASA bibliographic system ADS (https://ui.adsabs.harvard.edu/), which utilized MOST data or referred to the mission numbered 196. Many more publications utilized the MOST results as an auxiliary data source.

[3] The CMOS Concept Study contracted by the Canadian Space Agency is available at https://www.astro.utoronto.ca/~rucinski/ForArchives