The CoRoT Legacy Book

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Across the Atlantic: Canada's MOST

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1. Windows of opportunity

In the mid-1990s, it seemed like the only way Canadian astronomers could have direct access to space-based ultra-precise photometry for asteroseismology was to be a minor partner in a European satellite mission. In fact, with this in mind, in 1996 Jaymie Matthews (University of British Columbia) submitted an unsolicited proposal to the Canadian Space Agency for Canada to participate in Eddington at a level of a few Can$M.

Then two unexpected windows opened right after one another.

The first window was built by aerospace engineer Kieran Carroll and opened by astronomer Slavek Rucinski. Rucinski attended a talk by Carroll whose company, Dynacon Inc. had developed a new Attitude Control System (ACS). Carroll explained that this system could stabilize a microsatellite (mass <100 kg; dimensions <1 m) with pointing accuracy of about 1 arcminute. This was about 100 times better than the previous best for such a small platform with such low inertia.

Carroll was looking for potential missions which could demonstrate the new ACS technology on orbit. Rucinski thought there might be an astronomical application and presented a poster at the next CASCA (Canadian Astronomical Society/Societé canadienne d'astronomie) annual meeting, soliciting ideas from the community for a space astronomy mission on a payload of low mass, low volume, low power and modest pointing accuracy. Jaymie Matthews recognized immediately the potential for a stellar photometry satellite and Tony Moffat thought there might applications to Wolf-Rayet stars.

Then the second window opened. The Canadian Space Agency (CSA/ASC) – founded less than a decade earlier – issued an Announcement of Opportunity for space science with a microsatellite. Rucinski, Carroll, Matthews, Moffat and Dimitar Sasselov submitted in 1997 a proposal for a satellite first called STEDY (for STEllar DYnamics, and playing on the steadiness of the proposed pointing system). STEDY was one of 54 proposals, and the *only* one with astronomical goals. It was selected as one of 6 proposals for a six-month Phase A competition.

Matthews took over as Principal Investigator, David Guenther and Gordon Walker joined the team, and the contractors were Dynacon, and CRESTech (Centre for Research in Earth & Space Technology). John Pazder became the optics designer and Peter Ceravolo would fabricate the main optics.

The project was renamed MOST, for Microvariability & Oscillations of STars/Microvariabilité et Oscillations STellaire. Its original scientific objectives were: (1) asteroseismology of solar-type stars; (2) asteroseismology of roAp (rapidly oscillating Ap) stars; (3) characterization of Wolf-Rayet star winds and search for pulsations; and (4) measurement of exoplanet albedo.

MOST won the Phase A competition and was selected to be Canada's first microsatellite and first space telescope.

2. A suitcase in space

MOST was designed to fit inside the secondary payload envelope of a Delta II rocket, to place it into a Sun-synchronous low-Earth (820-km) dusk-dawn orbit. From that vantage point, it would have a Continuous Viewing Zone (CVZ) about 54° wide, allowing uninterrupted monitoring of stars for up to 8 weeks at a time. MOST would stare out above the shadowed portion of the Earth with the solar panels being illuminated continuously by the Sun "behind" the satellite.

The small volume available to "hitchhike" on a Delta II meant MOST had to have the mass and dimensions of a suitcase: 54 kg; $60 \times 60 \times 30$ cm. The aperture of the optical telescope: 15 cm. Maximum power consumption: 30 Watts. No space, mass or power for a separate star tracking system, so the MOST instrument combined science and tracking functions, with twin 47–20 CCDs in the focal plane, custom-packaged by E2V.

Although the Dynacon ACS technology promised pointing which was an order-of-magnitude better than had ever been achieved with a microsat, the accuracy was still only 1 arcminute. Sharp images are not most important for precise photometry, but reliably collecting all the light from a stellar PSF (Point Spread Function) is critical for micro-magnitude precision. Walker and Matthews took inspiration from photoelectric astronomical photometry, where the cathode of a phototube is illuminated by the pupil image of the telescope, projected by a Fabry lens to avoid the star image wandering over the inconstant response of the cathode.

For the MOST photometer, the detector would be a CCD, and multiple pupil images would be projected by a 6×6 array of Fabry microlenses. One would be illuminated by a target star; others would provide sky background values. The entire array (fabricated by Advanced Microptic Systems in Saarbrücken, Germany) also provides redundancy for damage to any one microlens.

To keep costs low and reliability high, it was decided that the MOST telescope and instrument would have no moving parts. No focusing knob for the telescope? The design is athermal, with components of different CTE (Coefficients of Thermal Expansion) chosen so that the structure keeps the same focus across a wide range of temperature. No mechanical shutter to end exposures? The CCDs have frame transfer buffers for rapid transfer of data charge to end each exposure. The only moving parts on the entire satellite are the spinning reaction wheels of the ACS, and a door which can close if there is risk of the instrument pointing directly at the Sun.

The initial mission design is described by Walker, Matthews et al. (2003).

In the meantime, the Canadian mission acquired two Austrian connections. Rainer Kuschnig was hired to become MOST Instrument Scientist, thanks to his engineering and astrophysical training and his experience with photometry from the Hubble Space Telescope FGS (Fine Guidance Sensor). Werner Weiss, after the disappointment of EVRIS, joined the MOST Science Team in exchange for an additional ground station. Stations in Vancouver, Toronto and now Vienna enhanced data downlink and operational flexibility. The scientific and data processing savvy added by Weiss and his team enhanced the entire mission immeasurably.

3. The little telescope that could

Less than six years after it was first proposed, MOST was carried into orbit aboard three-stage Russian Rockot (a former Soviet nuclear missile, designated an SS-19 Stiletto by the US military), through a contract with the German-Russian consortium Eurocket and the Krunichev Space Research & Production Facility[1] (Fig. I.4.2). The launch date was 30 June 2003, one day before Canada's 136th birthday.

The total cost (from Phase A to Phase E) was 7M US$.

The next six months were dedicated to commissioning the satellite. Two things were evident early on – one good, one not so good. On the positive side of the ledger, the Attitude Control System was working better than the engineers' most optimistic hopes. On the negative side, there were higher levels of stray light (due to scattered earthshine reaching the MOST instrument focal plane) than expected. The stray light is mainly modulated with the orbital period of MOST (101 minutes) and the team quickly adopted data processing and reduction strategies to mitigate the modulated background levels in the photometry (Figs. I.4.1 and I.4.2).

[1] The original plan to launch as the secondary payload of the Canadian synthesis aperture radar satellite, Radarsat II, was abandoned when that mission fell far behind schedule. Had it been known that MOST would be the primary payload on a Rocket, there would have been less tight restrictions on dimensions, but the satellite design was locked in by the time the change in launch vehicle took place.

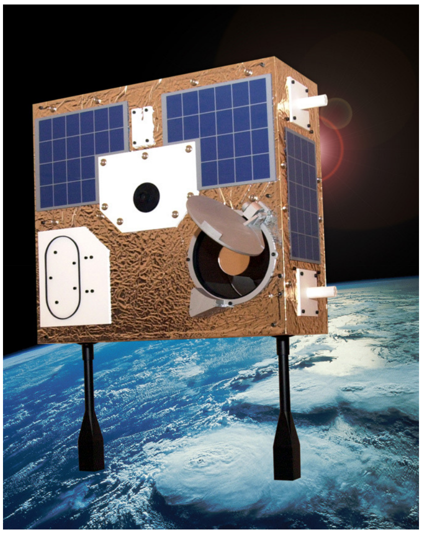

Fig. I.4.1. Model of the MOST microsatellite. Credit: Canadian Space Agency.

Fig. I.4.2. The launch of MOST on 30 June 2003, aboard a Russian Rockot from the Plesetsk Cosmodrome. Credit: EUROCKOT, Khrunichev Space Research & Production Centre.

Science commissioning was carried out during October–December 2003. The first Science Commissioning Targets (young solar-type star kappa 1 Ceti and beta Cephei pulsator delta Ceti) resulted in major scientific findings (Rucinski et al. 2004; Aerts et al. 2006) and kappa 1 Ceti became a regular return target for MOST in the early years of its mission (Walker et al. 2007).

In January 2004, MOST monitored its first Primary Science Target: the bright Sun-like star Procyon. Ground-based radial velocity (RV) measurements had indicated that this star was pulsating in solar-type p-modes, but the MOST light curve did not reveal any oscillations above the detection limit (Matthews et al. 2004). This null result – in which the MOST team described Procyon as a "flatliner" – defied expectations due to scaling relations and was extremely controversial. Later, MOST took part in a coordinated campaign to observe Procyon, with spectrographs around the globe, to detect and characterize the p-mode eigenspectrum of the star (Huber & Bedding 2011). The Procyon controversy sparked by MOST led to a better understanding of convection and pulsation in stars through cooperation among observers and theorists around the world.

MOST was intended to be a 1-year-long mission to observe 10 bright stars. As of the writing of this article, MOST has been operating for almost 13 years, and has collected about 5000 light curves.

Some MOST science highlights include: direct measurement of differential rotation and the period-latitude relation in a young solar-type star (Rucinski et al. 2004; Walker et al. 2007); measurement of the albedo of exoplanet HD 209458 b (Rowe et al. 2008); determining the power spectrum of accretion in the disk of a T Tauri star (Rucinski et al. 2008; Siwak et al. 2011); asteroseismic fitting of the internal magnetic field of several roAp stars (Gruberbauer et al. 2008); detection of a warm, volatile-rich super-Earth exoplanet (Dragomir et al. 2013); measurement of star-exoplanet interactions due to the tangling of the star's magnetic field with the magnetosphere of the planet (Walker et al. 2008); recognition of a relation between *g*-mode frequencies and internal rotation in SPB and SPBe (Slowly Pulsating B and Be) stars (Saio et al. 2007); detecting nonradial *p*-modes in red giants (at odds with theoretical expectations at the time); opening wider the window on the new field of red giant seismology (Kallinger et al. 2008); and detection of Co-rotating Interaction Regions in the winds of Wolf-Rayet stars (Chené et al. 2011).

CSA/ASC stopped funding of MOST operations in early September 2014. CSA/ASC sold the satellite to the MOST prime contractor (MSCI: Microsatellite Systems Canada Inc., formerly the Space Division of Dynacon, Inc.) and donated the UBC ground station to UBC.

MOST now operates in "pay-per-view" mode, where astronomers pay US$6K per week for photometry of their selected targets. The MOST team anticipates the satellite can operate in its current mode until 2020–22.

References

Aerts, C., Marchenko, S. V., Matthews, J. M., et al. 2006, ApJ, 642, 470

Chené, A.-N., Moffat, A. F. J., Cameron, C., et al. 2011, ApJ, 735, 34

Dragomir, D., Matthews, J. M., Eastman, J. D., et al. 2013, ApJ, 772

Gruberbauer, M., Saio, H., Huber, D., et al. 2008, A&A, 80, 223

Huber, D., Bedding, T. R., Arentoft, T., et al. 2011, ApJ, 731, 94

Kallinger, T., Guenther, D. B., Matthews, J. M., et al. 2008, CoAst, 153, 84

Matthews, J. M., Kuschnig, K., Guenther, D., et al. 2004, Nature, 480, 51

Rowe, J. F., Matthews, J. M., Seager, S., et al. 2008, ApJ, 689, 1345

Rucinski, S., Walker, G. A. H., Matthews, J. M., et al. 2004, PASP, 116, 1093

Rucinski, S. M., Matthews, J. M., Kuschnig, R., et al. 2008, MNRAS, 391, 1913

Saio, H., Cameron, C., Kuschnig, R., et al. 2007, ApJ, 654, 544

Siwak, M., Rucinski, S. M., Matthews, J. M., et al. 2011, MNRAS, 410, 2725

Walker, G., Matthews, J., Kuschnig, R., et al. 2003, PASP, 115, 1023

Walker, G. A. H., Croll, B., , Matthews, J. M., et al. 2007, ApJ, 658, 1328

Walker, G. A H., Croll, B., Matthews, J. M., et al. 2008, A&A, 482, 691

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