Space Astronomy in Canada

A white paper prepared by the **Joint Committee on Space Astronomy**
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Executive Summary

The last decade has witnessed notable successes in Canadian Space Astronomy. Canada has made significant contributions to a number of productive international small satellite missions, played a pivotal role in several high-profile stratospheric balloon experiments, and taken the lead in its own microsatellite mission. Canada has also taken the ambitious step of joining the James Webb Space Telescope (JWST) project as an international partner. The investments in infrastructure, training and industrial capacity made over the last decade leave us in the strong position of being capable of taking the lead in space astronomy missions of very significant capability (along the lines of a NASA Explorer-class mission). In this white paper we summarize the achievements of the last ten years and outline a roadmap for the next ten.

What we've achieved: recent notable successes of Canadian Space Astronomy

In the last decade Canada (through the Canadian Space Agency) has been directly involved the following seven Space Astronomy missions[1]. This list does not count indirect support via participation by Canadian investigators in international missions that did not receive direct funding by the Canadian Space Agency (CSA), such as WMAP and HST.

VSOP: (1997-2005): Space-based interferometry mission. Led by Japan. CSA provided $3.2 million to fund Canadian participation.

ODIN (2001-2006): Sub-mm orbital observatory. Led by Sweden. CSA provided $8.2 million to fund Canadian participation.

FUSE (1999-2007); Far-UV satellite. Led by USA. Canada provided two fine guidance sensors that allowed the observatory to be aimed at its targets with a very high degree of precision. CSA provided $6.4 million for Canadian participation.

BLAST (2003-2006); Balloon based experiment to study star-formation. Led by USA. Canada provided the gondola, the pointing control system, the data acquisition system, the flight and ground station software, the power system, and overall system integration. CSA contributed $2.4 million

MOST (2003-) Microsatellite to study stellar pulsations. Led by Canada. Designed and built in Canada. CSA contributed $14.4 million.

Herschel (2009-) Far-infrared and sub-mm telescope, probing some of the coldest and most distant objects in the Universe. Led by the European Space Agency. CSA contracts were worth $5.2 million.

Planck (2009-). Cosmic microwave background telescope. Designed to create all-sky maps of the anisotropies of the Cosmic Microwave Background radiation with uniquely high angular resolution and sensitivity. Canada provided data analysis tools and other software. CSA contributed $5.6 million.

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[1] Note also that the financial contributions listed were provided by the CSA, but with the caveat they should be interpreted with caution because of the implementation of full-cost accounting partway through the last decade. No attempt is made to incorporate full-cost accounting of early missions, so it is difficult to compare the true cost of early to later counterparts. Also, figures are not corrected for inflation.

Where we're going now: upcoming missions

NEOSSat (2011-). Surveillance microsatellite designed to track man-made earth-orbiting debris and also asteroids. CSA and Defense Research Development Canada are each contributing $11M.

EBEX (2009-2011). Balloon-borne polarimeter designed to measure the intensity and polarization of the cosmic microwave background radiation. The EBEX CMB polarimeter was test flown in June 2009, achieving the first demonstration in a space-like environment of a large array of Transition Edge Sensor bolometers and of a SQUID-based multiplexed readout system. Canada is contributing $0.5 million.

Astrosat (2010-). UV-Xray satellite led by the Indian Space Agency. CSA is providing $6.5 million.

JWST (2014-). Successor to the Hubble Space Telescope. See the White Paper by Hutchings for a status update. Canada is providing the Fine Guidance Sensor (guider) and the Tunable Filter Imager (science instrument). CSA is funding JWST at the level of $145 million.

Where do we want to go next? Studies by the Discipline Working Groups

In 2010 CSA embarked upon defining a Long-Term Space Plan. The plan is now complete and is presently a protected document awaiting cabinet-level approval. To gather information for this plan, CSA initiated a process to inform itself about the ambitions of Canadian researchers engaged in Space Astronomy. Since much of the motivation for doing astrophysics from space is to probe wavelengths that are inaccessible from the ground, CSA structured this process around the idea of different "disciplines" for space-based astronomy, each focused on a different region of wavelength space. Five separate "Discipline Working Groups" reports were commissioned. The five reports covered the following disciplines:

- High energy astrophysics
- Far infrared astronomy
- Cosmic microwave background
- Space based wide field UV-optical-NIR telescope
- UV astronomy, imaging and spectroscopy

The Discipline Working Groups were comprised of researchers from Universities across Canada as well as from HIA/NRC. The reports define science objectives, assess technological readiness, and analyze the international context for undertaking missions in the defined areas. We have incorporated some of the findings from these reports into recommendations below. Following from the Discipline Working Group reports, and using other feedback, the CSA has initiated two mission concept studies to further study the feasibility of programs targeting Dark Energy and X-ray astronomy (see below). These follow on the heels of two earlier concept studies initiated in 2007 that investigated an Oort Cloud Occultation Telescope and a Lunar Liquid Mirror Telescope.

Recommendations: A Roadmap for Space Astronomy in the Next Decade

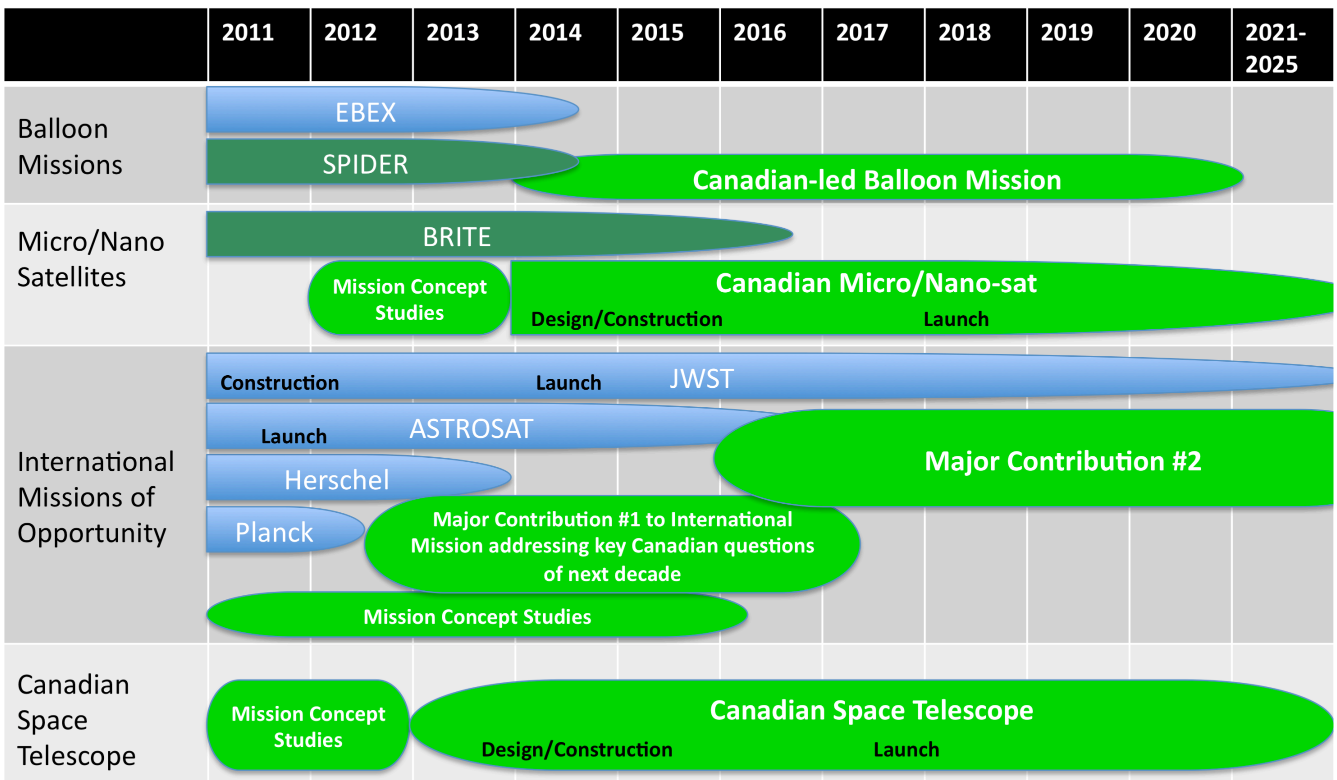
The considerable investment in space astronomy represented by the missions described at the start of this White Paper corresponds to a huge commitment to Canadian astronomy by the CSA. JWST is by far the most high-profile of the missions funded so far, and the central theme of the recommendations given below is that this commitment to JWST, coupled with investments in infrastructure, training and industrial capacity made over the last decade, leave us in the position of being able to take the lead in space astronomy missions of very significant capability. With this overall goal in mind, we now outline a proposed “roadmap” for Canadian Space Astronomy. In all cases, scientific excellence will drive the specifications of the missions while at the same time the missions provide the following benefits that are in-line with government priorities:

- They strengthen Canada's technological ability for space applications through increasing the number of Canadian-led instruments and partnering with international leaders to build the most capable international missions. By fueling this growth in our industrial knowledge, new commercial ventures will become possible.

- They train highly qualified personnel in both the academic and industrial sectors who are capable of leading substantial space research and technology and scientific efforts. We propose to capitalize on the superb training environment provided by rapidly developed small and medium sized missions to seed this training.

- They take space astronomy in Canada to the next echelon of excellence, leading ultimately the capstone of a Canadian-led small or mid-size space telescope along the lines of a NASA MIDEX-class mission

The landscape for the next decade in Canadian space astronomy, mapped onto space missions, is summarized schematically in the table below.



Roadmap Description

The roadmap is divided into 4 streams. A prerequisite for missions in all streams is potential for outstanding scientific results, coupled with benefits to Canadian industry, and training of highly qualified personnel. The small and medium size mission streams, including balloon-borne telescopes and nano/micro satellites, provide relatively short conception-to-launch timeframes and are an excellent means of training new personnel because the development time is commensurate with graduate degree durations and the relatively low cost makes it feasible to entrust trainees with significant responsibility. Internationally, many of the most accomplished space scientists and engineers for large missions have received their training in this manner.

For this roadmap we have listed missions that have already been conceived as examples for each mission category. We stress that the best science and technological development would be achieved by allowing a competitive selection of missions to fulfill each role. The examples provided here show that there is no absence of potential and excellent ideas within Canada.

Balloon-borne Missions

Canada's participation in a highly successful program of stratospheric balloon-based experiments has led to important breakthroughs and trained large numbers of HQP who have moved on to prominent leadership positions in international astrophysics and technology development. CSA's support of these missions has been critical and seems set to continue for the immediate future through EBEX and SPIDER, which will be collecting data through 2014. The next objective is to leverage this expertise by initiating a Canadian-led mission. This builds on previous missions in which other international partners have taken the lead, although Canadians have been important collaborators. Such a mission is a perfect fit for the renewal of Canada's balloon launch capabilities, one of the goals for the broader LTSP. The cost of a scientific balloon telescope is $5-15M, with partnership roles typically costing $1-5M.

Candidate Canadian-led balloon missions include:

- A far infrared telescope, building on Canada's expertise and heritage with the recently launched Herschel telescope and the conceptualization of the future SPICA/Safari instrument. The far infrared is where the processes that form planets, stars, and galaxies “shine” the brightest, allowing for images that directly address the questions, "how did structures form in the Universe?", "how did stars and planets form?", and "is there life outside the solar system?". Herschel, the first large FIR telescope in space, was launched in 2009 and will operate 3-5 years. New technology and ideas have evolved since the Herschel design was frozen, and there will be a unique opportunity to capitalize on these from a fast, timely, high altitude balloon platform. This mission would also be a technology pathfinder and demonstration for Canadian industry towards the successor to Herschel.

- A follow-up to CSA supported missions EBEX & Spider, which will be making new measurements of the Cosmic Microwave Background polarization. Cosmologists believe information about the first fraction of a second after the Big Bang may be encoded in this signature, providing a true exploration of the Universe's beginning. These measurements directly address the question, "How did the Universe begin?" In addition, EBEX and Spider test new, competing Canadian technology. A follow-up mission would combine the best of these two pathfinder missions and be a pre-cursor to a large international satellite mission.

- An ultraviolet imaging telescope, to capitalize on the high image quality and low atmospheric absorption to UV wavelengths probed at stratospheric altitudes. This would complement the IR-optimization of the JWST, coupling a wide-field capability to near diffraction-limited imaging and would target a range of science programs from star-formation to galaxy evolution.

In addition to the science objectives described above, Canadians are in a unique position to contribute to general-purpose technological development for stratospheric ballooning. Recent high-profile balloon flight successes, the advent of ultra-long duration balloon opportunities at mid-latitudes, combined with the increasing costs of satellites, has led to a considerable increase in interest in scientific ballooning. In particular, there is burgeoning interest in NIR, Visible, and Near UV observations. Many of these projects are hampered by the high cost, and technical challenges of building balloon-borne precision-pointed gondola platforms. Canada has the technical expertise to develop a flexible precision pointed platform which can be used to enable a wide range of experiments with substantially reduced turn-around times, increased reliability, and reduced cost, both for Canadian-led projects, and as leverage into international projects covering a broad range of science goals. A renewal of Canada's balloon launch capability should be coupled to platform development involving a partnership of Canadian universities and industry.

Micro/Nano Satellites

Canada leads the world in technology for small (size of a shoe-box to size of a suitcase) satellites and intends to invest heavily in the technology, infrastructure, and the training of individuals to cement our international leadership role. Unique gyroscope and pointing technology has been developed at the University of Toronto and Canadian industry. The MOST satellite is a clear example of what Canadians can do in space with a small payload, small budget, and excellent ideas.

The space astronomy roadmap for nano/micro-sats consists of a near term mission, The BRIght Target Explorer - Constellation (BRITE), that has already been recommended for funding through competitive peer review by CSA. BRITE is a novel constellation of 4-6 nano-satellites that will capture the light shed by luminous stars and in turn shed light on their structures and histories, uncovering unique clues to the origins of our own Sun and Earth. The BRITE Constellation is based on pioneering Canadian space technology and is being built in partnership with Austrian and Polish space scientists. The BRITE nanosats will scan the sky, measuring the brightness and temperature variations of the brightest stars on timescales ranging from hours to months. This data will help understand how stars and planets form.

MOST and BRITE represent a good start, but there are many ideas for a longer-term Canadian-led mission. Asteroseismology observations and searches for exoplanets require periodic, frequent measurements of stars. A mission along these lines follows closely in the footsteps of MOST and BRITE, and would be a natural choice for a longer timescale Canadian-led mission. These science goals make excellent use of Canada's proven technological leadership in fast, accurate pointing of low-power and mass payloads.

A single nano-sat telescope mission would cost $2-4M per satellite, while micro-sat astronomy missions may cost $10-30M.

International Partnership Missions

A substantial portion of Canada's international reputation for excellence in technology for space science missions has been garnered through collaborations on key space astronomy missions such as FUSE, Planck, Herschel, and now the James Webb Space Telescope. Canada's role as a key partner for international missions will continue through the next decade. Two example missions seem ready for immediate investment and should be looked at quickly (via an open and peer-reviewed process) to determine if participation is warranted:

- ASTRO-H is a joint JAXA/NASA mission that will explore the physics governing the Universe in extreme conditions. It includes 4 instruments: a focusing hard X-ray telescope with 12-m focal length on an extendible mast; a soft X-ray microcalorimeter having excellent spectral resolution; a soft X-ray CCD camera and a non-focusing soft gamma-ray detector. This is an "all-purpose" instrument that will be superb for studying supermassive black holes through cosmic time, active galactic nuclei, galaxy clusters, solar mass black holes, neutron stars, supernova remnants, to name a subset of foreseen targets. Launch is planned for 2014. JAXA has indicated that a Canadian instrumental contribution toward the metrology system in support of the very long focal length of the hard X-ray detector would be welcome.

- SPICA is a JAXA-led mission proposed to carry 3 instruments: a Mid-IR Coronograph, a Mid-IR Imaging Spectrometer, and a Far-IR Imaging Spectrometer. SPICA will shed light on how the earliest structures in the Universe formed. The proposed ESA participation consists of the cryogenic telescope assembly and a contribution to the operations in the form of a European SPICA ground segment. The SPICA mission is a very attractive option for a mission to be launched within the next 10 years. There are natural opportunities for Canadian involvement through the SAFARI instrument, especially given our expertise in FTS technology and software from Herschel.

The cost for contributions to these missions would be in the $5-25M range. On the mid- to long-term timescale the following are candidate missions

- An international mission (along the lines of the proposed Joint Dark Energy Mission, JDEM) employing wide field imaging in multiple bands has the potential to provide ground-breaking data to answer the question, "What is the nature of the dark components that seem to dominate the Universe today?" There is an American-led mission under consideration that is presently not envisioned as an open user facility, so contributions to the mission may be the best means for ensuring Canadian participation. NASA's initial technical analysis of the mission requirements identified technical capabilities (including guider systems) developed through the Canadian roles in JWST and FUSE that may be valuable for success.

Though this type of mission has a longer-term timescale than ASTRO-H and SPICA, development would have to begin immediately to meet the necessary timescales.

- The international Cosmic Microwave Background (CMB) community is converging towards a satellite for measuring the polarization of the CMB towards the end of the next decade. This will likely be a large international collaboration led by NASA or ESA. Canadian detector readout technology is often cited as the default for these missions and balloon missions presently under construction will cement our leadership in this venue. Canadians are well positioned to provide a major contribution in the form of readout hardware and associated software. Canadians are internationally renowned for the analysis of similar datasets.

On these longer timescales other interesting candidates exist, such as NASA's International X-ray Observatory (IXO), which is a large-aperture, observatory-class, spectroscopic X-ray telescope planned for a 2021 launch. IXO will be 100 times more sensitive than the current stable of X-ray telescopes in Earth orbit today, and is designed to study black hole evolution, strong gravity, cosmic feedback, and the distribution of matter and energy in the Universe. Another interesting mission is the Wide Field X-ray Telescope (WFXT), which is a proposed NASA mission dedicated to surveying the sky in the soft X-ray band. Contributions to these missions would be in the $10-75M range. We emphasize that these are examples only and other excellent candidates exist. Furthermore other targets of opportunity are expected to arise in the next decade that should be investigated. Mission selection should be guided by scientific excellence and the government's Science & Technology plan.

Canadian Space Telescope

Space science in Canada has come of age. Canadian industry supplies vital systems for international missions of opportunity, and Canadian space scientists have recently undertaken their own highly successful micro-satellite telescope mission, MOST. The community is ready to evolve to the next echelon by leading the design, construction, launch, and scientific analysis of a Canadian-led small to medium class space science satellite. While this mission would be Canadian-led, international participation should be considered, following a model similar to that adopted by most other nations whose national space agencies have progressed to the point where they chose to lead significant space science missions (e.g. Japan, India, Germany, Italy). This space telescope would generate new scientific insight, enhance Canadian industrial capacity, raise our training of highly qualified personnel to the highest international level, and, through demonstrating excellence in a very visible way, leave Canadian industry better positioned for future leadership of commercial ventures. A Canadian Space Telescope would embolden Canadian society by demonstrating the nation's capacity for engaging in cutting-edge science. The mission will have to be carefully designed to complement both the James Webb Space Telescope and next-generation large ground-based telescope projects. An ultra-violet mission is one exciting choice, because Earth's atmosphere is opaque to this radiation (so ground-based telescopes cannot probe it) but this region of the electromagnetic spectrum will not be probed by the James Webb Space Telescope. Furthermore, the vast majority of resonance lines for chemical elements lie in the ultraviolet, making this the optimal wavelength range for studying the interplay between the intergalactic medium and galaxy formation, which is one of the most important yet least understood areas of astrophysics. Two specific examples of possible Canadian-led missions are:

- A dedicated, diffraction-limited, UV-optical (~0.2–0.8 um) telescope with a 1m aperture that would offer Hubble Space Telescope-like resolution but with a ~100-fold increase in field of view. This wide-field imaging telescope would provide data that may reveal the nature of the dark components in the Universe and the evolution history of the Universe. The telescope would join together Canadian technology that has already been developed and is being deployed on other international missions of opportunity.

- A Canadian-led ultra-violet spectroscopic mission would be a small orbiting telescope equipped with a spectrograph capable of obtaining high signal-to-noise, low and high resolution (R = 1000 and 60 000) spectra in the UV regime (105 – 320 nm). It would have mirror aperture of about a meter or less, and be in low Earth orbit. A pivotal recognition is that, due to recent leaps in the quantum efficiency of UV detectors, a modest 0.5 – 1.0 m telescope can provide substantial improvements in sensitivity over IUE or FUSE.

The cost of these missions is likely in the range of $150-300M, with a portion of the funding likely coming from international contributions.

Challenges

The ambitious roadmap proposed above will be challenging to implement. The first challenge is to maintain a commitment at the national level to fund future Space Astronomy at something like the level of the current contribution to JWST. Commitment to large science projects in Canada is contingent on many factors, and a major complication is the highly distributed and somewhat amorphous way in which the government takes advice regarding major commitments that should be funded. Perhaps nothing would be more beneficial for the development of an ambitious Space Astronomy program than a very clear message, delivered in the LRP, of where the community wants to go next. Obviously, this is the context in which this White Paper is being written.

With the onset of JWST occurring halfway through the lifetime of the LRP2010 horizon, it seems certain that the profile of the CSA in the Canadian astronomical community will continue to rise. As this happens, a further challenge will be to ensure that the interface between the astronomical community and CSA becomes more seamless, as is presently the case (more-or-less) with the university community's integration with NRC through HIA. Although the Federal Government operates both CSA and HIA, CSA's mode of operation is considerably different from that of the HIA, with an emphasis on large industrial contracts and with relatively little day-to-day interaction with academic researchers. The resulting culture clash has, from time to, led to less than smooth implementation of funding commitments. Dealing with this has been a learning process on both sides. However, there is a clear impression that CSA is listening, and the appropriate mechanisms for smoothly interfacing with the academic community are now in place (most notably a Grants and Contributions program). Another example is the Space Science Enhancement Program, which promises to be a timely program for funding HQP. Further progress along this road is desirable, and the journey may be made smoother by implementing a process by which the astronomical community can inform the CSA of international opportunities (perhaps via RFIs) that in turn would enable CSA to respond to missions of opportunity more rapidly. At a higher level, we note that a major factor leading to closer integration between the CSA and the astronomical community is the camaraderie and mutual respect being developed by having academic researchers, CSA staff and engineers from industry working side-by-side on JWST. The natural conduit for these interactions has been a small group of in-house astronomers at the CSA. In the long run it is important that CASCA look for additional ways to engage with these astronomers, who have chosen to develop their careers at the CSA, but at the same time remain engaged in astrophysics and provide a natural line of communication with the CSA.