LRPIC report to the LRP2020 panel

Preamble

The Long Range Plan Implementation Committee was set up by CASCA on the recommendation of the LRP2010 panel, to monitor the progress of the Plan and report and advise as projects proceed. While the committee has no power to implement, it has taken on the task of following all LRP2010 and MTR2015 recommendations, and commenting or advising through the decade. LRPIC has held discussions at CASCA meetings, community-wide webex meetings, met at least monthly, and delivered reports throughout the decade. This report attempts to relate the history of the major LRP initiatives, and note issues that have arisen. Many of the projects have yet to be realized, and decisions and commitments are urgent for some. The coming decade may well be even more challenging, for reasons outlined here.

LRP2020 will have dedicated white papers on individual facilities and programs, so we do not here give details on the science or capability of LRP projects. We believe that our collective experience and expertise offer a useful perspective on the LRP process, and the events of the decade, which may guide thinking in preparing LRP2020.

SCOPE: the request from the LRP2020 chairs includes the following. “Within the purview of your committee, **what has happened since LRP2010 (and particularly since MTR2015), and where are we now? What do you think the LRP2020 panel needs to know to undertake prioritisations and to make recommendations? Note that this report should cover the past and present rather than making recommendations for the future.** It may be useful to explain upcoming decision points and what’s on the table as possible future options.

Overview

Overall, LRP2010 met with only partial success. Economic downturn, tough lobbying for individual items with federal governments, delays and political issues with CCAT, TMT, SKA, and JWST, declining CSA budget, delayed space policy, and unsuccessful efforts on Euclid and WFIRST. Generally, being a minor (~5%) partner on major projects put us out of control of our ambitions.

The table below lists the major LRP2010 facilities, and their evolution and status now. The text following goes into more detail and commentary on them. Note that the numbers in the columns are rough estimates for the most part - intended only to give the general situation.

Ground					
Facility	**Status**	**Share (%)**	**Funds ($M)**	**Success (% wrt full funding)**	**Community served**
TMT	Funding approved for in-Canada contracts. Project delayed 5 years and now protests a serious threat. Extra funding will be needed if and when construction proceeds. First light late in the 2020s. CATAC report for more details.	15	260	60?	all
SKA	Continued effort and 6% share defined. Money spent through the decade, but expected share not funded. Issues with membership. Forerunners in action (MeerKAT, ASKAP, CHIME) but SKA1 operation well into next decade. SKA2 a decade further away.	6	10	15?	all
MSE	Major involvement in design work and planning to date. Project now defined and costed but schedule not yet clear, and funding and partnership under CFI proposals. SOU signed by ACURA. First light well into next decade. Location and CFHT future depend on Mauna Kea politics.	17	5	10?	all
CCAT	Project shelved and replaced by smaller CCAT-prime. Canadian participation via university consortium seeking CFI funding. Construction now started. Canadian participation still needs definition. First light early in next decade.	10?	2	10	consortium
CHIME	The one project that was completed and is successfully operating. CFI funding and NRC infrastructure. Expanded science capability.	100	15	100	teams
JCMT	Partnership abandoned as ALMA ramped up as per LRP2010. Issues with ongoing interest and funding for time share. This has now ended but JCMT continues.	25 then 0	3	-	All to consortium

Arctic telescope	Several years of site investigation, but idea abandoned.	(100)	1	-	-
LSST	Not in LRP2010. The project is accepting only in-kind contributions for international partnerships. CADC and U T plans for data work in development	N/A	1-2	-	Group data access
Space					
WFIRST	Much time, effort, and funding spent on many aspects of joining, later mired in US cost-capping and uncertainty, and eventual failure to get government + GO share) funding. Not the LRP DE mission as hoped. On sky in mid of next decade.	~1	5	-	(team members + GO share)
Euclid	Too late to partner in hardware, but much time and effort in chasing ground-based ways to provide data. Small team partnership agreed via CFIS survey. Not the LRP DE mission as hoped. On sky early in next decade.	~3?	0	-	Team members
CASTOR	Has emerged as well-defined Canadian-led mission from a decade of studies. Wide science capability as well as significant DE contribution, and has substantial potential partners. No funding or govt approval at this point. On sky by mid-decade or possibly lost if Canada fails to commit.	40?	5	3?	All (plus DE teams?)
SPICA	Many years supporting participation and design work, now Canada has a potential hardware contribution. No funds and deadline in next year or two.	~5?	3	15	team
LiteBIRD	Canadian sensor readouts wanted and studies funded. Minor contribution needs commitment and funding. On sky in mid-decade.	~5	1	3	team
Hitomi	The only new space mission this decade. Hurried metrology unit delivered. Early mission failure. Follow-up XRISM mission	~3?	5	100	Team members

	has a few Canadians: ground calibration contribution.				
Athena	Participation in planning group but no hardware contribution defined or proposed. Launch late in decade, Needs LRP definition.	TBD	0	0	--?
JWST	From LRP2000, hardware delivered but substantial delays into 2021 launch has incurred extra and ongoing support commitment.	5	20	100	team+all
Astrosat	From 2000 LRP. Launched in 2015 and operating since. Minor support for science and operations. Ongoing collaboration in CASTOR-INSIST mission.	5	1	100	team+all

Money TOTALs for the decade

- funding achieved: $340m (mostly TMT)
- 25% average for LRP2010 missions
- $ 670 needed (TMT, CASTOR, MSE, SPICA)

Narrative of developments over the decade

ngVLA

Beginning in January 2015, the National Radio Astronomy Observatory developed a concept for ngVLA, based on input from the US and Canadian communities, including three science-focused meetings in the US in 2015-2017, from which the current concept emerged. NRAO also sponsored technical meetings to discuss radio technologies available in the coming decade. In 2017, NRAO opened a Project Office and Scientific and Technical Advisory Council. Canadians serve on each of these. Community engagement in ngVLA was furthered in three US science workshops in 2017-2019. The ngVLA project has been described at two Canadian workshops (Montreal 2017 and DRAO 2019). The ngVLA Science Book is published, with ~90 peer-reviewed chapters describing the range of ngVLA science. The Astro2020 process led to 86 science white papers that mention ngVLA - about 15% of the total. The ngVLA project is preparing for the Astro2020 panel a Reference Design for the project, and an independently reviewed estimate of construction costs. NRAO proposes that ngVLA include about 25% international contributions, and convened a workshop in May 2019 in Socorro where Canadian, Japanese, Mexican, and Taiwanese delegates discussed such contributions. The NRAO ngVLA team will meet with the Square Kilometre Array Organization in June 2019 to discuss

coordination between the two projects. Should ngVLA be endorsed by the Astro2020 panel, NRAO will submit a proposal to NSF in 2021 for funds for 13 years of design and construction, commissioning, and early science. Full ngVLA operations would then begin in Q2 2034.

The development of composite dishes at DRAO over the past decade or so, is a significant possible Canadian entry to ngVLA.

TMT

The details of TMT through the decade are given in the CATAC report. For completeness, it is noted here as a major LRP priority that almost made it. Funded at 80% of the requested level, and starting construction in 2015 (one year late, due to the delay in Canada's contribution), things were good. The subsequent protests and delays for further legal processes have prevented construction restart and have contributed to a significant increase in cost. It remains an unfinished LRP 2010 project.

The delay to TMT, and the uncertainty over future funding requirements and viability of the site have impacted other LRP priorities, most notably MSE. In particular it has been difficult for NRC and, to some extent, the University community, to fully support MSE development while these uncertainties linger. Other emerging ambitions in ground-based optical/IR astronomy have suffered to some extent from the fact that TMT construction has not yet restarted.

Whether and how the Mauna Kea protests are resolved could have a major impact on all MK facilities, and also on our LRP2020 plans. This will likely unfold throughout the LRP process, and possibly be quite divisive.

SKA

The centimetre-wavelength Square Kilometre Array (SKA) was listed as the second priority in the 2010 LRP, with the plan that SKA construction funds would eventually supplant the TMT at the top as the latter would be built by the end of the decade. Both projects have been delayed well beyond the 2010 projections.

The SKA project as a whole has made substantial progress in the decade. The SKA Organization was formed in 2011 to steer design and pre-construction activities, and Canada is a member with input into governance. Headquarters were established at Jodrell Bank, UK, in 2015. The project has been phased into two stages, with Phase 1 (SKA1) currently finishing a set of Critical Design Reviews and construction start currently anticipated in mid-2021. SKA1 is intended to be 10% of the collecting area of the ultimate SKA2 telescope. The two original drivers for SKA1 were tests of fundamental physics with pulsars and black holes and the history of neutral hydrogen in the Universe, while the other science goals (galaxy evolution, cosmic magnetism, cosmic dawn, cradle of life, transients, etc.) now also form a set of High Priority

Science Objectives that drive the SKA1 design. SKA1 was re-baselined in 2016/7 to account for increases in cost, with some, but not fatal, reduction in science capabilities.

The site decision in 2012 benefited both potential host countries, with South Africa hosting the SKA1-Mid dish-based component, building from the MeerKAT precursor, and Australia hosting the SKA1-Low aperture arrays (design still being finalized) and using the ASKAP precursor to investigate the potential of phased-array feeds in later versions of the higher-frequency dish component.

The various SKA1 subsystems have been developed by international consortia, with Canada (NRC with MDA) leading the Central Signal Processor (CSP) and achieving a coup by designing an improved SKA1-Mid correlator that meets performance requirements but with an estimated 20M Euro savings relative to the original design. Unfortunately the proposed Canadian composite dish technology was not selected for use, although Canada did develop low-noise amplifiers and digitisers for SKA1-Mid through the Dish Consortium.

A CFI grant to several Canadian universities (PIs Gaensler and Rosolowsky) is leading to the establishment of a radio data centre (CIRADA), which could be a prototype for a future Canadian SKA Regional (data) Centre.

Many Canadian scientists have joined and led various SKA Science Working Groups, and four of those working groups have been chaired by Canadians in the last five years. Canada has been represented on the Science and Engineering Advisory Committee by Spekkens since 2017, with Stairs taking over in mid-2019. A poll conducted in 2015 for the LRP Midterm Review indicated that roughly 30 Canadian researchers anticipated spending 25% or more of their time on SKA-related projects in the early science stages.

The mandate of the SKA Organisation is to oversee pre-construction activities, and Canada has a governance role in that process through its two positions on the Organisation's Board of Directors (Rupen and Spekkens are the current Board members, taking over in the last year from Fahlman and Gaensler). SKA governance during construction and operations lies with a treaty which will replace the SKA Organization by the SKA Observatory intergovernmental organization (IGO). Canada does not intend to sign the treaty in the immediate future, but will become an Associate Member through an accession process to be finalized by the IGO Council. This should still provide Canadian astronomers with reasonable access to the telescope, although the details are still being worked out. The nominal share for Canada stands at 6%, but funding has yet to be provided.

MSE

As noted in the MTR report, redevelopment of the CFHT site has been discussed in the Canadian community for two decades. The 2010 LRP recommended further development of the concept to build a wide-field dedicated spectroscopic survey telescope on the site. At the

time of the MTR, the estimated cost of this facility was about $250-$300M (2015); assuming equal shares among six partners this would represent a $40M contribution from Canada. The MTR supported this project, now known as the Maunakea Spectroscopic Explorer (MSE):

> *Recommendation: The MTRP strongly recommends that Canada develop the MSE project, and supports the efforts of the project office to seek financial commitments from Canadian and partner institute sources.*

The MTR recommended spending $5M in 2016-2020; a new request over LRP2010 but anticipating most of the construction funding would come after 2020.

In 2018, both Texas A&M and NOAO joined the project as observers, and a new call for science team membership increased the size of the team to over 380 (from 100). 2018 also saw the CFHT SAC and Board provide strong endorsements of MSE. Specifically, the SAC endorsed MSE as "the scientific future of CFHT", and recommended proceeding to the Preliminary Design Phase. The Board stated:

> *The Board resolves that the Maunakea Spectroscopic Explorer (MSE) is the scientific future of CFHT and affirms its intention to work towards an expanded MSE partnership to design, build and operate this transformational spectroscopic survey facility*

The partners conducted a major subsystem conceptual design study (2015-2017) which resulted in a revised budget of US$424 (about $520M Canadian dollars), including 20% contingency. US$8.7M has been spent on MSE, up to completion of the Conceptual design phase, which went through a successful review in January 2018. The project is now negotiating a Statement of Understanding to proceed to the two year preliminary design phase, which has an estimated cost of US$25M. The ACURA Board is recommending that their Institutional Council approve ACURA signing this statement, hopefully at the upcoming CASCA meeting. This is a sign of ACURA's support for MSE as a project discussed in the Canadian Astronomy LRP and MTR, though of course long-term support is contingent on MSE obtaining peer-reviewed funding, e.g. via CFI. A technically paced schedule anticipates construction starting in 2023, with science commissioning starting in 2029.

The next critical stages of technology development have been defined by the partnership (Canada, France, Hawaii, India, China, Australia) and coordinated through the MSE project office. Preliminary design of the spectrograph (led by LAM, collaborating with CRAL and CEA) began in 2019. Five overarching technology work packages have been identified for Canada: Enclosure, science instrument package (low and medium resolution spectrographs, and fibre transmission system), telescope structure and control, prime focus assembly and program execution software. To support this work, a 2020 CFI application is being prepared, led by Colin Bradley (UVic), with ten partner institutions (UVic, UBC, Manitoba, Waterloo, York, McGill, Laval, Toronto, Western, St. Mary's). It awaits other universities' approval at the time of writing. The proposal has industrial support from several companies in Quebec, Ontario and BC, as well as excellent support from NRC-Herzberg, CFHT, MSE Project Office and other interested parties including UH, Texas A&M and McQuarrie University (Australia). The request is for about $30M worth of technology design work and, if successful, will be followed up with a second

proposal for $40M to complete construction by 2027. This would provide approximately a 15% share in the project.

As a spectroscopic survey instrument, MSE has a natural synergy with many other facilities. Most crucially it relies on deep imaging from well-calibrated, homogeneous surveys covering a wide area of the sky. A crucial development here has been the formation of the UNIONS collaboration between CFIS and Pan-Starrs, together providing deep *ugriz* imaging over 5000 square degrees of northern sky (>30 degrees). This provides a significant portion of the ground segment for Euclid, thus providing access to that survey for about twenty Canadian PIs. For coverage of the significant amount of sky below 30 degrees, MSE (and Euclid) will likely rely on LSST imaging. While participation in Euclid and LSST may not be strictly necessary to access the data needed for MSE target selection, it would be an asset.

At the meeting of the Institutional Council (IC) of ACURA in Montreal June 21, 2019 a motion to sign the MSE SOU was discussed at length and passed unanimously. The Board of Management had previously discussed and recommended this action to the IC as of March 1, 2019 in a special meeting called for the purpose. The project needs a legally established body in Canada to sign the SOU to keep Canada associated with the project as it moves to the next phase in which a preliminary design will be developed by the partners. It was pointed out that our signature will encourage other partners to take the same step so it is a critical piece in the evolution of the MSE. It was also noted that this is not intended to be seen as jumping the queue for LRP2020, but merely a holding position. The full SOU document is available for the LRP panel, as far as we understand it.

Given the current standoff on Mauna Kea, it is clear that the MSE project needs to develop plans for an alternative site, and possible associations with facilities in Chile are in early discussion. The current partnership remains robust for the time being. The situation will unfold during the LRP process, so much attention and care will be needed in what is in LRP2020. .

CCAT and CCAT-prime

In LRP2010 the 25-metre CCAT was one of three mid-scale projects listed. Although a funding proposal for this was very favourably reviewed by CFI, plans for the large (and expensive) dish were put on hold until NSF funding becomes available to the US partners. In 2016 the CCAT team realized that a small, much less expensive telescope with a very wide field-of-view could be constructed and, because of the combination of the wide field and excellent site, it would enable exciting science projects. This was the beginning of CCAT-prime.

CCAT-prime is a 6-metre diameter telescope that is currently being fabricated by an international team with members in the US, Germany, Chile, and Canada. It will operate at submillimeter to millimeter wavelengths from a site at 5600 meters on Cerro Chajnantor in Chile. It will undertake large scale surveys that will place new constraints on dark energy and on

neutrino masses, while others will trace the dust emission responsible for the far infrared background, and the dynamics of the interstellar medium in the Milky Way, the Magellanic Clouds, and other local galaxies.
The summit of Cerro Chajnantor is the best (known) site on Earth for submillimeter astronomy; it has the lowest known precipitable water vapour, hence the most transparent atmosphere, crucial for work at 350 microns, something the Canadian partners hope to capitalize on by building a 350 micron camera for first light as part of the proposed Prime-Cam. Prime-Cam will be a multi-wavelength imaging and spectroscopic camera, one of the two first generation instruments for CCAT-prime. The other is a fully funded high resolution spectrograph known as CHAI that is currently being fabricated by the German and Chilean partners.

The CCAT-prime project involves four partners, Cornell University, a German consortium including the Universities of Bonn and Cologne, the Canadian Atacama Telescope Consortium or CATC (consisting of Waterloo, UBC, Toronto, and Alberta), and the host country, Chile.CATC aims to provide about 15% of the funding for the telescope and instruments, including the 350 micron camera..

Funding for the fabrication of the telescope, amounting to $30M USD, is secured through a mix of private and public money in the US and Germany. Fabrication of the CCAT-prime telescope began in March of 2019, with the final design review to occur in November 2019. The project plans a trial assembly in Europe, to be completed by December of 2020, so that the telescope can be disassembled and shipped to Chile in May of 2021. The installation is scheduled to be completed by August of that year, when commissioning will begin. March of 2022 should see the start of instrument installation, with first science by January of 2023.

CHIME

CHIME is a dedicated experiment to measure integrated 21cm emission from redshift 0.8 to 2.5. This yields precise constraints on Dark Energy, and volume maps of large scale structure. It was built with $11M CFI funding awarded in 2012 and saw first light in September 2017.

In LRP2010, CHIME benefitted from being the highest ranked mid-scale project. LRP assigned it an estimated cost of $15M (35% higher than its achieved cost) and the recommendation came with the caveat that "costs are uncertain as is the technical feasibility". CHIME is the only new LRP2010 facility that has been built.

CHIME was extended to trigger and record fast radio transients with a $5.5M CFI grant in 2014.The telescope is producing world-leading science, with several hundred fast radio burst detections, and key publications in the field.

CHIME also has an instrument funded by NSERC RTI-1 to track and time up to 10 pulsars simultaneously; this instrument is operational and systematics are being investigated and

mitigated. The CHIME/Pulsar team has a data-sharing agreement with the North American Nanohertz Observatory for Gravitational Waves (NANOGrav) pulsar timing array consortium, so that CHIME pulsar observations can contribute to the aim of detecting low-frequency gravitational waves.

Operating costs for CHIME are about 2-3% of its construction costs. Operating funding exists for 5 years (began late 2017), after which time no operating funds are planned. While a decommissioning plan for the telescope exists, the question of whether to keep operating the telescope will be a key question for Canadian Astronomers.

LiteBIRD

The LiteBIRD mission will map polarized fluctuations in the Cosmic Microwave Background (CMB) to search for the signature of gravitational waves from inflation, opening a window on the universe a fraction of a second after the Big Bang. With three 5K-cooled telescopes, it will measure in 15 frequency bands between 40 and 402 GHz with 0.1K bolometers,

LiteBIRD is a JAXA-led mission that includes major planned contributions from NASA (the bolometer focal plane and cryogenic readout circuits), CNES/ESA (the mid- and high-frequency telescopes), and Canada (the detector readout system warm electronics). On May 21, 2019, the project was selected as a strategic large mission in Japan, and transitioned to phase A1. Launch is planned for ~2027.

Canada plays a key role in LiteBIRD, with hardware, software, and data analysis contributions. The Canadian DfMux bolometer readout system, first demonstrated with CSA funding on the EBEX stratospheric balloon mission, is a key element of for the telescope. One risk for the project is that the JAXA cost cap has not allowed for scenarios where a foreign contributor opts out. This means that a failure to move forward in the US, Europe, or Canada with the planned contributions will jeopardize the mission.

In Canada, LiteBIRD has been developed with STDP technology funding ($750K, 2012), a Mission Contribution Study (~$300k, 2018), and a Science Maturation Study ($150k, 2019). A draft AO that would provide modest (~$500K) technology development funding through STDP was published in 2019, and new Phase 0 funding is expected for 2019. LiteBIRD had not yet been conceived in 2010 and was not considered for LRP2010. CMB polarization appeared as the highest ranked mid-scale space project in MTR2015.

Hitomi/XRISM/Athena

Participation in Astro-H, renamed Hitomi after launch, was Canada's first involvement in an entirely X-ray observatory. By 2008, the JAXA-led mission was mature, but the absence of a metrology system to measure the position of the extensible bench was noticed. Making use of

Canadian heritage in active sensors, Canada proposed to provide the Canadian Astro-H Metrology System (CAMS) in return for science participation on the mission. This resulted in three Canadians named to the International Science Working Group, who could also involve their postdocs and students.

Hitomi experienced a catastrophic failure six weeks after launch, but nevertheless generated over one-dozen science papers. A de-scoped, rebuild mission (XRISM) was highly prioritized by NASA and JAXA. The CSA and NASA appointed Luigi Gallo to the International Science Team and Brian McNamara to the Resolve Instrument Team, which is XRISM's prime camera. Resolve is an X-ray microcalorimeter camera, and the most advanced X-ray spectrometer ever built. Canadian scientists will have access to XRISM observations in exchange for filter calibrations being measured at the Canadian Light Source, the Advanced Light Source in Berkeley, and other facilities. The expected launch date is early 2022.

The ESA-led Athena mission is the next flagship X-ray mission set to launch in 2031. Over the past decade there has been significant push from Canadian astronomers to participate in Athena. There have been opportunities to contribute to the warm electronics on the X-IFU (calorimeter) as well as opportunities to contribute spacecraft components to ESA (e.g. metrology, heaters, star-trackers….). To date, there has been no significant progress on this front.

WFIRST/Euclid/CASTOR

LRP 2010 listed a **dark-energy mission** as the top space priority. The nominal budget was stated as $100m, which puts it at a level similar to our JWST participation. That was the main intention, given that no costing or level of partnership had been established. The identified missions were Euclid, WFIRST, and a proposed Canadian-led complementary mission at shorter wavelengths.

1. **Euclid** was already under way. CSA supported a few individuals to participate in Euclid plenary and team meetings. It was clear right away that there was no hardware contribution available, especially at the LRP-suggested level. It was also noticeable that CSA was not regarded as a reliable partner by the Euclid team, as the chronic shortage of funds was apparent to all, even then. There was interest in Canada providing short-wavelength ground survey data, and CFHT and PanSTARRS were approached, both without success for the survey scale wanted. Eventually, via the CFIS survey program, a small group of Canadians has been accepted into the very large Euclid team. This is far from the LRP goal of a major DE mission participation.

2. Participation in **WFIRST** was then pursued, bearing in mind the late entry and lessons learned from the Euclid experience. CSA funded studies of a range of mission contributions, in full consultation with NASA, and these were narrowed down for more detailed study, with the

expectation that one or two wanted contributions would be offered. CSA engaged a project leader and team of astronomy advisors to participate in the process. The lack of funding for significant hardware persisted, but a proposal for an IFS contribution acceptable to NASA was in CSA's new funding request to the government. At the time, WFIRST NASA costs escalated, and a review placed the IFS on the descope list. There were further negotiations to save the IFS, with and without Canada, but eventually the government did not approve the funding and WFIRST was taken off CSA's wish list. Discussions on minor ways to be in the mission continue, but again the result is nowhere near the level of the LRP goal.

3. The Canadian wide field UV-blue telescope (thence named **CASTOR**) emerged from an extensive CSA concept study as a 1-metre-class wide field high-resolution telescope. The concept has had wide international interest as a significant UV facility to follow HST, GALEX, and UVIT, with science applications far beyond the DE support for Euclid and WFIRST that drove it initially. The cost is more than the LRP nominal amount, and has always been seen as a major difficulty, given the inadequate CSA budget. Further technical studies (detectors and optical coatings) advanced the mission, and the LRP-MTR called for a phase 0 study to clarify the design and cost, as it remained the only way to fulfil the LRP2010 top priority for space. Currently CASTOR has completed an extensive SMS, equivalent to a phase 0, and also has attracted serious and major partnership possibilities with IIA-ISRO and JPL-NASA. It is now regarded as urgent that CSA negotiate these partnerships and commit to the mission.
A leadership share of this potential partnership is in discussion, and will require of order the nominal $100m funding that LRP2010 mentioned.

The process of having to get government approval and funding for individual space missions remains a major stumbling block to achieving a meaningful LRP for space astronomy. It is also eroding our international reputation.

SPICA

The project has a long history of Canadian interest and preparation, that extends over the past decade. In June 2008, the first first SPICA contract was awarded to U Lethbridge via a CSA call for potential Canadian contributions to ESA Cosmic Vision missions. Tasked with identifying a meaningful role for Canada in the SPICA mission, it was initially conceived as similar in scope to Herschel (~$20 M).
In 2009, project funding issues resulted in SPICA lead moving from UK (RAL) to Netherlands (SRON). As a result SRON had to offload some of its assigned work-packages, and the High resolution FTS became available. Recognizing that this prestigious role was well matched to Canadian signature technology, academic strength and is mission critical, this opportunity was brought to CSA's attention and U.Leth was tasked with exploring Canadian role.

During 2008 to May 2016. U Lethbridge received three successive SPICA study contracts to establish a role in the mission for Canada. The work focussed on exploring the optimum solution

for the SAFARI high resolution spectrometer, which started as a Mach-Zehnder Fourier transform spectrometer. then briefly a Fabry Perot interferometer, before being consolidated as a polarizing Martin-Puplett Fourier transform spectrometer. Thence the following sequence of events:

. SPICA FTS Mechanism Phase 0 (Industrial contract awarded to ABB ended June 2015).
. SPICA proposal submitted to ESA's M5 call 5 October 2016.
. 7 May 2018 ESA selected SPICA as one of 3 finalists for M5
. 2015 STDP Cryogenic Translation Mechanism for FIR Astronomy (to spring 2019).
. 2016 -SPICA FAST Grant (A07 UL) Cryogenic Fabry-Perot for SAFARI (to March 2019).
. May 2019 STDP to raise SAFARI cryogenic FTS mechanism TRL to level 5.
. Final M5 submission deadline spring 2021.
. SPICA is the most advanced of the 3 mission finalists under ESA's M5 call and with the $300 M committed by JAXA enables an L-class mission for M-class funding.

Over the decade from 2008 to 2018, the CSA invested over $2.5 M in the SPICA project to establish and preserve a major role for Canada in the SAFARI instrument. As a result of this investment Canada is positioned to build the mission-critical, high resolution spectrometer of the leading infrared space observatory of the coming decades. Furthermore as a founding member of the SAFARI consortium, Canada's return on investment will be at least twice that of the highly successful Herschel space observatory. Canada is seen as a partner of choice and is now positioned to fully exploit the SPICA mission. This therefore remains a project that will soon need Canadian commitment and funding.

Data and Computing

The funding and management of digital research infrastructure (DRI) in Canada continues to present challenges. While CASCA has participated extensively in various Compute Canada capacity surveys, and on various committees, the past few years have seen computing infrastructure fall behind our competitors. This applies in both the data analysis and simulation sub-fields.

Following researchers expressing concerns about DRI capacity, Budget 2018 announced $572.5 million over 5 years in support of developing a national DRI strategy. The ISED Ministry announced an open call for proposals to manage this new national infrastructure/org, which ended after only a handful of weeks. Consequently, the only organization likely to input something into the competition was the U15 on the back of the Leadership Council for DRI having consulted extensively over the past four years. A steering committee of Gail Murphy (UBC), Lori MacMullen (UNB), Guillaume Borque (McGill) and Rafik Gourbran (Carleton) lead the proposal development. (The proposal guidelines required that any submission be endorsed by the U15 group and that each group could only submitted one proposal. The U15 determined to submit their own proposal rather than endorse a proposal from a separate group)

There was significant lobbying of the EngageDRI group from researchers nationally, including CASCA, the physics community and CADC. This lobbying focused on expanding the consultative role for the research community.

The submitted proposal is short on precise details, and is more a framework for a plan. A not surprising situation given the lack of time. One of the key steps is to form an Applicant Board which will govern the incorporation of the new organization. One of the key concerns about Compute Canada has been regional and researcher representation, and the new organization proposes a User Council that advises the Board and will have two members on the Board. A further 25% of Board members are suggested to be independent, but beyond that the precise mechanism for choosing Directors is not yet clear. Maintaining awareness of the selection process and connections to the Applicant Board will be important for our community.

A number of key milestones in setting up the organization are laid out in the proposal, with the operation of the Applicant Board being from July to December 2019, leading to the establishment of the inaugural Board in early 2020, with a view to hiring the CEO by June 2020 who in turn will lead the strategic planning process.

While the organization develops Compute Canada will continue to build our capacity.

Led by James Wadsley, the CASCA CDC constructed a letter of support for the proposal. The key concern for our community is to ensure that our voice is heard through the consultation processes. There is great potential for a new organization to to be adequately representative and responsive, and there is cautious optimism that many of the lessons learned in the three different versions of Compute Canada can be carried over.

However, in any national organization specific interests tend to be subservient to the whole organization. It may be that the best interests of computing for astronomy would be served by an astronomy-specific data centre as has been tried in other countries.

Recently, the Ontario Government was unwilling to match a new tranche of CFI funding to Compute Canada. As a result of this decision and larger than expected portion of the recent hardware bid will go to WestGrid. This is some
what beneficial to CANFAR which is, largely, operated inside WestGrid.

LSST

It is notable that the LSST is missing from the entirety of the LRP 2010 white papers. However, in a recent survey, roughly 25% of Canadian astronomers now strongly desire access to LSST data products, either in real time or as data releases. A number of influencing factors occurred through the decade. Much of this was a matter of timing, in that the bulk of funds required by the

NSF to guarantee that the LSST would be built were not awarded until roughly 9 months after the completion of LRP 2010. More practically however, Canadians were unaware of many policies regarding international membership (some policies were yet to be set) in the LSST - in 2010 it was unclear if international membership was even allowed. Moreover, the Canadian community was yet to fully appreciate the difficulty in generating the necessary funds for membership, a fact that was likely exacerbated by the continued delay to TMT construction. Finally, there was a lack of overall ownership of, and leadership of a white paper specifically addressing Canadian interests in the LSST. All of these factors produced an atmosphere of uncertainty, and so it may not be surprising that the LSST was not in LRP2010.

Since 2015 a small group of Canadians became individual LSST members, thanks in part to a funding initiative by the Dunlap Institute. This involvement was acknowledged in the MTR report, as were the various synergies with other proposed and existing Canadian facilities. Very recently, LSST has announced that international partners will be engaged strictly via in-kind contributions. This opens up the possibility of national participation through CADC or other contributions

There are two fronts being pursued:

- Develop an in-kind contribution to LSST that would be significant enough as to provide national level data rights. This would likely involve approaching NRC to fund this activity as part of its mandate to support Canada's ground based telescope.

- Renee Hlozek / UoT-Dunlap leading a CFI proposal to build out the computing systems needed to enable science with a Canadian LSST Alert Science Platform. Such a platform would be open nationally.

CADC has had discussions with the LSST team and people at the NSF on how Canada can become a full partner in the project. CADC hosting the Public LSST dataset and providing world-wide access to that dataset would make a valuable and substantial contribution. In addition, CADC is providing (has been for sometime) consultation support to LSST on software issues [LSST is using openCADC implementations of Virtual Observatory protocols to enable VO access modes for LSST]. The ongoing software consultation and provisioning of a Public archive would be a significant enough that this should provide national access. Agreement on that would come through negotiation between NRC and NSF/DOE after agreement in principle from the LSST BoD. A call for Letters of Interest to provide InKind contributions is expected in November with responses completed by March 2020.

A three-pronged approach is envisioned, in which NRC would fund some base infrastructure (storage and archive systems) to enable Canadian access, CFI would fund a project to build the computing platform that will enable effective use of that access, and Dunlap/UoT/Waterloo and NRC would partner to enable a national Canadian LSST Fellows program.

The cost of the ‘public archive’ will be driven by what LSST expects it to provide. $1-1.5M / year may be appropriate.

We note that LSST has critical synergies with many other LRP priorities, most notably CASTOR, MSE and TMT. The extent to which LSST partnership is required to maximize and exploit these synergies remains unknown at this time.

LRP2010 project summary lists and notes

Successes

- CHIME completed and functional. Exceeded expectations and scope widened to enable pulsar and FRB science.
- Hitomi CAMS delivered and flown in short time. 3 Canadians on science team. Unfortunate demise of mission soon after launch.
- TMT approval with specific funding at ~80% level of ask. But project delayed
- JCMT left as per LRP and ALMA operating with significant Canadian success
- (LRP2000) Astrosat launched and operating, now in 5th year. CSA science support.
- (LRP2000) JWST hardware delivered and supported to and beyond launch. Delays far beyond what was expected in 2010.
- BRITE satellite constellation joined and operating.

Abandoned

- Euclid and WFIRST participation as major dark energy priority
- CCAT project abandoned. Replaced (with TBD Canadian share) by CCAT prime.
- Arctic telescope, after several years of site testing.
- (LRP2000) MOST decommissioned

Delayed significantly TMT, JWST

Still unfunded for partnership SKA, SPICA from LRP2010
MSE, CASTOR, LiteBIRD, CCAT-prime since MTR2015

Limited participation LSST, Euclid, XRISM

Was there a good balance of facility for all and expert team/group only?
(Yes, but we consider wide community access vital for large projects)

Major partnerships/leadership expected in TMT, MSE, CASTOR only
Major new funding needed for these, plus SKA – all are urgent if we are to remain in them.

Funding has been obtained or managed via CFI, NRC, CSA. It is notable that there are several LRP-associated facilities now seeking CFI funding. This may incur some perceived competition among projects, and thus need careful LRP2020 attention.

LRPIC has noted and listed what was successful in the LRP2010 and MTR 2015 reports, and also where there were difficulties and unpredictable changes that might be considered in LRP 2020 planning. These have been transmitted to the LRP 2020 panel.

What has appeared since LRP2010?

ngVLA
Hitomi, XRISM, Athena
MSE and partnership
CASTOR partnerships, LiteBIRD
CSA studies and proposals Colibri, EPPE, POEP
Operating NEOSSAT, BRITE in space
CFHT, Subaru, Gemini partnerships
Exoplanet science
FRBs and Pulsars with CHIME
GW events
Political issues potentially affecting all Mauna Kea facilities.

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B. McNamara, N. Murray, I. Stairs, R. Abraham, R. Kothes, J. Rowe, R. Thacker