Draft version December 17, 2014
Preprint typeset using LaTeX style emulateapj v. 05/12/14

# CASCA GROUND-BASED ASTRONOMY COMMITTEE: REPORT TO THE 2015 LONG-RANGE PLAN MID-TERM REVIEW

P. Barmby[1] C. Heinke[2] J. Hutchings,[3] G. Joncas,[4] L. Parker,[5] E. Rosolowsky,[2] J. Willis[6]

## 1. INTRODUCTION

This report updates the status of Canadian ground-based observatory facilitiesand presents the recommendations of the CASCA Ground-based Astronomy Committee (GAC) to the Mid-Term Review panel. Canadian astronomers are fortunate to have access to a wide variety of ground-based telescopes. Each of these facilities fills a unique need, and many serve dual purposes, for example science and instrumentation development and/or student training. In an era of multi-wavelength astronomy, the GAC believes that Canadian astronomers need access to multiple world-class facilities. As these facilities become more and more expensive and the landscape of world astronomy changes, our relative share of facilities will likely be smaller than it has been in the past. As experience with ALMA shows, Canadian success is possible even with a $\lesssim 10\%$ share of a world-class telescope; we hope that the community will find a way to advocate for access to multiple such facilities.

Background information on current and future facilities and their capabilities are given in Table 1[7] Figures 1 and 2 compare papers produced and average impact per paper of both the telescopes discussed here and their comparators. All of our large overseas telescopes are highly productive, with CFHT in the top quartile and Gemini in the top half for both papers produced and impact per paper. Canadian oversubscription rates for overseas telescopes have historically between 2 and 4 but with substantial variability depending on, e.g., instrument availability.

## 2. EXISTING FACILITIES

### 2.1. *Small telescopes in Canada*

Small telescopes at Canada's national observatories, DAO and DRAO, remain productive and well-subscribed. The DRAO's 7-element Synthesis Telescope has completed the Canadian Galactic Plane Survey, a panoramic radio survey with arcminute resolution, and is now in (oversubscribed) proposal mode. Working with the single-aperture 26-m Galt radio telescope at DRAO, it is arguably the world-leading instrument for wide-field imaging of polarized low-frequency radio emission. The Galt Telescope is also used for spectral surveys like the Global Magneto-Ionic Medium Survey, and its electronics and receivers are undergoing a major overhaul. The DAO's 1.8 m and 1.2 m optical telescopes are in good condition, have subscription rates $> 1$, and produce $> 10$ refereed papers/year, covering a wide range of topics (e.g. stellar magnetic fields, SN spectroscopy, solar system). 60-70% of time on the 1.2 m is now automated observing; automating the 1.8 m is the next DAO priority.

University observatories are generally shifting to outreach and student training, with Toronto's David Dunlap Observatory now leased to the Toronto Centre of the RASC to run astronomy education and outreach programs. The exception, OMM (Observatoire du Mont-Mégantic) run by Université de Montréal and Laval, operates a 1.6 m telescope with wide-field IR and/or optical cameras in queue mode. Optical and/or infrared spectrographs (plus the above) are available in classical mode. OMM time is available to the full Canadian community, and is oversubscribed by a factor of 1.6.

Partnerships between our national facilities and major universities have enabled innovative, relatively inexpensive new telescopes to be developed quickly to pursue compelling science. The Canadian Hydrogen Intensity Mapping Experiment (CHIME) is an \$11 million partnership between UBC, McGill, Toronto, and the DRAO. CHIME will map the intensity of the redshifted 21-cm H line over redshifts from 0.8 to 2.5, across half the sky. The experiment will measure baryon acoustic oscillations over the time period when dark energy's effect on the universe's expansion begins to dominate. It was the highest ranked mid-scale project in the LRP, and has received CFI and provincial funding. A reduced-scale "Pathfinder" telescope is currently gathering data.

The NRC-HIA and Toronto have studied the advantages of mountain sites on Ellesmere Island in the Canadian High Arctic; months of continuous darkness, high clear-sky fractions, and excellent (median $0.72''$) seeing. Further development of the High Arctic is not a priority for NRC in the current ten-year plan, though an exoplanet transit survey with a small telescope is ongoing. **We recommend that the national observatories retain the staffing and financial capability to operate the DAO and DRAO, and assist in the development of novel small telescopes, sites, and instrumentation.**

### 2.2. *Canada-France-Hawaii Telescope (CFHT)*

CFHT celebrates its 35th anniversary in 2014. Changes since the 2010 LRP have included completion of the first round of large projects in 2012B and initiation of a second round in 2013A, decisions to proceed with two new instruments (SITELLE and SPIRou), and addition of several new associate partners (Korea, China). SITELLE is due to arrive at the telescope in

[1] University of Western Ontario
[2] University of Alberta
[3] NRC Herzberg Astronomy & Astrophysics
[4] Laval University
[5] McMaster University
[6] University of Victoria

[7] Subaru and the JVLA are used by a small number of Canadian astronomers and are not under Canadian control; they are listed in Table 1 for completeness but are not extensively discussed in this report. Single-experiment facilities such as the South Pole Telescope are also not discussed here.

early 2015 and SPIRou in 2017. The 'ngCFHT' proposal to upgrade the telescope has been renamed 'Maunakea Spectroscopic Explorer' (MSE) and is discussed further below. The CFHT's immediate future contains some tension between various events: the arrival and commissioning of the new instruments, particularly SPIRou; the desire of community members from both France and Canada to use CFHT for extremely large (> 100 night) surveys either with SPIRou or SITELLE or the existing imagers; and the possible deconstruction of the telescope so that MSE construction could begin. Operation of UKIRT by CFHT, with SPIRou as the sole instrument, could provide a way for all of these future events to occur, but there are many administrative obstacles and its unclear if this will be possible. Recommendations for the future of CFHT are discussed in §**??**.

### 2.3. *Gemini*

The Gemini partnership has evolved since the writing of the LRP. The UK has now left and Australia will pull out at the end of the next partnership agreement (end of 2015). When the UK left the partnership the other partner shares increased, but when Australia pulls out there will be a need for new partners and funding to pay for Gemini operations. Australia, at least for 2016, will continue to contribute to operations costs in exchange for observing nights and starting in 2015 Korea (KASI) will do the same. The plan is for KASI to eventually join the partnership at approximate the level of Australias share. There have also been significant changes in proposal modes available at Gemini with the introduction of large and long programs (LLP) and fast turnaround programs, starting in 2015. Canadians fared well in the first round of LLP; it is anticipated that this will be a popular observing mode with Canadian proposers and may increase our oversubscription rate on the telescope.

Gemini is now operating on a bare-bones budget, but has funding earmarked for the next two instruments. The next instrument to arrive at Gemini will be GHOST, which promises to be a workhorse high resolution optical spectrograph ideally suited for studies of stellar chemical abundances, precision radial velocities and follow-up of transient objects (targets of opportunity). The instrument to follow GHOST is not yet well-defined but there is process underway including feasibility studies. While the instrument is also planned to have workhorse capability, it is clear that the US community is keen for this instrument to have synergy with the LSST. Pressure at Gemini is not very high, but the impact of Canadian research from Gemini is higher than the for other partners, and will likely go up with the new large and long programs. Gemini will never be a wide-field telescope and so our continued involvement requires that Gemini continue to offer innovative and efficient science opportunities for small fields. **For the remainder of this LRP the GAC recommends our continued involvement with Gemini, but looking beyond the next few years it will be important to evaluate the costs and benefits of membership in the Gemini partnership in the context of other facilities, particularly our level of involvement in the TMT.** While the Gemini white paper gives several reasons for continued involvement in both Gemini and TMT, there is significant scientific overlap between these facilities.

### 2.4. *Atacama Large Millimetre/submillimetre Array (ALMA)*

Since LRP2010, ALMA has embarked on Early Science operations and concluded its construction phase. The first Early Science call for proposals (Cycle 0) issued in March 2011 has been followed two more calls, on roughly annual timescales. These calls have attracted a record number of proposals globally. Early science and science verification data have already led to over 150 papers. In October 2013, the final ALMA antenna was delivered to the observatory, marking the end of the construction phase of the telescope. Even so, not all of the antennas are integrated into the array and many of ALMAs capabilities are still being commissioned. The observatory has a development plan in place and is steadily developing all of the planned capabilities of the telescope. Notably, long baseline capabilities were recently demonstrated by the observatory leading to a broad impact public press release showing the disk around HL Tau. The remaining major construction hurdles are (1) full commissioning of all antennas, including the integration of the ALMA Compact Array and ALMA Total Power antennas, (2) outfitting all commissioned antenna with all receiver bands and (3) development of polarimetric capabilities, primarily in continuum modes. ALMA capabilities are being developed into the future through the ALMA Development program. The Canadian community is involved in the development of ALMA Band 1 (30–50 GHz) and in software to improve the scientific exploitation of ALMA results.

The Early Science results demonstrated by the telescope are impressive and it is clear that the fully commissioned telescope will easily meet its key science goals. While the Early Science calls have been offered clearly as shared risk opportunities, the observatory has had difficulty in maintaining the observing efficiency required to complete the science plan approved by the Science Review panels. Much of this deficit has come from unanticipated delays, for example, from a workers strike in 2013 or poorer than typical weather. The delays and subsequent loss of scientific observing time has led to low completion fractions. Array time is balanced among ALMA regions, so Canadian proposals compete within North America on scientific quality alone. While these results of the Early Science calls for proposal are subject to low-number statistical fluctuations, Canadian-led projects received 7.2%, 8.3% and 3.6% of North American ALMA time during Cycles 0-2 respectively. This compares to a nominal budgetary share of 7.25% of the North American ALMA operations. While the significant drop in Cycle 2 success rate is vexing, it appears that the community is responding. As the newest national telescope facility, NRC and the Canadian submillimetre community have worked to make ALMA accessible outside the traditional user base. Efforts like Community Days and training opportunities run by NRC should continue, especially in later cycles when a significantly larger fraction of the array time becomes accessible for science. The current ALMA agreement runs through 2021 but negotiations for the future of ALMA may fall within the MTR period. As such **the GAC affirms continued priority for ALMA in national plans as we are only now beginning to see the returns on our large national**

**investment.**

### 2.5. *James Clerk Maxwell Telescope (JCMT)*

The JCMT has undergone major changes since the LRP. SCUBA-2 was commissioned in 2011 and the Legacy Surveys began collecting data with it in 2012. Four of the seven surveys have now completed their data acquisition, although at a lower sensitivity level than had been envisioned at the time they were proposed. SCUBA-2 is proving to be a reliable and performing instrument, although the lack of time and resources from the pulling out of the major partners prevented the commissioning of the Canadian ancillary instruments (POL2 and FTS2). Canada stopped funding the telescope as of September 2014, and the UK will stop in January 2015. The operation is in the process of being transferred to the East Asia Observatory (EAO) on 1st February 2015. EAO is the lead and majority partner of the new JCMT collaboration, with contributions from a consortium of UK universities and a consortium of Canadian universities. In addition to the cash contributions from the 6 Canadian universities (McMaster, Lethbridge, Alberta, Western, Waterloo, Dalhousie), there is also a commitment to keep the JCMT archive at CADC open and ingesting new data for at least the first 2 years. The details of future operations (e.g. PI versus survey mode, eligibility to propose PI projects) are still under discussion, but continued Canadian access to the JCMT appears to be secure until 31 January 2017. Access to survey mode will remain but, possibly, PI time will only be accessible to those Canadian institutions that contribute cash to JCMT operations. **The GAC applauds universities for moving forward in supporting the JCMT.**

## 3. FUTURE FACILITIES

### 3.1. *Thirty Meter Telescope (TMT)*

The time since LRP2010 has seen much activity on TMT, but at the time of writing, Canada still has no commitment to the funding required for the proposed partnership. As construction begins, this appears to be a last chance, which will be resolved by the time the MTR panel has completed its work. Given this fluid situation GAC feels it is unwise to propose other ways forward on the issue in this White Paper.

Briefly, the initiative has been with ACURA to move the case forward, working with the Coalition for Astronomy, CASCA and its committees, individual Canadian universities, and the broader TMT partnership. NRC is not permitted to make the case to government. The currently negotiated share for Canada is approximately 20%, and the construction plan has Canada responsible for the enclosure and the NFIRAOS adaptive optics capability. The other partners, all of whom have committed funding, are China, Japan, India, UC and Caltech, while NSF has promised substantial funding support later in the decade.

TMT has been the prime future optical-NIR facility in the LRP, and this has been the message to the government for the entire time since LRP2010. If we fail to achieve this, it will require a major re-assessment of our plans for ground-based astronomy. In general, we may consider two broad alternatives: a reduced share of the partnership, and none. While the TMT corporation must have considered how to deal with these scenarios, none has been announced or publicly agreed.

Much of the TMT activity noted above has been carried out by a few individuals and has not involved the participation of the general astronomy community. While some aspects are naturally sensitive and confidential, we feel that this has been a significant omission. **Any scenario short of the currently proposed TMT share must be discussed and agreed within the broad community, and folded in with adjustments of other projects and priorities.** This should be a significant task for the MTR panel, before issuing their report in late 2015, by which time the current TMT plan will have been decided. However, public debate on alternative plans would be very unwise while the considerable current effort is under way for the existing plan.

### 3.2. *Maunakea Spectroscopic Explorer (MSE)*

The Maunakea Spectroscopic Explorer is an international collaboration which seeks to redevelop the current CFHT site to host a 10m class telescope optimised to perform leading wide-field spectroscopic surveys. The project was originally named the Next Generation CFHT (ngCFHT) project and has been renamed to reflect the significant development of the project and the broadening of its collaborative scope. MSE remains a project founded on significant Canadian participation yet has grown to involve scientists from institutes in 12 nations and has received strong expressions of national support. In particular, France has ranked MSE Development as a top priority in their 5-year Prospective, China has signed an MOU with CFHT/MSE to contribute technical effort to the Design Phase, and India has recently sent an Expression of Interest indicating they will shortly join the design phase. The science impact of MSE would be greatly increased by being on-sky in the mid-2020s; such a timescale would require a funded "decision-to-proceed" as early as 2018, i.e., before the next LRP.

In 2014 the CFHT board expressed its strong support for MSE by founding a funded project office to develop all aspects of the project (scientific, technical, financial and political) over a four year period. This leadership shown by the CFHT board was in turn based upon positive statements from the CFHT SAC which has issued strong and continued support for the project, referring to it as "transformational", "world-leading" science. The future, successful development of MSE requires continued leadership and strong support from the Canadian community, including the contribution of in-kind effort to the project office and the design studies to ensure that Canada is well placed to compete for and contribute to the construction of MSE. A decision also needs to be made about the relative importance of short- and mid-term activities at CFHT and deconstruction of the telescope. **The GAC is very enthusiastic about the promise of MSE and recommends that MSE construction take precedence over other CFHT activities: if MSE is funded and ready-to-go, construction should not be delayed.** Depending on the timeline of MSE, this could be a change from the 2010 LRP which recommended at least a 5-year lifetime on CFHT for SPIRou. GAC notes that since 2010, the MSE project has developed considerably, while SPIRou's delivery date has slipped and as expected, the landscape of extrasolar planets has changed, for example with the selection of TESS for a 2017 launch.

### 3.3. *Large Synoptic Survey Telescope (LSST)*

The LSST was the top priority in the 2010 US decadal survey and is now under construction with first light expected in 2019. LSST is a US-led project run as a public-private partnership, with some international affiliate members. It was not ranked as a priority in LRP 2010 but Canadian astronomers are becoming increasingly interested, with about 20 potential PI members having submitted letters of intent to join the project in 2012. Several aspects of the LSST science case (e.g., extragalactic imaging, Kuiper belt objects) play to existing Canadian strengths, although opportunity for Canadians to influence the project directions at this date may be limited. Other countries have or are in the process of negotiating national access to the LSST data, but at this point it is unclear what the cost for full Canadian access would be, or how costs versus benefits would work out. In-kind contributions from Canada (archiving, FTEs) seem unlikely to be a sufficient buy-in for data access, since the LSST project already has these issues well in hand. The GAC notes the general difficulty in finding telescope operations funding: this applies not just to LSST but to other facilities as well. **Without definite costs the GAC is unable to make a recommendation on LSST, but additional information may become available in the next few months and we suggest that the MTR panel investigate further.**

### 3.4. *Cerro Chajnantor Atacama Telescope (CCAT)*

Canadian participation in CCAT, a 25-m single-dish submillimetre telescope, was a recommendation of LRP 2010. The project has gone through a number of milestones since 2010, including a preliminary design review in 2013 and acquisition of the site in 2014. A consortium of ten Canadian universities is one of the CCAT partners. Funding is a currently major issue for CCAT: a request to the US NSF for construction funds was turned down, and Caltech left the partnership. Additional partners are being sought, and the construction start has been pushed back to 2015. A proposal to CFI for Canada's share of the construction costs is currently pending, with a decision expected during the course of the MTR (March 2015). Options for Canada's share of operating funds are currently being explored. **The GAC recognizes that having a single-dish facility will maximize science output from ALMA and supports supports Canadian participation in CCAT. As with TMT, however, a primary decision point on CCAT will be reached before the MTR is complete.**

### 3.5. *Square Kilometre Array (SKA)*

Many decisions regarding the future of the SKA have been made since LRP2010. Of note, 10 countries including Canada convened the SKA Organization (SKAO) in 2011 to oversee the pre-construction design phase of the telescope. The SKAO has planned to develop the observatory in three phases: precursor telescopes (the extant Australian SKA Pathfinder and MeerKAT in South Africa) followed by SKA Phase 1 (10% of final array) and then SKA Phase 2 (100% of final array). The SKAO decided that Phase 1 construction will be split over Australian and South African sites in order to integrate the precursor telescope infrastructure but Phase 2 would be concentrated in Africa. The frequency coverage of the telescope will be split among three different technology solutions including dipole antennas (low frequencies), single-pixel receivers (mid-range frequencies with wide bandwidth) and phase array feeds (mid-range frequencies with narrower bandwidth but wider sky coverage). The SKAO is currently designing SKA Phase 1 aiming to balance a construction cost cap vs. the scientific capabilities required to meet science goals. The nominal cost cap for SKA1 is €650M so a 10% Canadian share is roughly $100M.

The SKA was identified as the second highest priority for a ground-based facility in LRP2010 and the scientific promise of the facility remains great. Since the LRP, community expertise and interest remains strong around all of the key science goals of the telescope. Notably, the funding and construction of CHIME, excellence in pulsar astronomy, and ongoing work in the study of cosmic magnetism driven by the Canadian Galactic Plane Survey have positioned the Canadian community for continuing scientific leadership within the SKA. The major unknown with respect to Canadian participation in the SKA is the funding for development of the telescope during Phases 1 and 2. With clearer costs and capabilities emerging from the pre-construction phase in the next 16 months, the observatory will be seeking formal commitments for Phase 1 construction from member countries in 2016. It has been difficult to effectively advocate for the SKA given the state of funding for the top priority, the TMT. The relatively small Canadian user base is also a concern: if SKA were available tomorrow, few Canadian astronomers would be prepared to use it for science. (A similar situation also applied to ALMA but NRC has done effective professional outreach, broadening the ALMA user-base beyond the submillimetre community.) The 2010 LRP suggested that Canadian use of the JVLA would be an important 'training ground' for SKA, but the GAC is not sure how to quantify whether this is happening. The GAC believes that the discovery space for SKA is huge and the strong industrial buy-in suggests that SKA would be a strong sell federally. SKA is larger in both cost and opportunity than MSE and this is something that the MTR panel will need to consider carefully.

## 4. CONCLUSION

While one way to plan for future facilities is to articulate current science challenges and identify the facilities best equipped to meet them, a plan that focusses only on the science of today will not serve tomorrow. The GAC believes that we need to foresee (or direct) future interests and try to make them possible for Canadian astronomers through national facilities. Since almost all major facilities led to breakthroughs in science areas not foreseen at all by those who designed them, the only guarantee of success is opening up 'discovery space'. All of the facilities discussed in this report offer new avenues of exploration; the GAC's opinion is that TMT, SKA, and MSE all stand out as future facilities with potential for truly transformative science.

We thank D. Bohlender, R. Carlberg, D. Crabtree, A. Gray, R. Lamontagne, N. Law, and K. Vanderlinde for discussions.

TABLE 1
Ground-based telescopes owned or accessed by Canada

| Facility | Wavelength | Diameter/FOV or other | Instruments | Canadian share |
|---|---|---|---|---|
| Existing facilities | | | | |
| DAO | optical | 1.8m (classical) | opt camera & spectrographs | 100% |
| | | 1.2m (queue or classical) | high-res coude spectrograph | 100% |
| DRAO | radio | 25.6m | 408 MHz to 6.6 GHz receivers | 100% |
| | | synthesis array, 7 × 9 m | continuum img (408 & 1420 MHz); HI spect | 100% |
| OMM | optical | 1.6m, queue & classical | Opt, IR cameras & spectrographs | 100% |
| CFHT | optical/NIR | 3.6m, wide-field | opt, NIR imagers; spectropolarimeter | 45% (nominal) |
| Gemini | optical/NIR | 2 x 8 m, ∼arcmin FOV | many opt - mid IR instruments | 18.65% |
| Subaru | optical/NIR/MIR | 8m, wide-field | many opt - mid IR instruments | few nights/yr via Gemini |
| ALMA | mm/submm | interferometer | 6 bands from 75 GHz to 700 GHz | 2.8% (budget), no GT |
| JCMT | submm | 14 m dish with ∼arcmin FOV | spectrometers and continuum imager | TBD |
| JVLA | radio | interferometer | 10 bands from 50 MHz to 50 GHz | Not defined |
| Proposed future facilities | | | | |
| TMT | optical/NIR | 30 m, ∼arcmin FOV | many opt - mid IR instruments | 20%? |
| MSE | optical | 10 m wide-field | multi-obj spectrograph | 20%? |
| LSST | optical | 8.4 m wide field | survey camera | ? |
| CCAT | submm | 25 m, 20 arcmin FOV | camera, heterodyne array | ? |
| SKA | radio | interferometer | 50–350 MHz, 0.35–14 GHz | 10%? |

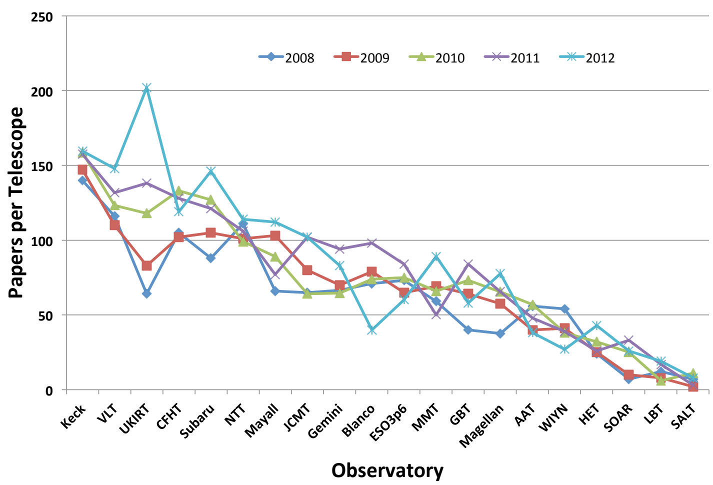


Fig. 1.— Productivity of Canadian telescopes and comparators, over the period 2008–2012. Courtesy D. Crabtree.

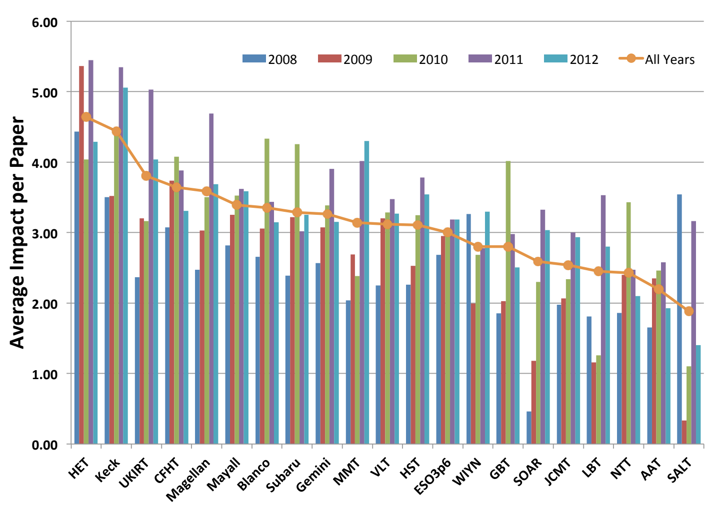


Fig. 2.— Average impact per paper of Canadian telescopes and comparators, over the period 2008–2012. Courtesy D. Crabtree.