Report on ALMA for the LRP Midterm Review Committee

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May 18, 2004

(1) Status of the project, both internationally and in Canada, in the year 2000, i.e. shortly after the release of the original LRP report.

By mid-2000, the bilateral ALMA project had assumed much of its current structure. The basic parameters of the array had been laid out: the site (at 5000 m in the Atacama Desert in northern Chile); 64 antennas, each 12 m in diameter; four initial receiver bands (covering the 3 mm, 1.3 mm, 0.8 mm, and 0.6 mm atmospheric windows) with room in each cryostat for 6 additional receivers to cover all the atmospheric windows from 7 mm to 0.3 mm; phase correction provided by radiometers monitoring the water line at 183 GHz; polarization capabilities; a flexible correlator with some limits to the minimum spectral resolution in very narrow and very wide bandwidths; reconfigurable from 300 m to at least 5 km; and sophisticated software to provide users with pre-processed images. The first meeting of the ALMA Science Advisory Committee (ASAC) took place in March 2000. The total budget had been set (although not funded by the agencies) at US$562M (Y2K dollars). The political structure of ALMA was a 50-50 partnership between Europe (represented by ESO) and North America (represented by NSF). Many technical, political, and practical issues remained to be worked out and none of the international agreements to bring ALMA into existence had been signed or even drafted.

The preliminary version of the Long Range Plan presented to the Canadian community in June 1999 identified ALMA as the highest priority for a ground-based facility for Canada. Informal discussions had been underway between HIA, NSF, and NRAO about how best to bring Canada into ALMA since before 1998. The support of senior levels of NRAO management for Canada's participation in ALMA was a key factor, as was our ability to leverage the correlator expertise at DRAO (to be used to build a new correlator for the proposed EVLA) as part of our participation in ALMA. In June 1999, NSF, NRC, and ESO signed an MOU that provided the framework for an extensive joint design and development program. The early release of the LRP facilitated the participation of Canadian representatives (Lorne Avery, Canadian Project Manager, and Christine Wilson, Canadian Project Scientist) in some of the first technical discussions on ALMA, which occurred at the tri-annual URSI meeting held at the University of Toronto in August 1999. Simon Lilly gave an invited talk at the first ALMA Science Meeting in Washington D.C. in the fall of 1999 and a Canadian (Christine Wilson) was included among the North American representatives on the ASAC.

(2) Developments on the international scene for the project since 2000.

NRC and NSF signed in November 2000 a Letter of Intent endorsing U.S.-Canadian collaboration in the construction and operation of ALMA. In September 2001, the NRC, NRAO, and AUI signed an MOU to establish the North American Program for Radio Astronomy (NAPRA) to promote the policy of no national boundaries in applications for observing time on NRAO telescopes, including ALMA. The duration of the agreement is for 10 years, or through the first five years of operation of the EVLA correlator, whichever is longer. These documents established the NAPRA framework by which Canada committed to seek US$20M (Y2K) for participation in ALMA construction and US$10M (Y2K) to develop the EVLA Correlator. Canada was invited to join the international ALMA Coordinating

Committee (ACC), where it was represented by NRC-HIA (Simon Lilly until January 2002, and then Jim Hesser) until the ACC was replaced by the ALMA Board in February 2003. Hopes for a balanced trilateral project were disappointed when the Japanese government failed to appropriate the necessary funding. During 2002, terms for the Bi-Lateral Agreement between ESO and North America, including a Project Plan, were developed, both with Canadian input.

ALMA will be an observing facility of ESO and NRAO, rather than a stand-alone facility such as Gemini. The Integrated Product Team approach is used for construction and operations, with balanced leadership from Europe and North America in each IPT. During operations, users will interact with ALMA Regional Centres (ARCs, one each in North America and Europe). The ACC established an ALMA Management Advisory Committee (AMAC), which in June 2001 initiated in-depth, bi-annual reviews of ALMA by experienced project managers of comparably large, complex projects. There are parallel Science Advisory Committees in both Europe and North America; two Canadians (Christine Wilson, Doug Johnstone) serve on the North American committee.

Both ESO and NSF have approved funding for ALMA construction. Their representatives signed the Bi-Lateral agreement on 26 February 2003, thereby bringing ALMA into existence, beginning its construction, and replacing the ACC with an eight member Board of Directors. Under its terms, Canada is assigned one of four North American seats on the ALMA Board (currently Jim Hesser) plus one observer (currently Lewis Knee). The Board appointed Dr. Massimo Tarenghi Director effective 1 April 2003. The search for the other Joint ALMA Office (JAO) key personnel (Project Scientist, Project Engineer, and Project Manager) is ongoing. The intent is to establish the JAO in Chile by Q4 2004.

On 16 June 2003, NRC and NSF signed the MOU envisioned in the 2000 Letter of Intent formalizing Canadian participation in the ALMA Board, ASAC, and time allocation committees. It defines our right of access to ALMA as: "applications from scientists at Canadian institutes for ALMA observing time will be regarded on the same basis as applications from scientists in the United States." NRC President Carty, Canadian Ambassador Giroux, and Hesser represented Canada at the groundbreaking ceremony in Chile on 6 November 2003. Construction of the access road and the construction workers camp began on 1 July 2003. All the land access issues in Chile were settled by 24 February 2004.

As of 1 April 2004, Japan has the funding to join ALMA at a significant level. Negotiations regarding their contributions and associated value are ongoing. It seems likely that they will bring some or all of the following hardware items: additional receiver bands; a compact array made up of primarily smaller telescopes; and an advanced correlator for their compact array. The Japanese contributions will improve ALMA capabilities, particularly for wide-field imaging and frequency coverage.

A detailed Work Breakdown Structure (WBS) has been developed for ALMA construction based on IPTs. Responsibility for all the items of hardware and software that must be built as part of ALMA has been assigned to workers in Europe and in North America. As in all large projects, communications and coordination require significant and continual effort. Project-wide coordination occurs at international "ALMA week" meetings; NRC-HIA (led by James Di Francesco) hosted the June 2003 one in Victoria. There have been a number of Preliminary Design Reviews and some Critical Design Reviews are coming up in the next year.

A key piece of hardware development has been the purchase of two prototype 12 m antennas. These antennas are currently being evaluated on the VLA site against ALMA's challenging specifications; one antenna has completed its tests, while the second is just starting tests. A Request for Proposals for the full construction run of 64 antennas for ALMA was issued on 17 December 2003. Proposals are due on 30 April 2004 and the goal is to issue a contract to a vendor or vendors by 15 September 2004.

In summary, ALMA construction is in full swing and there is a huge amount going on. The biggest current uncertainty is whether the construction contract for the antennas will come in as budgeted. Since the project has a fixed budget, any serious overruns in the costs of the antennas would impact the scope of ALMA.

(3) Developments in Canadian contributions toward the project since 2000.

In mid FY01-02, the NRC President provided ~C$2M to HIA to bridge towards funding expected for LRP projects in the 2001 Federal Budget; this included NAPRA work on ALMA and the EVLA correlator. Following the December 2001 budget, NRC allocated ~C$36M to LRP projects over five years beginning in FY02-03, of which approximately half was allocated for ALMA and EVLA work (including full support over the five years for the recommended Correlator and Receiver Groups). Within HIA, the Millimetre Astronomy Group Leader (initially Lorne Avery, and now Lewis Knee) acts as Canadian ALMA Project Manager to coordinate activities and to allocate and monitor HIA budgetary expenditures.

Accountability at the ALMA project level is based upon pre-agreed "Value" for each WBS element, which places responsibility for managing costs and risks on the suppliers. In Summer-Fall 2001, Canada negotiated an agreement with AUI-NRAO regarding our construction phase contributions (Valued at US$20M Y2K). These are: 64 Band 3 (3mm, 84-116 GHz) receivers; secondment of an HIA receiver expert to lead the Front-End IPT; participation in offline and other software development; and a contribution of expertise towards ALMA archive development. As well, there is a one-time cash contribution towards site infrastructure development in Chile.

Work Package	Value ($US Y2K)
Band 3 Receivers	$12.55M
Personnel and Software	$ 3.32M
Site Access "Fee"	$ 3.60M
Total	$19.47M
Commitment	$20.00M

The allocation of the Band 3 receivers to Canada is a major achievement and puts our work front and center within the ALMA project. Band 3 receivers will be essential for commissioning each antenna, as well as being workhorse receivers for science. The HIA receiver team led by Keith Yeung (Project Manager) and Stéphane Claude (Project Scientist) is now staffed. They completed successful Conceptual (6-7 June 2002) and Preliminary (29-30 March 2004) Design Reviews before panels of international experts. In addition to the Band 3 work, Charles Cunningham has been seconded to lead the Front End IPT during ALMA construction, with responsibility for a combined European/North American work package of ~US$70M.

Canada's other primary contribution to ALMA is software development. Although we had ambitious proposals to lead the development of the archive and one of the software subsystems, these had largely been allocated prior to our negotiations. Thus, our contributions to ALMA software are spread out rather than concentrated in a single area. There are three full-time people working on ALMA software, one based at DRAO and two based at the University of Calgary. Two of them are working on aspects of the ALMA Offline Software Subsystem (led by Joe McMullin at NRAO) and one is working on the ALMA Common Software Subsystem (led by Gianluca Chiozzi at ESO). In addition, there is a contribution to the ALMA Archive Subsystem from CADC in Victoria. There is also an "in-kind" contribution from Christine Wilson at McMaster University, who is the Subsystem Scientist for the ALMA Pipeline Subsystem and on ALMA Software Science Requirements committee.

Despite this diversified software effort, Canadians are playing significant leadership roles in the ALMA Pipeline (arguably one of the most visible software systems for the average ALMA user) and in pushing the design and capabilities of the ALMA Science Archive. An MOU has been developed between NRAO, HIA, and University of Calgary, and reviewed by McMaster University, which lays out the framework for the Canadian ALMA software development work. Russ Taylor has assumed the role of Canadian ALMA Software Manager.

The final part of Canada's direct contributions to ALMA is the so-called site access fee; all participants in ALMA give 18% of their contributed Value in the form of a cash transfer that goes towards construction costs that must be incurred in Chile. The site access fee was transferred to NSF in the fall of 2003 and is completely paid.

Efforts to secure opportunities for Canadian firms to bid on ALMA procurements are ongoing (initially led by Lorne Avery, now by Keith Yeung). NRAO selected a Canadian firm, DICOS, to provide the master laser for ALMA.

Within Canada, the Canadian ALMA Science Steering Committee was established in 2001 and has met annually. This committee has proved to be an excellent forum for discussing issues critical to Canadian astronomers, and will begin to play a larger role in organizing outreach efforts to the Canadian community as we approach ALMA Early Science in 2007. There are currently 7 members of the committee from across the country and we began rotating the membership last year. In addition, the project scientist has written regular ALMA reports in the CASCA newsletter since September 2000 and solicited involvement from Canadian astronomers in ALMA science and software developments as appropriate. There will be an ALMA lunch meeting at CASCA in June 2004 as well as an invited talk on ALMA Science from Suzanne Aalto-Bergman from Sweden.

(4) Approximate amounts of LRP funds spent, and how distributed (e.g. staff, contracts, equipment) up to now, and projections to 2005.

Canadian contributions to ALMA are funded primarily through the NRC, with additional funding from CFI and small in-kind contributions of scientist's time and money for teaching relief (particularly from McMaster University).

(a) NRC funding

As described in the preceding section, the ~C$36M LRP allocation identified by NRC in December 2001 is being used to support fully during FY02-03 to FY06-07 the first two items of the table in the preceding section. NRC funds are also used to support the CASSC meetings and participation by Canadians in ALMA

committee meetings (Board, ASAC, AMAC). Through FY06-07, HIA estimates that it will expend a grand total of ~C$11M Y2K on ALMA. Please note that this projection depends upon a number of assumptions and are meant to indicate approximate expected expenditures. It is particularly challenging at this time to project Band 3 production costs for which original estimates assumed the work would be done in house at HIA. The currently favoured approach to production after the prototypes are developed is to contract, or subcontract major subassembly, production to industry.

(b) CFI funding

The total CFI funding for ALMA is ~C$8M. This money is divided between the site access fee (US$3.6M Y2K) and ALMA software development (~C$2M). The site access fee was transferred to NSF in 2003.

(5) Approximate amounts of non-LRP funds spent and how distributed over the same period. Also non-LRP funds anticipated to be spent to the end of ALMA construction in 2012.

Through an internal competition process, the NRC supported the acquisition of precision CNC machine tools for the HIA shops, two of which (costing ~C$0.5M) were largely justified for ALMA prototype development. In addition, NRC-HIA covers the substantial time commitment for the NRC ALMA Board member and the Canadian ALMA Project Manager. NRC also provides legal counsel for the international agreements (the development of the Bi-Lateral Agreement and the NRC-NSF MOU were lengthy processes with numerous iterations).

The University of Calgary is providing infrastructure, system support, and startup support for the Canadian ALMA software development team at a level of about C$0.3M.

McMaster University will provide teaching relief for the Canadian ALMA Project Scientist starting in 2004. The value of this is approximately C$15K/yr or ~C$0.1M if the support is available through the end of ALMA construction in 2011.

(6) Anticipated status of the project, internationally and in Canada, in 2012 with continued support from LRP funds, and the amounts of funds needed over 2006-2012 to achieve this goal.

Note: This section deals with ALMA funding needs from 2007-2011 (rather than 2006-2010), which is a more natural reporting period for ALMA.

Construction of ALMA is scheduled for completion by Jan 1, 2012. “Early Science” observations are scheduled to begin in Q3 2007. By 2012, ALMA should be in full science operations mode for all antennas and their four primary frequency bands, although we may still be in an "Early Science" mode for frequencies using the receivers to be provided by Japan. The ALMA Science Pipeline should be working routinely as should the Observing Tool, proposal review process, and Archive, the three other main areas where there will be interaction with ALMA astronomer users. The ALMA Regional Centers in North America and Europe should be completely staffed and operations funding will be required at a steady-state level.

Funding is required: a) to complete Canada’s contributions to ALMA construction in FY07-08 to FY11-12; b) to meet our obligations towards Early Science operations, starting no later than 2005; c) to meet our obligations to full

operations starting in 2012. In addition, we anticipate there will be funding pressure to respond to international opportunities and/or to contribute to ALMA developments over and above the core deliverables (e.g., hardware or software enhancements, enhanced operational staffing, etc.).

HIA projects that its total ALMA commitment will require ~C$15M (~C$12M Y2K) for FY07-08 through FY11-12. Projections of the Band 3 production costs will become much more secure after the tendering process in 2006; until then the potential negative variance between assigned Value and production costs remain the major risk to Canada's ALMA construction contributions. Although Band 3 work currently has funding from NRC through FY06-07, assurance of future funding will be necessary when production-run contracts for major subsystems are let, which must occur in FY06-07 in order to meet ALMA milestones.

The Canadian ALMA software work at Calgary, HIA-DRAO, and McMaster is fully funded by the CFI grant through 31 July 2008; since our commitment is to provide FTEs of experienced software developers, we anticipate that our commitment will be fully met by that date.

According to the NSF-NRC MOU, "During the operational phase, NSF and NRC will make annual contributions to ALMA in approximate proportion to their relative contributions to construction of the array based upon the US$20M [Editor's note: Y2K] Canadian ALMA contribution. These contributions will begin at the time required by the ALMA project schedule." These terms result in a Canadian obligation for ~7% of the North American share of the annual operations budget.

Detailed planning is underway to prepare for initial operation of a three-antenna ALMA interferometer in Q2 2006 and for initial Early Science Operations with the six-element interferometer in Q3 2007. Staffing for Early Science operations is projected to begin in 2004, suggesting that Canada can expect to incur Early Science operations costs no later than FY05-06. Current projections are for a step function (rather than a linear ramp up) of operational expenditures during 2006-2008. Early Science operations costs will probably approach the steady-state level by 2009 or 2010. (The annual funds needed for ALMA operations in the steady state are discussed in the next section.) The Project is currently estimating the funds needed during Early Science operations and this estimate should be available within a few months.

(7) Estimate of ongoing annual support required beyond 2011 to permit an effective ongoing Canadian contribution to the project and/or its operation.

Estimates of steady-state operations costs are under active review by the ALMA Project, and should be available by mid 2004. A rough estimate suggests Canada will need C$3-4M/yr (Y2K) for steady-state ALMA operations. Moreover, as noted above, Canada faces Early Science operations expenditures beginning in 2005 with a major step function anticipated in FY06-07 or 07-08.

If Canada ceases to be involved in the JCMT when the current agreement expires in 2009, a case could be made – as suggested in the LRP - for redirecting those funds to ALMA operations from 2010 onwards. The total amount of resources available by redirecting current JCMT support (operations, development, staff) would total at most C$1.5M/yr (Y2K). Thus, if it were possible to secure Treasury Board approval for redirecting the current JCMT contributions to ALMA operations, additional core operational funding at least C$1.5-2.5M/yr (Y2K) will be required for ALMA. The nature of Canadian operational funding and the

possible roles that Canada could assume in ALMA operations are in the very early stages of discussion.

A major facility such as ALMA will also face on-going development over and above core operations. The associated costs are also being estimated at present and can be anticipated to be several millions of US dollars per year for North America as a whole.