Cornell Caltech Atacama Telescope

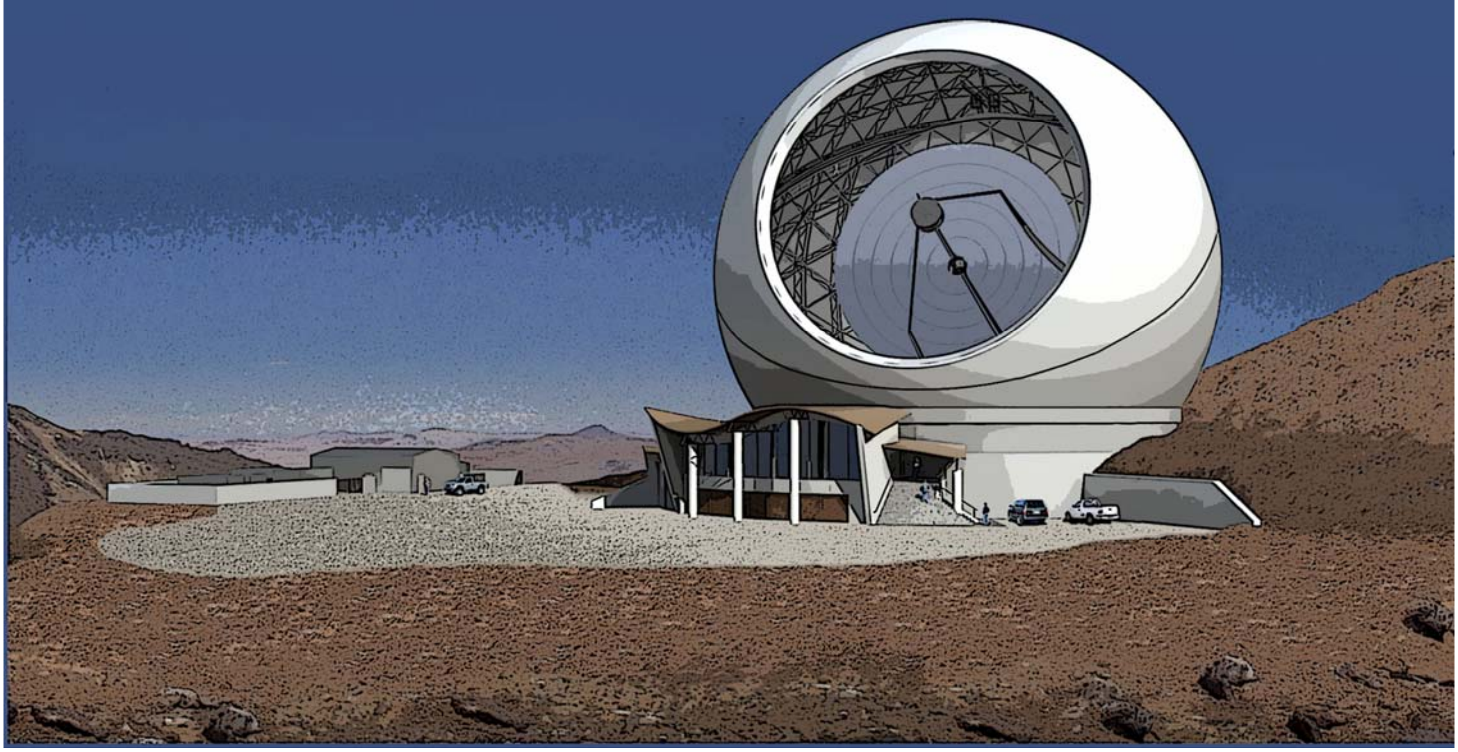
Feasibility/Concept Design Study

CCAT

Cornell University California Institute of Technology Jet Propulsion Laboratory

Report of the Study Review Committee

Submitted March 6, 2006



Report of the Review Committee Cornell Caltech Atacama Telescope Feasibility/Concept Design Study

Overview: Cornell University, the California Institute of Technology, and the Jet Propulsion Laboratory have performed a Feasibility/Concept Design Study for a 25 meter astronomical telescope. On 17, 18 January 2006 a comprehensive review of the study was conducted. Pursuant to the wishes of the partner institutions, an independent Review Committee was constituted and participated in the review to provide an expert assessment of the Study conclusions. This document is the Report of the Review Committee.

Members of the Committee

Robert W. Wilson (Chair) Harvard-Smithsonian Center for Astrophysics

Mark Devlin, Dept. of Physics, University of Pennsylvania

Fred Lo, Director, National Radio Astronomy Observatory

Matt Mountain, Director, Space Telescope Science Institute

Peter Napier, National Radio Astronomy Observatory

Jerry Nelson, University of California at Santa Cruz

Adrian Russell, Director, ALMA North America

I. Introduction

The Cornell Caltech Atacama Telescope (CCAT) is a very timely and unique facility, enabling sub-millimeter and far-infrared large scale surveys and observations of primeval galaxies, forming stars and proto-planetary disks from the ground, key issues of modern Astronomy. The combination of sensitivity and resolution of CCAT is crucial for probing the sky beyond the confusion limit. In the modern era of multi-wavelength astronomy, the submm/FIR surveys enabled by CCAT will complement important surveys at other wavelengths, such as the Sloan Digital Sky Survey, 2-Mass near-IR Survey, all-sky surveys by Spitzer and Chandra, and radio surveys such as NVSS. Furthermore, CCAT will be the crucial path-finder of interesting objects in the submm/FIR band that can be imaged in great detail with the Atacama Large Millimeter Array (ALMA).

CCAT is an ambitious project which pushes the limits of sub-millimeter radio telescopes. There is no doubt that the CCAT can be built. The question is cost and the key is to find an affordable set of technologies which will provide the performance. The committee was impressed by how far the Feasibility/Concept Design Study has gone toward identifying a workable set of technologies. The outside firms which contributed to the study are clearly experienced in building similar structures and delivered a lot of value in their studies.

The remainder of the report is laid out following Provost Burns' charge to the committee.

II. "The scientific goals and timeliness of the project and its profile within the next decade's horizon, as a world-class operation."

In the context of modern Astronomy where the history and geometry of the Universe are largely understood, the frontier of astronomy has been extended to the earliest epochs of galaxy and structure formation and to the direct observations of stars and planetary systems in formation. Large scale observations of the epochs near the peak of Cosmic Star Formation and beyond at $z \sim 1\text{-}4$ are critical to our further understanding of the evolution of the cosmos. The current lack of a large submm/FIR telescope limits extensive studies of cores of molecular clouds forming stars and planetary systems and the evolution of proto-planetary disks around young stars. The Kuiper Belt represents a new frontier in the study of the origin of the Solar system and the study of which provides important insights to the general process of planetary formation. CCAT again fills an important niche of having the sensitivity to study the properties of hundreds of Kuiper Belt objects, which is currently unfeasible to do.

Combined with ALMA, which provides unprecedented sensitivity and resolution to image submm/FIR sources, the CCAT will revolutionize Astronomy in the submm/FIR band and enable significant progress in unraveling the cosmic origin of stars, planets and galaxies.

Operation at 200 microns is a nice bonus given the surface accuracy of the telescope and the excellent site, but will be restricted to a small portion of the time and should not be emphasized in the scientific justification.

III. "The appropriateness of the telescope requirements as presented, in order to meet the scientific goals."

The major scientific drivers which set the requirements for CCAT appear to be the desire to detect hundreds of thousands of primeval galaxies at large redshift and cluster members at somewhat smaller redshifts. The argument that a 25 meter diameter telescope is needed to avoid confusion needs to be made carefully as the South Pole Telescope has been designed to have a similar field of view and may eventually have large field of view cameras at similar wavelengths. It is 10 meters in diameter, but otherwise comparable for cosmology studies. The confusion limit estimates are admitted to be uncertain, but are a massive technical and cost driver for the project.

The desire to do "filter spectroscopy" on the detected galaxies should be considered carefully with respect to the surface accuracy and pointing specifications. If the surface accuracy is insufficient, then the aperture efficiency will be a sensitive function of surface accuracy and may lead to flux errors too large for distance determination.

The committee strongly encourages the CCAT team to implement a sophisticated modeling package. This package should incorporate all known parameters of telescope and receiver performance to predict the overall performance of the system. Such a package will enable the team to optimize the design parameters of the telescope to maximize the scientific output.

IV. "The suitability of the explored technological paths to achieve the desired telescope requirements."

The CCAT is an extremely complex project which will require extensive planning and engineering to meet the specifications necessary to achieve the scientific goals. *The committee feels that the CCAT team has done a very good job identifying the technological hurdles that must be met. They have also provided a number of feasible options that are reasonable to achieve within the timescale and estimated budget of the project*. We will address the major issues here.

The Telescope:

The 25 meter specification for the CCAT is large by optical standards and small by radio standards. There are a number of 10 meter class optical telescopes that have been built such as Keck, Gemini, HET, and SALT. In the radio, the 100 meter Green Bank Telescope with proposed operations down to 3 mm is the largest pointed telescope in the world. In the millimeter band, the IRAM 30 meter telescope has been in operation for a number of years and the 50 meter LMT is currently under construction.

Major technical challenges faced by telescopes include the *net* wavefront error of the incoming light and the pointing of the telescope. In the end, the goal is to make sure that there is knowledge and control of all the light that enters the system. The CCAT hopes to achieve the diffraction limit of its 25 meter aperture while maintaining the forward beam efficiency of the system at as high a level as possible.

The wavefront error due to panel misalignment is possibly the most difficult technical challenge for the project and has received a great deal of attention in the report. Optical telescope performance is limited by the seeing at the site. Nevertheless, they have been able to routinely align their panels to achieve beams better than 0.05 arc-second. At first glance it would seem that the CCAT's challenge of measuring the panel alignment is then straightforward. However, the optical telescopes have, by definition, specular surfaces and are therefore able to use stars to align and correct the panels. The CCAT panels may not be able to do this, so a proxy must be implemented. The committee feels that while many of the options appear to be feasible, the level of risk warrants expending considerable resources to pursue a number of these options during the next phase of the project. The goal is to down-select to one or two in the next phase of the program.

The CCAT structure must be lightweight, rigid, easily transported and assembled, and within the budget of the project. The report does a good job of exploring the options. The HET truss option favored by the team appears to a reasonable technology to pursue. However, there is little chance that the structure will be rigid enough to have fixed panels, hence the need to have active panel actuators with closed-loop feedback on the panel alignment measurements. The anticipated bandwidth of this loop is expected to be 0.1 Hz (finite element analysis of the structure should be able to finalize this parameter). The committee feels that this feedback system is within the reach of current technology. However, the software burden seems to be underestimated. A study of this aspect should be provided in the next phase.

The report provides a very good start on the optical design. The committee feels that more work needs to be done to provide more detailed tolerance analysis of the entire system. This should include the effects of individual panel alignment (addressed very well in the report), the expected flexure of the telescope on appropriate length and time scales, the atmosphere, and the fundamental limits of the metrology systems. These numbers will be required in the early stages of the telescope structure and systems designs. ALMA Memo 535 provides information concerning the likely atmospheric pointing errors. If it is concluded that active correction for water-vapor-induced pointing errors is required the project will need to investigate Water Vapor Radiometer techniques, a technology that the project has not yet investigated. The impact of atmospheric stability on the accuracy of the laser ranging system also needs to be studied.

The committee strongly recommends that the shadowing of the primary mirror by the secondary support structure be minimized. Secondary struts extending to the edge of the primary minimize telescope emissivity, but provide a mechanical challenge. With this in mind, minimizing the weight of the secondary mirror should be considered a priority. The specification for a chopping secondary (presumably for single beam spectroscopy measurements) should be closely examined. Eliminating this specification would likely reduce the mass of the secondary and significantly simplify its control system. It would also reduce cost and risk.

The telescope dome represents a significant cost to the project. It will be larger than any dome that has been built, and at this size the current design also poses a potential technical risk. Smaller telescope domes have had mechanical problems as well and thermal and wind issues which have limited their performance, so there is potential for considerable risk. The 50 meter size of the CCAT dome is driven by the distance from the primary mirror to the secondary mirror. There is also a clearance from the secondary mirror to the dome opening. It is presumed that the greater the clearance, the less the wind load will be on the secondary mirror. The committee feels that the next phase of the study should include other dome options with more complete analysis of the thermal environment as well as the wind loading on the telescope and secondary mirror. Particular attention should be paid to minimizing the overall size and cost of the dome, without sacrificing telescope performance, and to minimize technical risks of the dome. While the dome is essential for protecting the telescope, its cost and technical risks should be minimized within a budget that will be under pressure from the demanding requirements of the telescope itself.

The Receivers:

The first light instruments for the CCAT include both short and long wavelength receivers. Both instruments pursue the science goals of the project. The short wavelength receiver takes best advantage of the unique telescope and site and should be considered the highest priority. The long wavelength receiver should also be aggressively pursued as it will provide a significant science return when the weather conditions are not appropriate for short wavelength observations. While an imaging spectrometer is desirable, it is considered lower priority than the others and should be seriously considered as a second-generation instrument.

The choice of detector technology is appropriate. Utilizing SCUBA2-like arrays and readout technology will represent a significant schedule, cost and risk savings. Still, the complexity of these systems can not be underestimated. The CCAT team should closely monitor the progress of the first generation receivers that utilize these detectors.
They will need to respond quickly to any new developments.

The receiver teams will need to investigate the optical designs more carefully. The use of lenses (especially warm ones) could lead to significant performance degradation due to the reduced bandwidth of the AR coating. There may be a significant development effort surrounding advanced broadband AR coatings. These resources may be better spent on reflecting optics.

The committee recognizes the advantages of a single 5 arcmin FOV array with a filter wheel. However, the FOV of the instrument can be as large as 20 arcmin. There may be a significant advantage to having multiple arrays in the same focal plane. While the array coverage may not overlap on the sky, scan strategies could be implemented to make the best of a variety of array/focal plane architectures.

V. "An estimate of the areas of risk and of the uncertainty of associated costs."

The overall budget, although it contains a significant contingency, is tight in several places and seems success oriented. That is appropriate at this stage in the project but will have to be watched as various costs are firmed up in the next stage.

All of the committee members have expressed a worry about the dome design, although none have identified a particular problem. Large domes have been a source of problems in the past and this is a totally untried structure at the scale of this project. That said, its structure appears more sound than the conventional domes. If the calotte structure is kept, it should be modeled very completely and the effects of all environmental forces including icing investigated.

Site costs appear low. ALMA found that M3's estimates were low by a significant amount and have had to increase the budget and descope elsewhere.

Planning to manage the final assembly on site yourself seems risky. The estimated costs seem low because of the amount of highly skilled labor which will be needed. The risk and cost can be reduced by planning to integrate and test as many of the complex metrology subsystems as possible in the US before going to the high site.

The estimated software costs seem low. Perhaps the required software will be developed by members of the consortium off budget, but the committee feels that the real costs will be higher than the estimate.

The costs for the cameras seem low. If descoping is considered for the cameras, the high frequency camera should clearly be given priority.

VI. "A candid assessment on the desirability to continue engagement into the next phases of the project, along the avenues explored by the Feasibility Study."

Combined with ALMA, which provides unprecedented sensitivity and resolution to image submm/FIR sources, the CCAT will revolutionize Astronomy in the submm/FIR band and enable significant progress in unraveling the cosmic origin of stars, planets and galaxies. CCAT is very timely and cannot wait.