CCAT: The next generation submillimetre survey telescope

(a white paper for the Midterm Review)

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1. Introduction

"How did structure form and evolve in the Universe?" This is one of the fundamental problems in astrophysics, and the next generation submillimetre survey telescope, CCAT, is a unique project geared towards the investigation of this question. CCAT will have a point source continuum sensitivity similar to that of ALMA (the Atacama Large Millimeter/submillimetre Array) at submillimetre wavelengths but will be much faster than ALMA when mapping in the continuum. A key feature of CCAT is its superb site located on the peak of Cerro Chajnantor that will allow CCAT to be optimized to observe at a wavelength of 350 microns.

New technologies are allowing us to build far infrared cameras of unprecedented size, fully populating the focal plane of the telescope. CCAT will have a large enough field of view to accommodate a detector 20 arcminutes in diameter and populated with greater than 100 kilopixels. When this larger and even more sensitive camera is combined with the excellent site, CCAT will map the sky 1000 times faster and with better resolution than SCUBA-2, the current state-of-the-art detector. CCAT will also be equipped with a variety of other instruments including spectrometers such as broad-band direct-detection low-to-moderate spectral resolution instruments (perhaps similar to the existing ZEUS and Z-spec at the CSO and Fourier Transform Spectrometers [like FTS-2 at the JCMT]), high spectral resolution heterodyne focal plane arrays [HARP at the JCMT], and polarimeters [POL-2 at the JCMT].

CCAT is currently a joint project between Cornell University, the University of Colorado, a consortium of Canadian universities, and the Universities of Bonn and Köln. Several other large institutions and national and international astronomy organizations are currently seeking to join the partnership.

With full science observing expected in 2021, CCAT will arrive at a time when ALMA will have been in use for years. Herschel has already reached the end of its lifetime and the CSO will close soon. After that only JCMT and APEX, a 12-m submillimetre telescope near ALMA will remain as submillimetre survey facilities. APEX, is likely to close when CCAT is completed, possibly with a transfer of APEX staff and equipment to CCAT. CCAT will be far more powerful than the JCMT in sensitivity, in its large field of view, and in short-wavelength coverage. As well, CCAT will cover the same southern skies that ALMA is able to view. Canada does not expect to be a partner in JCMT in an era when the community has access to CCAT.

Canadian contributions to CCAT will likely include the observatory dome, parts of the continuum cameras, subsystems for low-resolution spectrometers, heterodyne focal plane arrays, FTS, polarimeter, and software for both data analysis and for the data archive. Thus, CCAT will continue the legacy of the JCMT and guarantee that a strong Canadian academic tradition continues to flourish in the increasingly important area of submm science, training, and instrumentation.

An artist's view of the currently planned CCAT facility is shown as Figure 1 below. Detailed and up-to-date information on CCAT, including many publications plus a newsletter are available at the Observatory website: http://www.CCATObservatory.org. In this paper we focus on updating the information presented to the LRP.

2. Key Science Goals

The science case for CCAT has been described in several documents, including in the 2010 Long Range Plan. Here we briefly list the topics that encompass the Key Science Goals.

- What is the star formation history of the Universe?
- What controls star formation and black hole growth in galaxies?
- What determines the star formation rate and efficiency in molecular clouds?
- What is the origin of the stellar Initial Mass Function (IMF)?
- How do molecular clouds form and evolve?

CCAT is designed to be a general purpose observatory, open to PI proposals, but large community surveys are a central part of the observatory's mission.

3. Technical Overview

The CCAT project has been through a number of reviews including a conceptual design study (http://www.submm.org/doc/2006-01-ccat-feasibility.pdf) (2006), a recent update of the science case that led to a revision of the science requirements (http://www.ccatobservatory.org/docs/pdfs/CCAT_Science_Requirements_R1.pdf) (2012), an Engineering Design Phase (2012-2013), and an externally reviewed and extensive Preliminary Design Review (Sept, 2013). The site of the Observatory was formally handed over to the Observatory by the Chilean government in January 2014.

The site

An important aspect of CCAT is the really excellent site that has been acquired by the project. It is near ALMA, which itself is at a very good submillimetre site. However the CCAT site is significantly better even though only 600 meters higher. The figure of merit for a submillimetre observatory is the amount of water, measured as Precipitable Water Vapour (PWV), above the observatory site. Observing time requirements rise rapidly with increased PWV. The requirement for observations at 350 micron is that the PWV be less than 0.5 mm. The ALMA median PWV is 1.0 mm. The Mauna Kea (JCMT and CSO) median PWV is 2.0 mm. The median PWV at the CCAT site is 0.7 mm but for approximately 2/3 of the nights, when the inversion layer in the atmosphere drops below 5600 meter the PWV is well below 0.5 mm. Occasionally outstanding nights with incredibly low PWV have been seen when the inversion layer drops below 0.1 mm (see for example Figure 2).

The facility
The optimum design of CCAT is driven by the science requirements to be a 25 meter diameter antenna, enclosed, with a pointing accuracy of better than 0.35 arcsec and with a surface accuracy of 12.5 microns. Other key features of the design are a wide field of view and Nasmyth platform. This last (the Nasmyth) allows for a significant improvement in observing efficiency by permitting many instruments to be installed on the telescope and a rapid change from one to another to respond to changes in observing condtions.

However, as a part of prudent management, the CCAT team has recently updated planning for a potential descope in the event that there are insufficient funds committed in time to begin building to the optimum design. The main boundary condition on the descope studies is to not limit the science that can be achieved with CCAT. Instead these studies look at cost-savings from allowing the telescope to have a lower observing efficiency – so that science observations will take longer, but not so long as to be prohibitive. The one de-scope option that most affects the scientific capability is to move to a site at lower altitude and this option has been rejected. The descopes being considered are: decreasing the size of the primary, removing the Nasmyth focus, and removing the enclosure.

The Instruments
The originally planned suite of instruments for CCAT included both short and long wavelength cameras and moderate and high spectral resolution imaging spectrometers. However with new constraints (funding, technological, and timing) the current plan is for just two “first light” instruments to be built: the short wavelength camera (SWCam), shown in Figure 3 below, and the CCAT Heterodyne Array Instrument (CHAI). The primary wavelength for SWCam will be 350 microns but sub-cameras at longer wavelengths (to 2 mm) are planned too. Initially CHAI will be a 32 pixel dual band (460 and 830 GHz) instrument but an upgrade to 128 pixels is planned for later. (A multi-object moderate resolution spectrometer is also planned but is not part of the initial construction “first-light” plans for the facility.)

The result of combining the excellent site, the optimum telescope design, and the planned SWCam first light camera is to provide an unique and powerful facility for surveying the submillimetre sky. Figure 4 shows a comparison of CCAT to other facilities.

Partnership Developments
The CCAT team continues to develop and evolve. Initially there was an expectation that at least two thirds of the funding would come from U.S. sources, both private and public. At the end of June 2014 the (US) NSF declined to fund the CCAT telescope and instead urged the team to apply for a lesser amount of funding appropriate to the building of an instrument. This may have removed the requirement for public access to CCAT in the US. Another side-effect of the decrease in the US share in CCAT is that the Canadian CCAT consortium has taken on an increased leadership role in the project.

Following the NSF June decision one of the major CCAT partners, Caltech, decided to withdraw from the CCAT project, citing their other significant commitments and the uncertainty that the NSF decision produced in the CCAT project. However since that time there has been significant interest in CCAT from universities and observatories in other nations as well as from international agencies. These can, in principle, make up all of the shortfall in the CCAT funding model that resulted from the NSF and Caltech decisions.

The Canadian CCAT team, now including Saint Mary's University and University of Lethbridge in addition to the eight universities in our Canadian Atacama Telescope Consortium (CATC: Dalhousie, McGill, Toronto, McMaster, Waterloo, Western, Calgary and UBC), submitted a proposal to CFI as well as proposals to provincial funding agencies (for matching funds). A decision is expected from CFI in late March 2015.

Schedule

The CCAT project is currently delaying the start of construction because of the funding uncertainty following the decisions by NSF and Caltech. Initially planned for Sept 2014, the first construction contracts will now be prepared for a start in 2015. This moves all of the milestone dates one year later with first light now expected in late 2020 and full science (defined as greater than 50% of the time dedicated to science observing and both "first light instruments" available for use) planned for late in 2021.

Operations

The greatest challenge for CCAT lies in finding sufficient funds for operating costs over the long term. This problem was identified very early in this project and efforts continue to solve it. The University of Waterloo administration, through the office of the Vice-President, Research, has made this a priority and has held many discussions with funding agencies and Industry Canada on this issue. A number of possible directions and potential solutions have been suggested. It is too early to know now if this will produce the desired result.

The process of using the CCAT facility has been discussed extensively within the CCAT team. Much of CCAT's observing time, at least 50%, will be used for surveys. These will be "open" to any member of the CCAT team. In Canada this means that researchers at any of the Canadian consortium institutions will be able to participate in these surveys. It is the intention of the Canadian consortium that participation in these surveys will also be available to those working at other Canadian institutions but the details of this have not yet been agreed by all of the international CCAT partners. Proposals for "Principal Investigator" observations will be accepted from the entire Canadian community but again the precise details have not been agreed amongst all team members.

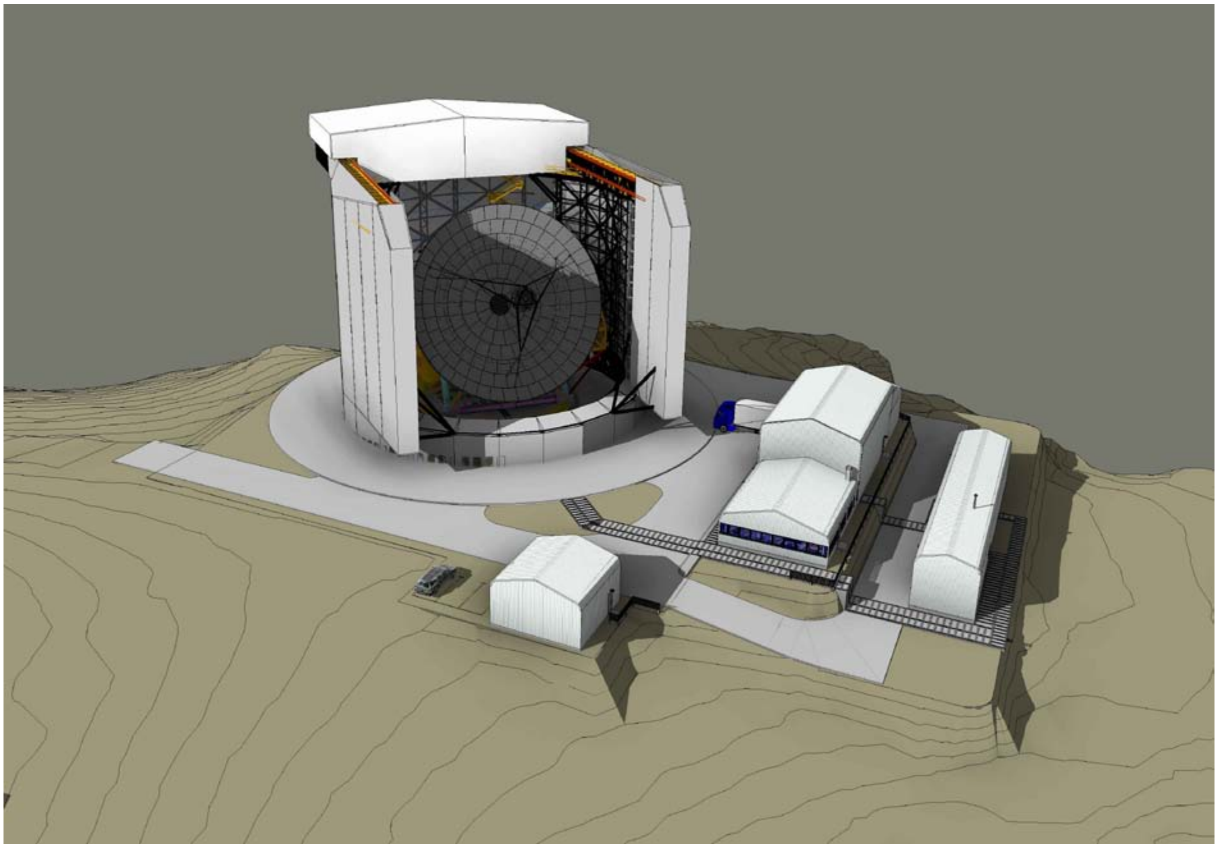
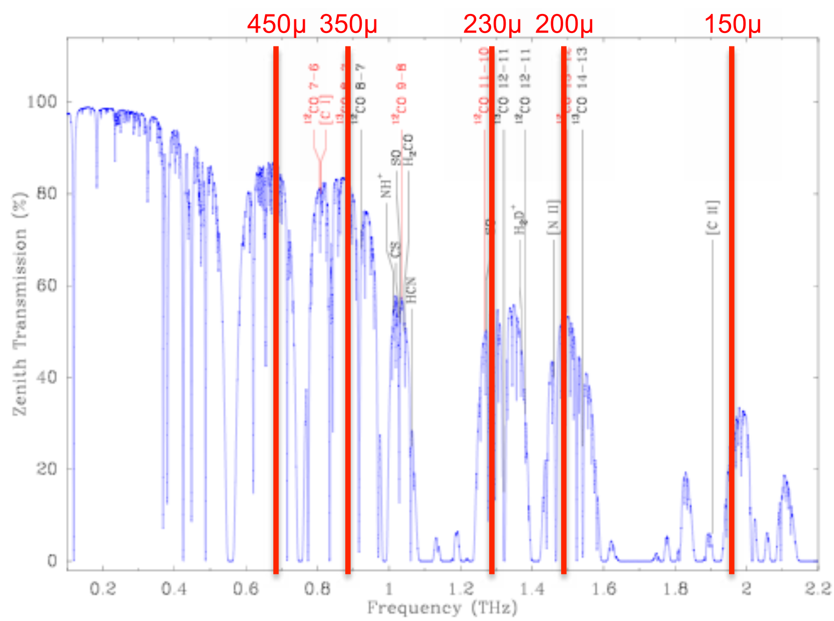


Figure 1: Artist's drawing of the Summit Facility including the telescope in the enclosure, the control/lab building, the mechanical building (at far right) and the vehicle shed (in front).

Figure 2: This data taken on Jan 24, 2005 at an altitude of 5500 meters shows that occasionally the PWV is extraordinarily low in the Atacama: in this case PWV=93 microns; permitting 50% transmission at the two 200 micron windows and even showing an amazing 20% transmission at the 150 micron band! (Marrone et al, 2005 *18th International Symposium on Space Terahertz Technology*)



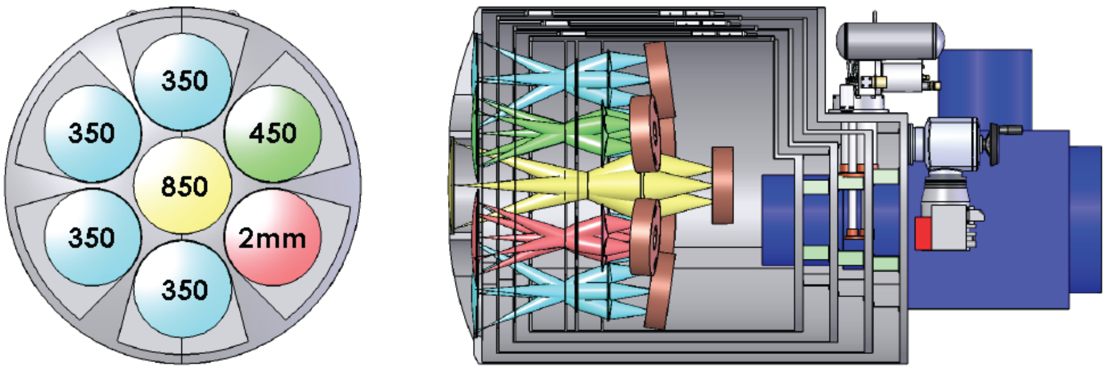


Figure 3: The first-light short-wavelength camera, SWCam, in its current configuration (Nov 2014) includes a long-wavelength, 2 mm sub-camera. The four 350 micron sub-cameras will each have 11,900 pixels. The other sub-cameras will have 7,200 pixels (450 micron), 2000 pixels, (850 micron) and 360 pixels (2 mm). All will be spaced at λ/D separation between the pixels and will fill a 6.0 arcmin field of view.

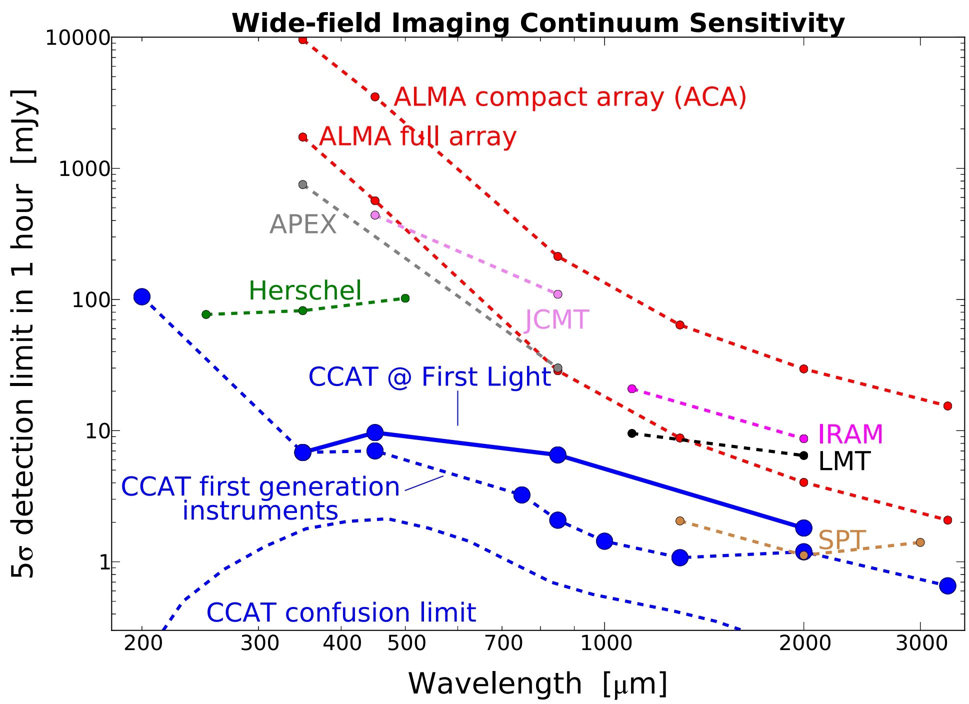


Figure 4: Comparison of CCAT's continuum wide-field imaging sensitivity with other submillimetre telescopes. The 5σ detection limit is for a 1 hour survey over a 1 deg^2 area on the sky. Also shown is the predicted CCAT extragalactic confusion limit for 30 beams per source. CCAT will have superior capabilities obtain deep, high resolution images over large areas.