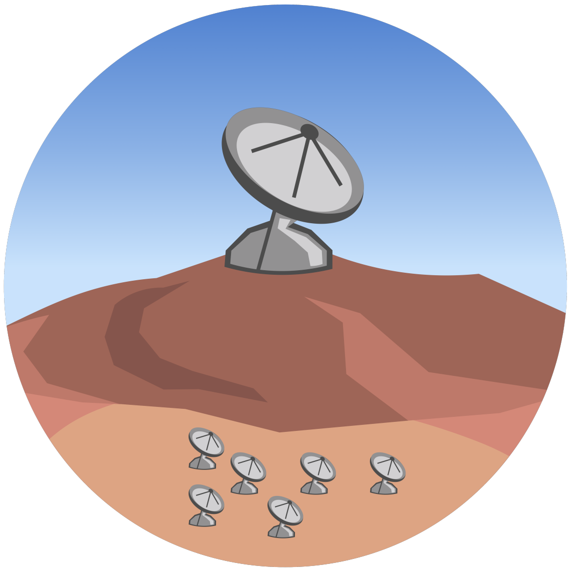

AtLAST Telescope Design: Preliminary Meeting Minutes & Notes

AtLAST-Memo-1 V.1

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Contents

List of Figures

List of Tables

Chapter 1

Introduction

1.1 Purpose

An AtLAST telescope design preliminary meeting was held on the 27th and 28th of July, 2020, to explore possible optical configurations (e.g. Cassegrain, Nasmyth, hybrid Cass-Nasmyth, Gregorian, Crossed-Dragone, etc) and structural design alternatives as well as corrections to the optics that could be included in the instrumentation (i.e. receivers and detector arrays). The purpose was to motivate the telescope requirements that distill from the science goals of AtLAST and converge on an ambitious yet realistic baseline telescope design from which the EU-funded Design Study will begin.

1.2 Scope

This document is limited to the minutes and discussion of the outcomes from the AtLAST Telescope Design Preliminary Meeting.

1.3 Reference Documents

A number of documents posted on `https://www.atlast.uio.no/documents/memo-series/` contain additional information in the form of notes and presentations. These are referenced in this document, and should be consulted for further, more detailed information.

1.4 Acronyms

AtLAST Atacama Large Aperture Submillimeter Telescope
BLAST Balloon-borne Large Aperture Submillimeter Telescope
DLFoV Diffraction-Limited Field of View
EBEX E and B mode Experiment
ELT Extremely Large Telescope
ESO European Southern Observatory
FoV Field of View
LMT/GTM Large Millimeter Telescope / Gran Telescopio Milimétrico Alfonso Serrano
LST Large Submillimeter Telescope
MTM MT-Mechatronics
PDR Preliminary Design Review
UiO Universitetet i Oslo (University of Oslo)
UKATC United Kingdom Astronomy Technology Centre

Chapter 2

Meeting content

2.1 Monday, 27-July-2020

In attendance: Claudia Cicone, Simon Dicker, Akira Endo, Thomas Greve, Richard Hills, Ted Huang, David Hughes, Hans Kärcher, Bernd Klein, Pamela Klaassen, Brett McGuire, Karl Menten, Tony Mroczkowski, Mike Niemack, Matthias Reichert, Carole Tucker, Friedrich Wyrowski

2.1.1 Overview of AtLAST science drivers (Claudia Cicone)

Claudia gave an overview of the broad science cases for AtLAST, noting that AtLAST aims for transformational leaps in observing capabilities and science impact, not incremental progress. Some of the requirements to carry out AtLAST science are the ability to:

- make pointed (targetted) observations of individual sources
- conduct wide surveys
- observe at multiple frequencies (not necessarily simultaneously), but this drives the need for multiple instruments on the AtLAST platform.
- reach lower frequencies than ALMA currently does (CC clarified this means observations down to 30 GHz, not just frequencies $\nu > 84$ GHz).

Claudia noted that some of the key AtLAST science drivers, for example the detection of faint broad components (e.g. line widths $\delta\nu > 3$ GHz at 230 GHz) of emission lines produced by outflows and inflows on circumgalactic medium scales (not accessible with interferometers, and so key driver for AtLAST), require stable baselines. This implies instrument stability requirements as well as the ability to modulate the signal sufficient fast to separate atmospheric drifts and astronomical signals.

Regarding instruments, it was noted that the only one concept first generation instrument that truly demands a large field of view (FoV) with today's technology (or technologies foreseeable in the next 5 years) is the widefield multi-chroic camera. Richard Hills noted however that instead of an integral field unit (IFU) at fixed spacing, a multi-object spectrometer (MOS) could take advantage of the large FoV (Cicone: e.g. similar to the concept of MOSAIC for the ELT or multi-object spectrometers under development for the LMT/GTM). Note: in order to be compelling, a MOS would have to have enough beams or bandwidth to be faster than ALMA, which has 3 times the collecting area. This likely means tens to hundreds of beams.

Karl Menten noted concerns about chopping/nutation, regarding baseline stability. A number of people responded that being able to slew fast (tens of arcminutes per second?) with a densely packed focal plane modulates the signal sufficiently w.r.t. the atmosphere.

2.1.2 AtLAST Designs (Hans Kaercher)

Hans gave an overview of the telescope designs[1] currently being considered, and some possibilities. This is largely from the point of view of structural/mechanical engineering challenges and overall costs (i.e. not considering the optics or science), though mention of the diffraction-limited field of view (DLFoV) came up in reference to Richard's presentation (see Section 2.1.3). Briefly, a single mirror design is ruled out. A 2-mirror Cassegrain could achieve a wide 2 degree DLFoV, and would be economical. A 3-mirror Nasmyth would have manageable costs and provides the feature that instruments can be mounted such that they are gravitationally-independent (i.e. they do not tip with changes in telescope elevation angle, they only rotate with azimuth). Ritchey-Chrétien with 2 flats is our proposed baseline, with the appeal of Nasmyth and Cassegrain mounts. Ritchey-Chrétien with relay was presented but immediately ruled out as an unreasonable structure. A number of designs such as a 3-mirror LSST type and 3-mirror plus 3 flats were presented, but the access and structure are difficult to realize. The LSST approach would have manageable costs and good performance, but changing instruments may prove too difficult and instruments would move in elevation. A 2-mirror off-axis Gregorian would exhibit less scatter and narcissus (standing waves as the receivers see themselves in reflection), but the mechanical design of the GBT is not a good model going forward. Rocking chair approach? Crossed Dragone would require a 41 meter secondary mirror (M2), and so the costs are likely prohibitive. Korsch designs (elaborated by Richard) us 3 mirrors and are the off-axis equivalent of the LSST approach. No structure has been worked out, but perhaps the rocking chair support would work. The question of *is the rocking chair structure too risky?* to develop for AtLAST, with the likely answer being *yes* as it would require much more resources to explore.

Richard raised the question of whether a slew speed of 3 degrees per second is necessary, and the data rates would be high if we have to read out much faster. Simon pointed out transition edge sensor (TES) detectors don't respond fast enough (< 1 ms), but Tony pointed out kinetic inductance detectors (KIDs) would (response times < 1 ms), as would heterodyne.

All: some discussion of active surfaces with laser or mm-wave closed-loop corrections / flexible body control (e.g. Kärcher & Baars, 2014). All agree this is a good idea, likely necessary to achieve the surface accuracy and beam required for the science goals.

Star cameras and pointing recovery, as used on balloons (e.g. such as those on EBEX or BLAST; see Vinokurov, 2010) were also discussed. There were no obvious objections, but follow-up discussion with Marie Rex, who worked on BLAST, and Will Grainger, who worked on EBEX, indicated star cameras would likely be very limited in daytime.

2.1.3 AtLAST Optical Designs (Richard Hills)

Richard presented[2] several optical designs, and provided extensive notes[3] as well. Richard noted in the introduction that throughput is a good metric, but the benchmark he prefers is throughput divided by wavelength-squared ($A\Omega/\lambda^2$), which scales as the number of beams on sky for a given wavelength. AtLAST going to 350 microns would start to exceed megapixels. Noted the curvature of the secondary essentially determines the focal plane curvature.

LSST-like 3-mirror assembly (TMA) would give near-perfect optics, but would need an optical stop. A Gregorian design is more flexible, with an adjustable focal length. 3-mirror Korsch 1 has no blockage, and corrects all aberrations. Cross-polarization is likely very low? A downside is the secondary mirror will be oversized, so spillover goes to the ground (extra noise) if the design doesn't account for this.

Richard pointed out that we need to consider more barebone, essential telescope designs in addition to the more ambitious/visionary ones, but we need to clearly delineate what scientific limitations will arise as a consequence of any potential descoping.

[1] https://www.atlast.uio.no/documents/memo-series/memo-public/2020-7-28-atlast-workshop-hjk.pdf
[2] https://www.atlast.uio.no/documents/memo-series/memo-public/optics-slides-reh.pdf
[3] https://www.atlast.uio.no/documents/memo-series/memo-public/optics-notes-reh.pdf

2.2 Tuesday, 28-July-2020

In attendance: Claudia Cicone, Martin Cordiner, Simon Dicker, Thomas Greve, Richard Hills, Ted Huang, David Hughes, Hans Kärcher, Bernd Klein, Pamela Klaassen, Brett McGuire, Karl Menten, Tony Mroczkowski, Mike Niemack, Matthias Reichert, Friedrich Wyrowski

2.2.1 Continued discussion from previous day

Richard Hills noted that the CCAT 25-meter had evolved to a Gregorian Design by Preliminary Design Review (PDR). This included a non-flat M3. They also explored 4-mirror designs, but found M4 had to be deformable and was thus infeasible in the scope of their studies.

2.2.2 CCAT-prime and CMB Designs (Mike Niemack)

Mike Niemack presented[4] the CCAT-prime and designs dedicated for CMB research (i.e. Simons Observatory, CMB-S4[5], CMB-HD[6], ACT), noting the CMB surveys optimize almost entirely on mapping speed (throughput).

CCAT-prime will operate up to 1.5 THz, somewhat higher than AtLAST's goal. They considered a Gregorian design, but the FoV requirement drove the design to a very large M2. While M2 for a Crossed-Dragone is large, the structure is more compact and has a clear aperture, making it appealing for a 6-meter survey instrument.

2.2.3 Receiver Considerations (Simon Dicker)

Simon presented[7] on receiver configurations. Because it is clear we want to host a number of different and diverse receivers, Simon discussed possible receiver switching mechanisms first. These include switching by

- mirror: easiest, most obvious way for e.g. Nasmyth, hybrid Nasmyth/Cassegrain, or Ritchey-Chrétien + flats designs;
- turret: really hard as you have to worry more about weight and cable wrap;
- rail: it could be convenient to mount the receivers on a rail system (e.g. for Ritchey-Chrétien, Crossed-Dragone, or Korsch designs).

One consideration is to avoid tipping the pulse tube coolers more than $\pm 50^\circ$ from the nominal operating position. If accounted for at the start, this should not be a difficult requirement.

For taking advantage of the field of view and introducing corrections to the focal plane, lenses may be considered. A number of groups in the CMB and ALMA communities are developing warm (room temperature) lenses (Chesmore et al., 2018).

Simon also pointed out that due to the inability to pack multiple instruments closely in the focal plane, as each receiver is in a bulky, vacuum-sealed cryostat and input/outputs for readouts and cryogenic interfaces is crucial, only about $\sim 50\%$ of the FoV is typically used in current CMB survey instruments.

One consideration is that horn-couple detectors may be placed closer to the cryostat window, as the spillover is better controlled. In contrast, bare detectors require longer optics tubes with baffling to control spillover.

Modularity was also noted as a very desirable feature for any receiver, due to transportation/shipping, installation, and maintenance constraints. If one receiver fails, not all observations have to stop.

And finally, the **natural frequency** of the telescope structure is important when you consider scanning speed goals and stability times for receiver or detectors gains. Since nutation/wobbling

[4] https://www.atlast.uio.no/documents/memo-series/memo-public/niemack_ccat_so_atlast_20200728r.pdf
[5] https://cmb-s4.org/
[6] https://cmb-hd.org/
[7] https://www.atlast.uio.no/documents/memo-series/memo-public/atlast_receiver_considerations_simon_dicker.pdf

is not an option for a ∼12-meter secondary mirror, the scan speed needs to be sufficiently high to modulate the atmosphere, but low enough to not severely impact the data rates (i.e. if the beam moves very fast, you have to record more data, at a higher rate).

Chapter 3

Summary and Outlook

I wanted to strongly support the suggestion/recommendations that the best path forward is to work towards an approach in the telescope design that maximizes the possibility of success, rather than attempt to achieve a more ambitious goal to explore and build a radically different telescope.

There was a general consensus from the meeting that we should build from previous experience (e.g. a shared heritage including the LMT/GTM and 2016 LST designs), rather than taking a large risk on a less proven design. As David Hughes noted, "The AtLAST project already has a number of significant advantages over the existing 12-m to 50-m class single-dish mm-wavelength [edit: and submm-wavelength] telescopes. These are: (a) a higher site than most telescopes . . . (b) improved M1 active surface accuracy (< 30 μm r.m.s.) and optical performance, offering greater instrument sensitivity and higher frequency observations (> 400 GHz) for AtLAST, compared to the 50-m LMT goal of 75 μm rms; (c) optimized larger field of view FoV (1-2 degs for AtLAST, compared to LMT 4 arcmin (currently) to LMT 12 arcmins (future upgrade)). Just having these 3 straightforward advantages with a more conservative telescope optical design can immediately offer orders of magnitude gains over the existing mm-wavelength facilities." The hybrid Nasmyth/Cassegrain design, in particular, can offer an advantage by allowing a broad range of instrumentation that would likely include facility and guest/P.I. instruments.

By building off this heritage, we have the opportunity to address several issues that have affected current and previous telescopes, including compensation for gravitational and thermal deformations (i.e. with an active surface incorporating live metrology, cooling/ventilation systems incorporated from the start, material choice). Among the issues mentioned in particular, were: operational & maintenance issues, access to the telescope structure, de-icing, repair to damaged segments, robust remote observation capabilities, and receiver cabin design.

Speaking from experience with the LMT, David Hughes also mentioned that the initial investment in telescope infrastructure will dominate the costs, while potential upgrades to the telescope relating to M1 and M2 would be subdominant by far.

Chapter 4

Recommendations

Table 4.1 briefly compares the designs discussed. It is clear that the hybrid Cassegrain+Nasmyth design is the lowest overall risk, with a good plan for hosting multiple instruments and the appeal that at least one instrument can be placed at a focus with only 2 mirrors for lower loading (i.e. lower system temperature or detector loading from warm elements in the optical path). Further, the structure will benefit from a long heritage of telescopes with a similar structural design. We therefore recommend we focus on the hybrid Cassegrain+Nasmyth design as a baseline. This is reflected in the AtLAST proceedings paper, Klaassen et al. (2020).

Table 4.1: *Risk Trade-off Matrix*

Design	Parameter Risk to AtLAST						
	Mirror #	Dev. risk	FoV	Cross-pol	Gravity dep.	Inst. #	Cost
Single Mirror on-axis	✓	✓	X	X	X	X	✓
Cassegrain	✓	✓	✓	-	X	-	✓
Nasmyth	-	✓	✓	-	✓	✓	-
Hybrid Cass/Nasmyth	✓	✓	✓	-	✓	✓	-
3-mirror LSST	-	-	✓	-	✓	✓	X
3-mirror + 2 flats	X	-	✓	-	✓	✓	X
Crossed Dragone	✓	X	✓	-	✓	✓	X
Gregorian	✓	-	✓	-	✓	✓	X
Korsch1	✓	X	✓	-	✓	✓	X

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