AtLAST Science Use Cases

Contents

Executive Summary

One of the key deliverables for the science work package of the AtLAST Horizon 2020 design study is a robust set of science-driven requirements for the telescope design. To begin the journey towards that document, we requested structured, but fairly general inputs from the worldwide astronomical community on what they would need the telescope to provide in order for them to deliver transformational science. This document summarises those inputs from the community. With this document in hand, we can delve deeper into the science cases the community provided in order to create those robust estimates of requirements.

Almost 30 science use cases were submitted from across the globe, covering science themes from the Solar System to the beginning of the Universe, focusing on gas and dust, structure, dynamics and variability. The submissions place broad constraints on properties like telescope diameter, field of view and sensitivity, as well as hinting at what kinds of instruments would best suit the community, with a slight preference for spectroscopic observations rather than continuum ones.

In many cases, large format cameras - whether continuum or spectral - with wide bandwidths are required to achieve the large area maps required to uncover population statistics unimaginable with the resolution and sensitivity available with modern facilities.

However, it is also clear that these large format cameras are unlikely to fulfil all of the science requirements put forth. The ability to place integral field unit (IFU) footprints throughout the large field of view was also suggested for a number of science cases which aim to understand populations in clustered but diffuse regions (i.e. local star forming regions or distant galaxy clusters).

To best support the community who have shown interest in developing the telescope, we find that a broad instrument suite and large throughput 'general purpose' facility is required.

AtLAST Science Use Cases

1 Introduction

In Mid-2021, we ran a community consultation to determine what kinds of science questions the world-wide astronomical community needed a new sub-mm facility to answer. To achieve consistent results and steer the community input into a common framework, we created a use case template (see Appendix C) for the community to fill out with the broad telescope requirements they think are necessary to induce a step change in our understanding of the (sub-)mm sky. This process is the first step towards building a scientifically justified set of requirements for the AtLAST telescope which can be presented to funding agencies at the end of the design study. They also serve as a touch point for understanding 1) which parts of the community we still need to engage, and 2) which types of telescope/instrument parameters are in tension, needing greater attention and discussion, and which are already commonly agreed upon.

Below, we present some summary statistics of the received submission, and in Section 2 we present the science probed by the use cases framed in the context of their science areas, exploring where they converge and diverge. The titles and lead authors of each use case are presented in Appendix A.

In total we received 28 submitted from scientists all over the world. There were contributions from 22 countries across 5 continents, with the breakdown of host countries of contributors shown in Figure 1.

From these submissions we were able to draw out four generalised science themes: The Sun and Solar System, The Milky Way, Nearby Galaxies, and The Distant Universe and Cosmology. In these categories we received 5, 10, 4 and 9 submissions, respectively. Much of the discussion in the next sections has the use cases broken down into these science themes, and whether continuum or spectroscopic observations are required to complete the science goals. From the use cases we extracted 81 requests for spectroscopic observations and 64 requests for continuum.

While the details of the telescope requirements most stretched by each science use case are discussed in greater detail in Section 3, we show in Figure 2 the pressures on the different (sub-)mm windows by science theme. In Figure 2a, we see a significant request for the atmospheric windows represented by ALMA Bands 6,7 and 8, while Figure 2b shows more of a concentration towards ALMA Bands 3, 6 and 7 and an increase again for Band 9. This reflects the different types of science being achieved with spectrometers and continuum cameras. A mapping of the ALMA Bands to both wavelength and frequency is presented in Appendix B.

In Figure 3, we present the types of spectroscopic or continuum observations requested by science theme. For spectroscopy, we asked whether the scientist would prefer a well sampled Heterodyne device, an Integral Field Unit (IFU) or Multi-Object Spectrograph (MOS). For continuum observations, with the understanding that there would be large format cameras, we asked whether the scientists required simultaneous multi-chroic observations, or whether single band observing would be sufficient. For most cases, we find a well sampled heterodyne or a single band continuum camera is sufficient for the general science cases, but with specific reasoning and rationale presented for the other observing modes - as described more fully in Section 3.

Together, the broad science coverage of the use cases, and the range of telescope parameters they require, shows that the community are really looking for a multi-purpose observatory able to cover a broad range of science topics.

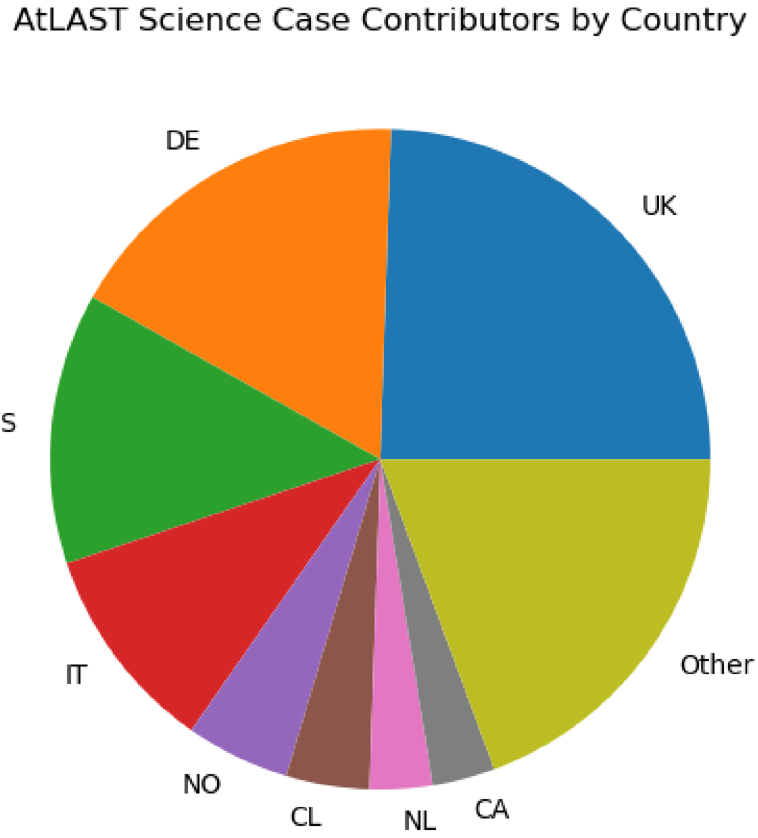
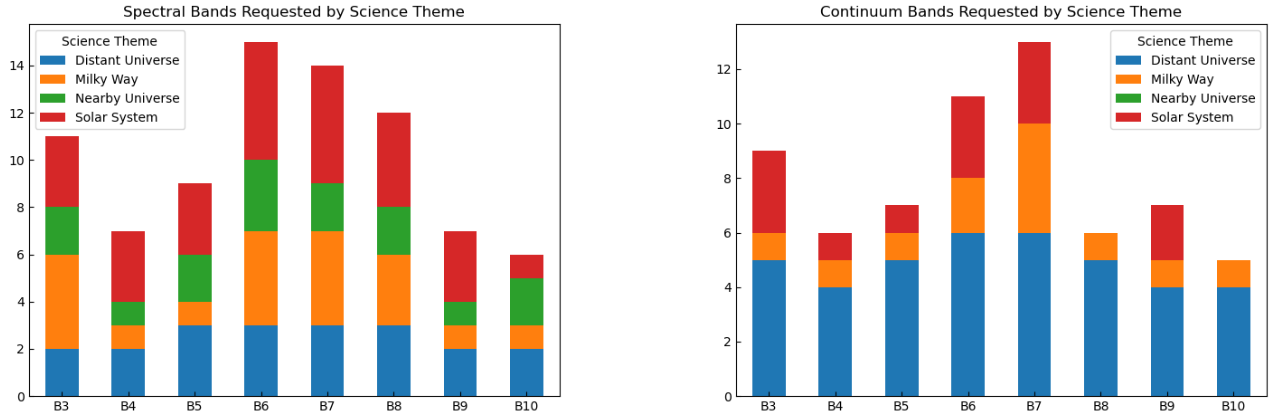


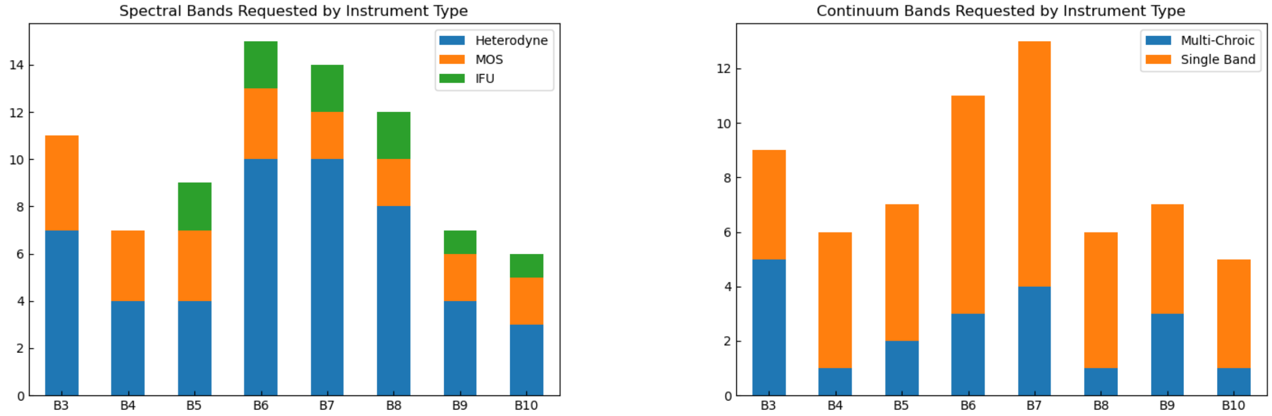
Figure 1: Locations of scientists who were part of the submitted use cases, either as lead or contributing author. For the graphical representation, those countries with less than 3 contributors are lumped into 'other', submissions from ESO are listed under 'DE', and those from SKAO are listed under 'UK'.



(a) Spectroscopic Bands requested by Science Theme

(b) Continuum Bands requested by Science Theme

Figure 2: Spectroscopic and Continuum bands requested by Science Theme. The labelling on the x-axis corresponds to the canonical ALMA bands defined in each spectroscopic window, the frequency ranges of which are given in Appendix B.



(a) Types of Spectroscopic instruments requested by Science Theme

(b) Types of Continuum observations requested by Science Theme

Figure 3: Spectroscopic and Continuum observations by broad instrument type as defined in the text. The labelling on the x-axis corresponds to the canonical ALMA bands defined in each spectroscopic window, the frequency ranges of which are given in Appendix B.

2 Science Themes

From the submitted use cases, we have been able to derive four broad science themes, as presented below. This grouping doesn't imply that these science cases are all asking for the same type of observations, but helps frame the types of telescope/instrument requirements needed for the science themes to be realised. It also allows for better communication within the science working groups going forward.

These themes center around the Sun and Solar System, the Milky Way, Nearby Galaxies, and the Distant Universe and Cosmology. Some of these boundaries are more fluid than others. For instance, we have chosen here to treat the bulk of the Magellanic Cloud science cases as Nearby Galaxy science, because many of them are looking at populations in the Magellanic Clouds in similar ways to other Nearby Galaxies. However, we have placed the Circumgalactic Medium (CGM) links between the Milky Way and the Magellanic Clouds as part of the Milky Way science case because it is being explored differently than the CGM surrounding other Galaxies.

In this section we outline the science cases in these four themes to set the context for section 3, where we expand on the most relevant telescope/instrument requirements for the science cases in each theme.

2.1 Solar System

Most of the sub-mm emission from the Sun comes from the chromosphere. Studying this emission and understanding its thermal and magnetic properties helps us understand phenomena like solar flares and the energy passing through this layer and into the corona. Understanding this in the Sun, where we can *resolve* the emission, allows us to transfer that knowledge to other stars.

As with the Sun, many planetary atmospheres in the Solar System can be resolved out with interferometers like ALMA. This means it is impossible to study the temporal and spatial variations in these atmospheres on the Giant planets, Mars and Venus with interferometers. Current single dish facilities can monitor the temporal variations, but the signals will get beam diluted with the comparatively large beams. Higher spatial resolution is also required to study icy moons; for instance, the oceans of Enceladus are tricky to study because modern facilities don't have the spatial resolution to separate its emission from that of Saturn (less than $10''$ away).

Comets are quite extended on the sky, and so are also filtered out by interferometers. Thus, by studying them with moderate resolution and great sensitivity, we should gain valuable insights on the pre-biotic molecules which seed the Solar System and which could point towards the origins of life.

2.2 The Milky Way

The science case for studying dust, chemistry, magnetism, dynamics and variability within our own galaxy primarily revolve around the formation of stars and the gas, and dust produced in evolved stars.

Large area studies of the Galactic Plane will constrain the initial mass function (IMF) and its relation to the core mass function (CMF) beyond the local (low-mass) censuses to date. They will allow us to constrain the dust opacity spectral index, the Galactic magnetic field, the transitions to and from molecular gas clouds, and the chemistry of the interstellar medium (ISM) in a global sense. With dedicated surveys of star forming regions we extend our survey statistics beyond the local star-forming regions in the Gould's Belt, to the more typical environments stretching from here to the Galactic Centre. Dedicated polarisation studies of evolved stars will inform our understanding of dust and chemical evolution in these regions, and regular monitoring of all of these types of environments will further constrain variability in them, leading towards a better understanding of accretion and ejection events.

To further constrain the evolution of our Galaxy, we can look to portions of the circumgalactic medium (CGM) which emit on such large scales that they are completely filtered out by interferometers. Studying, for instance, the Southern Fermi Bubble will allow us to quantify feedback from nuclear regions while studying the Magellanic Stream informs the kinematics of the tidal CGM.

2.3 Nearby Galaxies

With the sensitivity and resolution achievable with a facility like AtLAST, evolved star studies comparable to those currently undertaken in the Milky Way can be undertaken in the Magellanic Clouds and beyond – unlocking another dimension in the interplay between mass loss and chemical evolution because of their much lower metallicities.

Similarly, CO and CI surveys of nearby galaxies gives insights on the cold gas properties, a robust determination of the CO to H_2 mass function and the ability to study the 'multi-phase' interstellar medium (ISM) out to $z{\sim}0.5$. This then links directly to the diffuse CGM of these same galaxies. This emission has been neglected by previous facilities because of its highly extended and diffuse (i.e. faint) nature, but plays a vital role in galaxy evolution.

2.4 Distant Universe and Cosmology

A large area spectroscopic and photometric survey at submillimetre wavelengths with the resolution, sensitivity and mapping speeds of AtLAST will enable the investigation of several key extragalactic science questions.

AtLAST's wavelength coverage probes the peak of the dust spectrum of star-forming galaxies from $z = 1$ up to cosmic dawn and a plethora of spectral features therein. With this information, we can probe strong cooling lines and can map the reionization of the Universe up to $z = 10$ – getting at the properties of the very first galaxies.

With broad spectral coverage, we can determine redshifts and dust properties for a large sample of normal star-forming galaxies which will enable the investigation of clustering of sources, further understanding of the role of environment in galaxy evolution, and quantifying the contributions of obscured star formation to the cosmic star formation rate density.

It will be possible to study galaxy clusters through both their thermal properties, and the relativistic Sunyaev-Zeldovich effect: as the largest structures in the Universe, galaxy clusters are sensitive to fundamental cosmological parameters and are excellent cosmological probes against which theory can be tested.

Detailed measurements of submillimetre emission lines across large cosmological volumes will also allow us to map large scale structure using baryonic acoustic oscillations observable in matter clustering as a standard ruler to measure the expansion history of the Universe, and test models of dark energy and inflation and probe deviations from the ΛCDM model.

3 Telescope requirements by Theme

The diversity of submitted use cases within the science themes means that there are a number of telescope requirements constrained by the clustering of these use cases. Below, we highlight the 3-4 most important properties for each of the science themes. This isn't to say that these are the only constraints put on the telescope requirements by each science case, but that these are the ones most strongly constrained within that science theme.

3.1 Solar System

Specific to Solar System science is the need to include non-sidereal tracking. In addition to requiring high enough resolution to separate the atmospheres of planets and their icy moons, short cadence observations and rapid response to targets of opportunity (TOOs) will be required to quantify transient storms in the atmospheres of planets and moons.

Non-Sidereal Tracking

Because Solar System bodies move with respect to background stars, the telescope will need to be able to track these non-sidereal objects.

Repeat observations / time variability

The Sun rotates on a $\sim$ 1 month timescale and to capture a full solar rotation will require daily observations to properly quantify the Chromosphere. Planetary atmospheres vary on short timescales (hours), and so repeated observations are required to capture that variability. If storms develop in an atmosphere, then the telescope needs to be able to respond quickly to that TOO.

Resolution

Resolutions of 1-$2''$ at the highest frequencies are required in order to spatially resolve the atmospheres of icy moons from those of their host planets (i.e. Enceladus is a maximum of $10''$ from Saturn).

Sensitivity and Bandwidth

Both Solar and Solar System cases require broad spectral coverage to study the composition of the primordial (i.e. cometary) and modern day system. Broad spectral coverage maximises the number of species detectable in a single observation, and also allows for line stacking for faint targets / lines while minimising calibration uncertainty.

3.2 The Milky Way

The key telescope requirements for understanding the Milky Way are fast scanning and large bandwidths at high spectral resolution. These constraints, complimented by high spatial resolution, will lessen beam dilution in marginally resolved regions while simultaneously minimising beam de-polarisation as well. In addition to these main characteristics, fast repeats and multi-chroic observations are required to properly capture variability in the interstellar medium (ISM) of the Milky Way.

Fast Scanning

Many of the Milky Way science cases require mapping of the Galactic Plane. To make these surveys feasible, the telescope needs to have a fast scanning mode. For example, for shallow, large area surveys, it is unlikely that the telescope will dwell for more than 10s at any point. With large format cameras, this necessitates fast scanning/slewing.

A minimum continuum camera footprint of $10'$ is required for such a camera in order to allow continuum observations to be combined with the larger scale images of facilities like *Planck*. Even though AtLAST is a single dish telescope, it can still only capture emission on size scales smaller than the distances to calibration sources, and proper overlap with *Planck* images is crucial for putting that emission into the larger context.

High Spectral Resolution, Large Bandwidth

To properly constrain the chemistry of the ISM, spectral resolutions down to at least 0.05 km s^{-1} are needed (for reference, ALMA gets to $\sim$ 0.01 km s^{-1} at the higher frequencies), with many cases setting a minimum threshold of 0.1 km s^{-1}. This needs to be traded off with the large bandwidths required by many of the science cases (8-16 GHz) which will both capture the continuum emission in the line free regions as well as minimise the number of passes required for full spectral coverage of each atmospheric window.

Multi-Chroic Continuum observations

Simultaneous multi-chroic observations are needed for a number of cases to 1) minimise the cross band calibration uncertainties when building up Spectral Energy Distributions (SEDs) and quantifying the dust scaling factor (κ_ν) as well as to 2) avoid washing out variability signatures (in both the SEDs and κ_ν) by observing different bands at different times.

Repeat Observations

To quantify variability in accretion and ejection mechanisms, we need repeat observations of statistical samples of objects (whether they're forming or evolved stars). The cadence of the repeats depends heavily on the science case, but can vary from monthly to yearly.

3.3 Nearby Galaxies

Many of the telescope requirements for the submitted Nearby Galaxy cases are very similar to those for our own Galaxy, focusing on spectral resolution and Bandwidth.

Spectral Resolution

Again, to quantify chemistry and dynamics in the ISM and CGM requires high spectral resolution (up to 0.1 km s^{-1}), but with the caveat that binning up to 10 km s^{-1} could lower the overall spaxel count and therefore data rates.

Large Bandwidth

Larger bandwidths will drive down survey times for spectral scanning, but will also enable simultaneous observations of multiple species/isotopologues as has been shown with ALMA (i.e. simultaneous observations of ^{12}CO in the upper sideband with ^{13}CO and C^{18}O in the lower in ALMA Band 6). Bandwidths of at least 4 GHz at $\sim$ 900 GHz (ALMA Band 10) would enable simultaneous observations of CO and CI; thus capturing the CO bright and CO dark portions of Giant Molecular Clouds (GMCs) at the same time.

Large Field of View

To efficiently observe an entire cluster of galaxies in a single pointing, and to minimise calibration uncertainty, requires a large field of view. As an example, a 1 sq. deg. field of view could be expected to detect $\sim$ 40 galaxies with $z<0.5$.

3.4 Distant Universe and Cosmology

A number of the Distant Universe science cases require a large area survey, comparable to SDSS in sky coverage, and as such require fast mapping of large sky areas at sensitivities reaching below the confusion limit, multi-band photometry, and large bandwidth. In addition, several cases make strong arguments for achieving high frequency observations (ALMA band 9 and above). All require the excellent resolution and sensitivity that a 50m dish could provide; however, constraints on spectral resolution are not as stringent as in other science themes (i.e. only one science case requires resolution < 10 km/s).

Large Field of View

In order to overcome cosmic variance and sample the large areas of sky required for measures of clustering on different cosmological scales, up to thousands of sq. deg. sky coverage is required for a number of surveys. Fast mapping capabilities – e.g. large FOV and high sensitivity – make this possible, with efficiency improving if multi-chroic observations are possible simultaneously. Reaching a sensitivity of 0.1 mJy at ALMA band 6 would result in detecting approximately 10^4 sources per sq. deg.; a 1000 sq. deg. survey area area would thus reveal up to tens of millions of sources.

Multi-band photometry

Many of these science cases require 3+ bands of continuum observations over large sky areas. Simultaneous multi-band photometry would allow greater efficiency in sky surveys, but with the trade-off that this would mean fewer pixels at any given band.

Large Bandwidth

A large bandwidth is essential to capture spectral features over a broad redshift range, to maximise the cosmic volume probed by large area surveys, and will lower spectral scanning survey times.

High Frequency Observations

Two cases in particular make the case for sensitive, high-frequency ($>$ 600 GHz) observations. To resolve degeneracies between foreground dust components and Sunyaev-Zeldovich temperature signals, these high frequency bands are necessary. In modelling the dust properties of star-forming galaxies, high frequency observations are required to probe the peak of the dust spectrum at $z > 2$.

4 Telescope Requirements and Generalised Instrumentation

4.1 Telescope Requirements

Overall, there is general consensus from the submitted use cases that a 50m diameter telescope is required to push the boundaries of understanding because it breaks through a number of barriers seen in current observations. This diameter is fairly consistent with the longest baselines of the ALMA compact Array (ACA, 45m baselines), however with greater sensitivity and throughput (coming from the larger field of view), AtLAST opens up the ability to quickly scan large portions of the sky which the ACA just can't do.

Table 1 presents an overview of the range of telescope properties requested in the submitted cases. In all science themes, polarimetric observations are required, and for the more nearby objects, repeat observation with specific cadences are required to capture time variability on timescales of days to months (depending on the science case).

In terms of spatial sampling Table 1 presents two options, maps that when properly observed are fully sampled, and those that pick off specific parts of the field of view to sample. These distinctions came primarily from spectroscopic observations where the number of individual pixels is much more limited than from continuum cameras.

In the case of fully sampled mapping, this does not necessarily imply fully sampled cameras. Sparsely sampled detectors can generate fully sampled maps when the right mapping methods are applied. For the multi-object spectrograph (MOS) observations, the concept includes placing a number of fibres (or an IFU) at each position so that a number of small 'postage stamp' maps are created with a single pointing of the telescope.

4.2 Generalised Instrumentation

Within the submitted use cases, themes emerged with respect to the types of instrumentation required by the science. The generalised instrumentation suite to come out of this exercise comprises: a large format continuum camera, a highly multiplexed heterodyne, and a multi-object spectrometer. Overall, there was also a push for a wide bandwidth integral field unit (IFU), however the support for such an instrument was much lower.

To help guide the submissions, we suggested people think of current technologies like those in TolTEC [1] for continuum cameras, the 1000 pixel heterodyne reciever proposed in [2] and the ultra-wideband IFU discussed in [3] to give grounding in what is currently possible. For large format continuum cameras, there was little variation between requested capabilities, especially when considered against the spectrometer requests. The most notable variations being the more numerous requests for a multi-object spectrometer than those of the IFU.

4.3 Continuum Camera

As shown in Figure 2b, there is the desire to cover most of the (sub-)mm windows with a continuum camera. The bulk of the requests coming in at the 1mm (300 GHz) regime covering ALMA Bands 6 and 7, however it is clear from the distribution of requests that scientists want to probe as much of the dust continuum SED as they can, at as many redshifts as possible.

	Solar System	Milky Way	Nearby Galaxies	Distant Universe
Diameter (m)	50	50	50	50
Instantaneous Field of View (sq. deg)	-	> 0.03	1	-
Largest Angular Scale (arcmin)	~ 30	10	-	3600
Atmospheric Windows[a]	B3-B10	B3-B10	B1-B10	B1-B10
Spatial Coverage (sq. deg)	0.5	540	1000+	1000+
Sampling	Full	Full/MOS	Full	Full
Repeats	✓	✓	✓	✓
Time Variability		✓	✓	
Targets of Opportunity	✓	✓		
Fixed Schedule	✓	✓		✓
Time Critical	✓			
Polarisation	✓	✓	✓	✓
Spectral Bandwidth (GHz)	4-16	8-16	16+	16+
Spectral Resolution (km/s)	0.1	0.05	0.1	1
Continuum Bandwidth (GHz)	16+	16+	16+	16+
Continuum Resolution (km/s)	1/Band	1/Band	1/Band	1/Band

Table 1: Generalised telescope requirements pulled from the submitted use cases. The Atmospheric windows are listed with respect to the ALMA observing bands, for which a translation to wavelength/frequency is found in Appendix B

The general consensus was for at least 16 GHz of instantaneous bandwidth, with some science cases requiring that to be broken down into channels of order 1 MHz to allow for the removal of spectral line contamination.

The required angular resolution for the individual science cases are consistent with that of a 50m primary mirror, with only a few cases requiring the 1-2″ precision of the highest frequency observations. The largest angular scales required of the continuum camera were of order 10′, with many of the surveys requesting upwards of 1000 sq. deg for their overall footprints (e.g. sub-mm SDSS).

Studies of solar system objects and protostellar variability place constraints on being able to simultaneously observe in different wavebands which not only minimises uncertainty between observing bands, but allows for the SEDs of the objects to be timestamped together: variability on day-to-day timescales can then be attributed to science, not calibration uncertainty.

4.4 Spectrometers

For spectroscopic observations, there was a much clearer drive towards the 1mm (300 GHz) and shorter bands than in the continuum case, especially in the nearby Universe where there are CO (J=3-2, J=2-1) and CI $({}^3P_1 - {}^3P_0)$ transitions. For the distant Universe, there is a much broader request for virtually all bands, as the red-shift ranges of lines and SEDs are shifted to lower frequencies - including some rest frame IR and optical lines.

Many of the chemical surveys require full coverage of each (sub-)mm atmospheric window, with broad bandwidths (e.g. 8-16 GHz) to minimise the number of repeat observations required to fully sample the window. With requested spectral resolutions down to 0.1 km s^{-1}, this poses a technological challenge for both data collection and processing.

The largest angular scales requested are of order 0.03 deg (for things like the Sun), with resolutions enabled by a 50m diameter dish.

There were very few requests for simulataneous multi-band observations, and the variety instead comes in with respect to how different users want to use the large focal plane. First generation heterodynes won't be able to fill the focal plane, and so below we discuss the two observing modes most commonly requested for spectroscopic observations.

4.4.1 Highly Multiplexed Spectrometer

To maximise the efficiency of the spectroscopic surveys, a large format heterodyne is required. Being able to quickly and efficiently obtain fully sampled maps of a region (whether it be the Galactic Plane or a GOODS type field) will provide excellent statistics on the (sub-)mm sky. This means of order 1000 pixels or more are needed for the spectrometer.

4.4.2 Multi-Object Spectrometer

Not all science cases require a fully sampled map. In these cases, small clusters of spectrometers (or small IFUs) that are positionable throughout the large field of view of AtLAST would allow studies of smaller objects, like individual galaxies in nearby clusters or protostellar cores in a star forming region.

4.5 Other instrumentation requests

The generalised instrumentation above includes the parameters given for solar observing, however we note that instruments required to observe the Sun will require special coatings and considerations that were beyond the scope of this use case exercise. These parameters should be drawn out better in the following steps of the science case development.

There were a few requests for ultra-wideband heterodyne recievers, primarily in the blind surveys of the distant Universe. Here, the science cases requested the full atmospheric window across the full sub-mm range (ALMA equivalent Band 5 and higher) for line-intensity mapping studies at $z > 2.8$.

5 Next Steps

The submission of use cases was the first step in the community consultation to provide detailed, science driven, requirements for the telescope. Over the next 18 months, we will continue to probe these areas of interest to refine the requirements presented in the use cases. This will require more in depth analysis of:

- Why the science goals are important
- What the detailed requirements are to meet those goals
- What compromises are acceptable, and conversely, *not* acceptable
- How long such observations will take, using the sensitivity calculator when available
- What types of generalised instruments are required

This detailed work is expected to be taken on in a number of science themed working groups drawing on the enthusiasm for AtLAST style science already shown by the community.

A Submissions by Science Theme

Title	Lead Author
The Active Sun	Sven Wedemeyer
Synoptic Observations of the Sun	Sven Wedemeyer
The Chemistry and Dynamics of Planetary Atmospheres	Alexander Thelen
The Habitability of Icy Moons in the Solar System	Martin Cordiner
Tracing the earliest history of the Solar System through rotational spectroscopy of cometary volatiles	Martin Cordiner

Table 2: Submitted Use Cases for Solar System Science

Title	Lead Author
Our Molecular Galaxy - galactic plane ecology survey	Pamela Klaassen
A physico-chemical description of the ISM gas properties within 1 kpc: a molecular journey from cloudsto proto-planetary disks	Alvaro Hacar
AtLASTGAL: A multichroic continuum survey of the Galactic Plane	Andrew Rigby
Monitoring the Variability of Galactic and Extragalactic Sub-mm Bright Sources	Doug Johnstone
5000 Cores Covered: a full chemical and physical characterization of molecular cloud cores	Thomas Stanke
Molecular & atomic Milky Way CGM	Claudia Cicone
The multi-scale gas flow in the Milky Way: a comprehensive view of the gas dynamics in our Galaxy	Alessio Traficante
Constraining dust physics using multiband continuum polarimetry of evolved stars	Peter Scicluna
CI in nearby star forming regions: origin and small scale relation to molecular gas	Thomas Stanke
A survey of the dust polarised thermal emission from the Galactic Plane	Maite Beltran

Table 3: Submitted Use Cases for The Milky Way Science

Title	Lead Author
A sub-mm survey of the Magellanic Clouds	Peter Scicluna
A next generation CO line legacy survey of the nearby Universe	Tim Davis
Atomic carbon in nearby galaxies	Thomas Stanke
Circum-Galactic Medium of Galaxies	Claudia Cicone

Table 4: Submitted Use Cases for Nearby Galaxies Science

Title	Lead Author
Extragalactic surveys - a submm SDSS	Jim Geach
Cold gas in the Epoch of Reionization	Daizhong Liu
Searching and characterizing the molecular absorbers in the Universe	Chian-Chou Chen
SMG environment & clustering	Thomas Cornish
Evolution of dust emission in normal star-forming galaxies from cosmic dawn to cosmic noon:	Elisabete da Cunha
Variability of accretion onto the most massive black holes	Alastair Edge
AtLAST's line-intensity mapping survey: mapping the large-scale structure at high redshift	Jose Luis Bernal
Bringing light to elusive galaxy clusters (SZ)	Stefano Andreon
Resolved rSZ temperature profiles	Yvette Perrott

Table 5: Submitted Use Cases for Distant Universe and Cosmology Science

B Frequency Ranges of 'ALMA' Bands

ALMA Band	Wavelength (mm)	Frequency (GHz)
1	6-8.5	35-50
2	3.3-4.5	65-90
3	2.6-3.6	84-116
4	1.8-2.4	125-163
5	1.4-1.8	163-211
6	1.1-1.4	211-275
7	0.8-1.1	275-373
8	0.6-0.8	385-500
9	0.4-0.5	602-720
10	0.3-0.4	787-950

Table 6: Mapping of ALMA Observing bands to their Atmospheric windows

C Use Case Submission Template

C.1 Project Details

Title:

Principal Investigator:

Co-authors:

Time request:

C.2 Expected Observing Bands

Frequency Coverage (GHz)	Spectral line (heterodyne/IFU/MOS/other)	Continuum (multi-chroic/single band)	Other (please specify)
84-116 (B3)			
125-163 (B4)			
163-211 (B5)			
211-275 (B6)			
275-373 (B7)			
385-500 (B8)			
602-720 (B9)			
787-950 (B10)			
950+			
Other (please specify)			

C.3 Observing mode

☐ Normal
☐ Fixed schedule
☐ Time-critical override
☐ Collaborative & Coordinated
☐ Other

Details:

C.4 Comments on observing strategy

C.5 Polarisation products required

- ☐ XX
- ☐ YY
- ☐ XY
- ☐ YX
- ☐ Stokes I
- ☐ Stokes Q
- ☐ Stokes U
- ☐ Stokes V

C.6 Scientific Description

C.7 Target specifications

Type of observation:

- ☐ Individual pointings per object
- ☐ Individual fields-of-view with multiple objects
- ☐ Survey
- ☐ Other

Details:

Number of targets:

Multiple epochs/repeated observations? Yes/No

Rapidly changing sky position? Yes/No

Time critical? Yes/No

Required integration depth, and/or estimated time:

Average peak flux density per target:

Range of peak flux densities:

Expected polarised flux density:

C.8 Observational Setup

Central frequencies (GHz):

Total bandwidth (GHz):

Spectral resolution (kHz):

Temporal resolution (if required):

Comments:

C.9 Imaging considerations – CONTINUUM

Please indicate the specifications for instrumentation required for your science goals. For proposed instrumentation, see our SPIE paper [4, section 5.1] and for recent example specification see e.g. TolTEC [1]

Required angular resolution:

Mapped image size:

Largest required angular scales:

Number of output channels:

Output bandwidth:

Required rms:

Dynamic range within image:

Absolute flux scale calibration (if relevant):

- ☐ 1 – 3%
- ☐ 5%
- ☐ 10%
- ☐ 20 – 50%
- ☐ N/A

Relative flux scale calibration (if relevant):

- ☐ 1 – 3%
- ☐ 5%
- ☐ 10%
- ☐ 20 – 50%
- ☐ N/A

Comments:

C.10 Imaging considerations – SPECTRAL

Please indicate the specifications for instrumentation required for your science goals. For proposed instrumentation, see our SPIE paper [4, section 5.1]. Instruments may include, but are not constrained to, multiplexed heterodyne [see, eg 2], wideband IFU [see, eg 3], ultra wideband heterodyne and multi-object spectrograph.

Type of instrument (example types of instruments):

- ☐ highly multiplexed heterodyne [see, eg 2]
- ☐ Wideband IFU [see, eg 3]
- ☐ Ultra wideband heterodyne
- ☐ Multi Object Spectrograph
- ☐ Other (specified below)

Required angular resolution:

Mapped image size:

Fully Sampled or MOS:

Number of image channels:

Number of pixels:

Channel width:

Output bandwidth:

Required rms (Jy/beam or K):

Dynamic range within image:

Absolute flux scale calibration (if relevant):

- ☐ 1 – 3%

☐ 5%
☐ 10%
☐ 20 – 50%
☐ N/A

Relative flux scale calibration (if relevant):

☐ 1 – 3%
☐ 5%
☐ 10%
☐ 20 – 50%
☐ N/A

Required baseline stability:

Is a contiguous bandwidth required? If so, over what frequency range?

Comments:

C.11 Critical telescope specifications for your science

Which of the telescope specifications are most important to this project? If you could change one parameter by 10%, which would have the most significant impact? Why are we unable to do this science with existing facilities?

C.12 Data analysis

Processing considerations:

Data products:

Data product fidelity:

C.13 Other considerations

References

[1] Sean Bryan, Jason Austermann, Daniel Ferrusca, Philip Mauskopf, Jeff McMahon, Alfredo Montaña, Sara Simon, Giles Novak, David Sánchez-Argüelles, and Grant Wilson. Optical design of the TolTEC millimeter-wave camera. In Jonas Zmuidzinas and Jian-Rong Gao, editors, *Millimeter, Submillimeter, and Far-Infrared Detectors and Instrumentation for Astronomy IX*, volume 10708 of *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series*, page 107080J, July 2018. doi: 10.1117/12.2314130.

[2] Christopher Groppi, Andrey Baryshev, Urs Graf, Martina Wiedner, Pamela Klaassen, and Tony Mroczkowski. First Generation Heterodyne Instrumentation Concepts for the Atacama Large Aperture Submillimeter Telescope. *arXiv e-prints*, art. arXiv:1907.03479, July 2019.

[3] Sean Bryan, James Aguirre, George Che, Simon Doyle, Daniel Flanigan, Christopher Groppi, Bradley Johnson, Glenn Jones, Philip Mauskopf, Heather McCarrick, Alessandro Monfardini, and Tony Mroczkowski. WSPEC: A Waveguide Filter-Bank Focal Plane Array Spectrometer for Millimeter Wave Astronomy and Cosmology. *Journal of Low Temperature Physics*, 184(1-2):114–122, July 2016. doi: 10.1007/s10909-015-1396-5.

[4] Pamela D. Klaassen, Tony K. Mroczkowski, Claudia Cicone, Evanthia Hatziminaoglou, Sabrina Sartori, Carlos De Breuck, Sean Bryan, Simon R. Dicker, Carlos Duran, Chris Groppi, Hans Kaercher, Ryohei Kawabe, Kotaro Kohno, and James Geach. The Atacama Large Aperture Submillimeter Telescope (AtLAST). In *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series*, volume 11445 of *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series*, page 114452F, December 2020. doi: 10.1117/12.2561315.