

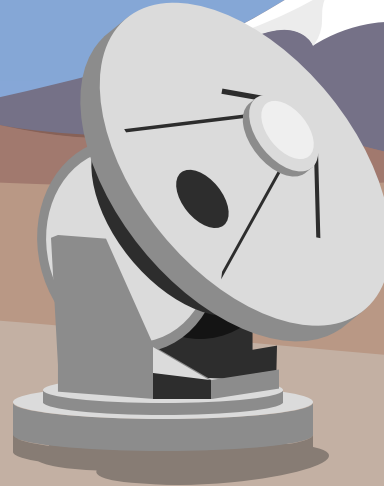
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 951815



**Mark Booth & Pamela Klaassen**

UK Astronomy Technology Centre, Royal Observatory Edinburgh, UK

*With many contributions from members of the AtLAST consortium*



# The Atacama Large Aperture Submillimeter Telescope (AtLAST)

# Outline



- Current status of project
- Science working groups
- Publication plan
- Sensitivity calculator
- Mainz conference



Powered by solar energy and equipped with hybrid storage solutions, enabling ~100% green operations

WP5 - Energy study

An international partnership open to collaborations (e.g. Japanese LST) where Europe has a central role

WP1 - Governance & Coordination

$\lambda_{\text{obs}}$  from 350  $\mu\text{m}$  to 10 mm  
Ambitious design driven by unique + transformational science goals

WP6 - Science Case

WP3 - Site selection

~5000 m site on the Chajnantor Plateau near APEX, maximising the scientific and technical synergy with the observatories on the Plateau

Multiple (6) instruments with large FoV:  
4 with  $D_{\text{FoV}} = 1$  deg  
2 with  $D_{\text{FoV}} = 2$  deg

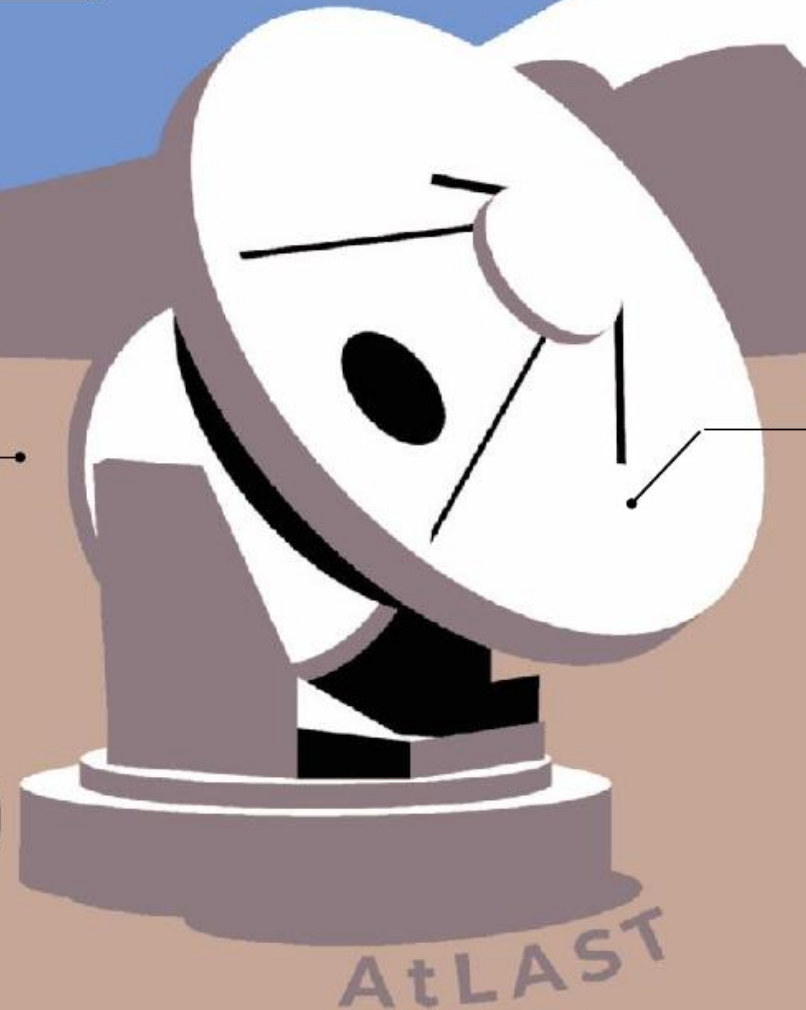
WG7 - Instrumentation

50-m diameter (2.6" res @ 600  $\mu\text{m}$  (500 GHz))  
2 deg FoV  
Fast scanning speed 3 deg/s  
Elevation range 20-90 deg

WP2 - Telescope Design

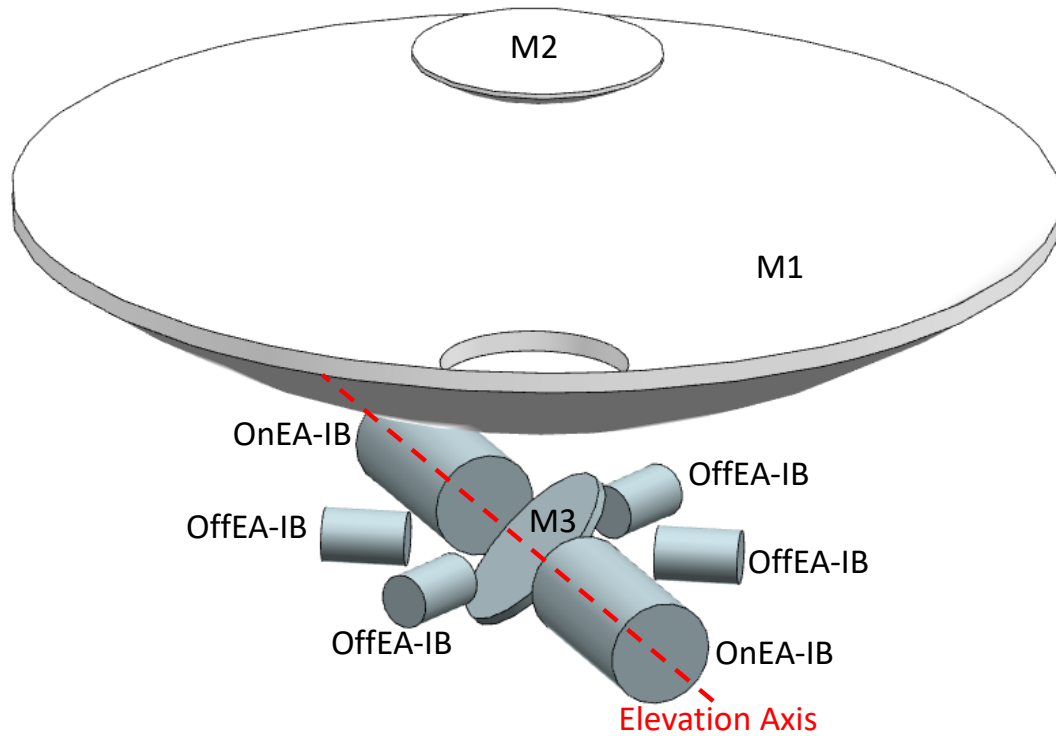
A flexible and efficient facility serving a broad community, performing PI observations and ambitious surveys

WP4 - Operations



EU Horizon 2020 Design Study: 1 March 2021 – 31 August 2024 (3.5 years)

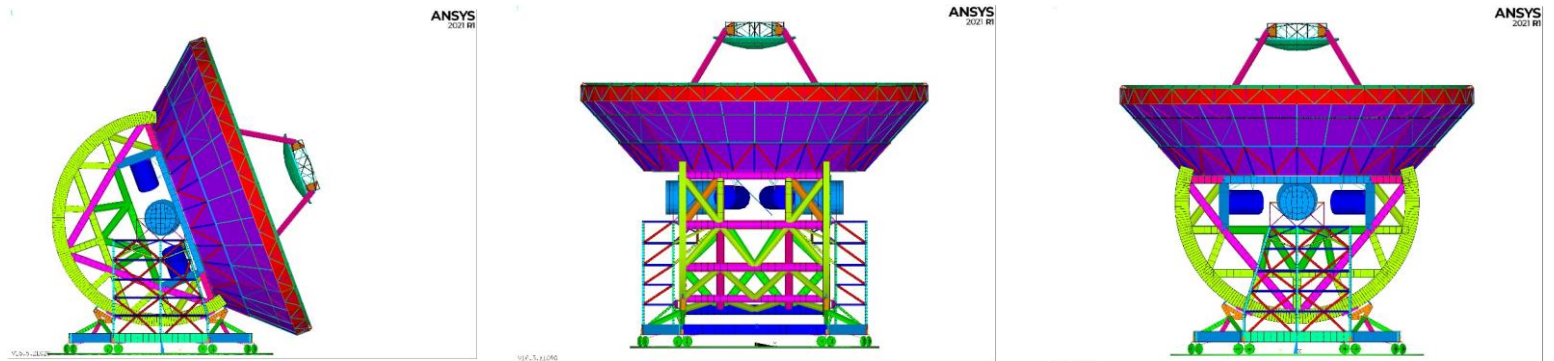
# AtLAST Telescope Design



OnEA-IB: On EL Axis Instrument Bay  
OffEA-IB: Off EL Axis Instrument Bay

See Mroczkowski et al. 2023

- 'Rocking chair' design
- 2 larger Nasmyth-mounted instruments (~4.5 m diameter)
- 4 smaller (~2.2 m) off-elevation axis instruments that move in elevation with the antenna structure.





# Environmental Sustainability Study

*Sabrina Sartori (UiO), Marianne Zeyringer (UiO), Isabelle Viole (UiO), Guillermo Valenzuela (UiO)*

## Goals

- Study how to supply the energy needs of the observatory as a stand-alone system
- Develop best practice guidelines for environmentally and climate positive telescope operations, positive and inclusive impact on the local community

## Technical challenges

- A sub-mm telescope operates day and night, instruments need to remain cool during operations, power supply has to be constant -> research on energy storage. Modelling of hybrid (electrochemical and hydrogen) storage system
- Backup supply needed in case of snow storms, etc
- Possible conspicuous power demand for cryogenics (24h)

## Advantages

- Climate positive operations, green astronomy
- Cost effective in the long run
- More independent, better handling of crises (e.g. energy crisis, pandemic, etc)



AtLAST WP5 team members visiting the new photovoltaic array of the Cooperativa Eléctrica San Pedro de Atacama (CESPA) in July 2022

See Viole et al. 2023 and  
Valenzuela et al. 2023





# Overarching Goal – Science Work Package

## Objectives

1. Robust analysis of unique science drivers for the telescope, and set of requirements for the telescope design (e.g. Field of View) based on those science drivers.
2. Creation of a telescope simulator and sensitivity calculator to demonstrate the capabilities of the telescope with its potential instruments, data volumes/rates, and how much observing time any given science case is likely to take.
3. Expectations for extragalactic observations of the ISM, CGM and IGM with AtLAST, in both local and distant galaxies, including mock catalogues.

- In this group, our focus is on **objective 1**
  - With a focus on the science the community wants/needs, what telescope capabilities will be required?



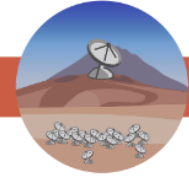
# Overview of use cases

## Summary of science goals & requirements

- Available on atlast website
  - <https://www.atlast.uio.no/design-study/wp6-science/>

|                                       | 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 <sup>a</sup>      | 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           |

## AtLAST Science Use Cases



### 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



# Solidifying into Science Case Studies

## – reminder from 2022

- **Aim:** deliver a fully justified case study detailing the science requirements for *each theme* by early 2024
  - **Outcome:**
    - ~10+ page document detailing:
      - observations
      - observing strategies
      - suggested instrumentation
      - precise constraints on telescope characteristics
- Being undertaken in *science theme* based working groups with an emphasis on why these properties enable ground breaking science

Summary & final overall requirements document to follow (end of study)





# Science themes

Themes from the submitted use cases:

- The Sun
- Solar System
- Our Galaxy
- The Nearby Universe
- Distant Universe and Cosmology

At the end of the day, if we don't have a specific and measurable science goal that pushes a telescope requirement, it's what funding agencies will cut when it comes to building the telescope

Two additional groups recently set up for Transients/Variability and VLBI

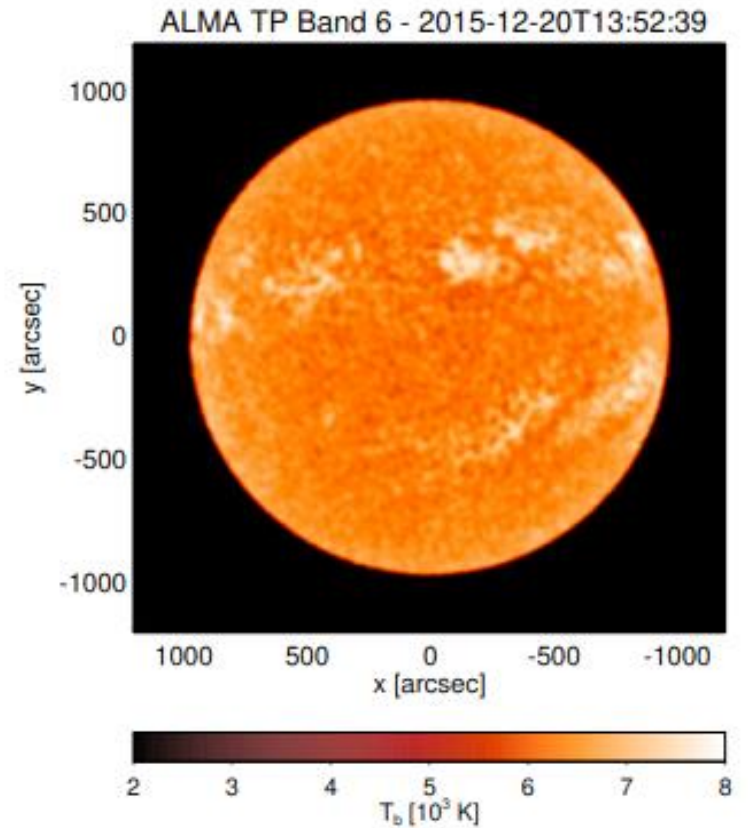
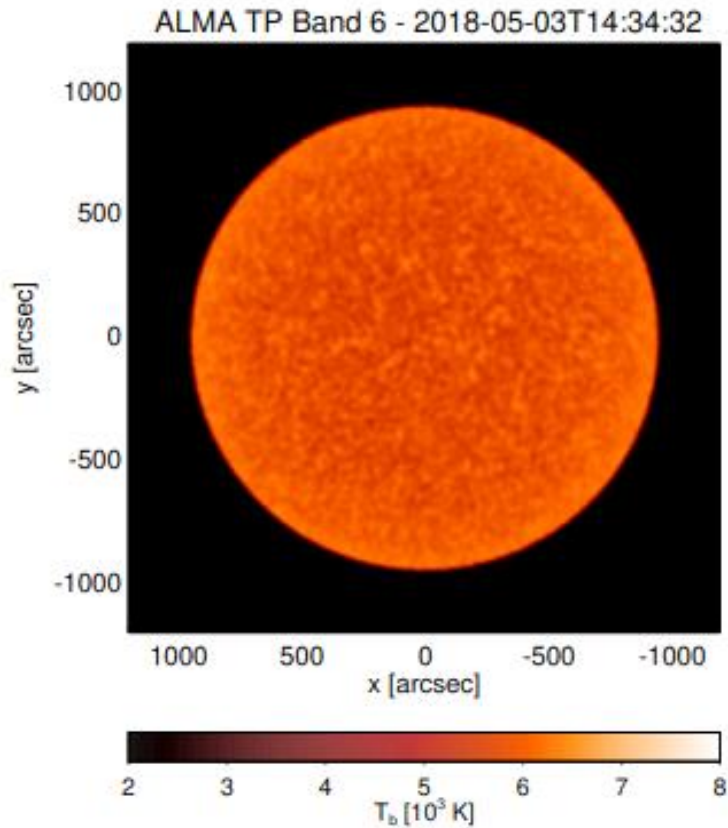
Using this structure to allow for a common frame of reference, we now need to delve into the details of how these science themes push the telescope requirements





# The Sun – Sven Wedemeyer

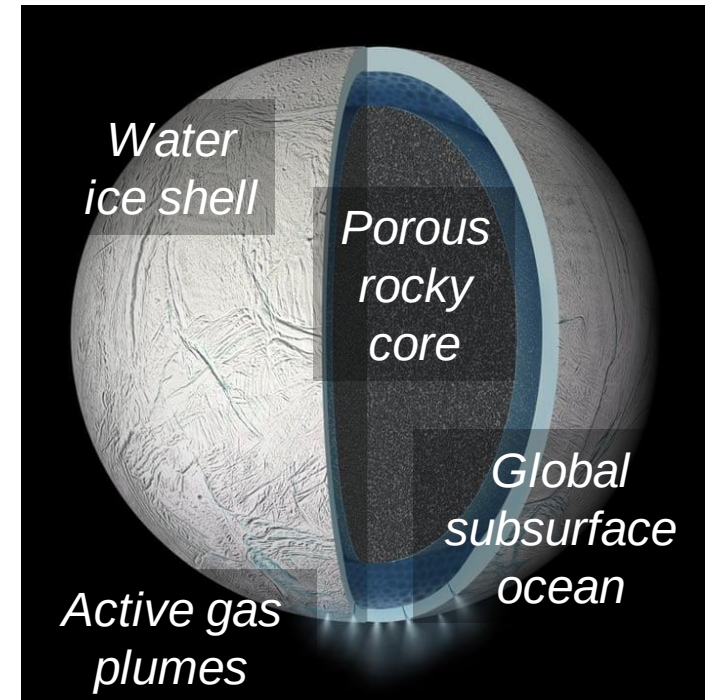
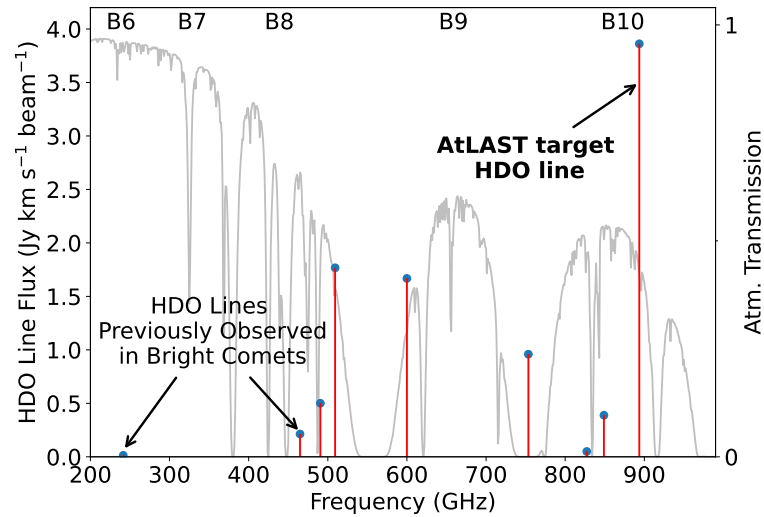
- Key Science Cases
  - Thermal structure
  - Solar flares
  - Solar prominences
  - Solar activity cycle





# Solar System – Alexander Thelen & Martin Cordiner

- Key Science Cases:
  - Planetary atmospheres
  - Plumes from icy moons
  - Comet spectroscopy

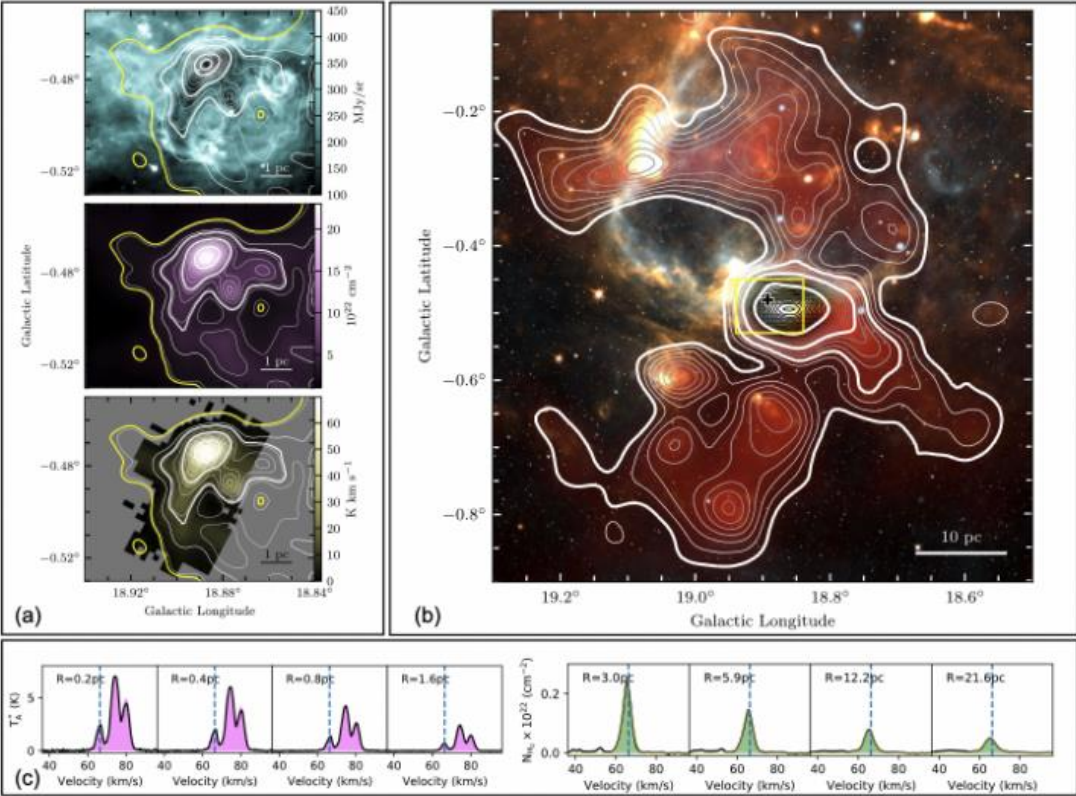




# Our Galaxy – Pamela Klaassen & Alvaro Hacar

## Key Science Cases

- Magnetic Fields
- Dynamics
- Ecology
- Disc evolution in star forming regions
- Debris discs around nearby stars



Peretto et al. 2023

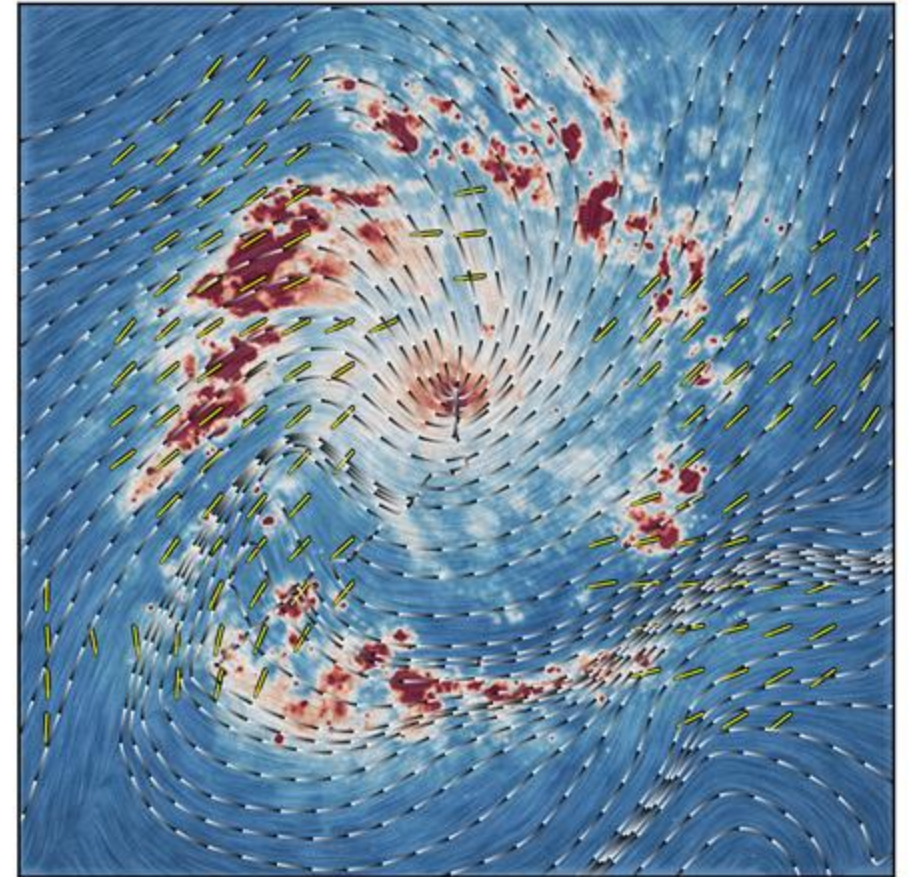




# Nearby Universe – Daizhong Liu & Matt Smith

- Key Science Cases
  - Interstellar medium
  - Magnetic fields
  - Physics of molecular and atomic lines

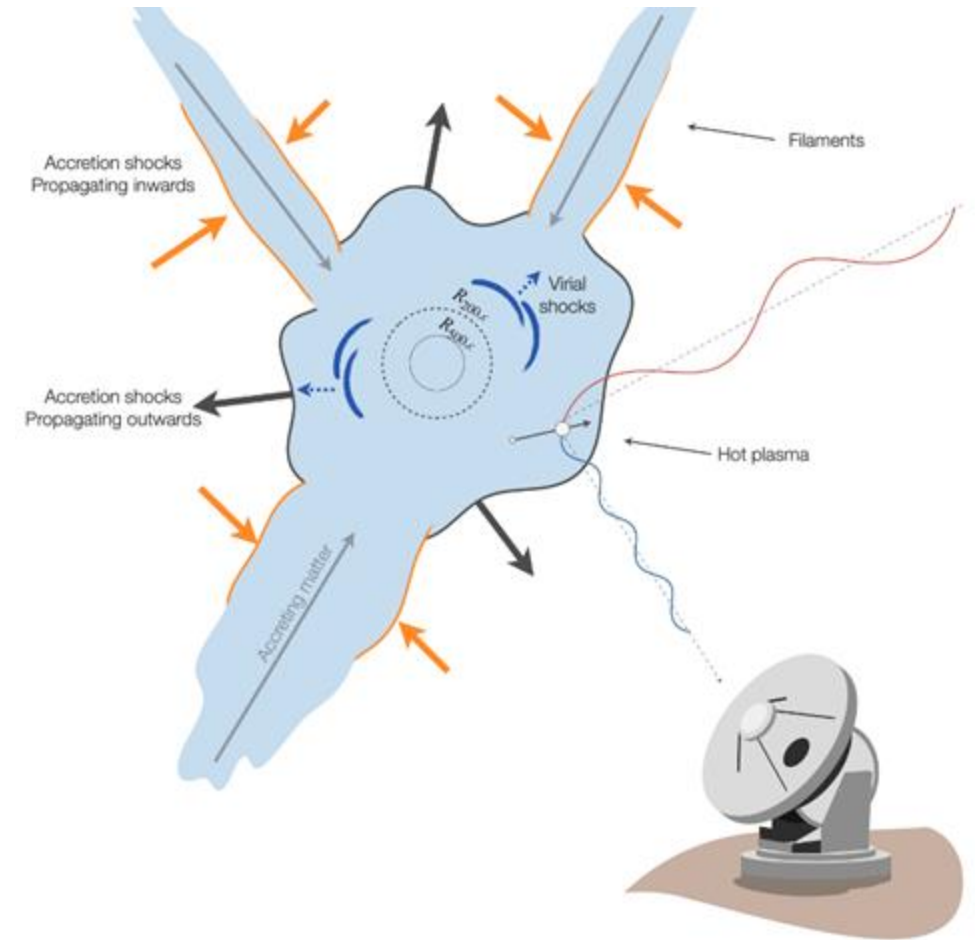
Starburst ring of NGC 1097: B-field orientation and direction within 1 Kpc



# Distant Universe – Minju Lee & Luca Di Mascolo



- Key Science Cases
  - Resolved Sunyaev-Zeldovich effect
  - Circumgalactic medium
  - Redshift survey

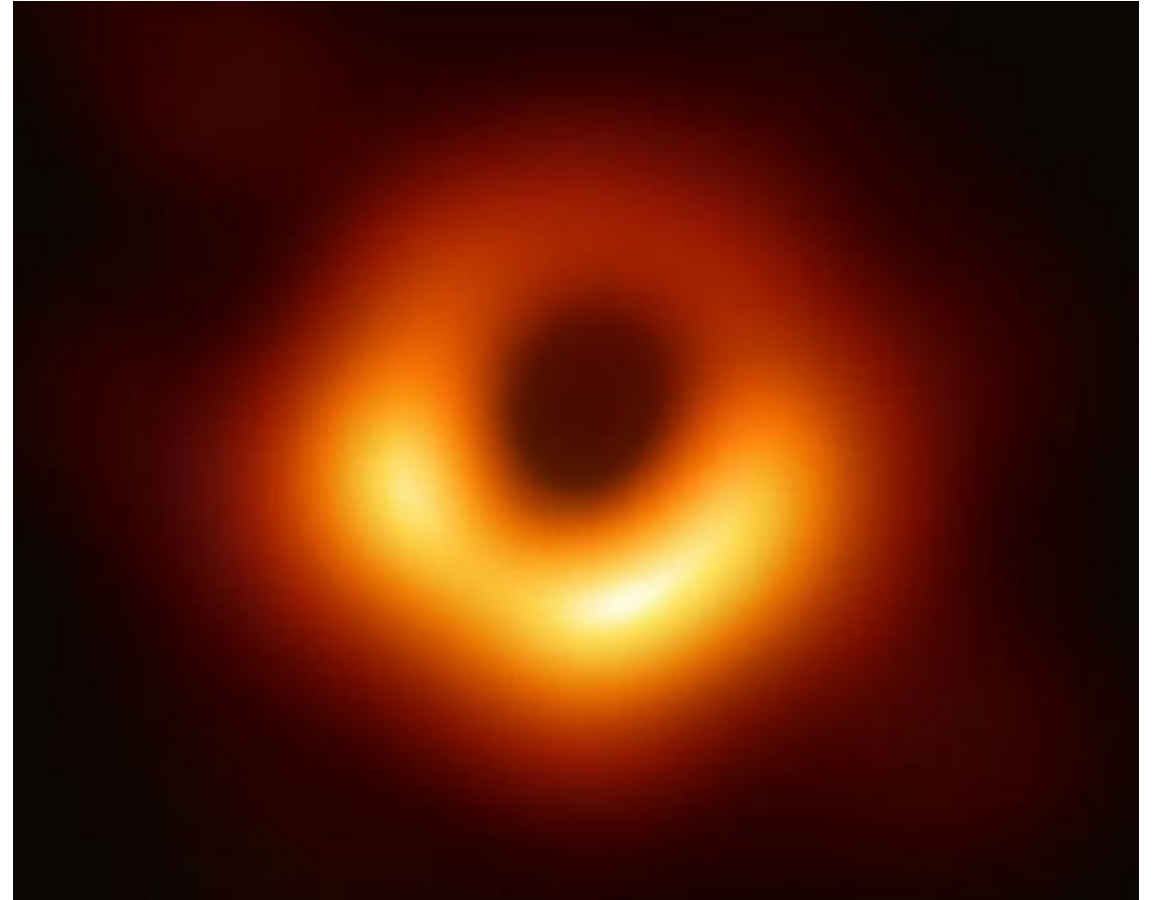




# Science Driving Additional Technical Cases

Two cases have recently been added for:

- Transients and variability – Tom Maccarone & Doug Johnstone
- VLBI – Geoff Bower & Kazu Akiyama



# Possible AtLAST instrumentation

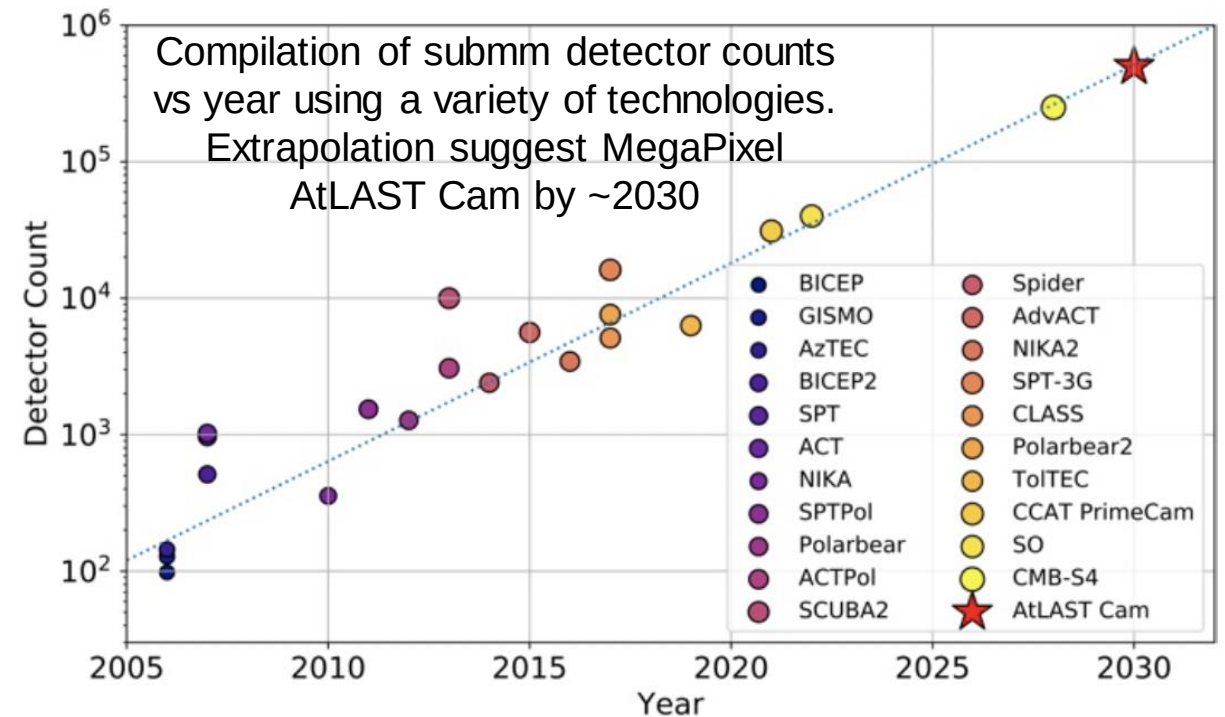


## Spectral lines

1. A 1000-pixels heterodyne focal plane array providing high spectral resolution  $\Delta v < 1$  km/s [Groppi+19]. Pixels can be deployed in many ways: from a single-band, uniformly filled FoV (maximising mapping speed) or smaller arrays covering multiple bands
2. A multi-object spectrograph (MOS)
3. A direct detection, ultra wide bandwidth integral field unit (IFU), with  $R \sim 300-1000$ , effective receiver noise temperature comparable to quantum noise limit

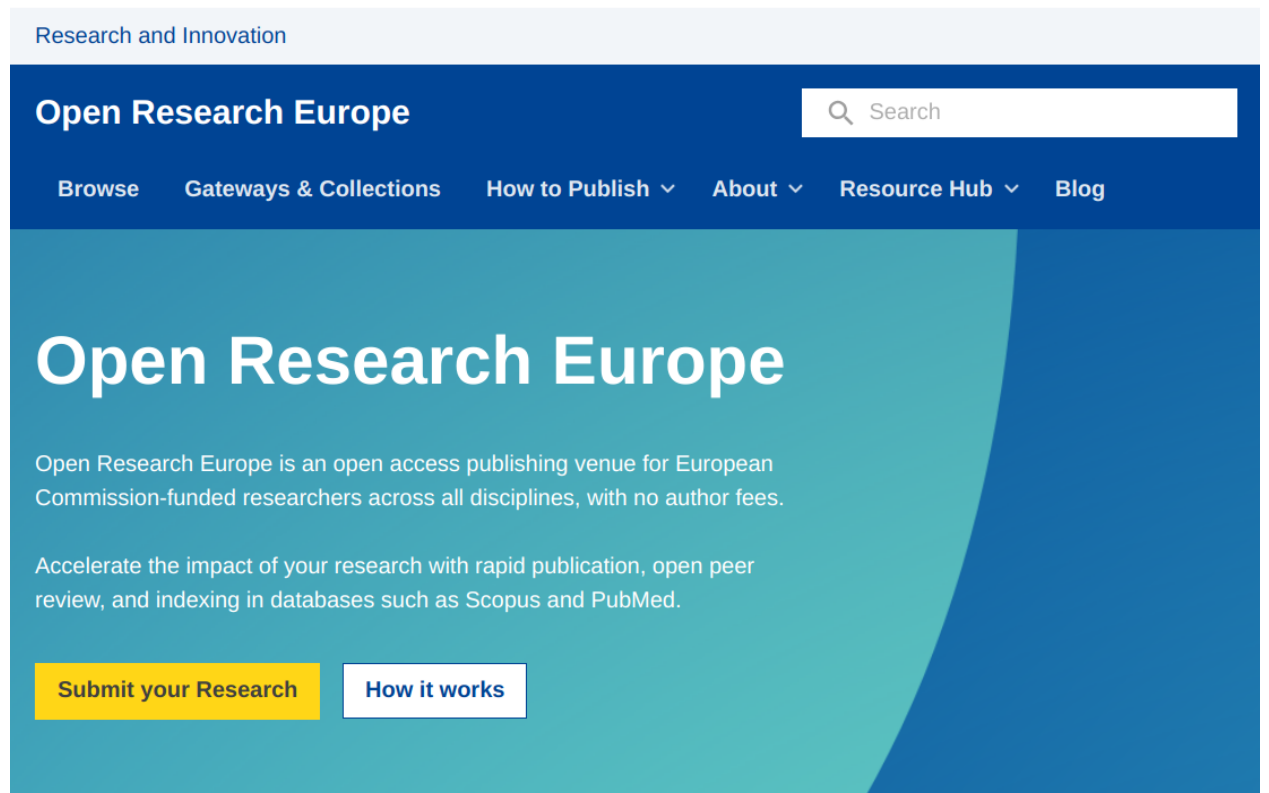
## Continuum detectors

- "AtLAST Cam": a single or multi-chroic continuum camera comprising  $\sim 0.5$  million detectors likely exploiting kinetic inductance detectors (KIDs)



# Publication Plan

- White papers will be submitted to Open Research Europe – an open access journal designed for publishing results from EU funded projects with a post publication, transparent peer review.
- A short summary of the white papers will be written up as an SPIE Proceedings.
- An extensive summary along with a matrix of telescope requirements will be written up as deliverables to the EU.





# Timeline for the White Papers

- 15th January: Complete drafts ready for review by individual science working groups.
- 15th February: Complete drafts ready for review by science working group leads and coordinators.
- 1st March: Article submission.



## Web Client

<https://senscalc.atlast.uio.no>

## Sensitivity Calculator

| Parameter                           | Value                                                            | Allowed range |
|-------------------------------------|------------------------------------------------------------------|---------------|
| Elevation                           | <input type="text" value="45"/> <span>deg</span>                 | 25 - 85       |
| Observing frequency                 | <input type="text" value="100"/> <span>GHz</span>                | 35 - 950      |
| Bandwidth                           | <input type="text" value="100"/> <span>MHz</span> <span>▼</span> | > 0           |
| H <sub>2</sub> O profile percentile | <input type="text" value="25"/>                                  | 5 - 95        |
| Number of polarizations             | <input type="text" value="2"/> <span>▼</span>                    |               |
| Sensitivity                         | <input type="text" value="3.0"/> <span>mJy</span> <span>▼</span> | > 0           |

Calculate integration time or sensitivity?

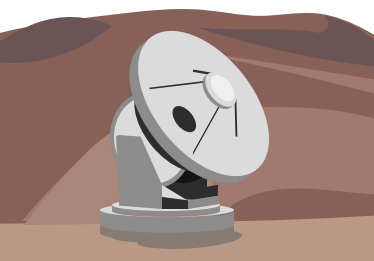
☒ Integration time ☐ Sensitivity

6.7636 s

Calculate

Reset

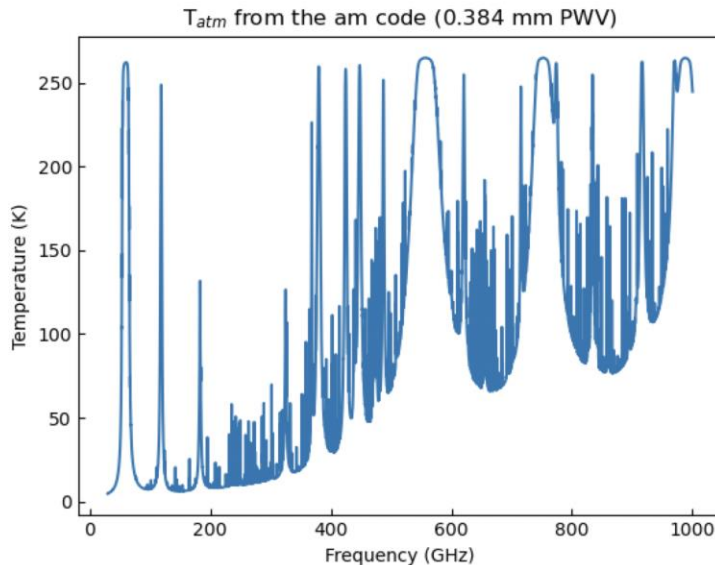
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 951815





# Sensitivity Calculator

- The sensitivity calculator is Python based and available on Github: [https://github.com/ukatc/AtLAST\\_sensitivity\\_calculator](https://github.com/ukatc/AtLAST_sensitivity_calculator).
- The SEFD takes the atmosphere into account using the *am* model



## The Sensitivity Calculation

The following is a description of the underlying calculations that the software performs.

The sensitivity of a single dish telescope for an integration time  $t$  is given by:

$$\Delta S = \frac{SEFD}{\eta_s \sqrt{n_{pol} \Delta \nu t}}$$

or conversely, to obtain the integration time required for a given sensitivity  $\Delta S$ ,

$$t = \left( \frac{SEFD}{\Delta S \eta_s} \right)^2 \times \frac{1}{n_{pol} \Delta \nu}$$

where

- $SEFD$  is the system equivalent flux density
- $\eta_s$  is the system efficiency
- $n_{pol}$  is the number of polarizations
- $\Delta \nu$  is the bandwidth

More details  
available in the  
documentation



# The Atacama Large Aperture Submillimeter Telescope Design Study

Results, Science and Next Steps

Johannes Gutenberg University Mainz

21-24 May 2024



## TOPICS

mm/submm observations, near and far, including polarimetry • the Sun and Solar System • Milky Way • Local and Distant Galaxies • the Warm and Hot inter- and intra-cluster/group/galactic media • the Circumgalactic medium • Cosmology and Large Scale Structure • Time-domain and Transients

## ORGANIZERS

Claudia Cicone • Pamela Klaassen • Tony Mroczkowski • Matthias Reichert

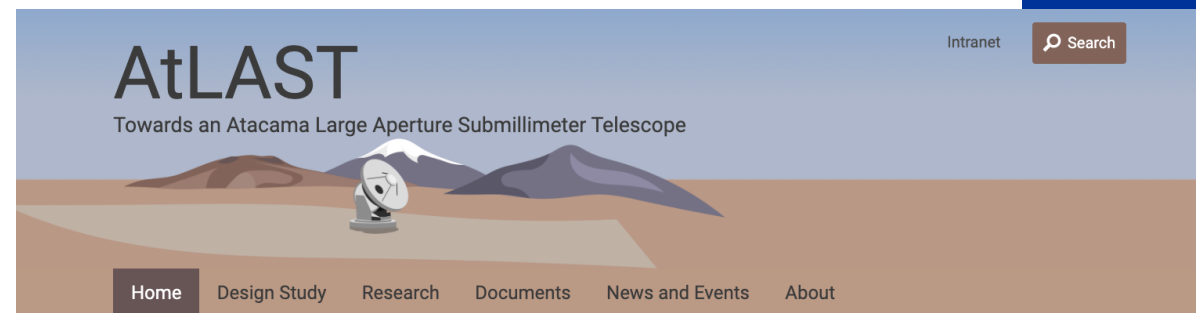
*Image credits: Luca Di Mascolo, Tony Mroczkowski, and Giuseppe Puglisi.*

<https://www.atlast-telescope.org/atlast2024.html>

# Thanks!

## Follow our updates:

- Updates released through our newsletter, website ([atlast.uio.no](https://atlast.uio.no)) and on social media. We are on X [@atlast\\_design](#) and LinkedIn
- Contact Mark Booth ([mark.booth@stfc.ac.uk](mailto:mark.booth@stfc.ac.uk)) or Pamela Klaassen ([pamela.klaassen@stfc.ac.uk](mailto:pamela.klaassen@stfc.ac.uk)) if you have any questions.



Welcome to the webpage of the Atacama Large Aperture Submillimeter Telescope project. AtLAST is a concept for a next generation 50-meter class single-dish astronomical observatory operating at sub-millimeter and millimeter wavelengths, run as a facility telescope by an international partnership and powered by renewable energy.

### The design study

The EU-funded AtLAST design study started in March 2021 and will last three years.

→ [Discover the project](#)

### Research goals

AtLAST will open a new space of discoveries in many fields of Astrophysics and Cosmology.

→ [Read more](#)

### The team

The design study is carried out by an international consortium of universities, research institutes and industry.

→ [Meet the team](#)

## News



Measuring the wind at 5000 meters elevation

May 5, 2023 3:05 PM



"This is cheap. This is good. We want this."

Dec. 14, 2022 11:40 AM



AtLAST's energy researchers on a field trip to San Pedro de Atacama



Workshop on Renewable Energy Communities in San Pedro de Atacama

# Q+A



Q: What efforts are being made to ensure chosen science cases are what the funders will fund and not just favourites of the researchers that happened to get involved?

A: Both funding bodies and this study are pulling priorities from community feedback. At this point we're expanding the major science themes into requirements for the telescope – and in the final report to the EU, we expect to funnel into structured high level cases in plain language (for funders to understand). Feedback between publication of white papers and compilation of overview document will help with this.

Q: What is setting the 1st March deadline?

A: We want to have the white papers published in advance of the next EU Horizon funding deadline.





# Q+A

Q: Have you looked into JWST+ALMA and whether that highlights any new science?

A: We're keeping an eye on this, but it's still a little early.

Q: Are you still looking for collaborators to contribute?

A: Given the lack of time before the deadline, we're not looking for any new science cases, but we are certainly happy to have help in expanding the ones we have.

Q: Is the sensitivity calculator just for heterodyne observations or is there a way to use it for continuum observations?

A: You can set a large bandwidth for continuum observations.



# Q+A



Q: ALMA has not had as much interest in band 10 projects as expected. Is it worth it for AtLAST?

A: We certainly have a number of teams keen on band 10, including high-redshift surveys, nearby galaxy line surveys and polarimetry. In the continuum, confusion is much less of an issue at the highest frequencies.

Q: Are you ensuring to differentiate from planned far-IR space missions?

A: This is a good point and we'll certainly make sure to mention this in the papers and overview document.

