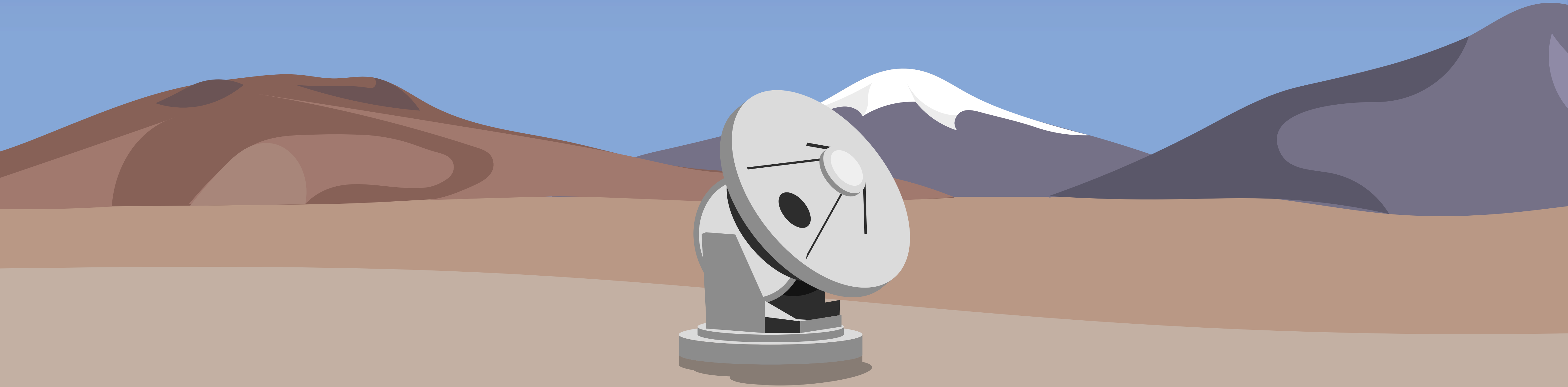
Tony Mroczkowski (ESO), on behalf of AtLAST.

with many contributions from members of the AtLAST consortium

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



Progress with the Atacama Large Aperture Submm Telescope

29 June 2023, the mm Universe (LSPC, Grenoble)

Goals of the EU-funded design study

A comprehensive design study for the Atacama Large Aperture Submillimeter Telescope

- A new telescope design driven by **transformational and unique science goals** WP6, WP2
- **50-m diameter** single dish, with a high throughput and FoV of 1-2 degrees diameter WP2
- Located at **a high dry site** in the Atacama desert, enabling observations at frequencies >500 GHz WP3
- An **international partnership** that is open to collaborations (e.g. the Japanese LST team, UK, US, Canada, Taiwan, etc), where Europe has a central role WP1
- A **facility telescope** with open time and flexibility to host and operate multiple instruments WP4
- The first astronomical observatory that – from the design study stage – is planned to be fully powered by **renewable energy (solar)** WP5

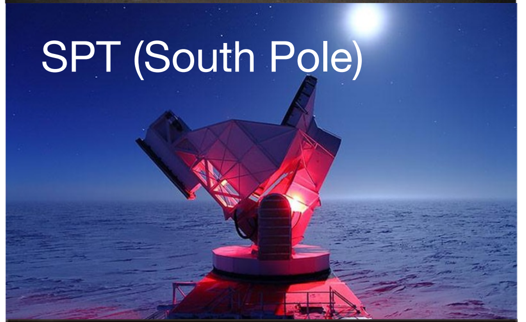
Why do we need a *new large* submm single dish?

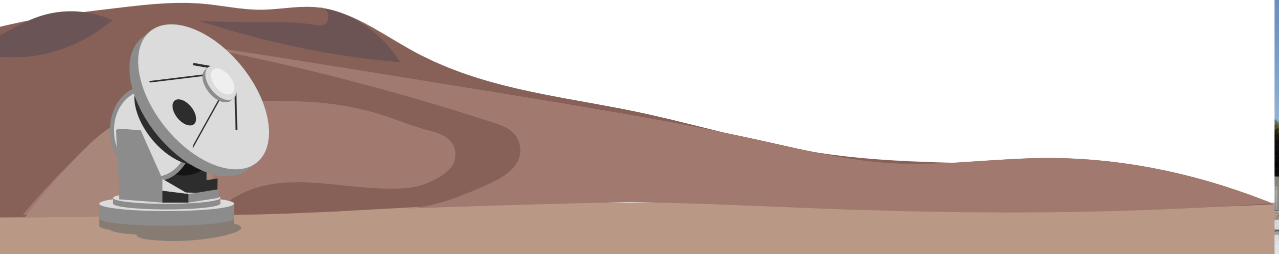
Current facilities have been productive, but we have to consider the next generations of (sub)mm astronomers:

- Small aperture → small collecting area **and** low spatial resolution → **confusion noise limited** → get only extreme sources.

- Existing large aperture facilities (e.g. 50m LMT, IRAM 30m, Nobeyama 45m, 100m GBT, SRT) cannot observe at **frequencies ν ≥ 400 GHz** (due to e.g. design, surface accuracy, atmosphere). There is scientific pressure to deliver high-frequency observations (e.g. to sample closer to thermal SED peak, FIR lines, etc)

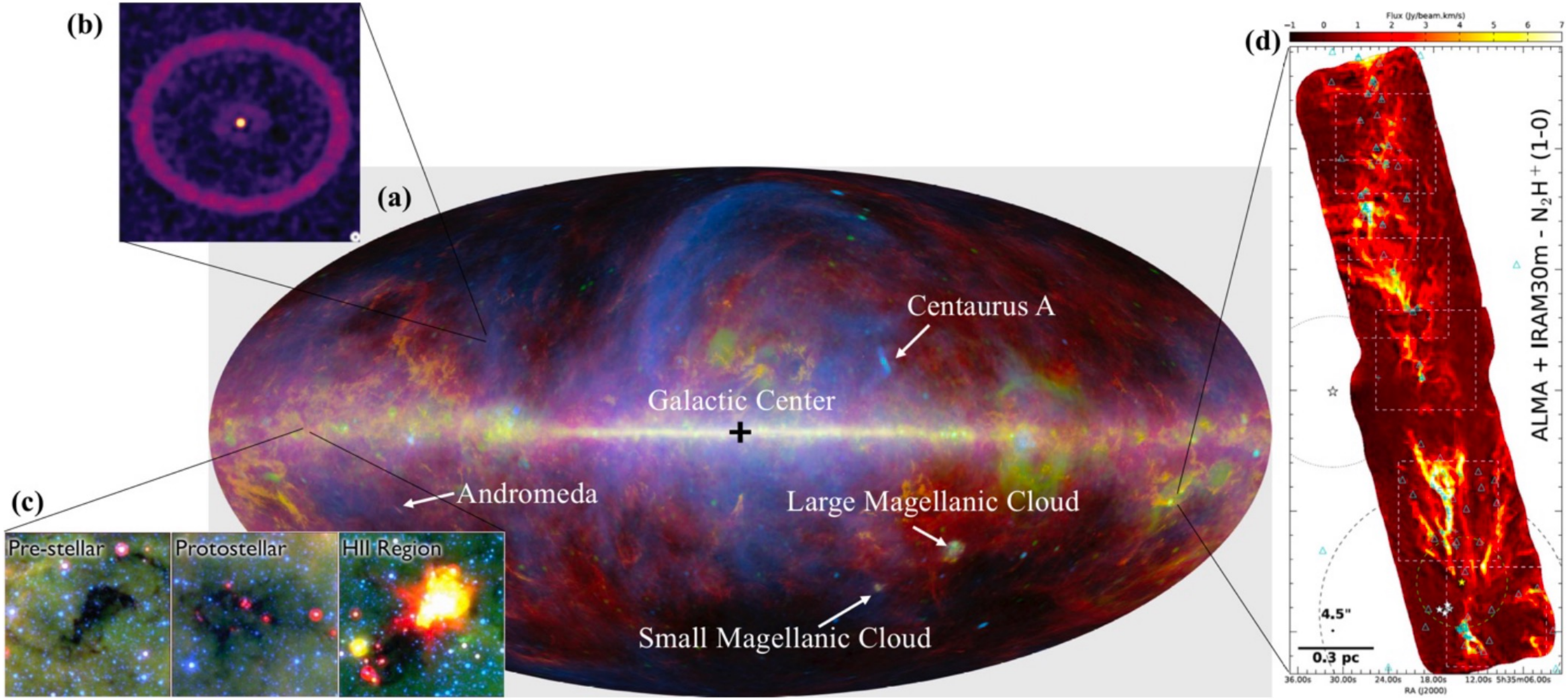
- Small FoV → **low mapping speed** → several science cases ask to map very large fields (1000s of deg^2)





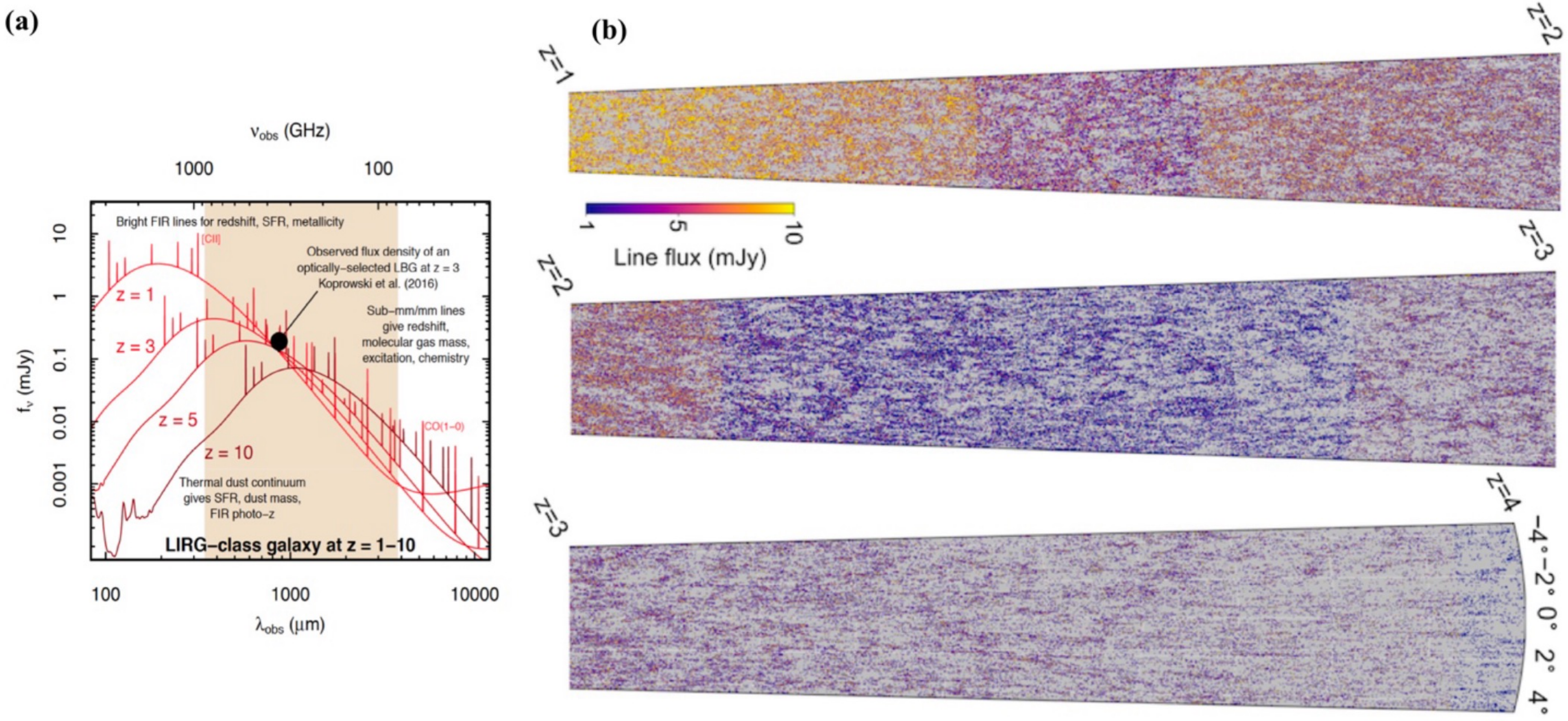
I – The Galactic Plane of the Milky Way

AtLAST Goal = To perform the deepest, highest resolution, and most complete survey of molecular gas clouds, dust, protostars, and protoplanetary disks in our own Galaxy and in the Local Group



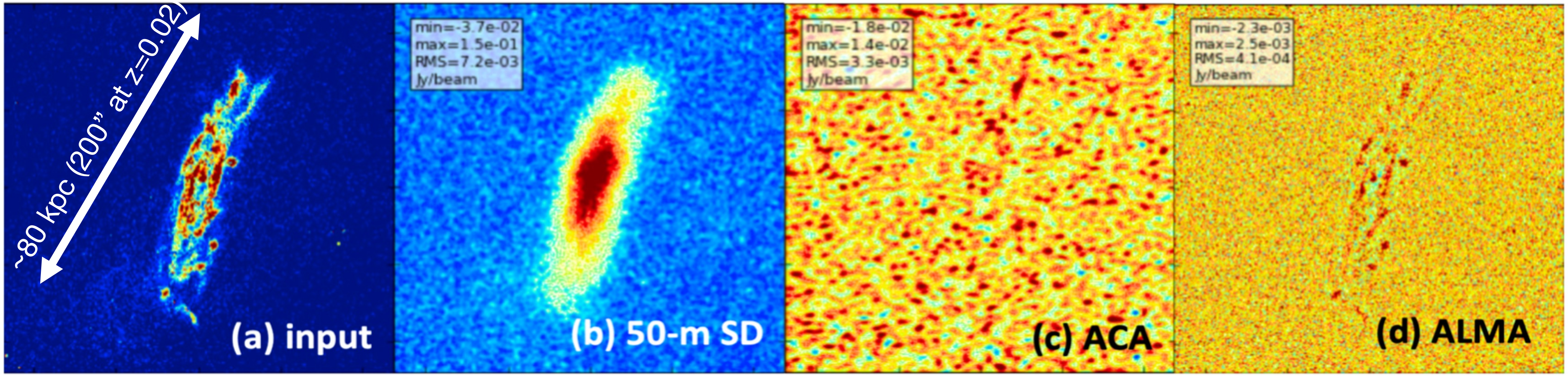
II – A sub-mm SDSS-like extragalactic survey

AtLAST Goal = To perform the deepest, highest-resolution, widest and most complete imaging and spectroscopic survey at (sub)mm wavelengths of the extragalactic sky, similar to the Sloan Digital Sky Survey (SDSS) at optical wavelengths



III – The hidden Circumgalactic medium

<u>AtLAST Goal</u> = To detect and image the cold material stored within galaxy haloes that is invisible at other wavelengths and so understand the baryon cycle that shapes galaxy evolution



Modelled CO(3-2) emission from ISM and CGM of a local massive (M^* ~10^{11} M_{Sun}) star forming (SFR=11 M_{Sun}/yr) galaxy (post-processing of SIMBA simulation, courtesy of D. Narayanan)

10 hours with a 50-m single dish equipped with a *<u>single ALMA detector (much worse than what AtLAST will do!)</u>*

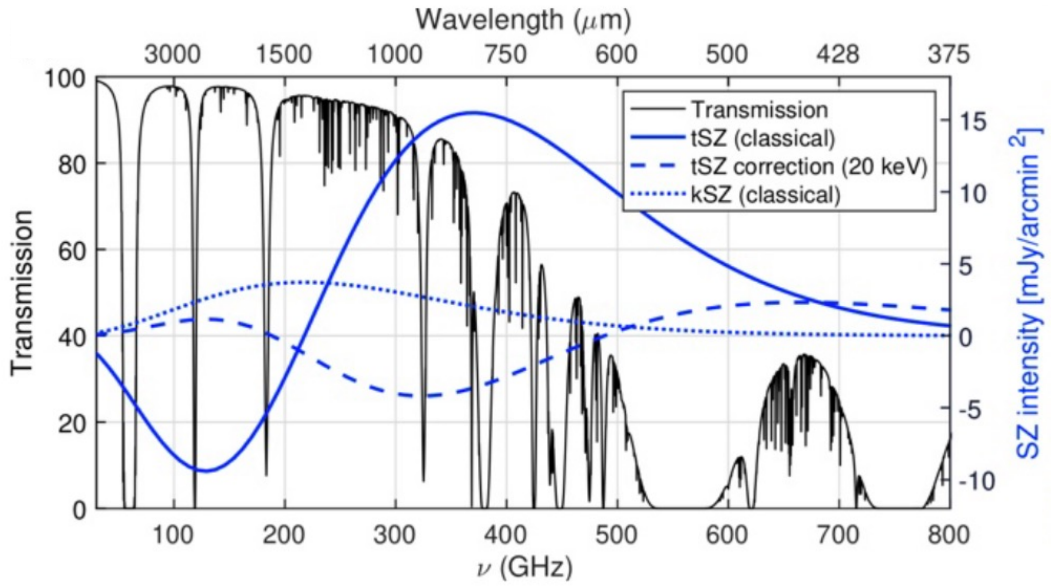
10 hours with ACA (mosaic map)

10 hours with ALMA (mosaic, 576 pointings)

This exercise shows that any diffuse extended (~100 kpc-size) molecular CGM reservoir around galaxies (especially at z~0) would remain completely undetected with current facilities *(Cicone+19, Astro2020 white paper & AtLAST proposal)*

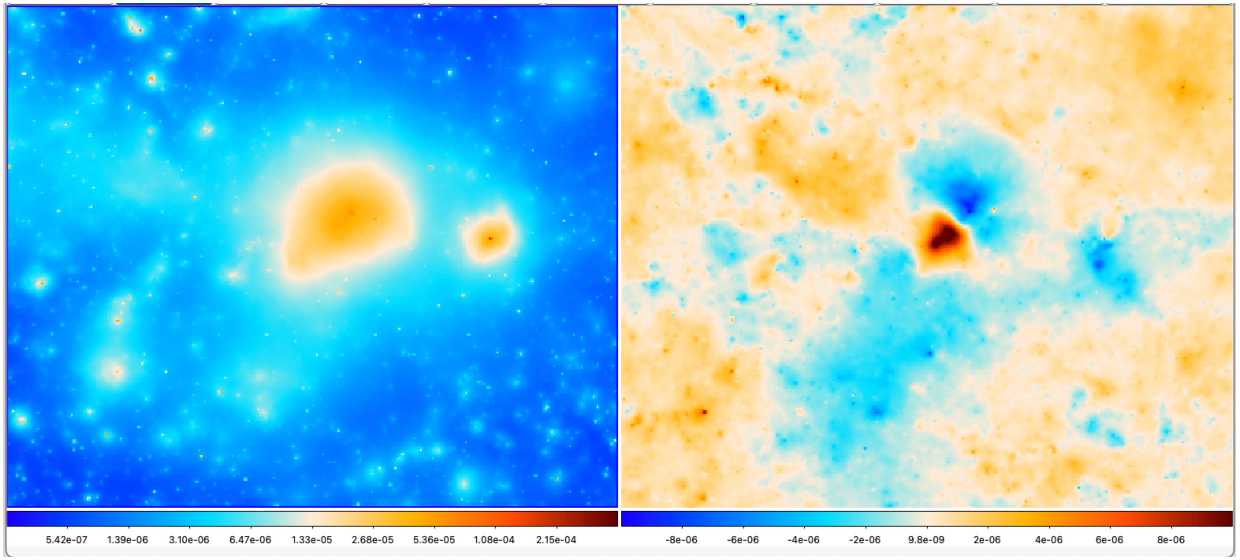
IV – The SZ effect down to galaxy scales

<u>AtLAST Goal</u> = To detect and resolve the thermal and kinetic SZ effect from the filaments connecting large scale structures between galaxy clusters, down to individual galaxies, and out to the earliest large scale structures



Thermal SZ

Kinetic SZ



Images from the Magneticum simulation (no noise included, courtesy Veronica Biffi & Klaus Dolag; see Hirschmann et al. 2014)

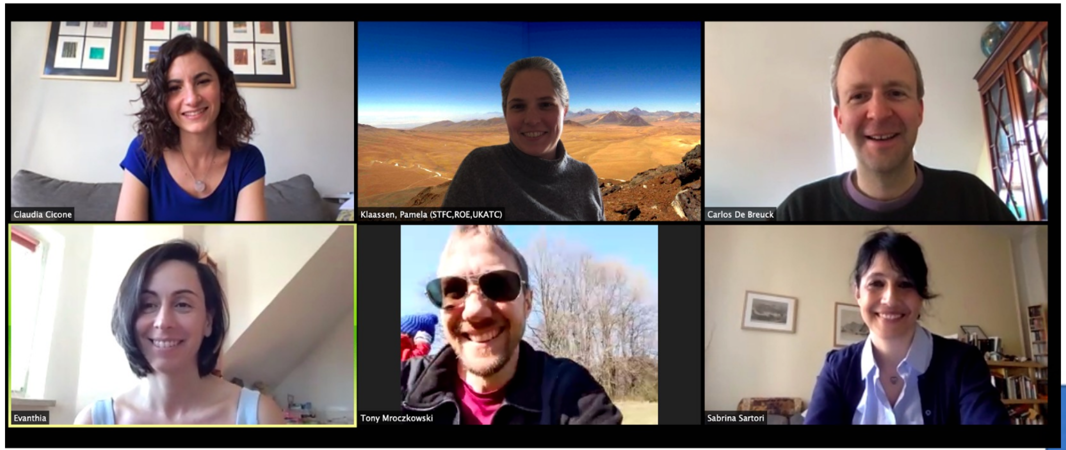
- tSZ probes gas thermal energy (~ proxy for total gravitational mass)
- kSZ measures gas momentum along line of sight
- Both have z-independent surface brightness

AtLAST will enable SZ studies in protoclusters and down to massive galaxy scales (angular res of a few arcsec + broad frequency coverage + high sensitivity enable detection and separation of small scale structures)

Project implementation

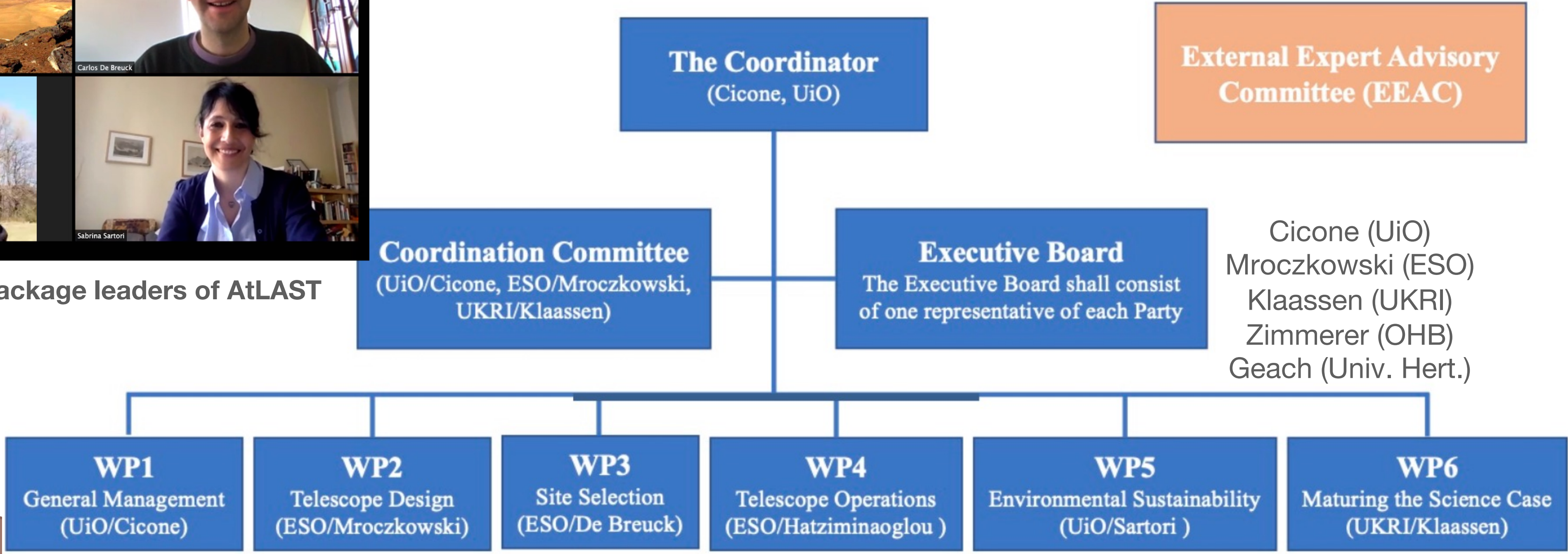
- Timeline: 1 March 2021 – 31 August 2024 (3.5 years)
- Total cost ~3.5M EUR, funded under EU's Horizon 2020 call "Development and long-term sustainability of new pan-European research infrastructures", specific topic "design studies" (proposal submitted = Nov 2019)
- 5 Partners: University of Oslo (2 departments: astro (ITA) & renewable energy (ITS)), ESO, UKRI, OHB DC (ex-MTM), University of Hertforshire; 6 deeply interconnected work packages


AtLAST Grant Agreement
(275 pages)

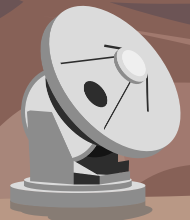


Work Package leaders of AtLAST

Check the AtLAST website: https://www.atlast.uio.no

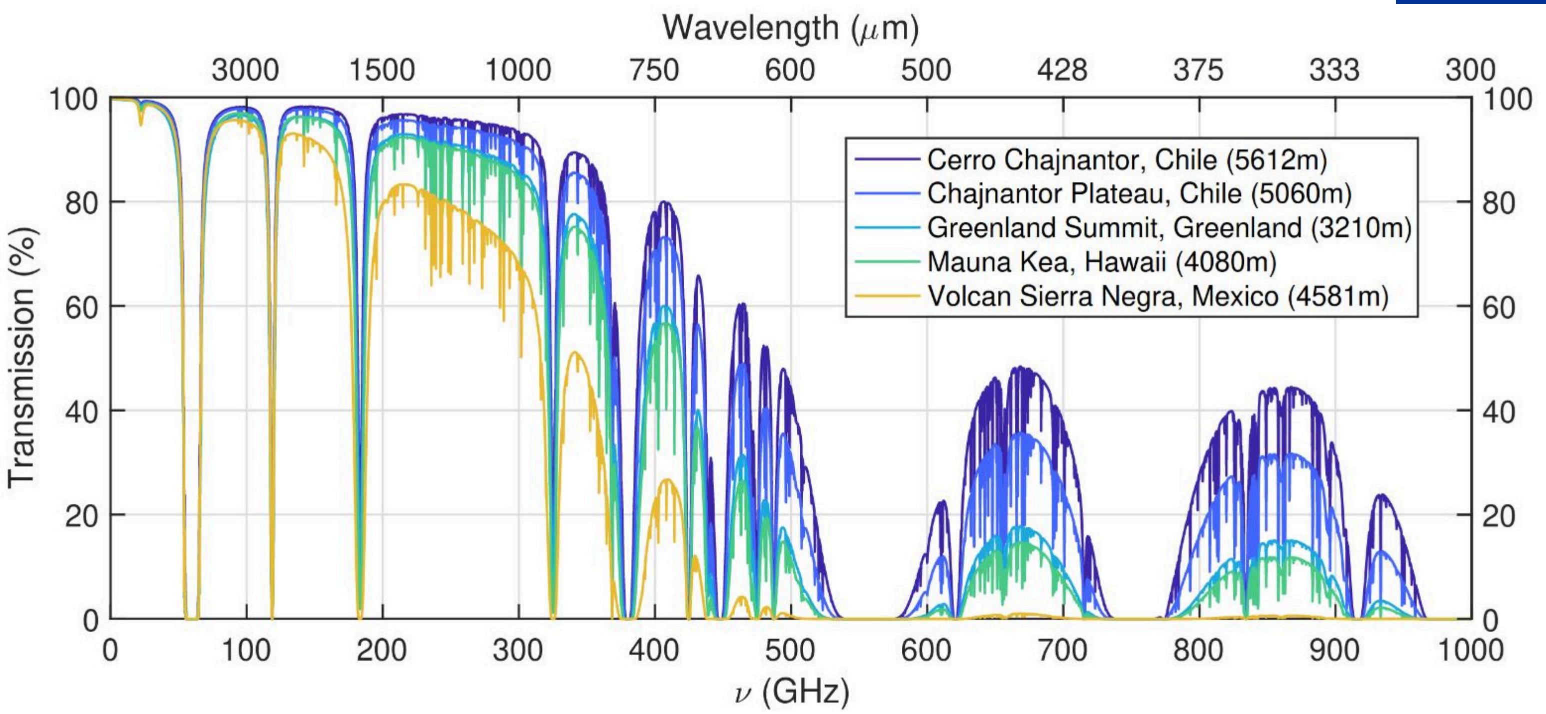


Cicone (UiO)
Mroczkowski (ESO)
Klaassen (UKRI)
Zimmerer (OHB)
Geach (Univ. Hert.)



WP3 – AtLAST Site Characterization

- WP3 is characterizing 2 prospective sites (Site I below) around the Chajnantor plateau, at 5100 meters above sea level.
- The median transmission is better than nearly anywhere in the world with a telescope, except for a modest improvement at Cerro Chajnantor (5600 m, DYST/CCAT-p).
- The use of existing roads and infrastructure will also reduce the costs and environmental impact of the AtLAST observatory.



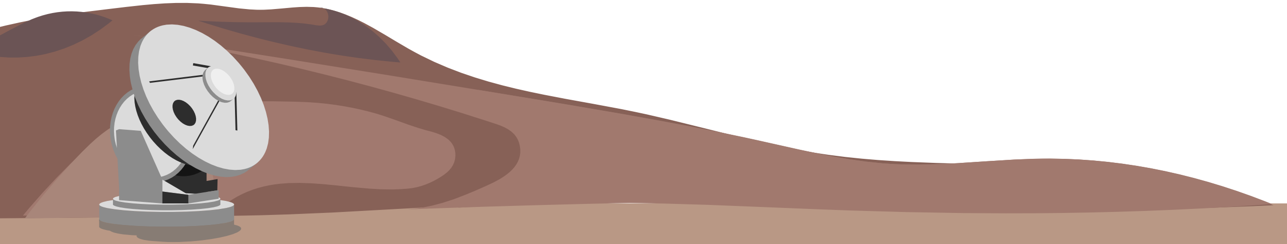
WP2 – Antenna design

Tony Mroczkowski (ESO), Hans J. Kärcher (OHB-external), Matthias Reichert (OHB), Thomas Zimmerer (OHB), Richard Hills (Cambridge), Mike MacIntosh (UKRI), Martin Timpe (OHB), Aleksej Kiselev (OHB), Pierre Dubois (OHB), Daniel Bok (OHB), Patricio Gallardo (Chicago), Simon Dicker (Penn), Roberto Puddu (PUC), Michael Niemack (Cornell)

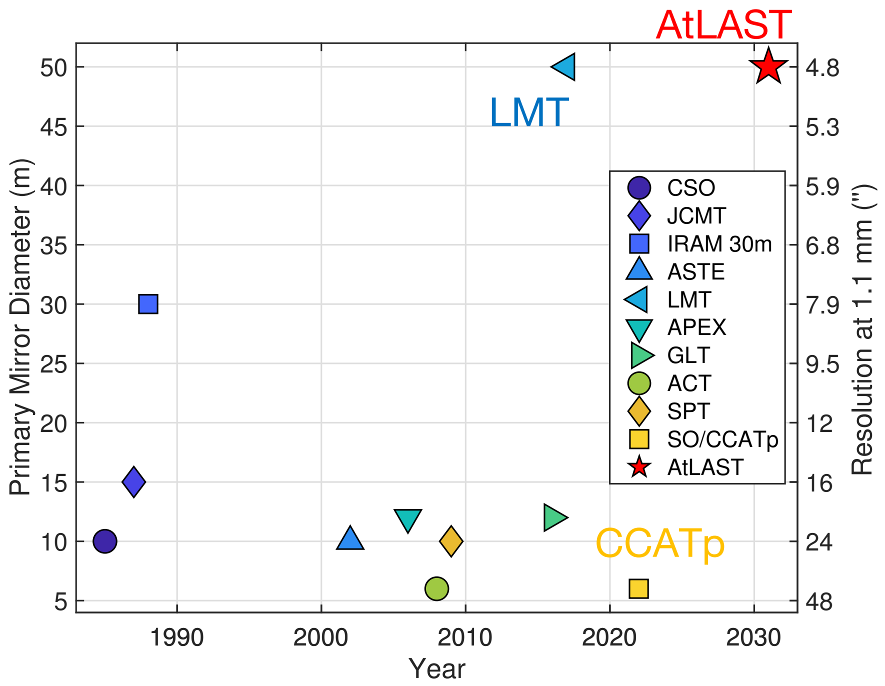
Initial analysis of key requirements as outlined in AtLAST proposal:

Specification	Minimum	Goal	
Wavelength Range	0.35-3.5 mm	0.35-10 mm	✔
Aperture (M1)	40 m	50 m	✔
Field of View	1 deg	2 deg	✔
Surface Accuracy	30 μm RMS	20 μm RMS	✓
Solar observations	Sun avoidance	Solar observations allowed	✓
Elevation Range	20 to 90 deg	20 to 90 deg	✔
Azimuth Range	-270 to +270 deg	-270 to +270 deg	✔
Pointing Accuracy (uncorrected)	2 arcsec	0.5 arcsec	✓
Max. Scanning Speed	1 deg/s	3 deg/s	✔
Site Altitude	> 4800 m	5100-5400 m	✔
Enclosure	None	None	✔
Wind/Snow/Ice/Earthquakes	Same as ALMA/APEX	Same as ALMA/APEX	✔

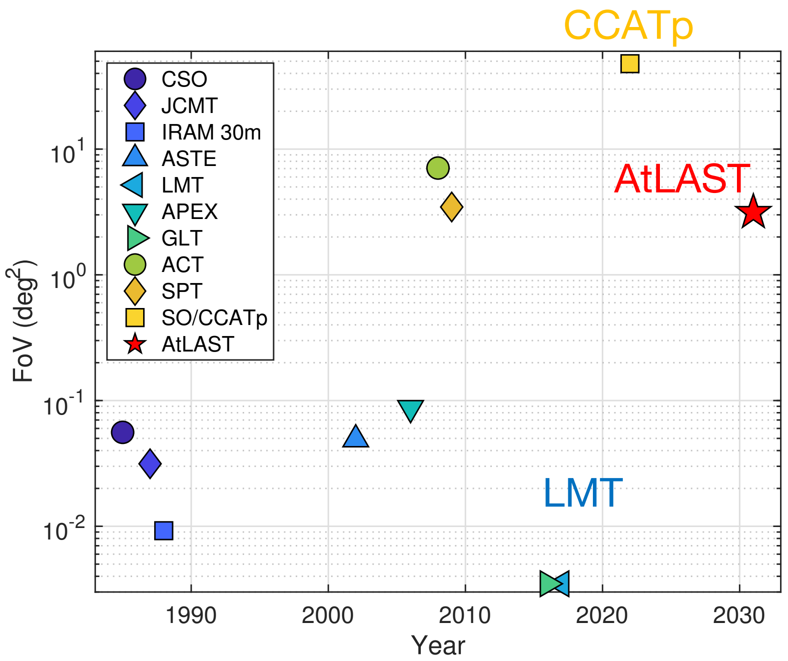
- Wavelength range, D=50m and FoV goals taken as granted
- Half Wave Front Error of 20 μm very demanding: needs active reflector optics (similar to ALMA antennas, 4 times better than LMT). Degraded by wind, gravity, thermal influences
- Solar is technically feasible
- Elevation range = 20-90 deg
- Pointing accuracy ~ 0.5” refers to tracking accuracy and astronomical pointing. Blind mechanical pointing ~2.5”
- Max scanning speed = 3 deg/s accepted
- No enclosure. Service tower needed



Combination of large aperture and FoV makes AtLAST unique

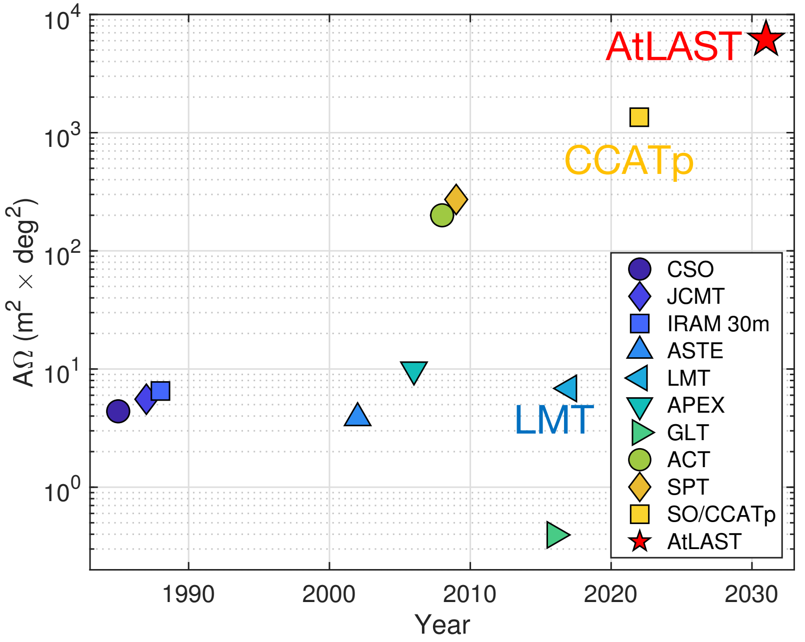


Primary Mirror Diameter: driven by the need for both resolution and sensitivity (collecting area)

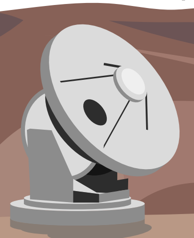


Field of View (FoV): driven by the need for large angular scales and fast mapping

Throughput of AtLAST = 6000 m^2 deg^2: at 0.85mm we need >3 million beams (pixels)



Throughput (AΩ): driven by the need for fast mapping speeds and sensitivity in wide surveys



Note: Plots include only single dish facilities that can observe at least up to 270GHz (1.1mm)

Initial Optical Design at Proposal

Proposal & grant agreement phase

- This was the notional design in the proposal and grant agreement.
- Due to mechanical interference / space constraints, the 4-mirror approach was quickly abandoned to explore alternate designs

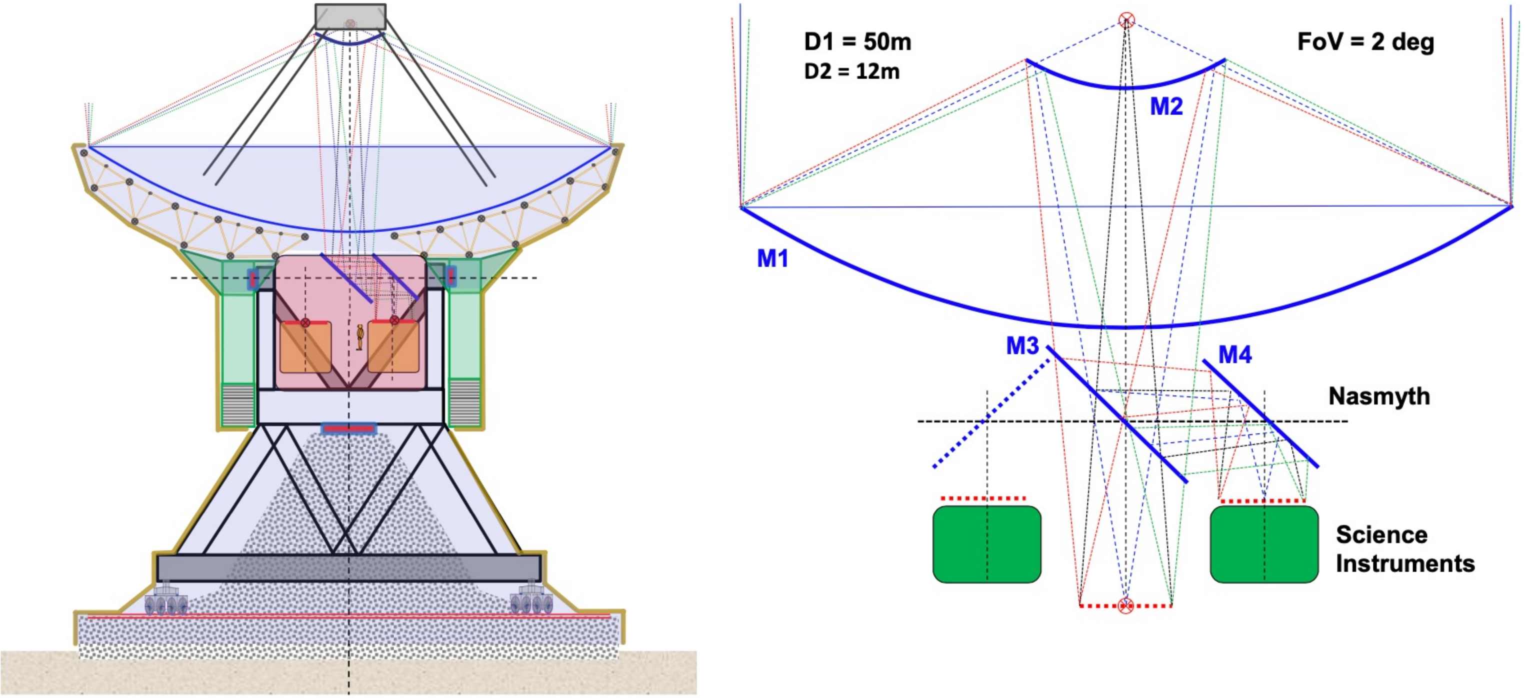
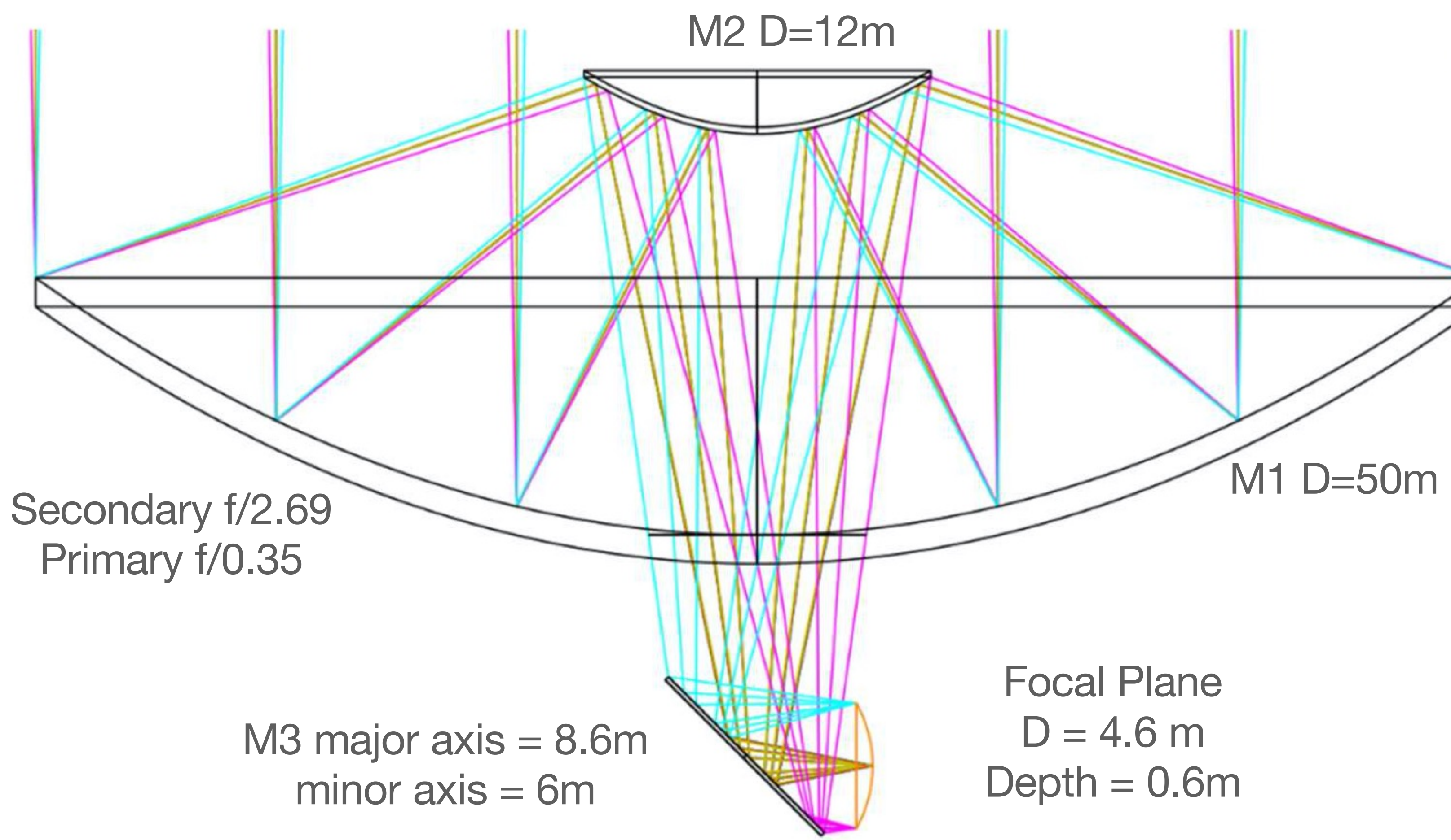


Figure 1: Hybrid Nasmyth/Cassegrain optics from GA [RD01]

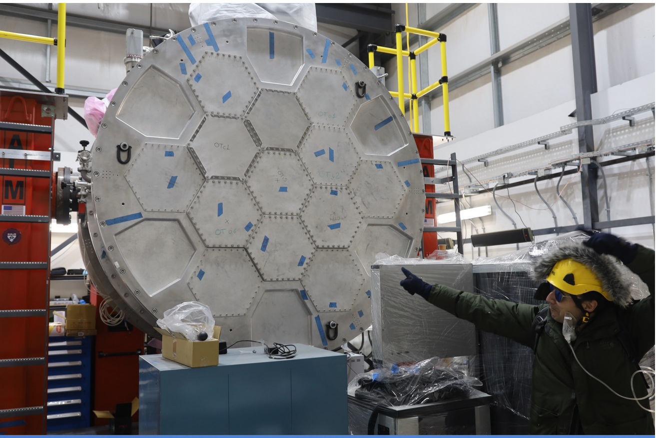
AtLAST Optics

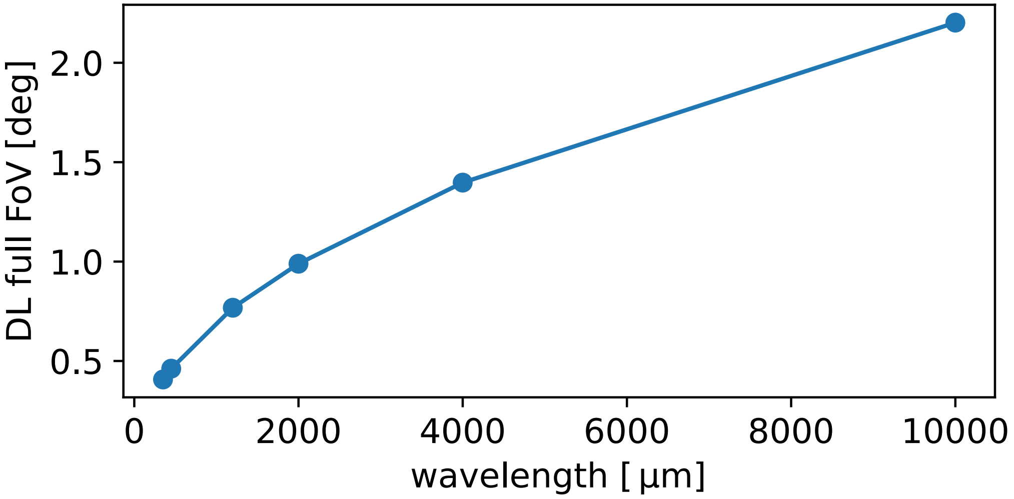


- **Focal plane has large size** (D=4.6m) and significant **curvature** but camera size is only a modest (~x2 diameter) scale up from that planned for CMB-S4
- **Diffraction-limited FoV** delivered by telescope is **~0.45 deg at 0.45mm and 1.4deg at 4mm**
- Correction of aberrations in instruments and by shaping M3 will greatly increase the DLFoV values

Preferred layout from "Basic Layout Options – by Richard Hills", June 2021, memo available on AtLAST website

AtLAST Optics

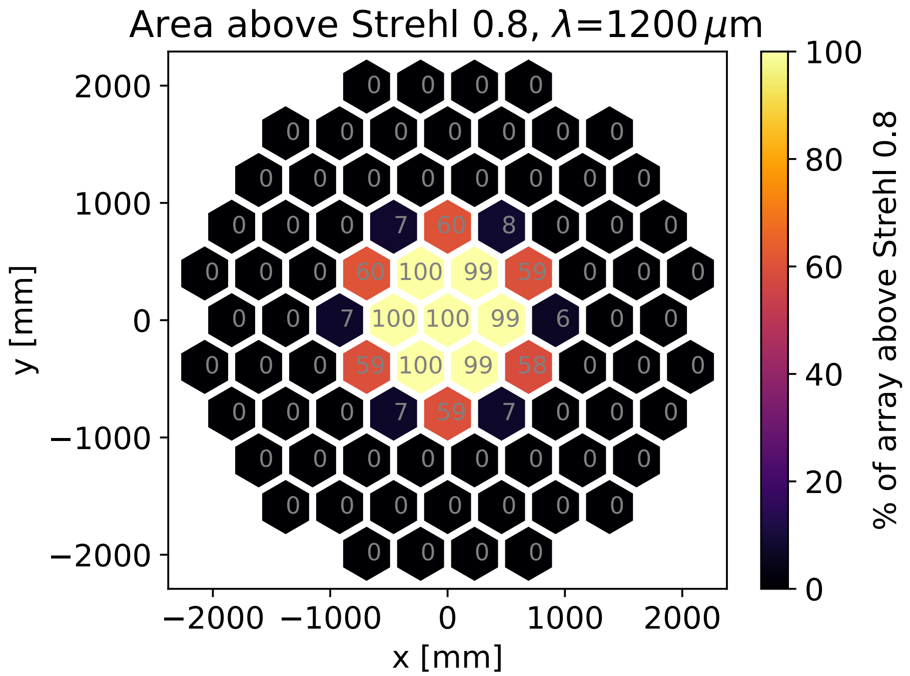


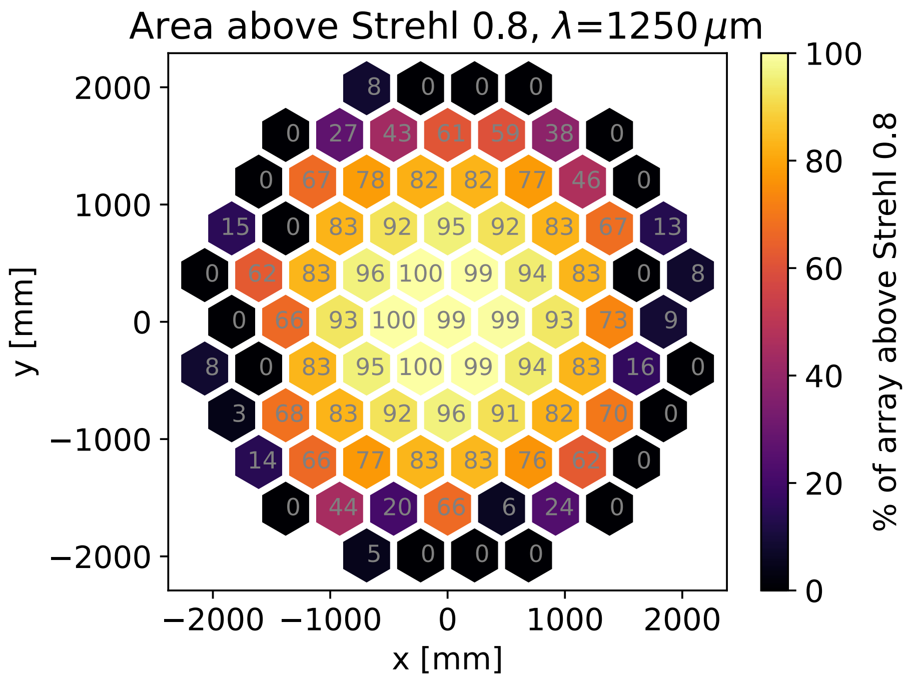


AtLAST beams and corrections to be presented in upcoming memos from Patricio (Pato) Gallardo (left), available on AtLAST website (including the above plot)

- **Focal plane has large size** (D=4.6m) and significant **curvature** but camera size is only a modest (~x2 diameter) scale up from that planned for CMB-S4
- **Diffraction-limited FoV** delivered by telescope is **~0.45 deg at 0.45mm and ~1.4deg at 4mm**
- Correction of aberrations in instruments and by shaping M3 will greatly increase the DLFoV values

Correcting the diffraction limited FoV

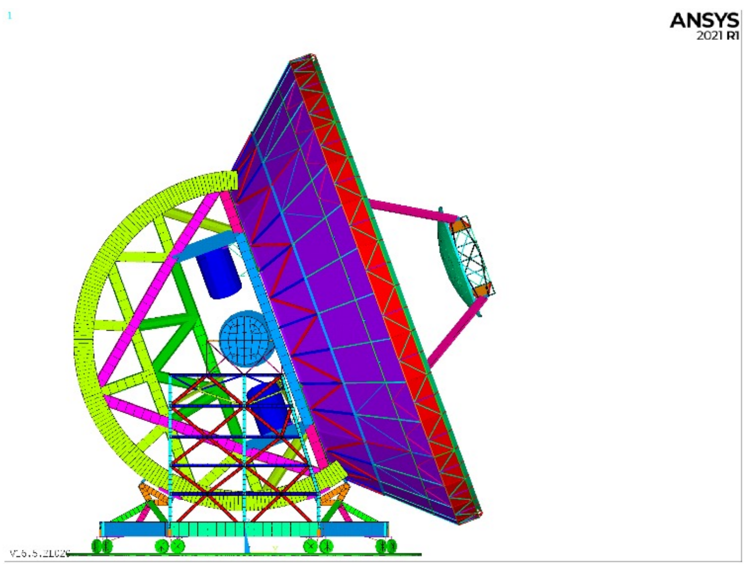


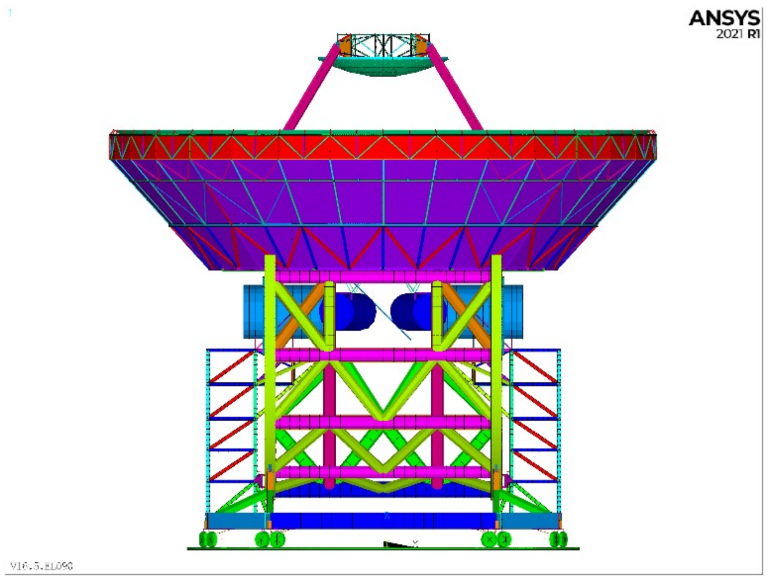


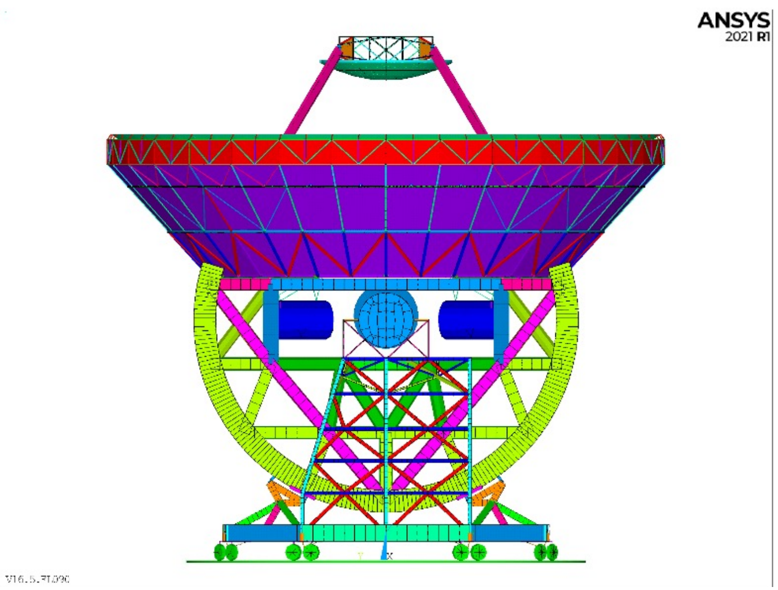
- Using prisms and biconic lenses in the cryostats, one can recover a large fraction of the 2 degree geometric FoV at 1.2 mm (and higher). The concept is similar to the CMB-S4 optics (see Gallardo et al. SPIE and URSI proceedings)
  - New memos led by Pato Gallardo will present the AtLASToptical solutions.

AtLAST evolution of the baseline design

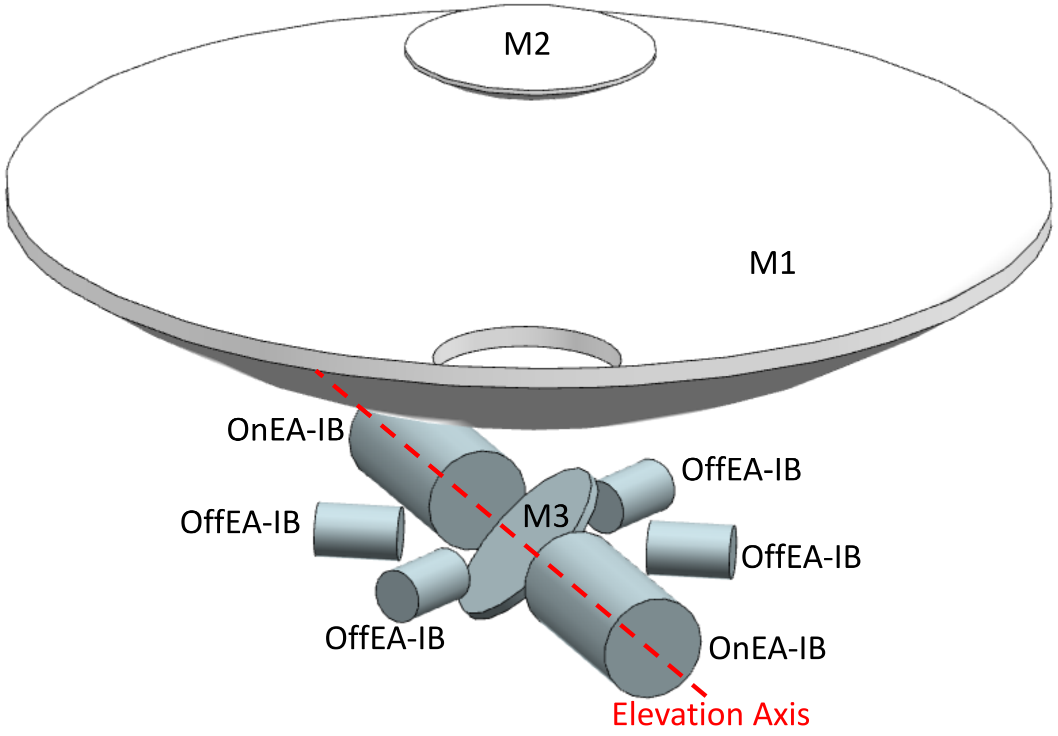
- These computer aided design (CAD) models show the rocking chair concept and instrument placement.
- Note this has evolved further, including the use of 2 azimuthal tracks for stability and load distribution.





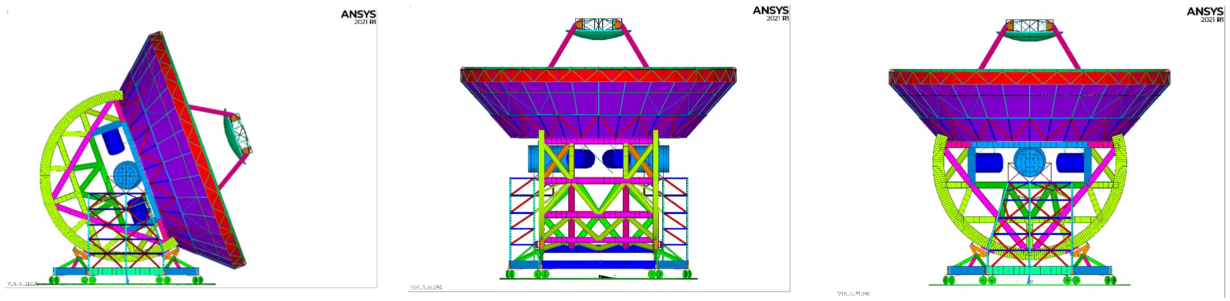


AtLAST instrument positions



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

- Design for the nominal instrument locations.
- 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.



Possible AtLAST instrumentation

Spectral lines

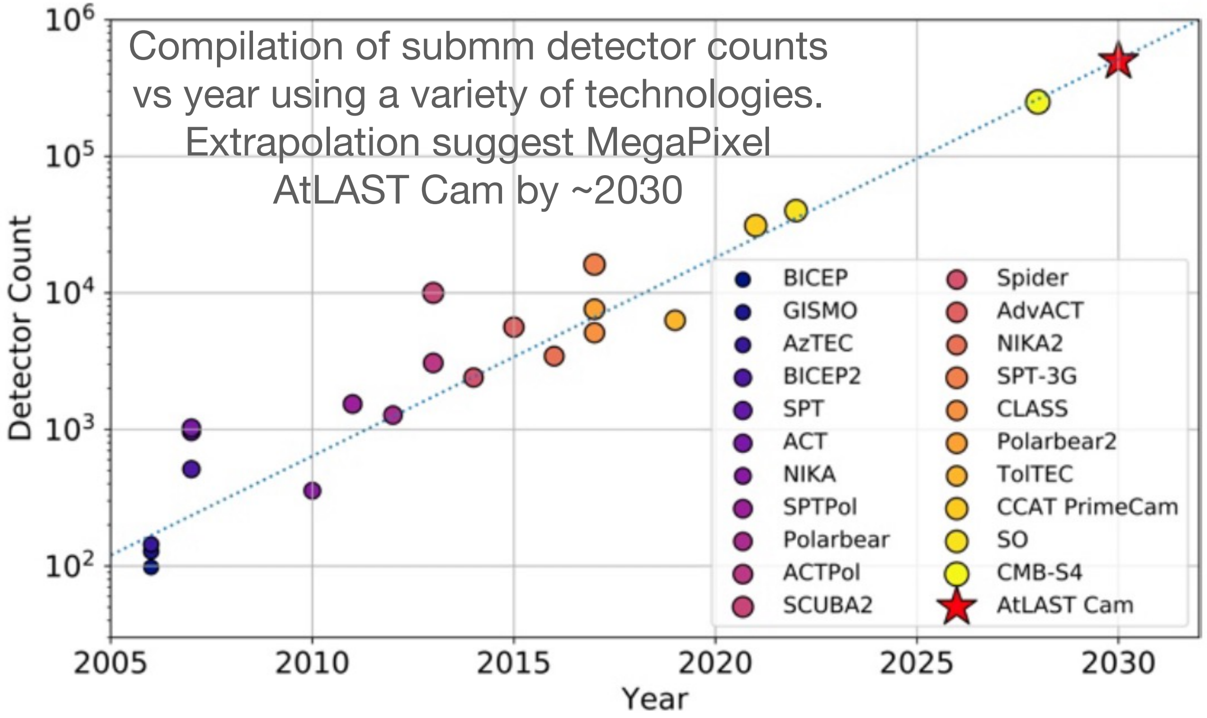
1. A 1000-pixels heterodyne focal plane array providing high spectral resolution dv < 1 km/s [Groppi+19]. Pixels can be deployed in many ways: from a single-band, uniformly filled FoV (maximising mapping speed) or smaller arrays covering multiple bands

2. A multi-object spectrograph (MOS)

3. A direct detection, ultra wide bandwidth integral field unit (IFU), with R~300-1000, effective receiver noise temperature comparable to quantum noise limit

Continuum detectors

- ”AtLAST Cam”: a single or multi-chroic continuum camera comprising ~0.5 million detectors likely exploiting kinetic inductance detectors (KIDs)



AtLAST Proposal, 2019 (see also SPIE paper Klaassen+20)

Next Steps

What we need by Aug 2024:

- We are working to identify concepts that need the most development: prototyping, field tests, etc.
- As a community, we need concrete, robust forecasts covering the many, many science cases a fully-outfitted AtLAST can achieve.
- A sensitivity calculator and example notebooks for forecasting are available here: https://github.com/ukatc/AtLAST_sensitivity_calculator.
- Contact us to get involved. Talk to Luca Di Mascolo (pictured on right) here at the workshop!
- More generally, contact the science work package leads: Pamela Klaassen & Mark Booth, Luca Di Mascolo (Trieste) & Minju Lee (DAWN) for Distant Universe, Matt Smith & Daizhong Liu for Nearby Galaxies, Alvaro Hacaro & Pamela Klaassen for Milky Way, and Sven Wedemeyer, Alexander Thelen, & Martin Cordiner for the Sun and Solar System.
- Funding pathways? We need the full community's support to make this happen.

Luca Di Mascolo

Thanks!

Follow our updates:

- Updates released through our website (**atlast.uio.no**) and on social media. We are on Twitter **@atlast_design** and LinkedIn

- Opportunities to collaborate, use this form: https://www.atlast.uio.no/about/contact/index.html

- Use the sensitivity calculator: https://github.com/ukatc/AtLAST_sensitivity_calculator

- Save the date for the AtLAST 2024 workshop at the University of Mainz, **21-24 May 2024**