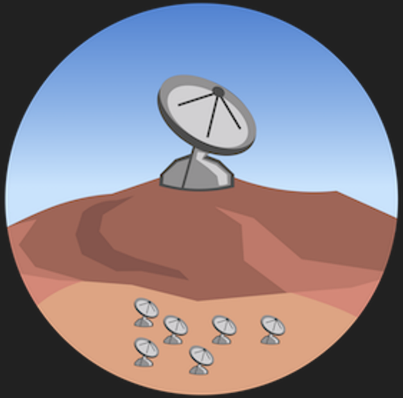
The Atacama Large Aperture Submillimeter Telescope (AtLAST):

A Next-Generation Widefield Submillimeter Single Dish near ALMA



Tony Mroczkowski (ESO)
Claudia Cicone (University of Oslo, Norway)
Pamela Klaassen (UK ATC, Edinburgh, UK)
On behalf of the AtLAST collaboration

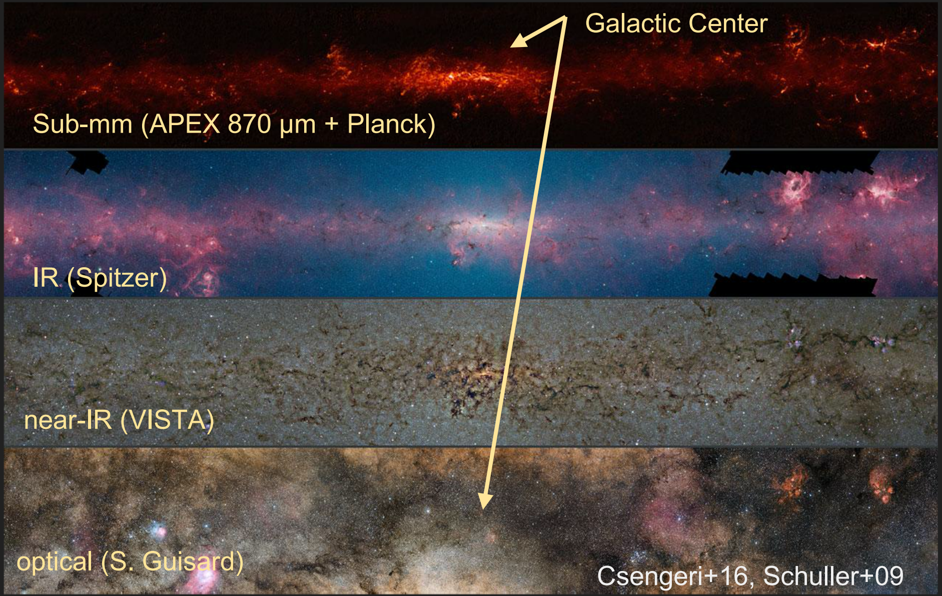
Outline

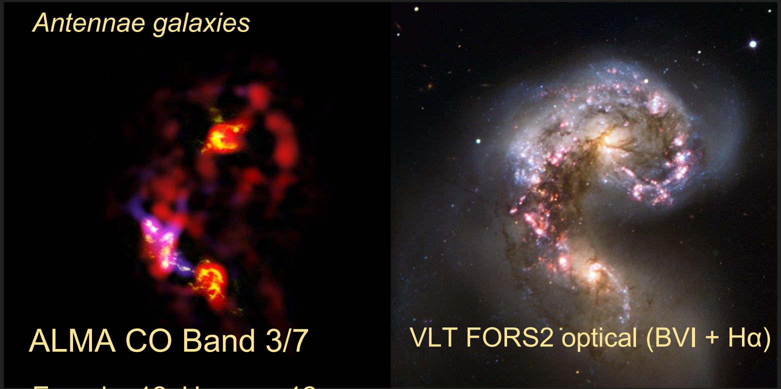
- Motivation for AtLAST & introduction to H2020 Design Study
- Science drivers
- Galactic and extragalactic surveys
- Deep extragalactic observations of the CGM and Sunyaev-Zel'dovich effect
- Telescope technical design study and future instrumentation
- Site selection study
- Operations model and environmental sustainability study
- Expected outcomes of the Design Study and next steps
- Collaboration opportunities

Astronomy at (sub-)mm wavelengths

~50% of light in the Universe emitted in FIR/sub-mm bands: access to tracers of cold gas and dust (raw material for star formation):

- Formation of stars and planetary systems
- Baryon cycle (gas and dust from ISM to IGM scales)
- Early, obscured assembly of galaxies and galaxy clusters





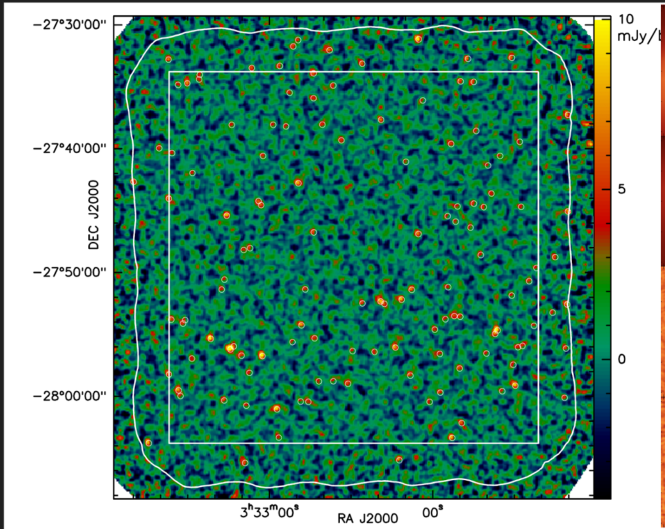
Espada+12, Herrera+12

High-z dusty star forming galaxies discovered by wide (sub-)mm surveys (SCUBA/JCMT, LABOCA/APEX, SPT) → some of them are extreme z~3-4 proto-clusters

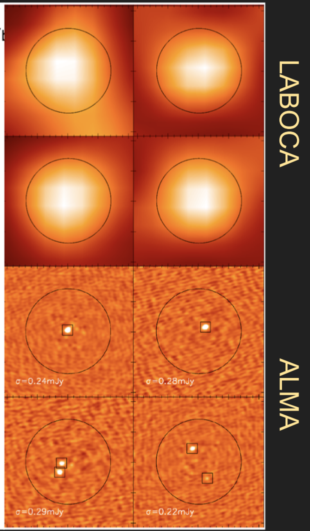
protocluster of dusty SF galaxies at z~4 (Miller+18, Oteo+18)

Single dishes vs interferometers: why we need both

- Interferometers are powerful follow-up machines but optimized to deliver high-res images and narrow-band spectroscopy of individual targets or small (~ few 10” to ~ a few arcmin wide at most) well-defined fields
- New sources (positions and redshifts) unlocked almost exclusively through single-dish observations
- Single dish telescopes can be a flexible platform for testing new instrumentation



APEX/LABOCA 870µm map of the Extended Chandra Deep Field South discovering 126 high-z dusty star forming galaxies (Weiss+09)

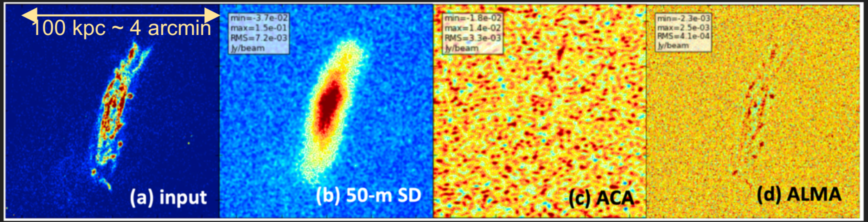


ALMA follow-up (Karim+13, Hodge+13)

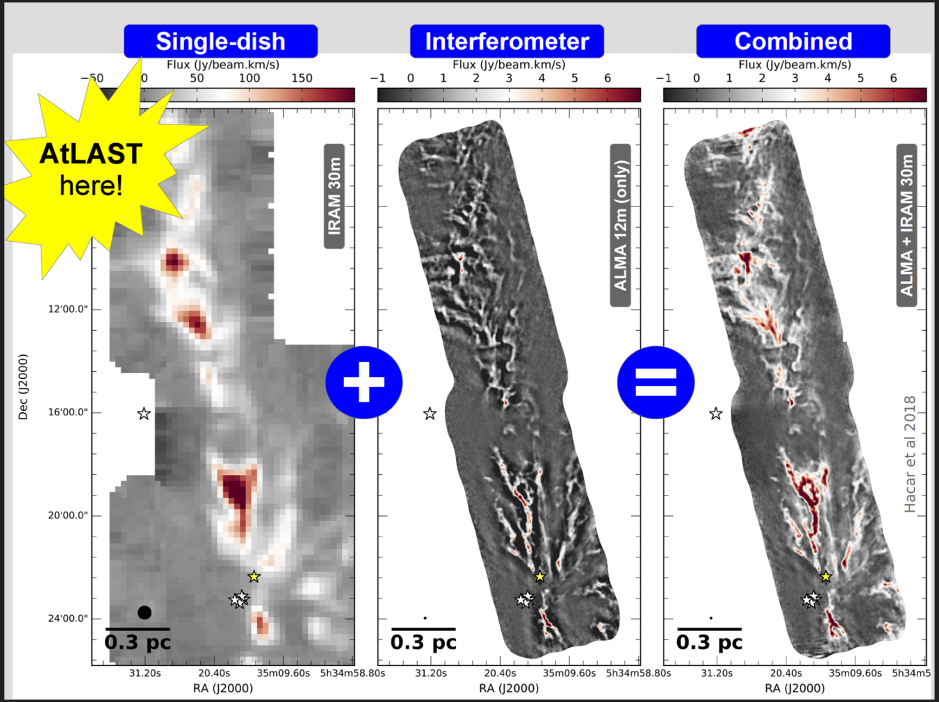
We need “the best of the both worlds”. With ALMA, we have phenomenal interferometric capabilities, but without AtLAST, ALMA and other possible mm/submm facilities will soon reach a “source-starving” regime.

Single dishes vs interferometers: why we need both

- Intrinsic limitation to **any** interferometer:
  - Filtering of large-scale structures: **huge** issue for many science cases, esp. ISM/CGM/IGM
  - Can lead to underestimating masses of “known structures” (inc. Orion!) by >1 order of magnitude
  - Extended structures (CGM/IGM) may never be identified without a sensitive single dish



Cicone+19: molecular CGM of a z=0.02 galaxy as seen by a 50m dish equipped with an ALMA receiver vs ACA/ALMA in 10 hours

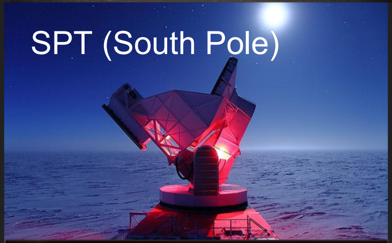


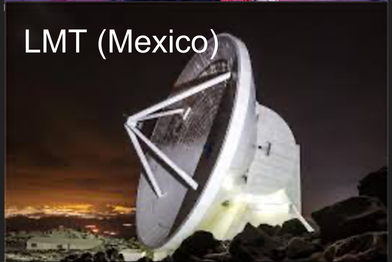
Hacar+18: $N_2H^+(1-0)$ in Orion Integral Shape Filament: without single dish, ALMA (300 pointings, 4’x20’ field) misses >90% of flux in the filament. Gets much worse at higher frequencies!

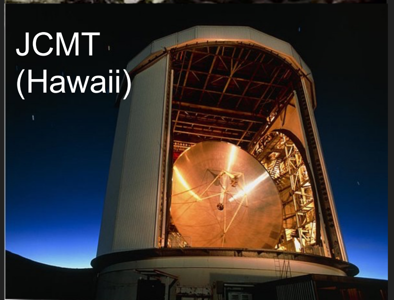
Why do we need a new large sub-mm single dish?

“Existing single dish facilities are very unlikely to remain competitive in the late 2020s, even considering reasonable upgrade paths” (ESO single dish WG strategy report, 2015). Why?

- Small aperture (small collecting area, low spatial res → **confusion noise** → get only extreme sources)
- Existing large aperture facilities (e.g. 50m LMT, IRAM 30m, Nobeyama 45m, 100m GBT) cannot observe at frequencies $\nu \geq$ 400 GHz (due to e.g. design, surface accuracy, atmosphere). Scientific pressure to deliver observations at $\nu \geq$ 500 GHz ($\lambda \leq$ 600 μm) → reduce redshift and temperature selection effects by sampling closer to peak of dust emission
- Small FoV → low mapping speed

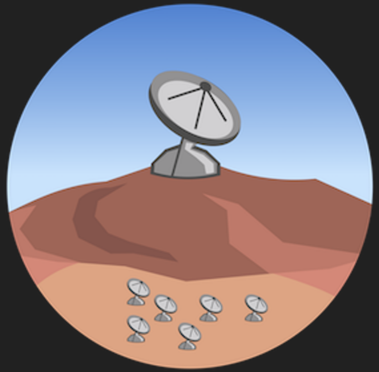






AtLAST in a nutshell

Telescope requirements set by ***unique*** science drivers:



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

The collecting area + field of view will enable a transformational leap in discovery potential

To map the sky 10^5 times faster than ALMA, down to unprecedented sensitivity/resolution for a single dish, and to wavelengths as short as λ~350 μm (ν=850 GHz)

Organization of the Design Study

Project timeline = 3 years
March 2021 - Feb 2024

WP leaders of AtLAST

Coordinator
(Cicone, UiO)

Coordination Committee
(Cicone, Mroczkowski, Klaassen)

Executive Board
(WP leaders, and representatives for MTM and Uni Hert)

External Expert Advisory Committee

WP 1
General Management
(Cicone, UiO)

WP 2
Telescope Design
(Mroczkowski, ESO)

WP 3
Site Selection
(De Breuck, ESO)

WP 4
Telesc. Operations
(Hatziminaoglou, ESO)

WP 5
Enviromental sustainability
(Sartori, UiO)

WP 6
Maturing the Science Case
(Klaassen, UKRI)

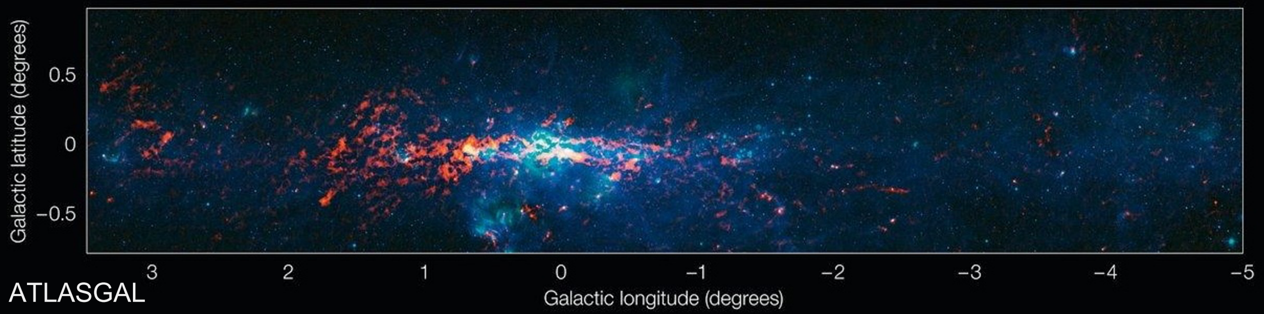
New Science Enabled by AtLAST

Key Themes:

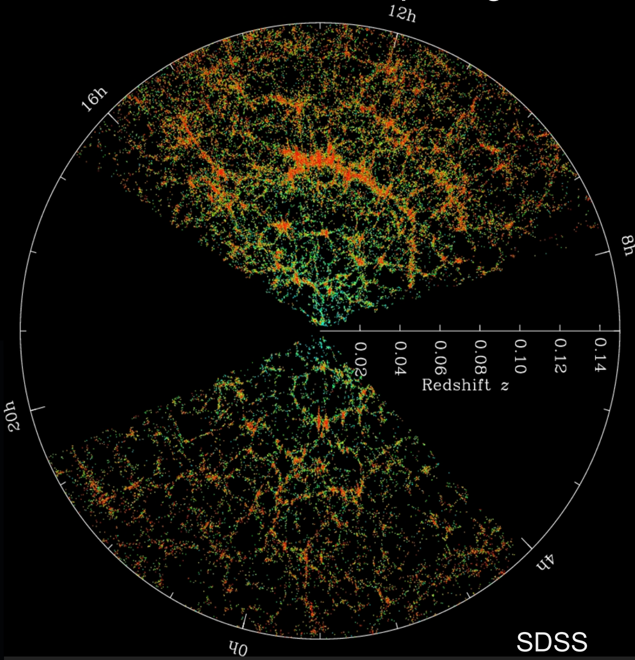
- The most complete sub-mm surveys ever!
- Life cycle of the Local Universe
- Baryon Cycle of the Distant Universe
- New measures of SZ and the Early Universe

Astro 2020
Decadal Survey on Astronomy and Astrophysics
The National Academies of SCIENCES ENGINEERING MEDICINE

~20 white papers discussing AtLAST
See the list at atlast-telescope.org



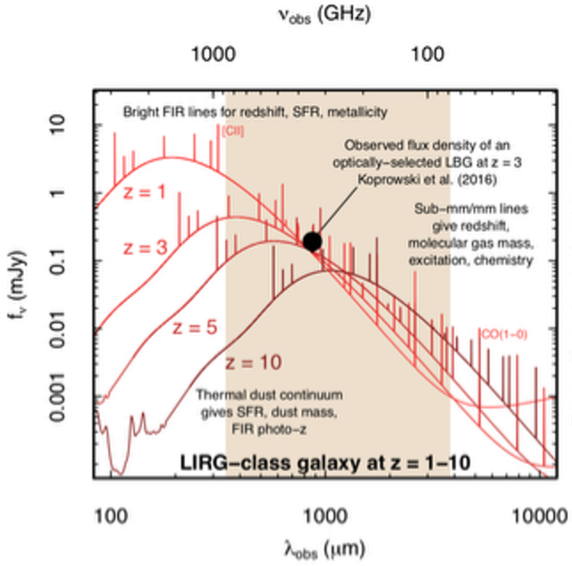
ATLASGAL



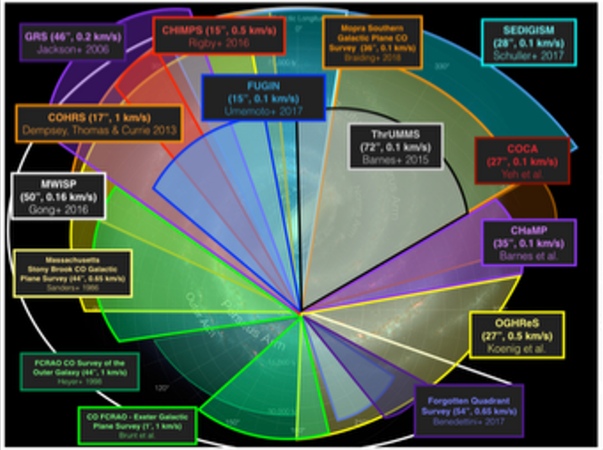
SDSS

Enabling new types of Survey Science

- Ultra-deep Surveys
  - To understand the distribution and properties of dark matter
- Sub-mm SDSS
  - Mapping galaxy evolution out to *z~10*
- Our Molecular Galaxy
  - What is the ‘fingerprint’ of our Galaxy?
  - What does the transition from atomic to molecular gas really look like?

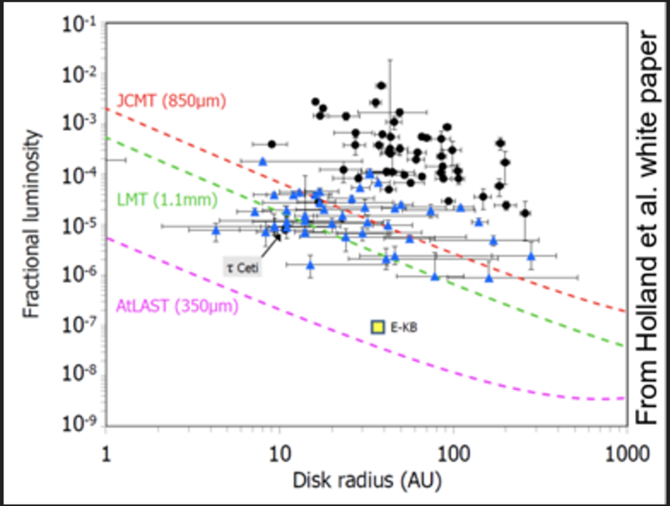


From Geach et al. white paper

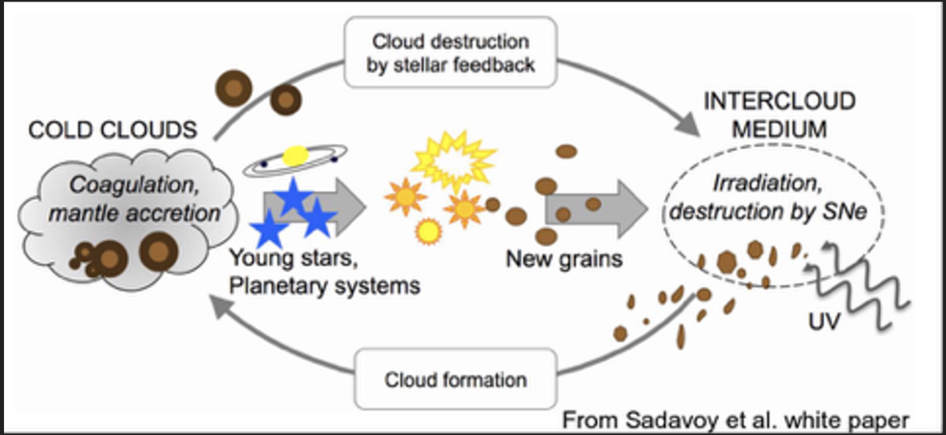


From Stanke et al. white paper

Enabling new Local Universe Science

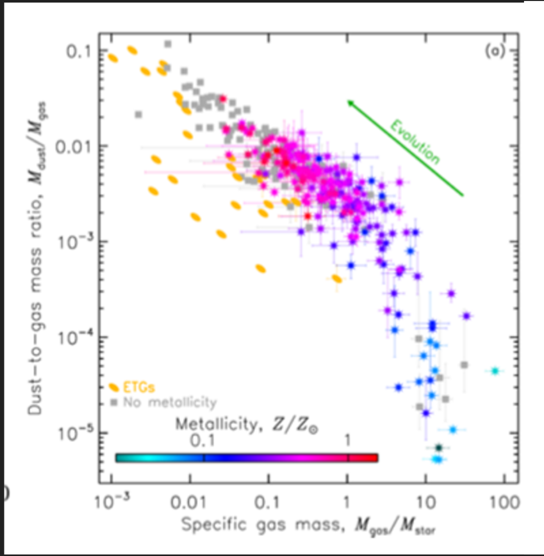


- Life cycle of Dust
  - Thermal regulation, from star forming regions to evolved stars
- Protostellar Variability
  - Quantifying accretion bursts
- Phase Transitions in the ISM
  - PDRs: Hot ionised to Warm/Cold Atomic to Molecular



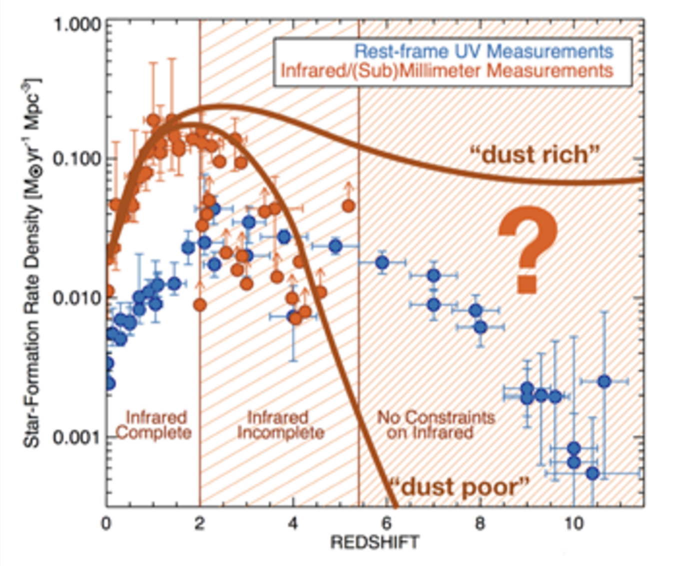
- Debris Disks
  - How unique is the Edgeworth Kuiper Belt?
- The CGM
  - What feeds and depletes the ISM?

Enabling new Distant Universe Science



From Galliano et al. 2018

- Tracing Dust composition across the Universe
  - Understand κ and β as a function of z
- Supermassive Black Hole Feedback
  - How do they shape the evolution of their host galaxies?



From Casey et al. white paper

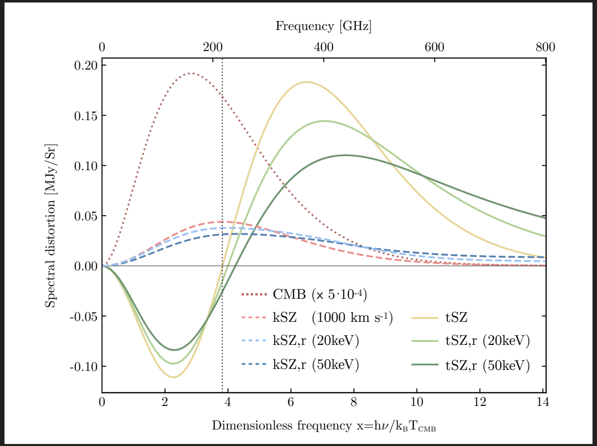
- Survey of High-z Star Forming Galaxies
  - What is the star formation rate density of the Universe?
- Mapping Galaxy Clusters
  - Create a complete sub-mm catalog of clusters and proto-clusters from their formation to the local universe

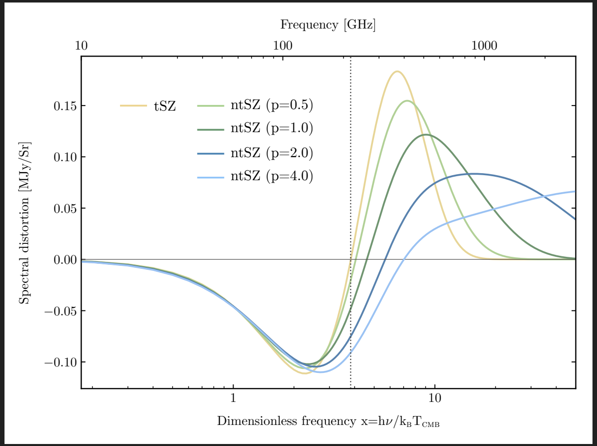
Enabling Studies of the Clusters and Cosmology

- Measure multiple components of the SZ effect
  - Quantifying the kinetic and relativistic Sunyaev-Zeldovich effects (i.e. motion and temperature of hot gas)
  - All aspects of the SZ are redshift-independent in surface brightness (see Mroczkowski et al. 2019 for a review)

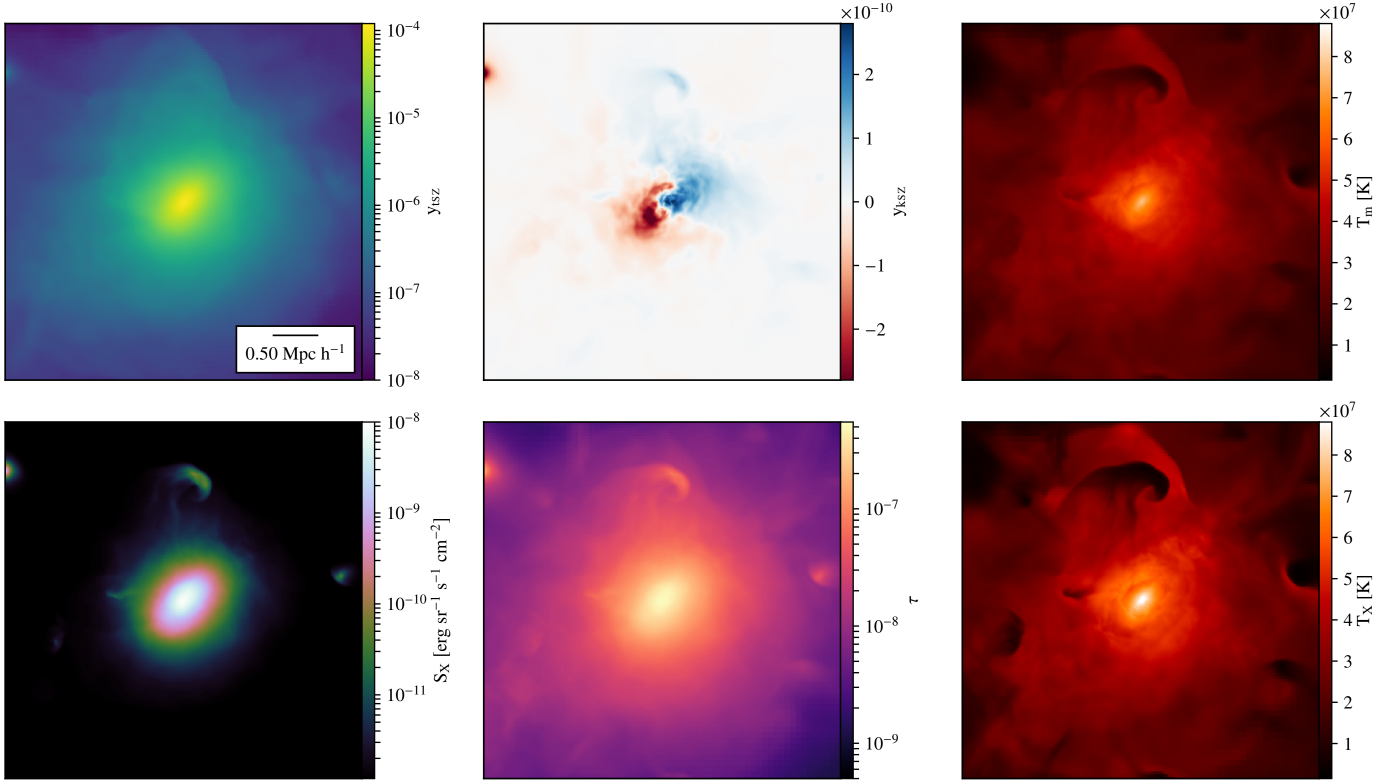
- Use high spatial and spectral resolution SZ to measure the warm-hot Universe
  - Most of the baryons are thought to be in this phase; AtLAST will test the predictions from cosmological volume simulations.
  - Direct constraints on the large scale WHIM in and between galaxy clusters

- Study the Earliest epoch of Galaxy Formation
  - How, and when, did metal enrichment happen in the EoR?





Observable intra-cluster gas properties



Observable properties of a simulated cluster extracted from the Omega500 simulations in Nelson et al. 2013.

Figure is from the Sehgal et al. 2019 white paper on CMB-HD (2019BAAS...51c..43S)

Long Baselines / mm-VLBI?

- The RMS noise (for a point source) is: $$S_{\mathrm{rms}} \propto \frac{T_{\mathrm{sys}}}{\sqrt{N t \Delta\nu A_{\mathrm{e},1} A_{\mathrm{e},2}}}$$

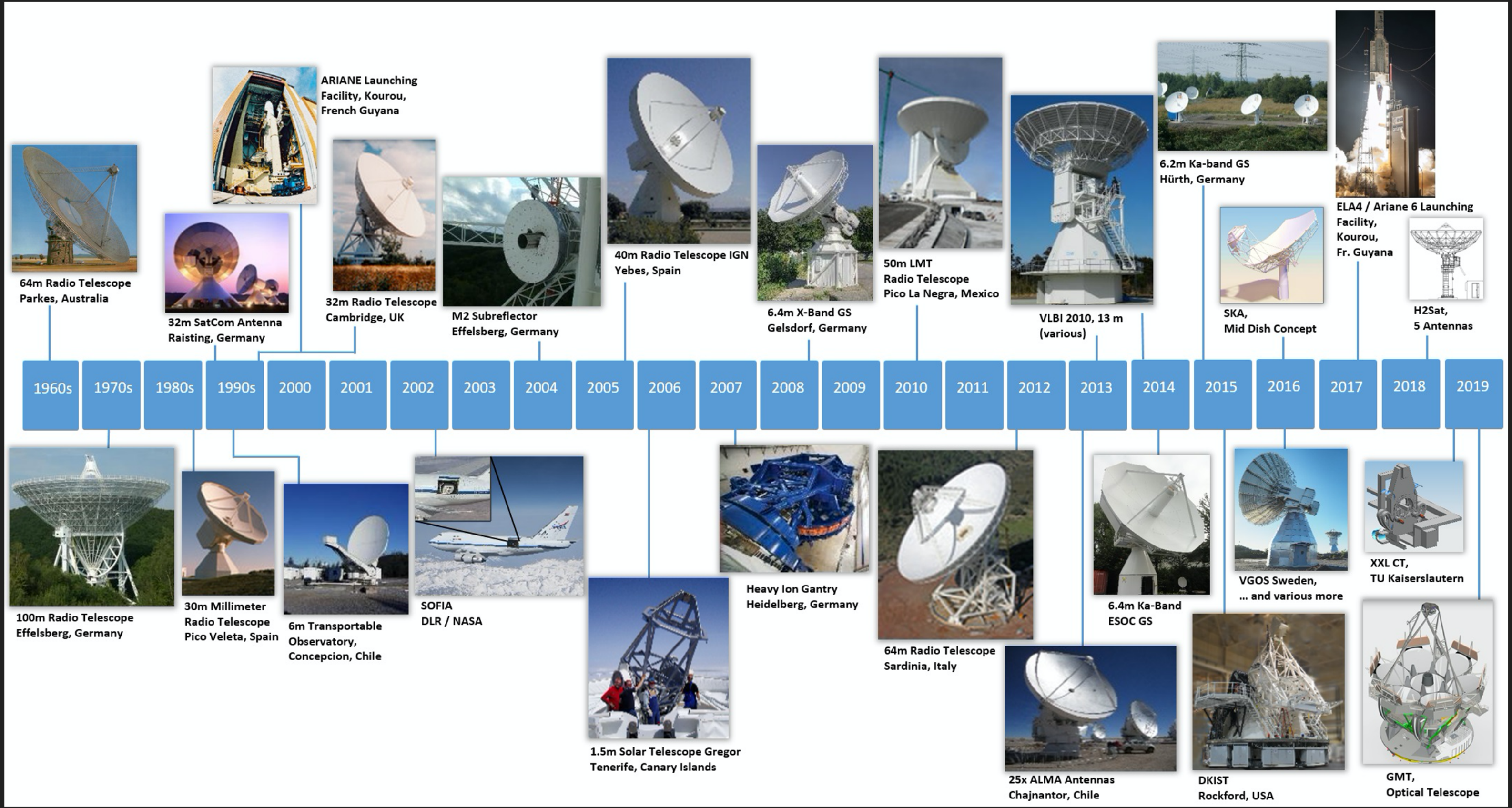
where N is the Number of baselines, *t* is integration time, $\Delta\nu$ is bandwidth, T_{sys} is system temperature, and A_e is the effective area. → Baselines where one antenna is >4 times larger will be 4 times more sensitive.

One idea that came out of the ALMA Long Baselines workshop is that a long baseline upgrade to ALMA involve AtLAST-like antennas could exploit the large FoV by simultaneously tracking a nearby phase calibrator for removal of phase fluctuations (as was done by CARMA PACS; see e.g. Pérez et al. 2010).

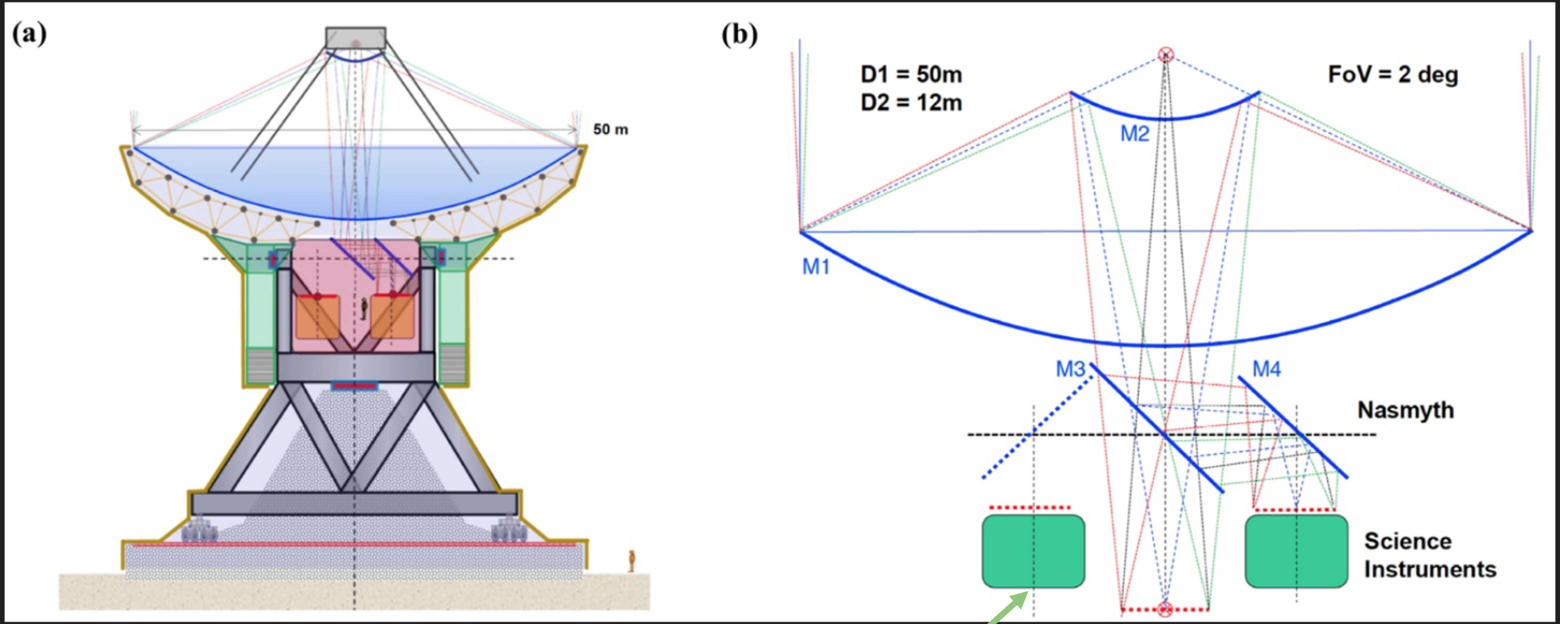
AtLAST Telescope Design

- Led by Tony Mroczkowski at ESO, for external oversight and guidance to meet science requirements, and Matthias Reichert at OHB Digital Connect GmbH (formerly MT Mechatronics; www.ohb-digital.de), for internal management of the design work.
- OHB has many years of experience building some of the largest telescopes in operation (as shown on the next slide).
- One of the largest work packages, they will be working first on a baseline telescope design that will inform the science forecasting tools, followed by a fully-engineered, construction-ready design to be delivered roughly 2 years into the project.

Telescope Design



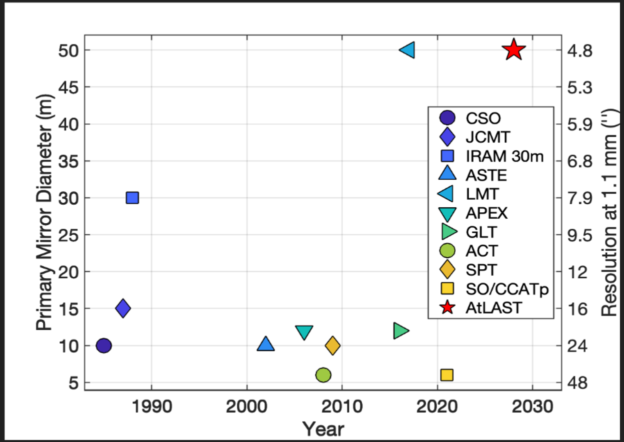
Baseline telescope design

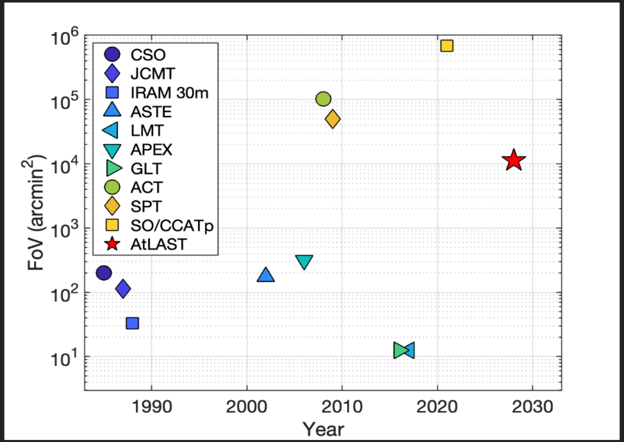


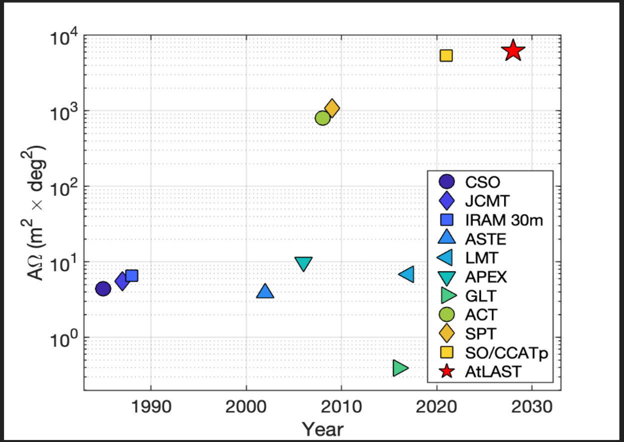
~4 Nasmyth-mounted instruments

1 Cassegrain-mounted instrument

Baseline telescope design overview

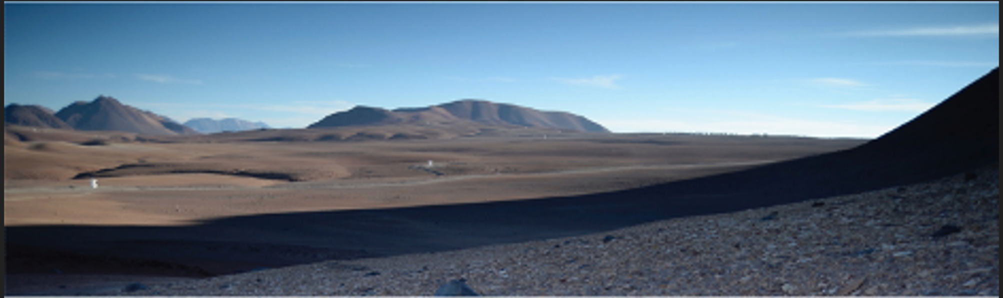


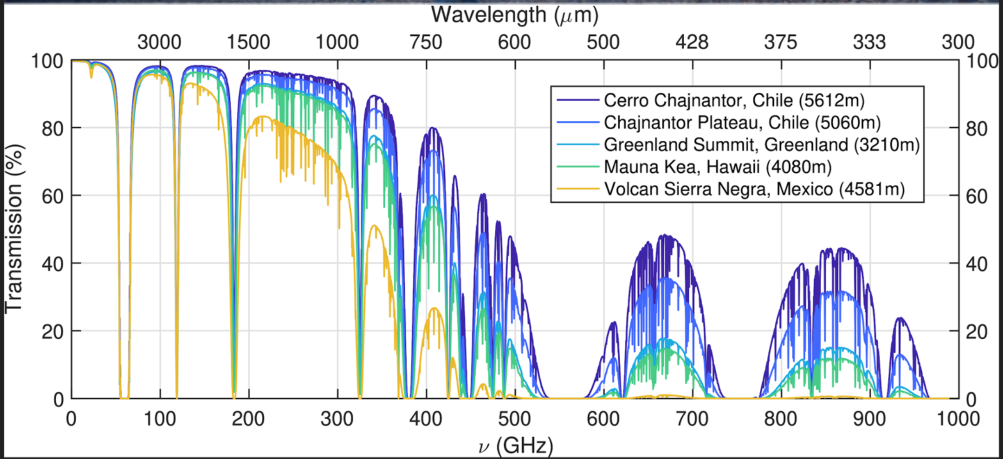




1. Primary Mirror Diameter: driven by the need for both resolution and sensitivity (collecting area).
2. Field of View (FoV): driven by the need for large angular scales and fast mapping
3. Throughput (AΩ): driven by the need for fast mapping speeds and sensitivity in wide surveys.

Site Selection activities
(WP3, led by C. De Breuck at ESO)

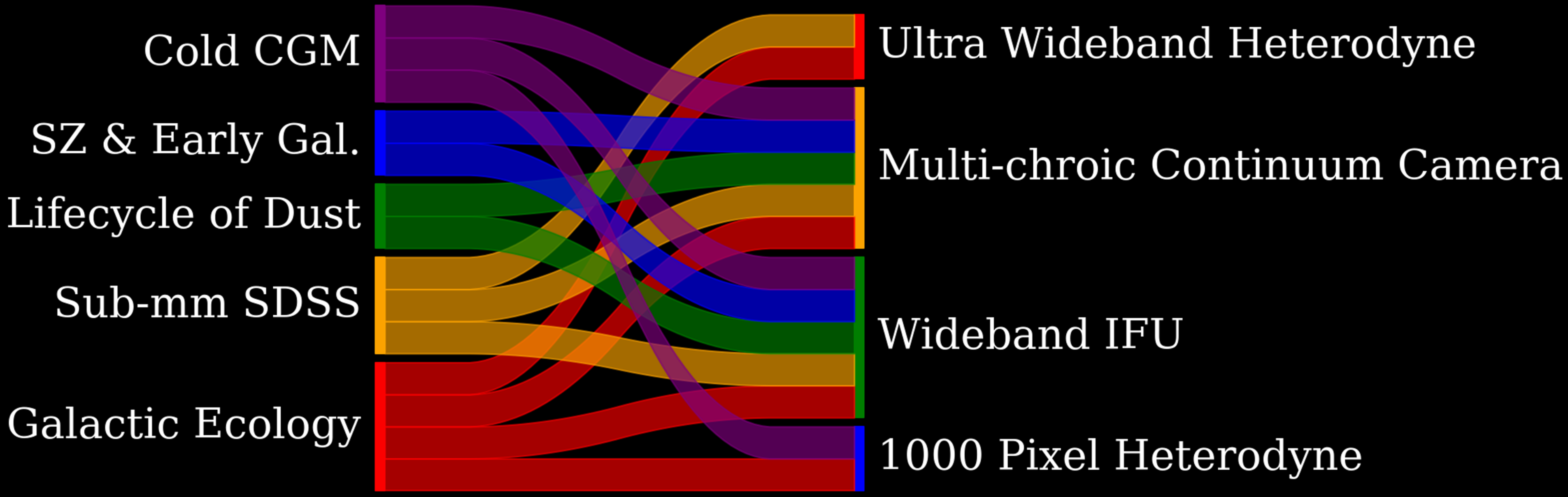




- We are looking at high and dry places around the Chajnantor plateau (~5100 meters).
- The transmission is better than nearly anywhere in the world with a telescope, except for a modest improvement at the peak of Chajnantor, where CCAT-prime will be (5600 meters). However, Chilean labor law, accessibility, safety, and wind conditions all lead us to favor a more accessible site at < 5500 meters.
- The use of existing roads and infrastructure will also reduce the costs and ecological footprint of the observatory.

Instrumentation

Need a diverse instrument suite to handle the varied science cases driving AtLAST

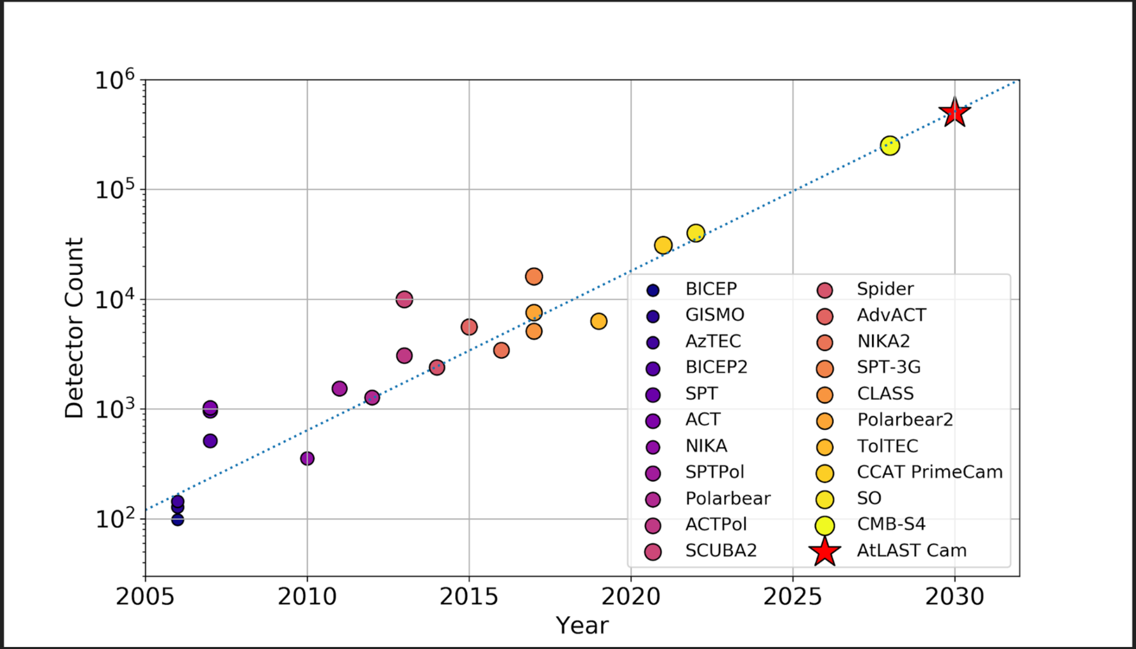


Detectors: how do we populate the focal plane?

Answer: Time is on our side.

The number of detectors in instruments leading the field grows by a factor of 10 every ~7 years, so we expect to be in the megapixel regime by the end of this decade.

Over the ~30 year lifetime of AtLAST, this could reach >10 gigapixels.



Operations plan

(WP4, led by E. Hatziminaoglou at ESO)

- AtLAST operations model
  - Science operations (on-site vs remote, visitor/service mode)
  - Data flow system (from acquisition to delivery, raw vs processed data)
  - Discussion of GTO & DDT
  - Technical operations (e.g. scheduled maintenance)
  - Operations budget
  - Links to site: logistics with transportation, safety issues, gender/diversity dimension

- Adaptation of existing infrastructure
  - ALMA road to the Chajnantor Plateau
  - Existing power supply options
  - Data transfer infrastructure to base camp
  - Use existing facilities during construction and operations (e.g. Sequitor, ALMA OSF)

ALMA Operations Support Facility (OSF)

APEX control room in Sequitor (C. Duran)

Environmental sustainability study

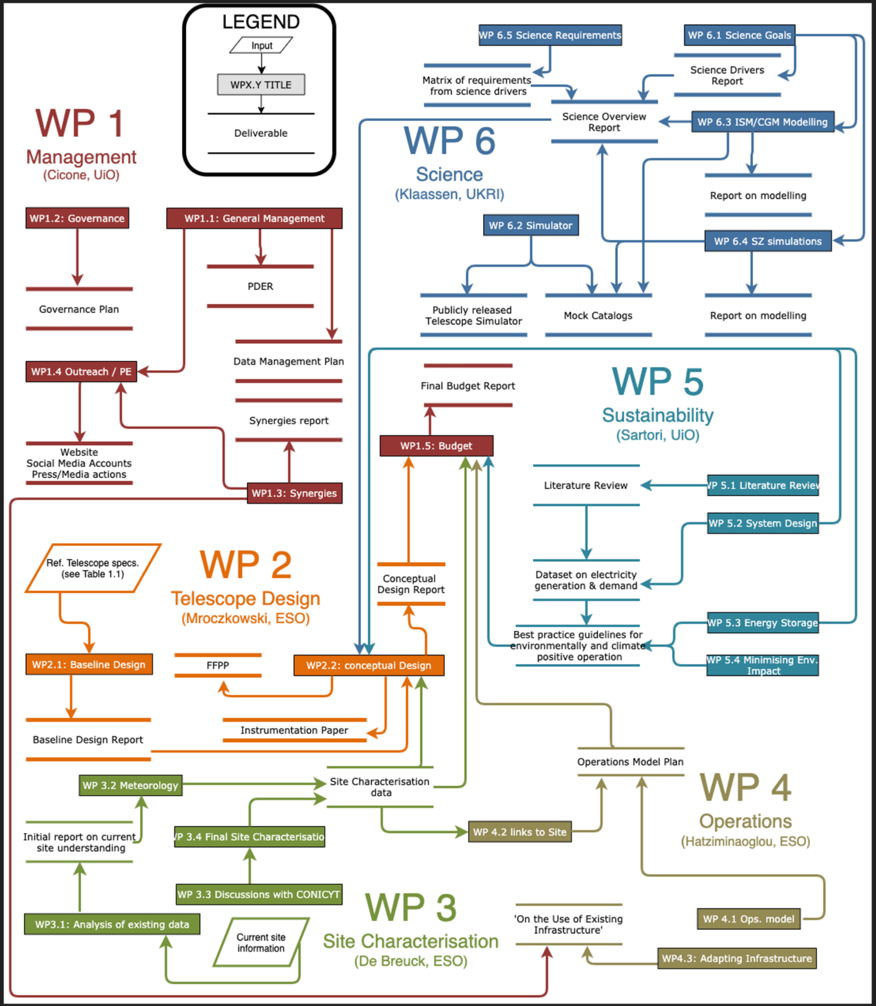
(WP5, led by S. Sartori at University of Oslo)

- Design a renewable based energy system for the telescope infrastructure
    - Combine 40 years of weather data and model interannual variability of solar and wind energy
    - Energy supply for telescope observations + operations
    - Explore options to provide energy to local communities
- Study a novel hybrid energy storage system (batteries + hydrogen)
- Best practice guidelines for environmentally and climate positive operations (involving local communities)

The Granja solar plant in the Atacama desert in Chile

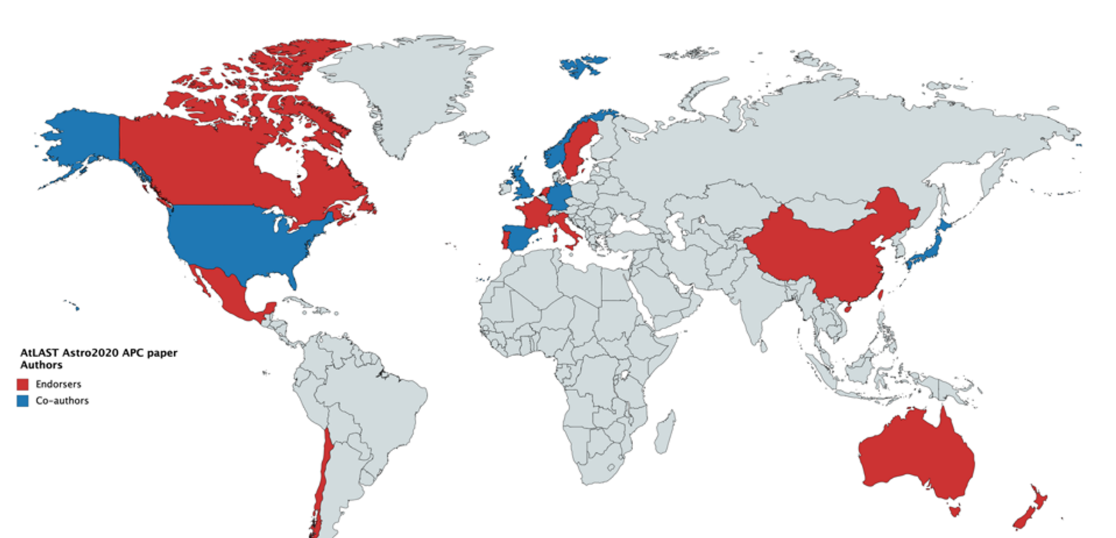
Outcomes of Design Study

- Science case overview
- ***Conceptual technical design*** of the telescope (~ PDR phase)
- Final telescope and instrumentation requirements (for the next phase e.g. construction)
- Complete **site** characterization and principle agreement
- Operations model inclusive of synergies with existing infrastructures
- Full ***environmental sustainability*** study
- ***Budget*** for building and operating the telescope
- Recommendations for ***legal entity*** and international governance structure



Where and how to collaborate?

- Internally, through positions now or soon to be opened: 2 PhDs at UiO, 1 postdoc at UiO, 1 postdoc at UK ATC
- As external collaborators:
  - **WP6 for science input**:
    - Input from multiwavelength studies and simulations
    - Become a member of a subject specific sub-group
  - **WP1 for synergies** with existing or planned projects: e.g. SRT, CTA, SKA but also LSST, ELT, ATHENA.
  - **WP2 for future instrumentation**: mm/submm detectors, IFUs, heterodyne arrays, etc.



Map of endorsers and co-authors of AtLAST Astro2020 papers

Final remarks

- We are collecting emails and information from interested collaborators: **atlast-telescope.org** (follow link to Google Form)
- Apply now to these EU-funded positions:
  - 1 PhD student to work on extragalactic predictions for AtLAST at UiO (Cicone/Shen)
  - 1 PhD student to work on environmental sustainability study at UiO (Sartori)
  - 1 Postdoc at UiO to work on site measurements in collab with ESO (Sartori/De Breuck)
  - 1 Postdoc at UK ATC to work on science case and telescope simulator (Klaassen)
- Design study to start in March 2021, stay tuned :)
- Our SPIE proceedings paper, led by Pamela Klaassen, is now available on arXiv.org (2011.07974). This paper, and the associated talk at the Dec SPIE meeting, will describe the design study in more detail.