From Star Formation to Cosmic Structure

The Transformative Science of AtLAST

Extragalactic Science Cases

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AtLAST Extragalactic Science Working Groups

WG-1: Deciphering the **Astrochemical Diversity** across Extragalactic Environments

WG-2: Charting the **Gas Flows around Early Galaxies** with AtLAST

WG-3: AtLAST **Hunting AGN** - Unveiling massive BHs through mm Continuum Emission and Variability

WG-6: Probing the Early Universe and **Physics beyond the Standard Model**

WG-7: Resolving the **Cosmic Infrared Background**: Tracing Star Formation from the Dawn of Galaxies to Today

WG-17: Surveying **Galaxy Clusters (in formation)** in the Distant Universe

WG-18: **Transient** Millimeter Sky

WG-22: **Highest Redshift** Galaxies

WG-23: **Cosmology** with Submillimetre Galaxy Magnification Bias

WG-24: Determination of **Halo Mass Density Profiles** at kpc Scales through Magnification bias

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High, Intermediate, and Local Redshift Universe

Deciphering Astrochemical Diversity across Extragalactic Environments

The missing chemistry

- Molecular lines encode density, temperature, metallicity, turbulence, radiation and feedback, but current broad inventories cover fewer than 15 nearby galaxies and only a handful of high-z sources.

Why AtLAST

- Sensitivity to map **faint, extended emission across full galaxy disks**, from centres to outskirts and outflows, without the missing-flux limitations of interferometers.

Proposed Observations and/or Requirements

- multi-species line surveys across Bands 3–10
- wide-band, multi-beam heterodyne spectroscopy
- ~1” spatial resolution; ≲2–3 km/s channels

Takeaway: *AtLAST builds the first population-level chemical atlas of galaxies, turning molecular complexity into a diagnostic of star formation, feedback and the baryon cycle.*

High-redshift (z>1) galaxies

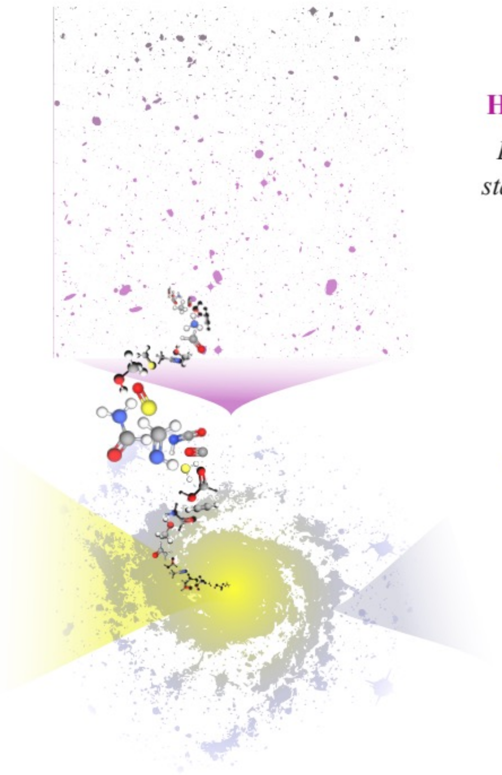
Effects of extreme AGN and starburst regions onto the ISM?

Nearby galaxies (< 100 Mpc)

Variation of ISM chemistry across environments?

Redistribution and processing of chemical species by outflows?

Relationship between molecular complexity and baryon cycle of galaxies?



Low-mass galaxies & low-density environments

How do they differ?

Where does molecular gas form and condense?

Bouvier+2025 ESO Expanding Horizons White Paper

Bulk of molecular gas
CO isotopologues
+ high-J CO SLEDs

Dense gas
HCN, HNC, HCO+
CS, N_2H+

Feedback
SiO, HNCO, CH_3OH
H_2S + line wings

CO-dark gas
[CI] and [CII]
low-metallicity ISM

AtLAST SCIENCE · WG1-2 · Claudia Lagos et al.

Charting cold gas flows around early galaxies

The missing baryon cycle

• At z > 2, this **diffuse CGM reservoir** is still poorly constrained, while simulations disagree strongly on inflows, outflows and baryon content.
• Inflow/Outflow balance is key to understand galaxy growth, enrichment, feedback, and quenching mechanisms.

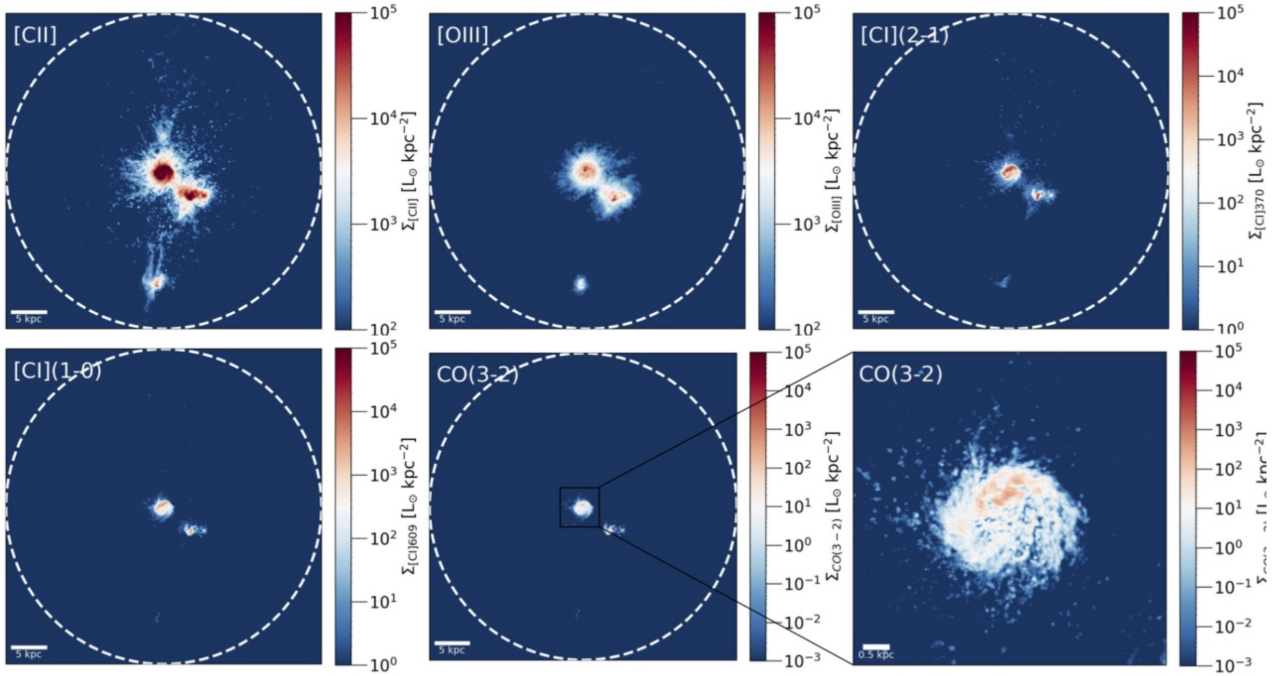
Why AtLAST

• A 50-m single dish can recover faint, extended emission on large angular scales that interferometers filter out.

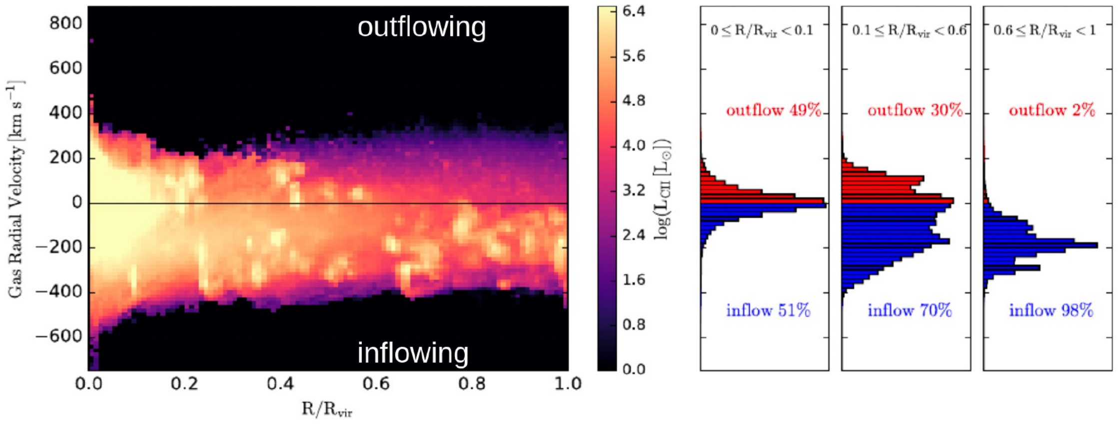
Proposed Observations and Requirements

• Massive SFGs, M ≳ $10^{10.5}$ Mo, at z ≈ 2–6
• Wide field line maps in [CII], [CI], CO + dust continuum. Bands 1-10.
• Recover scales of a few Rvir with high spectral resolution
• ALMA/MUSE synergy

***Takeaway:** AtLAST makes the hidden CGM measurable enabling direct baryon cycle and galaxy-evolution tests.*



Mock FIR/sub-mm line maps of a z = 6.5 galaxy system (Schimek+24)



Inflow/Outflow [CII] gas as function of radial velocity and distance (based on Munoz-Elgueta+24).

Resolving the Cosmic Infrared Background

Hidden Star Formation from the Dawn of Galaxies to Today

- At λ > 250 μm, only ≈20–40% of the CIB is resolved.
- Missing light dominated by high-z dusty star-forming galaxies.
- Key to understand origin of dust in Early Univ. + cosmic SFRD

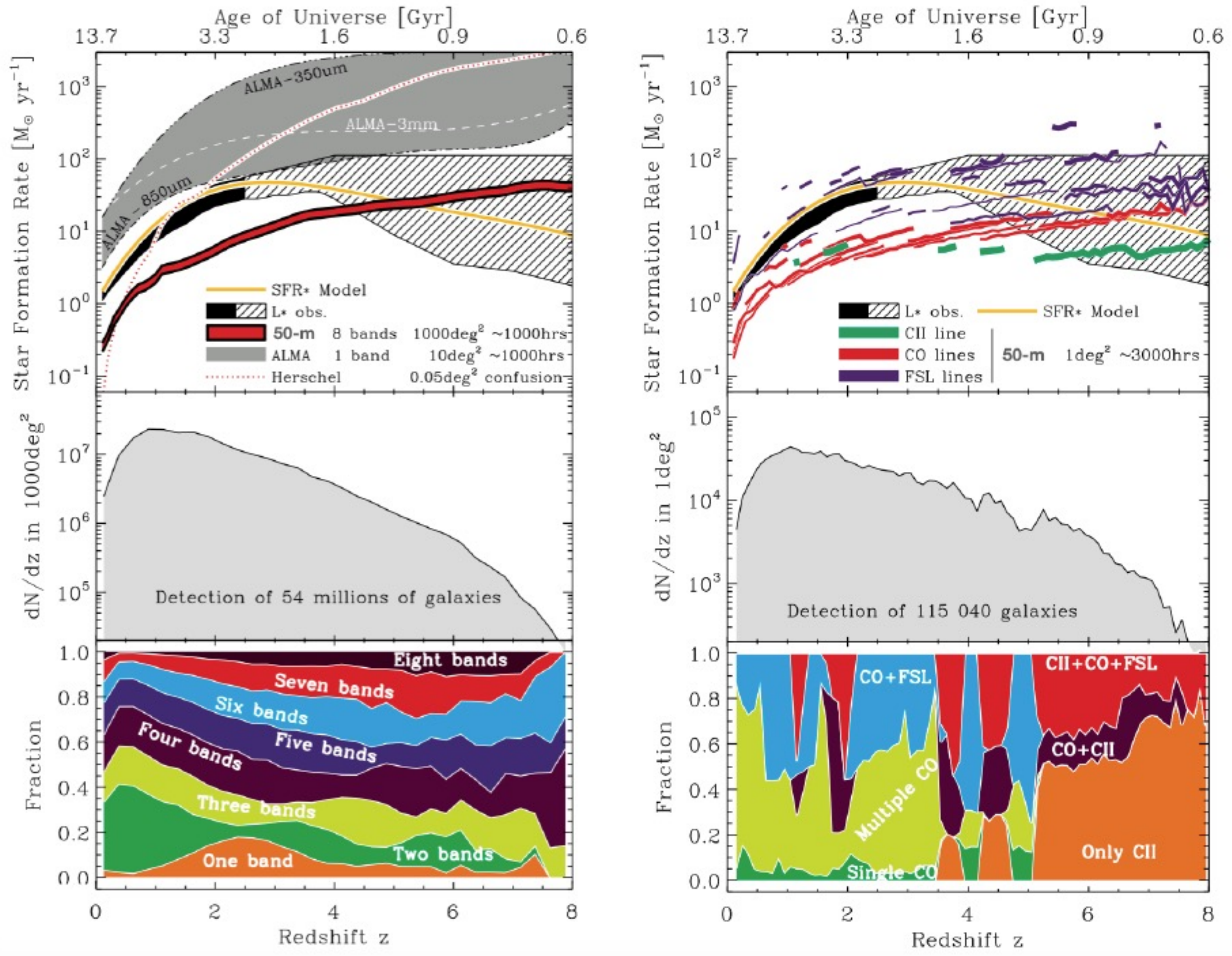
Why AtLAST

- A 50-m single dish with **huge multiplexing** can go deep and wide at 350 μm–3 mm, overcoming Herschel confusion and ALMA small-field statistics.

Proposed Observations and Requirements

- Wide: 1000 deg^2 continuum survey in 1000h for simultaneous ALMA 3-10.
- Deep: 1 deg^2 blind line survey in 3000 hr, R ≈ 750, z<7

***Takeaway:** AtLAST turns the unresolved CIB into a census of obscured star formation.*



Parameter space accessible to the wide (continuum) and deep (lines) proposed surveys (Van Kampen+2024).

Surveying galaxy clusters in formation in the Distant Universe

The missing scales of Galaxy Clusters in Formation

- Span tens of Mpc^2, but lack large-scale mapping.
- Host extended gas reservoirs (~50 kpc, CGM/IGM), but mostly unexplored.
- Major contributors to SFRD of the Universe (20-50%), but lack statistics.
- Nascent ICM through Sunyaev Zeldovich.
- Current facilities provide only zoom-in, inhomogeneous samples.

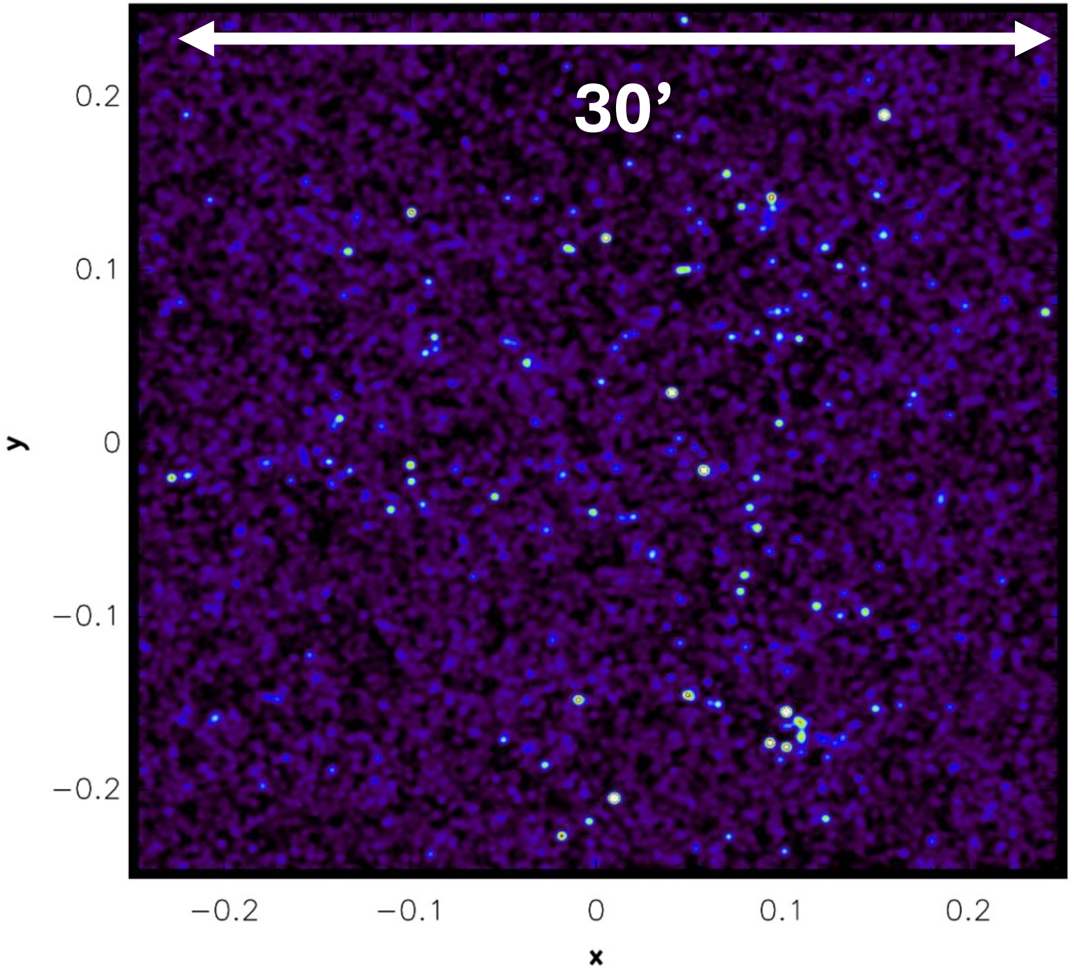
Why AtLAST

- Fast mapping and large FoV for statistical samples of protoclusters.
- Can resolve individual member galaxies, recover extended gas reservoirs, quantify SF and gas budget of full structure.

Proposed Observations and Requirements

- Systematic mapping of galaxies within high-z clusters in formation: 30–950 GHz for z = 2–7 + access to CO sled, [CI], [CII] + dust cont.
- 2° FoV, high multiplexing, 1-2" spatial resolution, 150 km/s

Takeaway: *AtLAST provides the missing sub-mm scales of how galaxies, gas, and dark matter assemble into the first clusters.*



Mock image at 2.4mm of the CO(3-2) line for galaxies in and around a simulated z=1.74 cluster in formation (Van Kampen+24)

Transient millimeter sky

The hidden (sub-)millimeter flash

- Many explosive and variable events are dust-obscured, evolve too fast, and trace a wide variety of phenomena: SN, TDEs, FRB, compact object mergers, stellar flares, BHA...
- The mm/sub-mm transient sky is still largely unexplored.

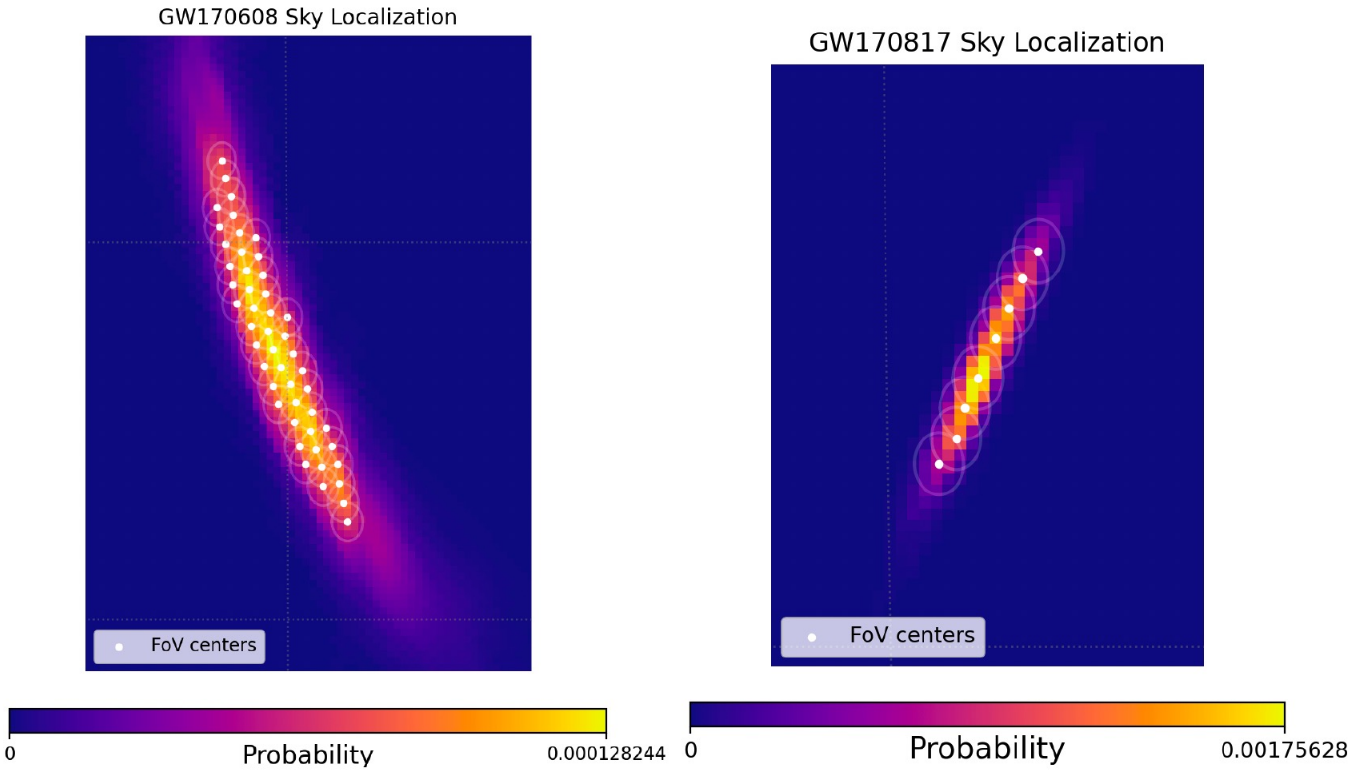
Why AtLAST

- Unmatched FoV (deg^2) , high mm sensitivity + fast mapping.
- Unique for blind transient surveys and rapid triggered follow-up.
- Synergies with the wide field surveys of the 2030s: Rubin, Roman, Einstein Probe, CTAO, ULTRASAT...

Proposed Observations and Requirements

- fixed-cadence monitoring + rapid-response ToOs
- 30–350 GHz wide-band continuum + selected lines
- 10–100 deg^2 surveys, FoV > 1 deg^2, ~1” arcsec resolution
- real-time VOEvent-linked transient pipeline

Takeaway: *AtLAST turns the mm sky into a discovery engine for fast, obscured and multi-messenger transient events.*



Rapid-response mapping of gravitational-wave localizations (WG1-19)
Tens of deg^2 surveyed at mJy (left) and μJy (right) sensitivity within 3h.

Mapping the highest redshift luminous galaxies

How the first luminous galaxies formed?

- Unexpected overabundance of bright galaxies at z>10 by JWST.
- Formation channels remain an open question:
“Outliers in typical environments” vs “Environment dependent”
- Roman provides statistical sample of candidates to follow-up.

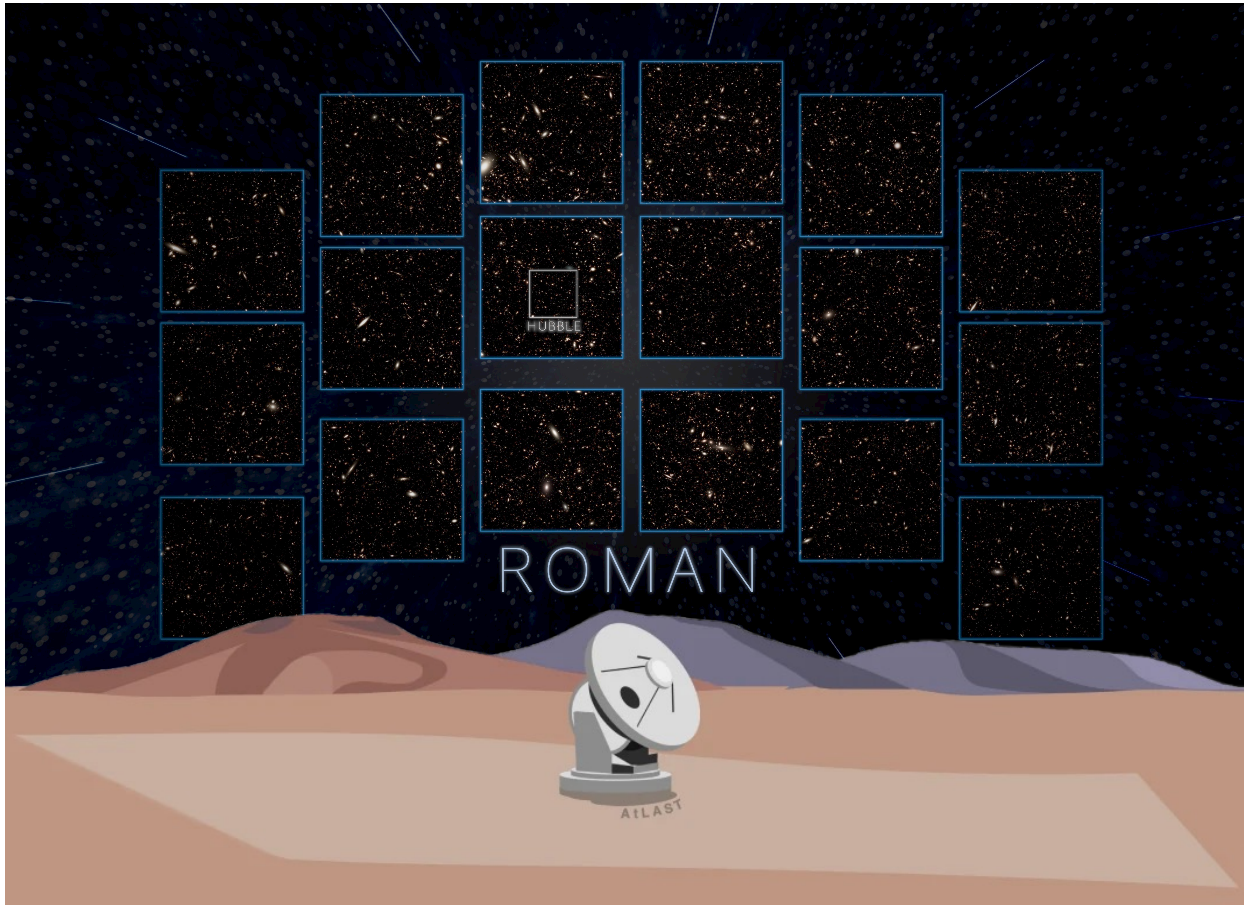
Why AtLAST

- Wide-field IFU to map [OIII] 88 μm emission around selected candidates, obtain redshifts, measuring clustering, and early metal enrichment.

Proposed Observations and Requirements

- 3500 hr survey
- 400 bright Roman candidates at z ≈ 10–15
- 160–220 GHz line + continuum IFU mapping
- 10 arcmin^2 per target; raster scan mode

Takeaway: *AtLAST turns the brightest z>10 candidate galaxies into a 3D map of the earliest cosmic web.*



Cosmology with sub-mm magnification bias

Magnification bias as cosmological probe

• Foreground objects slightly changes the observed number counts of background SMGs.
• Statistical excess becomes an independent probe for cosmological parameters, complementary to cosmic shear but without relying on galaxy shapes.

Why AtLAST

• Large FoV (2 deg) for **homogeneous SMG catalogues.**
• Large aperture to **suppress confusion and measuring number count slopes directly.**

Observational need

• Wide Area 1000–5000 deg^2 multi-band continuum survey
• Bands 3-4 + 6-7 needed; Bands 8-9 desirable
• 5σ ≲ 1 mJy at 220-270 GHz

Magnification bias workflow

Foreground lenses
Euclid / LSST galaxies & clusters

↓

Background SMGs
AtLAST high-z dusty galaxies

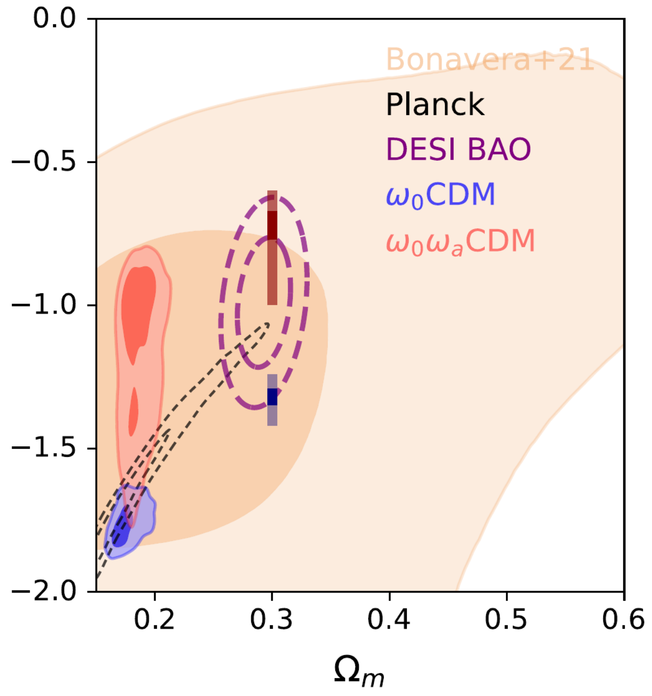
↓

Cross-correlate
number-count excess vs. lens position

↓

Cosmology
Ωm, σ8, w0, wa, Σmv

Forecast / current contours



Preliminary w0–Ωm probability contours show complementarity with Planck and DESI BAO (WG1-23) and pilot Magnification Bias tests (Bonavera+21).

Takeaway: *AtLAST turns magnification bias into an independent precision probe of cosmological parameters: dark energy, Ω_m, σ_8 and neutrino mass.*

“Typical” Observational Extragalactic Requirements for AtLAST

Broad frequency reach

- Continuum + lines from ≈30–950 GHz (Bands 1-10)
- CO sled, [CI], [CII], [OIII] + dust/SMG SEDs

Large, fast mapping

- Degree-scale FoV
- Uniform mosaics, OTF/raster/drift scans

Sensitivity + resolution

- 50-m aperture to beat confusion
- 1-2 arcsec localization
- μJy/sub-mJy continuum + faint-line limits

Instrument

- Multi-pixel KID/TES continuum cameras
- IFU/imaging spectrographs + heterodyne arrays
- Flexible surveys; rapid response where needed

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