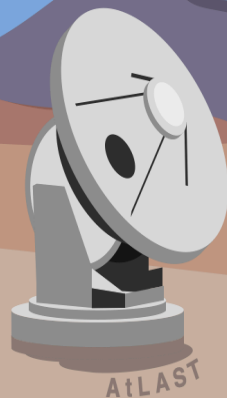




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Galactic Science Cases



Teresa Huertas-Roldán (IAC-ULL)



Universidad
de La Laguna



GOBIERNO
DE ESPAÑA

MINISTERIO
DE CIENCIA
E INNOVACIÓN



AGENCIA
ESTATAL DE
INVESTIGACIÓN

Thematic Classification

SOLAR SYSTEM & SOLAR PHYSICS

- WG1-4 · Solar Activity & Space Weather
- WG1-12 · Cometary HDO/H₂O Survey

ISM & MOLECULAR GAS

- WG1-5 · Prestellar Core Chemistry
- WG1-8 · Magellanic Clouds Survey
- WG1-9 · ISM Galactic Plane Survey
- WG1-15 · Missing Flux / ALMA Short-Spacing

ENERGETIC PHENOMENA & TRANSIENTS

- WG1-20 · Supernova Remnants & Cosmic Rays

STELLAR FORMATION & EVOLUTION

- WG1-10 · Kuiper Belt Analogues around Nearby Stars
- WG1-11 · mm Masers (2M2A)
- WG1-16 · AGB Winds → Planetary Nebulae

CHEMISTRY

- WG1-18 · Prebiotic ISM Chemistry

MAGNETIC FIELDS

- WG1-13 · Magnetic Fields: Line Polarization
- WG1-21 · B-Fields in SF Filaments (Dust Pol.)



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Our Active Sun as the Source of Space Weather



SCIENTIFIC QUESTION

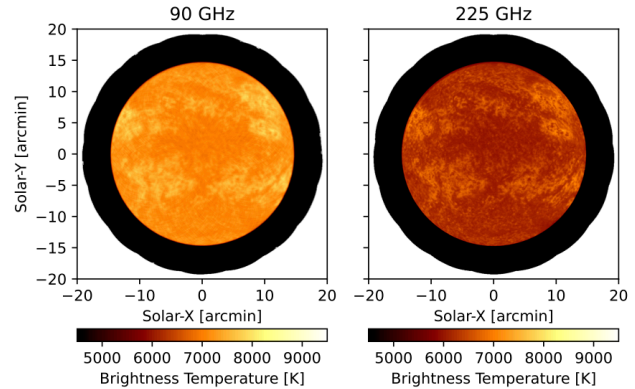
- How is magnetic energy stored and released in solar flares and CMEs?
- What drives solar wind acceleration and controls chromospheric thermal/magnetic structure?
- How do chromospheric conditions vary across the full solar disk with cadence < 1 min?

WHY ATLAST

ALMA	✗	High res. chromosphere, but tiny FoV — cannot scan full disk (2000"). Single band only.
IRAM-30m	✗	No solar observing mode. Not designed for solar science.
VLA/ngVLA	✗	Lower frequencies only — misses chromospheric thermal emission at mm.
AtLAST	✓	Capable of full-disk scans (<30 s) across 4–8 bands simultaneously.

OBSERVATIONAL OBJECTIVE

- Full-disk scans at 90–700 GHz with cadence < 1 min, at 2.2–16.8" resolution
- Multi-pixel multi-chroic camera with full Stokes I,Q,U,V at scan speed 3°/s
- Tomographic 3D reconstruction of chromospheric temperature and magnetic field structure during flares and CMEs.



Legacy solar-cycle monitoring database and access to global/magnetic context



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Leader: Sven Wedemeyer



SCIENTIFIC QUESTION

- What is the true D/H distribution in cometary water across dynamical populations?
- What fraction of Earth's water was delivered by comets versus processed disk material?

WHY ATLAST

ALMA	✗	Resolves out flux in extended cometary comae (>100"). Prohibitive for survey of 30 comets.
IRAM-30m	✗	No Band 10 (HDO 894 GHz). Sensitivity insufficient for statistical sample.
APEX	✗	12 m aperture — integration times far exceed feasibility for faint HDO lines.
AtLAST	✓	Fixed aperture, non-sidereal tracking, Band 5/8/10 simultaneous. $Q(\text{H}_2\text{O})=10^{28}$ mol/s in ~6 hr.

OBSERVATIONAL OBJECTIVE

- Quasi-simultaneous detections of HDO (465, 894 GHz) and H₂O (183 GHz) in ~30 comets over 6 years
- D₂O (404 GHz) for strong outgassers
- Spatial mapping across ~100" coma diameter.

First statistically robust D/H survey across all cometary dynamical populations

ISM vs disk ice constraints

First ground-based D₂O survey





SCIENTIFIC QUESTION

- What are the density/velocity structures of prestellar cores at 100–1000 au scales?
- What governs ionisation fraction and lifetime?
- How does environment modulate deuteration and collapse timescales?

WHY ATLAST

ALMA + ACA	✗	Filters all large-scale flux (>few arcsec). Cannot recover envelope up to 10,000 AU
IRAM-30m	✗	Resolves some cores but lacks Band 9 access and frequency coverage for multi-ion survey
APEX	✗	Adequate for Band 9 continuum but coarse resolution — cannot resolve core structure
AtLAST	✓	Resolves core structure (<1000 AU) at all target frequencies while recovering halos to 10,000 AU

OBSERVATIONAL OBJECTIVE

- Map ground-state transitions: oH_2D^+ (372 GHz), pD_2H^+ (692 GHz)
- Map high-J transitions: N_2H^+ , N_2D^+ (Bands 3,4,6-9)
- ~50 prestellar/starless cores
- Maps of $4' \times 4'$ per source with sensitivity 10 mK and spectral resolution ≤ 0.05 km/s. Multi-beam heterodyne.

First comprehensive ionisation fraction and deuteration survey of prestellar cores at 100–1000 AU





SCIENTIFIC QUESTION

- How do low-metallicity conditions affect molecular cloud lifecycles, SF efficiency, XCO calibration, and CO-dark gas fraction?
- How do large-scale gas flows regulate star formation?

WHY ATLAST

NANTEN	✗	2.6' beam — cannot resolve individual molecular clouds (~2–3 pc at LMC/SMC distance)
ALMA	✗	Filters extended emission. No wide-field mapping capability for 8°×8.5° contiguous survey
APEX	✗	Patchy, non-public data. 12 m beam too coarse at sub-mm for individual cloud resolution
AtLAST	✓	10" beam → 2.4–3 pc at LMC/SMC. Outside vantage avoids MW confusion. Contiguous 8°×8.5° maps

OBSERVATIONAL OBJECTIVE

Full contiguous spectroscopic survey of LMC + SMC + Magellanic Bridge

- in CO J=1-0→8-7, ^{13}CO , C^{18}O , [C I] 370/609 μm
- multi-band continuum for dust-to-gas ratio mapping

First pc-scale molecular inventory of the entire Magellanic system at sub-solar metallicity





SCIENTIFIC QUESTION

- What are the multi-scale physical conditions (density, T , kinematics) of the molecular ISM across the Galactic plane?
- How does ISM structure regulate star formation globally?

WHY ATLAST

IRAM-30m	✗	x8 longer integration/pixel for same sensitivity. 540 deg ² in ~8 years — not feasible
ALMA-ACA	✗	x10 longer/pixel. No single-pointing survey mode across hundreds of deg ²
APEX	✗	12 m sensitivity too low. 540 deg ² survey would take decades
AtLAST	✓	10 ³ -pixel heterodyne array (B7). 540 deg ² in ~1 year at ≤ 0.1 K

OBSERVATIONAL OBJECTIVE

- Wide-area spectral survey of ≥ 540 deg² in Bands 3, 6, 7 (CO + isotopologues, dense gas tracers)
 - ▶ Analogous to Hi-GAL + ATLASGAL, but higher sensitivity and angular resolution
- 60 kHz spectral resolution, 0.1 K sensitivity

First sub-0.1 K molecular line atlas of the Galactic plane across 540 deg²





SCIENTIFIC QUESTION

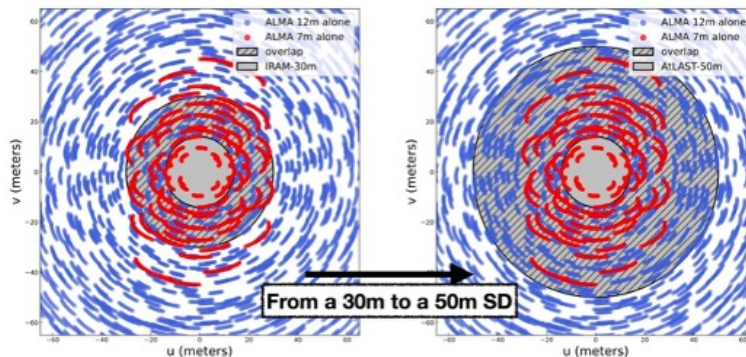
- How severely does interferometric spatial filtering distort molecular line spectra, flux recovery, and kinematic interpretation?
- How does the effect scale with frequency, source morphology, and ALMA configuration?

WHY ATLAST

IRAM-30m	✗	×2.8 less collecting area. No access to Band 8–10 frequencies
ALMA ACA-TP	✗	Poor image quality at Bands 8–10. Systematic missing flux even in compact configurations
APEX	✗	12 m — ×3.2 less collecting area than AtLAST. Sensitivity inadequate for high-frequency TP
AtLAST	✓	Larger collecting area. Covers all ALMA bands including 8–10 where no alternative exists

OBSERVATIONAL OBJECTIVE

- Systematic simulations + observations: quantify ALMA filtering effects configurations and source types
- AtLAST + ALMA 12m arrays at >350 GHz (ACA+TP is inadequate)



Bononomi et al 2024

No adequate current single-dish solution at these frequencies





SCIENTIFIC QUESTION

- What are the physical and chemical impacts of SNR shocks, CRs, and energetic photons on the ISM?
- Does triggered star formation near SNRs differ from quiescent regions?
- What is the CR distribution (e^- vs nuclei) responsible for γ -ray emission?

WHY ATLAST

IRAM-30m	✗	~20" beam — insufficient resolution to match γ -ray PSF ($\sim 0.1^\circ$) for CR mapping
ALMA	✗	FoV far too small for objects subtending $\sim 1 \text{ deg}^2$. Cannot map entire SNR extents
APEX	✗	12 m — sensitivity insufficient for large-area spectral mapping of evolved SNRs
AtLAST	✓	10" resolution over full SNR extent ($\sim 1 \text{ deg}^2$) in all bands. Unique CR property maps for CTA

OBSERVATIONAL OBJECTIVE

Multi-band mapping of 4 evolved Galactic SNRs in:

- CO J=1–3, isotopologues
- SiO (shocks)
- RRLs (photoionization)
- C I (atomic phase)
- dust continuum at 345/870 μm .

Full-extent CR distribution maps of Galactic SNRs and direct benchmark for CTA γ -ray science





SCIENTIFIC QUESTION

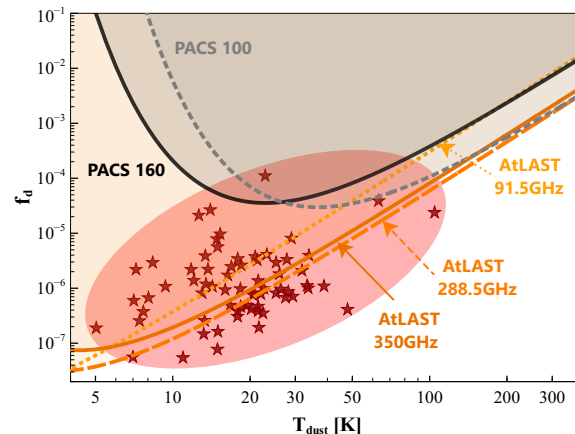
- Are Kuiper belt-like discs (fractional luminosity $\sim 5 \times 10^{-7}$) common around nearby main-sequence stars?
- How do disc properties (mass, morphology, spectral slope) correlate with stellar type and planetary architecture?
- What is the collisional evolution history of planetesimal belts in the Solar neighbourhood?

WHY ATLAST

JCMT	✗	Confusion limit too high to reach Kuiper belt dust levels. $2 \times$ confusion noise at $850 \mu\text{m}$
ALMA	✗	Filters large-scale emission from nearby discs extending $> \text{arcsec}$. Needs prior single-dish detection
Herschel	✗	Decommissioned. FIR only — sub-mm sensitivity insufficient. Confusion-limited at longer wavelengths
AtLAST	✓	50 m lowers confusion limit to Kuiper belt levels. Recovers all extended flux. $860 \mu\text{m}$ in ~ 1 hr per star

OBSERVATIONAL OBJECTIVE

- ~ 500 nearby main-sequence stars
- Unbiased sub-mm continuum survey at Bands 7, 8, 10
- Map size $\sim 2''/\text{target}$, Angular resolution $2\text{--}4''$, sensitivity of $140 \mu\text{Jy}/\text{beam}$ (B7)
- Use multi-band KID/TES continuum camera
- Temporal resolution few s for stellar flare mitigation



First detection of Kuiper belt-level debris discs around nearby main-sequence stars

SCIENTIFIC QUESTION

- What mechanisms drive mass-loss in evolved stars?
- How do magnetic fields launch and collimate stellar winds and protostellar jets?
- What is the pumping physics of high-frequency SiO, H₂O, and CH₃OH masers?

WHY ATLAST

ALMA	X	Cannot execute degree-scale time-domain surveys. No wide-field mapping of maser populations
APEX/JCMT	X	Lack sensitivity and FoV for a Galactic-scale census at sub-mm frequencies
IRAM-30m	X	Limited frequency coverage. No capability for degree-scale polarimetric maser surveys
AtLAST	✓	Large area, 0.3–10 mm, multi-beam, full-Stokes — no other facility matches

OBSERVATIONAL OBJECTIVE

- Wide-area Galactic plane maser surveys in SiO (>215 GHz), H₂O (183, 321, 325 GHz), CH₃OH (>350 GHz)
- Monthly monitoring ~200 evolved stars + massive YSOs
- Full-Stokes polarimetry
- Sensitivity sub-mJy / < 0.1 km/s channel

First Galactic-scale census of mm/sub-mm masers with full-Stokes polarimetry





SCIENTIFIC QUESTION

- What resolves the 'missing mass' problem in pPN/PN evolution?
- How do ionized jets form and evolve?
- What tracers probe rotating circumbinary disks?
- Where does the PDR boundary lie?

WHY ATLAST

ALMA/NOEMA	✗	Resolves compact structures but filters halos. Cannot recover diffuse mass at arcmin scales
IRAM-30m	✗	No Band 8/10 access — C I lines at 492 and 809 GHz completely inaccessible
APEX	✗	12 m — mmRRL/salt detection infeasible in survey mode. No Band 10
AtLAST	✓	~1–2 mJy/channel sensitivity. Bands 5/7/8/10. Recovers halos on degree scales. Southern targets

OBSERVATIONAL OBJECTIVE

- Point-source survey of 30 compact pPNe: mm-RRLs H22 α –H33 α , salts NaCl/KCl, C I (B7–8,10)
 - Spectral resolution 0.5–2 km/s
- OTF maps of 20 extended nebulae (AGB/pPN/PN) in CO isotopologues (B3,6,7), HCO⁺/HCN/HNC/CN, C I
 - Up to 625 arcmin²

Resolution of the missing mass problem and first detection of PDR boundary in AGB/pPN envelopes

Dedicated talk



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Leader: Teresa Huertas-Roldán



SCIENTIFIC QUESTION

- Can the building blocks of life be synthesized in the ISM?
- Was the proto-solar nebula enriched in COM material by the interaction of a SNR?
- Do prebiotic COMs form in low-metallicity environments and in external galaxies?
- Do the formation and inheritance processes of COMs link the chemical composition of the proto-solar nebula with planetesimals and cometesimals?

WHY ATLAST

LMT / SRT	✗	Do not cover 30–50 GHz — the 'sweet spot' where large prebiotic COMs are brightest
ALMA	✗	Filters parsec-scale extended emission. Confirmed flux loss even with Band 1 data
Yebes-40m	✗	Has 30–50 GHz but has not reached confusion limit. 40 m limits sensitivity
AtLAST	✓	Only facility covering 30–50 GHz + multi-window simultaneous + FoV $\sim 2^\circ$ for full CMZ

OBSERVATIONAL OBJECTIVE

- Targets: G+0.693 (GC), SNR-impacted SFRs (W44, SHREC catalogue), LMC, SMC and external galaxies
- Ultra-sensitive broadband spectral surveys at 30–50 GHz + simultaneous 7/3/2/1 mm (Bands 1/3/5/7) Sensitivity ~ 1 mJy/beam within $\Delta v \sim 0.2$ km/s
- FoV $\sim 2^\circ$ — covers the full CMZ
- Multi-beam wide-bandwidth HET

First detection of nucleobases, sugars and amino acid precursors in the ISM and external galaxies

 Dedicated talk



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Leader: Izaskun Jiménez-Serra





SCIENTIFIC QUESTION

- What is the 3D geometry and strength of magnetic fields at cloud-to-core scales?
- What role does ambipolar diffusion play in filament collapse?
- Can mass-to-flux ratio gradients be measured from core envelopes to centers?

WHY ATLAST

JCMT/POL-2	X	10–15" resolution — cannot resolve filaments and cores in nearby clouds
SOFIA/HAWC+	X	Limited dynamic range and FoV. Decommissioned — no ongoing access
ALMA	X	Probes only <1" fields. Filters large-scale polarized emission entirely
AtLAST	✓	Large FoV (tens–hundreds arcmin ²) + arcsec resolution + ~0.1% polarization sensitivity

OBSERVATIONAL OBJECTIVE

- Goldreich-Kylafis effect tomography in CO(1-0)/CS(2-1) toward GC
- CO linear polarization in striation regions
- Zeeman effect in CN(1-0) toward prestellar cores
- Collisional polarization of HCO⁺ multi-J to trace ambipolar diffusion
- Maps of arcmin² - deg², spectral resolution 0.05–0.3 km/s and full Stokes I,Q,U,V

First tomographic 3D mapping of magnetic field geometry from cloud to core scales





SCIENTIFIC QUESTION

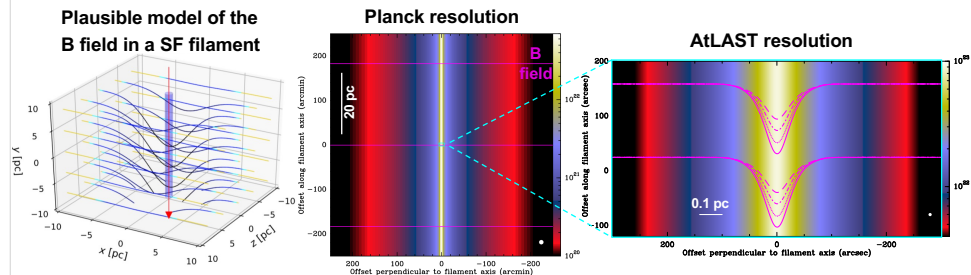
- How do magnetic fields regulate filament formation, fragmentation into prestellar cores, and disk growth via accretion streamers?
- Can partial tomographic 3D B-field reconstructions be achieved across molecular clouds?

WHY ATLAST

Planck	X	5–10' resolution — two orders of magnitude coarser than filament scales
JCMT/POL-2	X	10–15" resolution, limited dynamic range, insensitive to extended cloud emission
ALMA	X	Probes <1" fields only — no extended emission recovery, no cloud-scale coverage
AtLAST	✓	1.5–6" resolution, wide FoV, 6 simultaneous bands (350–1150 μm) for depth tomography

OBSERVATIONAL OBJECTIVE

- All $A_V > 3.5$ regions in nearby ($d < 3$ kpc) molecular clouds
- Multi-band continuum polarimetric survey in 6 simultaneous bands
- Stokes I, Q, U
 - ▶ Reference case: Taurus ~ 2 deg² in ~ 200 hr
- Angular resolution 1.5–6", sensitivity 0.5–70 MJy/sr



Partial 3D B-field tomography of nearby molecular clouds via 6-band simultaneous dust polarimetry

