MASS MASTER IN ASTROPHYSICS AND SPACE SCIENCE

Characterizing the Large-scale Recovery Capabilities of Atacama Large Aperture Submillimeter Telescope (AtLAST)

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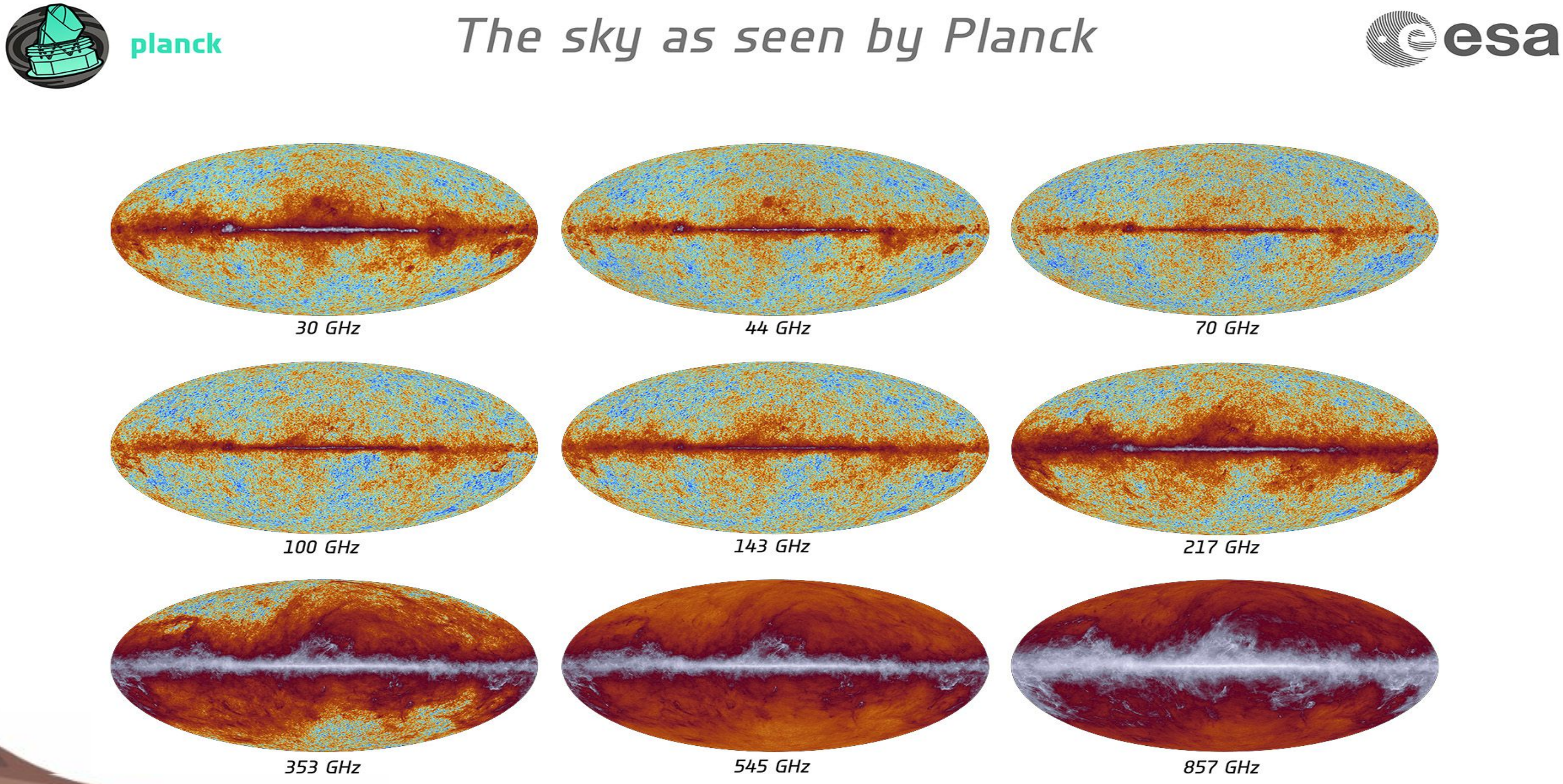
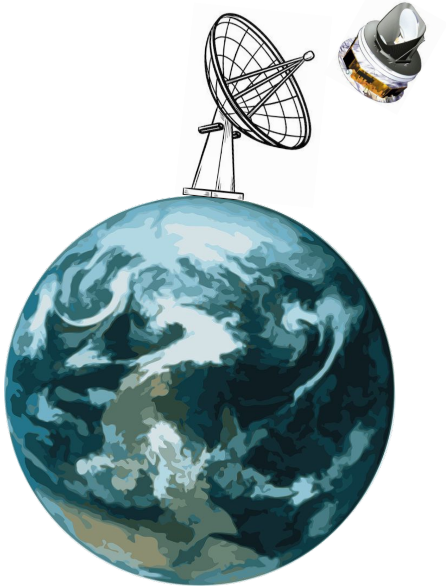
credit: www.atlast.uio.no

Unveiling the (Sub)-Millimeter Sky



➡ Why Need a Single Dish ?

30m telescope - IRAM



Large Single Dish

- Enhances sensitivity to fainter extended emission
- Maximizes sky coverage in a short time

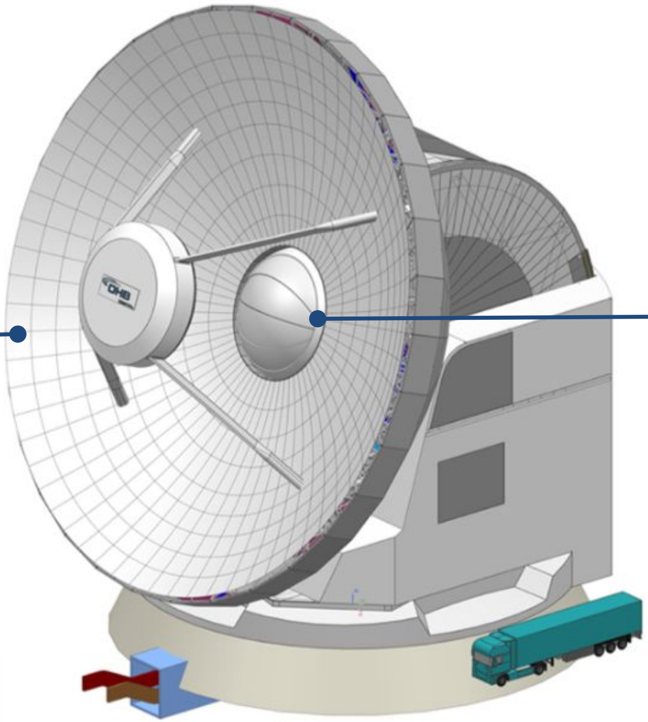
➡ Exploring (Sub)mm Universe with AtLAST

Atacama **L**arge **A**perture
Submillimeter **T**elescope

Site: Chajnantor Plateau

Klaassen et al. 2020

Dish diameter: 50 m



Field of View : 1° - 2°

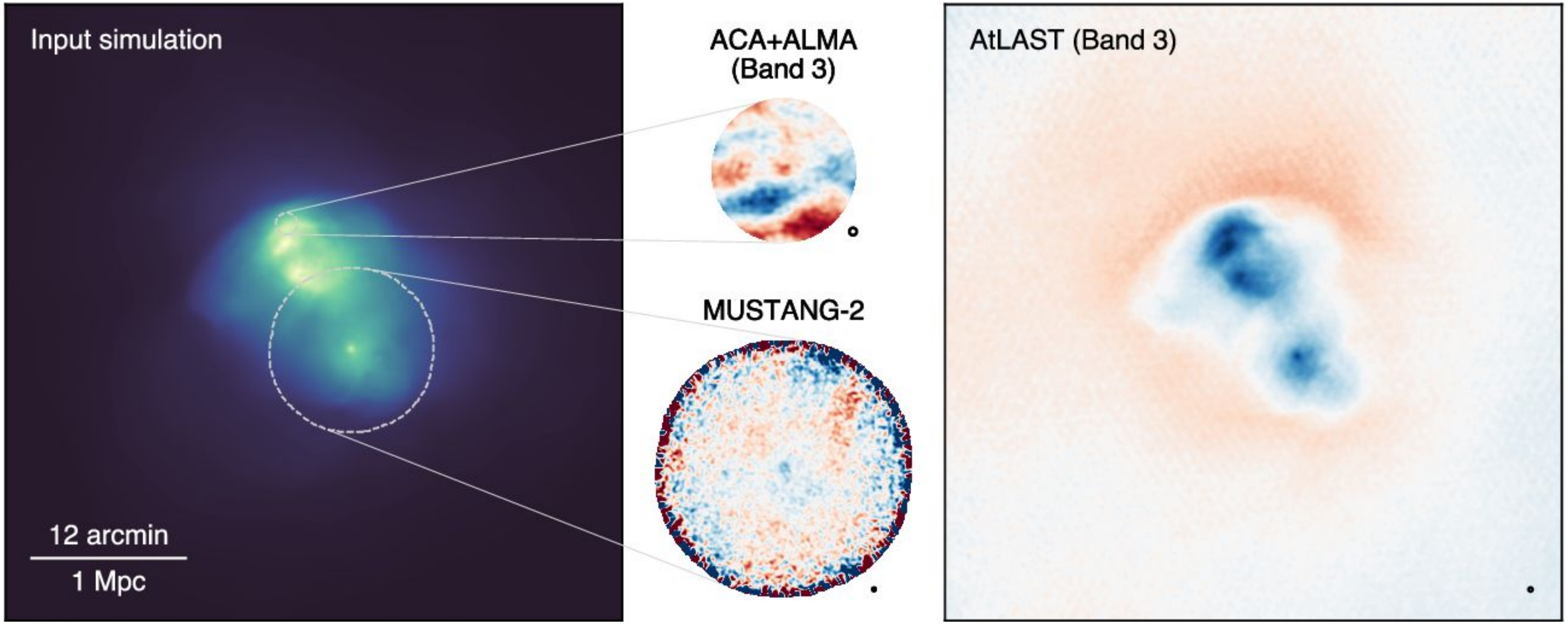
Fast Scanning Speed !

~ 3°/s

Mroczkowski et al. 2025

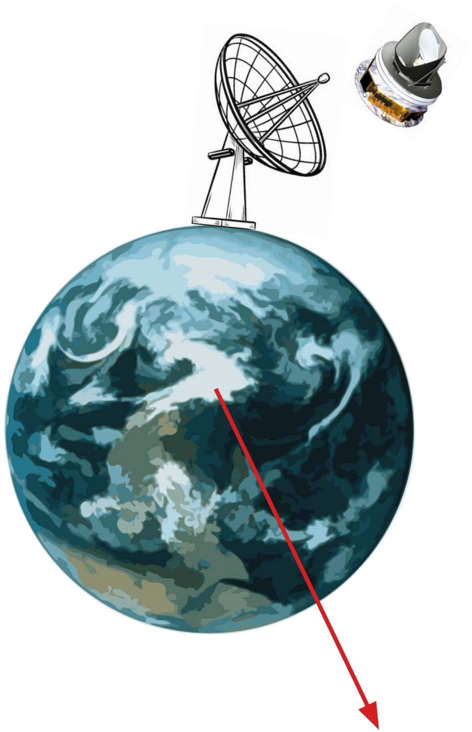
AtLAST CAD model (Mroczkowski et al. 2025)

➡ Key Observational Advantage of AtLAST



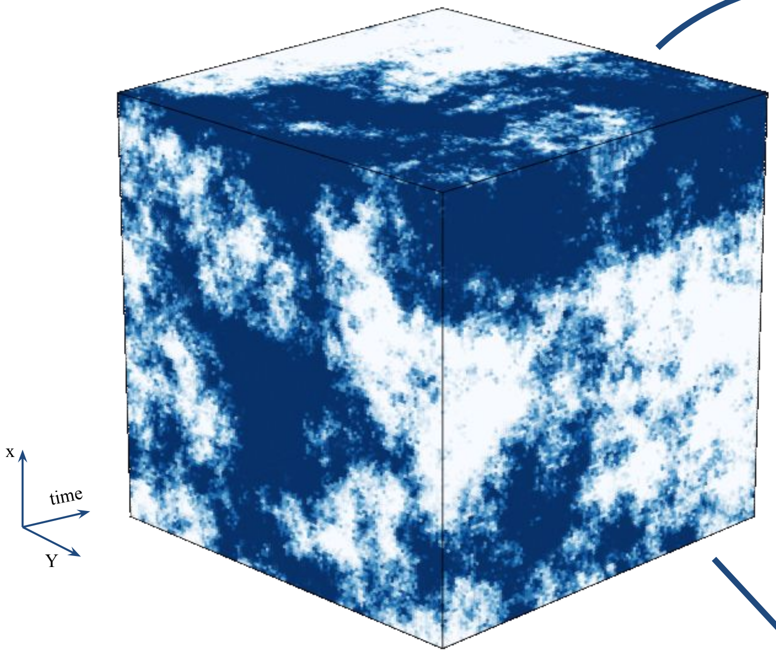
Di Mascolo et al. 2025

➡ Main Challenge for Ground-based Observations:

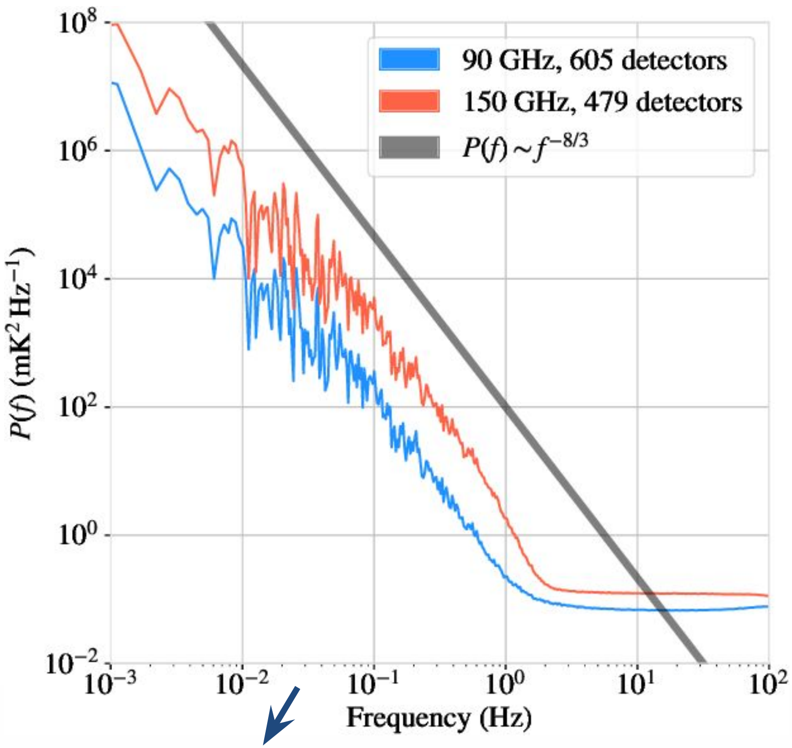


Earth's Atmosphere !

➡ Atmospheric Fluctuations in Ground-Based (Sub)mm Observations



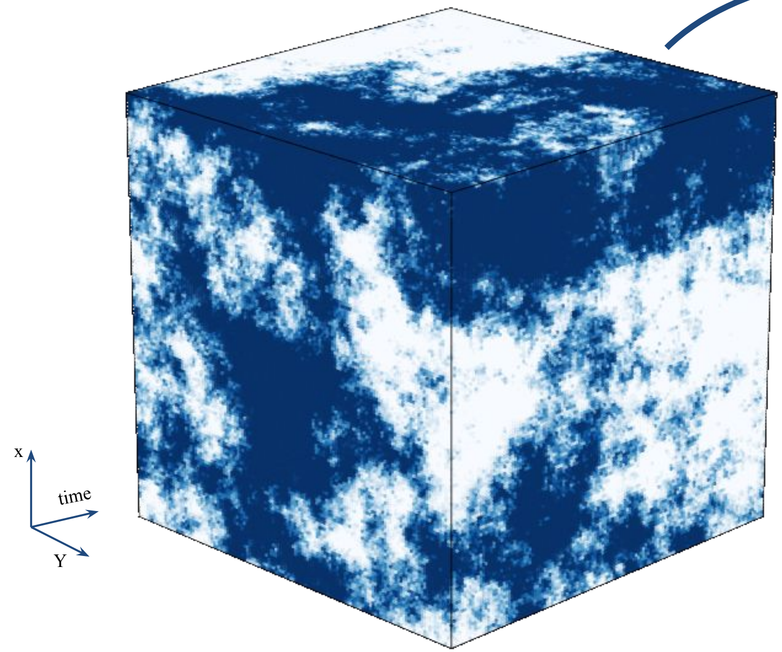
credit: https://thomaswmorris.com/maria



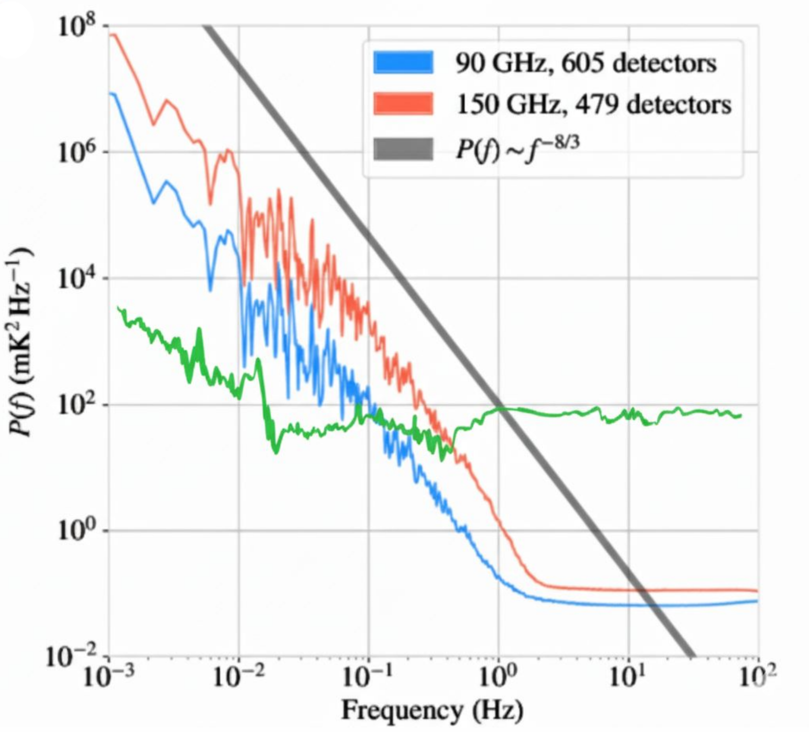
Large-Scale turbulence evolves slower than small-scale turbulence.

Morris et al. 2022

➡ Atmospheric Fluctuations in Ground-Based (Sub)mm Observations



credit: https://thomaswmorris.com/maria

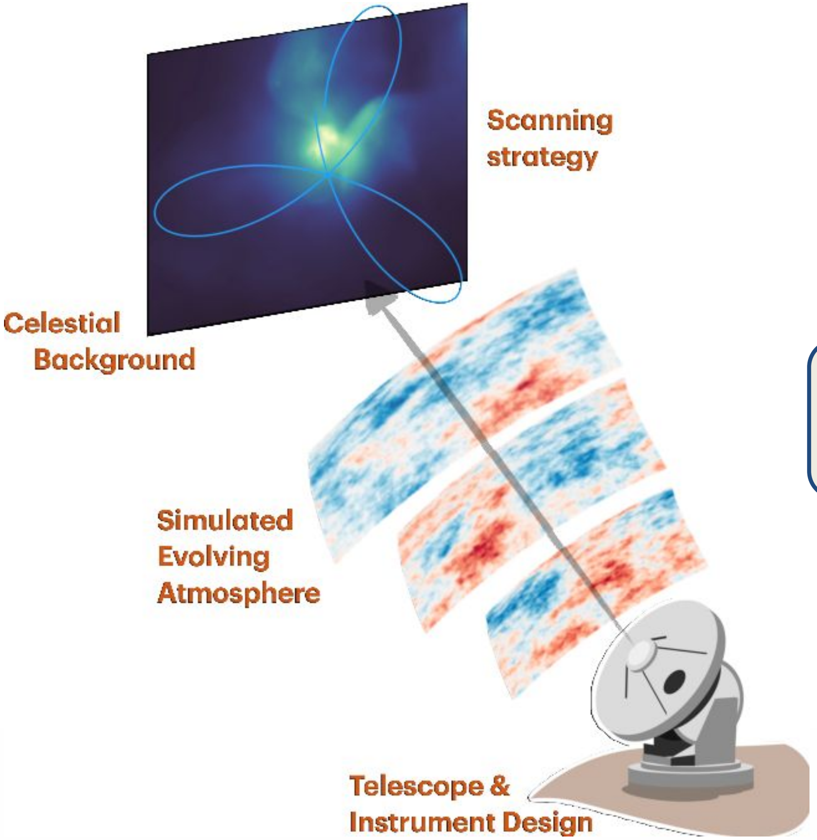


Morris et al. 2022

➡ Motivation: Large-Scale Recovery

- Exploring the ability of such a large aperture single dish telescope to recover extended diffuse emissions under realistic observing conditions.

- Characterizing the impact of different scanning strategies on the telescope's performance in large-scale recovery.



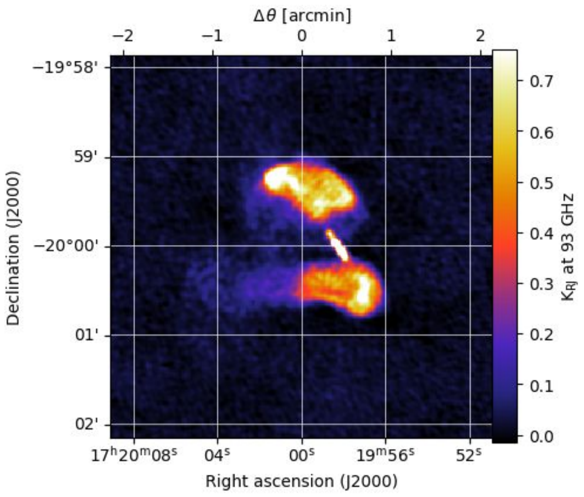
van Marrewijk et al. 2024

maria
A multipurpose virtual telescope simulator

Van Marrewijk et al. 2024

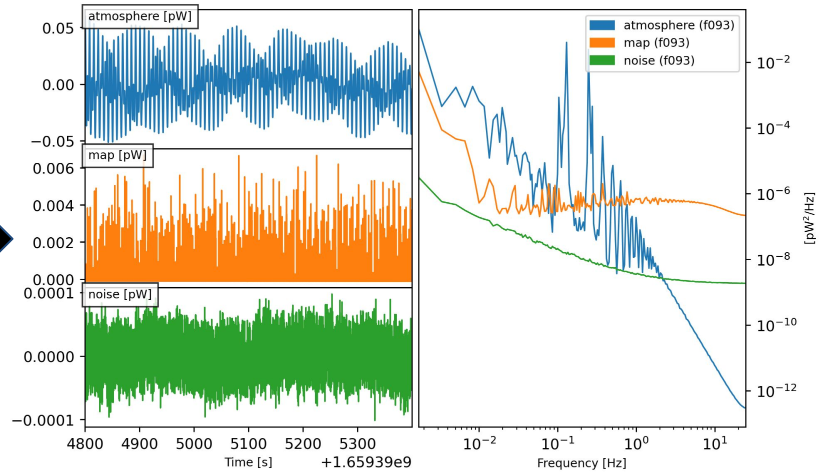
➡ Approach: Generating TOD and Output map with maria

Input map

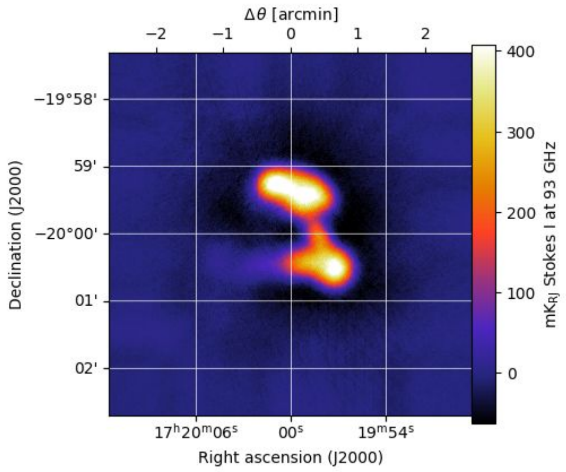


Radio Galaxy 3C288 at z = 0.246
(Bridle et al. 1989)

TOD & Power spectra



Output map

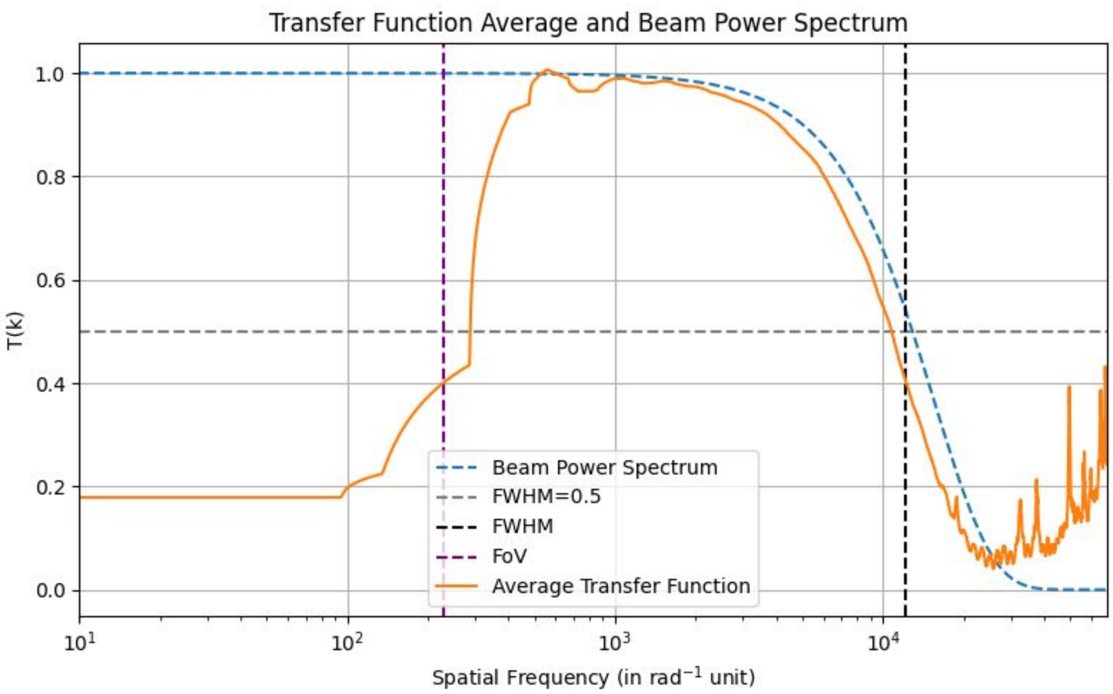


➡ Analysis: Transfer Function Estimation

Transfer function averaged over atmospheric realizations:

$$\overline{T} = \frac{1}{N}\sum_{k=1}^{N}\sqrt{\frac{PS_{\text{output}}(k)}{PS_{\text{input}}(k)}}$$

- ➔ $PS_{output}(k)$ and $PS_{input}(k)$ are the 1D power spectra of the output and input maps respectively
- ➔ N is the number of atmospheric realizations



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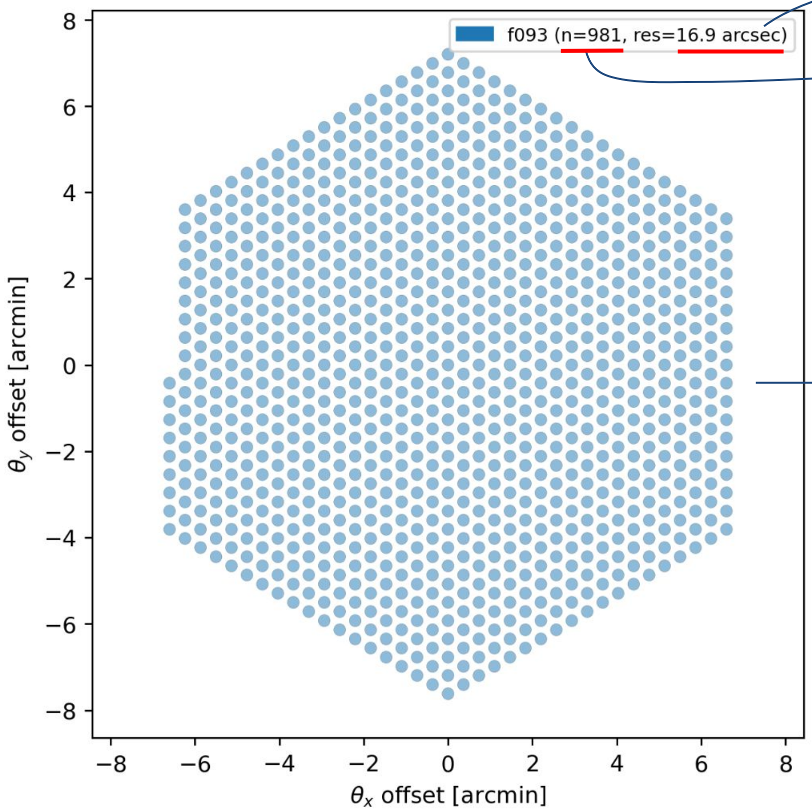
➡ Array Configuration of AtLAST-like Telescope

- **Observation:**
  - Observing frequency: **93 GHz**
  - Frequency bandwidth: **53 GHz**

Primary Dish Diameter: **50 m**



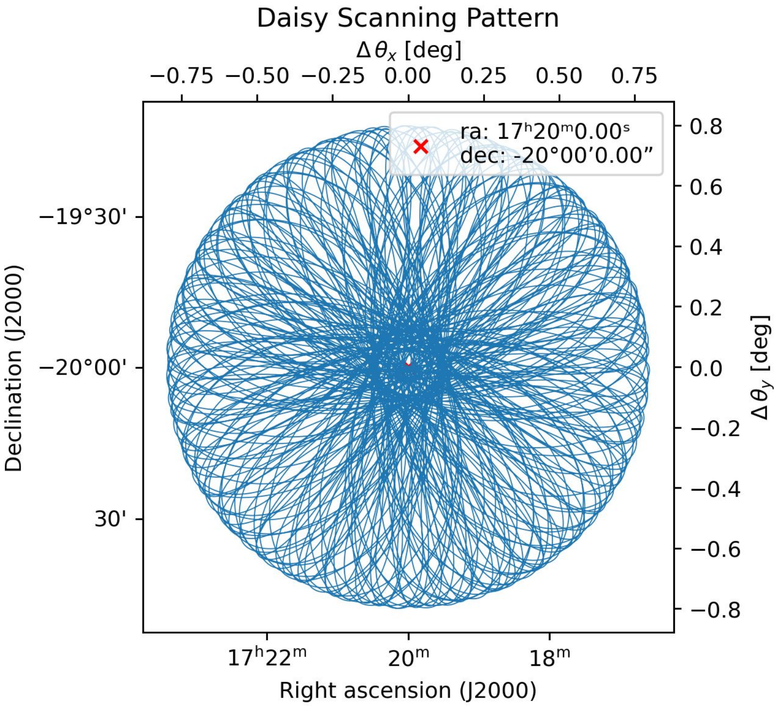
Beam Resolution

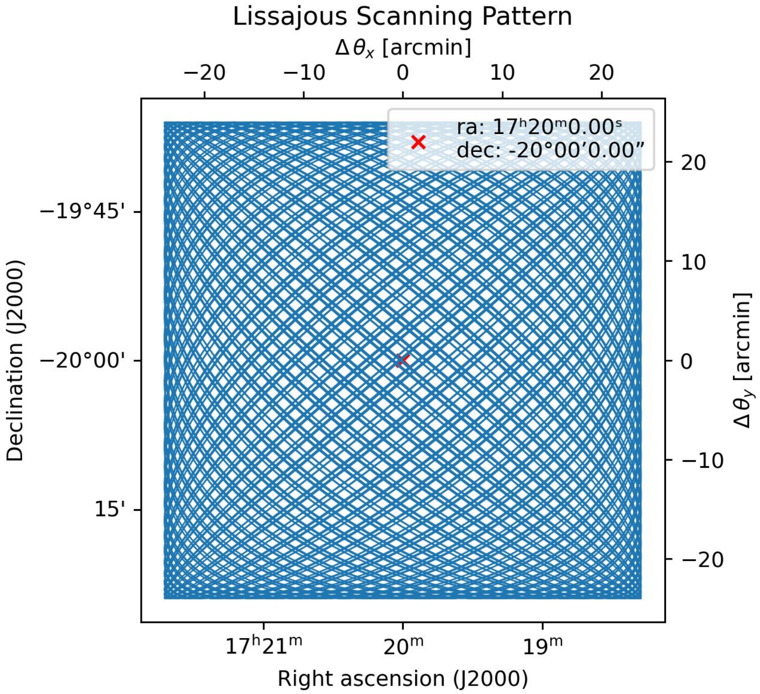
No. of Detectors

Detector spacing: **1.5f - λ**

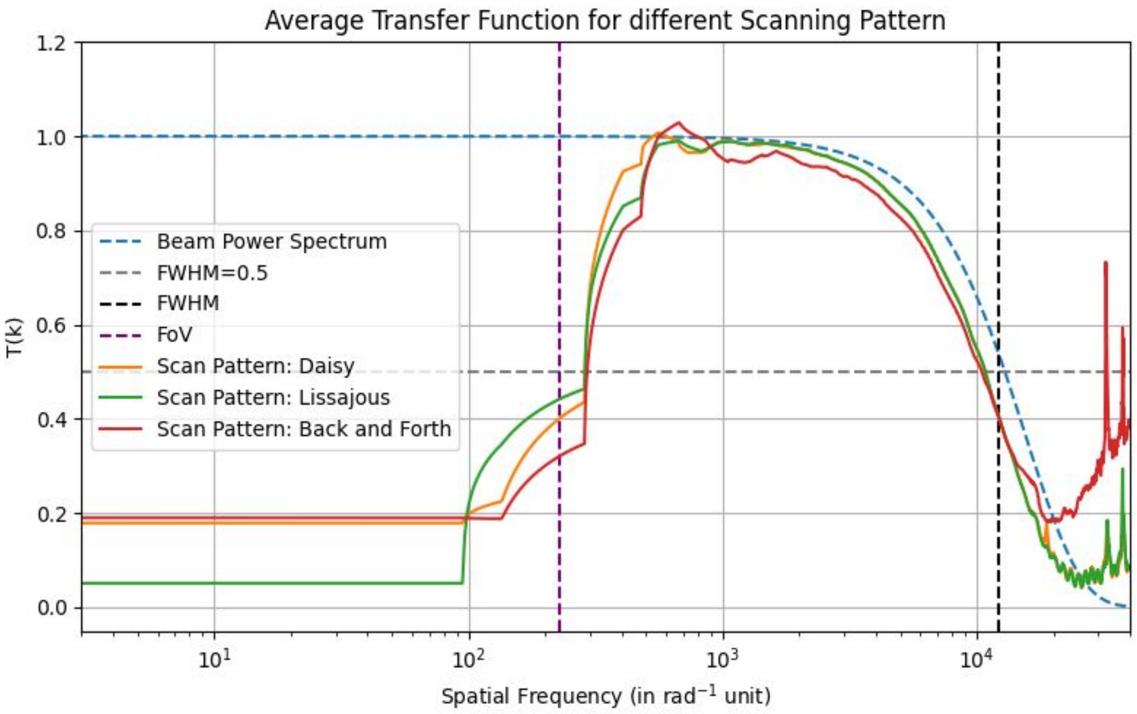
Field of view (FoV): **0.25°**

➡ How Single-Dish Scans the Sky ?



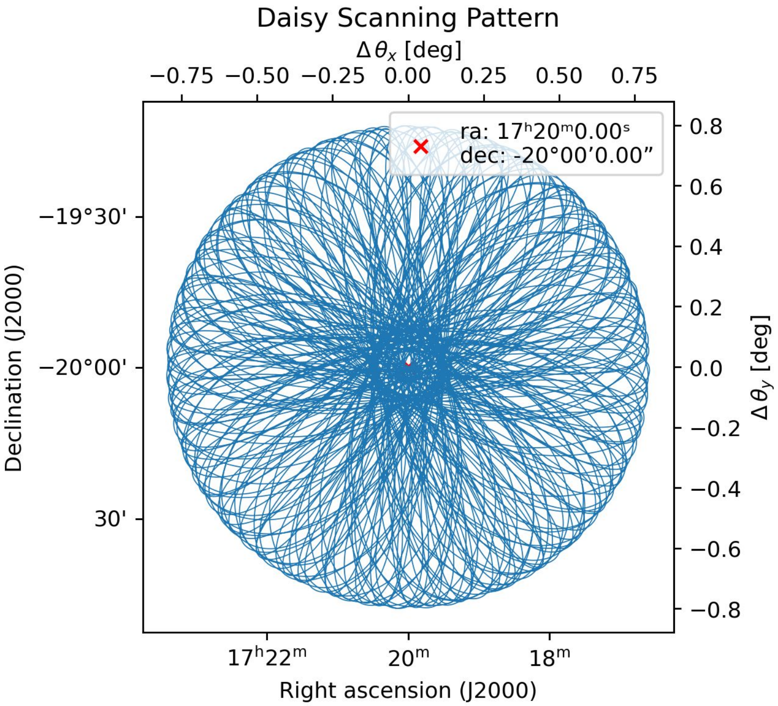


➡ Result: Dependence on Scanning Pattern



- **Minor difference** in corresponding **transfer functions** among these scanning patterns.

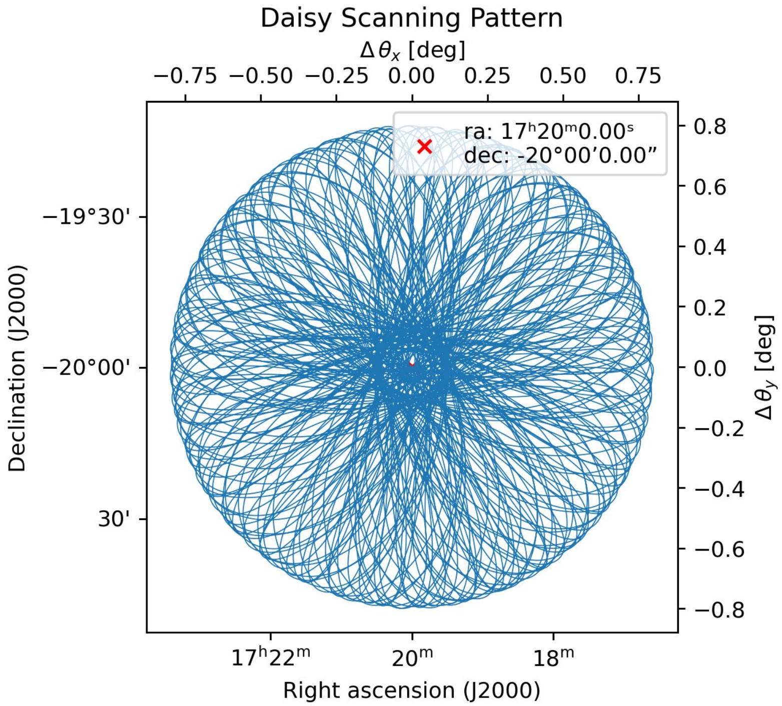
➡ Parameters Defining the Scan Strategy



➔ **Scanning parameters:**

- Radius
- Speed
- Pattern
- Scan time
- Sampling Rate

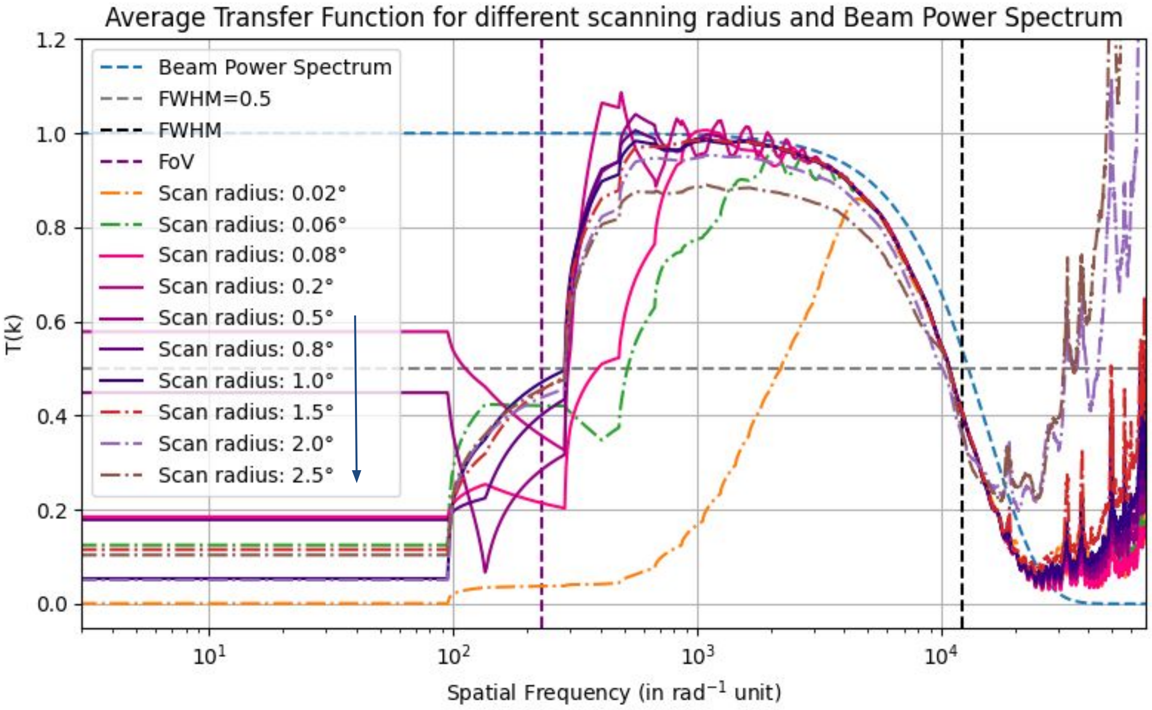
➡ Parameters Defining the Scan Strategy



➔ **Scanning parameters:**

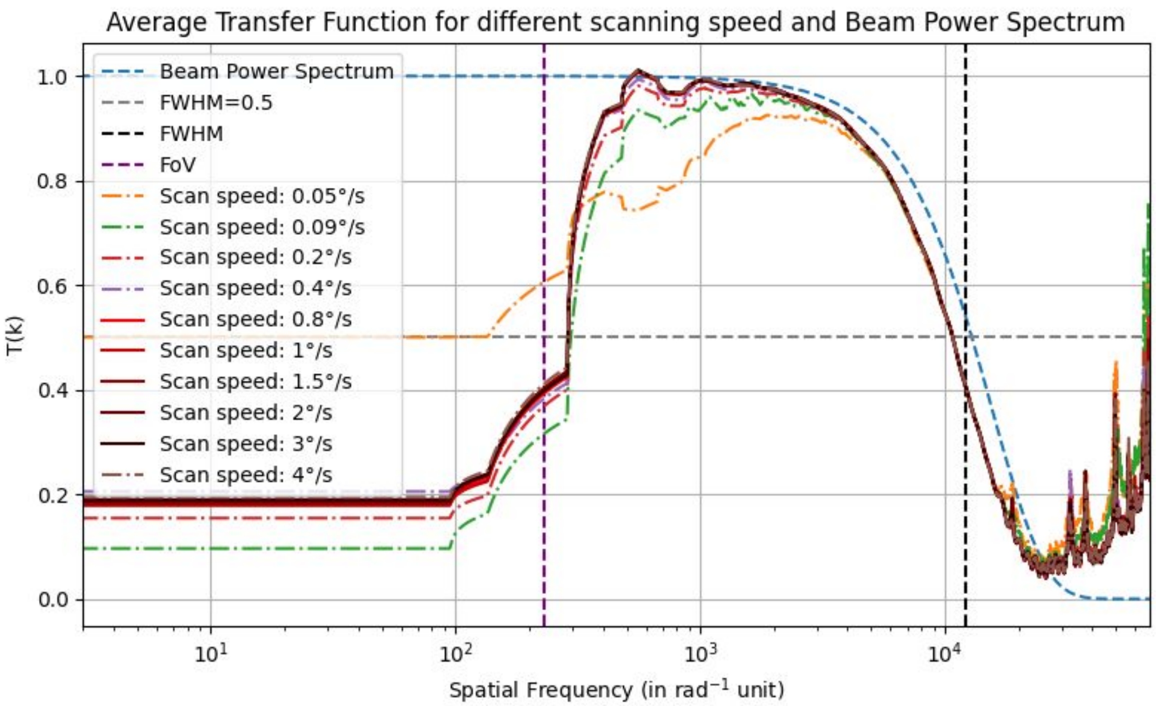
- **Radius** (0.02° - 2.5°)
- **Speed** (0.05° s^{-1} - 4° s^{-1})
- Pattern : **Daisy**
- Scan time : **10 minutes**
- Sampling Rate : **50 Hz**

➡ Result: Dependence on Scanning Radius



- At scanning radius ≥ 0.5° (= 2xFoV), the corresponding transfer functions ~ 1
- Below 0.08°, large-scale modes are filter-out.

➡ Result: Dependence on Scanning Speed



- At scanning speed $\geq\ 0.8°s^{-1}$, the corresponding transfer functions ~ 1
- Below $0.09°s^{-1}$, large-scale modes are attenuated.

➡ Conclusion & Future Work

- Simulated an **AtLAST-like configuration** to scan the mock sky under realistic observing conditions and therefore reconstructed the sky signal.

- Characterized the telescope performance in **recovering large-scale signal** in (sub)mm regime through transfer function.

- Analysed how the choice of the **observing parameters** i.e. **scan radius**, **scan speed** and **scan pattern** can influence **recovery of fainter extended emission.**

- A potential future extension is to incorporate **full 2° FoV (currently considered 0.25°), multichroic detectors** and **polarization** maps**.**

- The need for a substantial storage capacity and high-performance computing resources to **reduce the computational time** and support **complex analysis.**

- A quantitative characterization of the **dependence on detector spacing** for a large focal plane array is required for achieving an instantaneous Nyquist sampling.

APPENDIX

➡ Atmospheric Fluctuations at (Sub)mm Wavelengths

Atmospheric Fluctuations (Errard et al. 2015) depend on:

- Wind
- Water vapor
- Turbulence
- Temperature

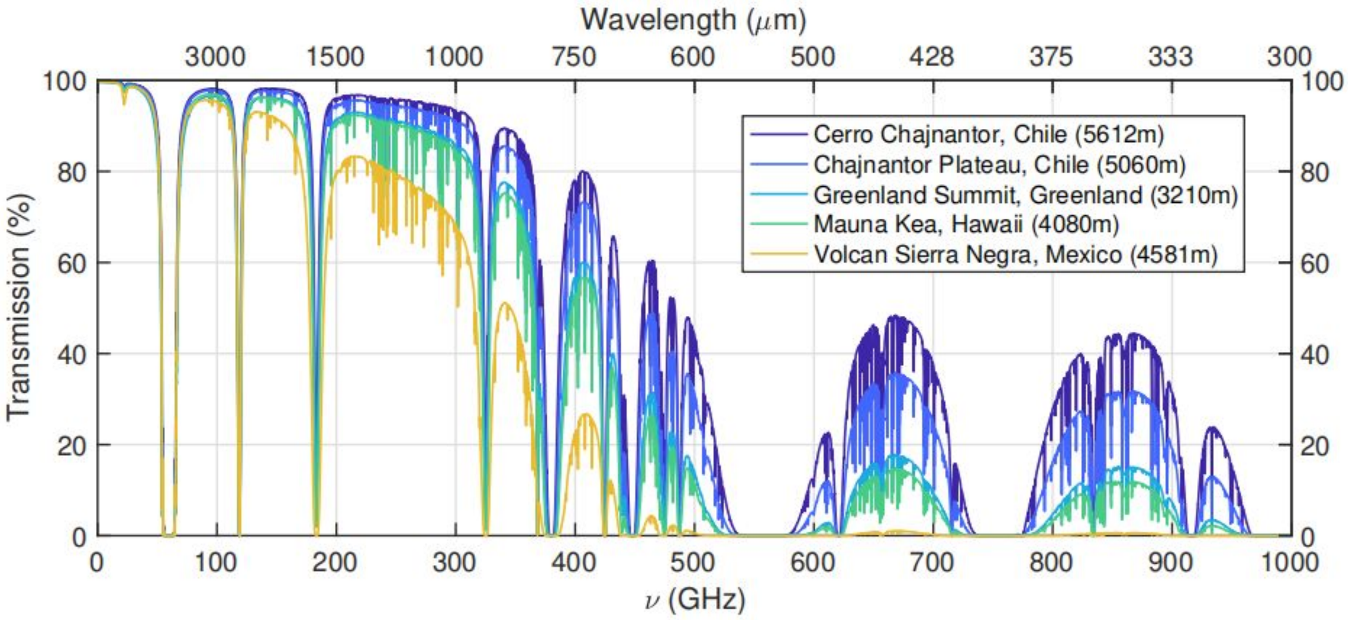
⇨ **Kolmogorov-Taylor Frozen turbulence hypothesis:**
(Kolmogorov, 1941; Taylor, 1938; Morris et al., 2025)

Power spectrum associated with atmospheric fluctuation ← $$P(f) \propto f^{-8/3}$$ → **Temporal frequency**

➢ Lower-frequency atmospheric fluctuations contaminate large-scale (sub)mm signals observed by ground-based observatories

➢ This limitation leads to the requirement of advanced observational strategies to recover large-scale astronomical signals

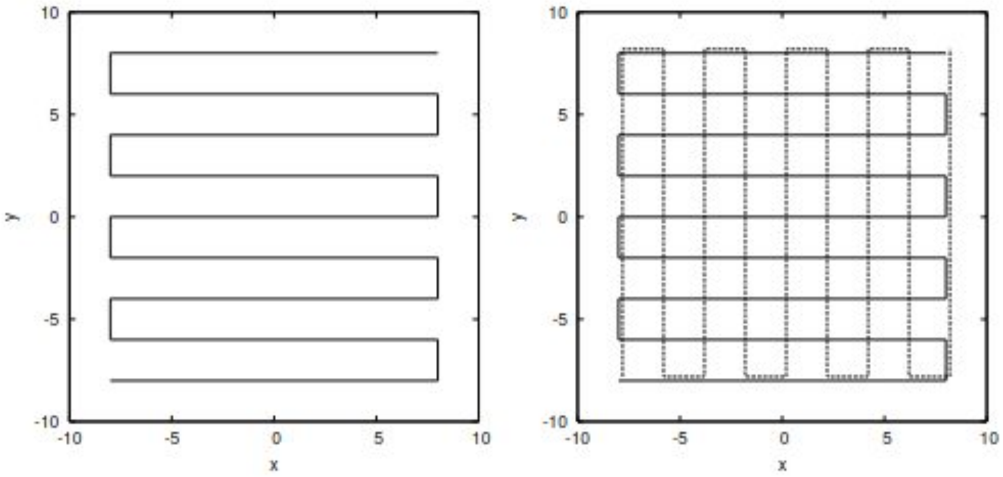
➡ AtLAST's Site on Llano de Chajnantor Plateau in Atacama:

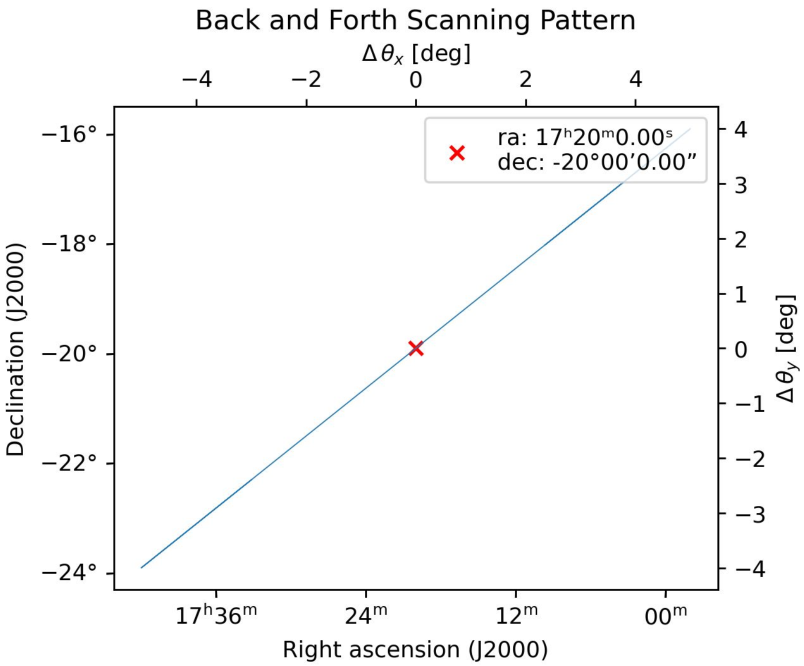


Atmospheric transmission at several world-class sites for (sub)mm survey

(Klaassen et al. 2020)

➡ How Single-Dish Scans the Sky ?





➡ **How Single-Dish Scans the Sky : Daisy Scan**

$$\vec{x}_{\text{outer}} = r_{\text{outer}} \sin(\phi_{\text{outer}}) \exp\left(i \frac{\phi_{\text{outer}}}{n_{\text{petals}}}\right),$$

$$\vec{x}_{\text{inner}} = r_{\text{inner}} \sin\left(\phi_{\text{outer}} + \frac{\pi}{2}\right) \exp\left(i \frac{\phi_{\text{inner}}}{n_{\text{petals}}}\right),$$

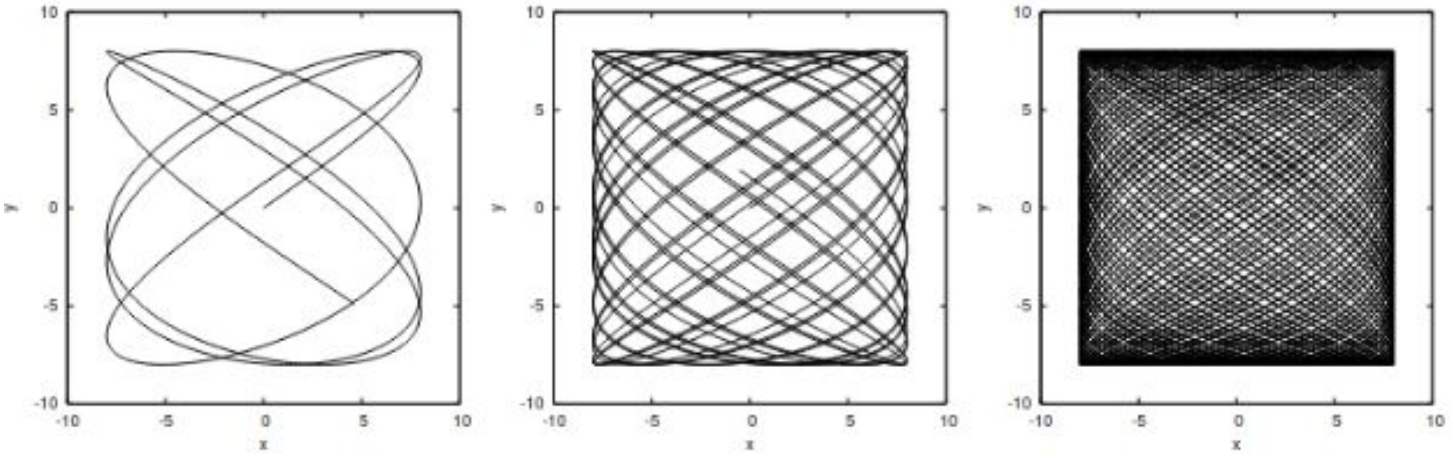
$$\vec{x}_{\text{scan}} = \vec{x}_{\text{outer}} + \vec{x}_{\text{inner}},$$

$$\text{RA, Dec} = \text{Re}[\vec{x}_{\text{scan}}],\ \text{Im}[\vec{x}_{\text{scan}}],$$

- $r_{inner} = 0.15\ r_{outer}$
- $\phi_{inner} = \sqrt{2}\ \phi_{outer}$
- $n_{petals} = 10/\pi$

van Marrewijk et al. (2024)

➡ How Single-Dish Scans the Sky : Lissajous Scan



Kovacs 2008

➡ Maximum Recoverable Scale (MRS)

$$\theta_{\mathrm{MRS}} = \kappa \frac{\lambda}{L_{\mathrm{min}}}$$

$$D_{\mathrm{SD}} \geq \frac{1.18 L_{\mathrm{min}}}{\kappa}$$

Minimum Baseline

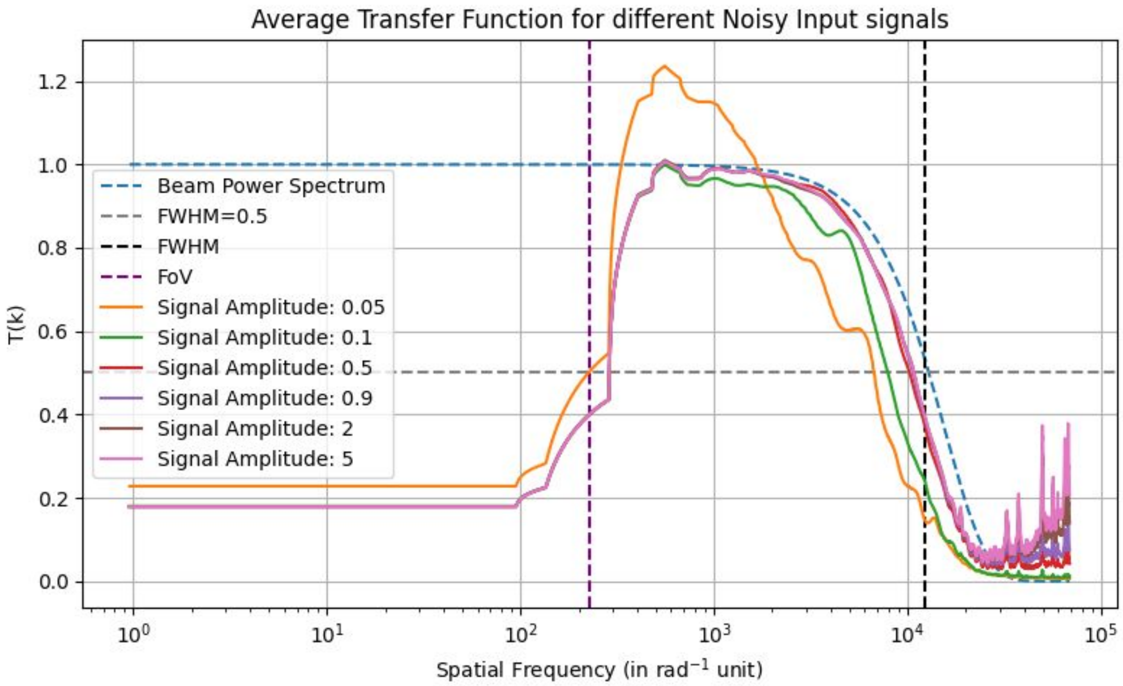
Frayer (2017)

➡ AtLAST Parameters

Parameter	Value
Wavelength (λ) range	0.3–10 mm
Primary mirror diameter	50 m
Field of View (FoV)	2° (1°)
Number of instruments	≥ 5
Scan speed	3°/s
Acceleration	$1°/s^2$
Elevation (EL) range	20°–90°
Azimuth (AZ) range	±270°
Mount type	AZ–EL

Mroczkowski et al. 2025

➡ Dependence on different Input Signals:



➡ Confusion Limit

- The “confusion limit” term refers to a limit within which there are many detected sources in an observation that it is hard to spatially distinguish individual sources apart from each other

- Source distribution in sky fixed
- Gaussian beam

$\boldsymbol{\sigma_{conf} \propto \theta_0}$ → FWHM of the beam

Wavelength	ATLAST FWHM (arcsec)	SPIRE FWHM (arcsec)	SPIRE 1σ confusion (mJy)	ATLAST 1σ confusion (mJy)
250 μm	1.26	18.2	5.8	0.40
350 μm	1.76	24.9	6.3	0.45
500 μm	2.52	36.3	6.8	0.47

Table A.1: Comparison of ATLAST vs SPIRE confusion noise across wavelengths

Nguyen et al., 2010