Atmospheric Effects in Ground-Based Observations of the Cosmic Microwave Background

The Case of the LSPE/Strip Telescope

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Co-supervisor: Stefano Mandelli

Università degli Studi di Milano

July 6, 2021

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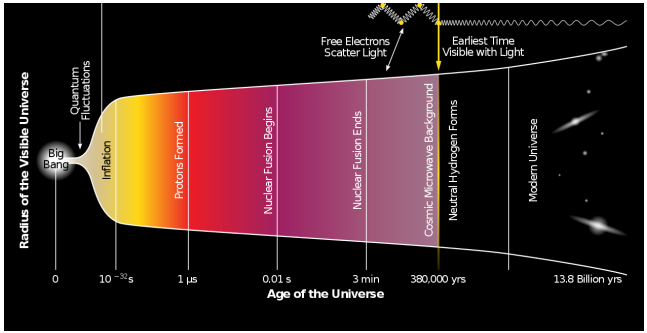
The Cosmic Microwave Background



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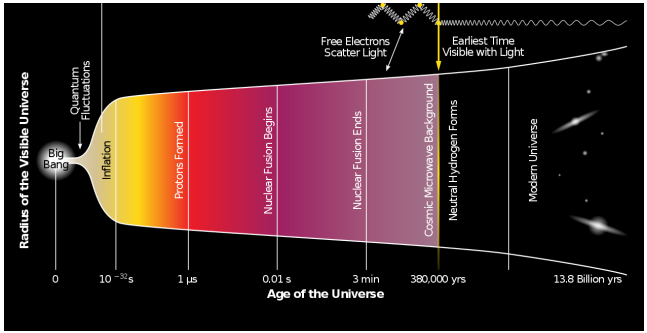

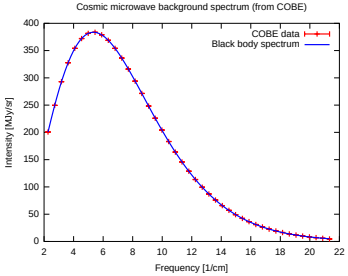

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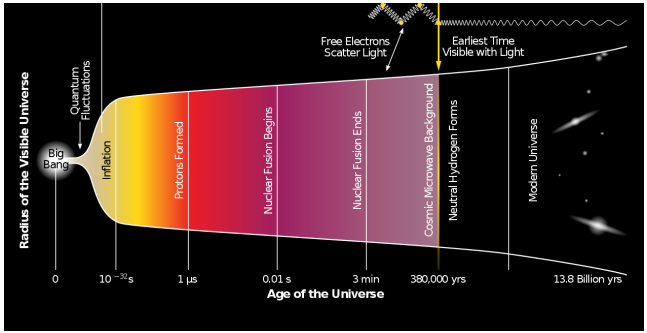
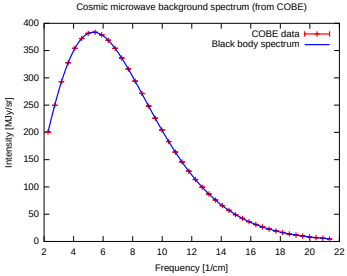
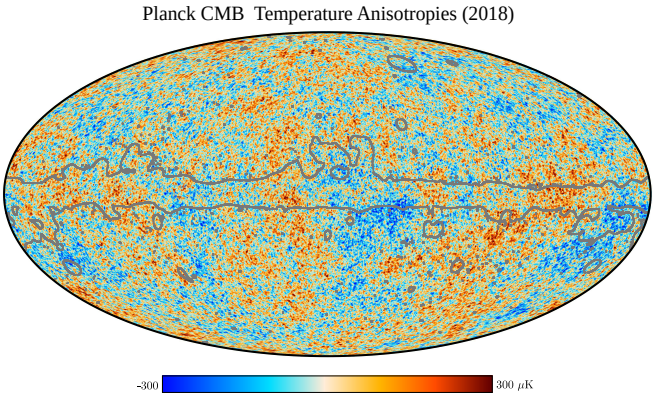




Universe expansion $\rightarrow \sim 2.73K$

Intensity Anisotropies



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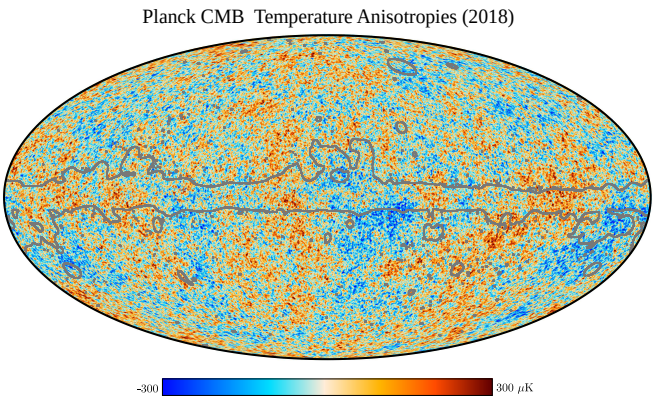


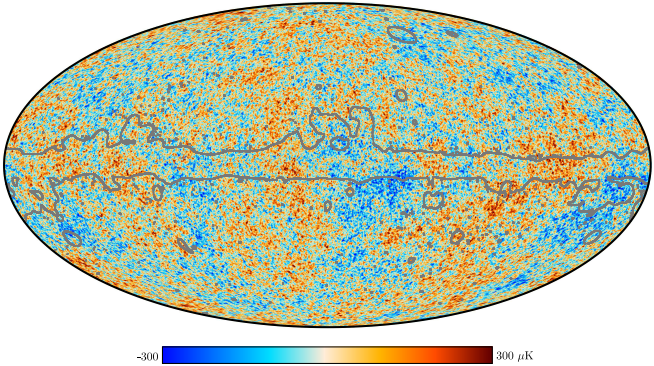
Temperature Power Spectra (C_l)

$$\frac{\delta T(\theta,\phi)}{\bar{T}} = \sum_{l=0}^{\infty}\sum_{m=-l}^{l} a_{l,m} Y_{l,m}(\theta,\phi) \tag{1}$$

$$C_l = \frac{1}{2l+1}\sum_{m}\left\langle a_{l,m} a^{*}_{l',m'}\right\rangle \tag{2}$$

Intensity Anisotropies

Planck CMB Temperature Anisotropies (2018)



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$\downarrow$

Density contrast in primordial plasma

CMB Polarization

CMB photons

$\downarrow$

Thomson scattering events during recombination

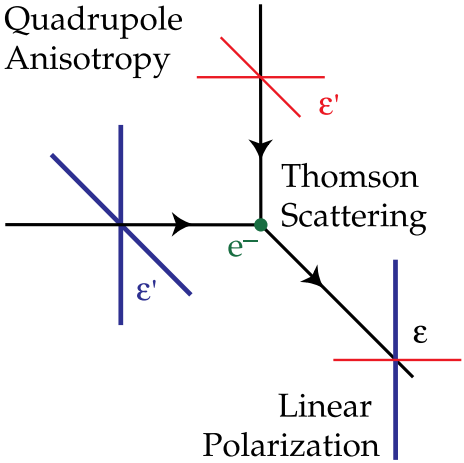
CMB Polarization

CMB photons

↓

Thomson scattering events during recombination

→



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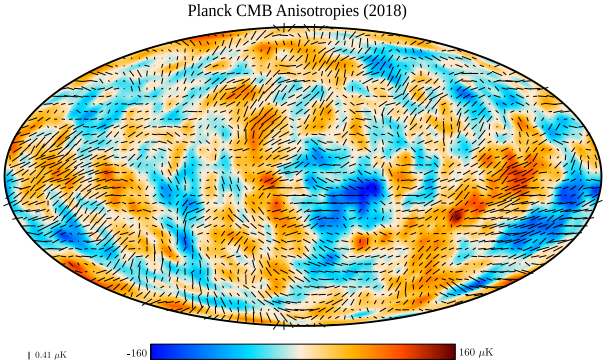

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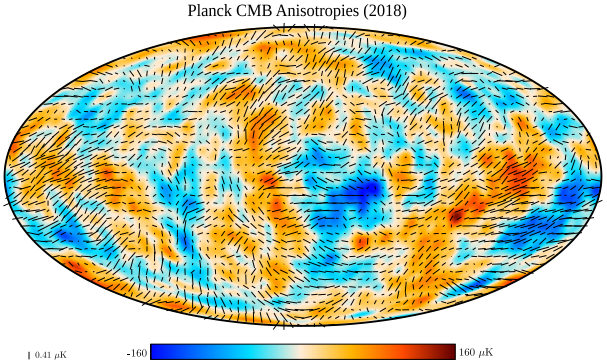

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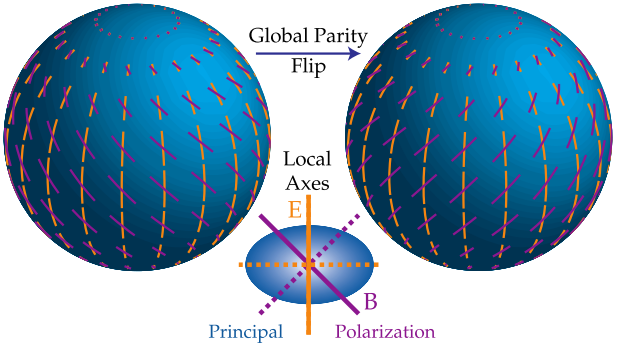

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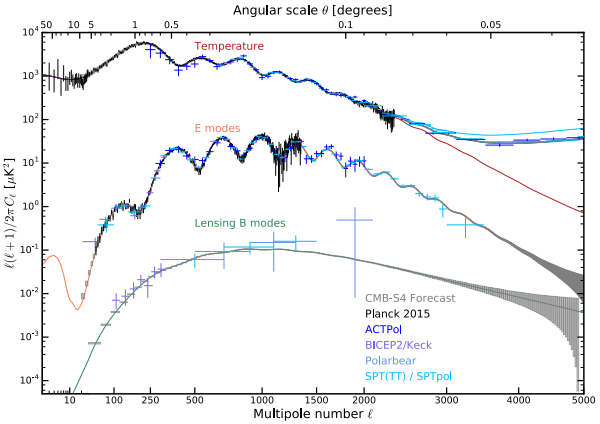
Linear combinations:

E- and B-modes

PGW B-modes

State of the art & prediction:



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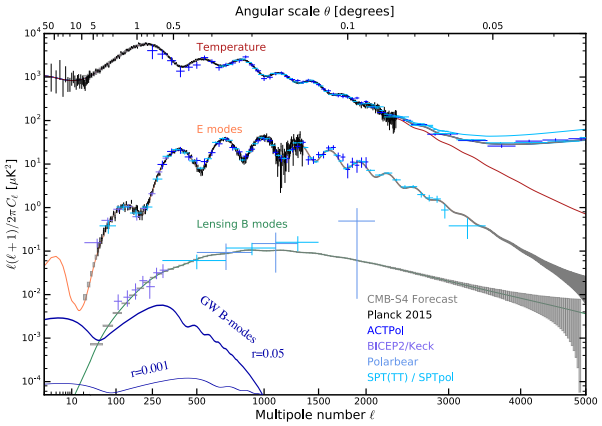

B-Modes → Primdordial Gravitational Waves

Smoking Gun Inflation!

↓

Solves some Big Bang problems

LSPE/Strip

LSPE/Strip

- Upper limit to B-modes intensity

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- Upper limit to B-modes intensity
- SWIPE $\rightarrow$ balloon-borne, 140 GHz to 240 GHz

LSPE/Strip

LSPE Large Scale Polarization Explorer

Agenzia Spaziale Italiana

Istituto Nazionale di Fisica Nucleare

- Upper limit to B-modes intensity
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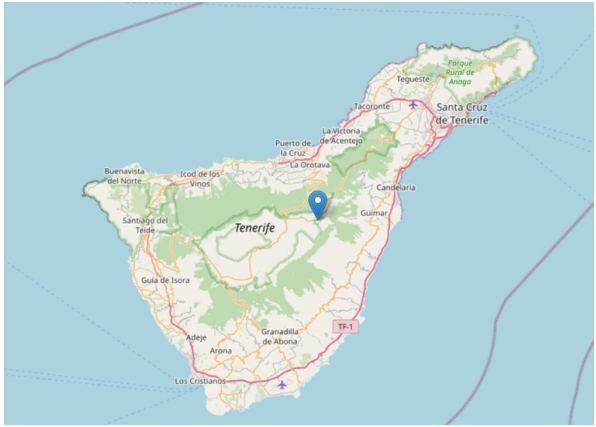

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- Upper limit to B-modes intensity
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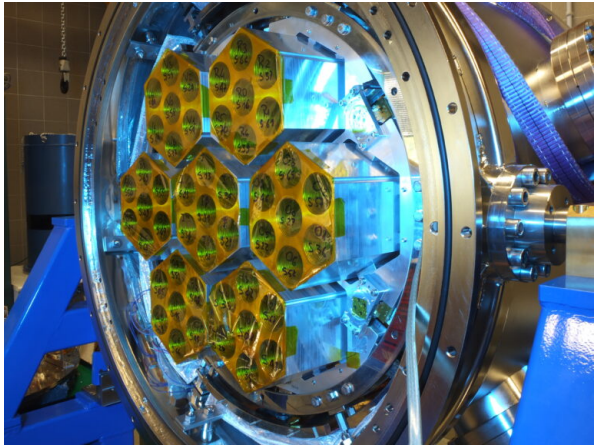
Focal Plane → polarimeters
43 GHz (Q-band)
95 GHz (W-band)



Atmospheric Effects in CMB Observations

Atmospheric emission:

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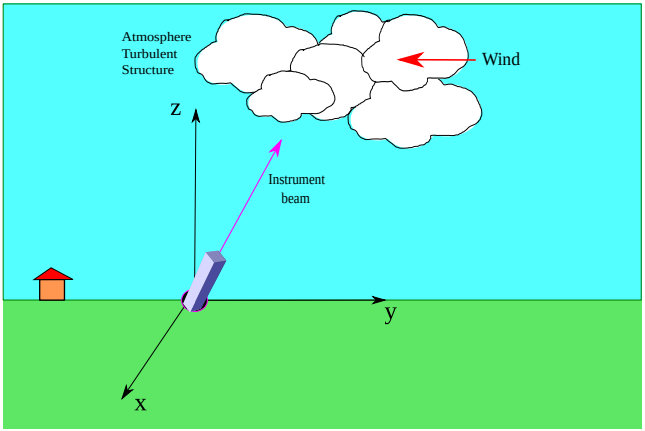
Temporal & spatial correlation in detected signal



Atmospheric Radiative Transfer

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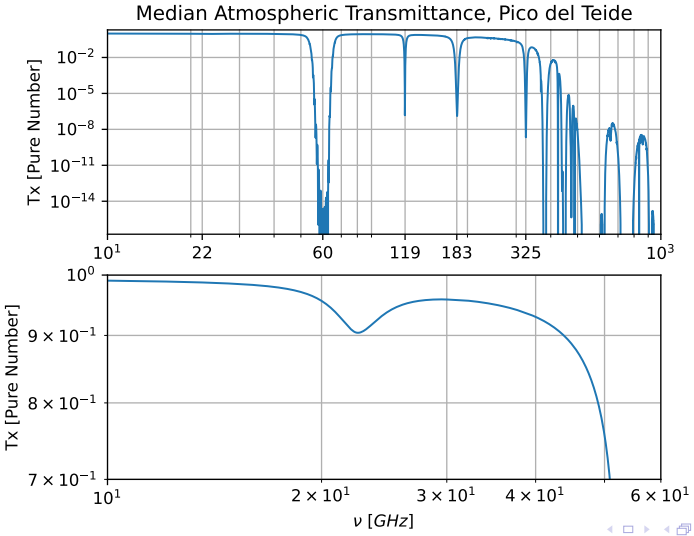

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Radiative Transfer Equation

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Atmospheric Brightness Temperature

$$T_{atm}(\nu) = T_{sky}(\nu) - T_{CMB}(\nu)e^{-\tau_A(\nu)} \tag{5}$$

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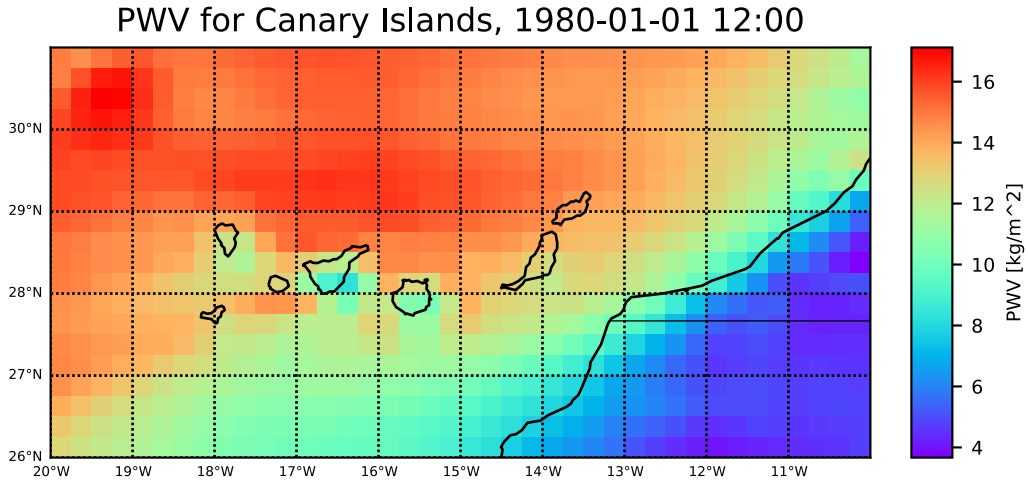
ECMWF ERA5 Atmospheric Reanalisys



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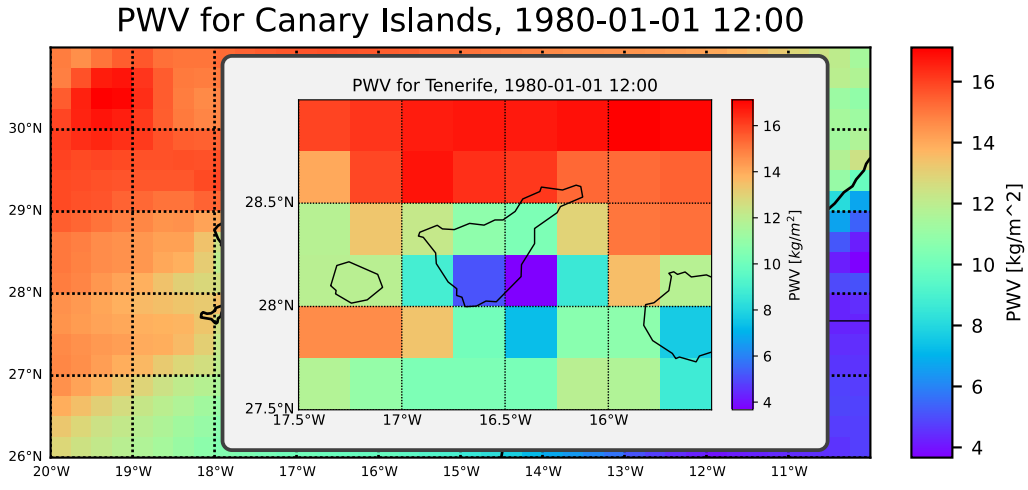

CDFs `.fits` File

Statistical picture:

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Statistical picture:

- Set of *CDFs* for every hour, month, relevant parameter

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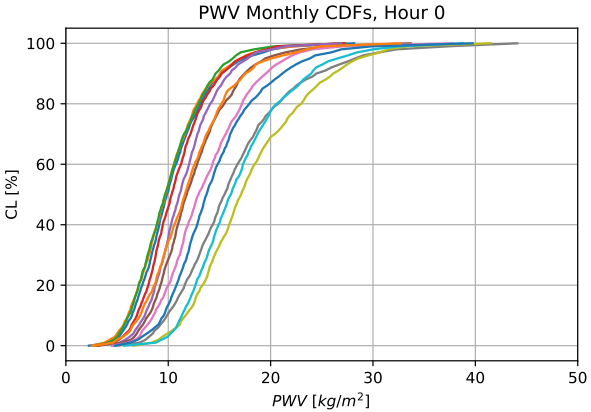

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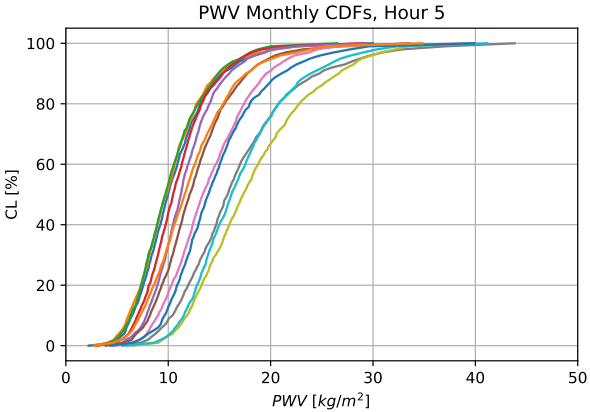

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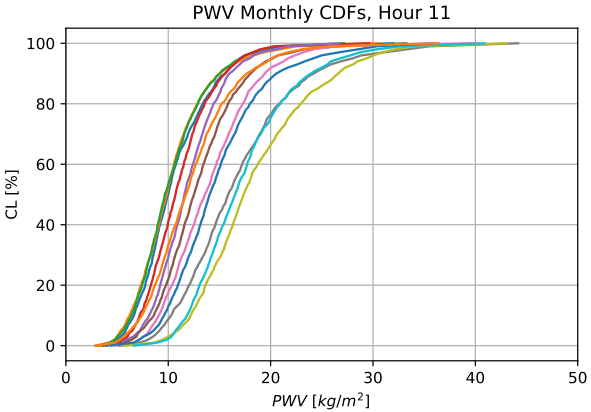

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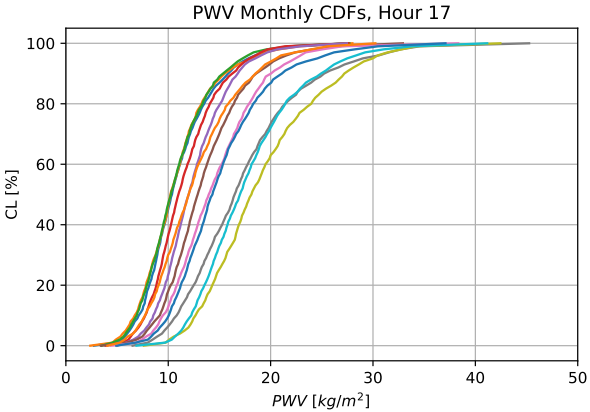

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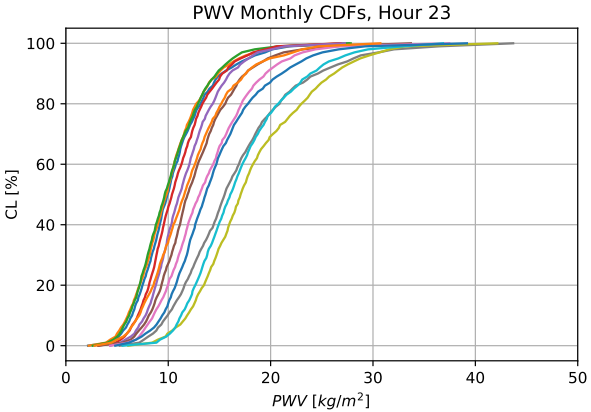

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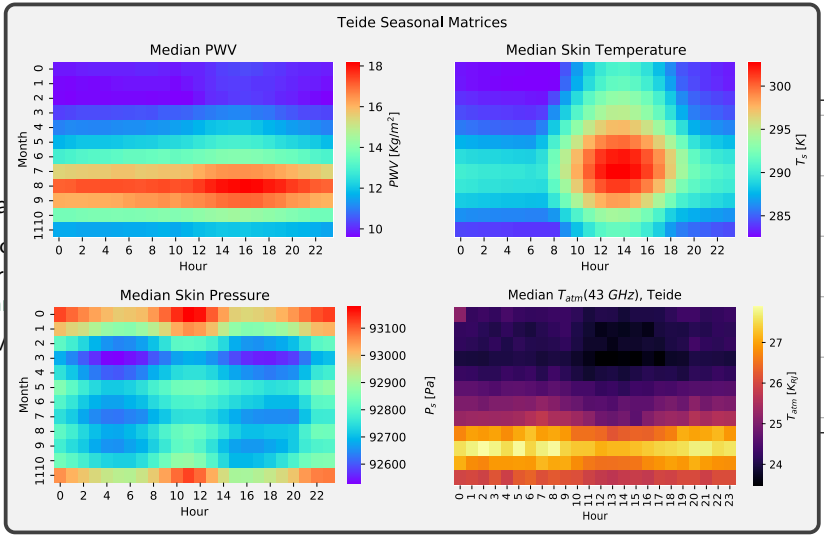
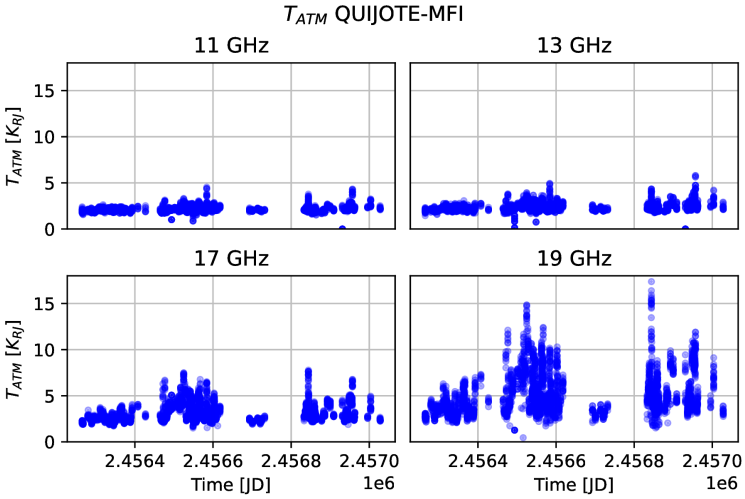


QUIJOTE-MFI Dataset & Simulations



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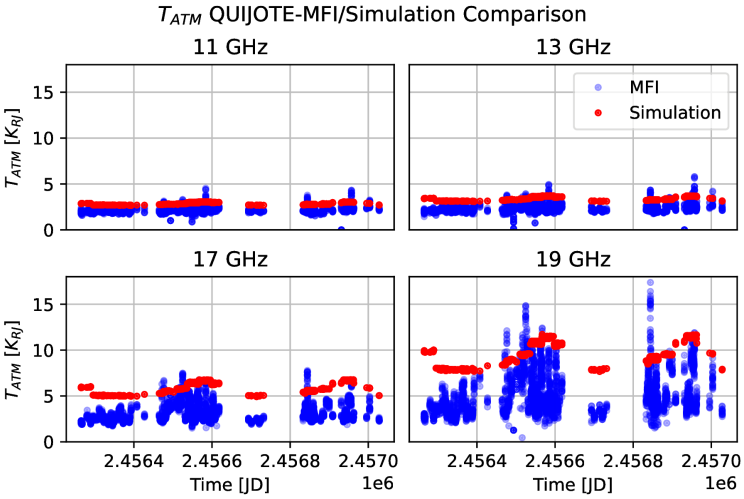
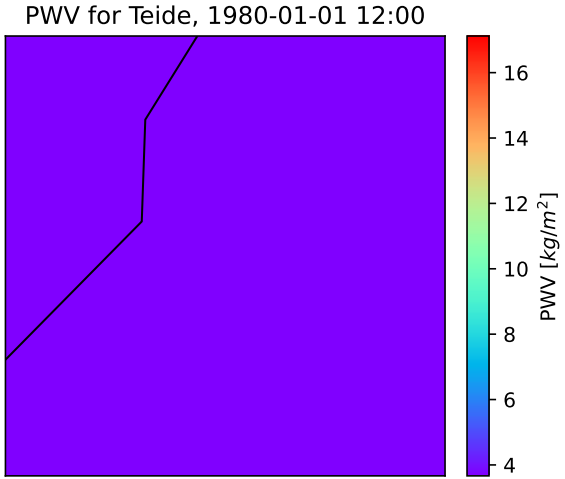


ERA5 Spatial Resolution



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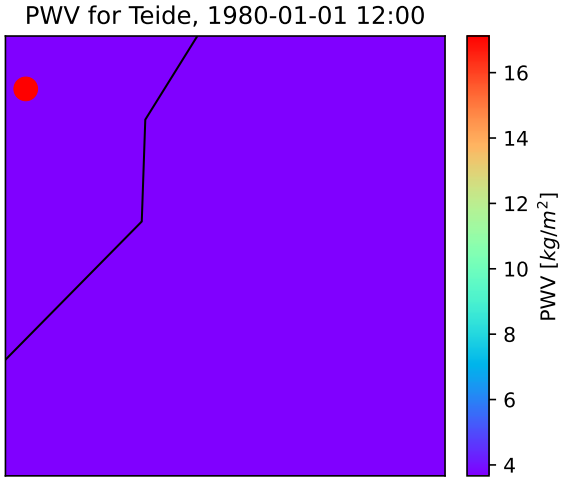

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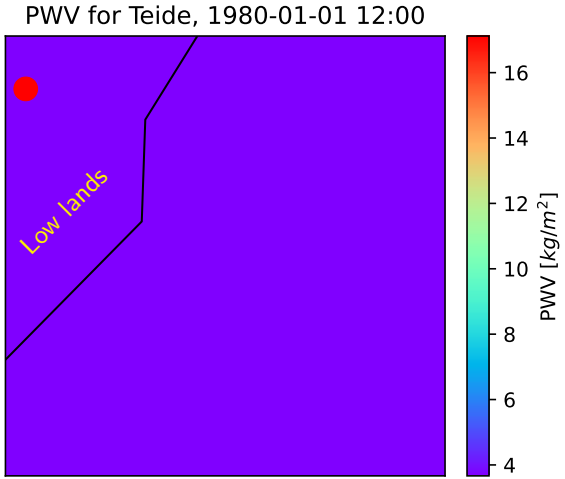

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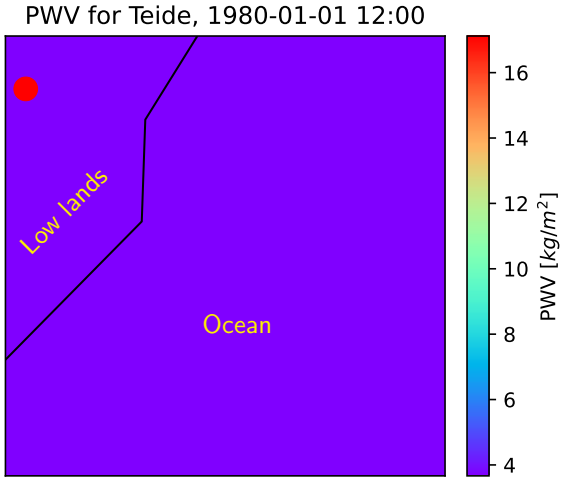

Calibration Coefficient

Balloon probe measurements performed at Teide observatory:

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- High spatial resolution

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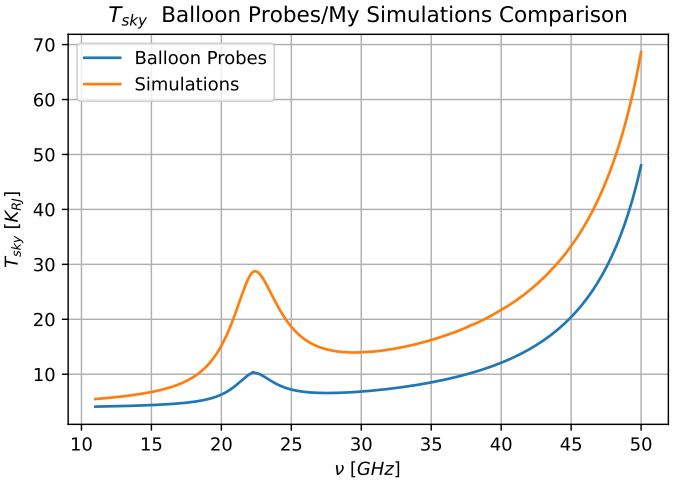

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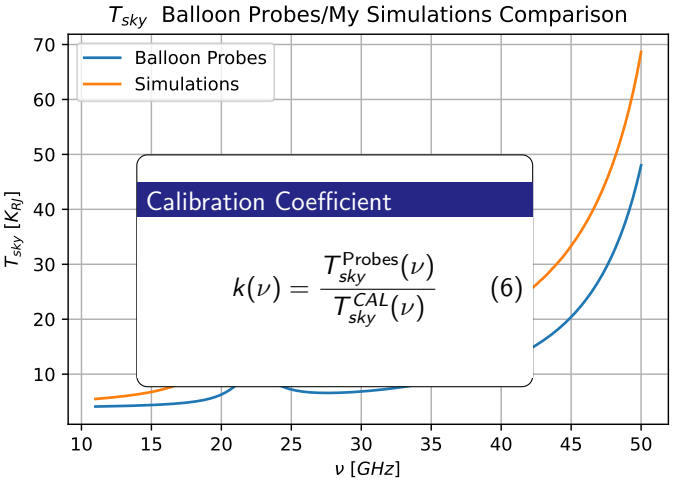

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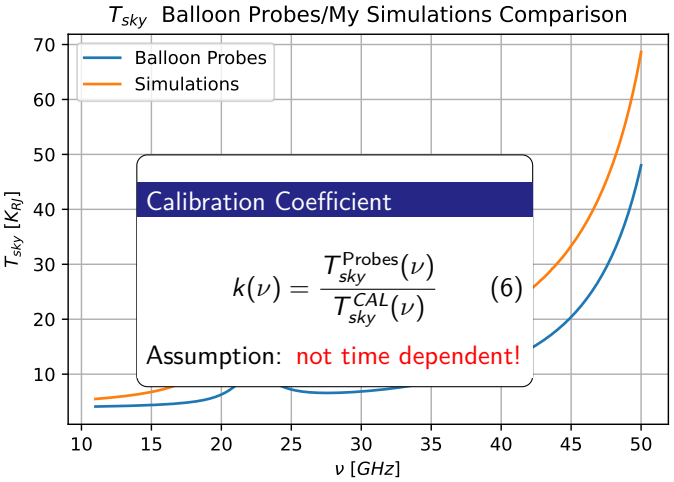

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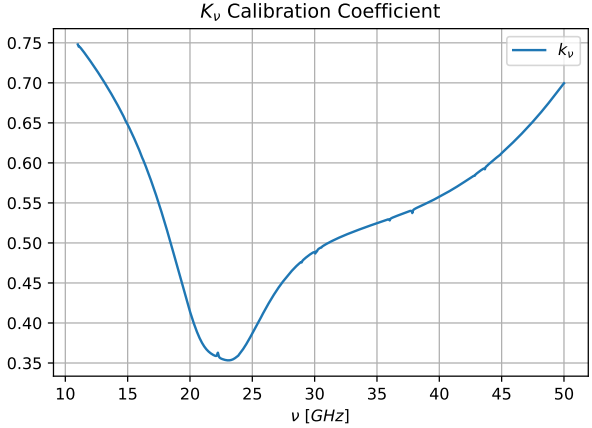

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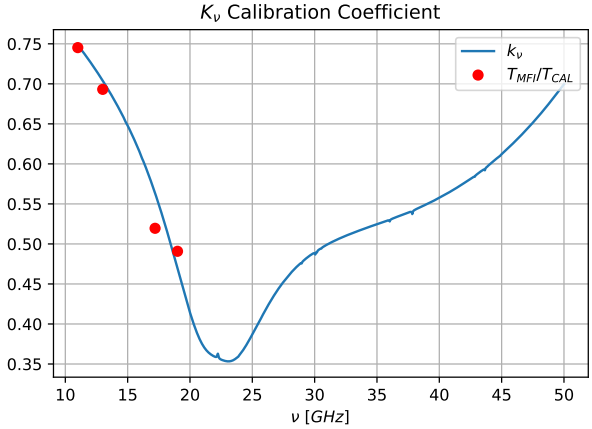

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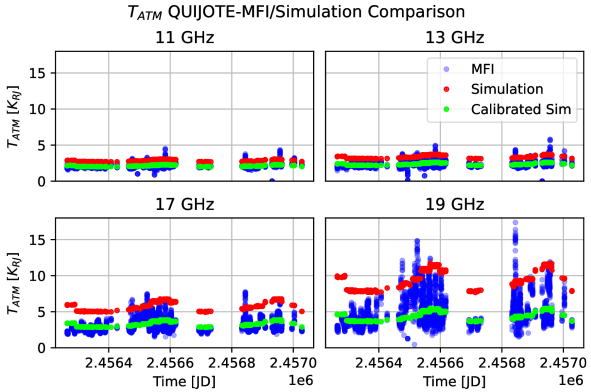

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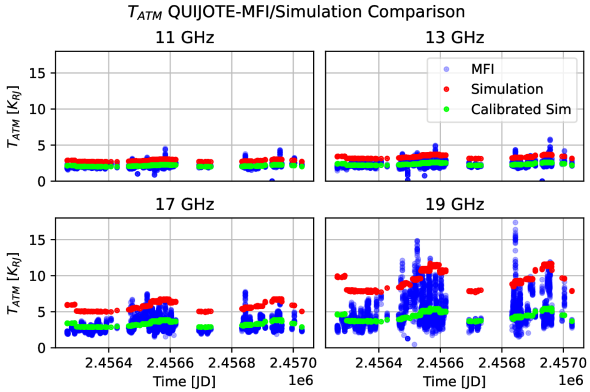

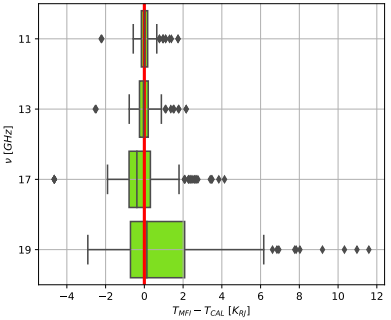

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Thank you!

tatmget

`Python` 3 script to simulate statistical populations of seasonal T_{atm} matrices (Open source and GNU GPLv3 licensed when accomplished)

tatmget

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Overview:

- Calls `CAL` methods to simulate T_{sky}s

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Improvements:

- Output populations of meteorological parameters only

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- Output populations of meteorological parameters only
- Output uncalibrated or calibrated T_{atm}s

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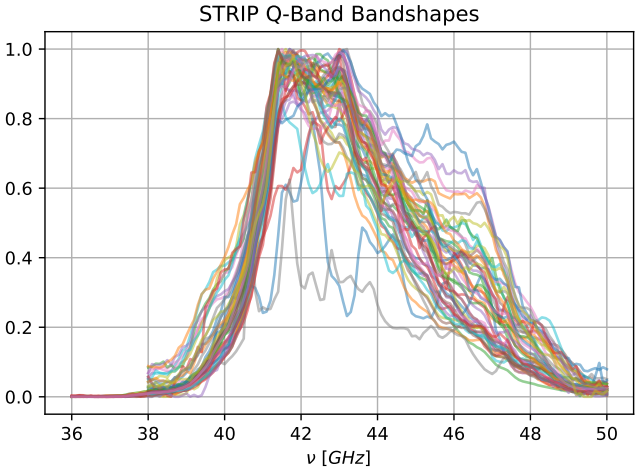
- Output T_{atm}s convoluted with arbitrary bandshapes
  $\rightarrow$ execution time reduced by a $\sim$ 15 factor from first version

Strip Q-Band Bandshapes



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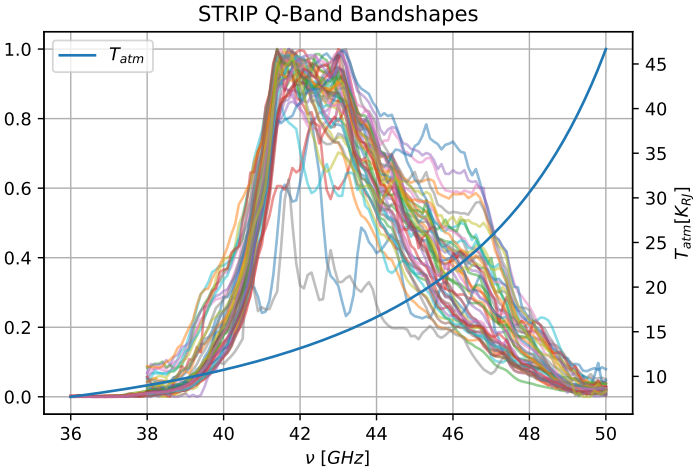

Bandshape Integration

Convolution Integral

$$T_A^{atm} = \frac{\int_0^\infty \mathrm{d}\nu \; T_{atm}(\nu)\mathrm{BS}(\nu)}{\int_0^\infty \mathrm{d}\nu \; \mathrm{BS}(\nu)} \tag{6}$$

Bandshape Integration

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- 9900 elements $\times$ 288 hours $\times$ 49 detectors $\rightarrow \sim$ 1250 CPU hours

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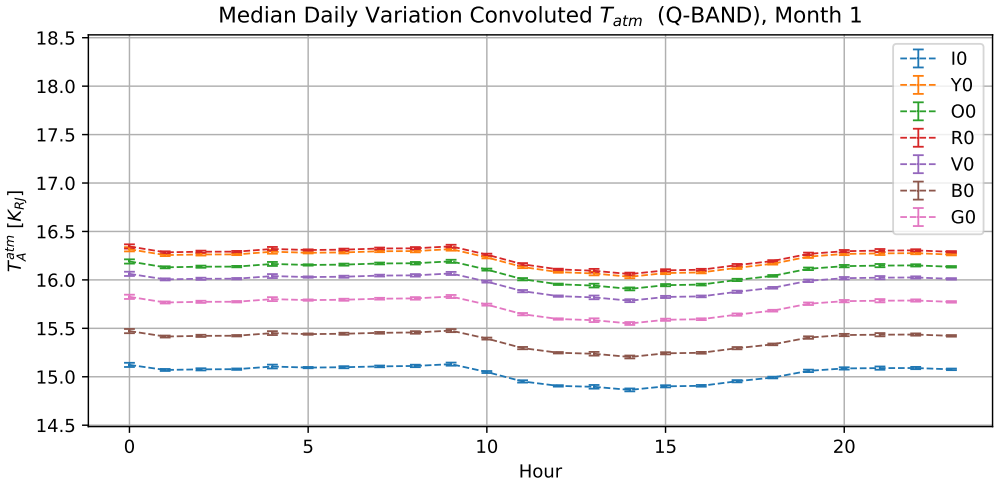

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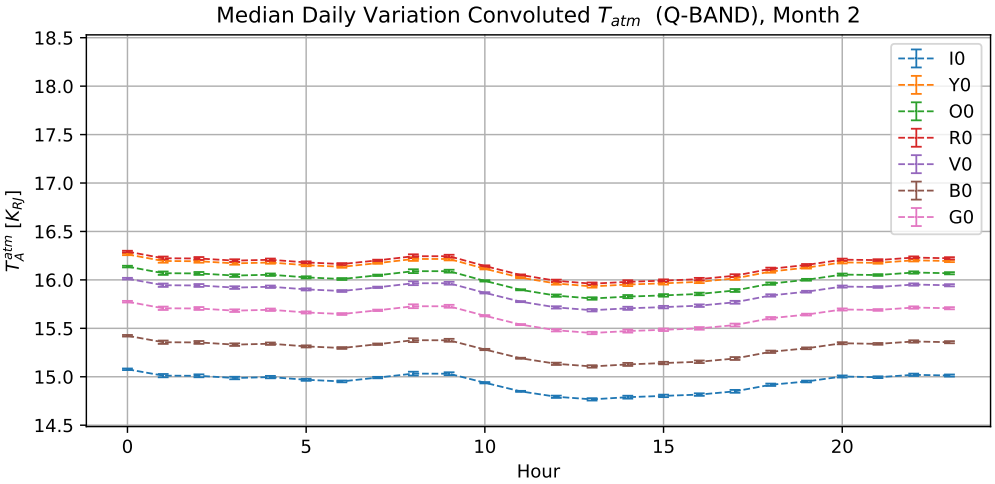

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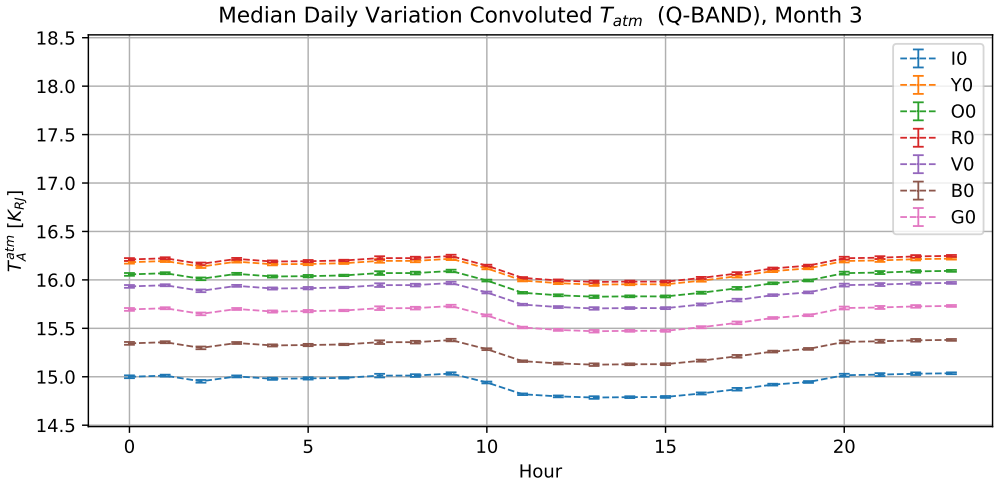

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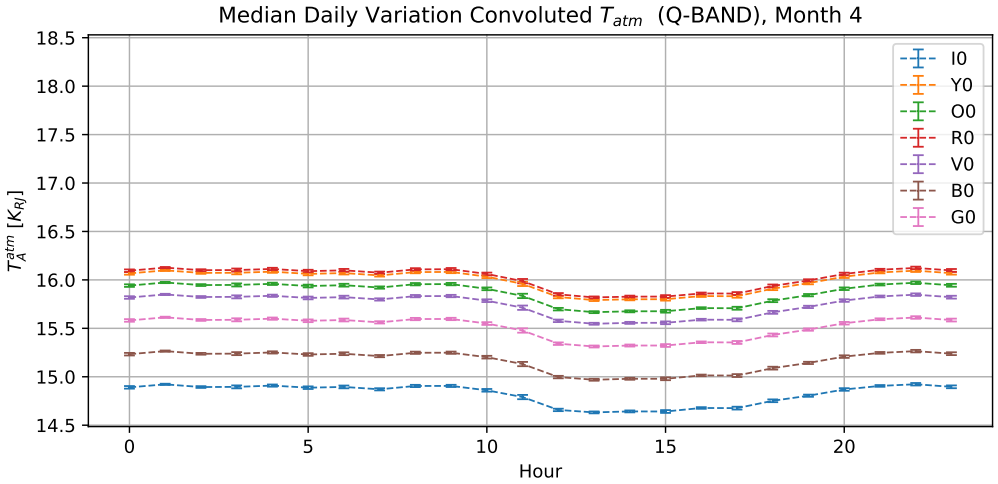

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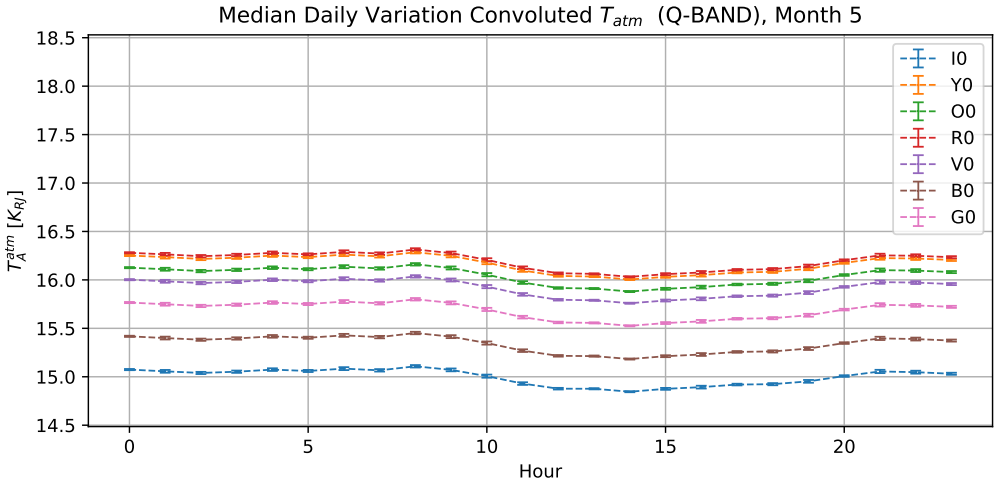

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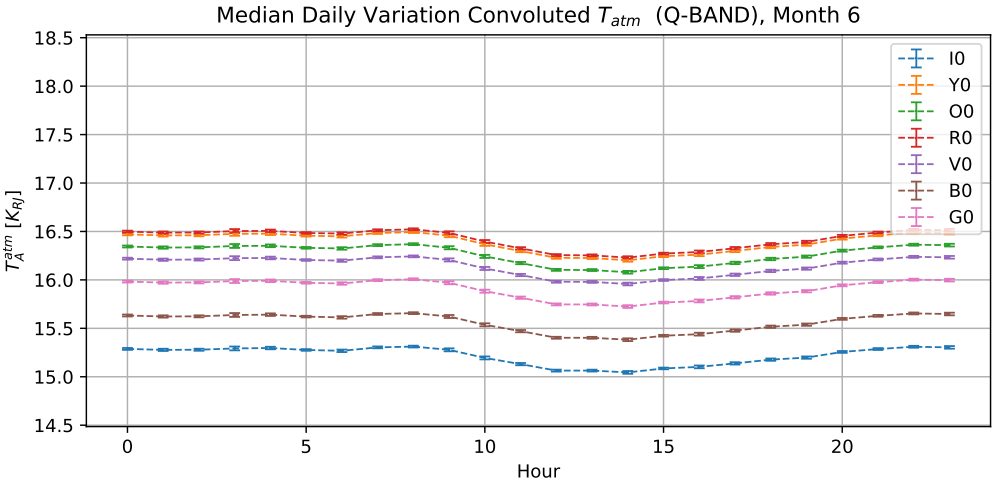

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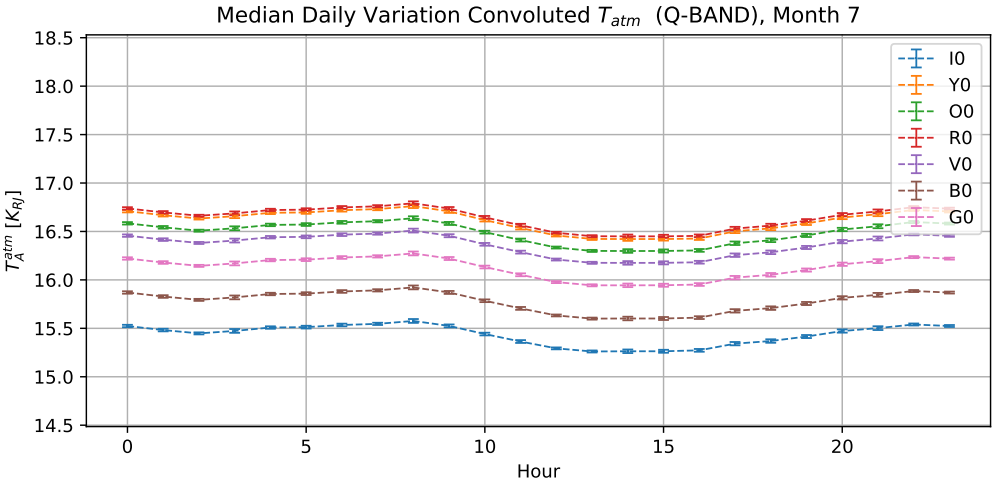

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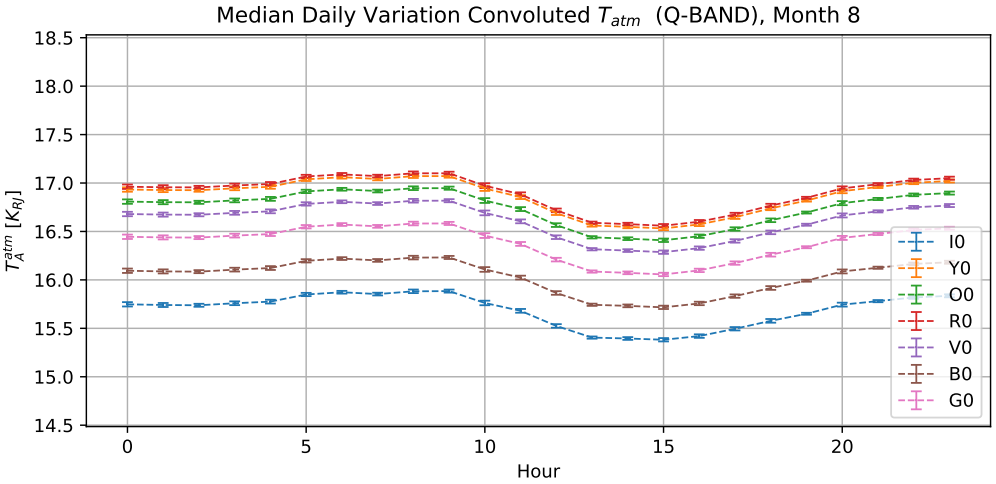

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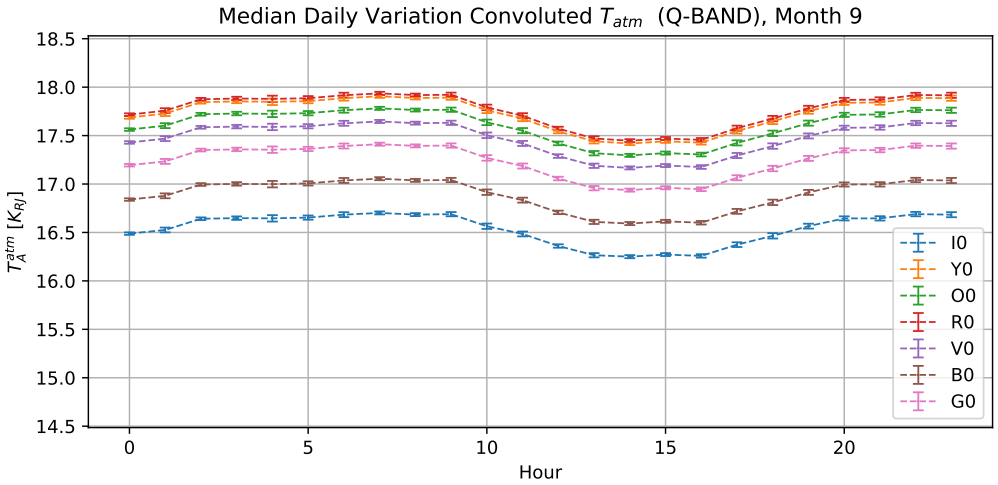

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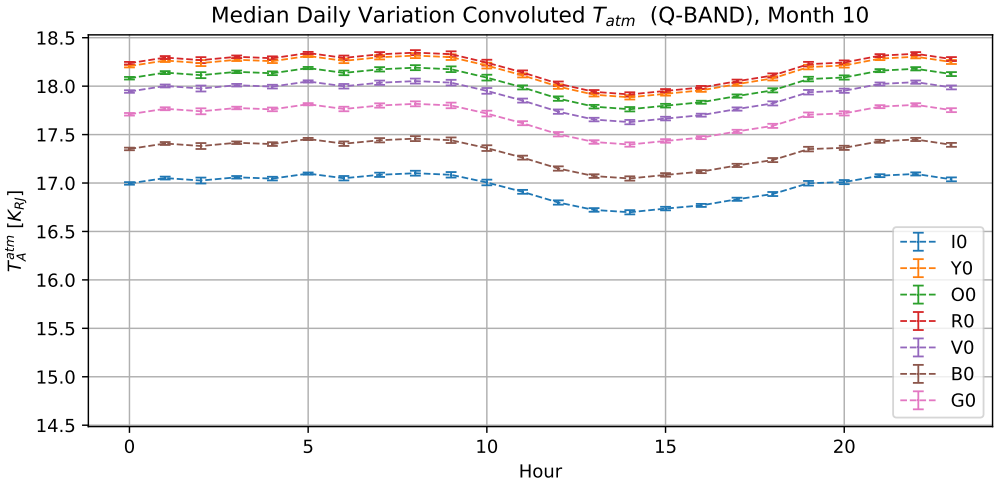

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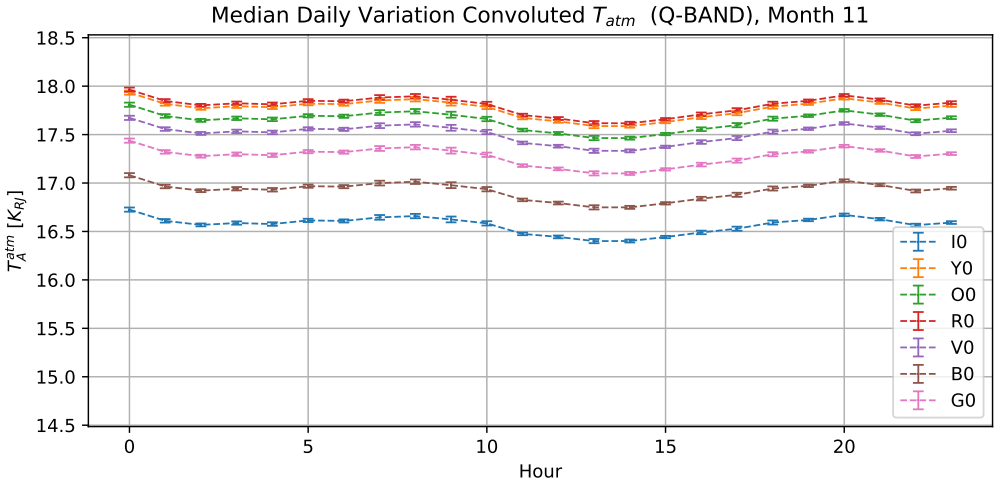

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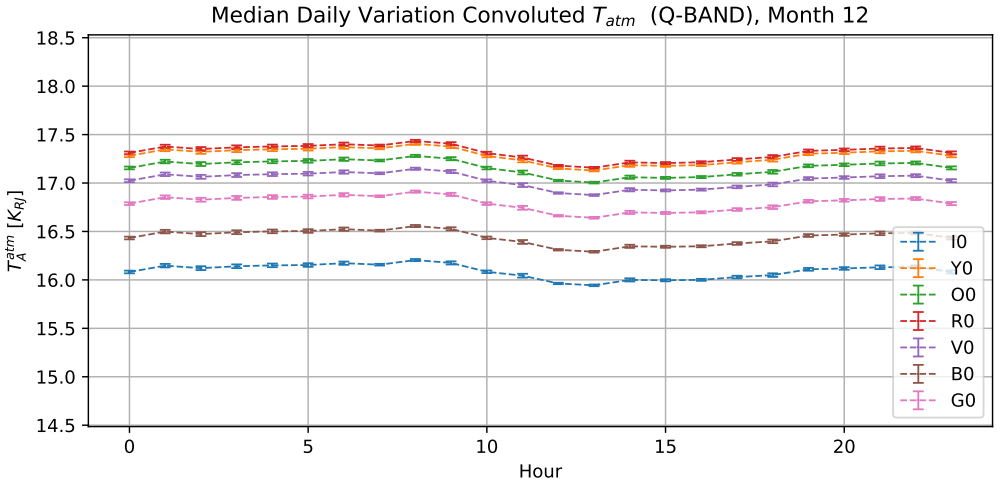

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- INDACO $\rightarrow$ 50$\times$ E5-2683V4, 2.1 GHz cores; 2000 TB RAM (Max)

Sensitivity (Single Detector)

$$\Delta T_A^{atm} = \frac{T_A^{atm}}{\sqrt{\Delta\nu_{\mathrm{eff}}\tau}}, \quad \tau = \frac{1}{50}s \tag{7}$$

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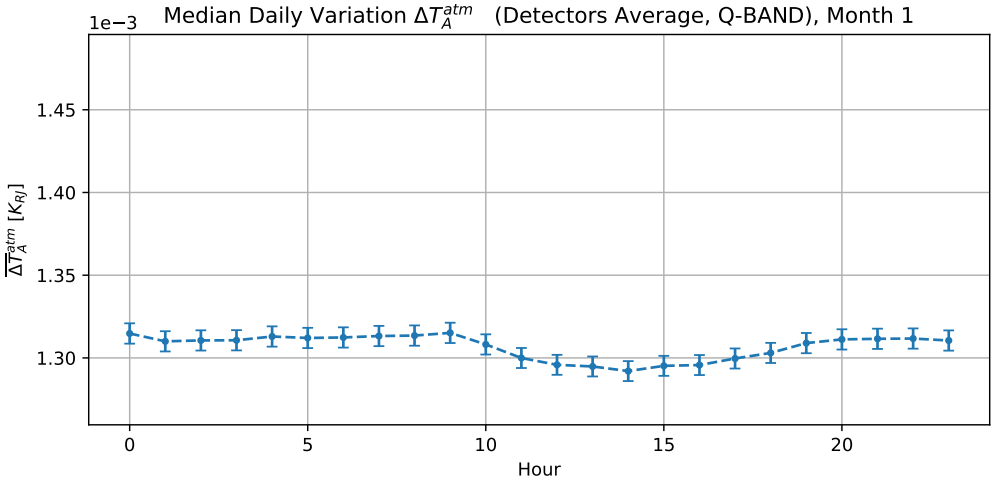
$$\Delta\nu_{\mathrm{eff}} = \frac{\left[\int_0^\infty \mathrm{d}\nu \, \mathrm{BS}(\nu)\right]^2}{\int_0^\infty \mathrm{BS}^2(\nu)} \tag{7}$$

White Noise Load



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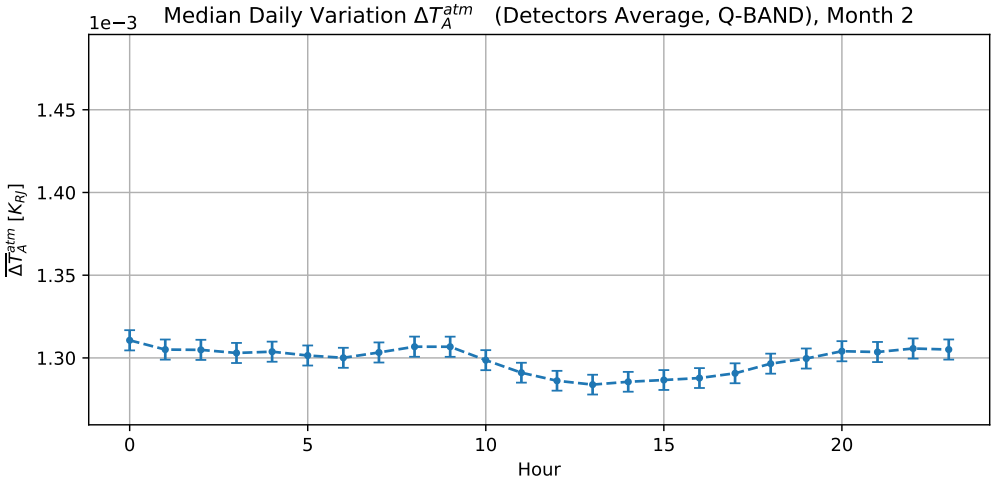

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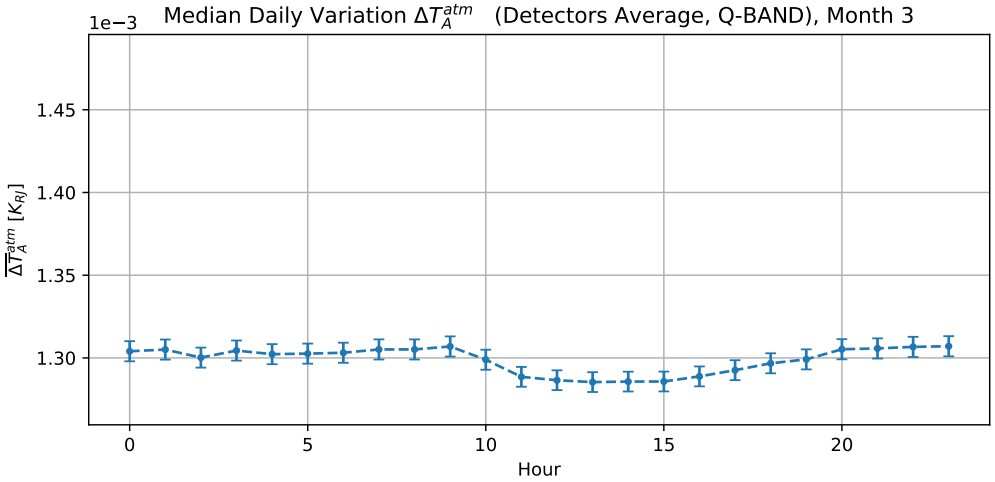

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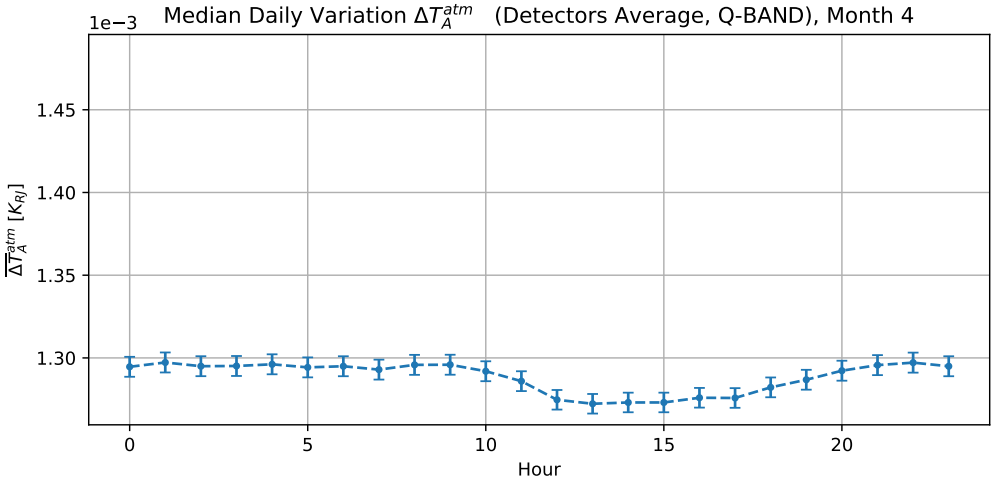

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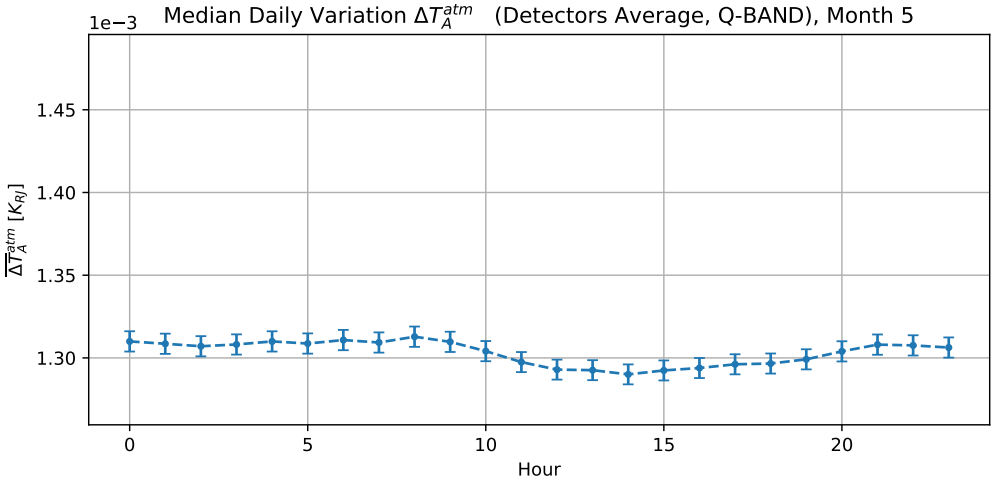

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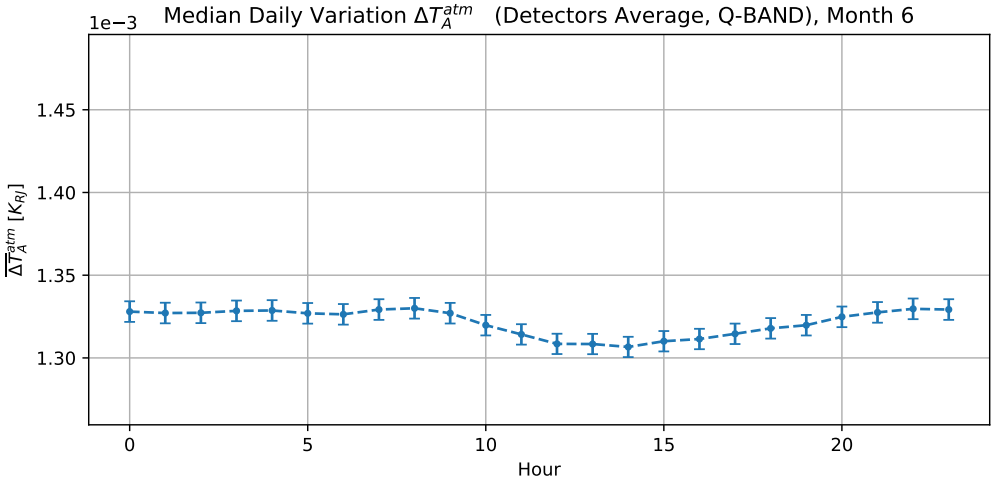

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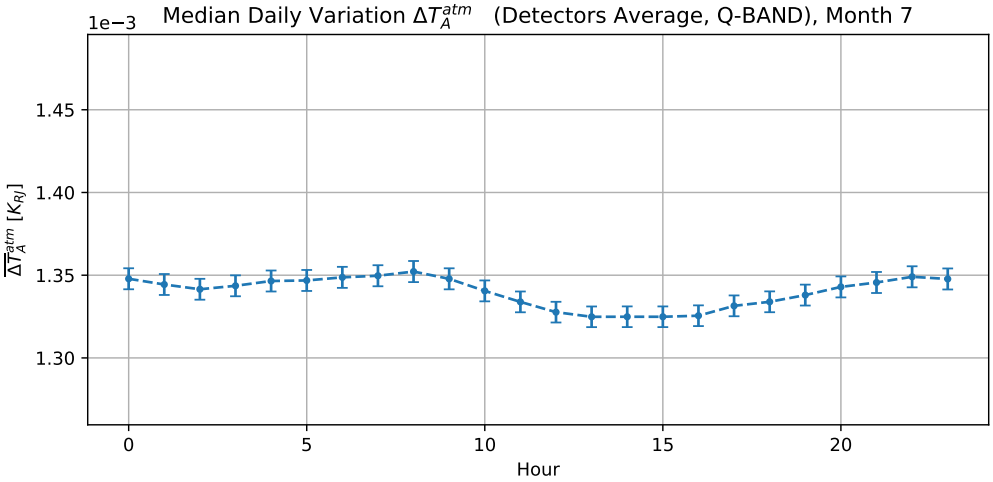

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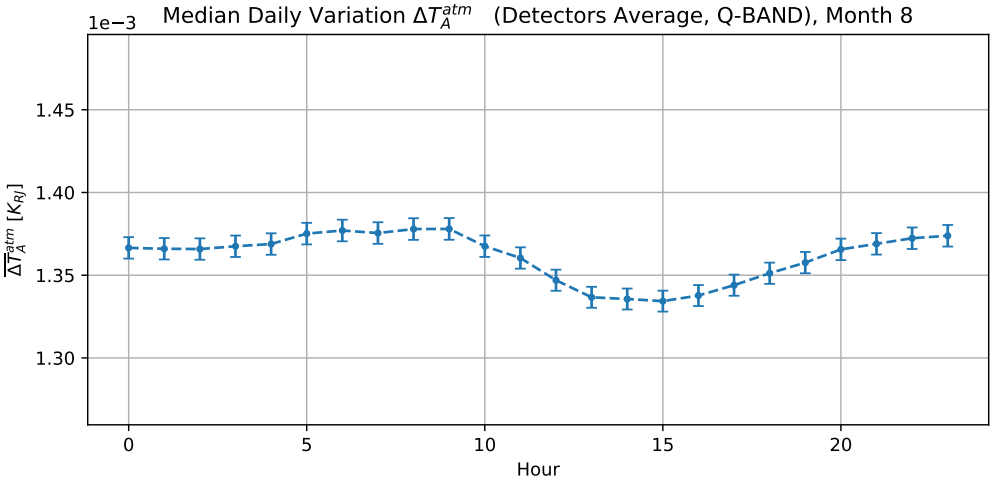

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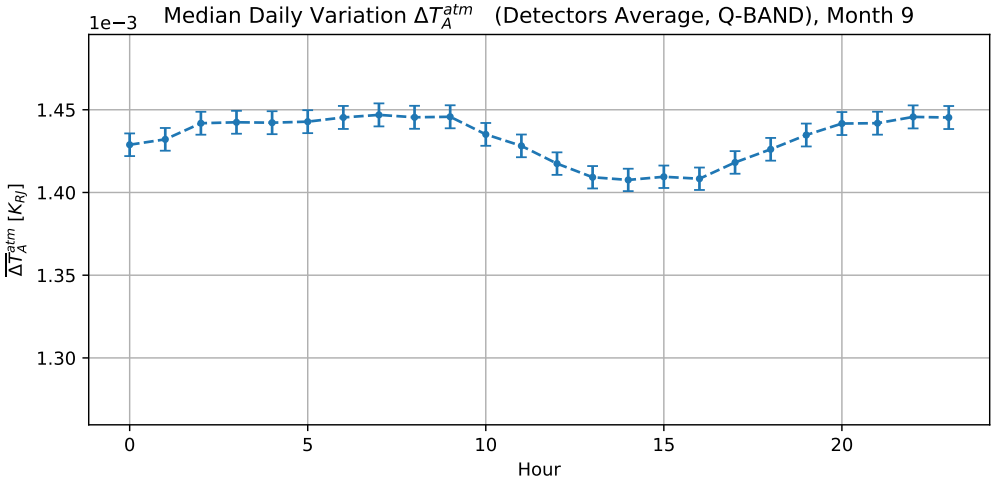

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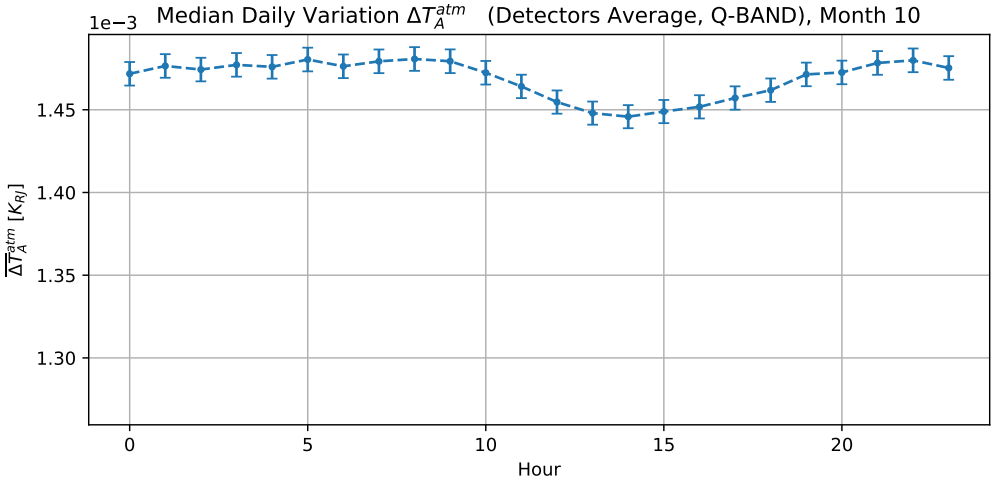

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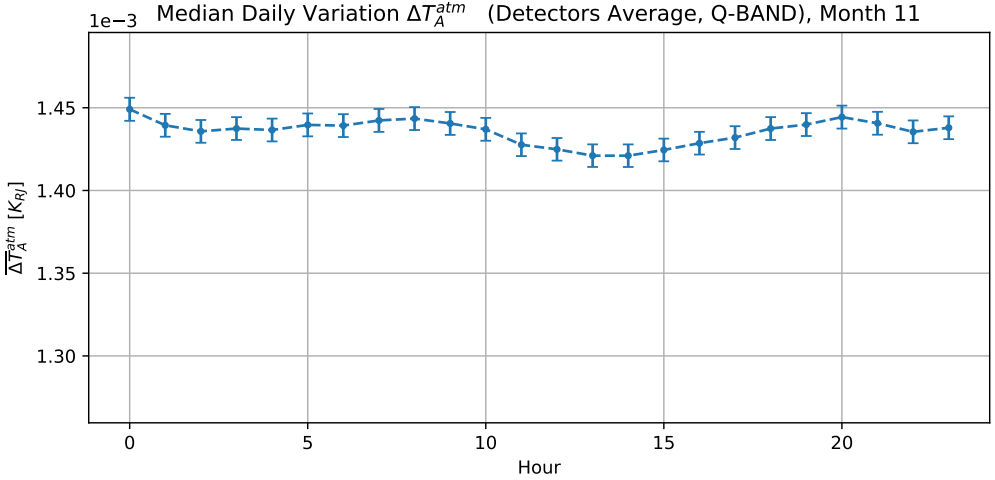

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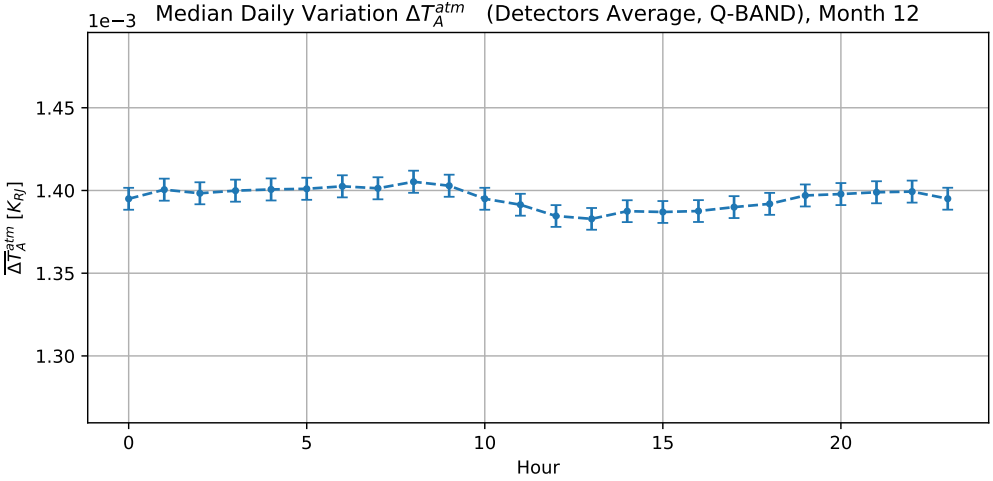

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