First On-Sky Data from SPT-SLIM

CO Line Intensity Mapping with on-chip mm-wave spectrometers from the South Pole

Jessica Zebrowski
University of Chicago
6-3-25

LIM as a New Cosmological Probe

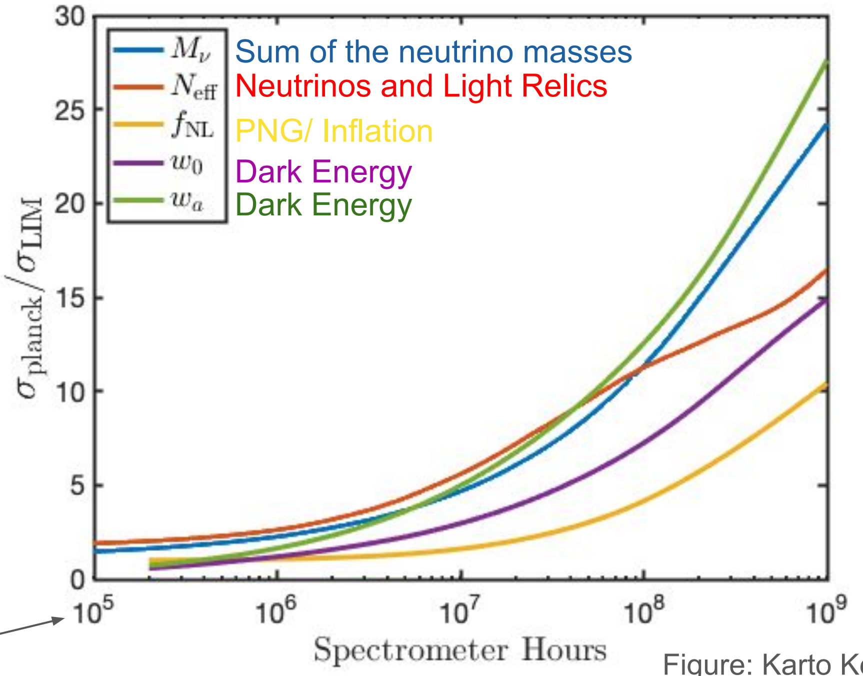
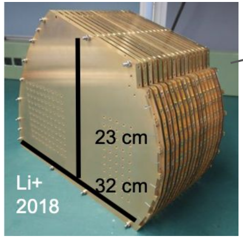
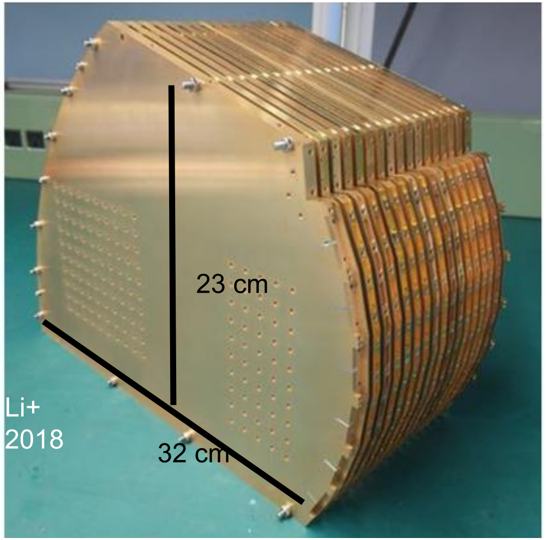


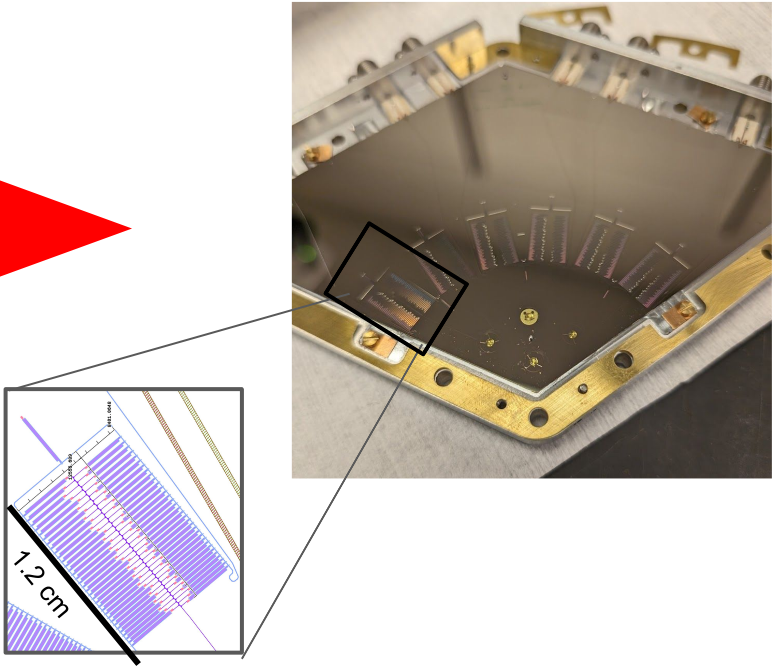
Figure: Karto Keating



Need to increase instantaneous sensitivity

On-Chip Spectrometers: A Scalable Technology

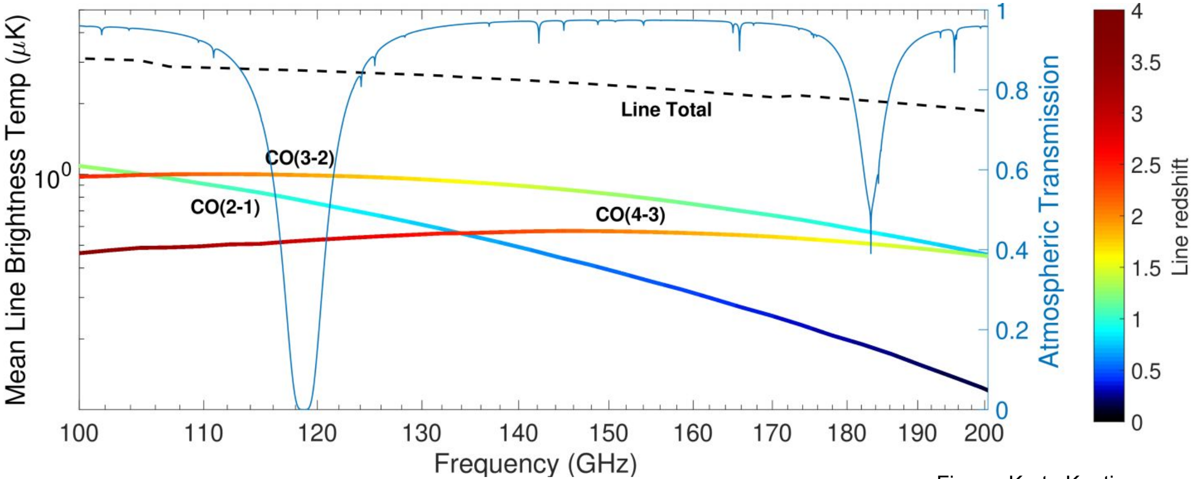




TIME grating: R = 100, 60 spectral channels
32 x 23 x 1 cm = **~ 736 cm^3**

SPT-SLIM Filterbank: R = 100, 65 spectral channels
1.26 x .84 x 0.05 cm= **~ 0.5 cm^3**

SPT-SLIM: SPT Shirokoff Line Intensity Mapper



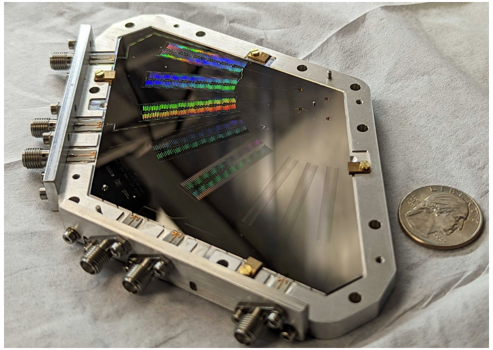
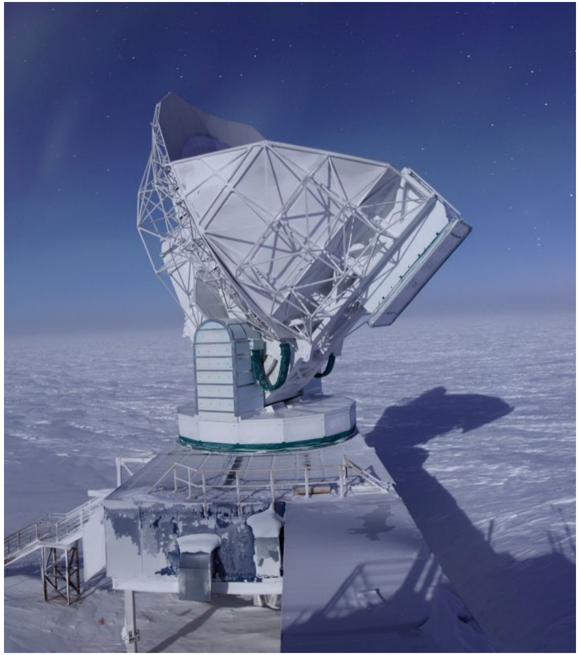


Figure: Karto Keating

- Demonstrate the LIM measurement using on-chip mm-wave spectrometers -- **scalable, a unique technological advantage in the field!**
- a high-density, 9-pixel dual-polarization focal plane
- 120-180 GHz, sensitive to CO at $0.5 < z < 2$
- Deployed Nov 2024 to the South Pole Telescope

SPT-SLIM: SPT Shirokoff Line Intensity Mapper



Argonne National Laboratory: T. Cecil, C. Chang, M. Lisovenko, V. Yefremenko, C. Yu

Boston University: **K. Karkare,** A Lapuente

Cardiff University: **P. S. Barry,** C. Benson, G. Robson

Fermilab: **A. Anderson**, B. Benson, M. Young

Center for Astrophysics Harvard & Smithsonian: G. Keating

McGill: M. Adamic, M. Dobbs, J. Montgomery, M. Rouble, G. Smecher

SLAC: C. Zhang

The University of Arizona: D. Marrone, D. Kim, H. Tailor

The University of Chicago: E. Brooks, J. Carlstrom, K. Dibert, K. Fichman, T. Natoli, A. Rahlin, J. Zebrowski

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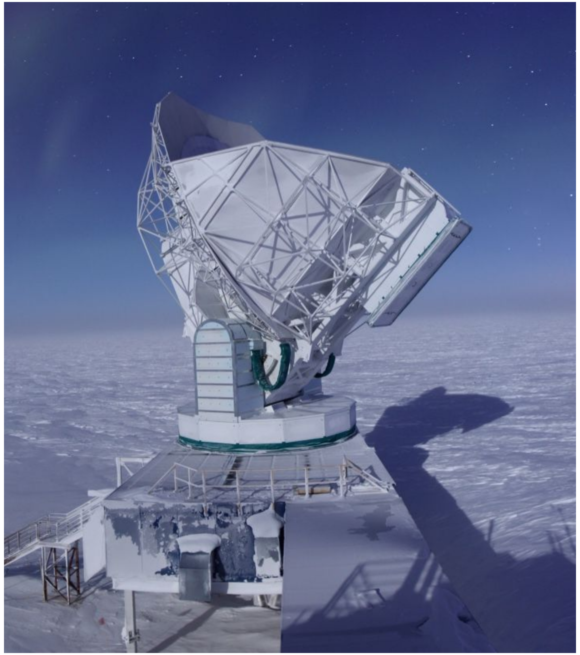

Argonne National Laboratory	T. Cecil, C. Chang, M. Lisovenko, V. Yefremenko, C. Yu
Boston University	**K. Karkare**, A Lapuente
	Talk Friday Morning!
Cardiff University / Prifysgol Caerdydd	**P. S. Barry,** C. Benson, G. Robson
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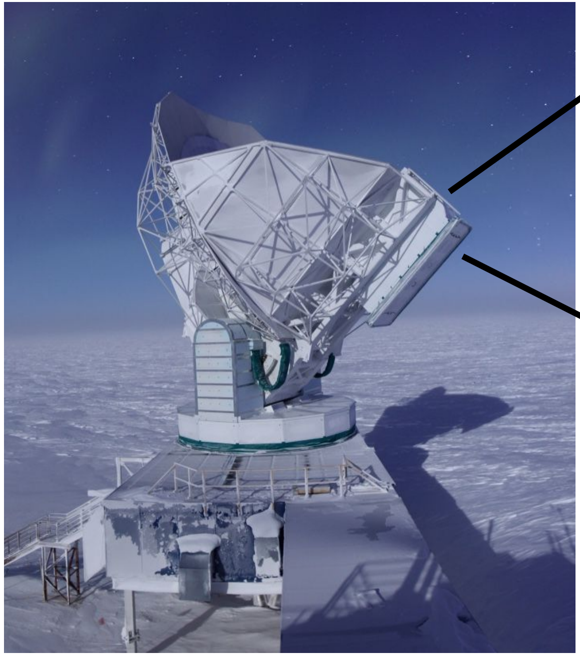
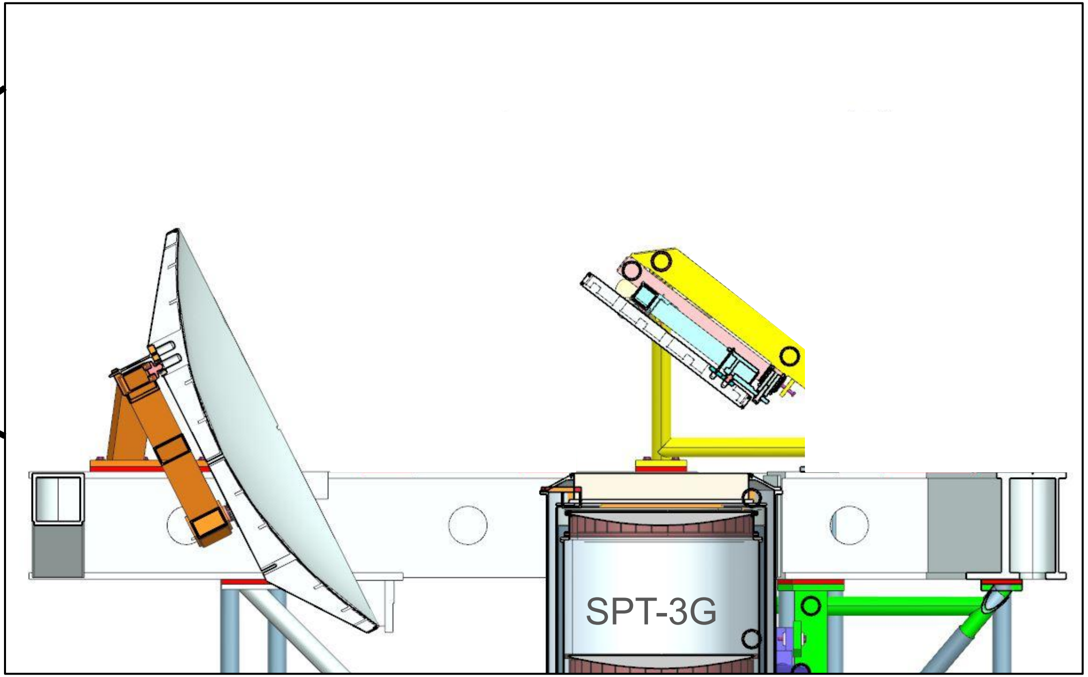
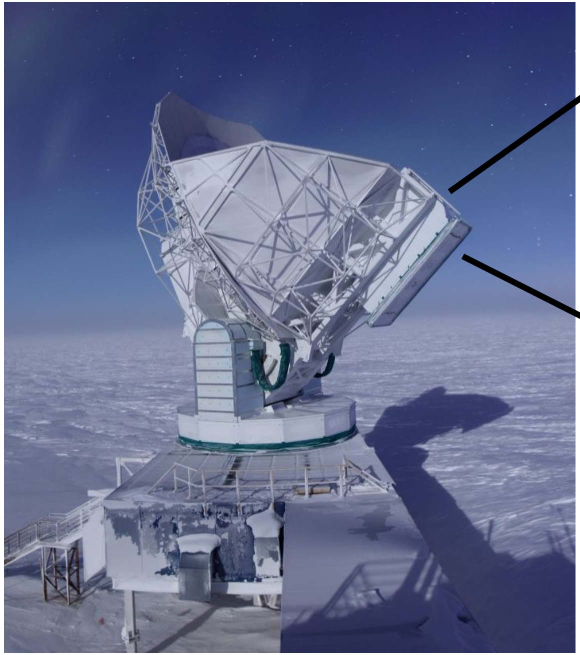
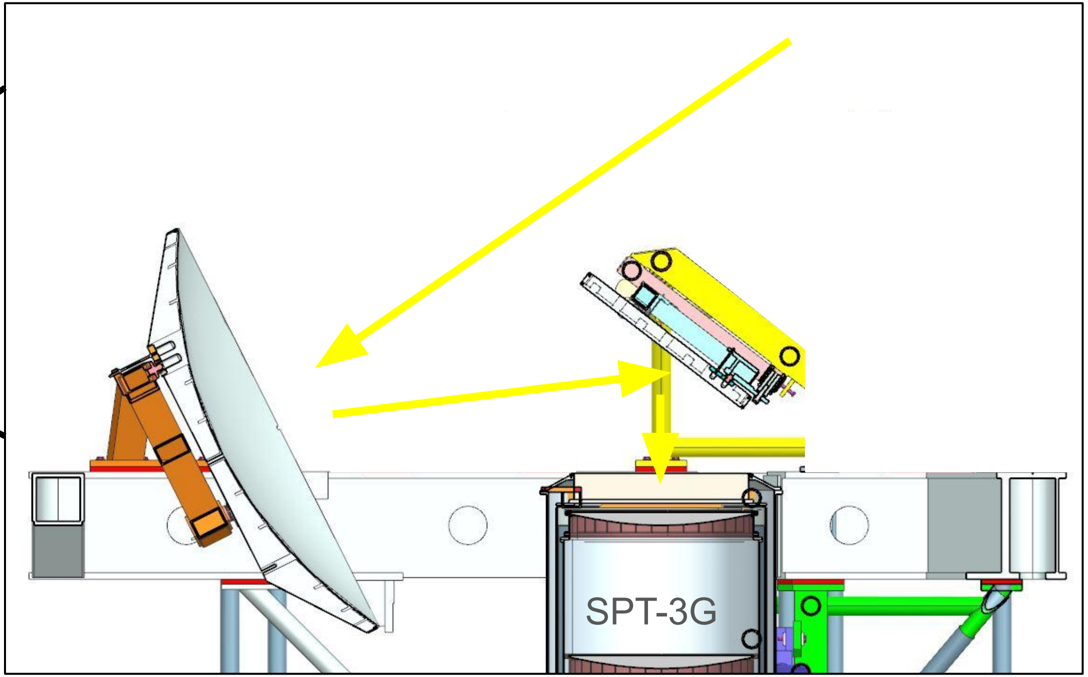




The South Pole Telescope: a 10-m off-axis gregorian telescope at Amundsen-Scott South Pole Station

SPT-SLIM: SPT Shirokoff Line Intensity Mapper





The South Pole Telescope: a 10-m off-axis gregorian telescope at Amundsen-Scott South Pole Station

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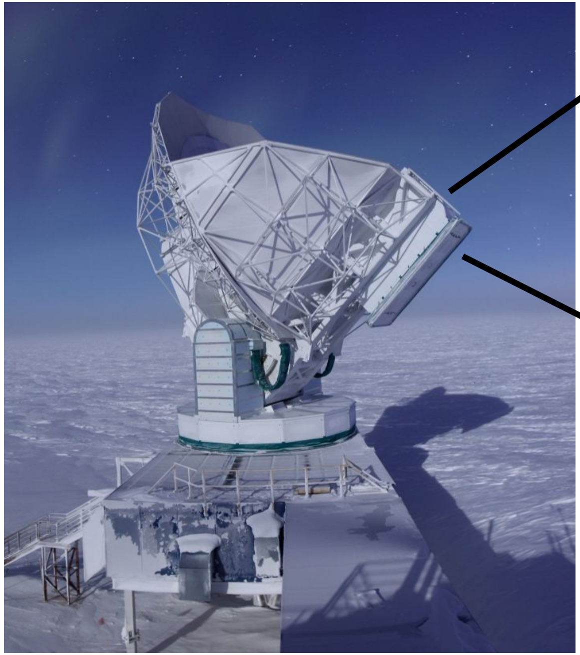
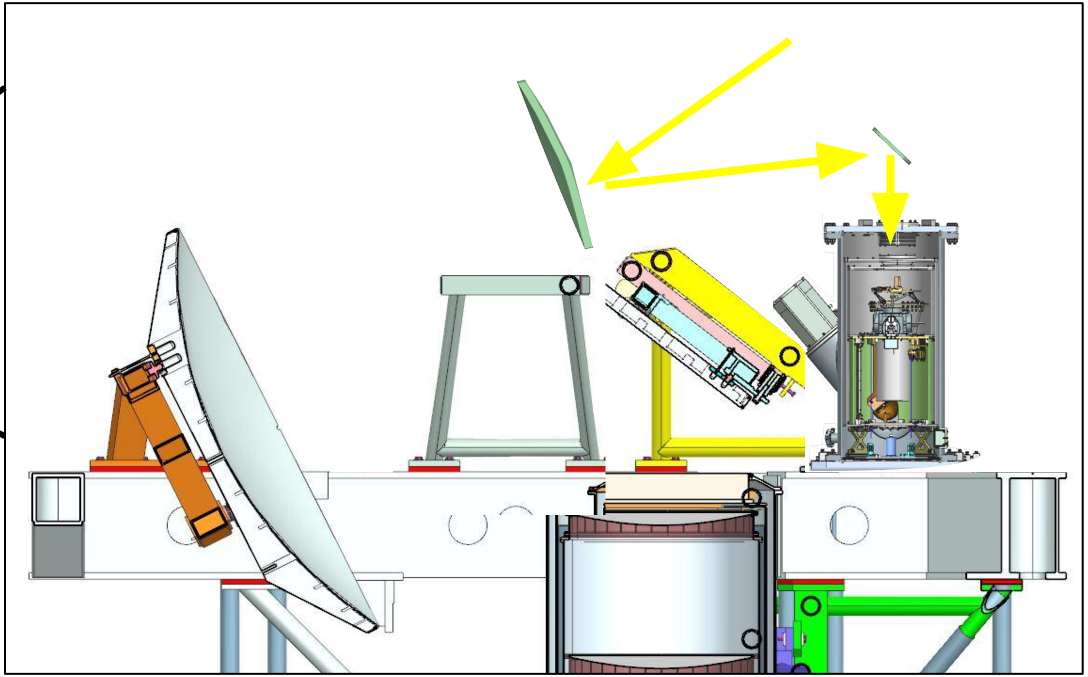
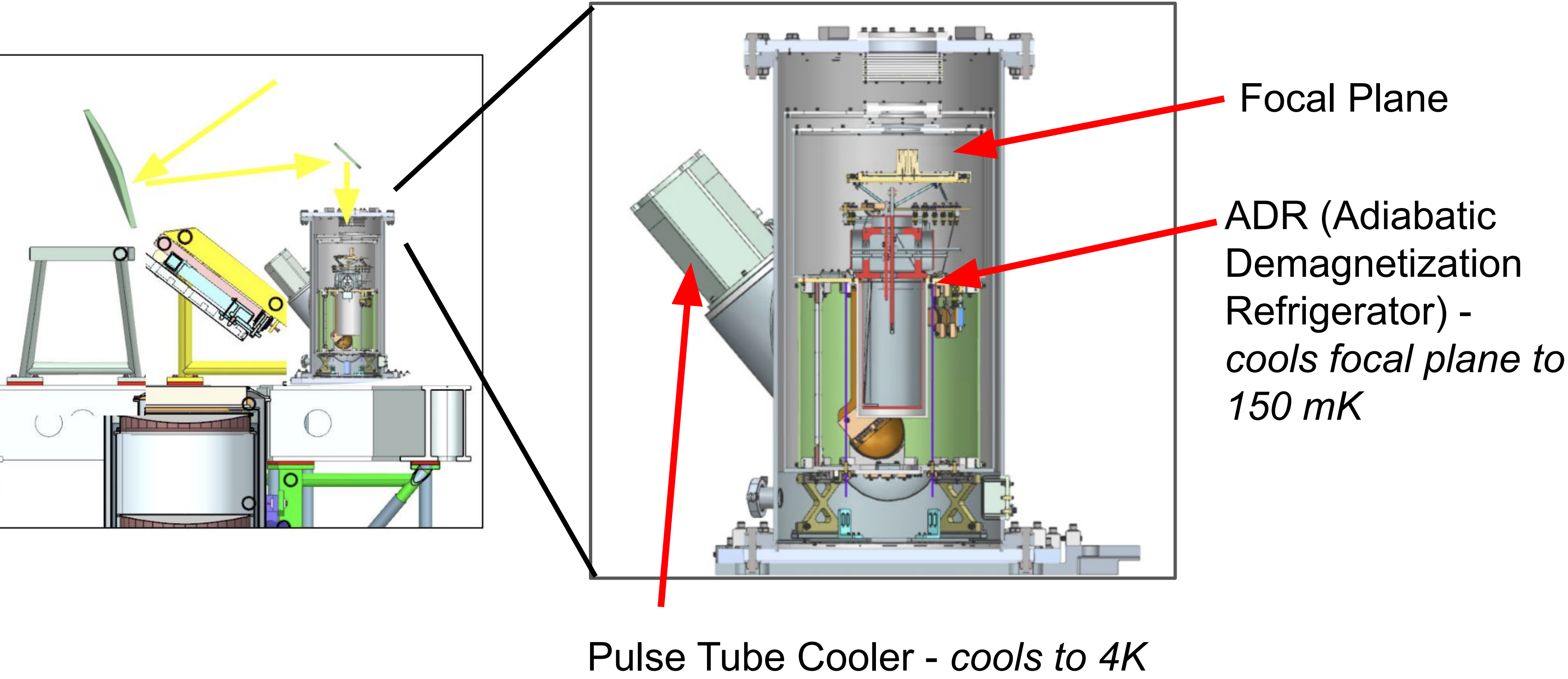




SPT-SLIM has two auxiliary mirrors to pick off the main SPT beam, while not disturbing the SPT-3G CMB experiment

SPT-SLIM: SPT Shirokoff Line Intensity Mapper



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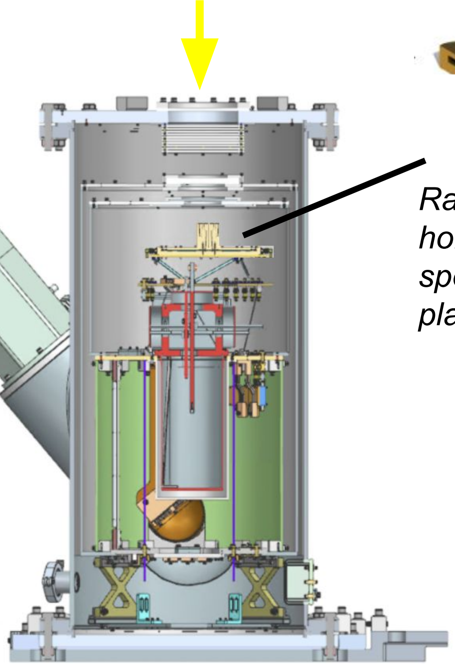
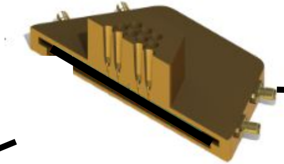
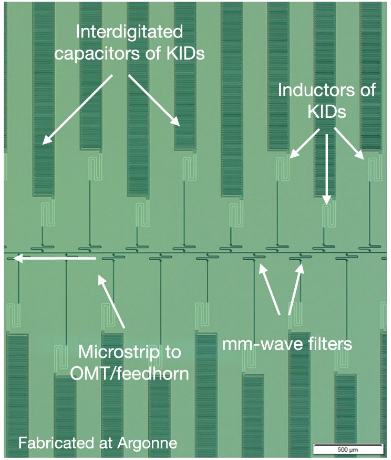


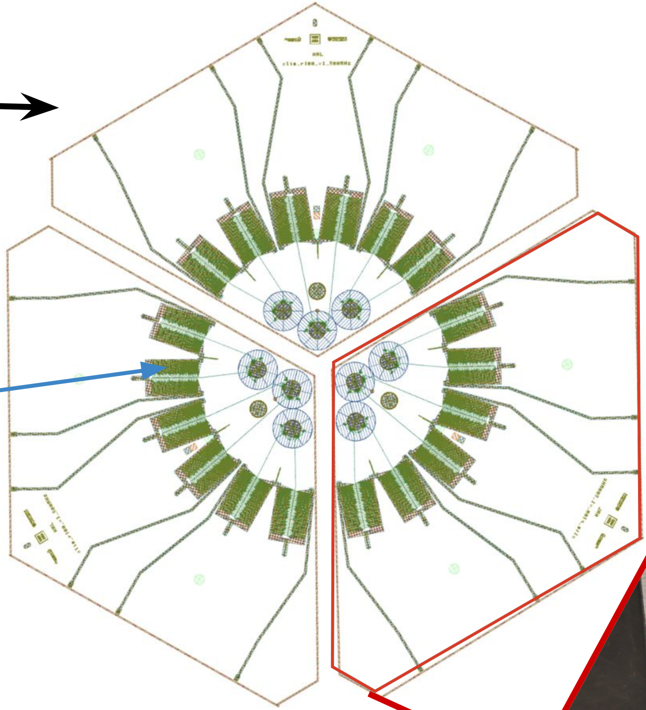


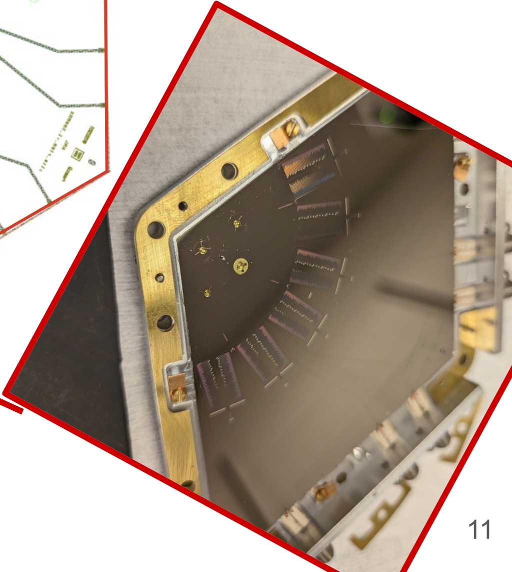
Radiation admitted by conical horns and coupled to spectrometer filterbanks by a planar OMT

KID filterbanks

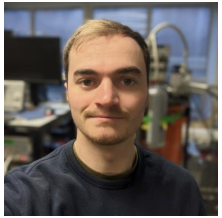


Fabricated at Argonne (C. Chang ++)





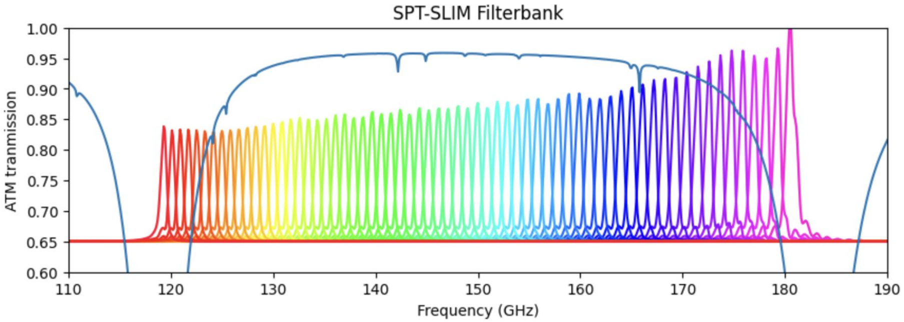
Focal plane consists of 3x "submodules" each with 3 pixels / 6 filter banks, tiled together in a scalable package.

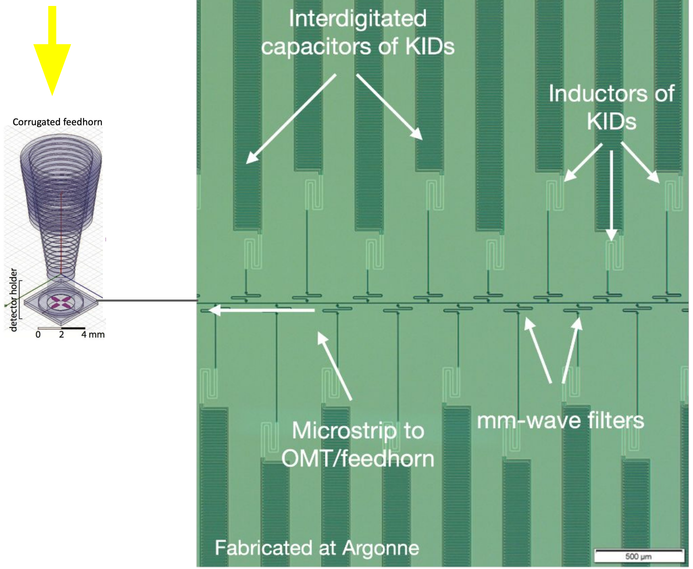


Designed at Cardiff (P.Barry, G. Robson)

On-Chip Spectrometers

- Filterbank design has R=100 with 65 channels in frequency range 120-180 GHz.





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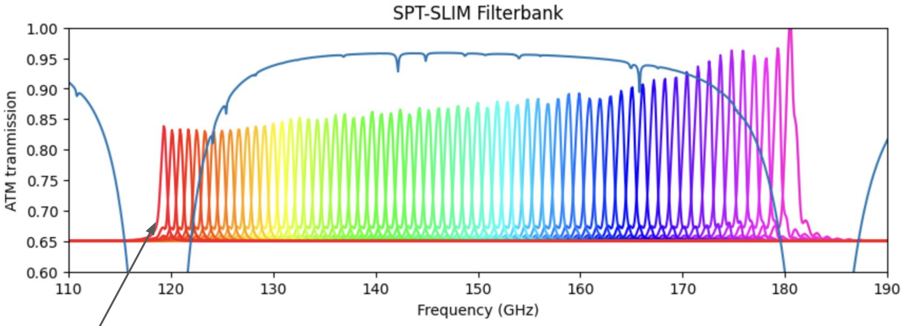

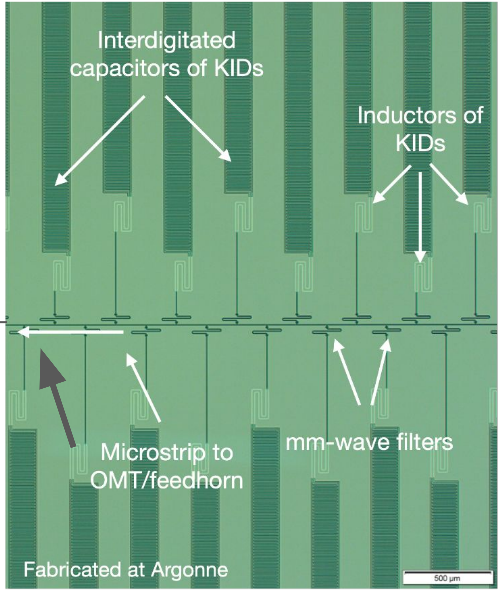

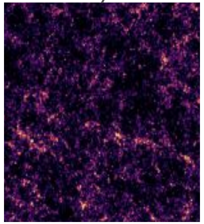

120 GHz

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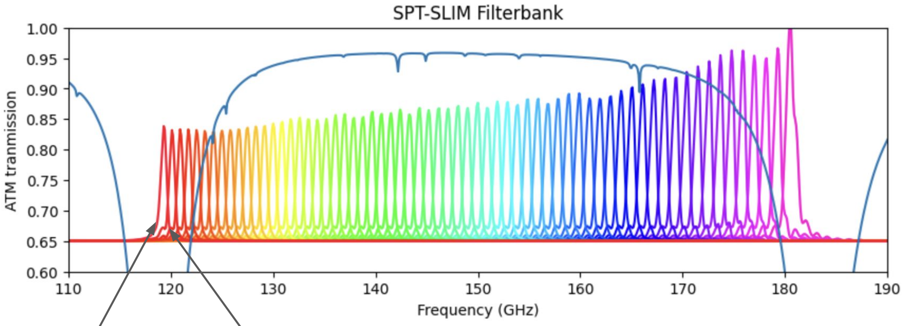
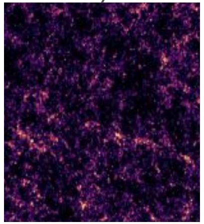
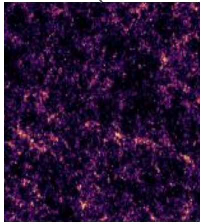
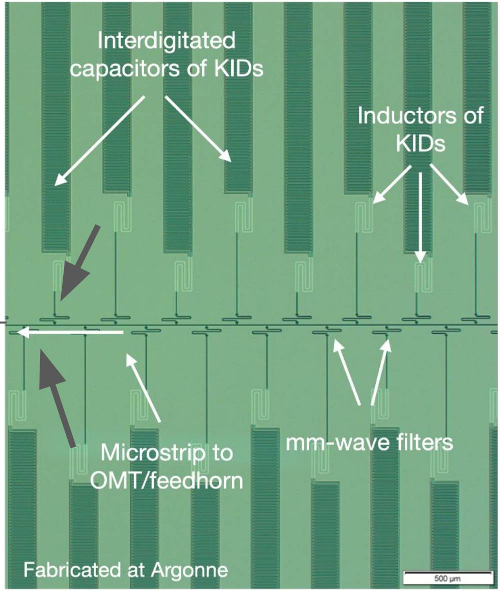




120 GHz



121 GHz



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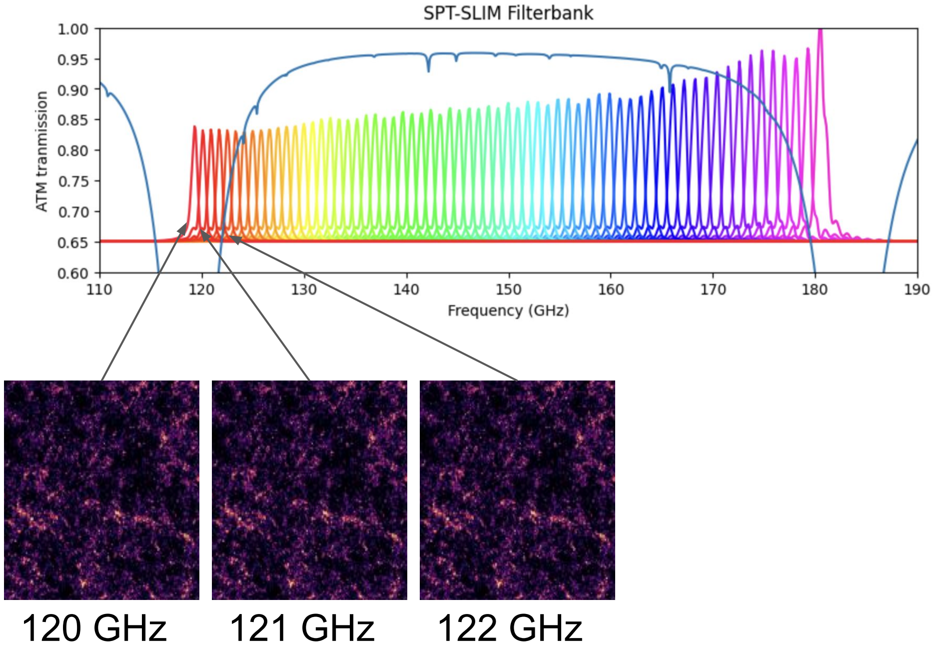

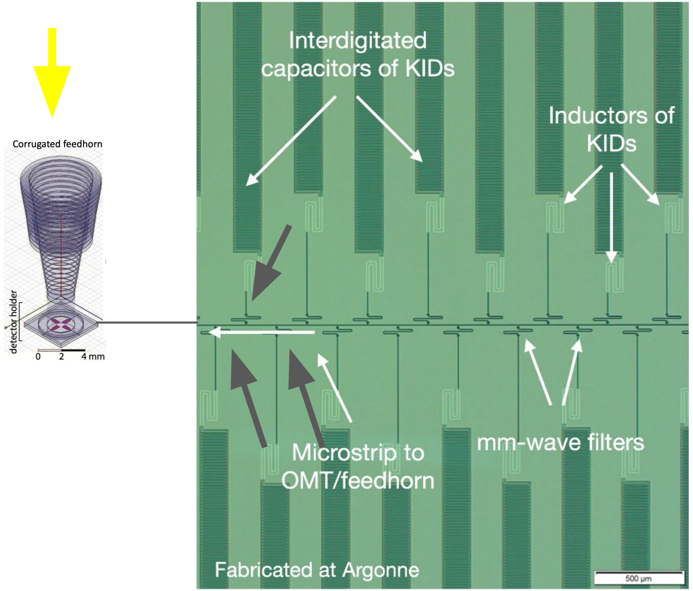

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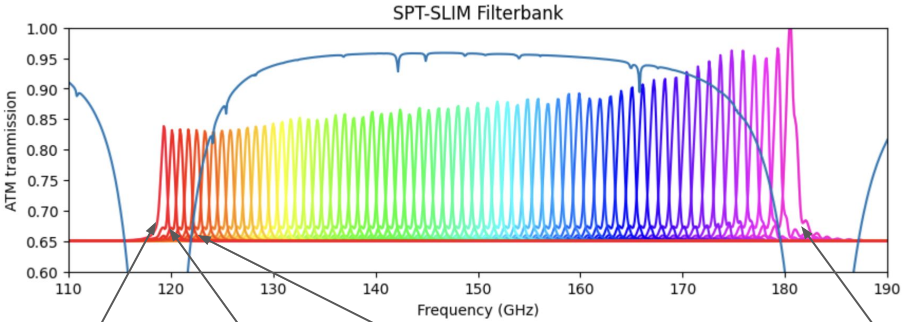

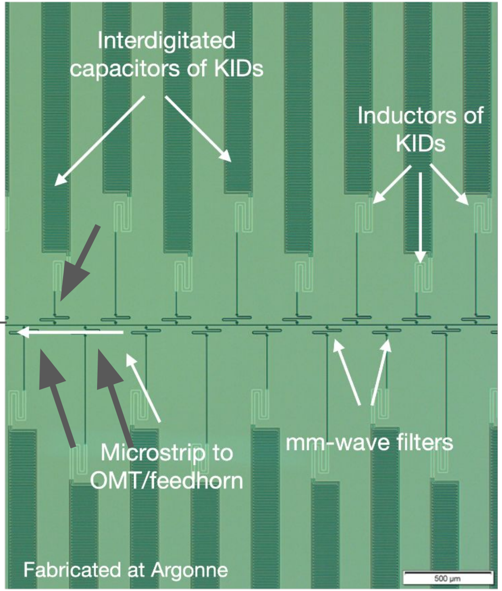

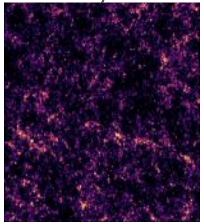
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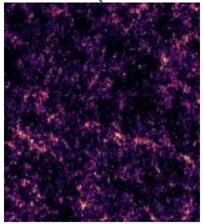
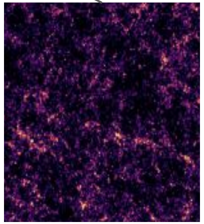
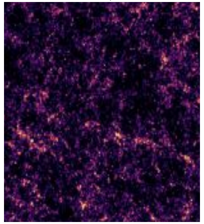

121 GHz


122 GHz

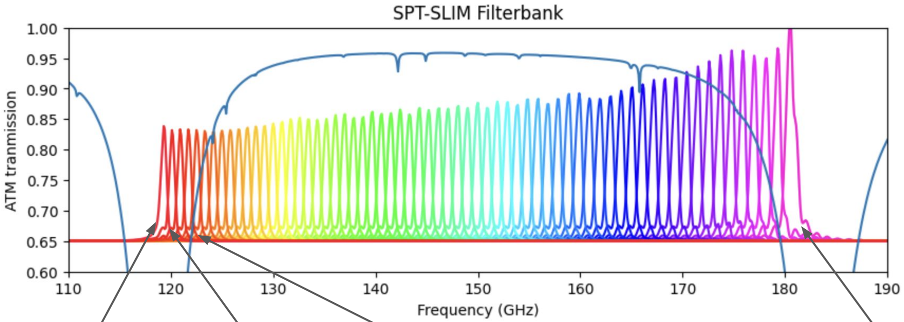
. . .

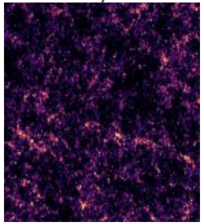

180 GHz

~65 maps, with 18 detectors going into each single frequency map

On-Chip Spectrometers

One Spectrometer (~65 detectors)





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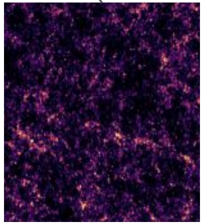
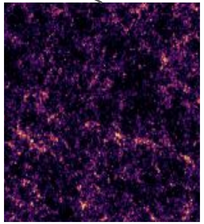


121 GHz



122 GHz

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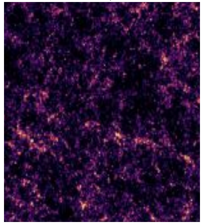
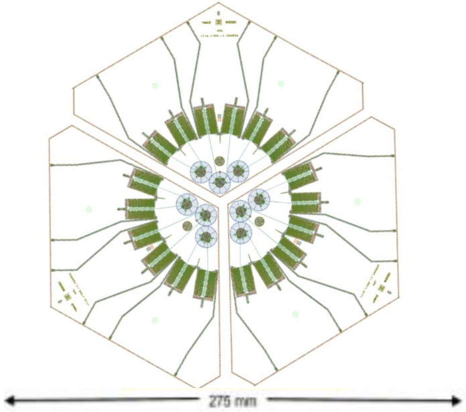


180 GHz

x 18 =

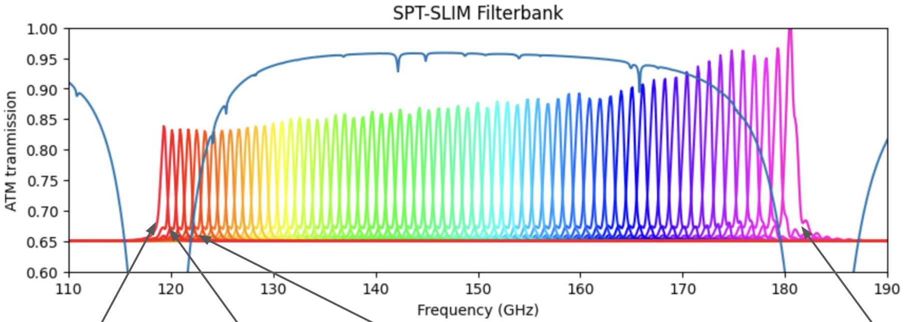


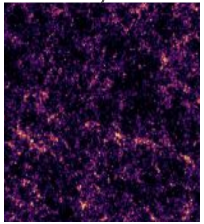
One SPT-SLIM
Focal Plane

~65 maps, with 18 detectors going into each single frequency map

On-Chip Spectrometers

One Spectrometer (~65 detectors)





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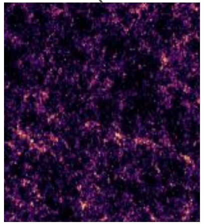

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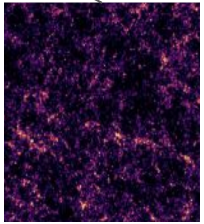

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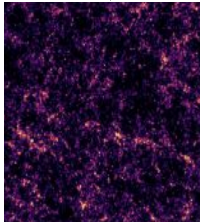

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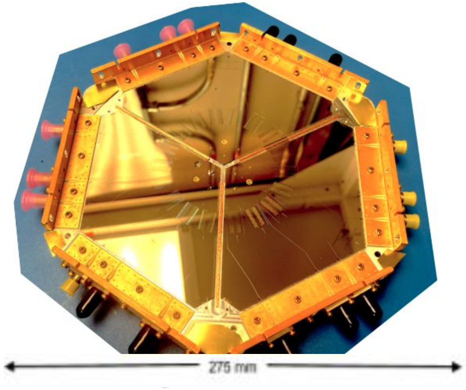
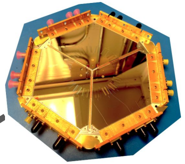
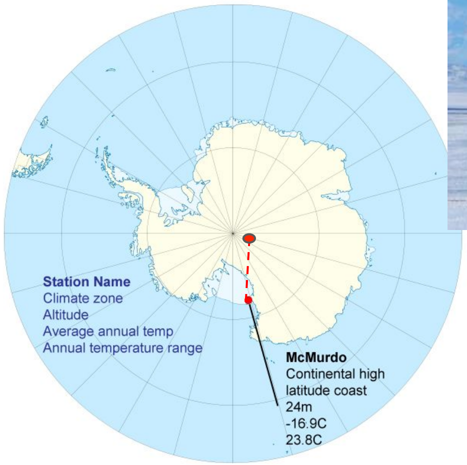


One SPT-SLIM Focal Plane

~65 maps, with 18 detectors going into each single frequency map



Fragile equipment
carried by hand

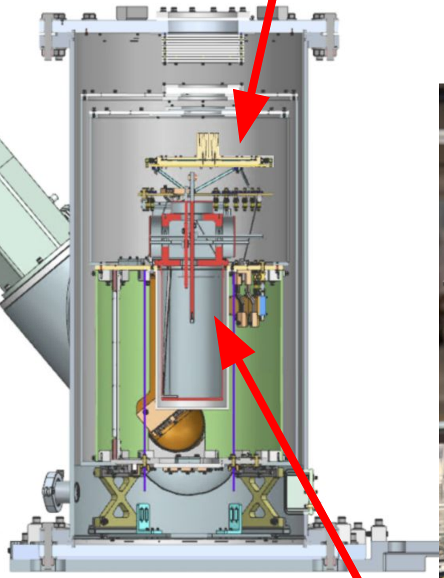


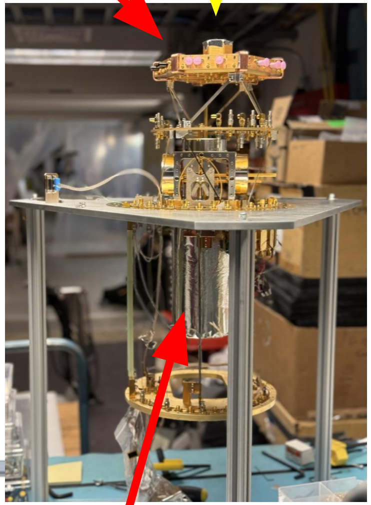
Rest of the equipment
in the cargo hold

Cargo Arrived: Dec 3rd, 2024

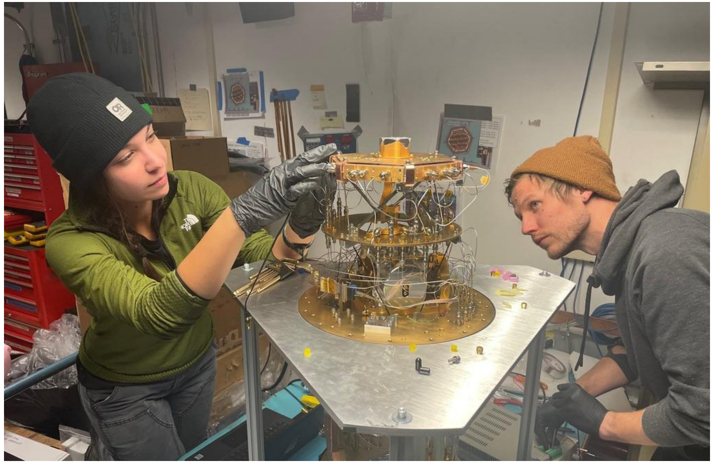
SPT-SLIM Cryostat Assembly

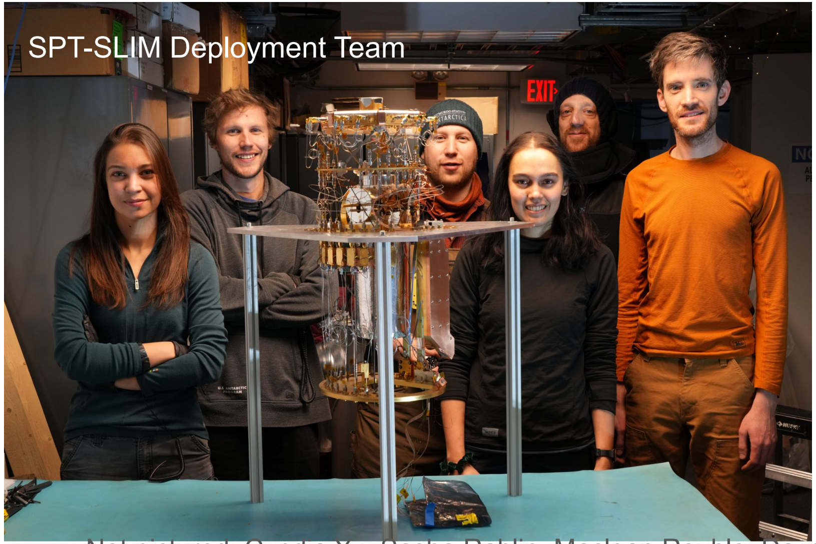
Focal Plane





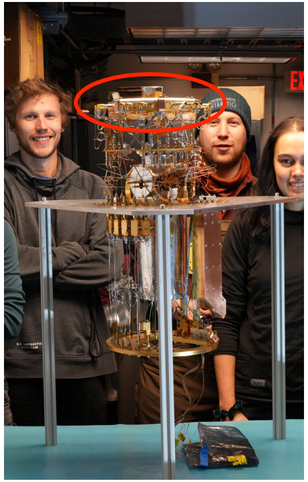
ADR (Adiabatic Demagnetization Refrigerator)

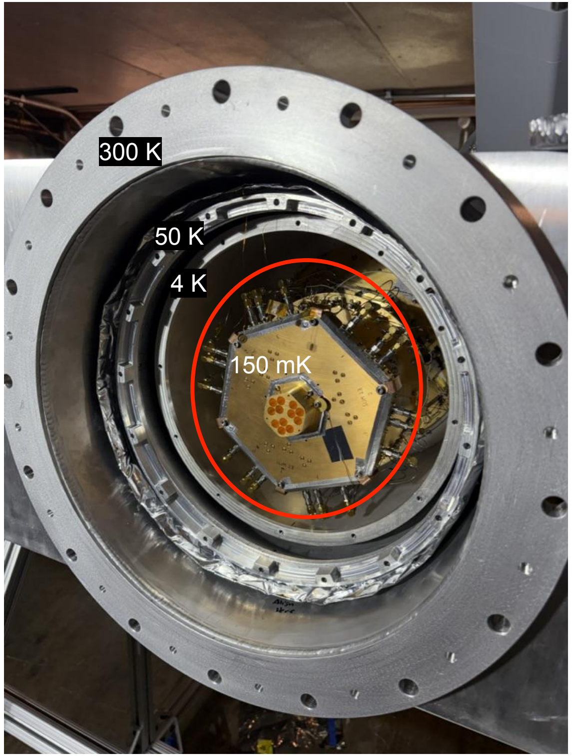




Not pictured: Cyndia Yu, Sasha Rahlin, Maclean Rouble, Dave Pernic

First SPT-SLIM Cooldown at Pole: Dec 16th





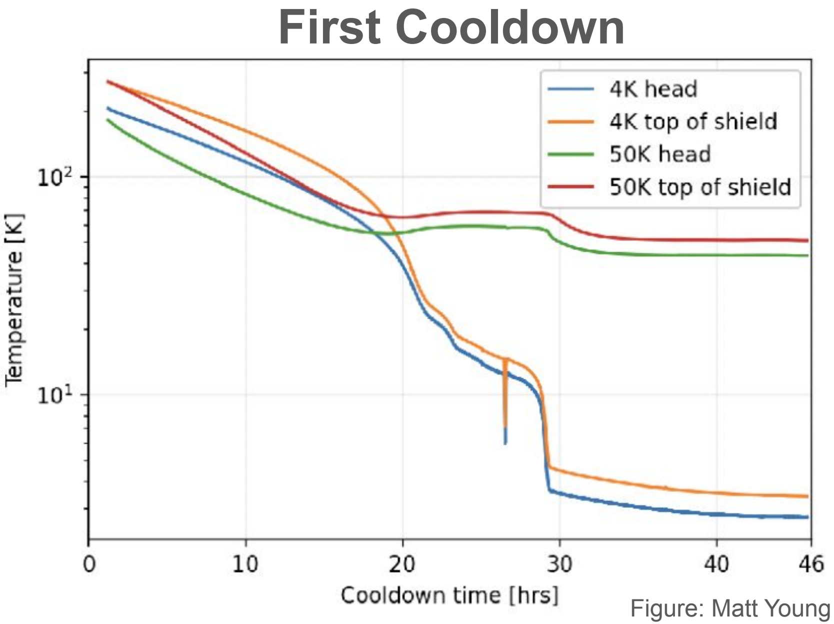
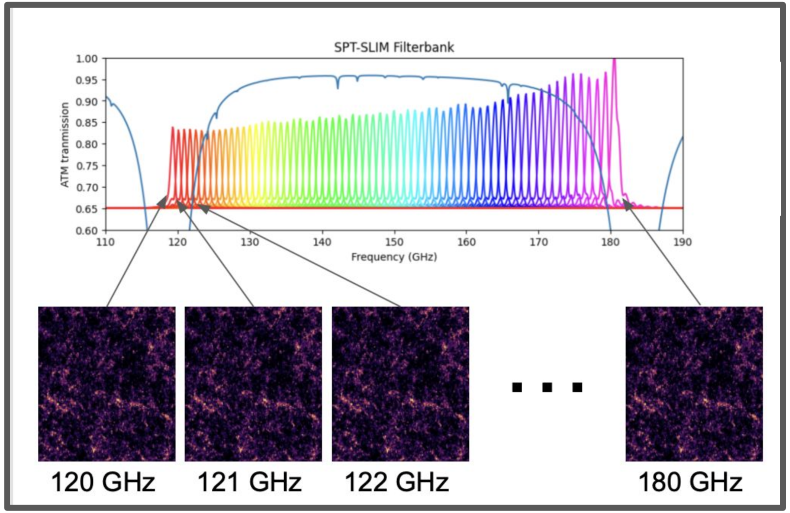
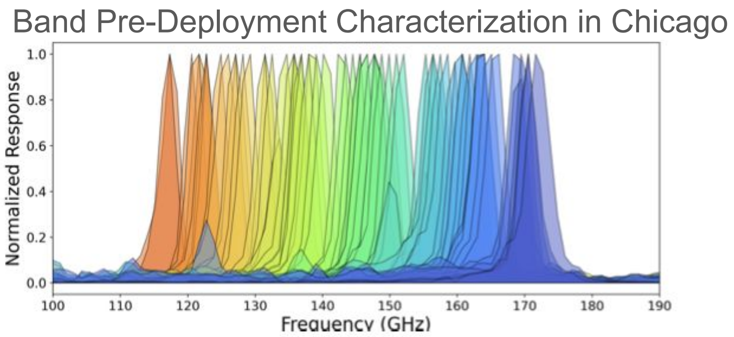


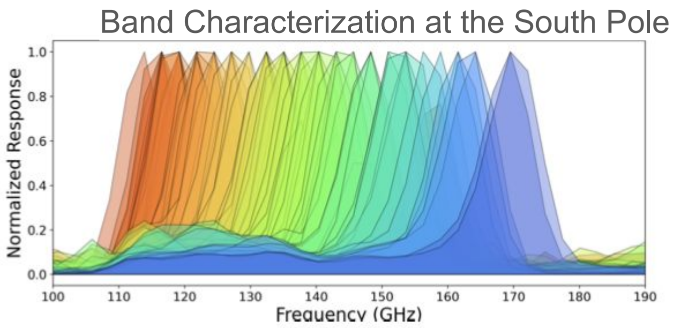
Figure: Matt Young

The cryogenic performance is in agreement with model expectations, enabling an observing efficiency of up to 81% with < 0.1mK temperature stability.

On-Ground Characterization Campaign







SLIM Detector Characterization Team

K. Dibert (Chicago)

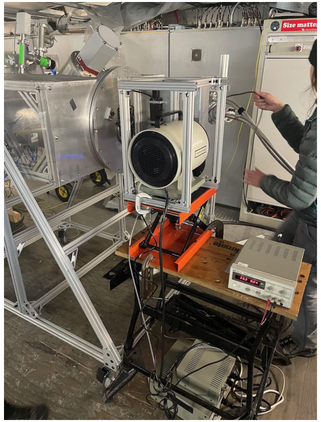
K. Fichman (Chicago)

Maclean Rouble (McGill)

& T. Natoli. C. Yu

Figures: Kyra Fichman and Chris Benson

On-Ground Characterization Campaign



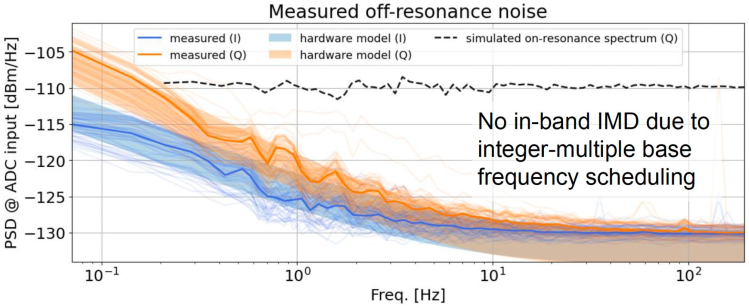
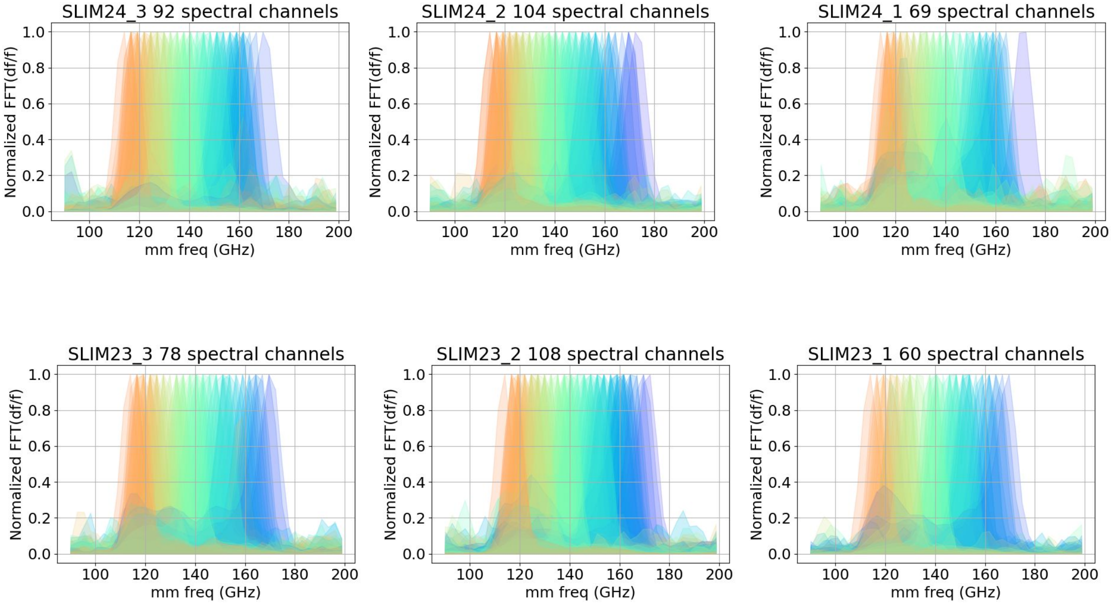
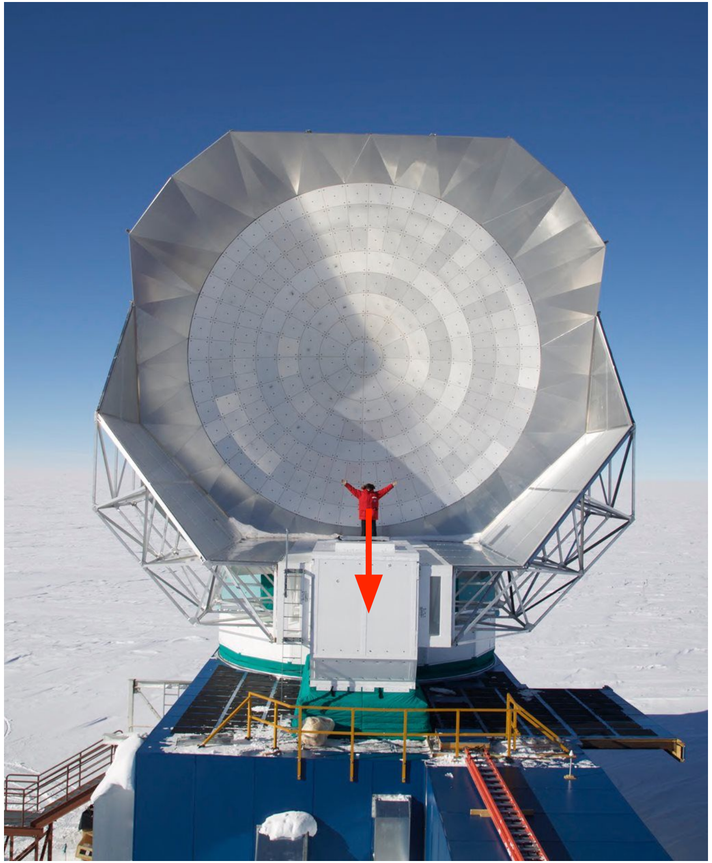


Figure: Maclean Rouble

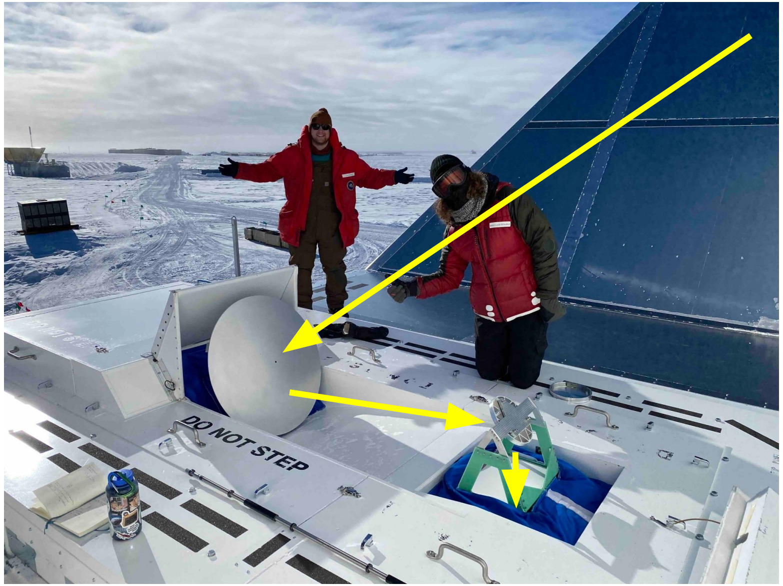


Figures: Karia Dibert

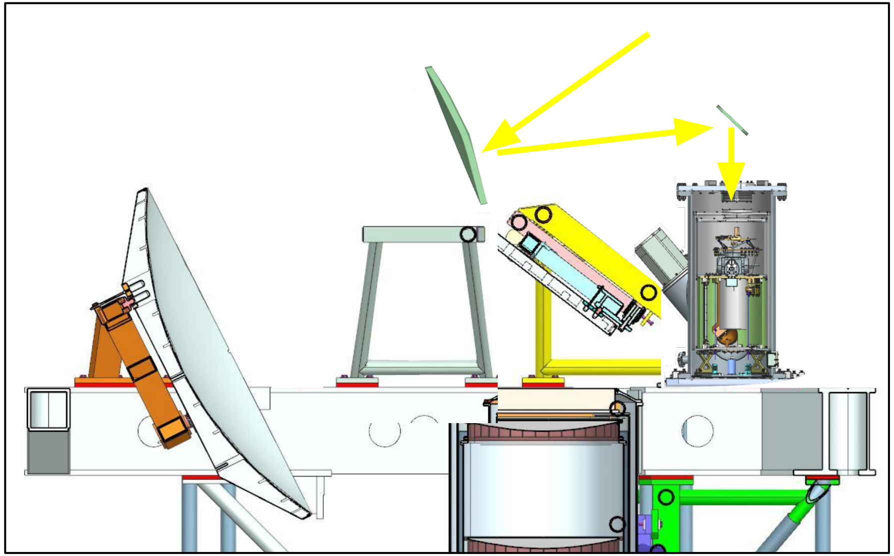
Lifting SPT-SLIM into the Telescope



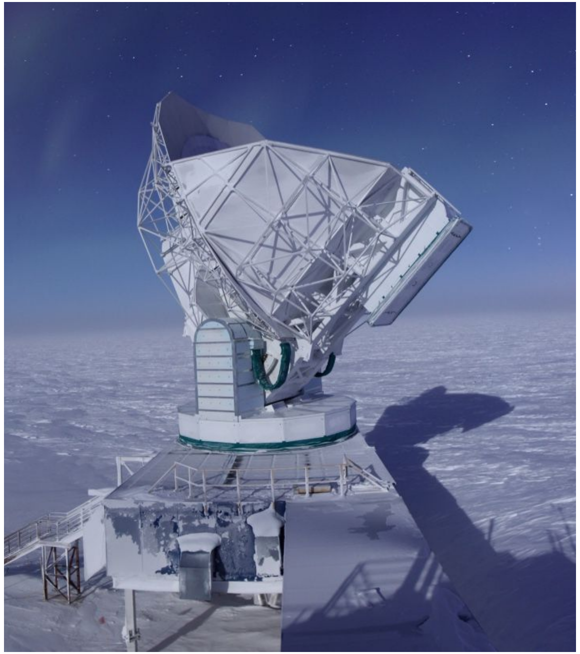
SPT-SLIM Optics

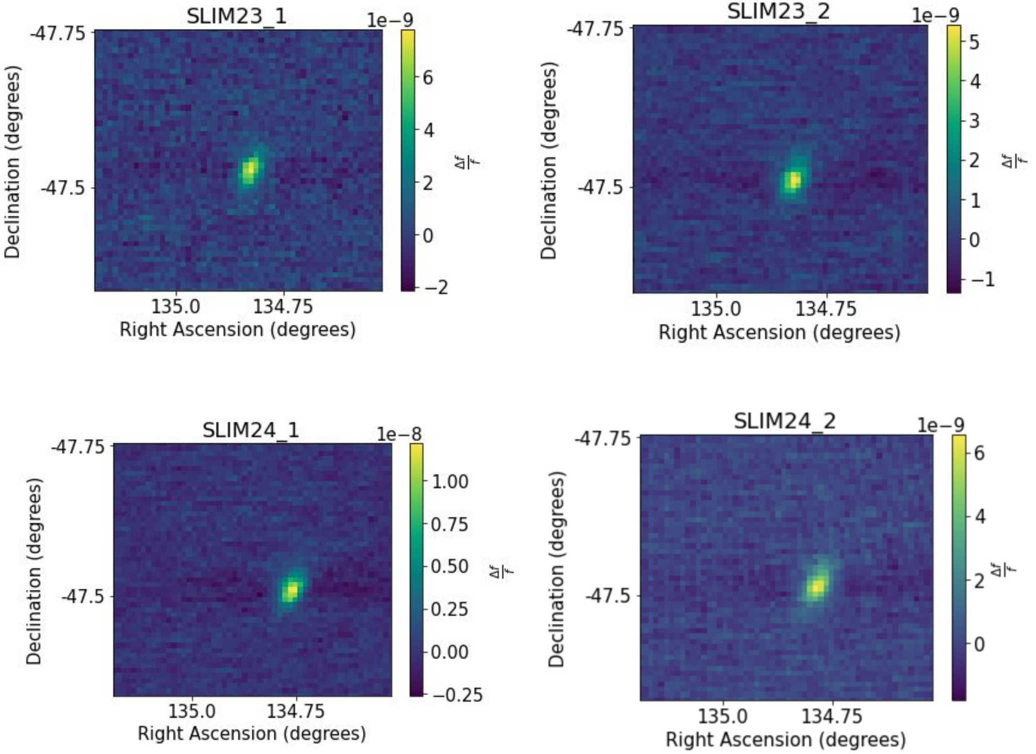


Optics: D. Kim, A. Anderson, K. Karkare



Jan 15th SPT-SLIM First Observed Source: RCW 38

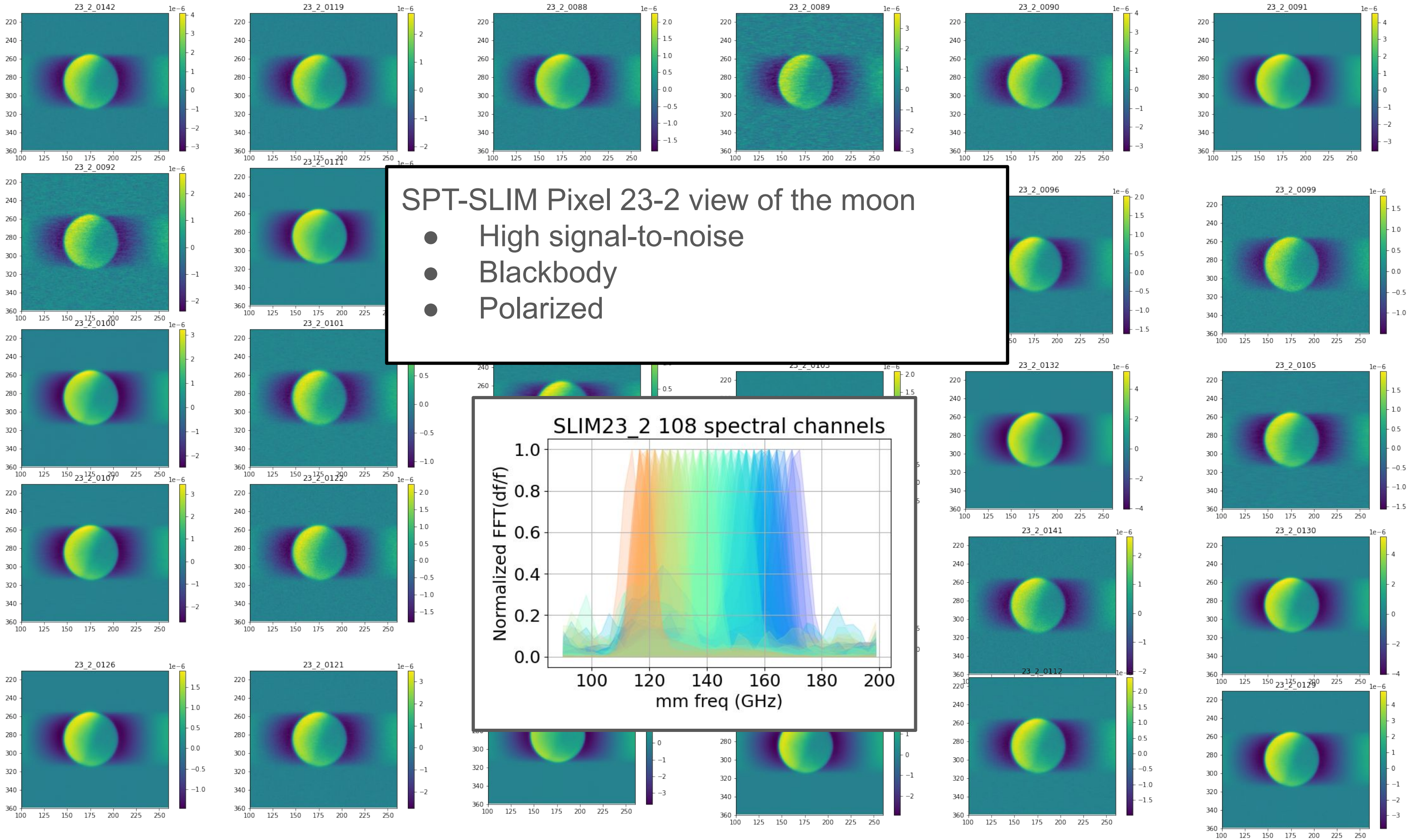




Filter-and-bin mapmaker, 4th order polynomial filter

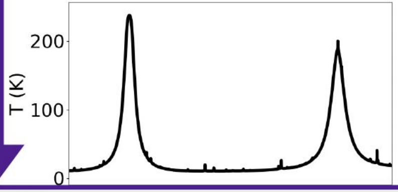
SPT-SLIM Pixel 23-2 view of the moon

- High signal-to-noise
- Blackbody
- Polarized

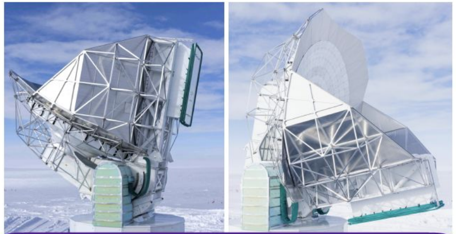


Atmospheric Calibration

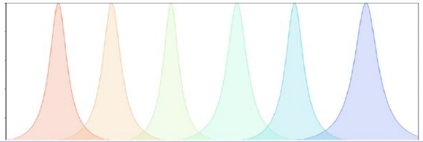
Obtain precipitable water vapor estimates from atmospheric tipper data.



Use *AM* software to generate atmospheric spectra for each observation.



Obtain MKID frequency response data from elevation slews.

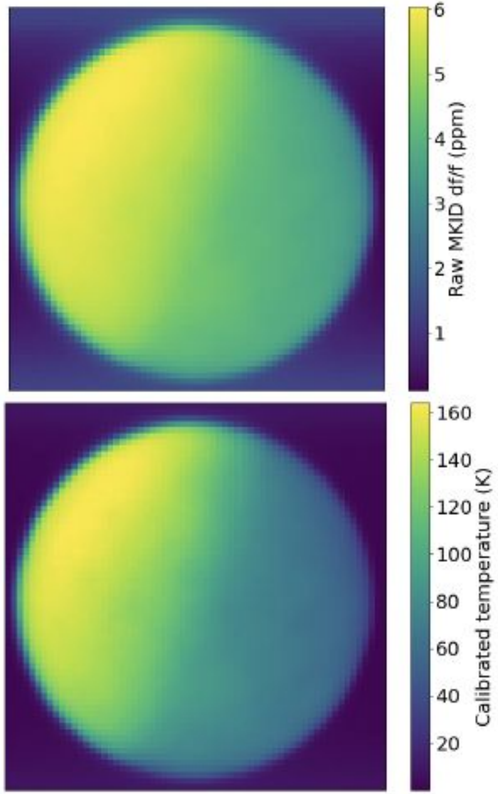


Obtain MKID bandpasses from Fourier Transform Spectrometer data.

Combine bandpasses with simulated atmospheric spectra to simulate atmospheric loading.

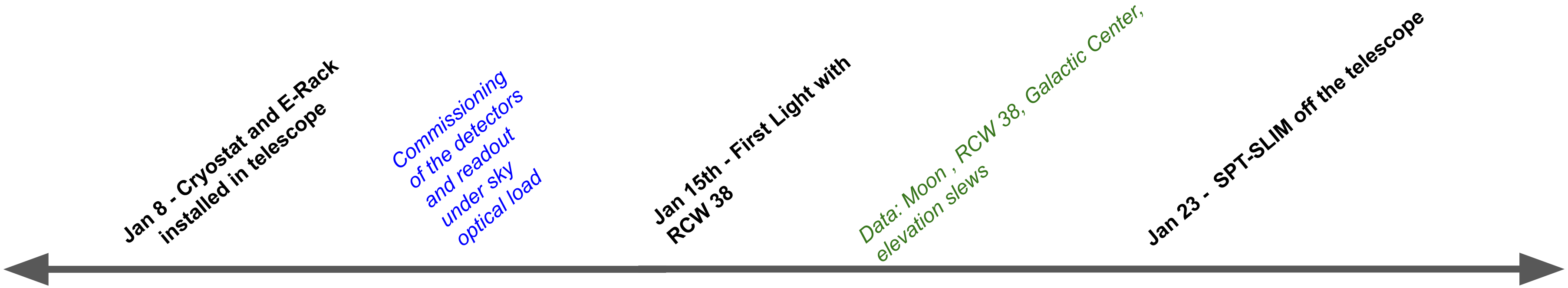
Fit MKID response data with a loading model, fitting jointly for detector response parameters and optical sidelobe power.

Moon



Figures: Karia Dibert

SPT-SLIM: Year 1 Observing Campaign



Commissioning:

- noise “stares”
- elevation slews (detector performance under changing optical load)
- refrigeration cycle optimization
- detector biasing optimization
- optimization of frequency placement

all optimizations to increase signal to noise of detectors, detector yield, and understanding if this performance lines up with expectations

Data:

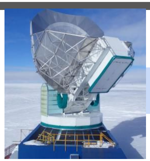
RCW 38, Moon, Galactic Center Observations (Sagittarius A*, Sagittarius B2), Mock Cosmology Field Scans - *analysis in progress!*

Given our limited schedule due to cargo delays, our focus was commissioning the receiver, understanding performance, and taking astrophysical source and calibration observations

SPT-SLIM: This is just the start for on-chip spectrometers!

2024 | 2025 | 2026 | 2027 | 2028 | 2029

SPT-SLIM Y1
Deployment:
CO Data



SPT-SLIM Y2
Deployment

SPT-SLIM Data Analysis

- Deployment of mm-wave on-chip spectrometers for line intensity mapping

- Deployment of more sensitive detectors and a deeper field survey