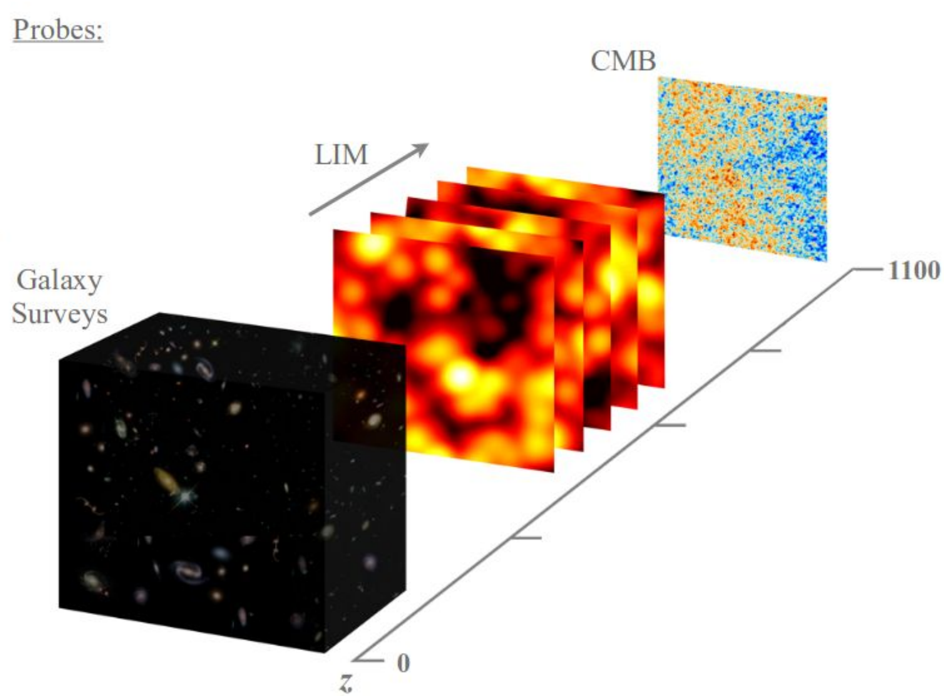
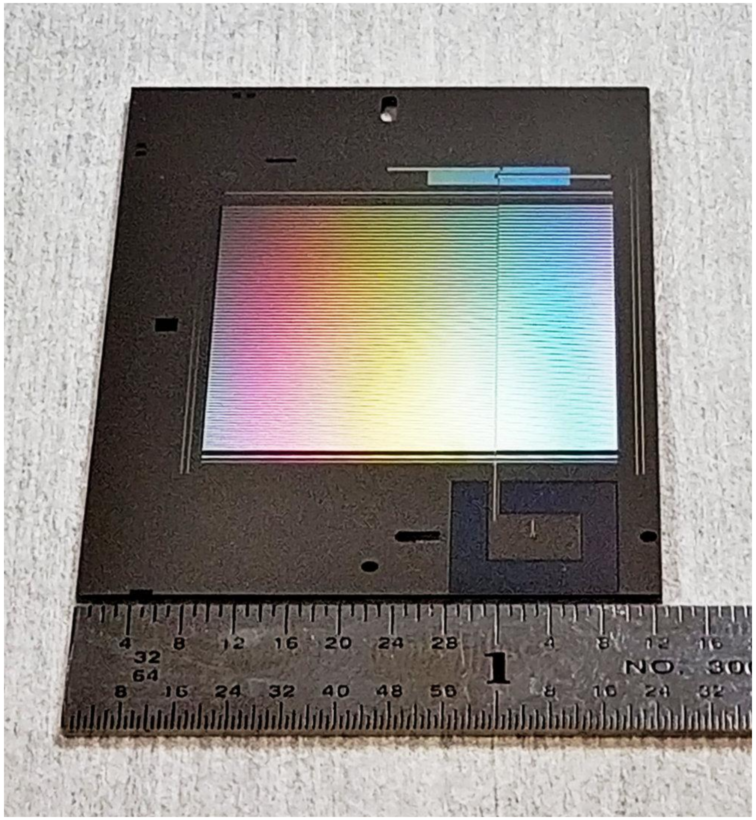
Cosmology with On-Chip Superconducting Millimeter-Wave Spectrometers





Kirit S. Karkare
NSF/Schramm Fellow @ University of Chicago/Fermilab
CPAD, 2021-03-19

Outstanding Questions in Cosmology

Did **inflation** set the initial conditions that we see in the CMB?

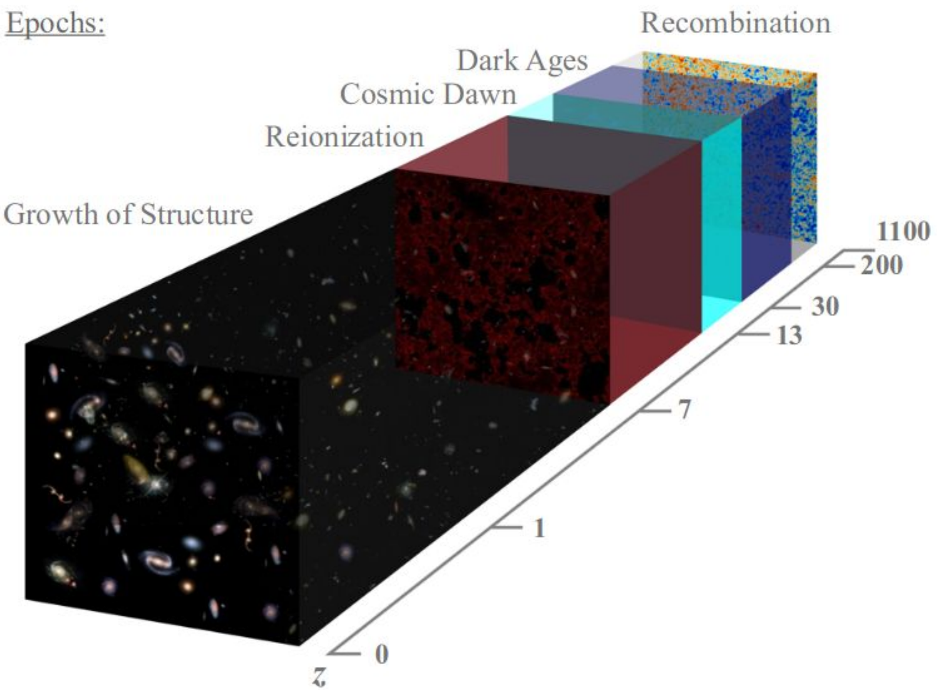
What is the **dark matter**?

What is the **dark energy** causing the present-day acceleration?

Tensions, e.g. Hubble constant

Line intensity mapping white paper
arXiv: 1903.04496

Observables of Large-Scale Structure



Line intensity mapping white paper
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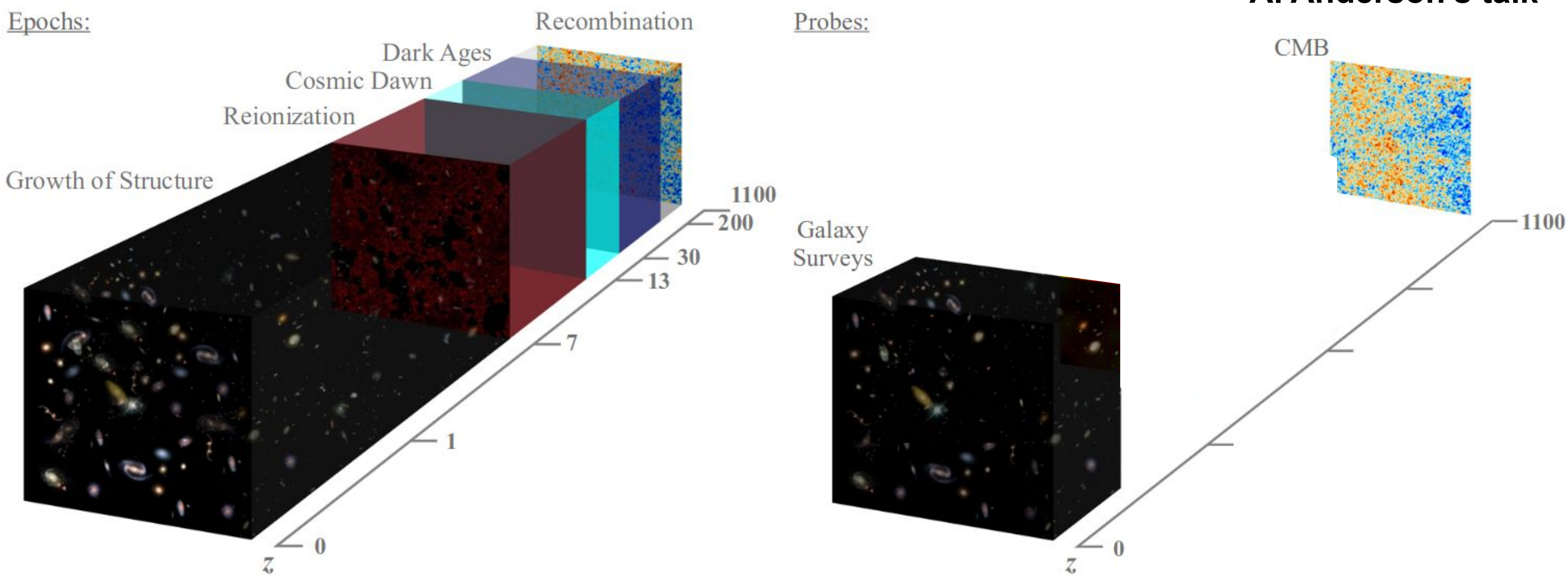
Observables of Large-Scale Structure

A. Anderson's talk



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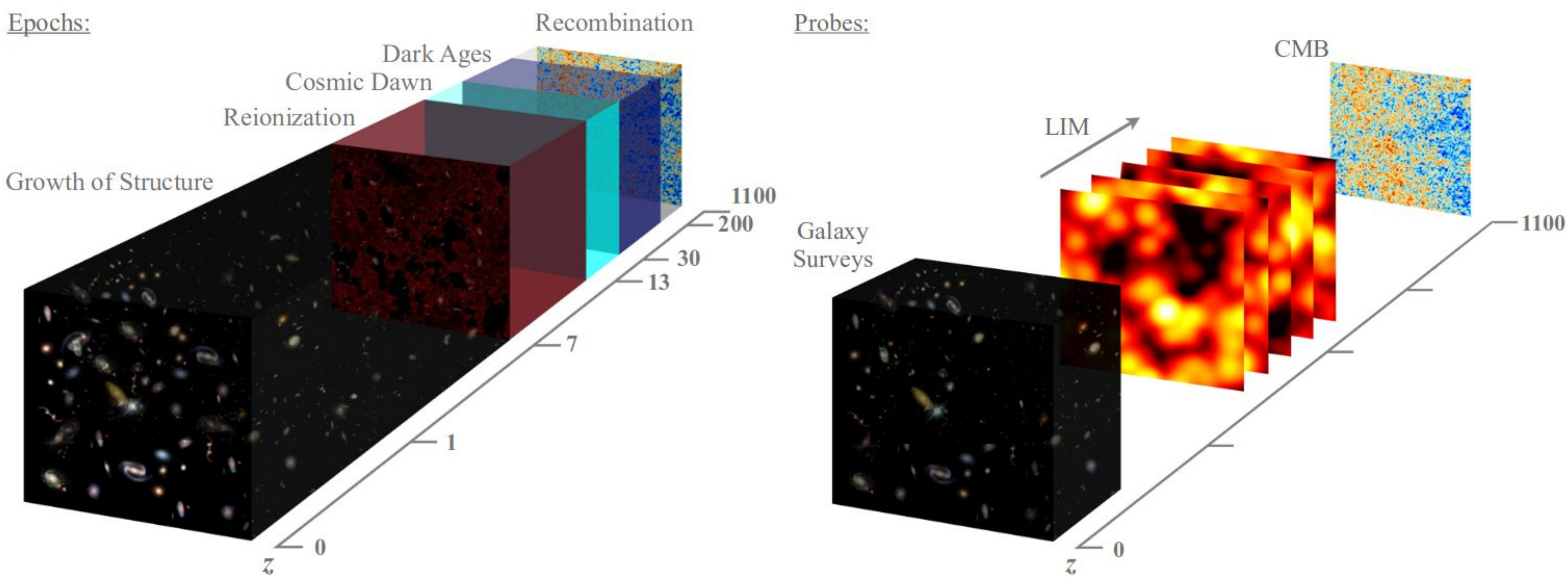
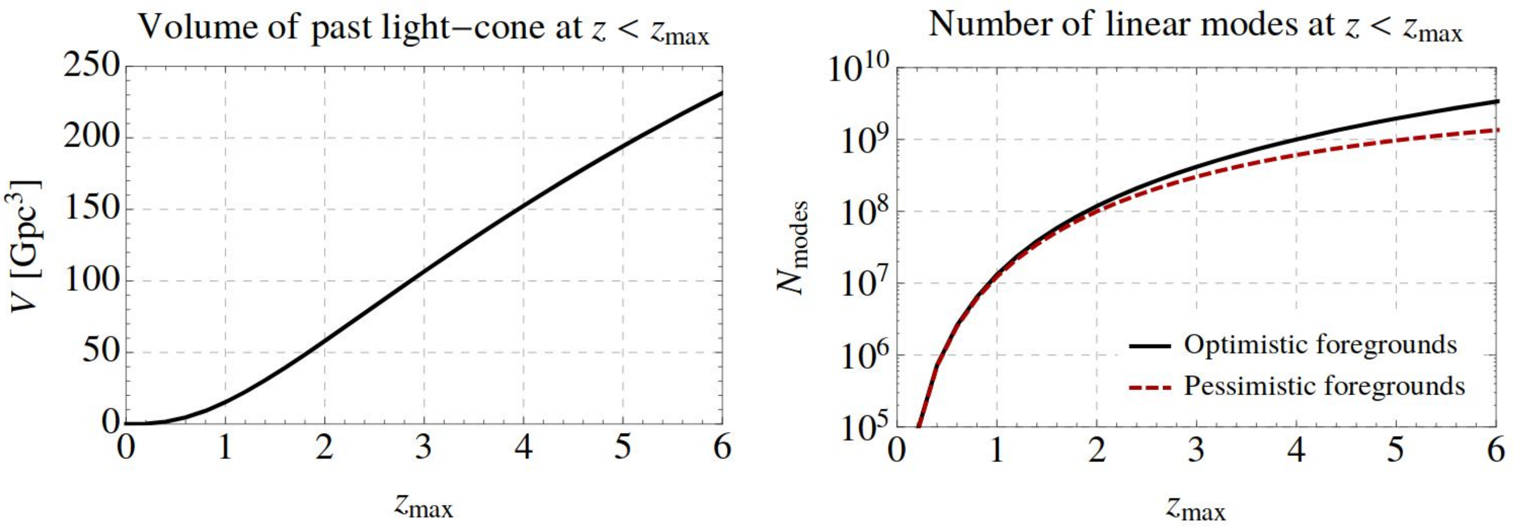


"Line Intensity Mapping" (LIM): using low angular resolution observations of a spectral line to map a 3D volume (wavelength → redshift), *without resolving individual sources*.

Why consider LIM?

$$\frac{1}{\sqrt{N_{\mathrm{modes}}}}$$

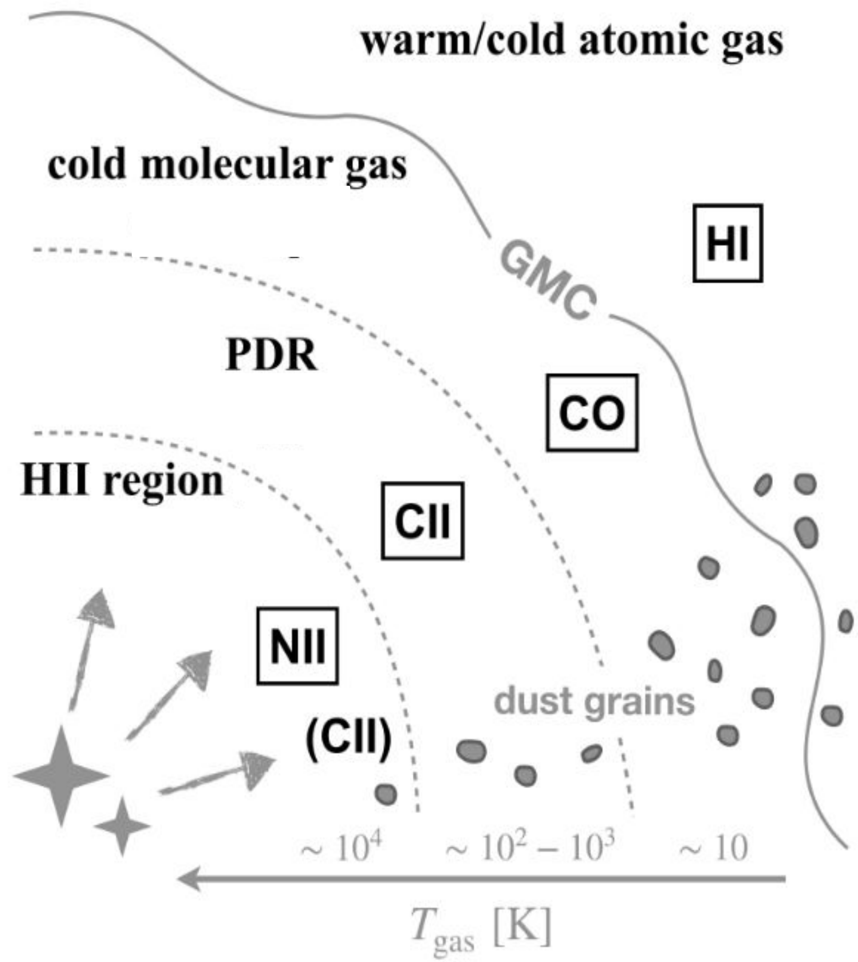
- Precision in cosmology scales with the survey volume/mode count
- **LIM is much more efficient at measuring high-redshift structure**



HI Stage 2 White paper
arXiv: 1810.09572

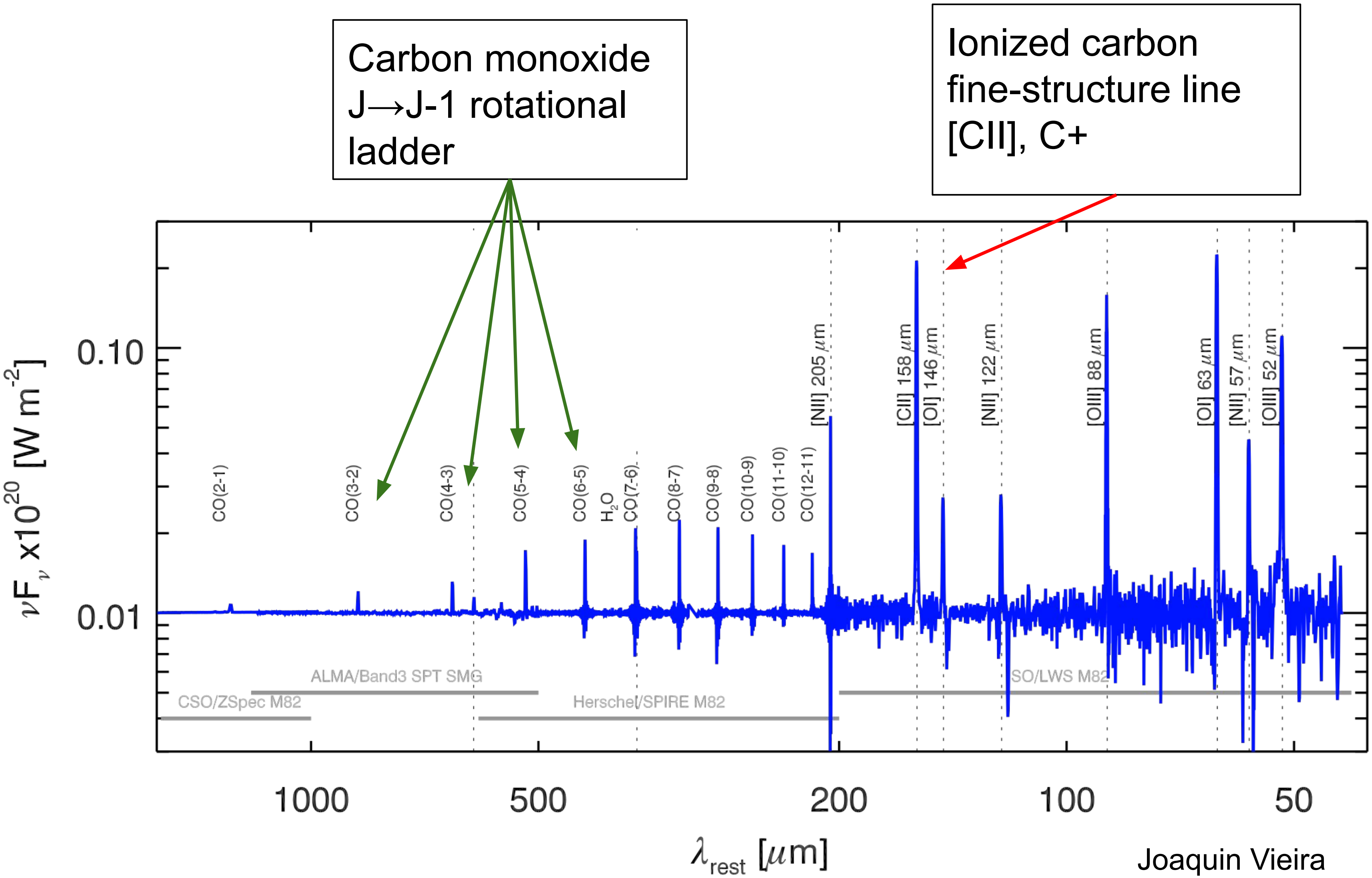
- Larger volume for tighter constraints on **non-Gaussianity** and tests of multi-field inflation (Moradinezhad Dizgah+ 2019)
- Measure the **expansion history** during the matter-dominated era (Karkare & Bird 2018) - test dynamical dark energy

Far-IR Lines in Star-Forming Galaxies



Sun+ 2019

Far-IR Lines in Star-Forming Galaxies

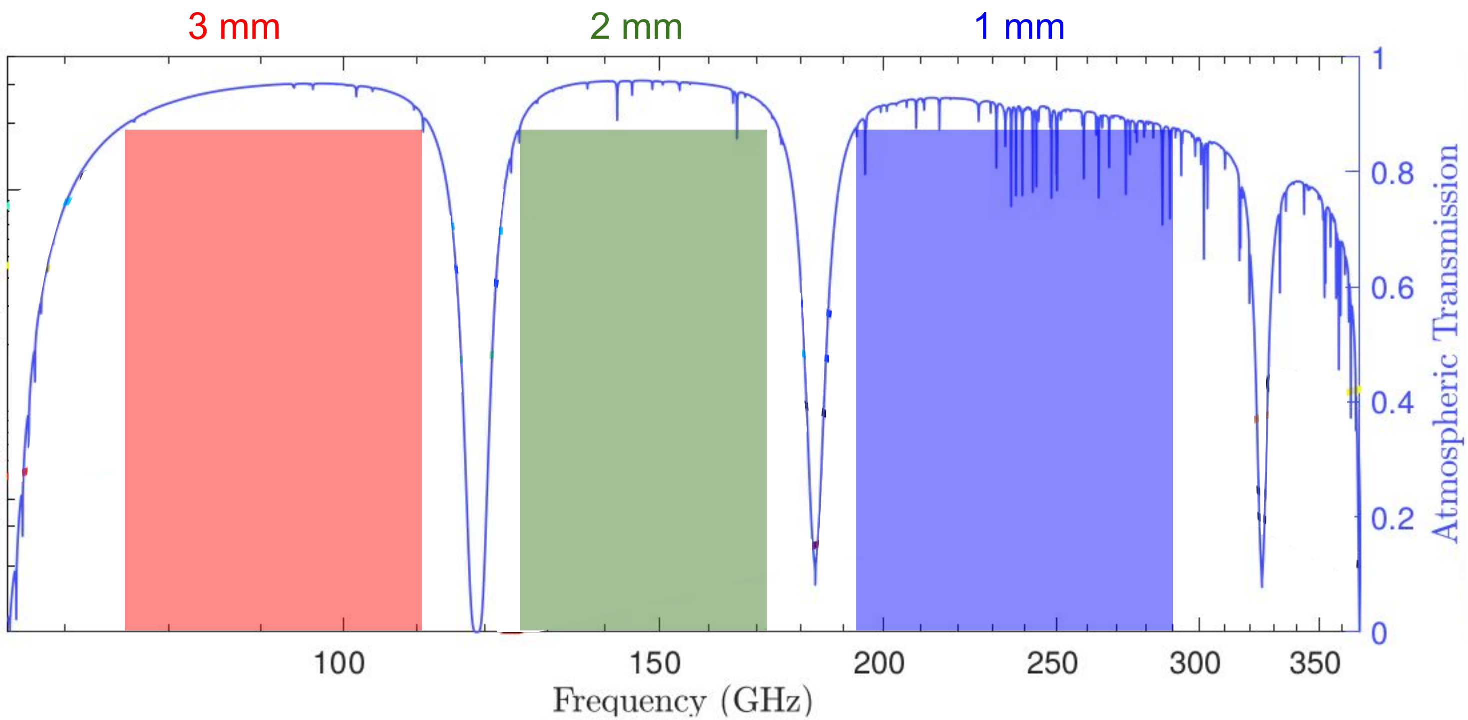


Joaquin Vieira

LIM at mm wavelengths

CMB instruments observe in broad bands defined by mm-wave atmospheric windows.

Karto Keating



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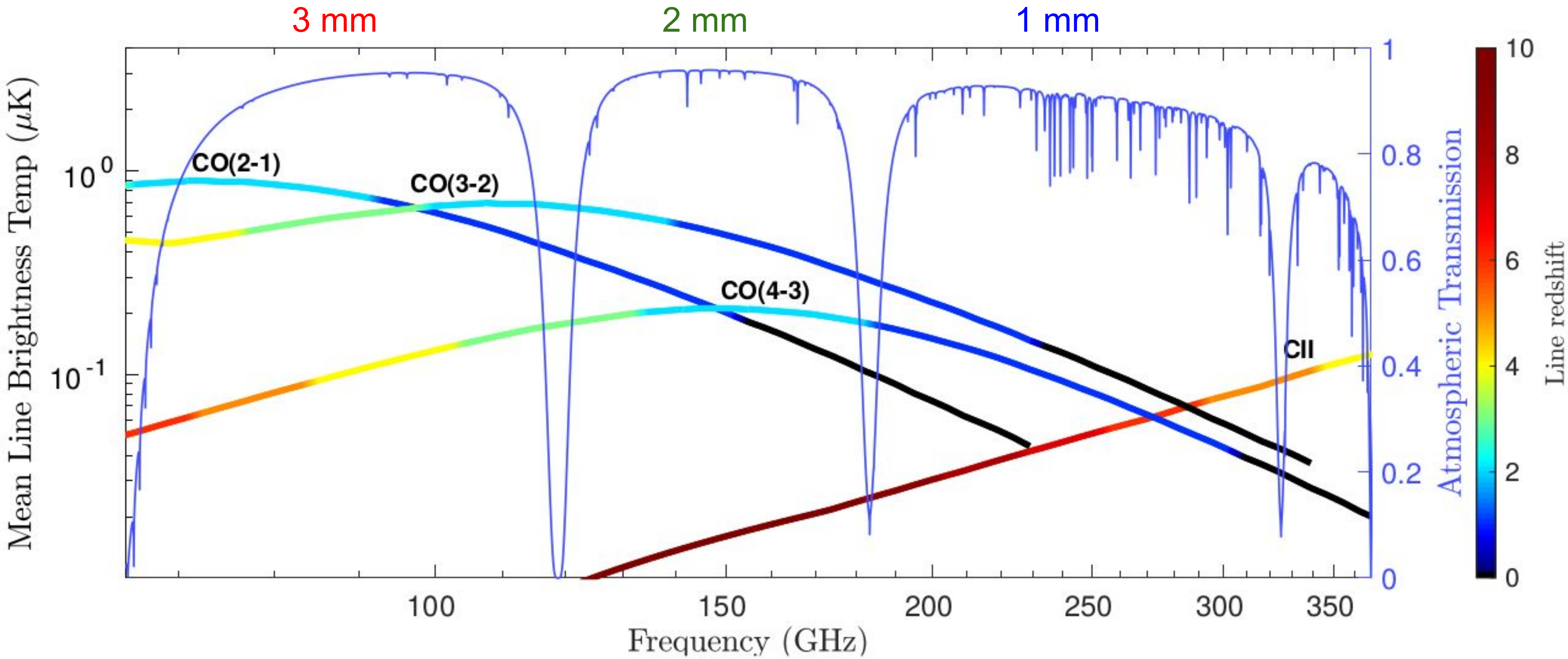
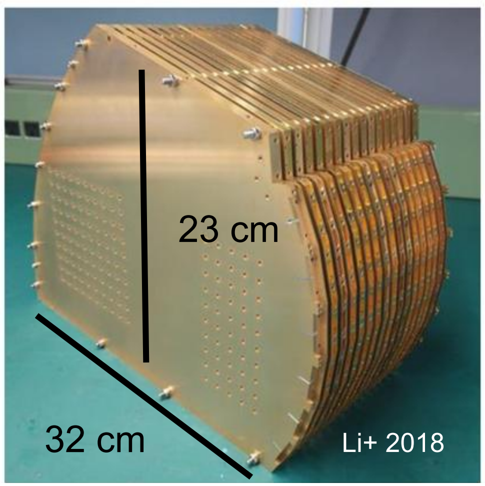


For LIM, just add moderate-resolution spectroscopy to access 3rd dimension!

On-Chip Spectroscopy Enables Large Arrays

Space inside the telescope is at a premium.

Instead of using a diffraction grating (or Fabry-Perot or Fourier Transform Spectrometer), print a spectrometer on a silicon wafer.



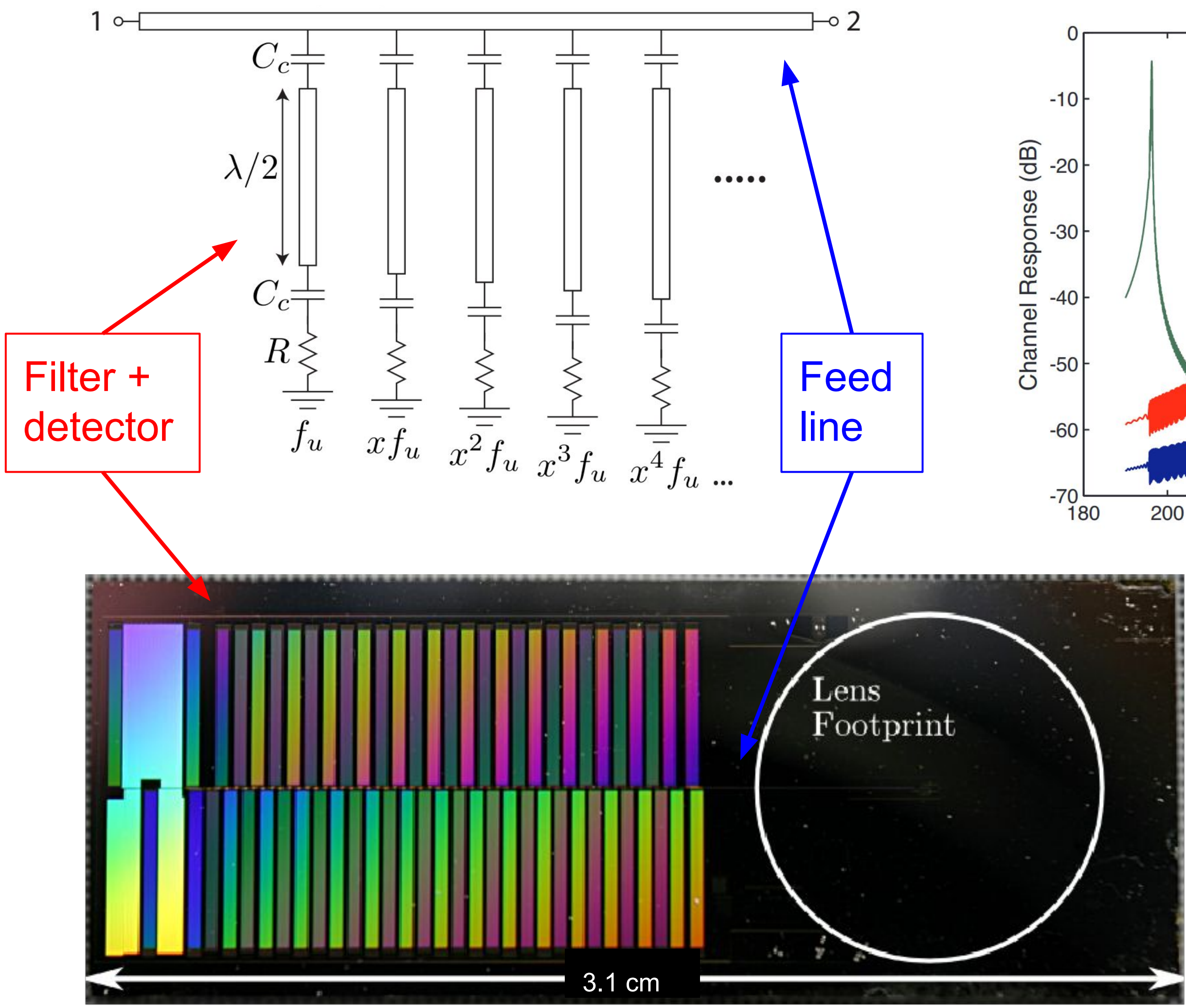
Compare one spectrometer:

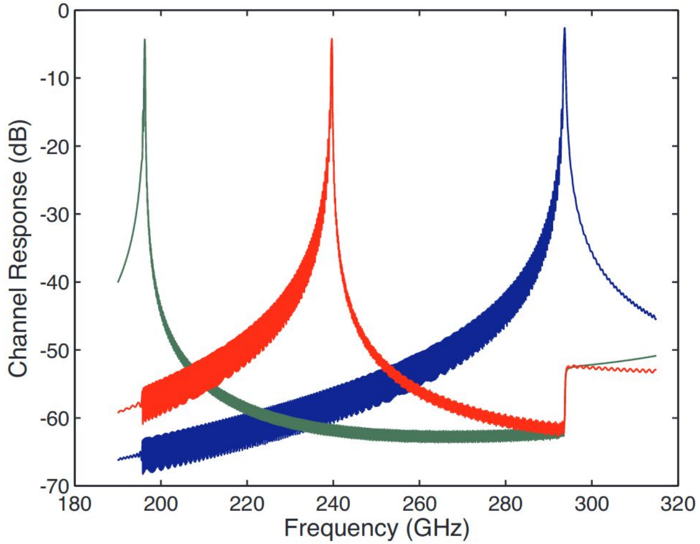
TIME grating
32 x 23 x 1 cm **~ 736 cm^3**

SuperSpec
3.6 x 5.7 x 0.05 cm **~ 1 cm^3**

Could pack orders of magnitude more spectrometers in a given volume!

SuperSpec: A Filter-Bank Spectrometer Printed on Silicon

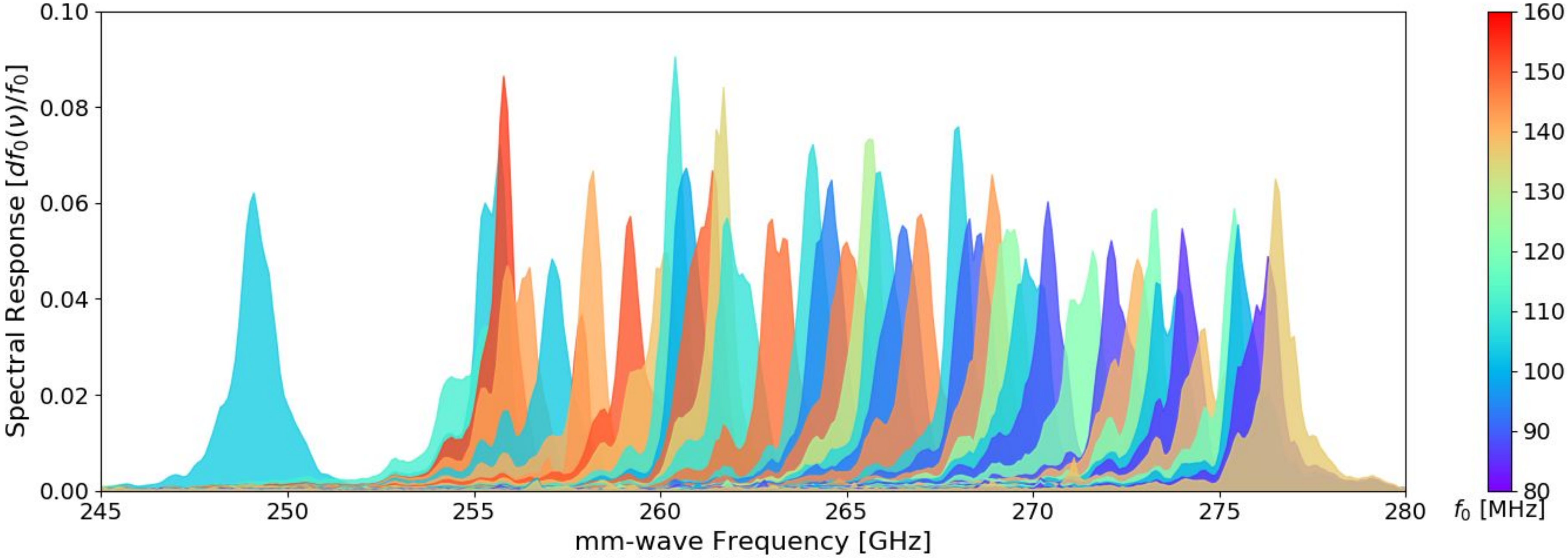




Kovacs & Zmuidzinas 2010

Spectral Profiles

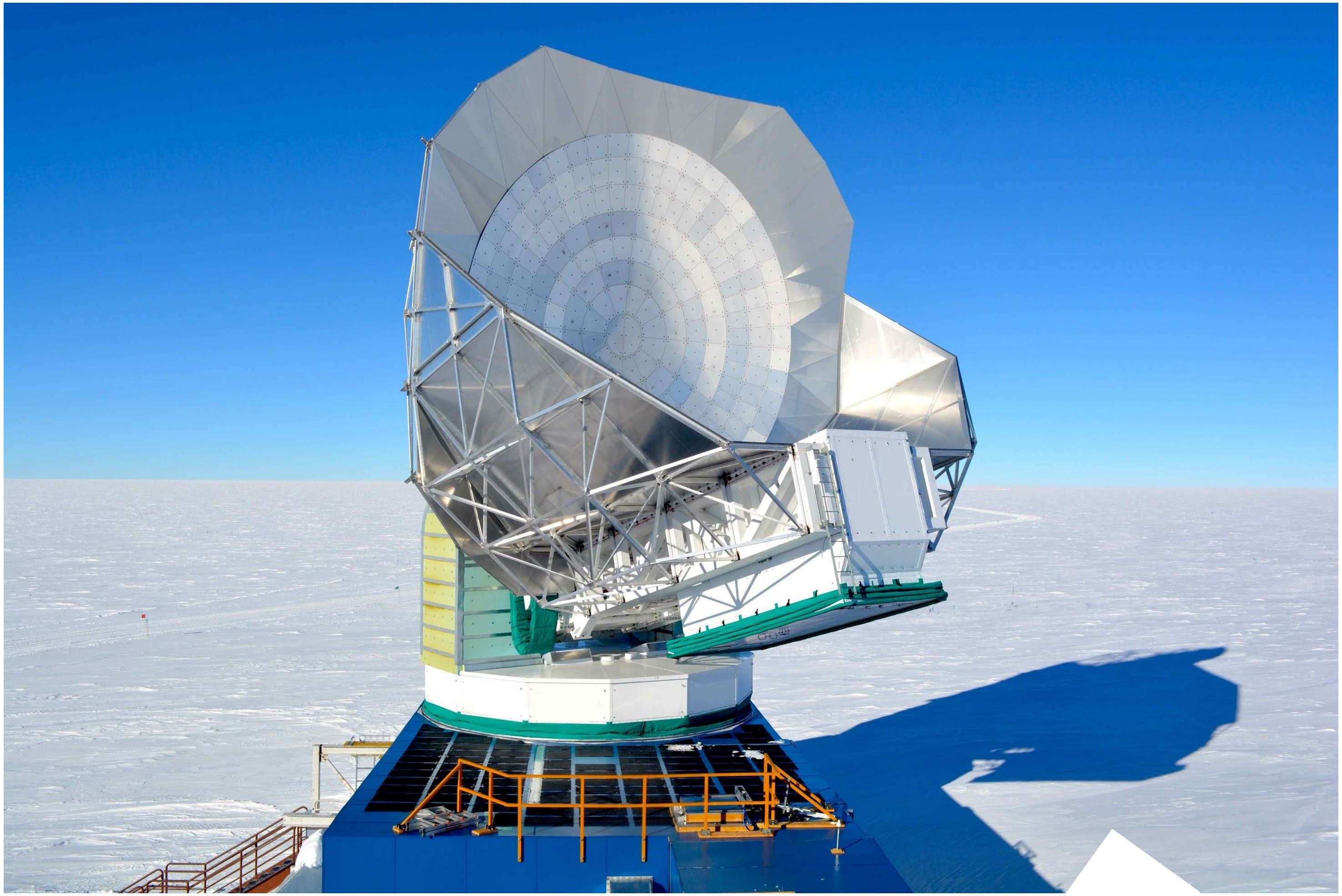
Karkare+
J. Low Temp. Phys. 2020



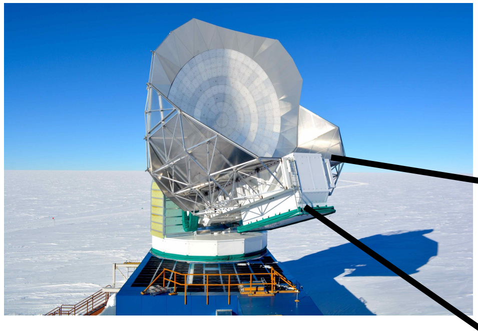
The filter bank works: each channel sees a different mm-wave frequency.

Noise levels are suitable for ground-based observations.

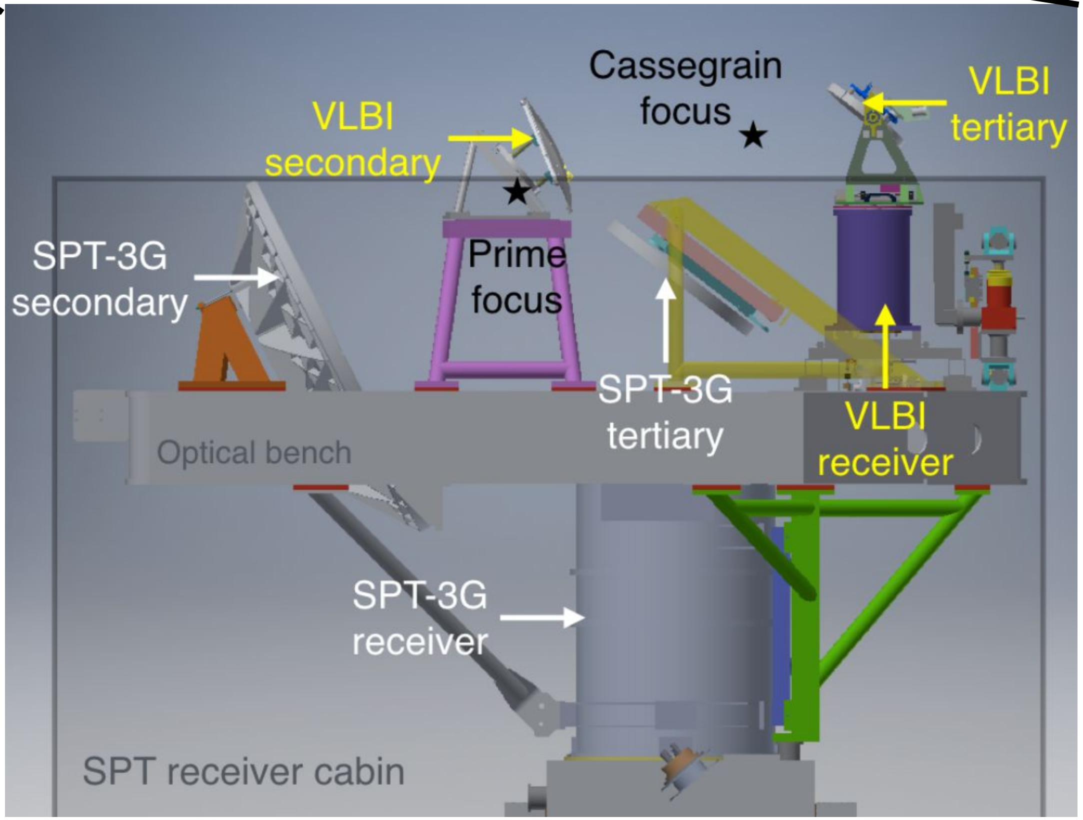
The South Pole Telescope



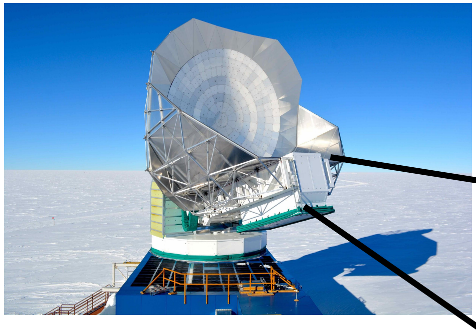
Inside the SPT Receiver Cabin



Kim+ 2018



Inside the SPT Receiver Cabin



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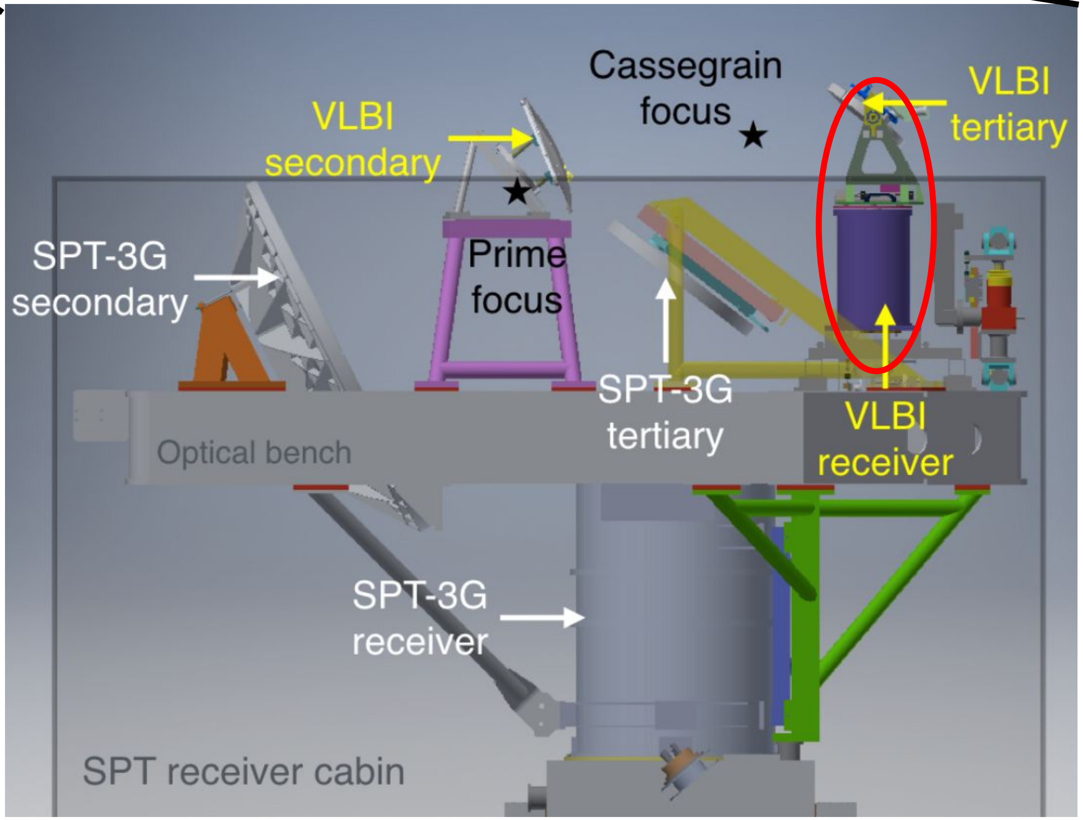
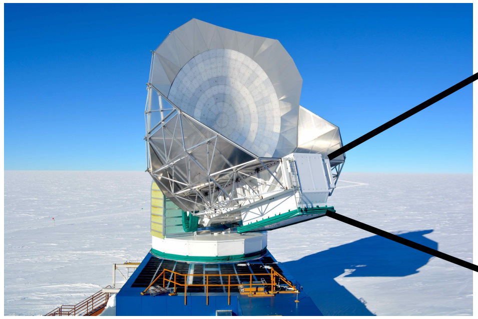
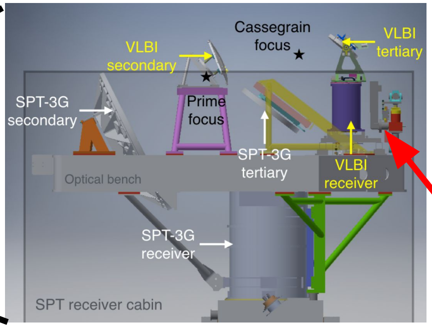
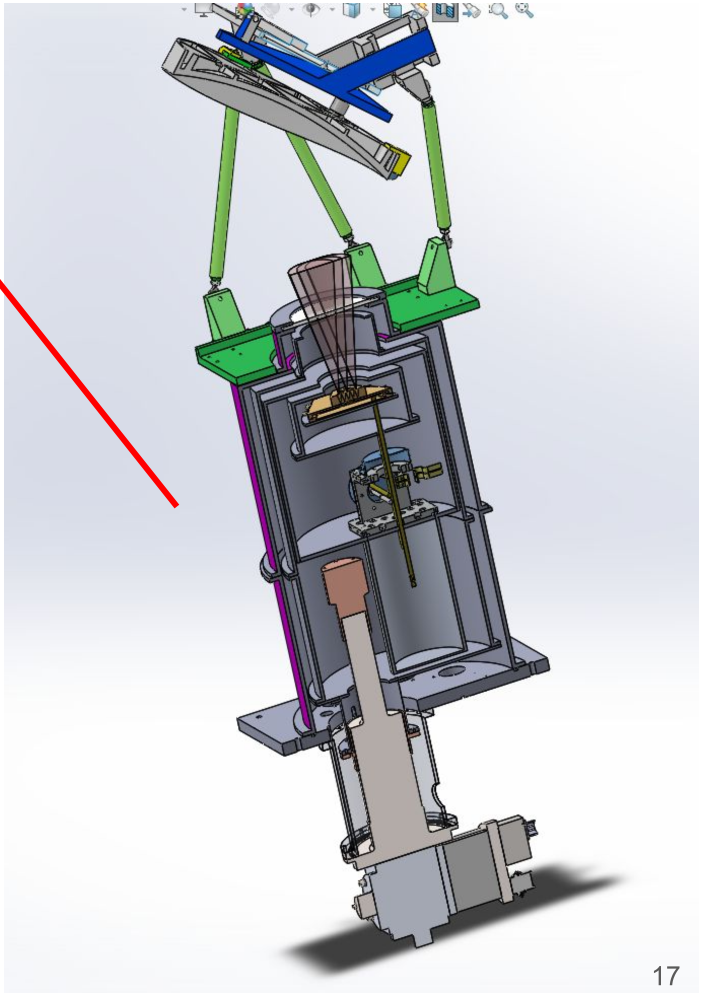


SPT-SLIM: SPT Summertime Line Intensity Mapper







Just funded through Fermilab LDRD!

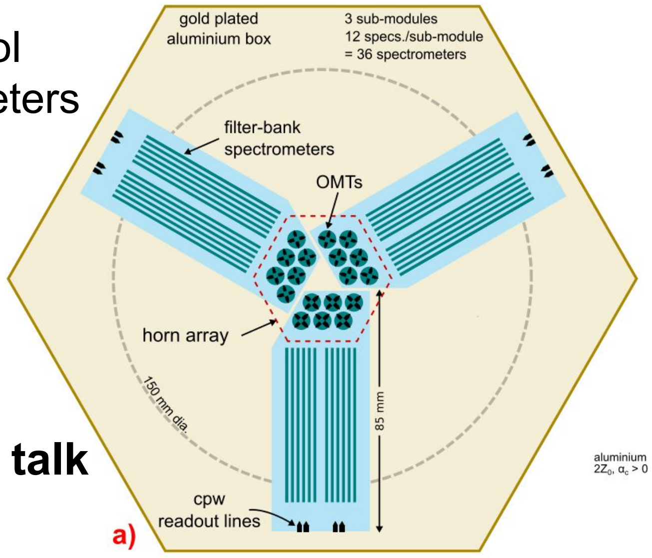
LIM pathfinder using on-chip spectrometers

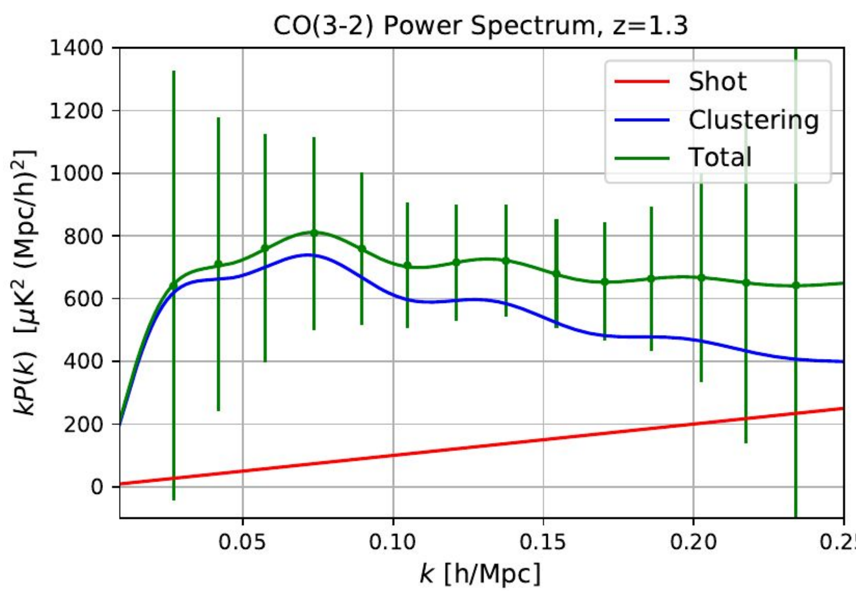
Observe in 2022/2023 Austral summer season (SPT-3G remains in place)

SPT-SLIM: SPT Summertime Line Intensity Mapper

Goal: First demonstration of LIM with on-chip spectrometers

18 dual-pol spectrometers





P. Barry's talk

Anticipate >5σ detection of CO power spectrum (and constrain molecular gas content at z~1.5)

SPT-SLIM will validate technology/analysis needed for LIM cosmology!

Summary

Millimeter-wave line intensity mapping detects galaxies through far-IR emission lines, and will probe inflation, dark matter, and dark energy beyond the redshift reach of traditional galaxy surveys.

On-chip spectrometers will enable filled focal planes with orders of magnitude more detectors than current instruments.

SPT-SLIM will demonstrate LIM with on-chip spectrometers in 2 years!