SPT-SLIM: Intensity Mapping Pathfinder with the South Pole Telescope

photo: Geoff Chen

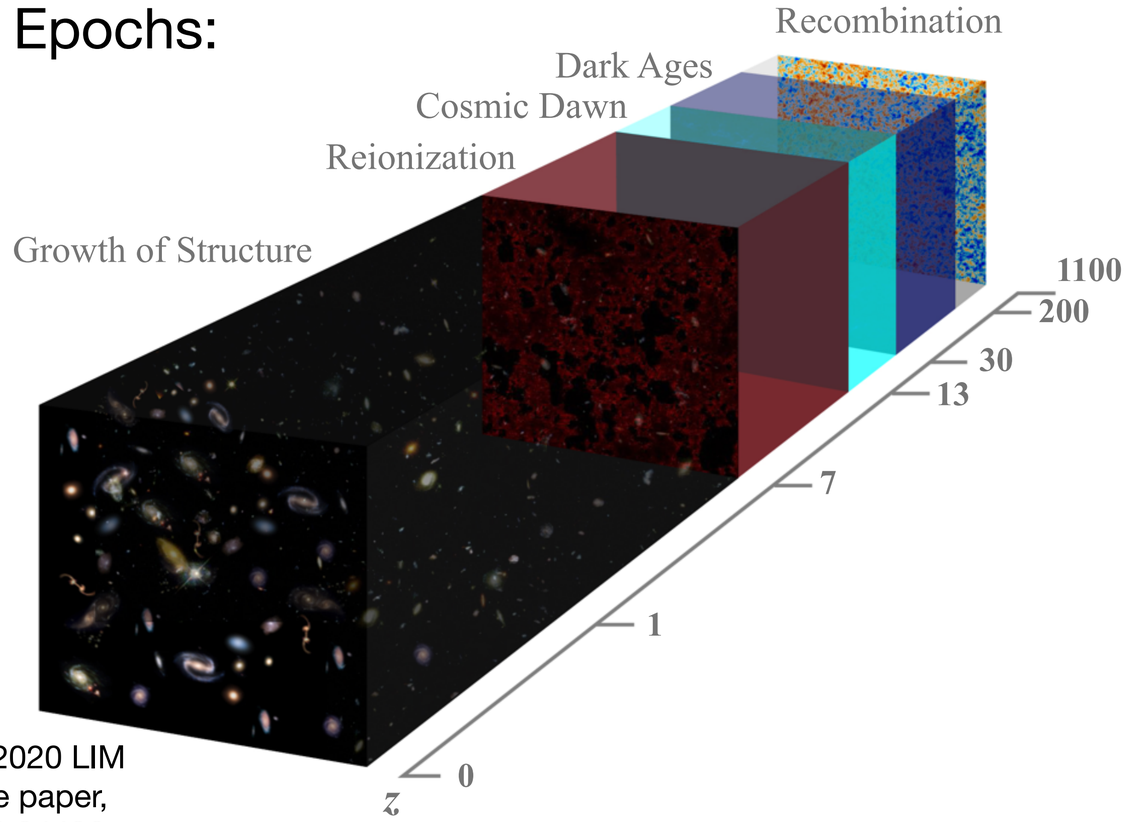
Adam Anderson - Fermilab

13 July 2021
DPF21 Meeting

Pete Barry
Brad Benson
Clarence Chang
Matt Dobbs
Matt Hollister
Kirit Karkare
Dan Marrone
Ryan McGeehan
Gethin Robson
Maclean Rouble
Erik Shirokoff
+ many others!

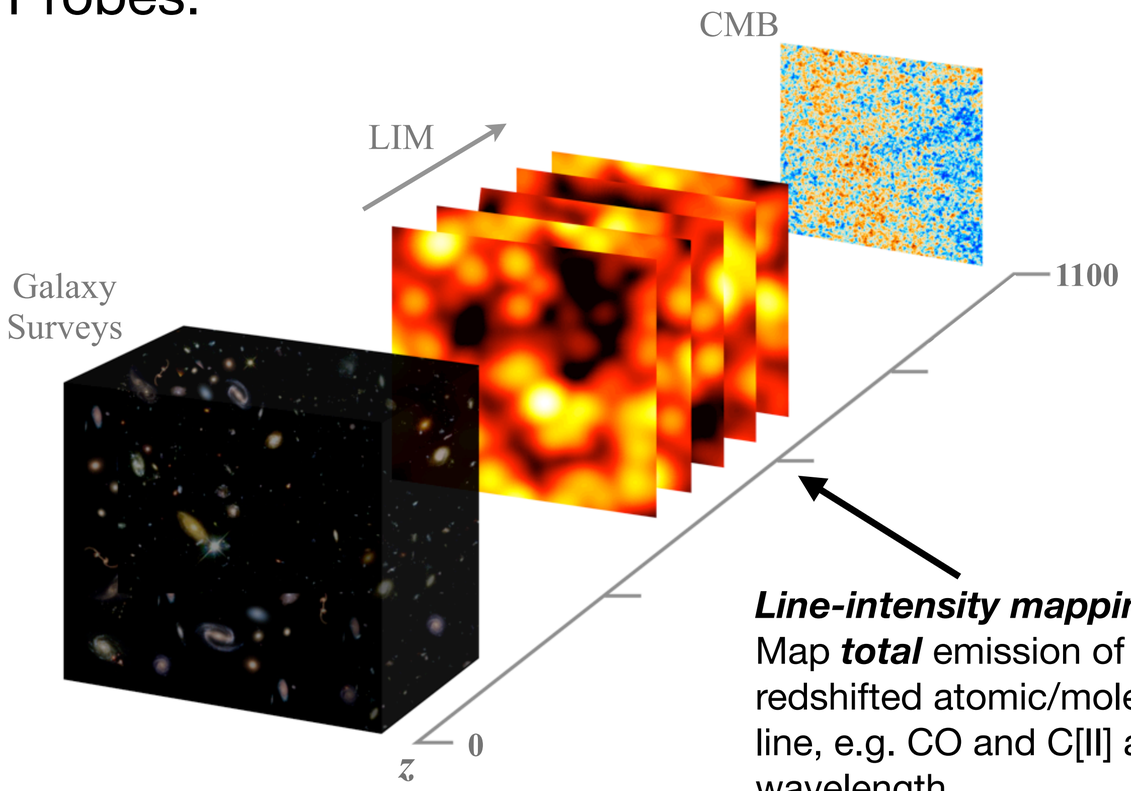
Line-Intensity Mapping (LIM)

Epochs:



Astro2020 LIM white paper, 1903.04496

Probes:



Line-intensity mapping - Map ***total*** emission of a redshifted atomic/molecular line, e.g. CO and C[II] at mm-wavelength

- Large redshift range $z > 3$ that is relatively unexplored: provides information on expansion history of universe, reionization, star-formation, ++
- LIM is efficient: we measure *all* sources and do not need to threshold on galaxies
- Multiple lines available across radio, millimeter, IR

LIM with Millimeter-Wavelength Tracers

- CMB community has invested decades in R&D on detectors, cryogenic optics, and survey design for observing in the 20-300 GHz range
- The CII line and the CO rotational ladder over $1 < z < 10$ redshift to the ground-based CMB observing frequencies
- ***Transfer our CMB expertise to line-intensity mapping***
- Many small experiments (TIME, COMAP, CONCERTO, EXCLAIM, TIM, …) trying this with extremely diverse approaches: coherent detectors vs. bolometers; grating spectrometers vs. fourier transform spectrometers vs. …

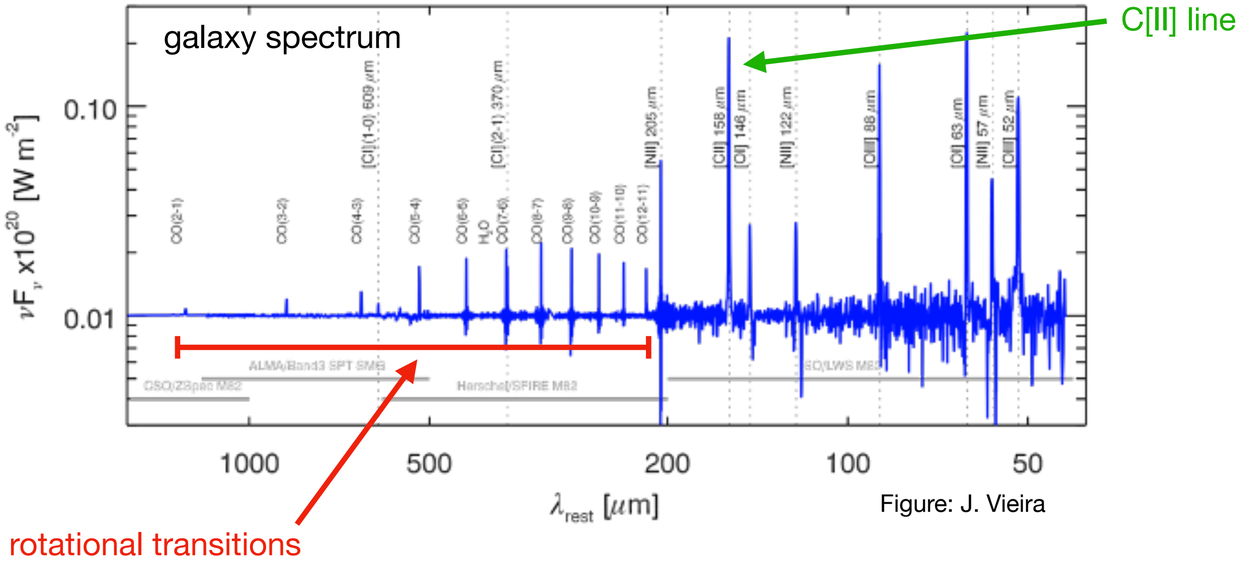


Figure: J. Vieira

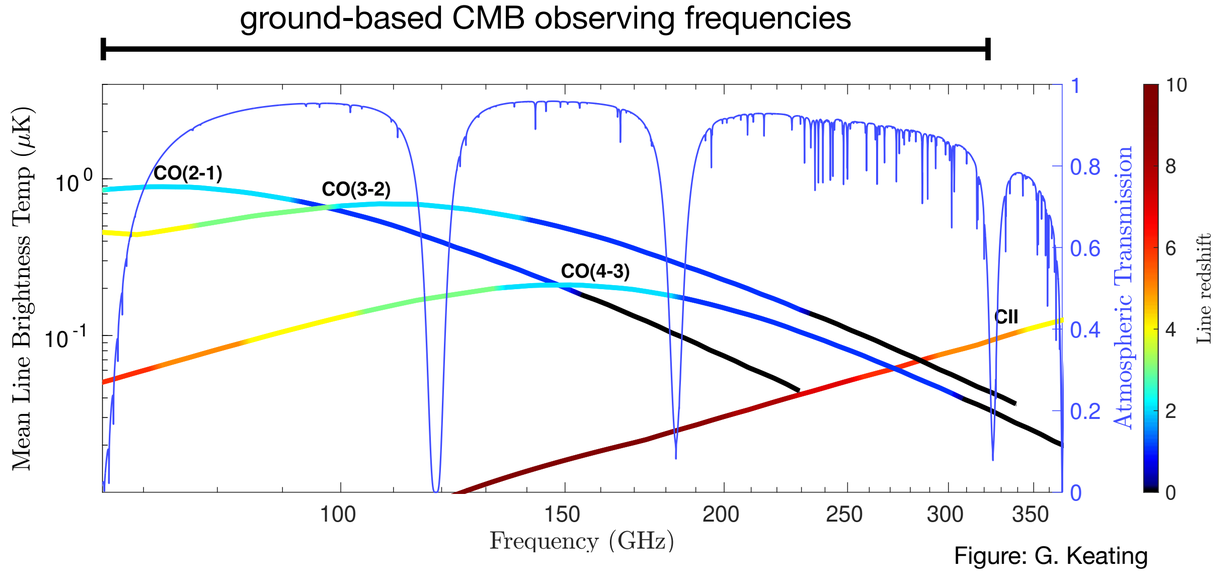


Figure: G. Keating

On-Chip Spectroscopy

- Couple antenna to an RF filter-bank to achieve tunable narrow-band response, filling the atmospheric frequency “windows” used for ground-based observations
- Couple a microwave kinetic indutance detector (MKID) to each filter channel
- Readout with frequency-domain multiplexing with MUX factor O(~10^3)
- Demonstrated in few-pixel field tests, but not in monolithic arrays needed for future surveys
- Development of on-chip mm spectrometers for large-scale structure surveys endorsed by *DOE Basic Research Needs Study on HEP Detector Research and Development* (2020)

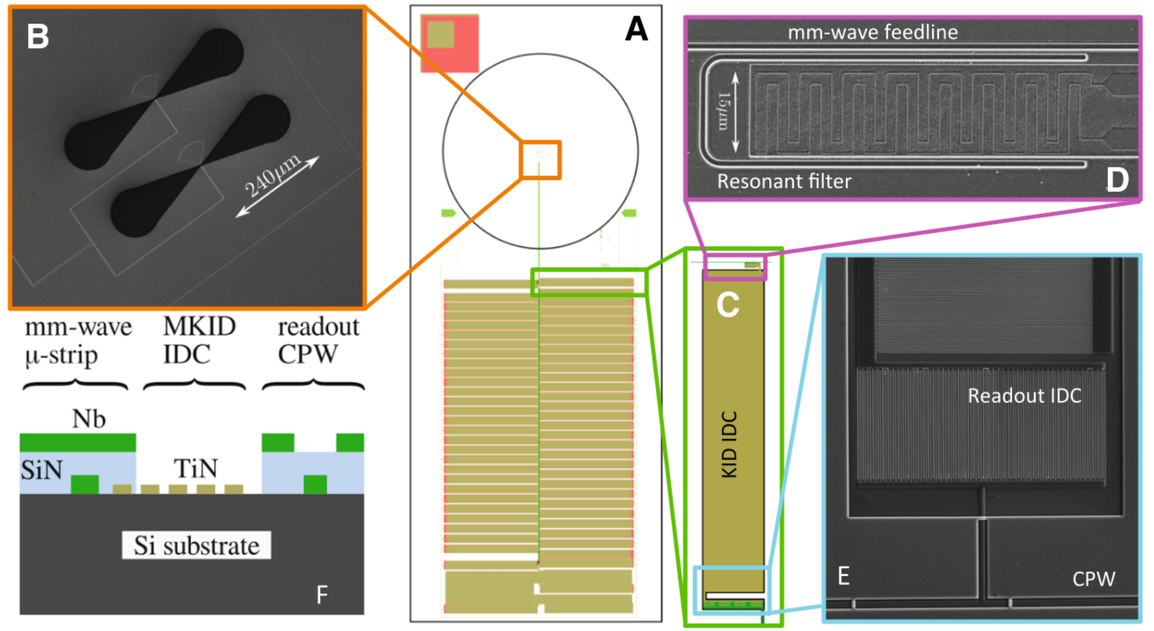
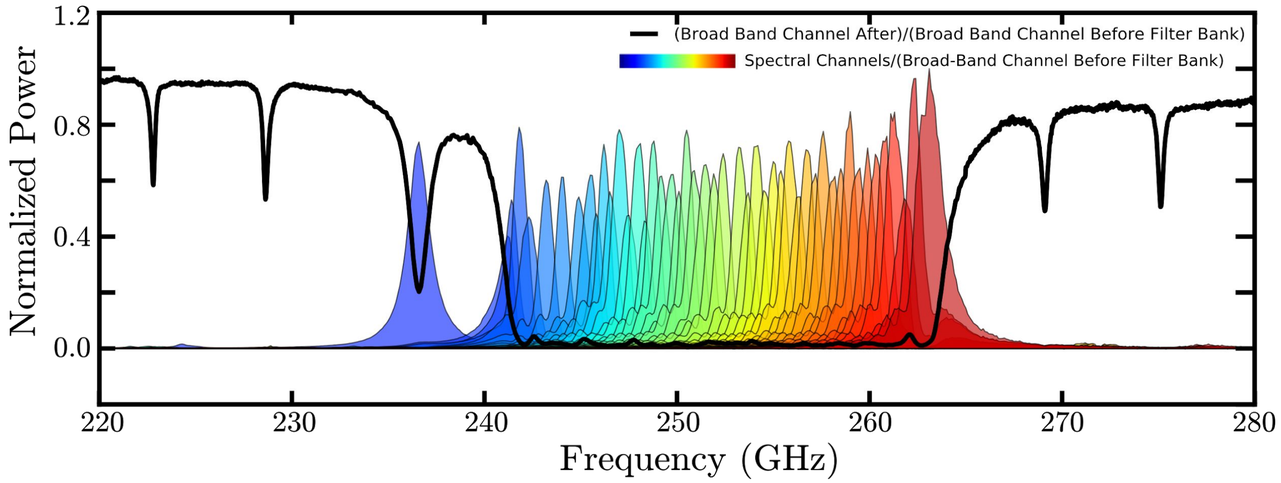


Figure: K. Karkare, et al. 2002.04542



SPT-SLIM: South Pole Telescope Summertime Line-Intensity Mapper

Argonne:
T. Cecil
C. Chang
Z. Pan

Cardiff:
P. Barry
G. Robson

Harvard / CfA:
G. Keating

Fermilab:
A. Anderson
B. Benson
S. Simon
M. Hollister

McGill:
M. Dobbs
M. Rouble

U. Arizona:
D. Marrone

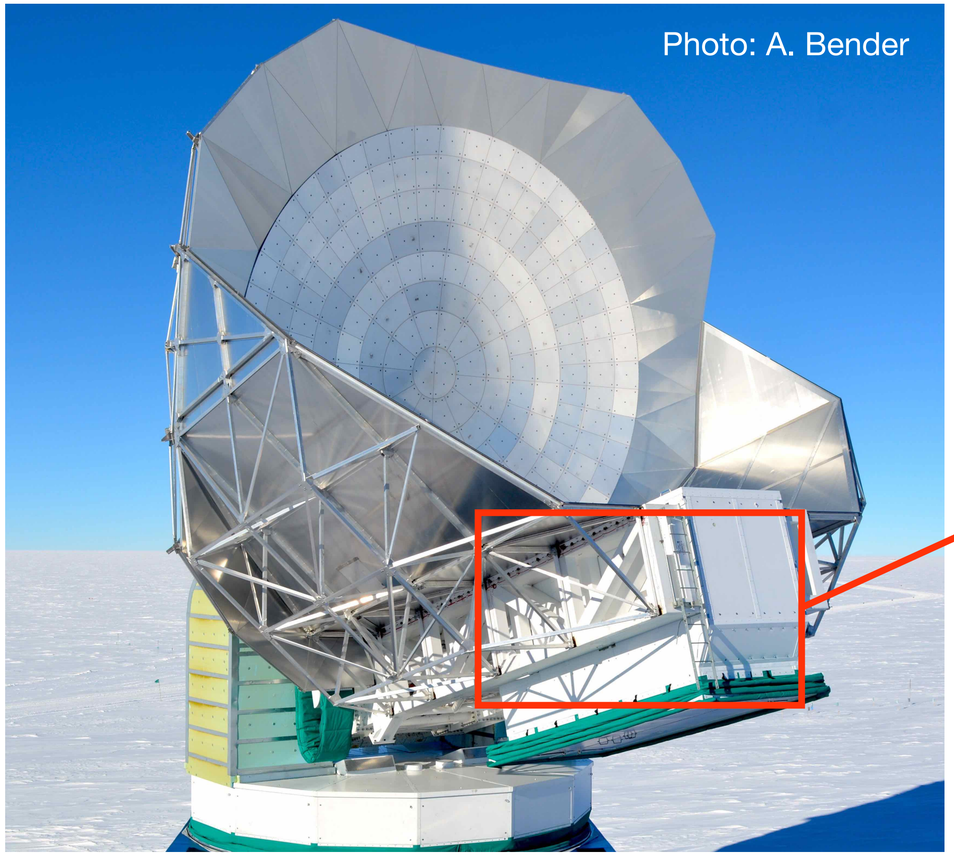
U. Chicago:
K. Karkare
R. McGeehan
J. McMahon
E. Shirokoff

SPT-SLIM Experimental Concept

South Pole Telescope is 10-m CMB telescope observing at 90/150/220 GHz during both austral winter *and summer* (see Sobrin, Gualtieri talks this session)

SPT optics include mount point for optional receiver, used by Event Horizon Telescope (EHT) during 2017-present

SPT-SLIM - Replace EHT cryostat with on-chip spectrometers and observe for one summer season



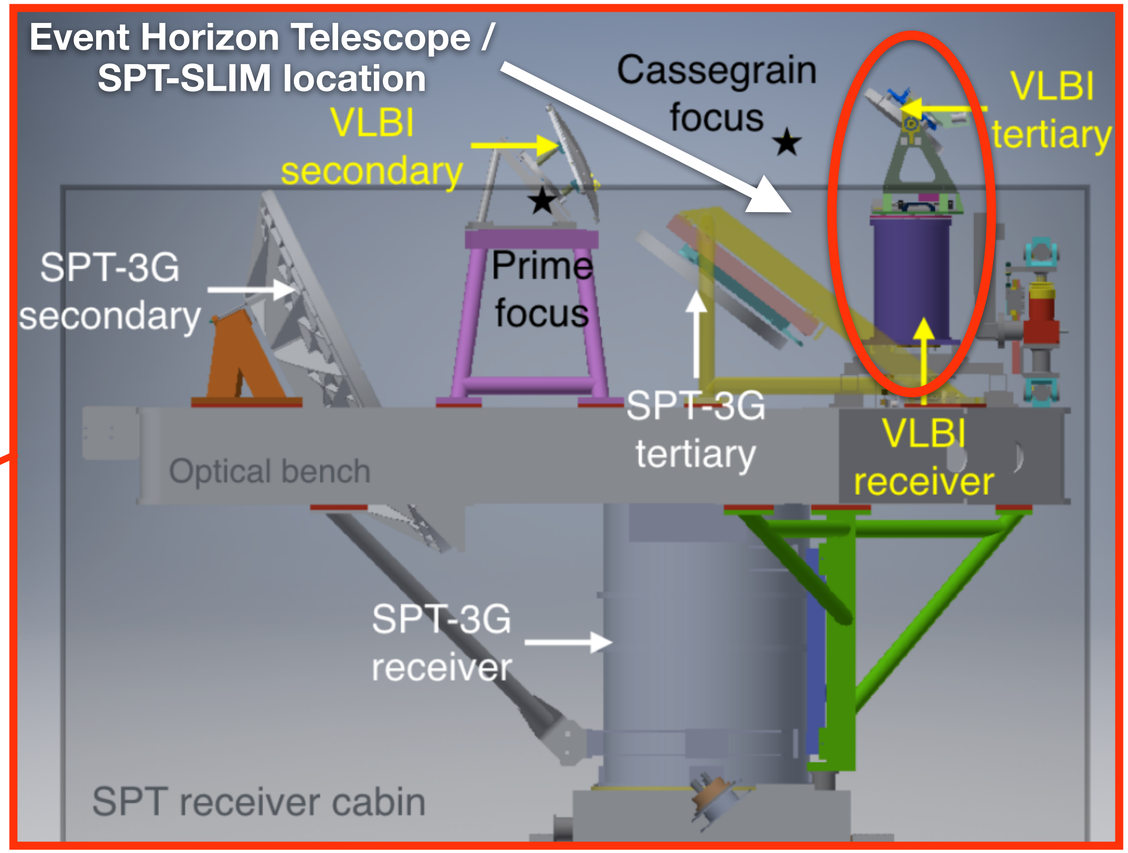
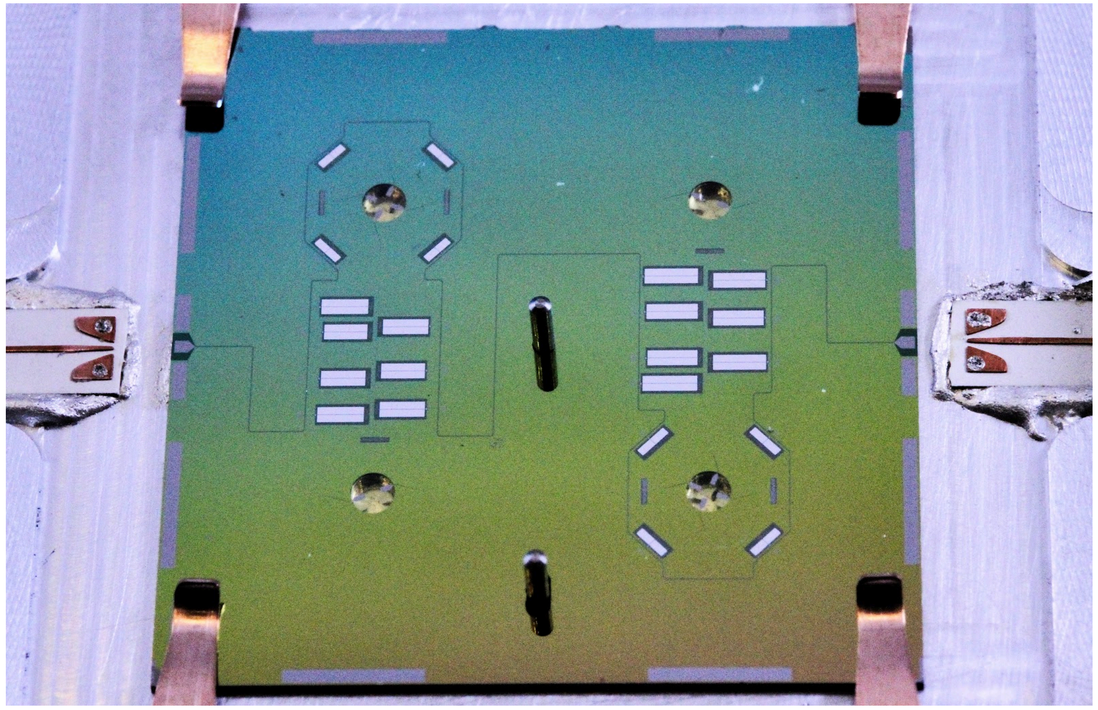


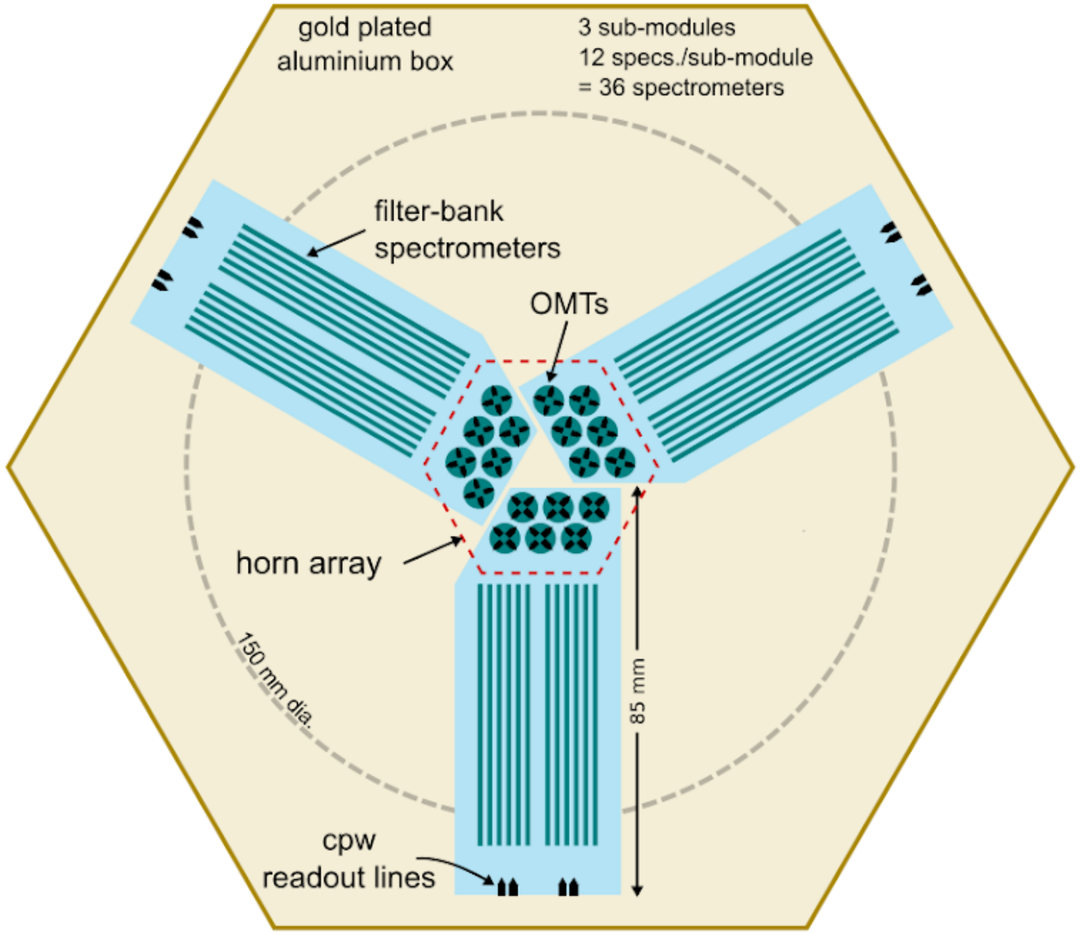
Figure: J. Kim, et al. 1805.09346

Detectors

- Baseline 18 dual-pol pixels with R~300 = 8640 detectors
- Detectors are Al MKIDs, read out in the 1-2 GHz band, with MUX factor of ~1000
- Filter banks are much larger than 1 pixel, so array them around perimeter and read out MKIDs from perimeter

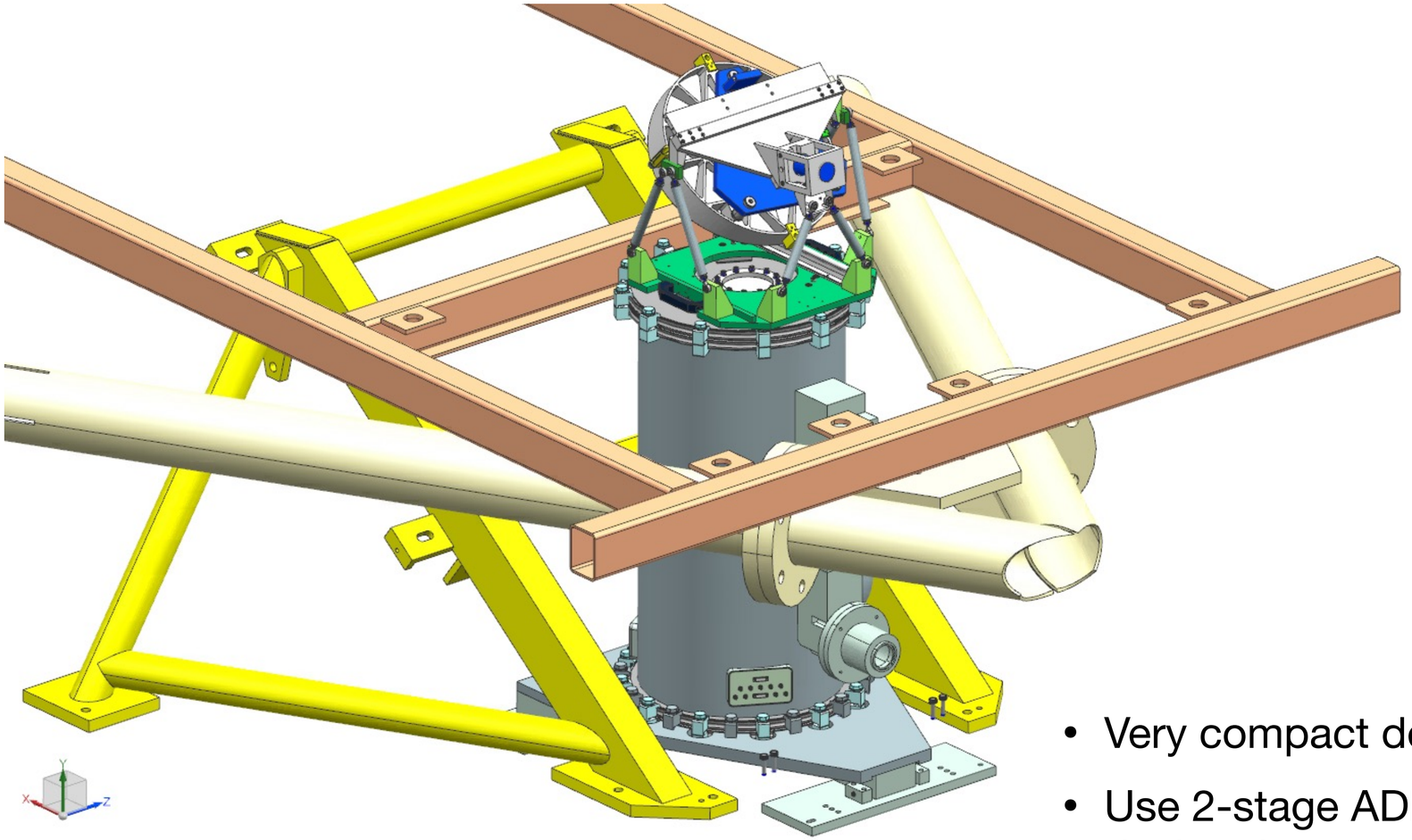


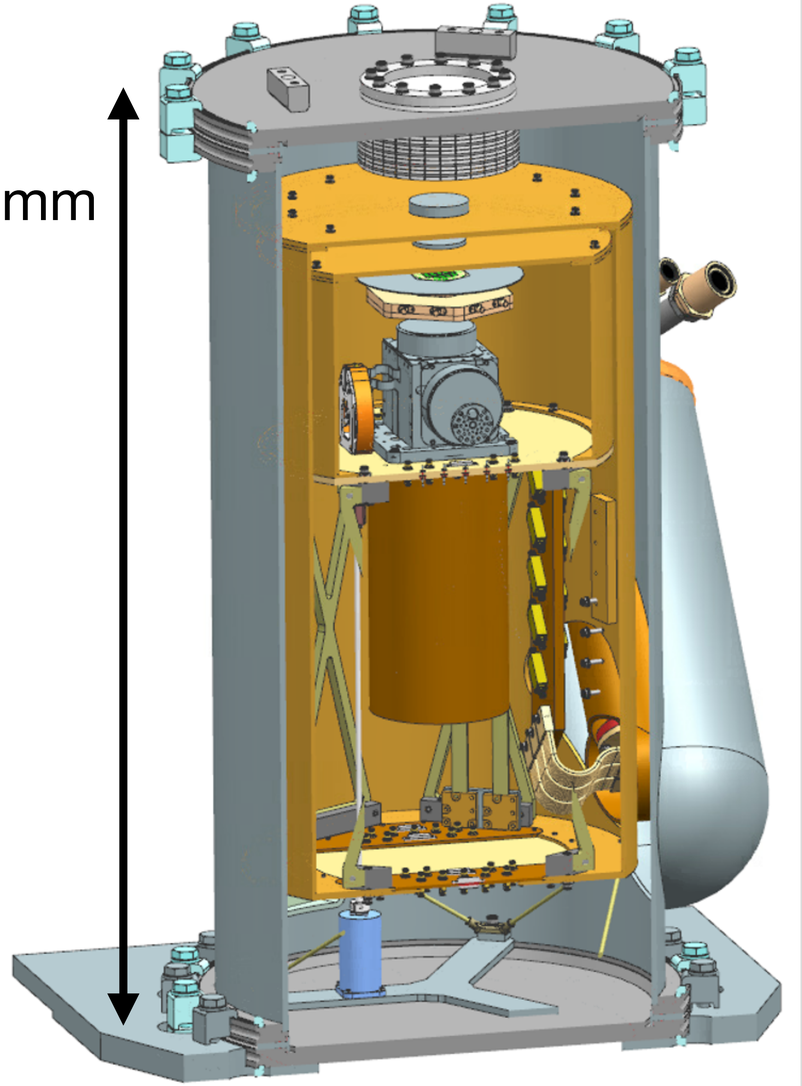
Prototype detectors fabricated at Argonne



focal plane package concept (P. Barry)

SPT-SLIM Cryostat

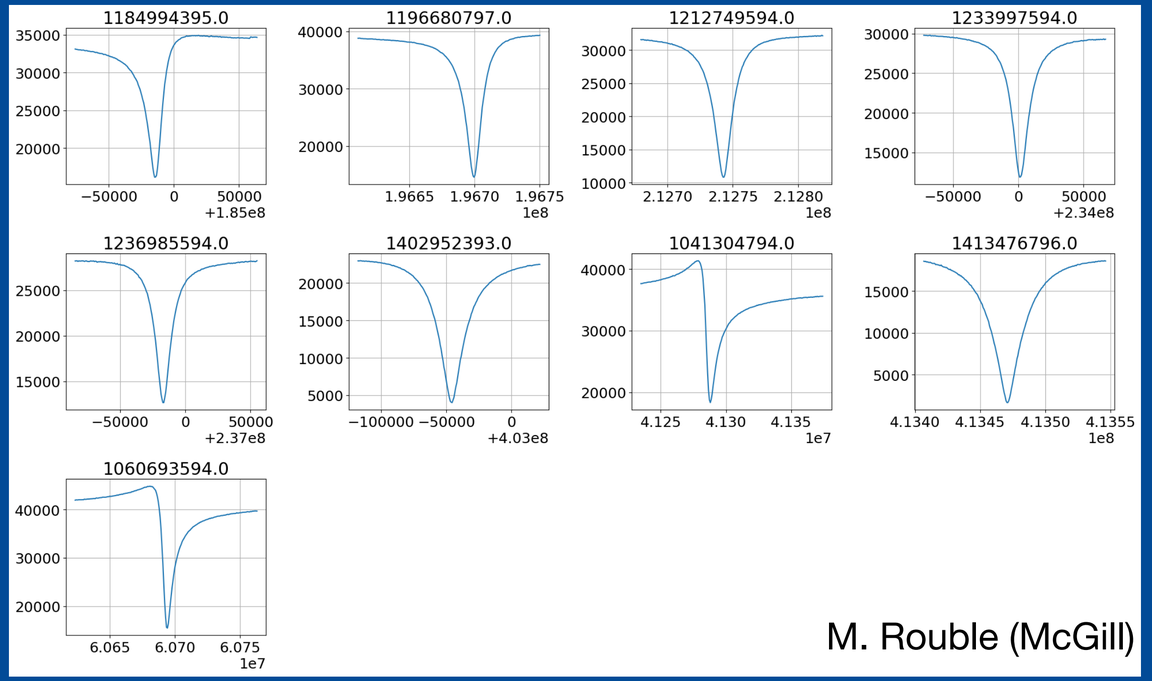




- Very compact design required to fit in SPT receiver cabin
- Use 2-stage ADR backed by PTC operated at 100mK—design that requires strict control of thermal loading

Next-Generation Microwave Readouts

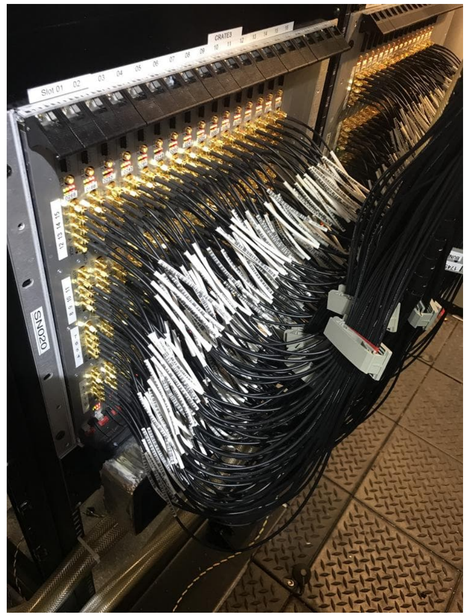
- Adapting “ICE” platform developed by McGill for readout of TESs receivers in CHIME
- Digital feedback in T linearizing SQUIDs i to tone-tracking
- Maintain legacy mot swapping RF mezza AD9082 chip:
  - 4x DACs (12 GSP per board, suppor baseband
- Enables reuse of ful developed for SPT-3 in effort!

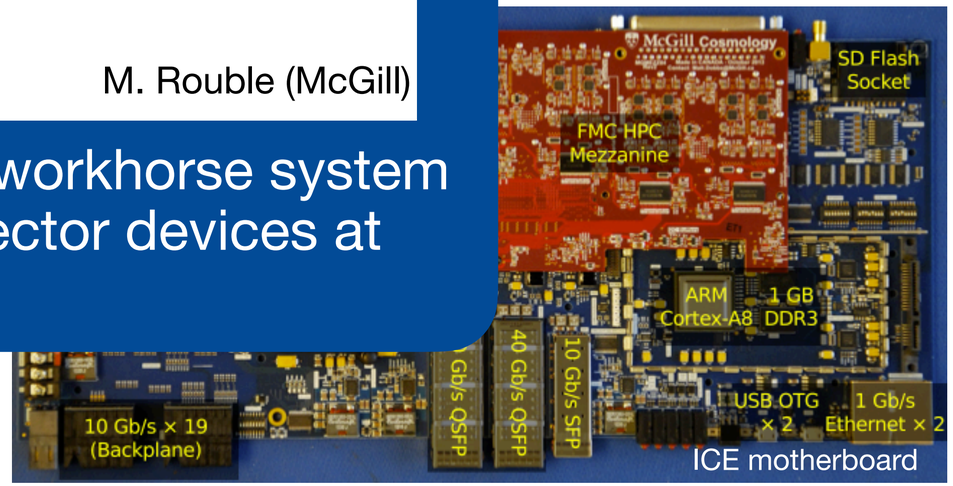


M. Rouble (McGill)

Already used as our primary workhorse system for characterizing test detector devices at Fermilab

Hundreds of ICE boards deployed in the field (1608.06262)



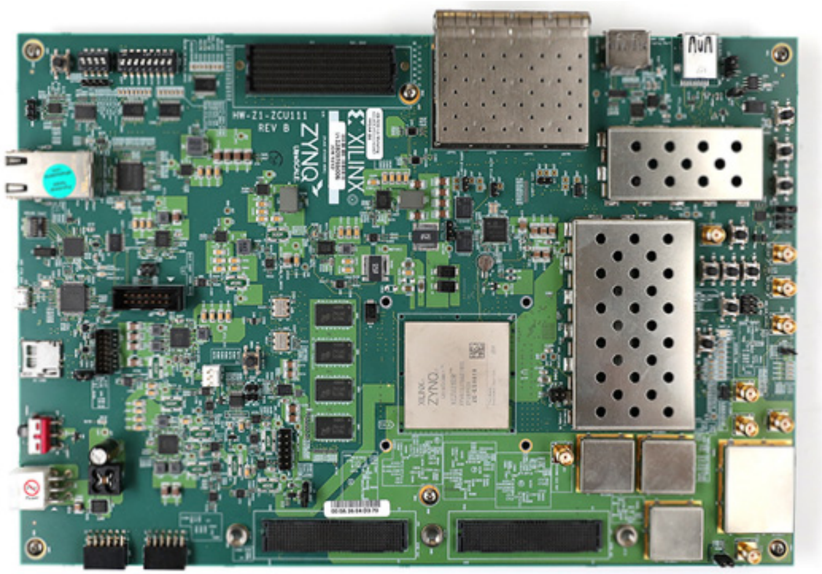


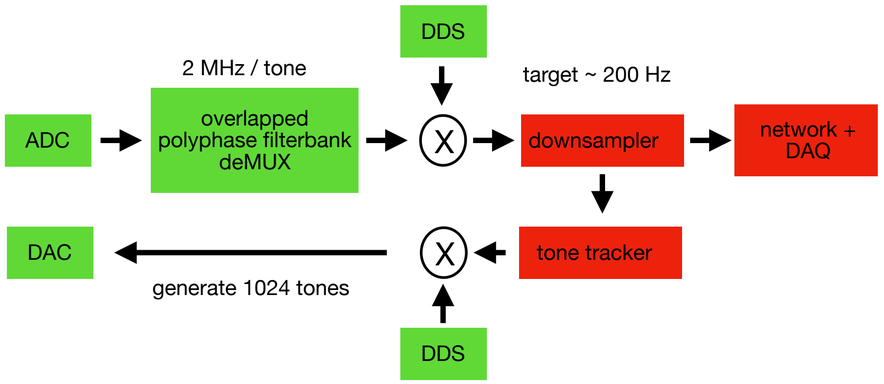
ICE motherboard

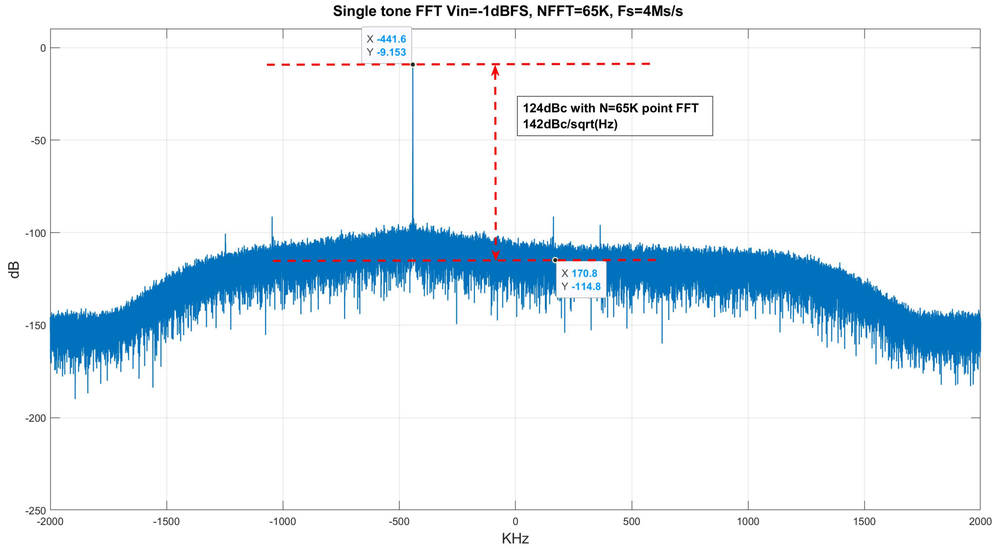
RFSoC Readout Platform

- Xilinx UltraScale+ RFSoC ZCU111 demo board (now old) has 8x ADCs (DACs) at 4 (6) GSPS
- MKID firmware developed at Fermilab (G. Cancelo, L. Stefanazzi, ++) demonstrated 1024x MUX over 2GHz bandwidth with adequate noise performance (path to 8k channels / board)
- Tone-tracking capability in development; drastically improves detector linearity, which is important for ground-based operations
- Key enabling technology for much larger MKID arrays in the future!

Xilinx ZCU111







Forecast and Experimental Outlook

- Conservatively expect 50-75% total observing efficiency for ~4 weeks, so >300 hours on-target time is realistic
- Raw sensitivity of SPT-SLIM should be sufficient to detect CO power spectra ($0.5 < z < 3$) with high significance in a single summer season

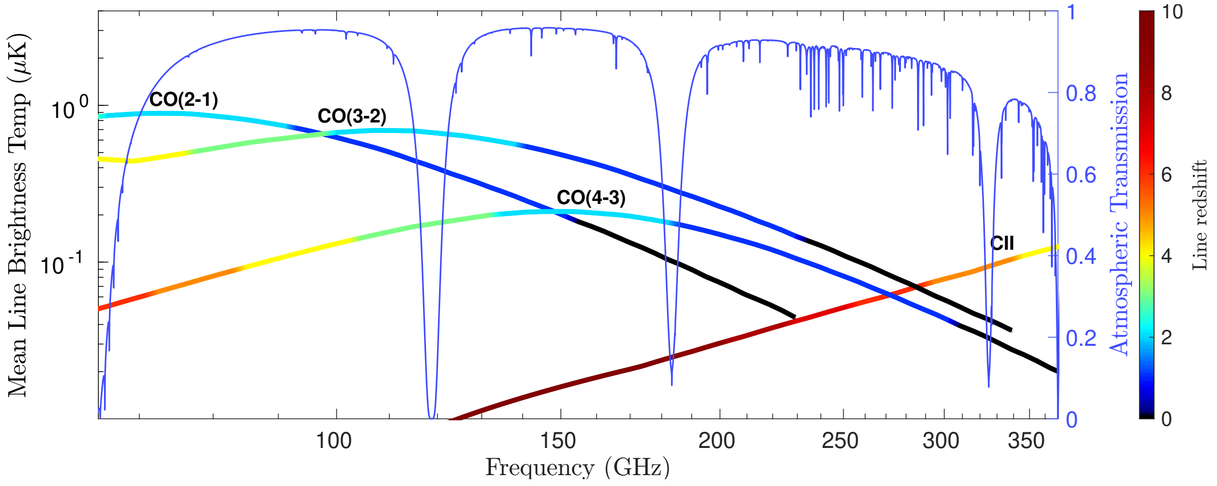
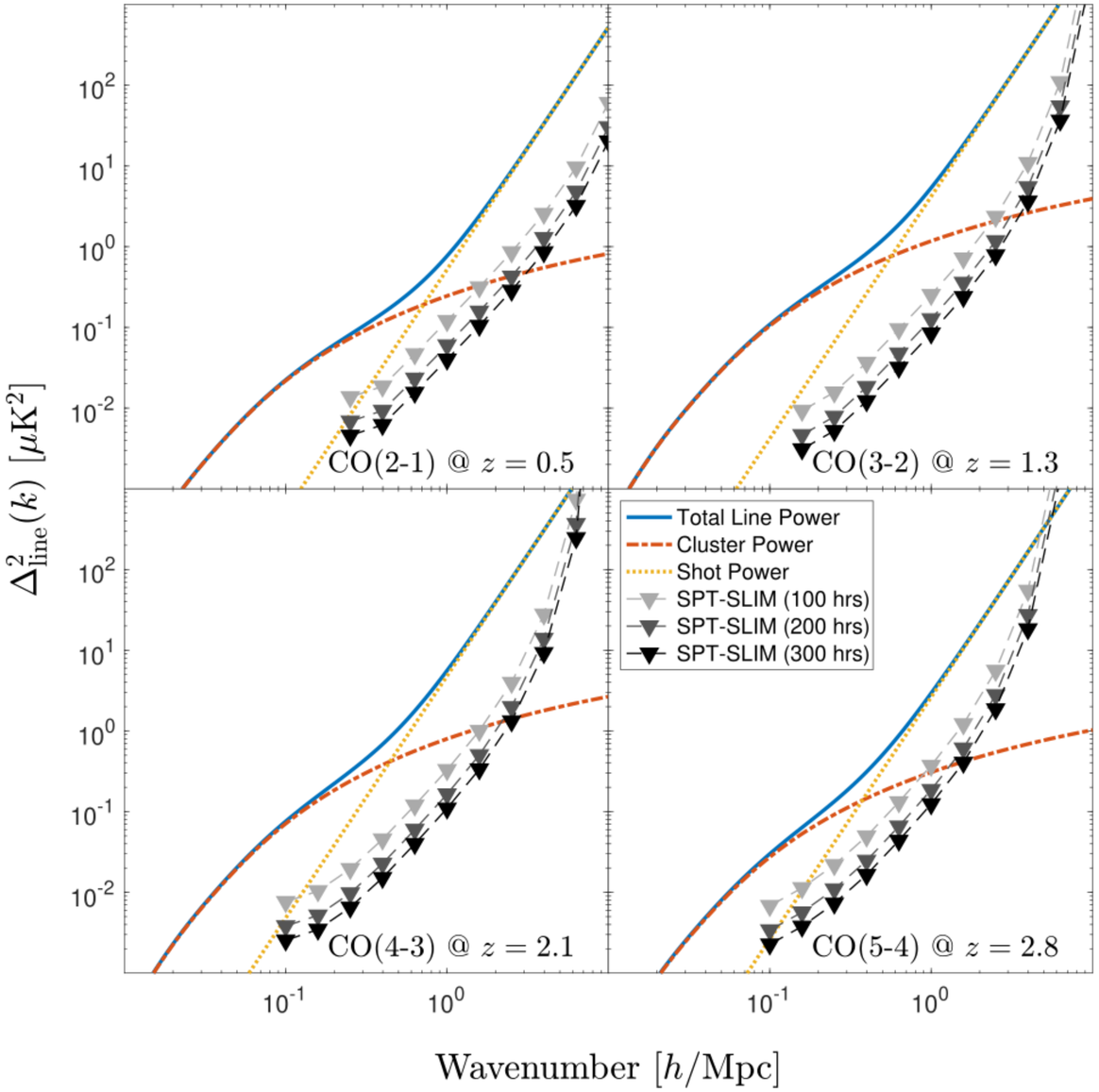


Figure: K. Karkare, G. Keating



Conclusions

- SPT-SLIM is funded by internal Fermilab LDRD funds, and target deployment to South Pole is 2022-2023 austral summer
- Demonstration of scaling up the on-chip spectrometer technology from single pixels to a full array
- High-significance detection of CO power spectrum is expected