
Photo: Karia Dibert

KIDs for Millimeter-Wave Cosmology

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Fermilab Cosmic Day
30 October 2023

Key Question

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- *Millimeter-wavelength intensity mapping*
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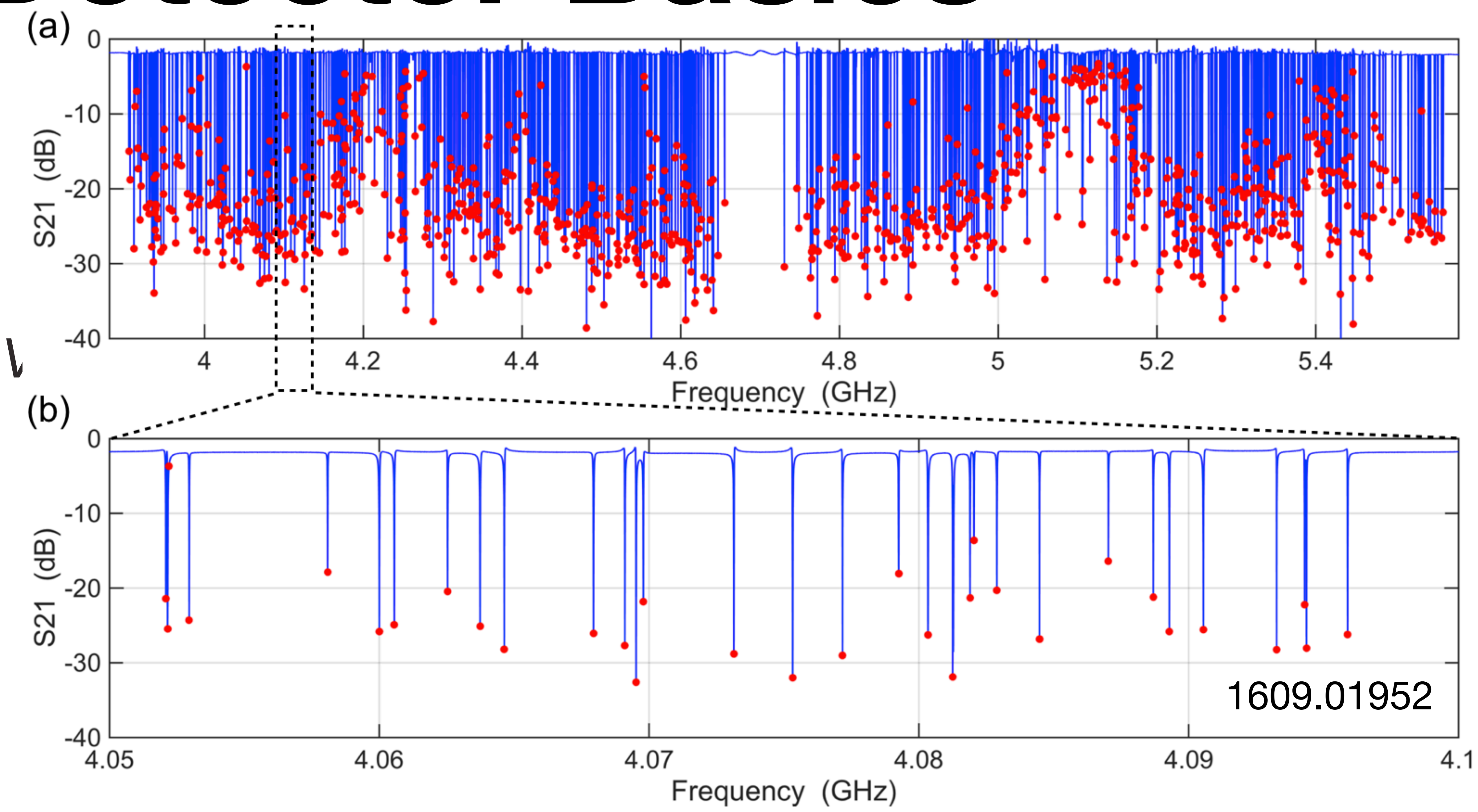
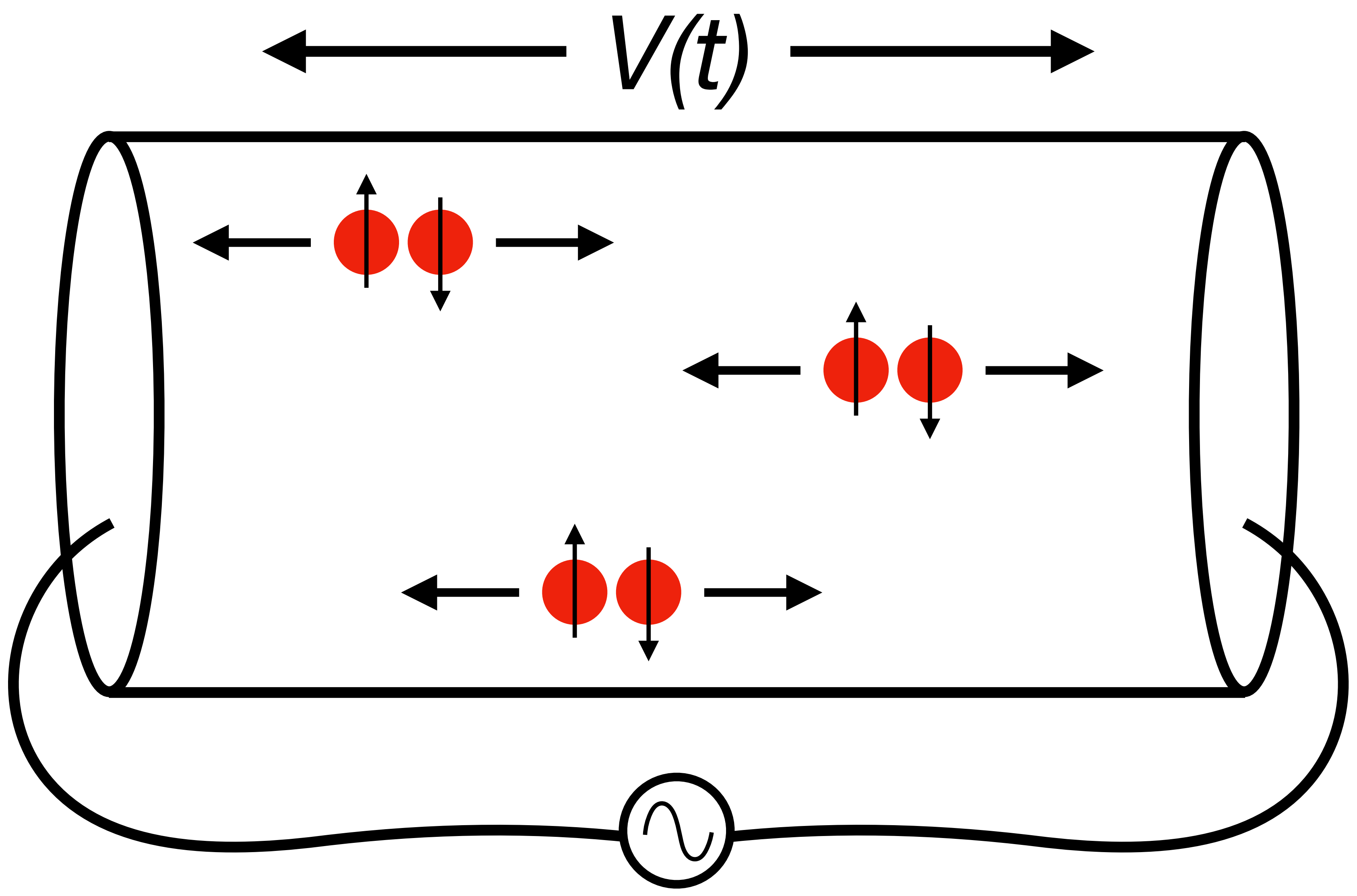
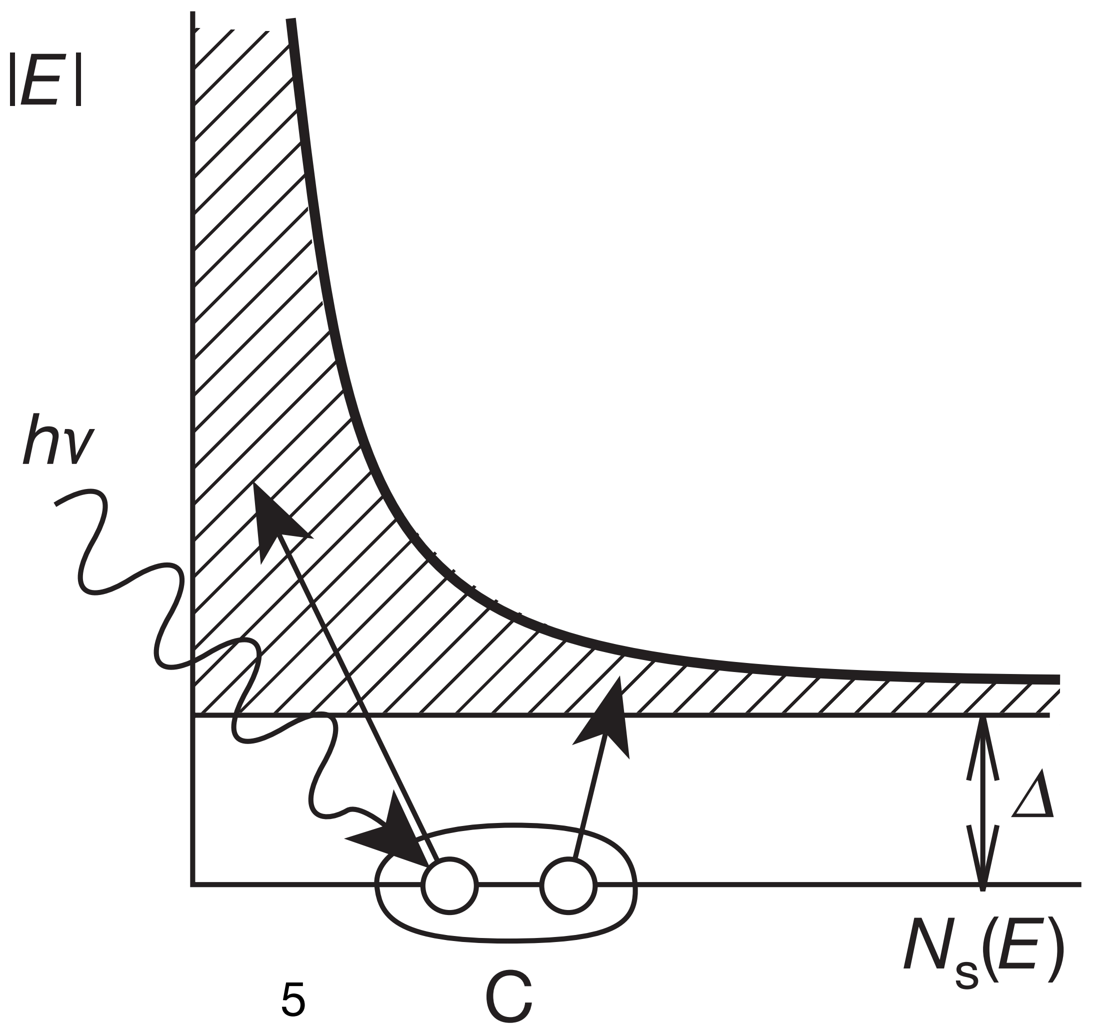
- *Millimeter-wavelength intensity mapping* ➔ ***SPT-SLIM***
- *High-frequency CMB observations* ➔ ***SPT-3G+***

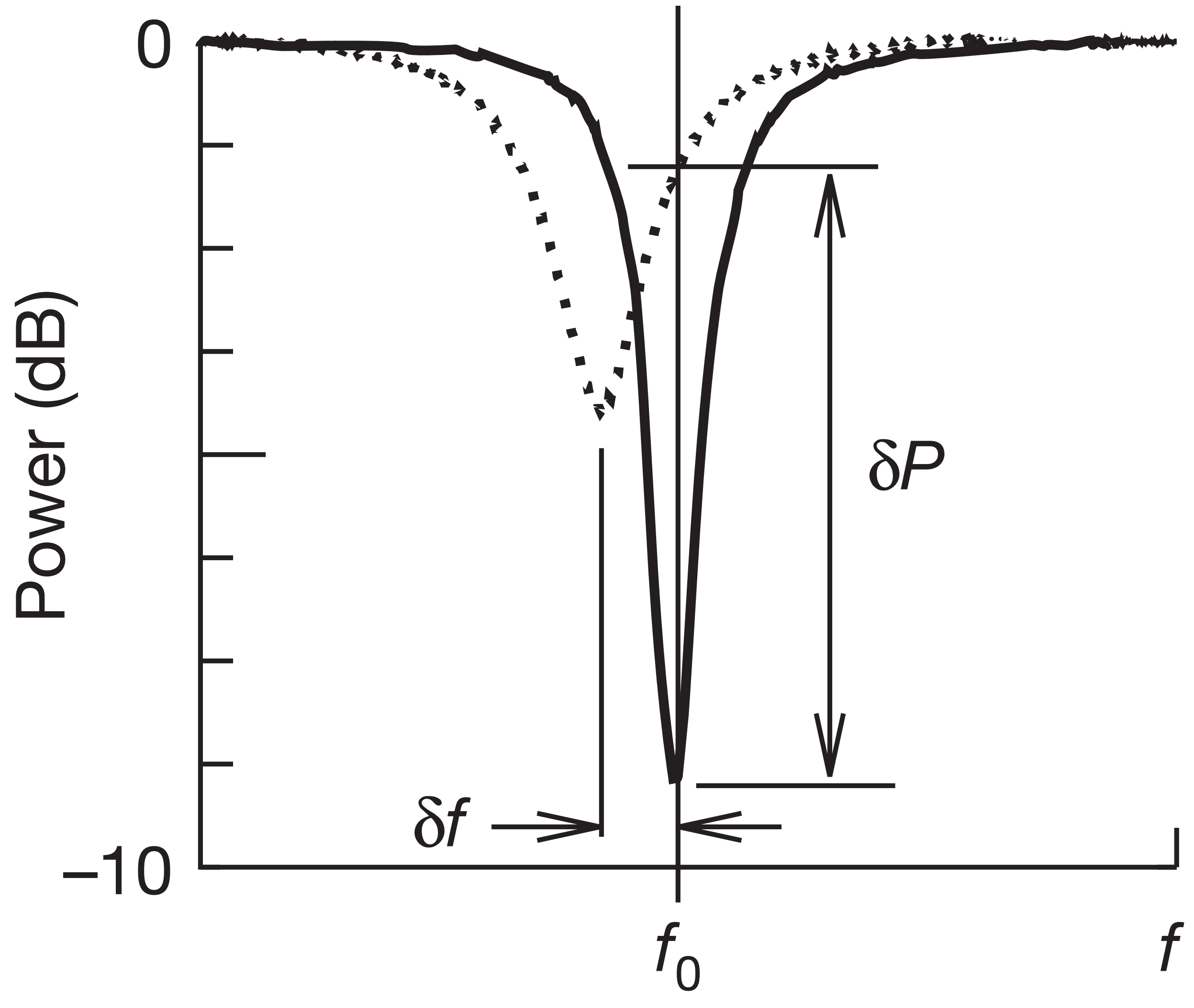
Kinetic Inductance Detector Basics

- Cooper pairs in AC potential have nonzero inertia, results in phase shift between I and V. ***Looks like an inductance: "kinetic inductance".***
- Breaking of Cooper pairs by e.g. photons, changes kinetic inductance.
- Create a sensor by coupling the superconductor in an LC circuit so that inductance can be sensed as a change in resonant frequency.





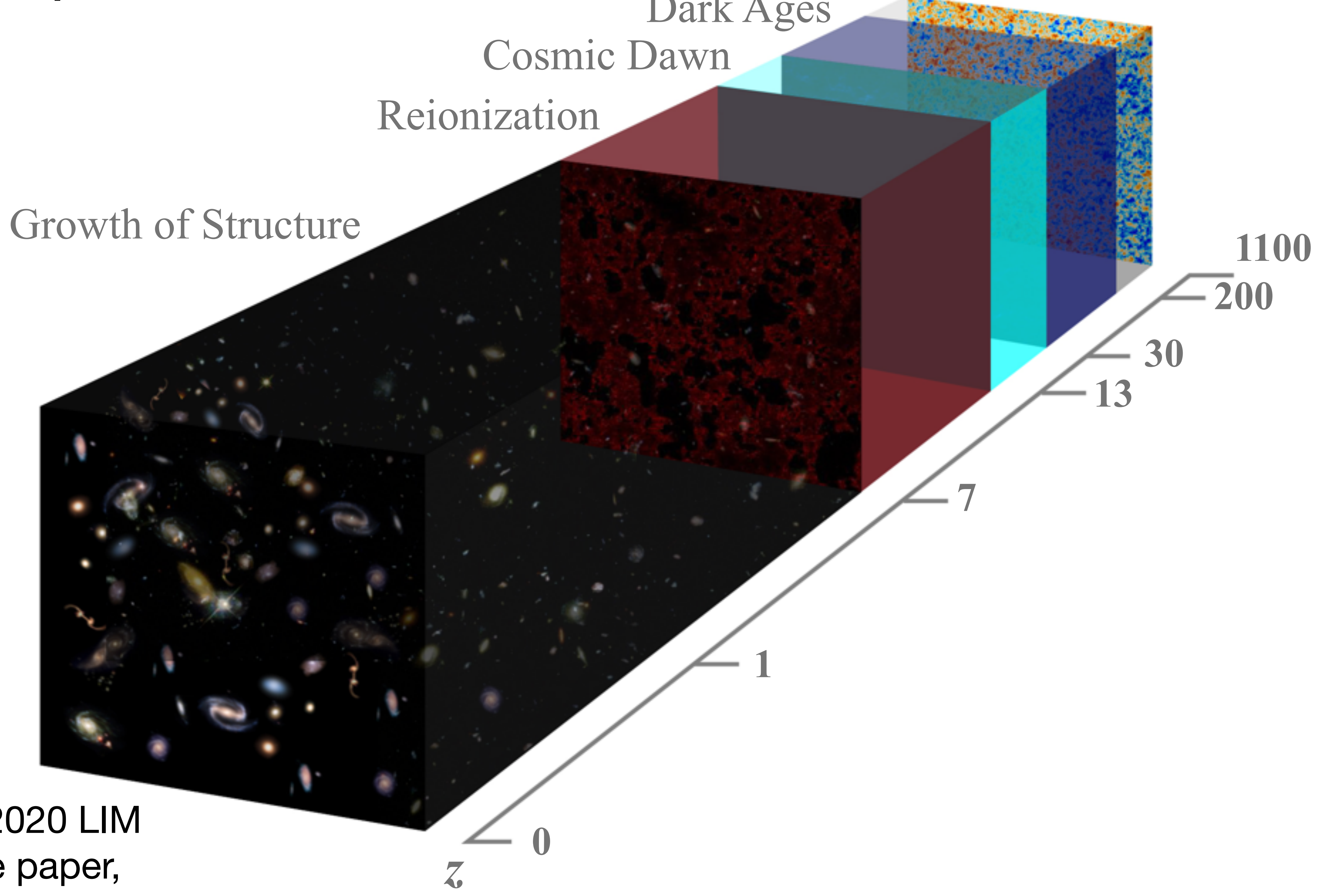




SPT-SLIM: Line Intensity Mapping

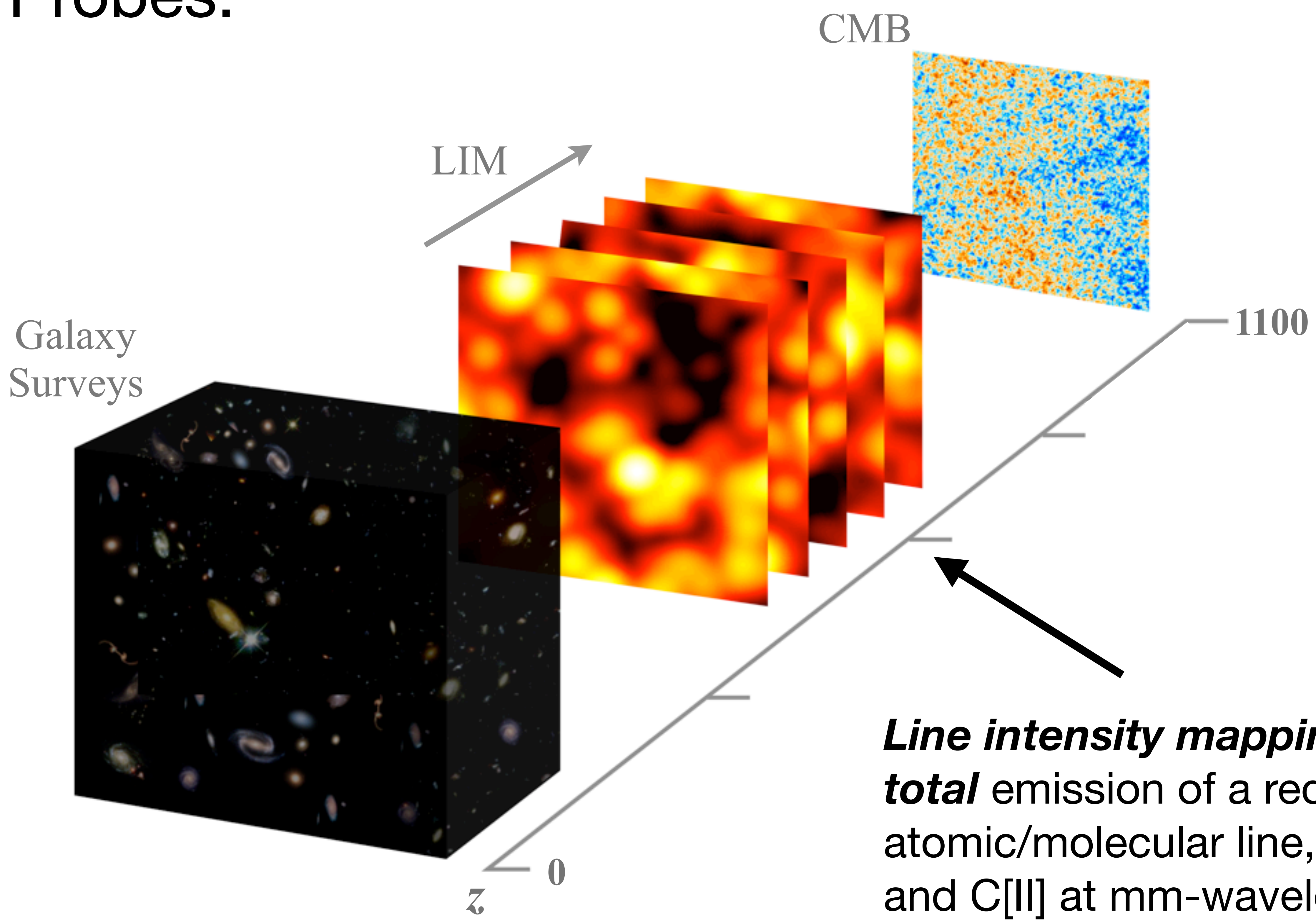
Line Intensity Mapping (LIM)

Epochs:



Astro2020 LIM white paper, 1903.04496

Probes:



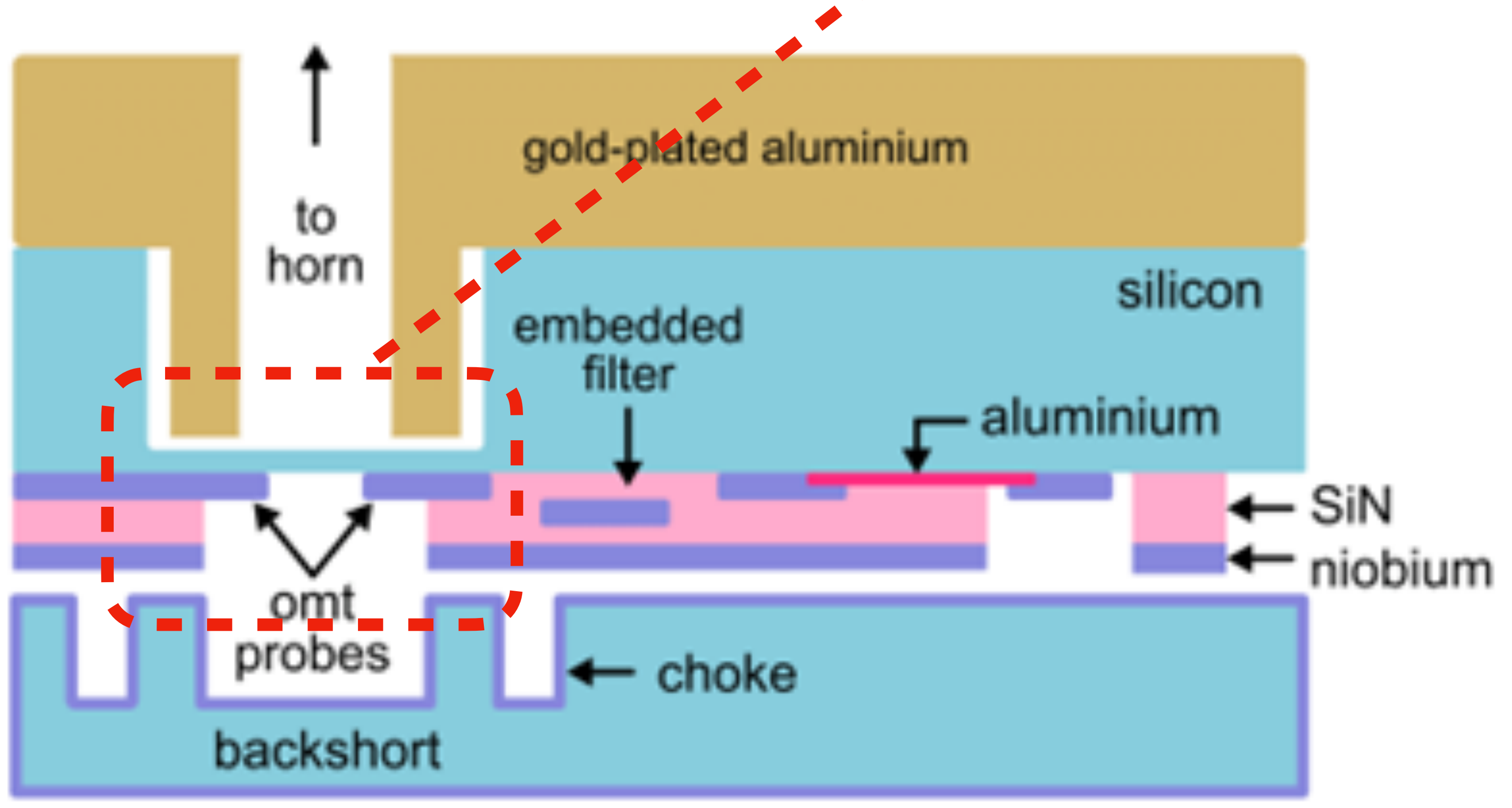
Line intensity mapping **-** Map ***total*** emission of a redshifted atomic/molecular line, e.g. CO and C[II] at mm-wavelength

- 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

P. Barry++ (2111.04633)

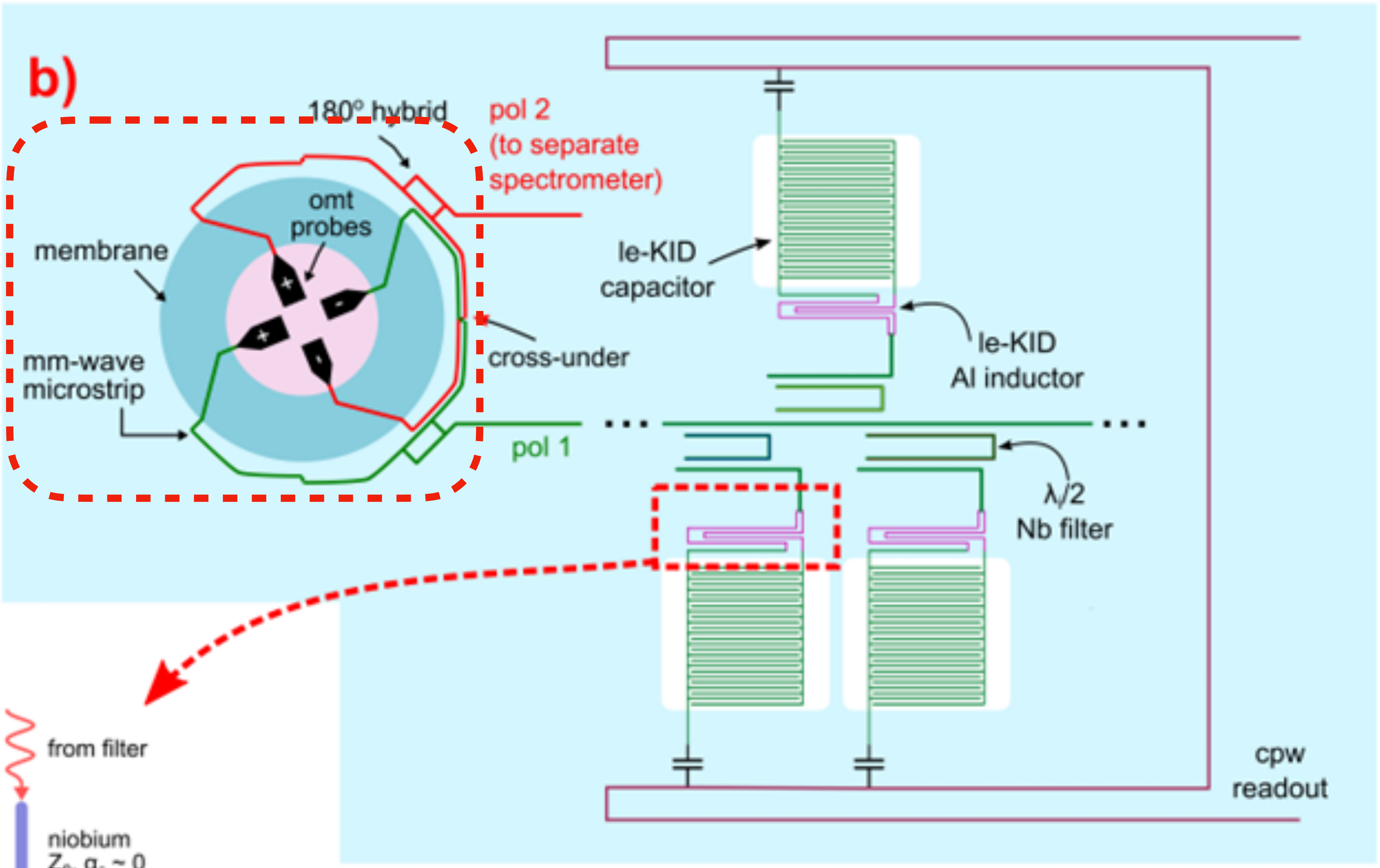
On-Chip Spectrometers

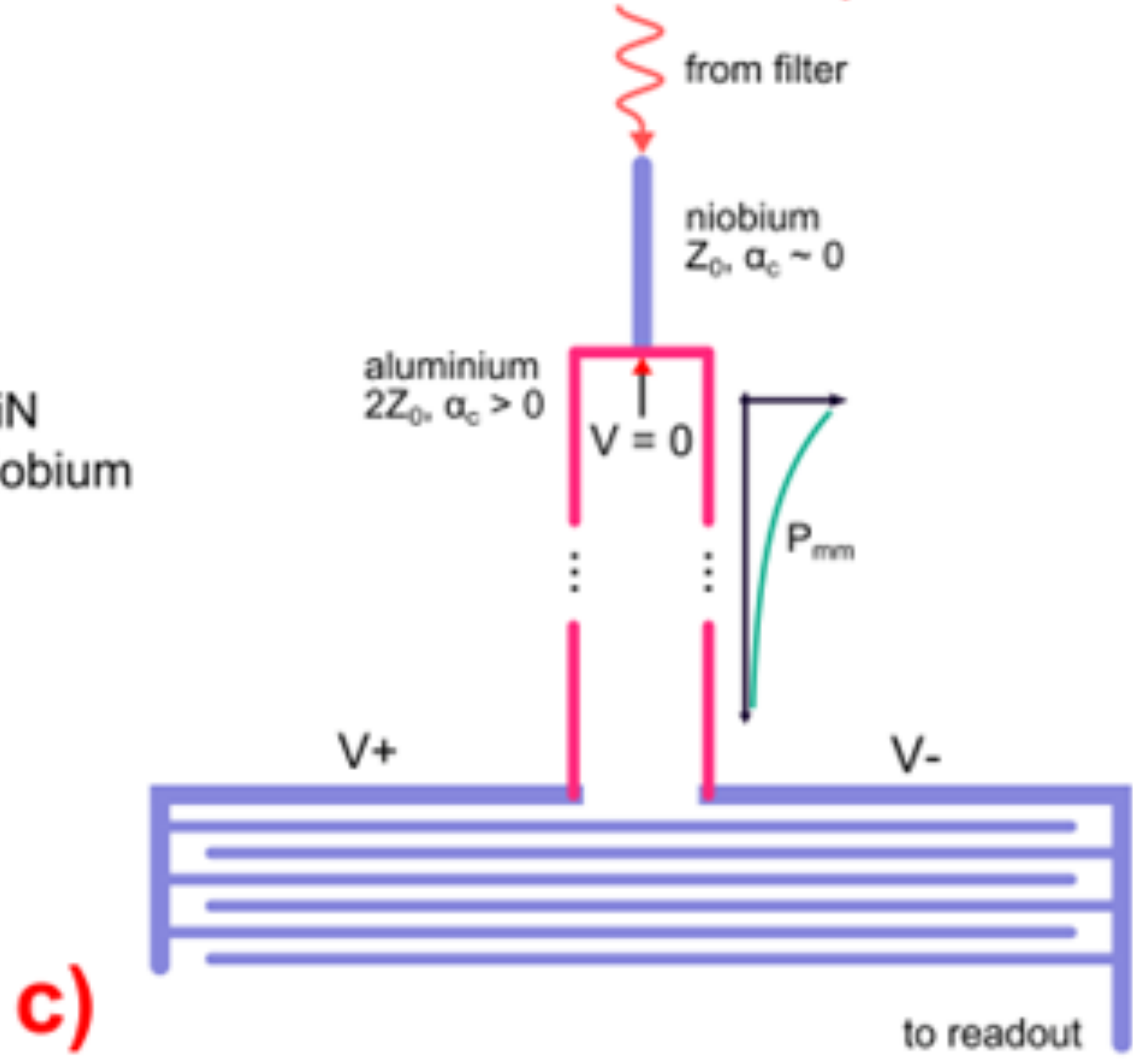
Light from telescope



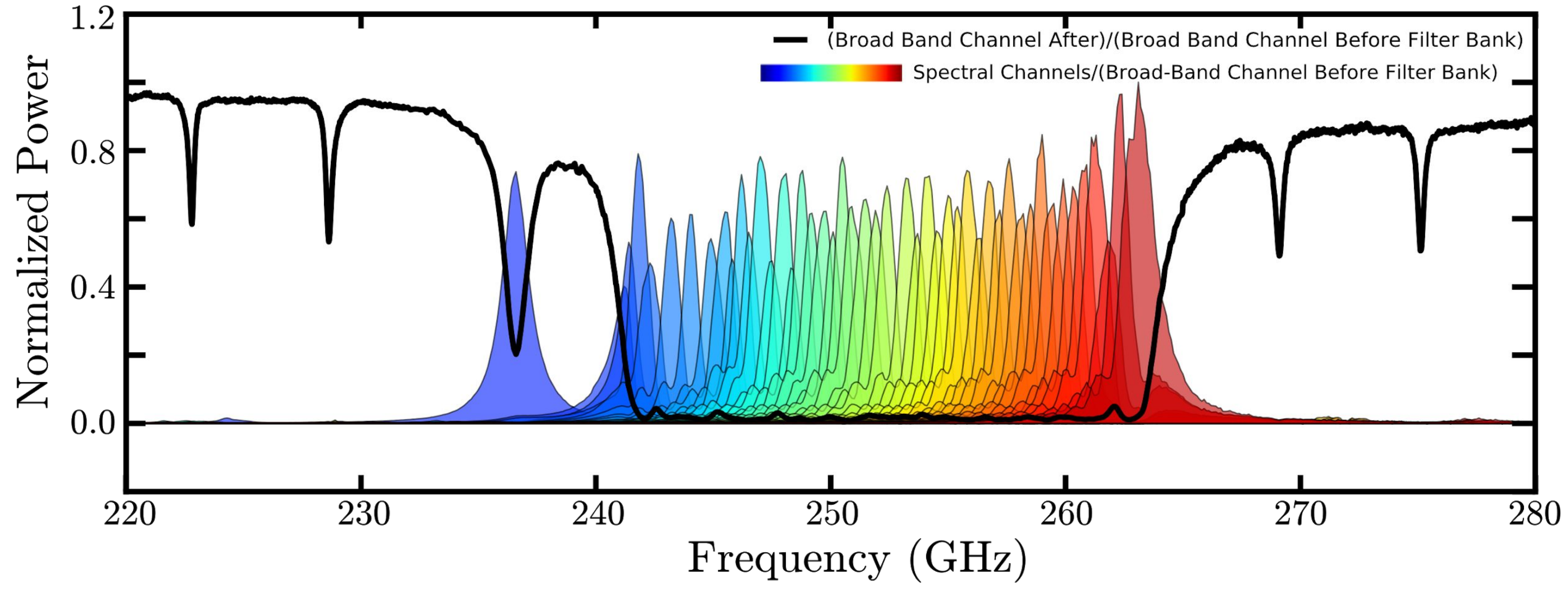
Cross section

Top view



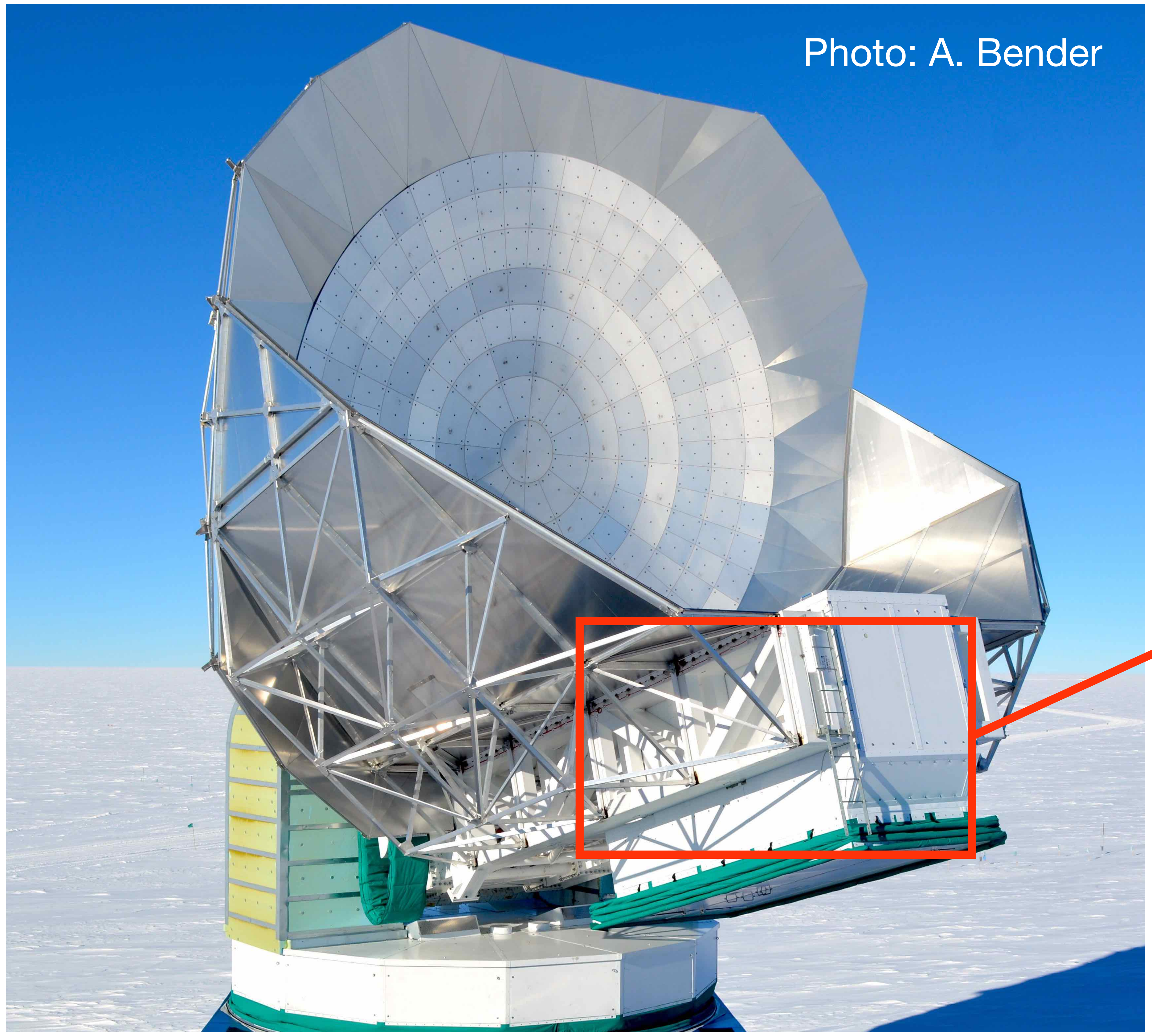


SuperSpec prototypes



SPT-SLIM Experimental Concept

South Pole Telescope is 10-m CMB telescope observing at 90/150/220 GHz during both austral winter *and summer*



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

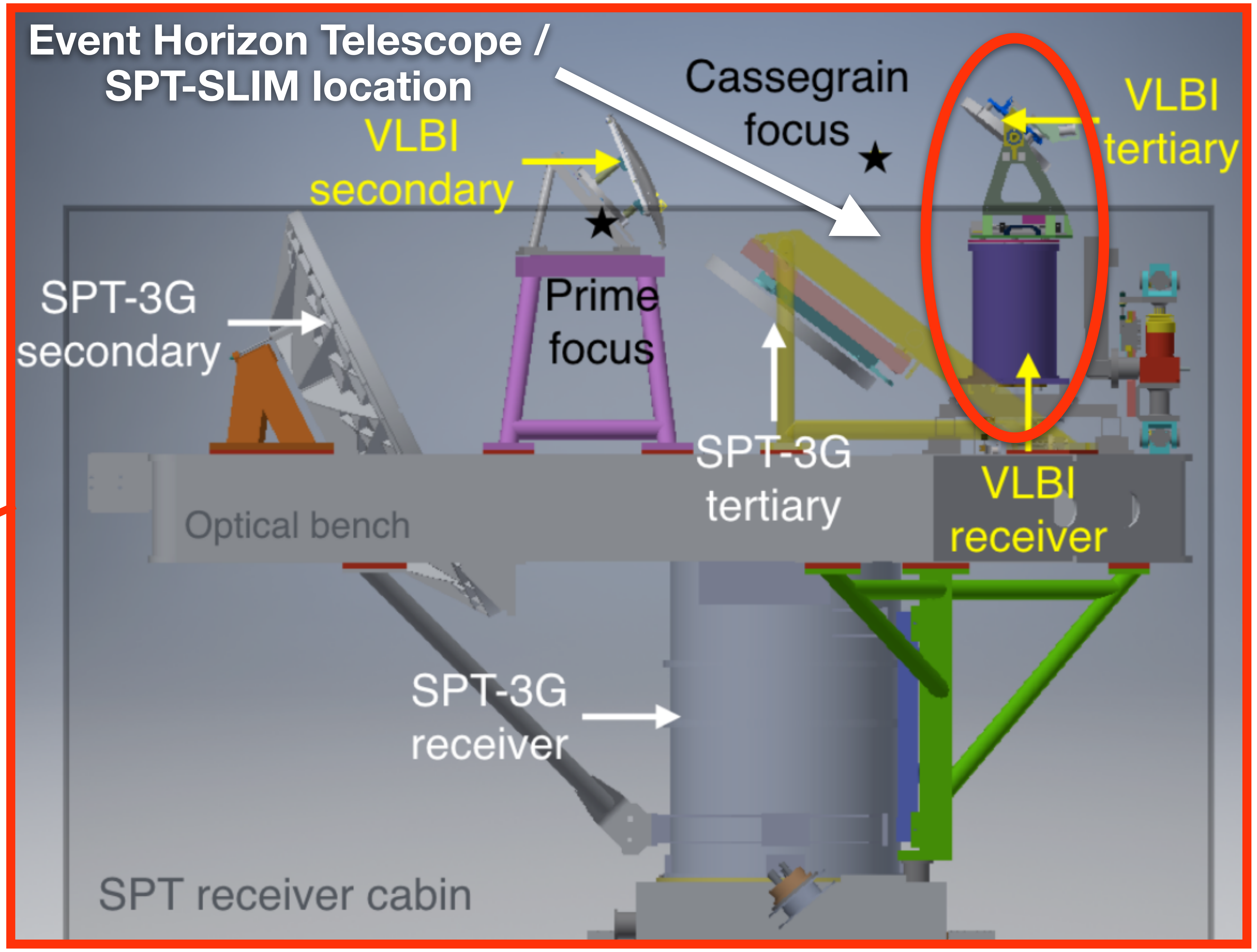


Figure: J. Kim, et al. 1805.09346

SPT-SLIM: South Pole Telescope Summertime Line Intensity Mapper

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C. Chang
Z. Pan

Cardiff:
P. Barry
G. Robson

Harvard:
G. Keating

Fermilab:
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B. Benson
S. Simon
M. Young

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K. Dibert
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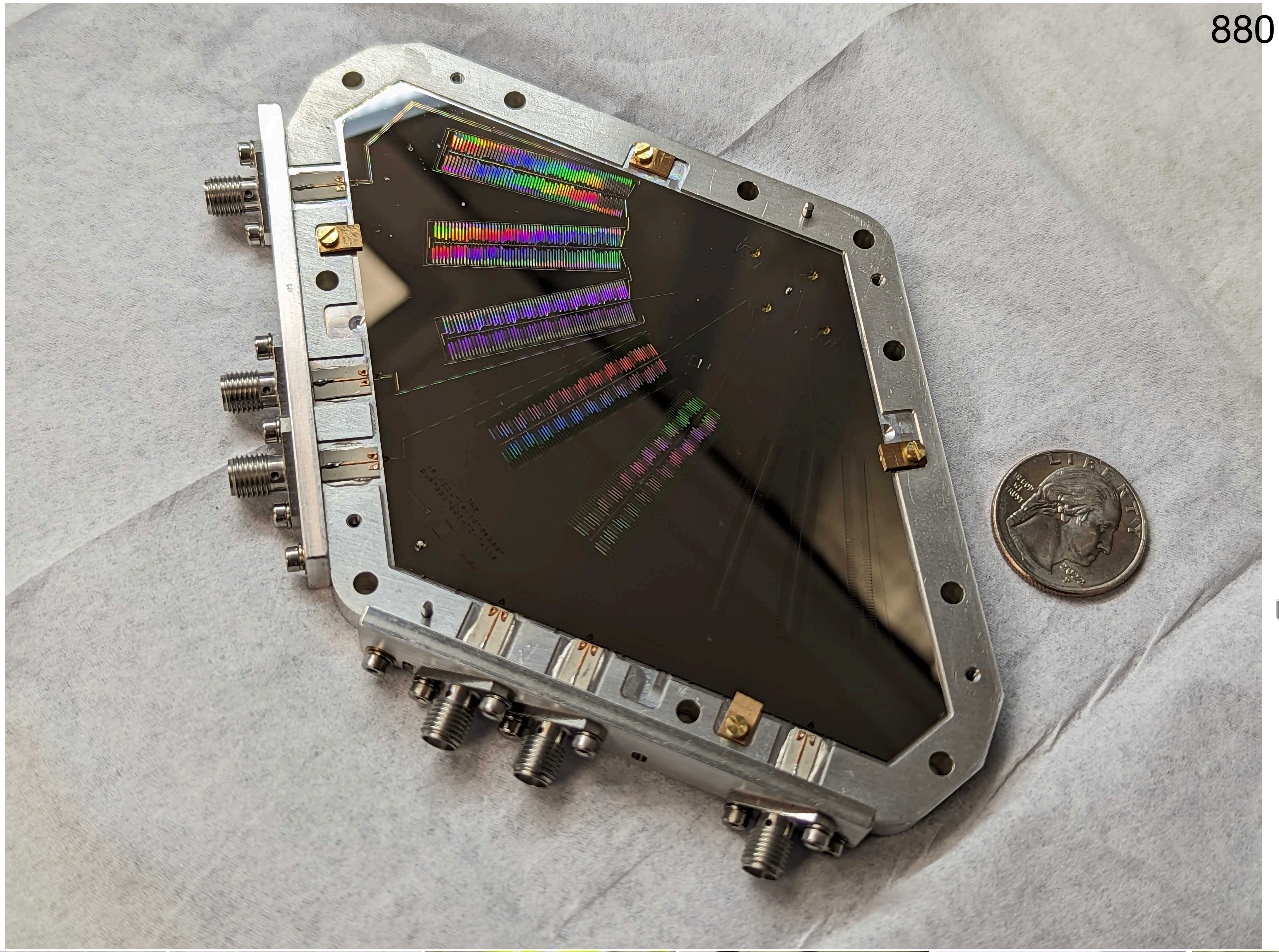
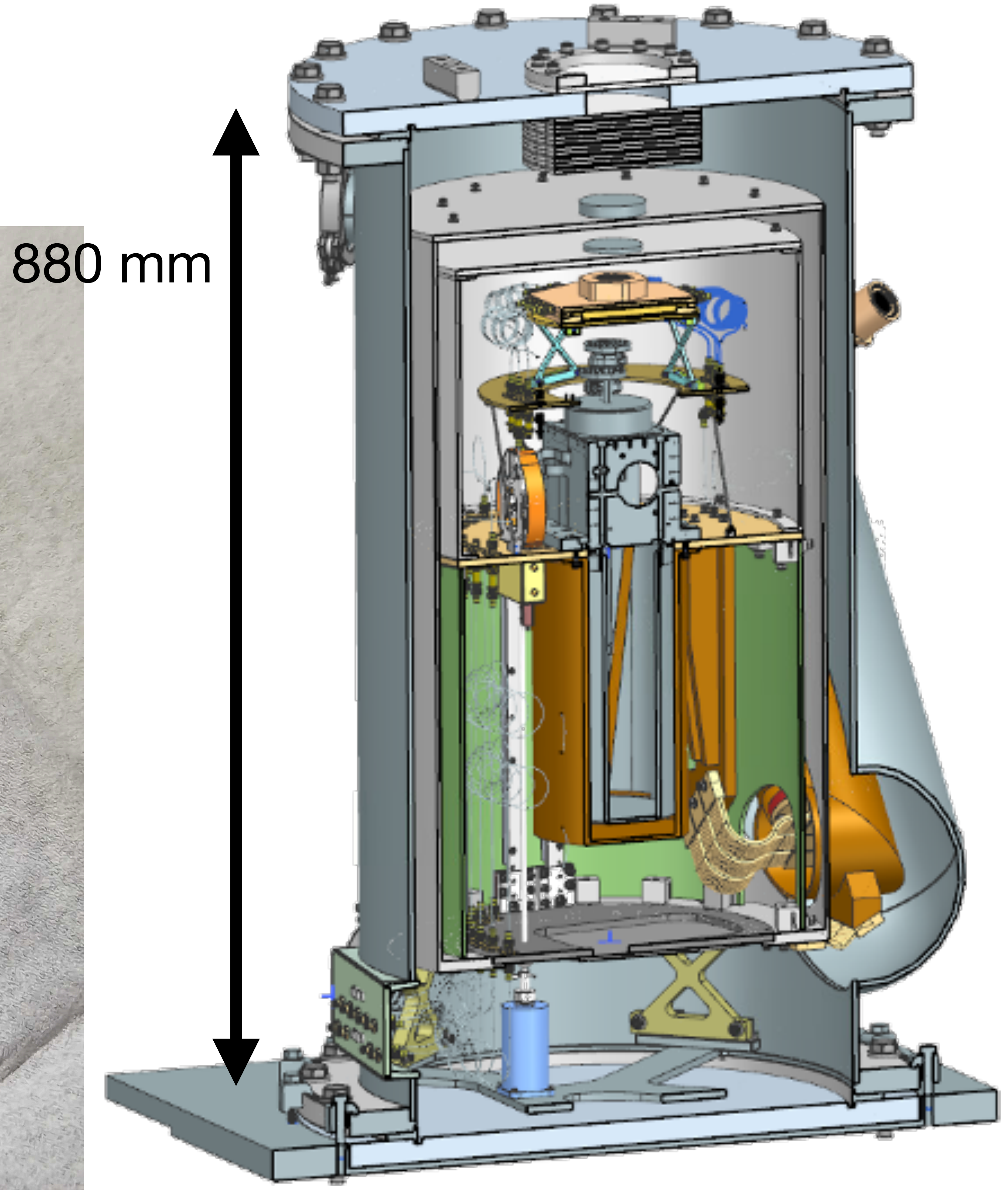
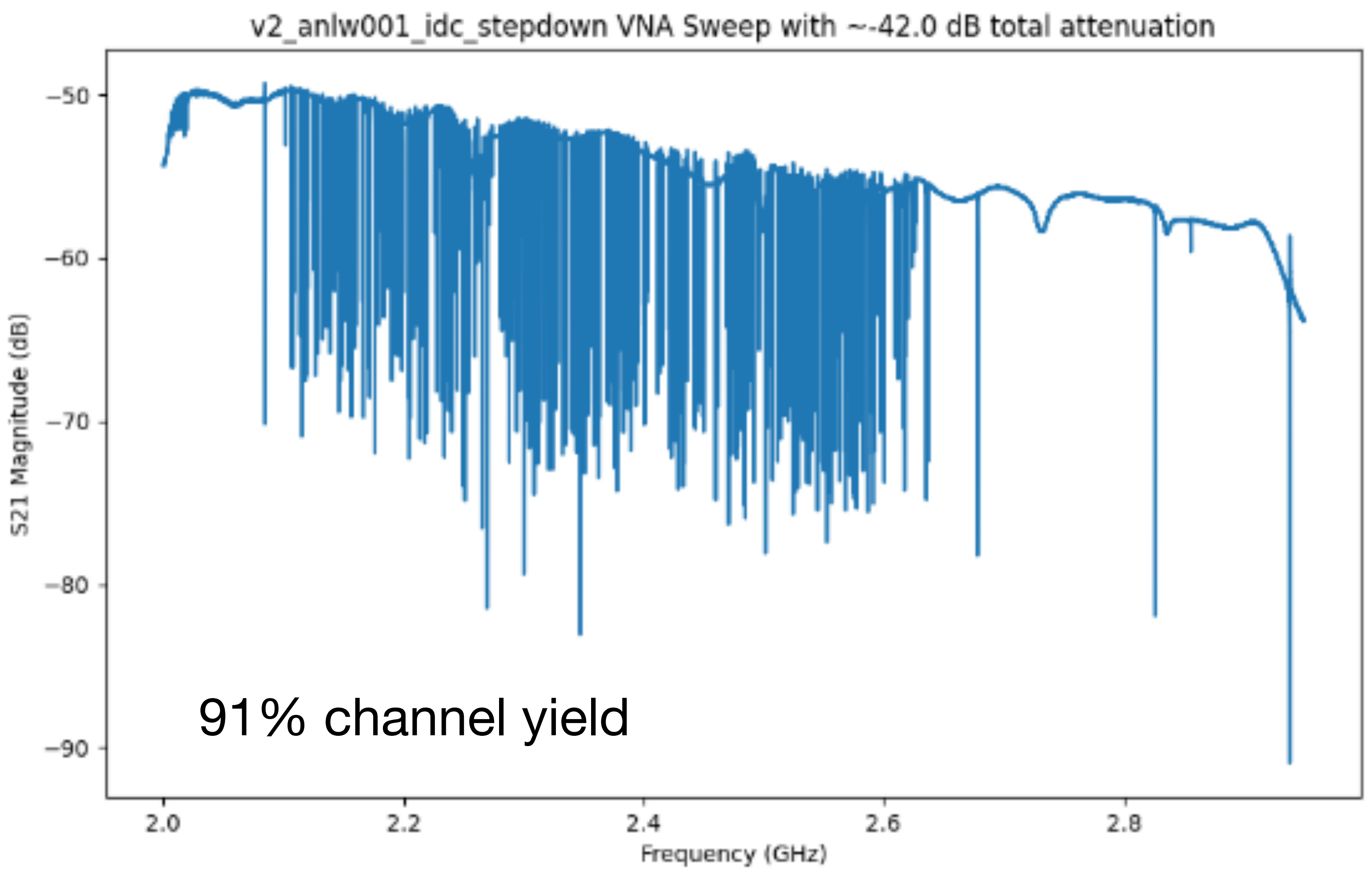
T. Natoli
J. Zebrowski

Three-Speed Logic
G. Smecher

SPT-SLIM Hardware







SPT-3G+: High-frequency CMB

Reionization, Recombination, and the CMB

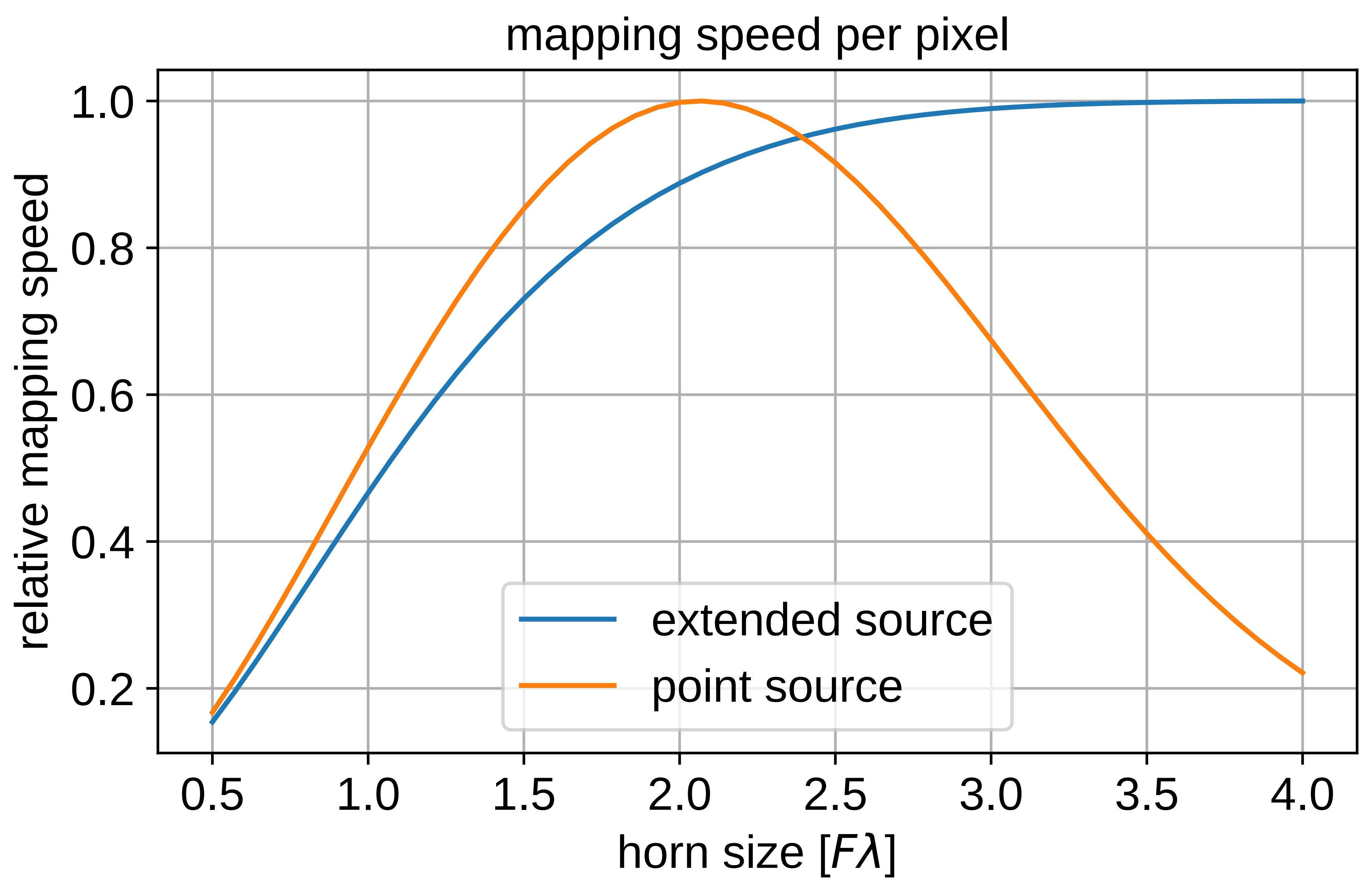
Recombination **Reionization**

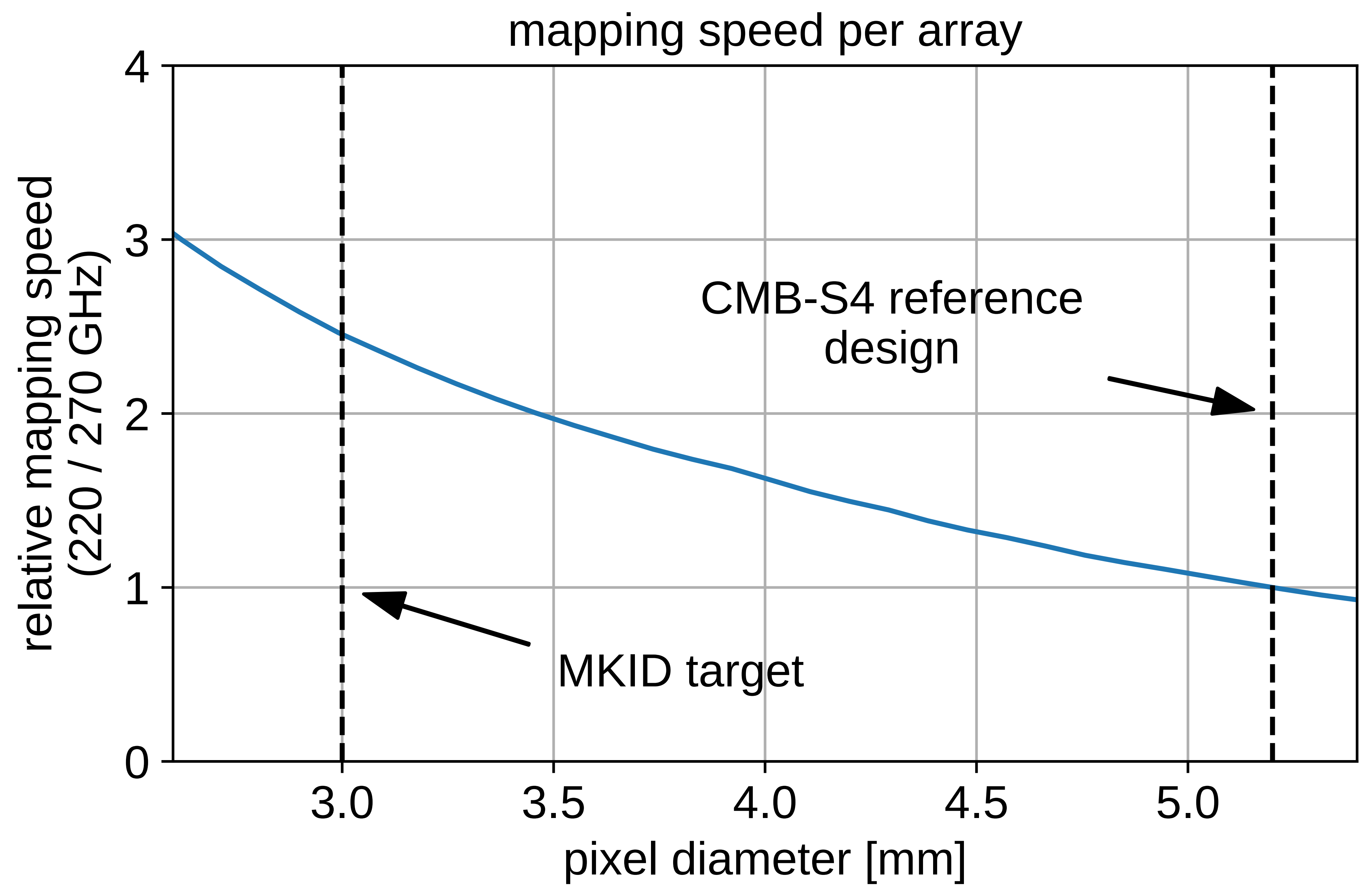
Redshift	~1100	~30	~15	~6	~4	~2.5
Age	~0.4 Myr	~100 Myr	~300 Myr	~1 Gyr	~1.6 Gyr	~2.7 Gyr

Secondary CMB anisotropies and sources targeted by upcoming CMB experiments (Simons Observatory, CCAT-prime, CMB-S4, …)

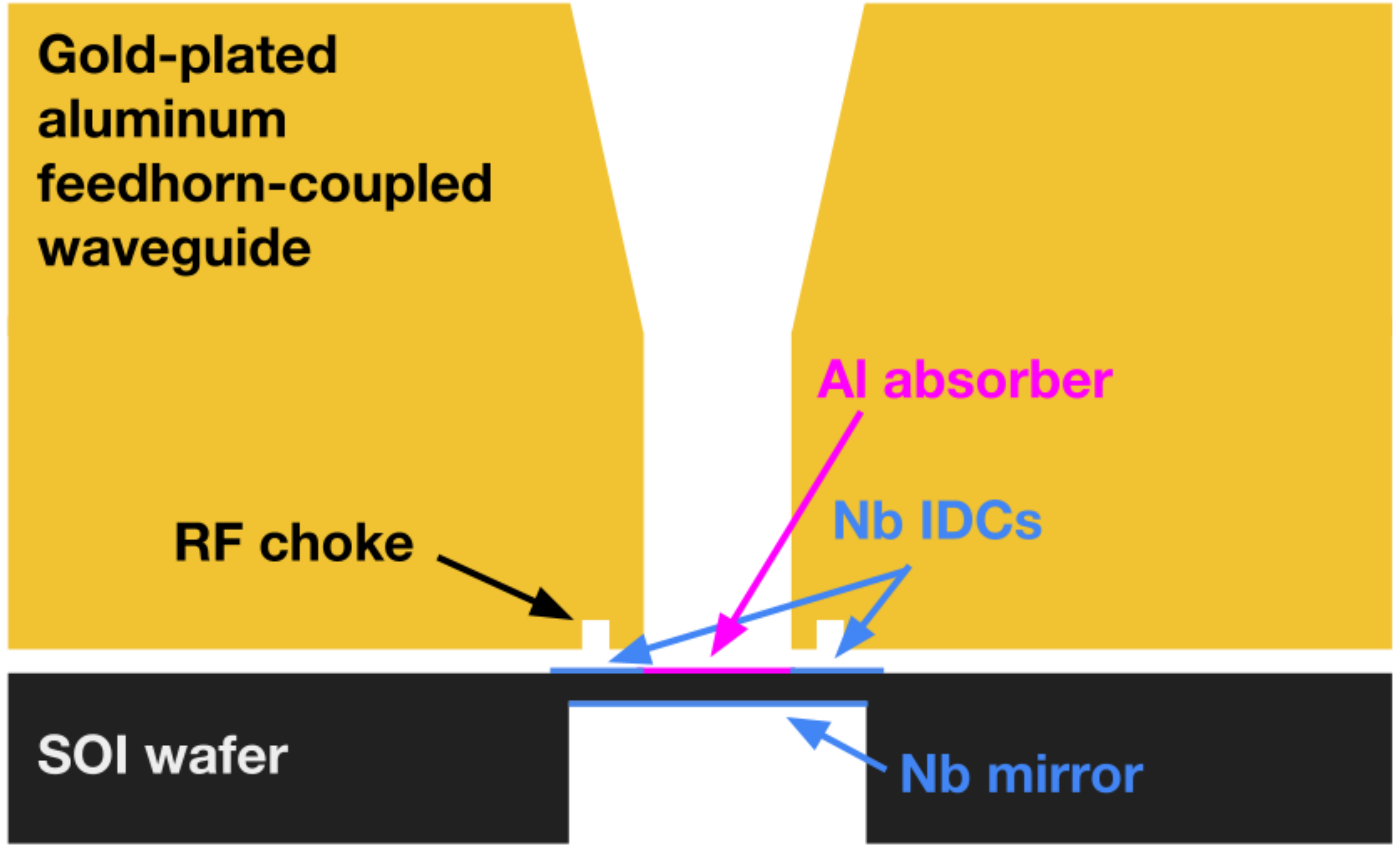
Mapping Speed of Arrays

- Mapping speed ***per pixel*** optimized for pixel sizes > 2Fλ
- But smaller pixels enable more uncorrelated detectors per array, so mapping speed ***per array*** tends to be maximized for small pixels down to 0.5-1Fλ
- Improvement of KIDs vs. TESs due to detector density is greatest at frequencies >150GHz
- ***Example:***
    - CMB-S4 220/270 GHz dichroic band is limited to ~2000 detectors / wafer
    - >3x increase in sensitivity possible by moving to denser arrays with smaller pixels



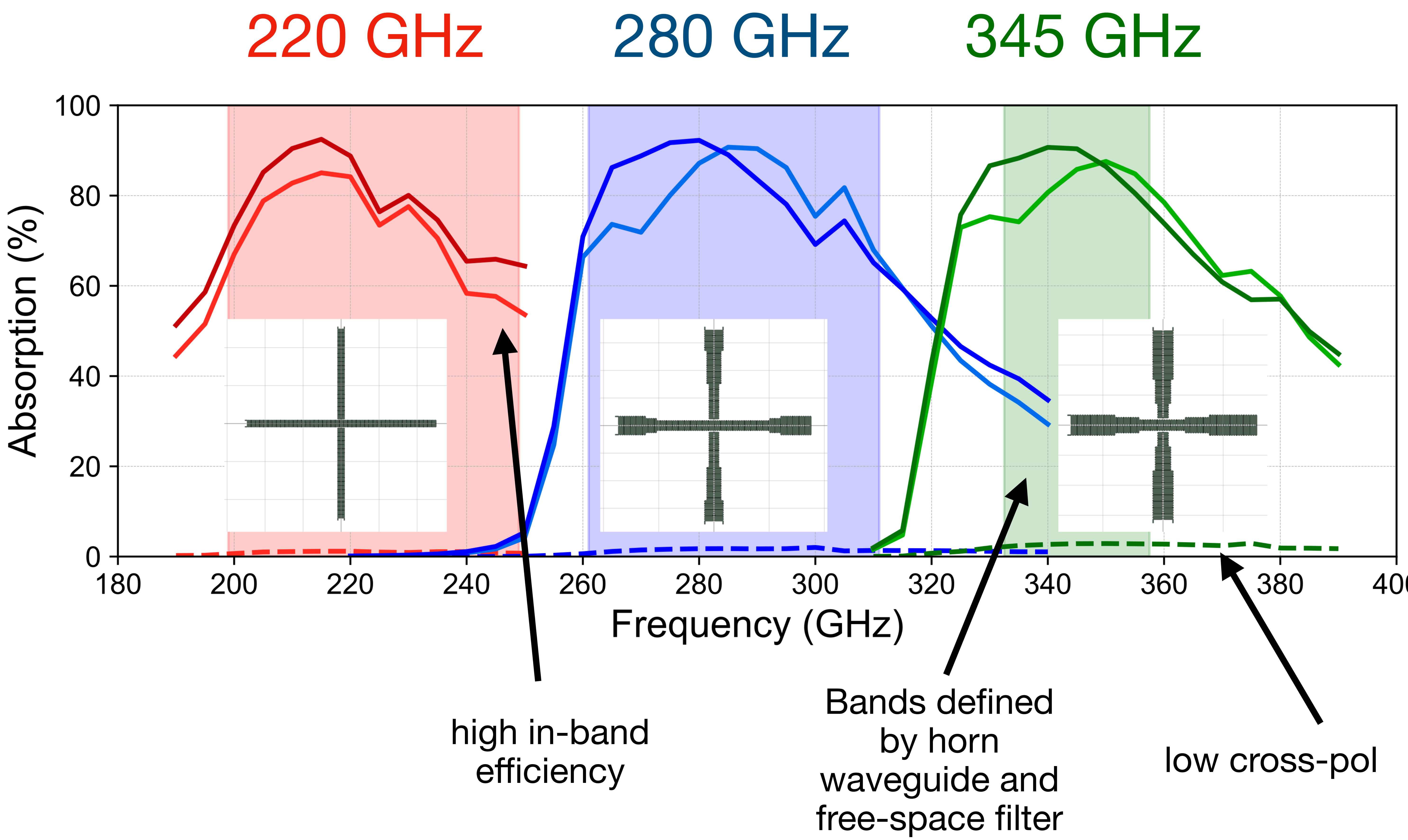


SPT-3G+ Detector Architecture

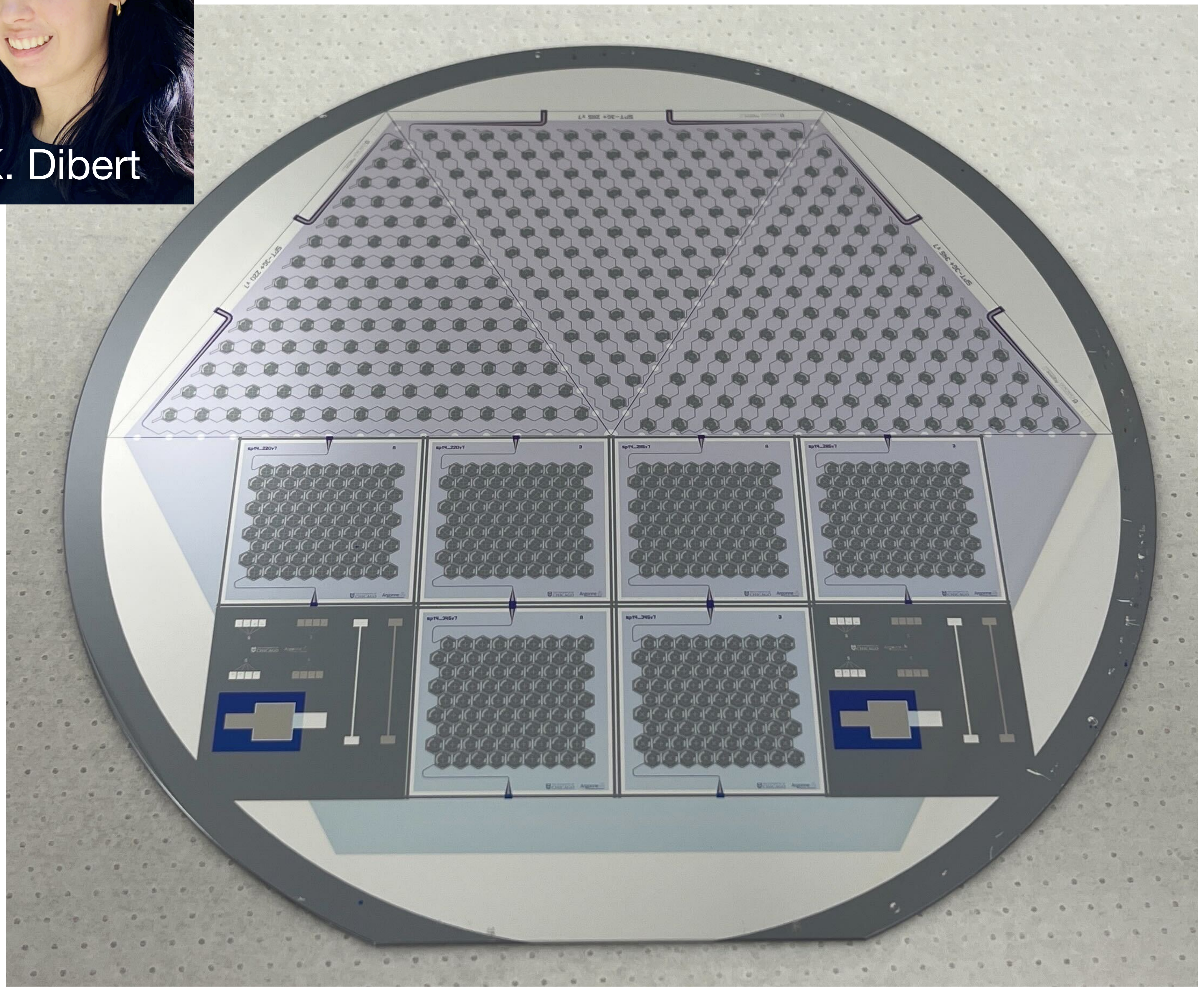


K. Dibert, P. Barry

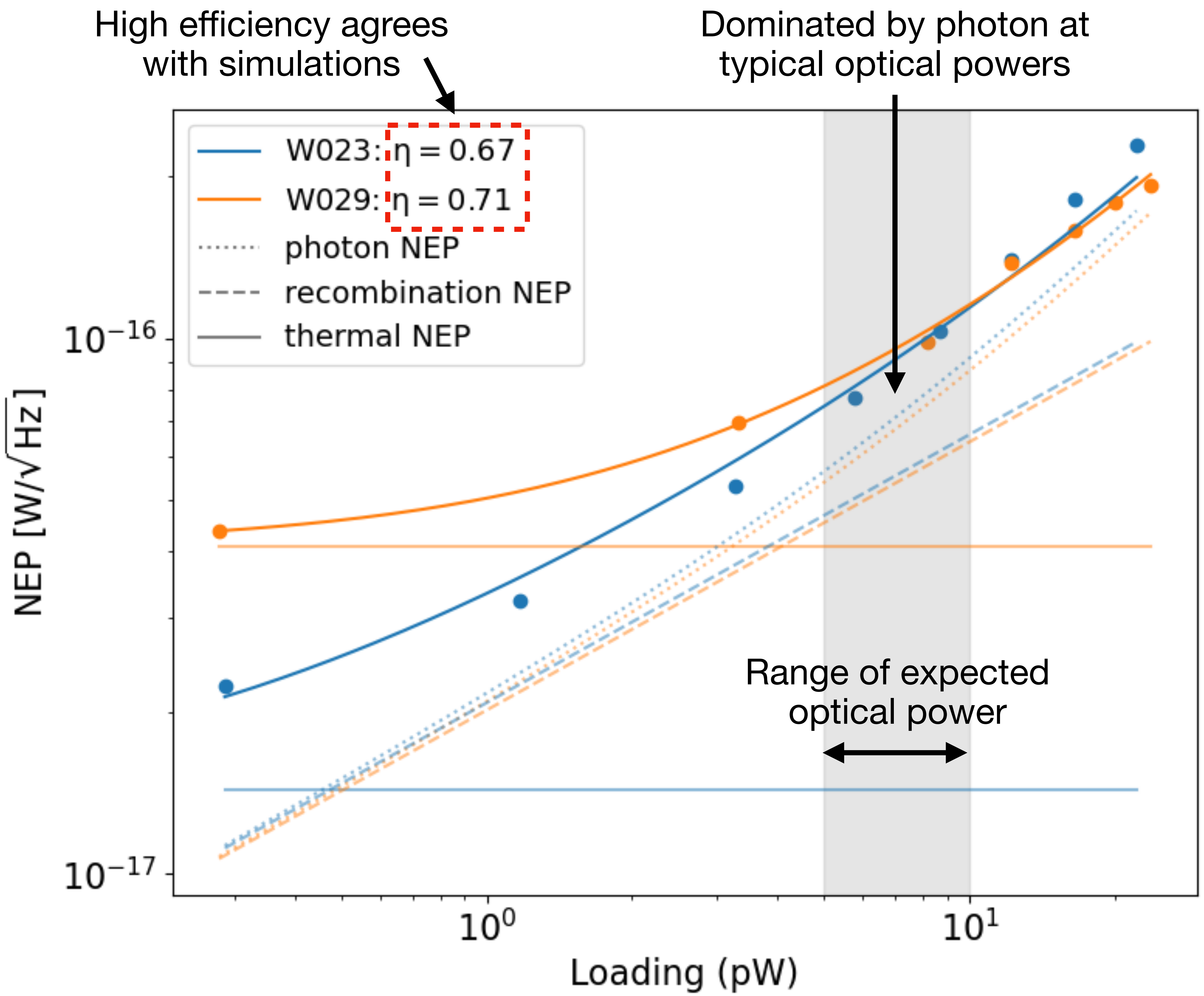
Bandpasses



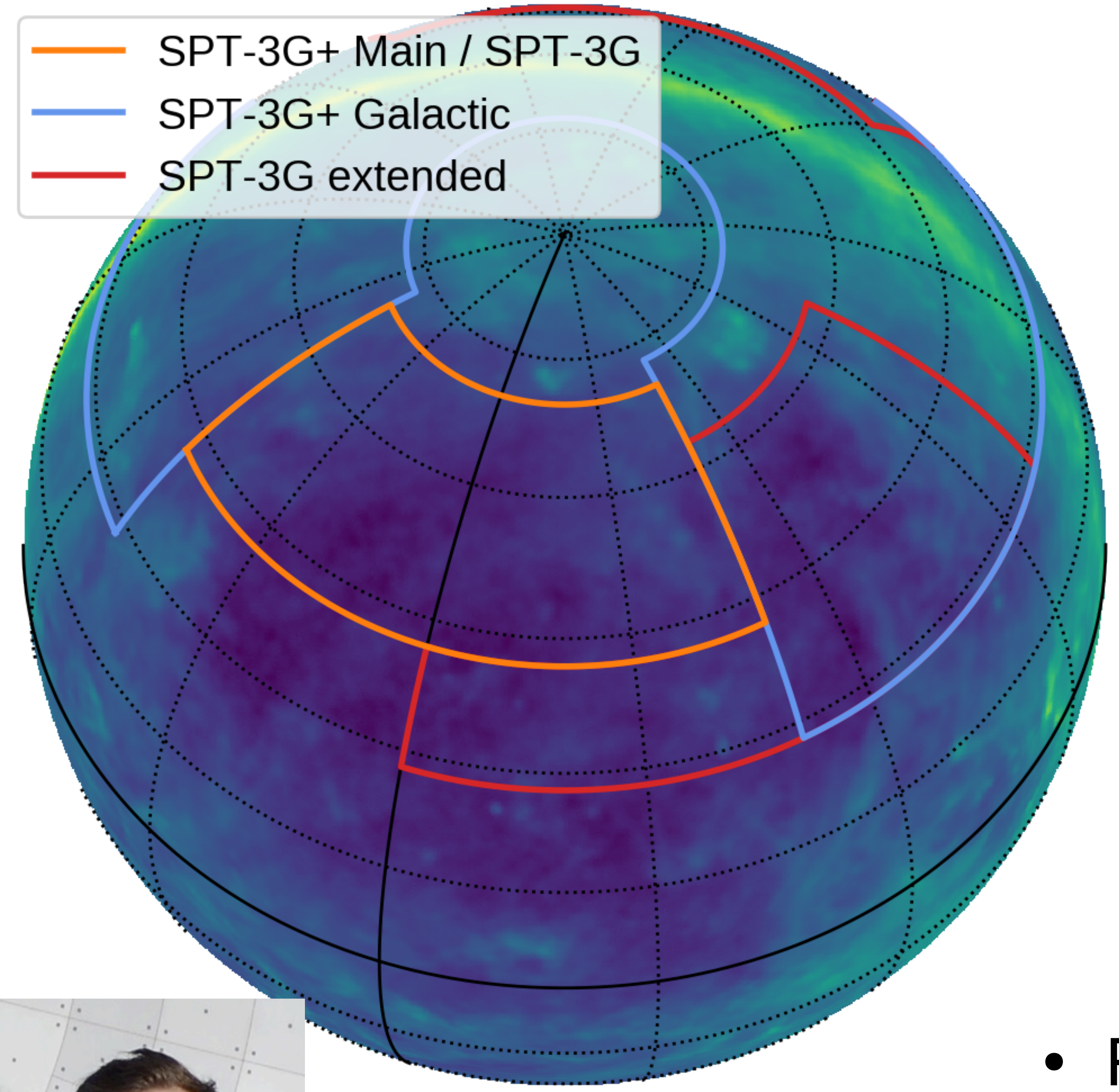
SPT-3G+ Detector Prototyping and Testing



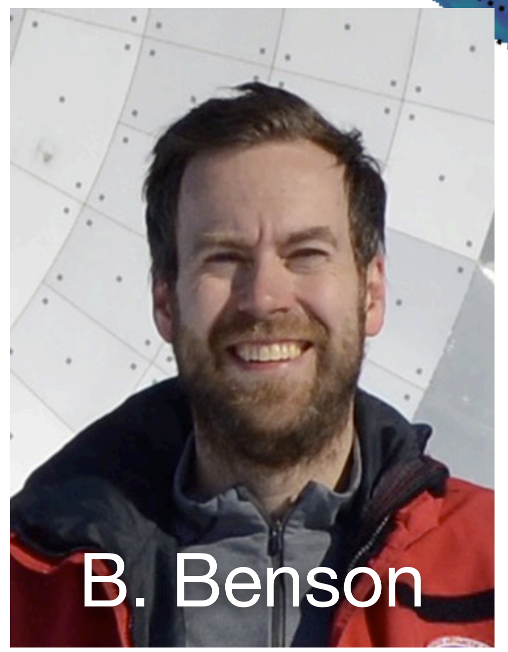
220 GHz detector test wafer fabricated at Argonne
(Karia Dibert, Tom Cecil)



SPT-3G+ Survey Concept



		Survey Depth [μK-arcmin]			
	Band	**Main (1500 deg²)**	**Extended (3000 deg²)**	**Galactic (7000 deg²)**	**Resolution [arcmin]**
3G	**95 GHz**	3.0	9	—	1.5
3G	**150 GHz**	2.2	9	—	1.2
3G	**220 GHz**	8.8	13	—	1.0
3G+	**220 GHz**	2.9	—	14	0.8
3G+	**285 GHz**	5.6	—	28	0.6
3G+	**345 GHz**	28	—	170	0.5



- Reuse the existing SPT primary and secondary optics, with a new cryostat containing KID-based CMB detectors at 220, 285, and 345 GHz.
- Continue to observe existing SPT "Main" field, but add 7000 deg^2 "Galactic" survey during the austral summer months

Conclusions

- Pushing the ***density frontier*** of mm-wavelength detectors using KIDs opens up new science opportunities beyond CMB-S4.
- Fermilab, together with Chicago and Argonne, is leading the development of two new cameras based on high-density KIDs:
    - SPT-SLIM - Pathfinder for mm-wavelength line intensity mapping
    - SPT-3G+ - High-frequency CMB
- SPT-SLIM deploys next year!