SPT-3G:

The Third Generation Camera and Survey for the South Pole Telescope

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URSI
05 Jan 2017

SPT

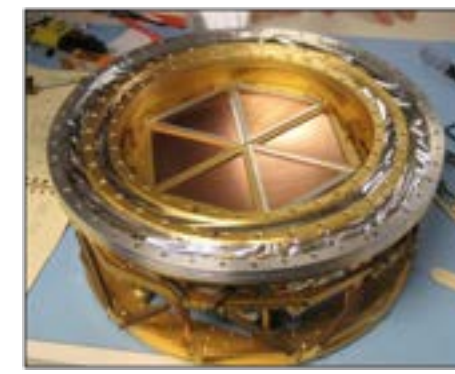
The South Pole Telescope

Telescope

- 10 meter off-axis sub/mm telescope
- located at the geographic south pole
- 1 deg^2 field of view
- ~1' beams
- optimized for fine scale anisotropy measurements

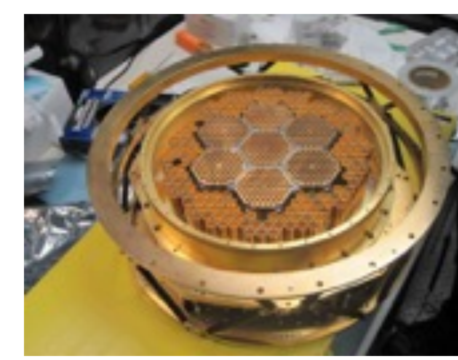
SPT-SZ Camera (1st Generation):

- 2007 – 2011
- 960 pixel mm camera, 1 deg^2 FOV
- 1.4, 2.0, and 3.0 mm
- completed 2500 deg^2
- 18 μK-arcmin depth, ~1 mJy



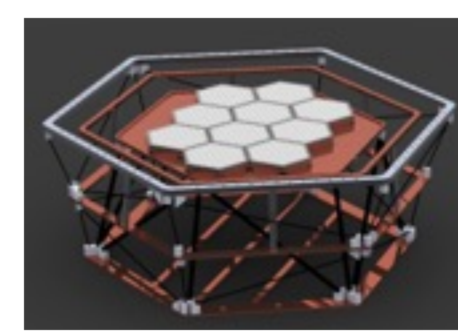
SPT-pol Camera (2nd Generation):

- 2012 – 2015
- 1600 detector mm camera, 1 deg^2 FOV
- 2 and 3 mm + polarization
- currently surveying 500 deg^2
- 4.5 μK-arcmin depth

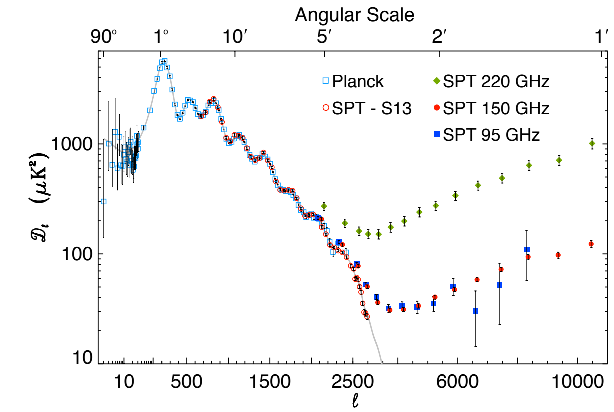


SPT-3G Camera (3rd Generation):

- 2016 – 2020
- 15k detector mm camera, 2.4 deg^2 FOV
- 1.4, 2, 3 mm + polarization
- planned 2500 deg^2 x8 deeper
- 2.5 μK-arcmin depth

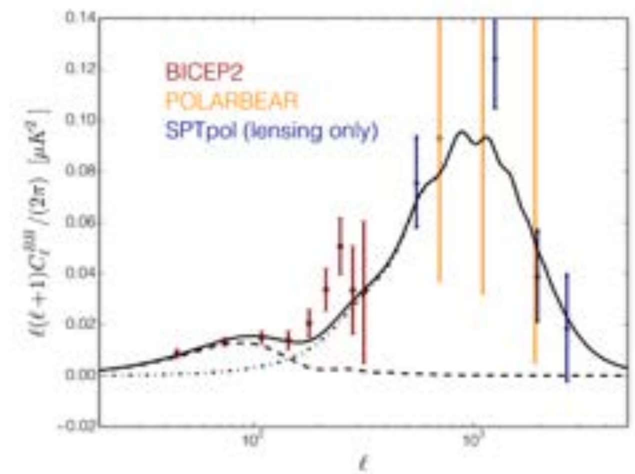


SPT Science



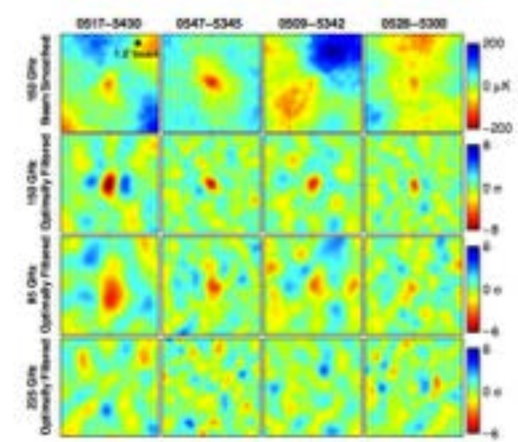
Cosmic Microwave Background:

- CMB power spectrum: Story *et al.* 2013 ApJ, George *et al.* 2014
- CMB Lensing: van Engelen *et al.* 2012 ApJ; Holder *et al.* 2013 ApJ
- Epoch of Reionization: Zahn *et al.* 2012 ApJ
- CMB Polarization: Hanson *et al.* 2013 PRL



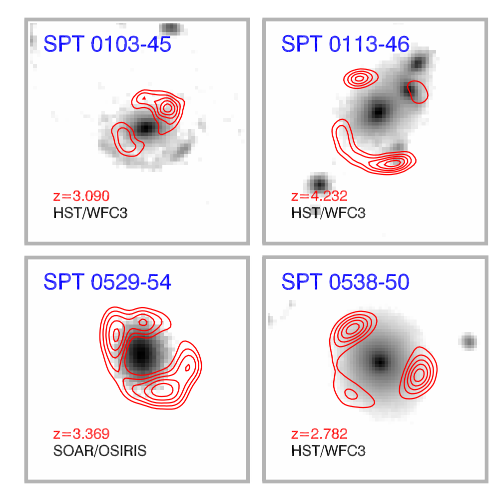
Galaxy Clusters:

- SZ cluster catalog: Reichardt *et al.* 2013 ApJ
- Cluster Cosmology: Benson *et al.* 2013 ApJ
- Cluster Astrophysics: McDonald *et al.* 2013 ApJ

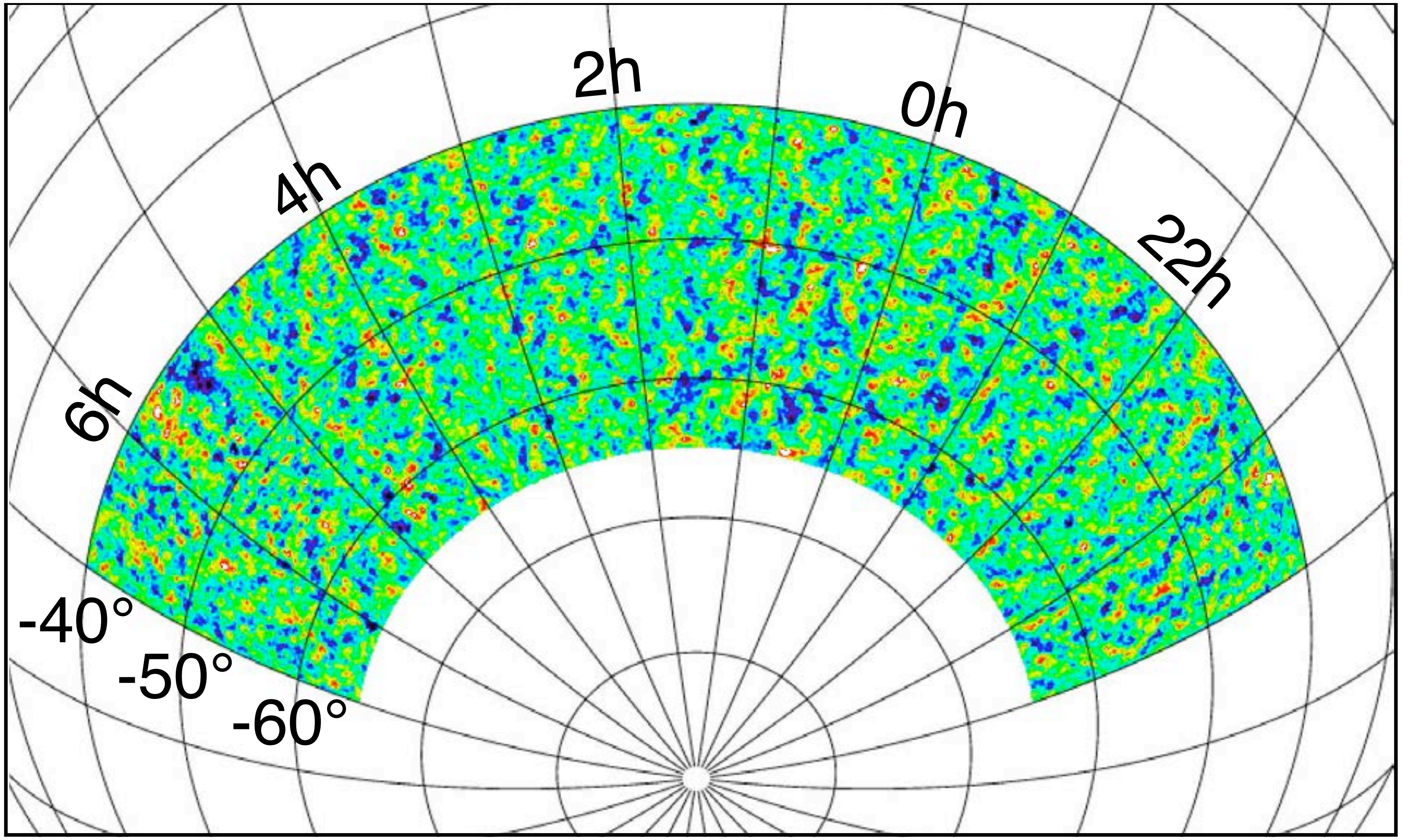


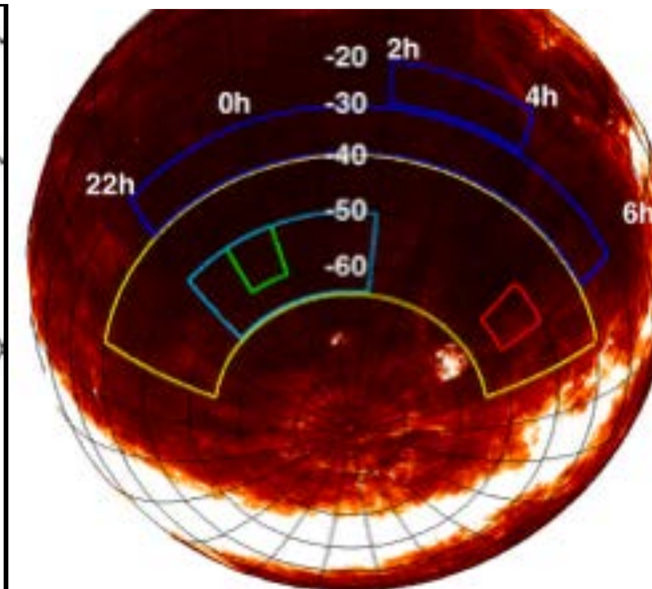
Galaxy Evolution:

- Catalog of mm sources: Mocanu *et al.* 2013 ApJ
- High-z strongly-lensed starforming galaxies: Vieira *et al.* 2013 Nature



2500 deg² SPT-SZ Survey





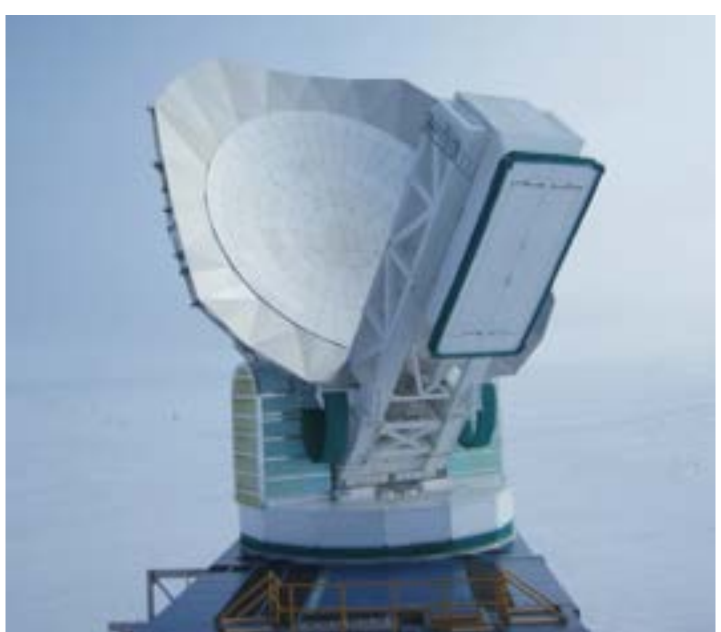
SPT-SZ

SPT-E, SPT-W

SPTpol deep

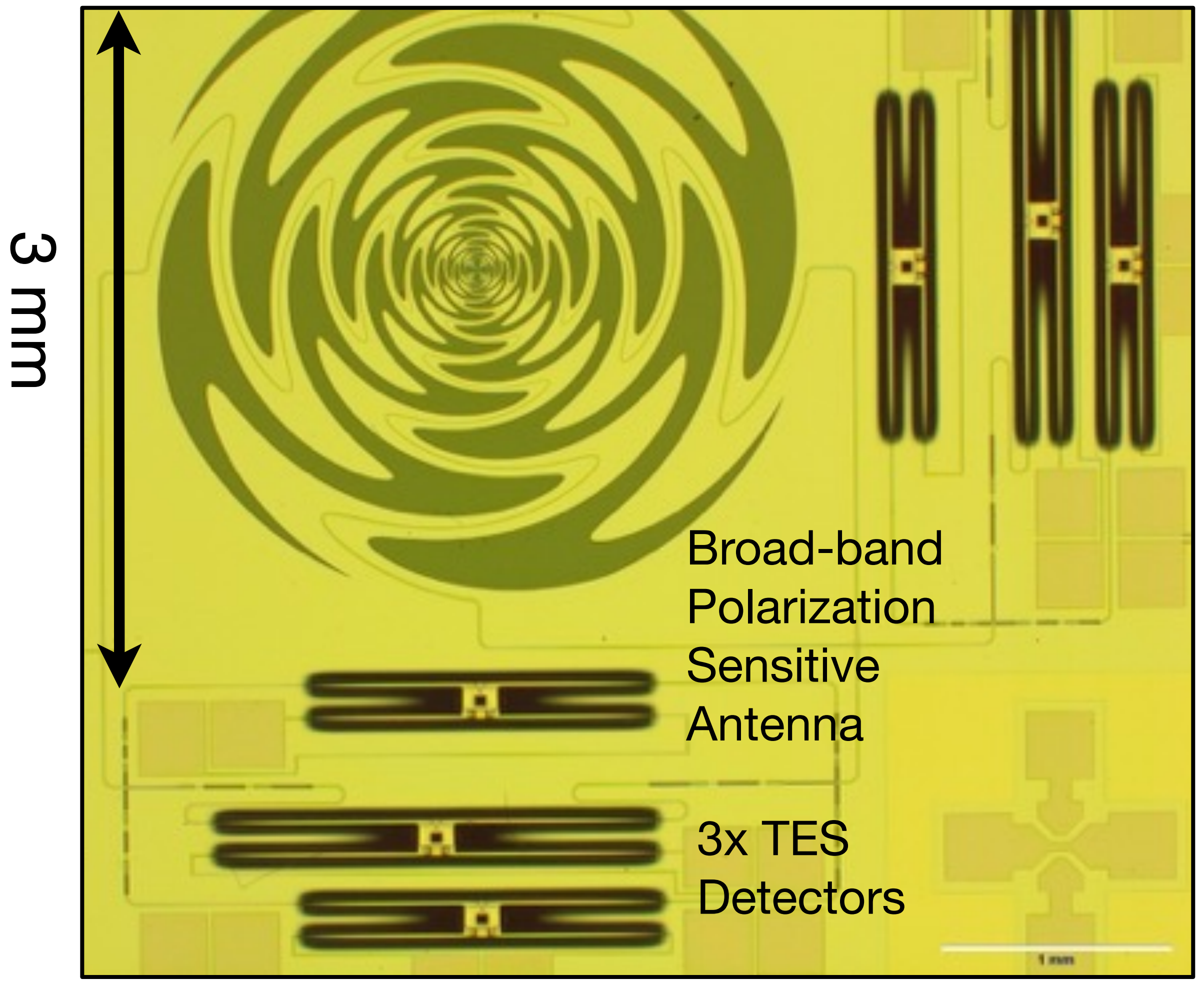
SPTpol

SPTpol-Summer



		SPT-SZ	2008 → 2011	Deep Field	2008 → 2013	SPTpol	2012 → 2014	SPT3G	2015 → 2017
band [mm]	FWHM [']	uK$_{CMB}$-arcmin	RMS mJy/beam	uK$_{CMB}$-arcmin	RMS mJy/beam	uK$_{CMB}$-arcmin	RMS mJy/beam	uK$_{CMB}$-arcmin	RMS mJy/beam
3	1.7	42	2	6	0.3	15	0.7	4.2	0.2
2	1.2	18	1.3	5	0.3	6	0.5	2.5	0.2
1.4	1	85	6.8	35	3	--	--	4	0.4
area [deg²]		2500		200		500		2500	

SPT-3G Mapping Speed



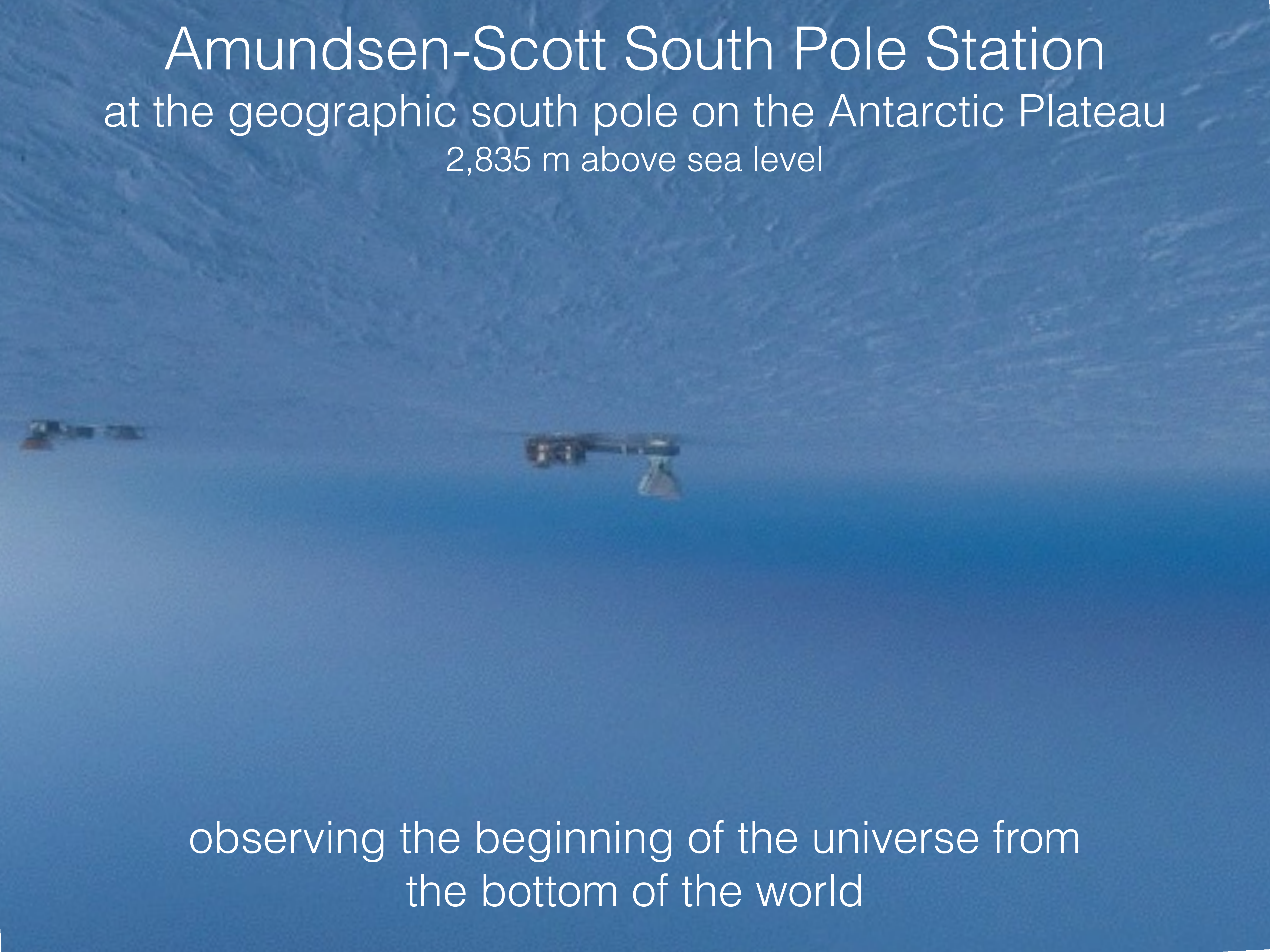
~20x Increase in Mapping Speed Relative to SPTpol:

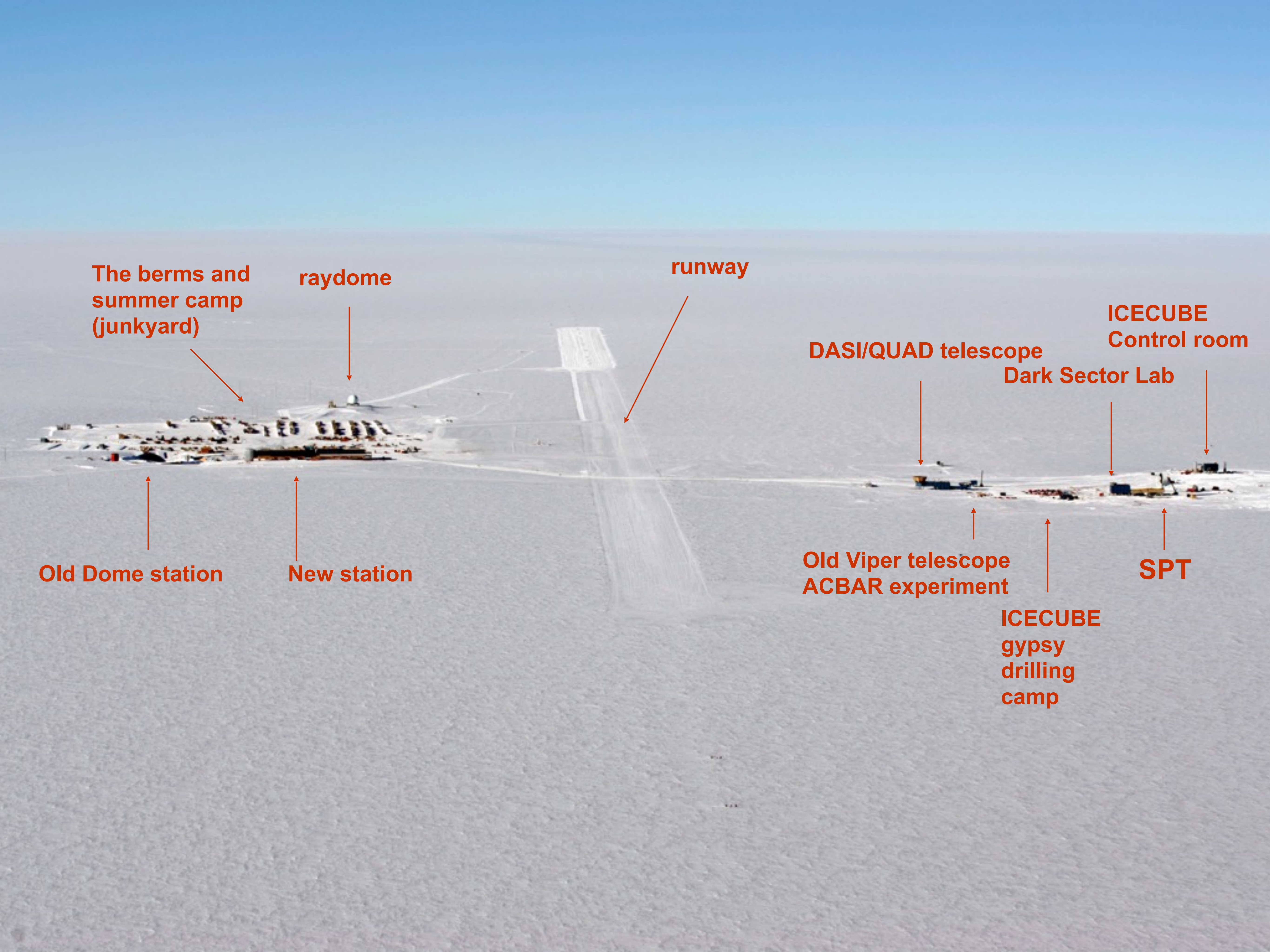
1) Multi-chroic pixels
   - 3-bands: 95, 150, 220 GHz

2) Increased field of view
   - 3x increase in area (2.8 deg^2)
   - use large aperture (720 mm diameter), low-loss alumina lenses

3) Reduce internal loading
   - Reduce from 30 K to 10 K
   - Zotefoam window supported by ~50 K alumina lens

Experiment	N_{bolo}	NET_T ($\mu K\sqrt{s}$)	$Speed_T$	NET_P ($\mu K\sqrt{s}$)	$Speed_P$
SPT-SZ	960	22	1.0	-	-
SPT-POL	1,536	14	2.5	20	1.0
SPT-3G	16,260	**3.4**	**43**	**4.8**	**17**


Amundsen-Scott South Pole Station
at the geographic south pole on the Antarctic Plateau
2,835 m above sea level
observing the beginning of the universe from
the bottom of the world


The berms and summer camp (junkyard)
raydome
runway
ICECUBE Control room
DASI/QUAD telescope
Dark Sector Lab
Old Dome station
New station
Old Viper telescope
ACBAR experiment
SPT
ICECUBE gypsy drilling camp

Recent South Pole CMB experiments at NSF's Amundsen-Scott Research Station

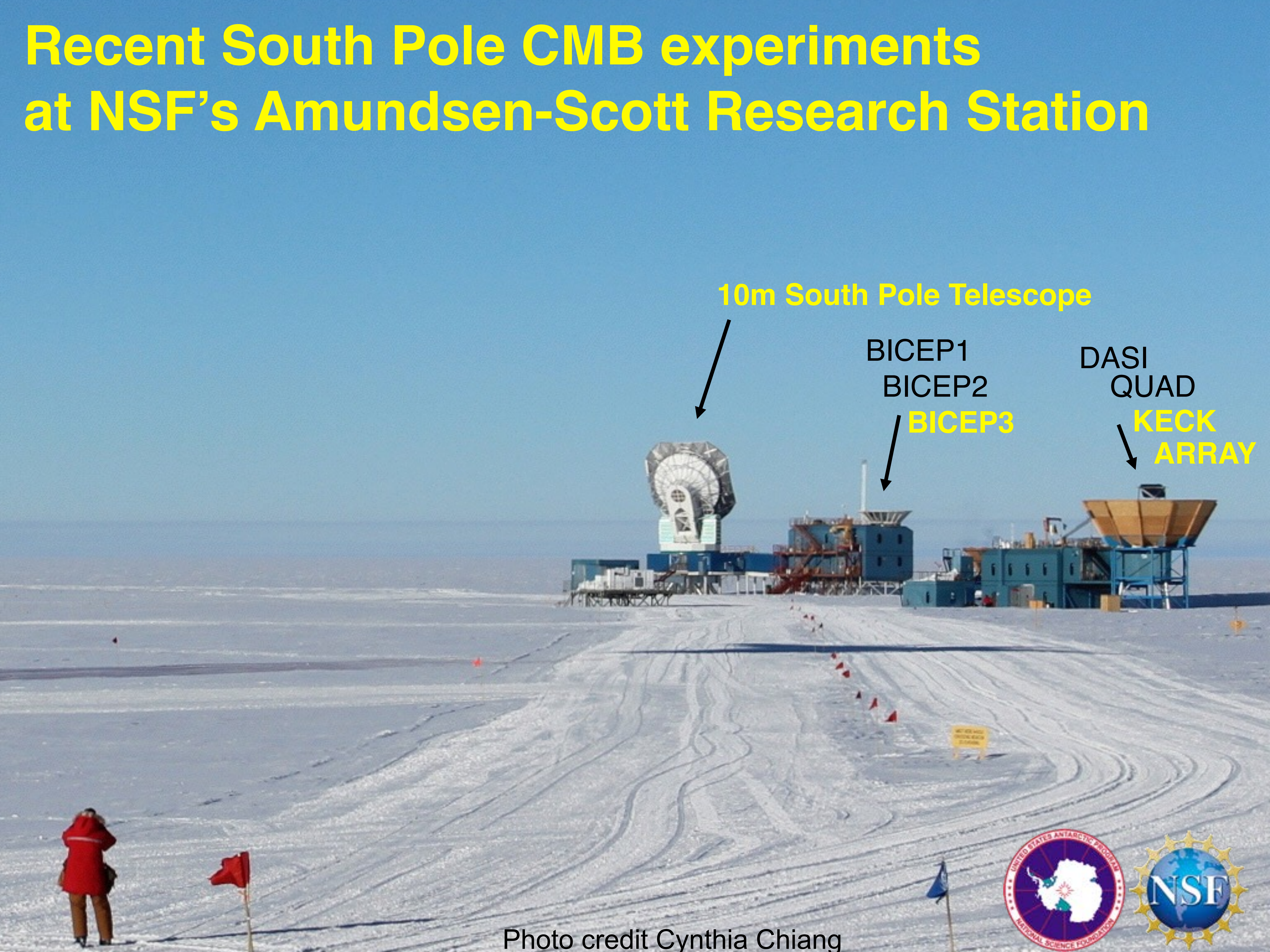
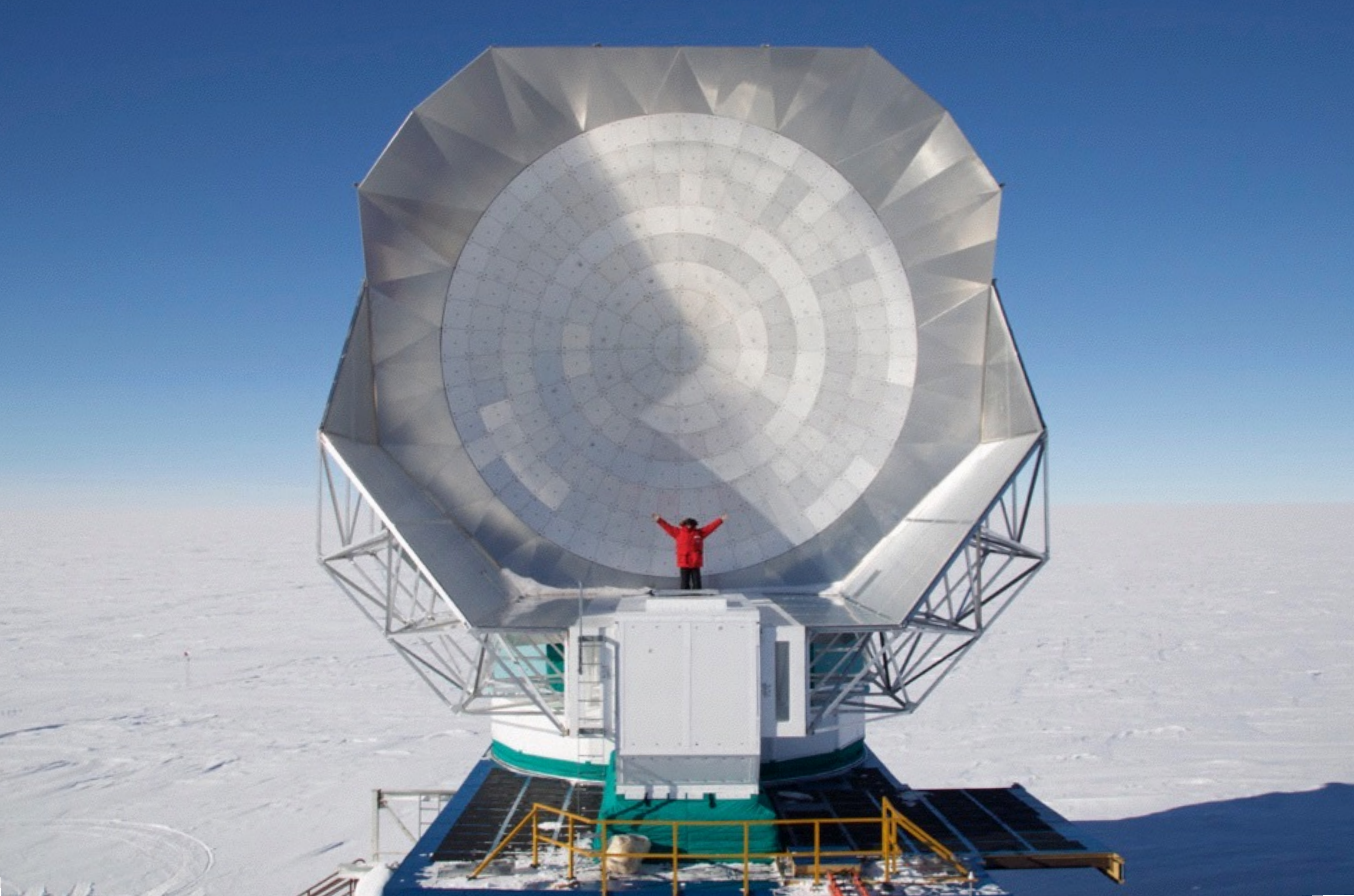
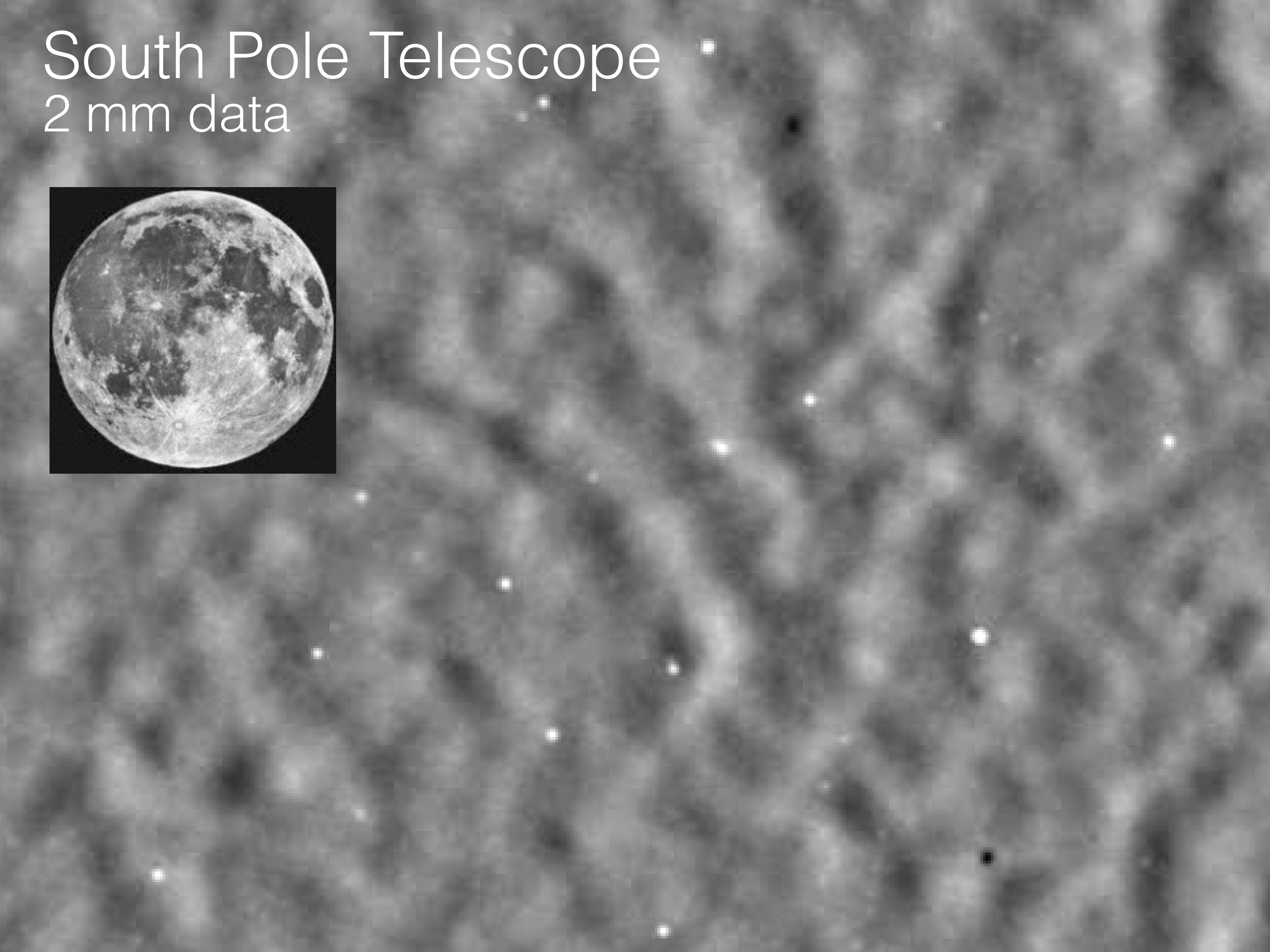


Photo credit Cynthia Chiang

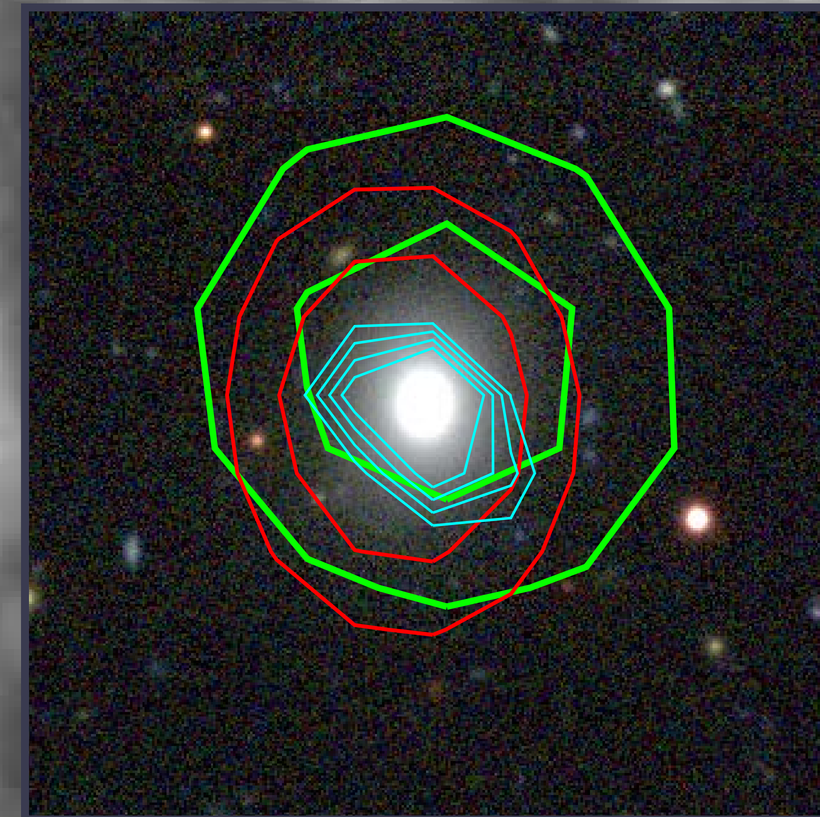
South Pole Telescope




South Pole Telescope
2 mm data

South Pole Telescope
2 mm data

Majority of the SPT sources are high redshift AGN with the jets pointed at us. They have radio, x-ray, and sometimes gamma-ray counterparts.



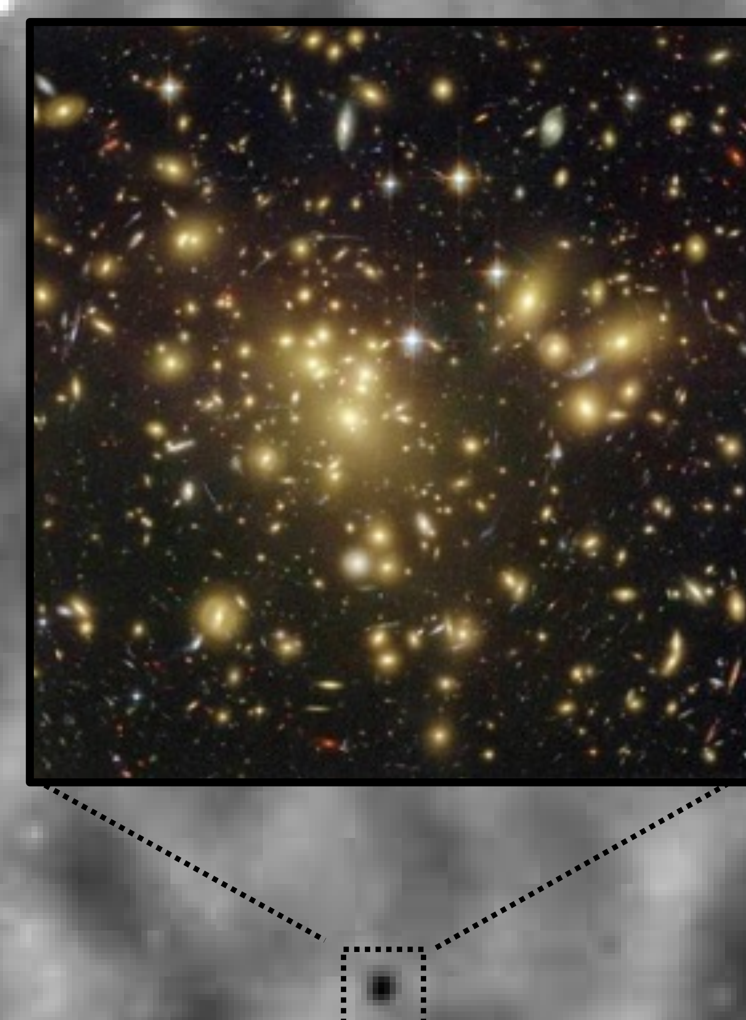
South Pole Telescope
2 mm data

Galaxy Clusters detected with the Sunyaev-Zeldovich effect

“Shadows” in the cosmic microwave background from inverse compton scattering

Use ‘em to measure Dark Energy

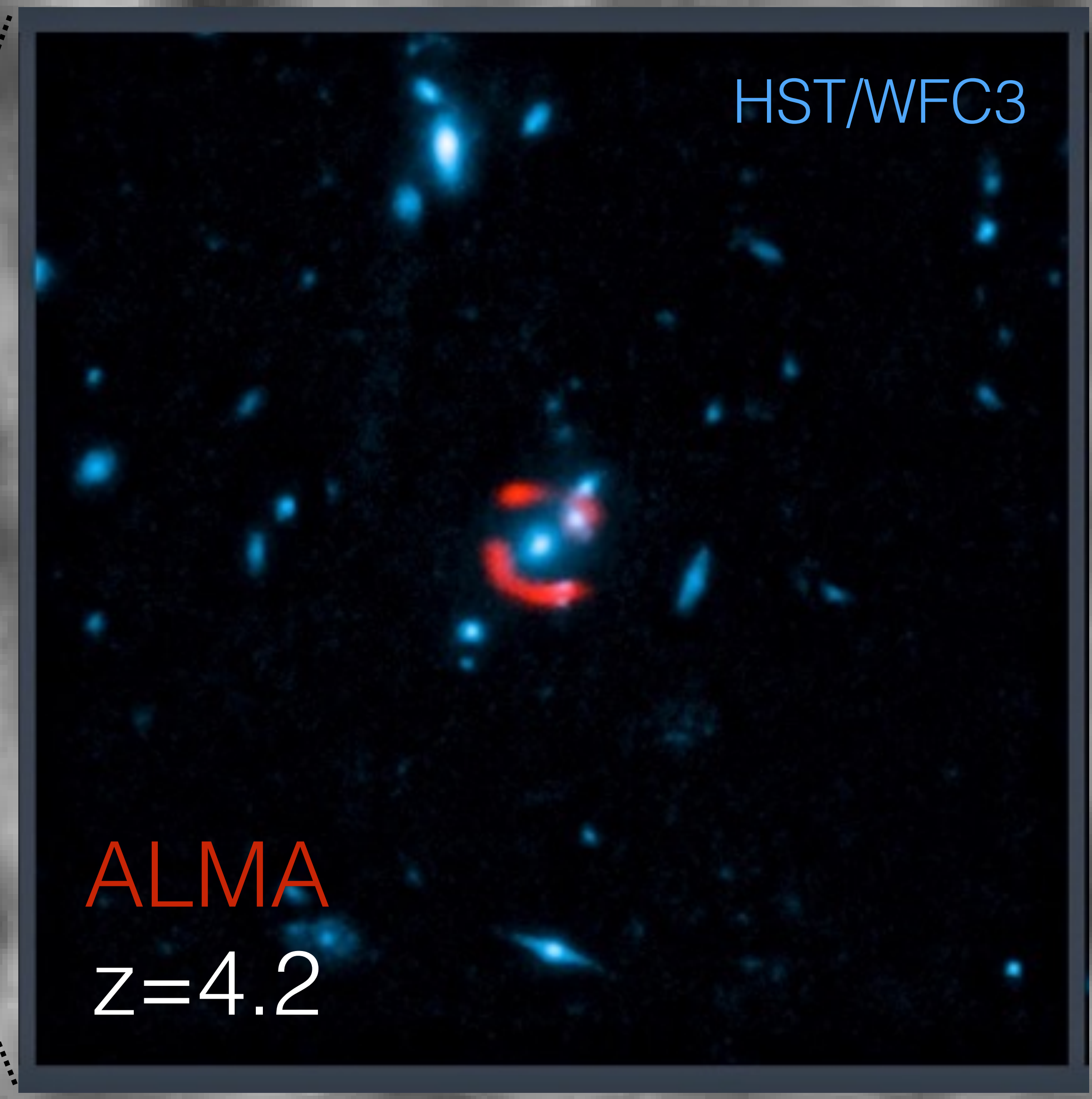
Probes the 2nd half of the history of the universe



South Pole Telescope
2 mm data

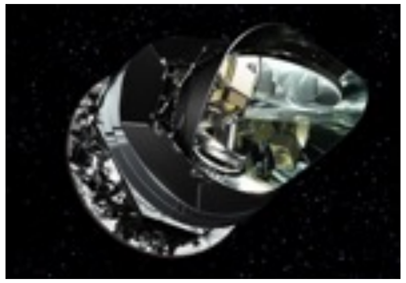
high redshift
strongly lensed
dusty starforming
galaxies

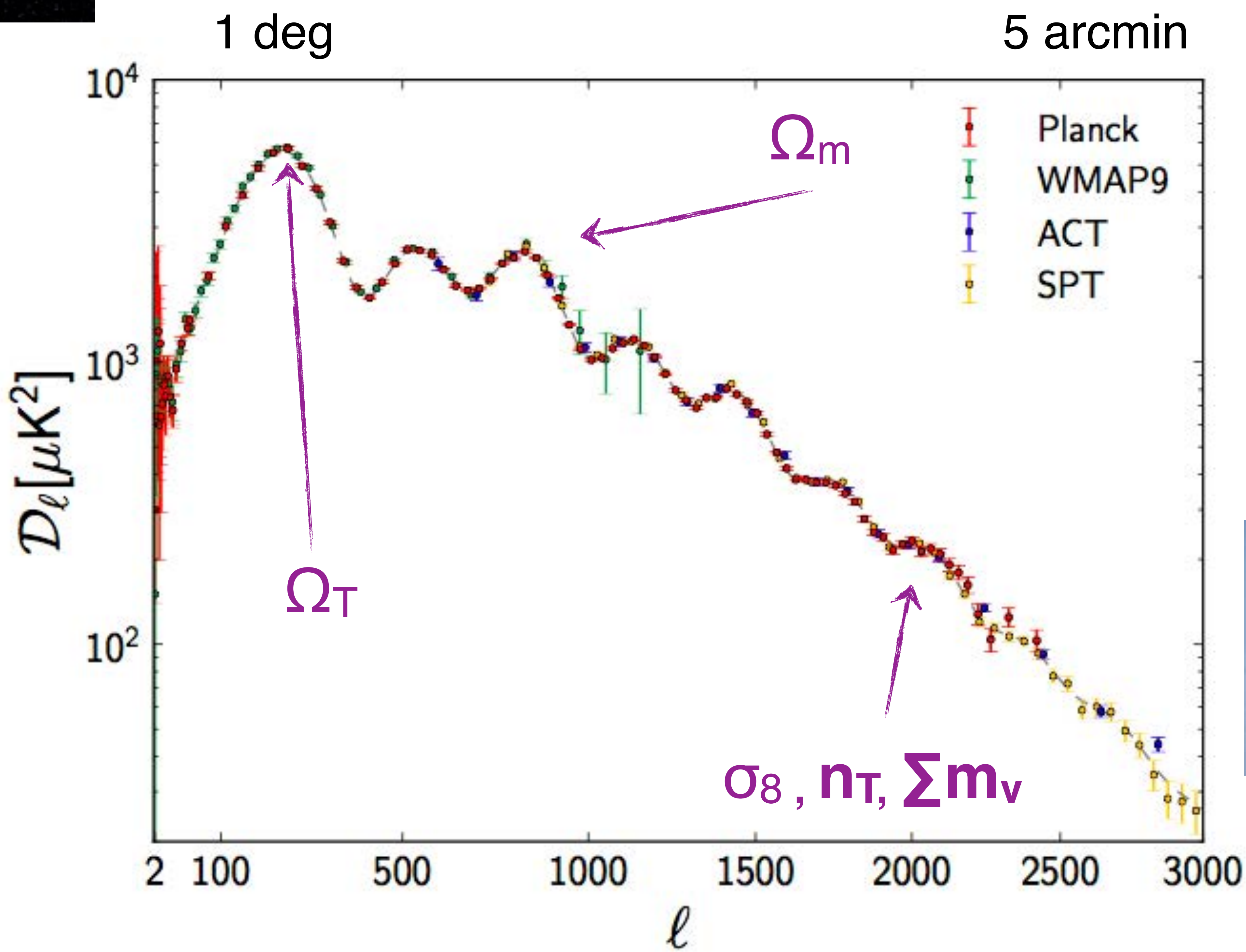
Use gravitational lensing as a cosmic telescope to study the first galaxies and directly image dark matter

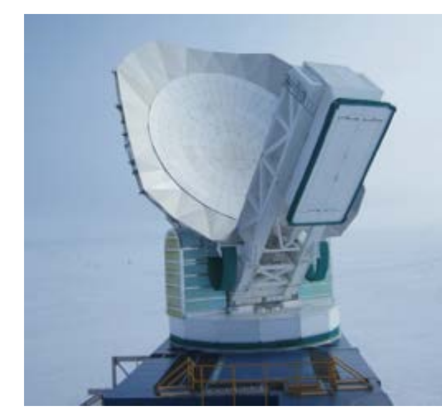


The angular power spectrum of the CMB

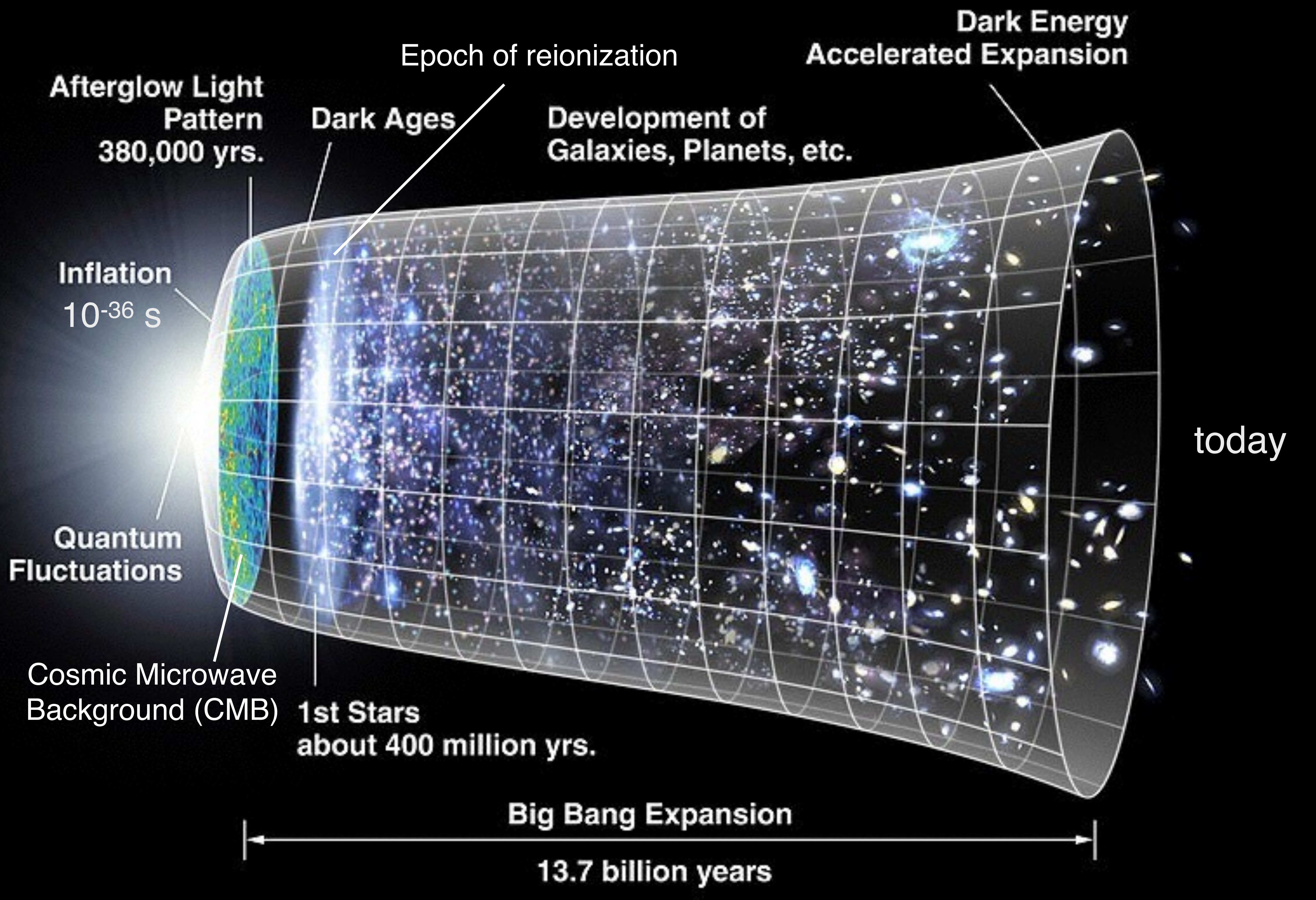
tells us the composition of the Universe
380,000 years after the Big Bang







Brief History of the Universe

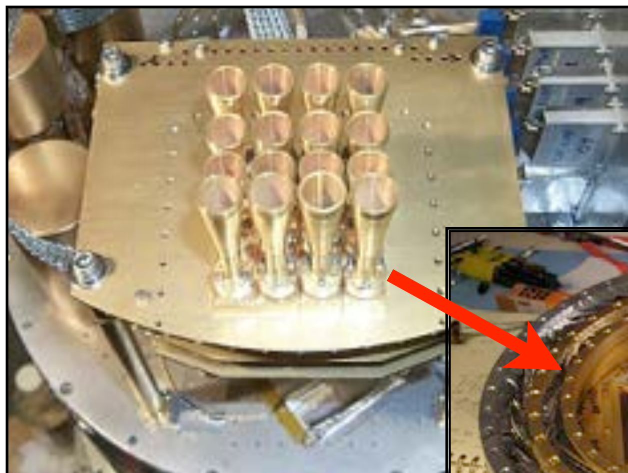


Evolution of bolometer arrays

Technological development is a mix of:

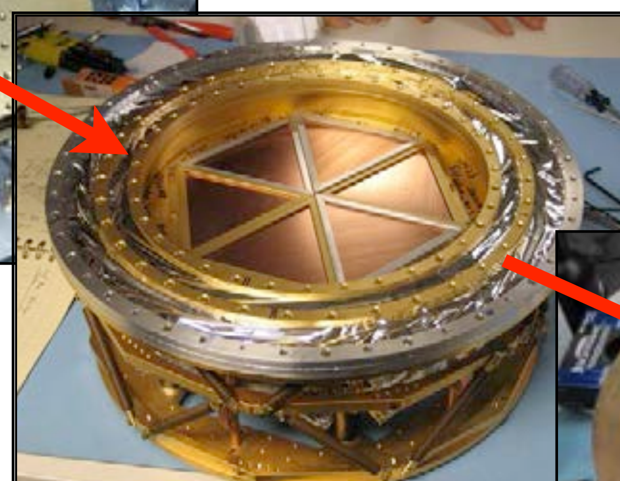
- condensed matter physics
- material science
- cryogenic techniques
- superconducting devices

2001: ACBAR
16 detectors



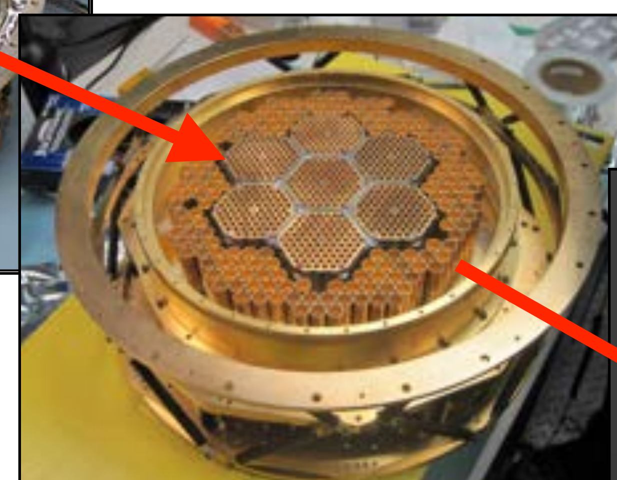
background-limited
noise performance

2007: SPT
960 detectors



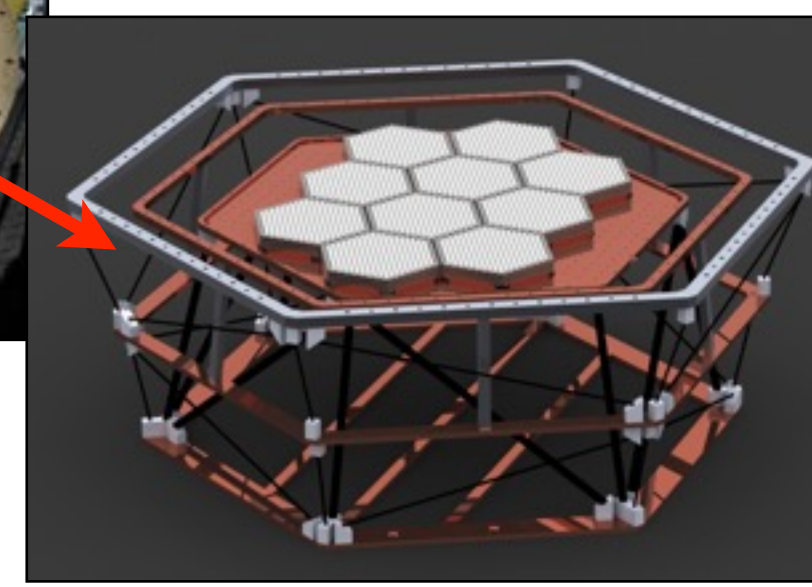
monolithic fabrication

2012: SPTpol
1600 detectors



polarization sensitive

2016: SPT-3G
15,000 detectors



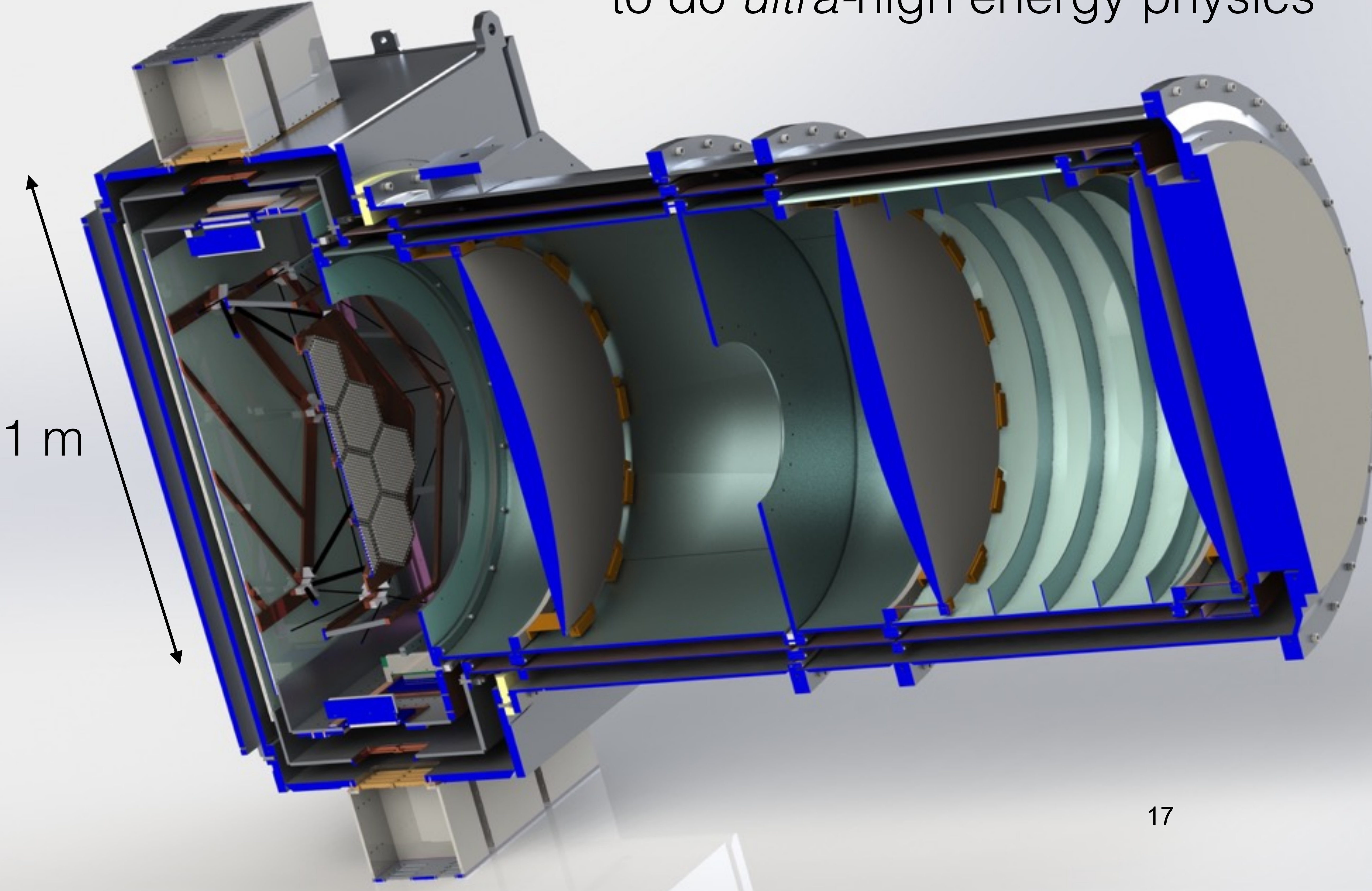
multi-chroic

Detector sensitivity has been limited by photon shot noise for last ~15 years.

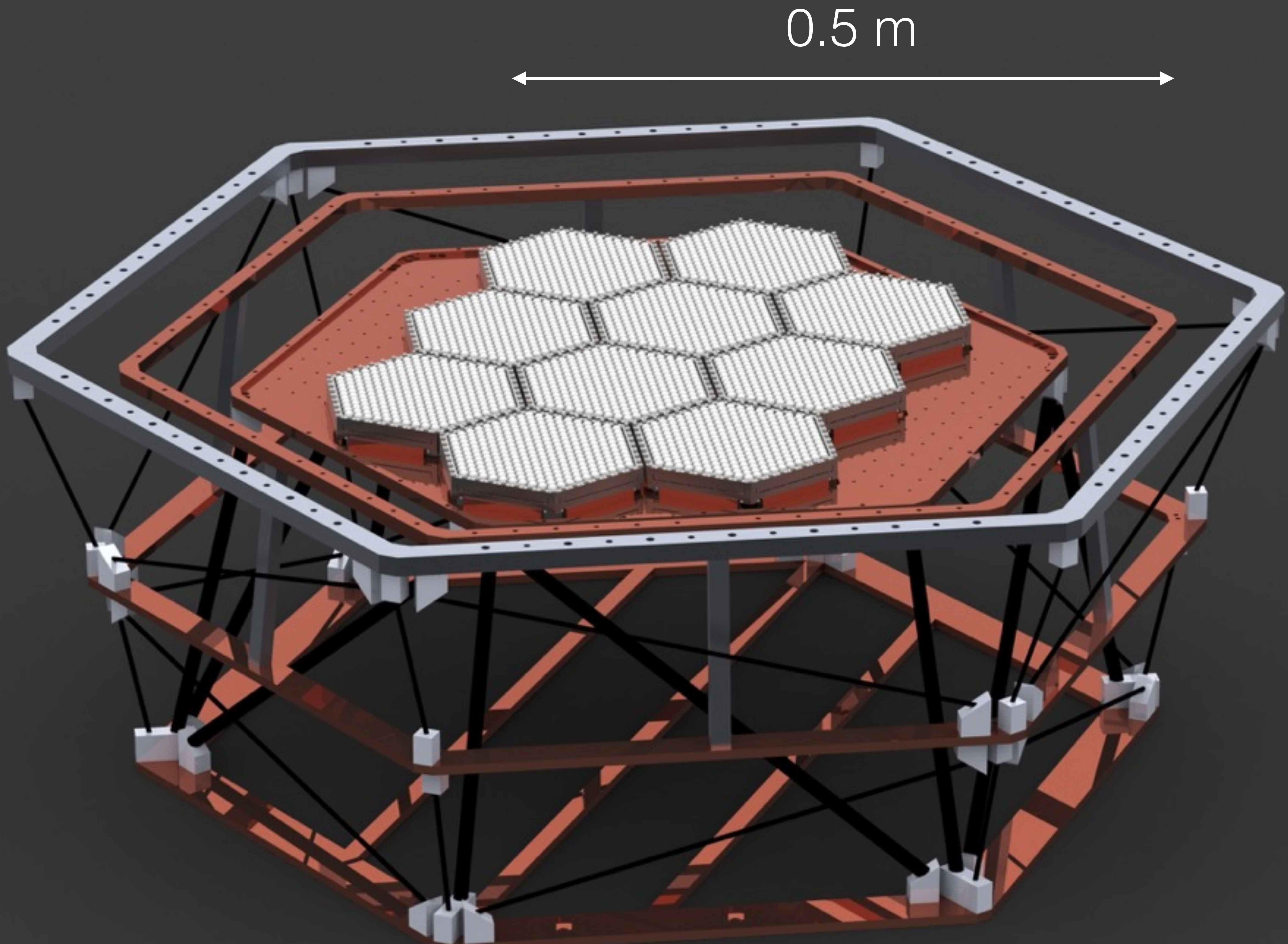
Further improvements are made only by making ***more detectors!***

The SPT-3G Camera

Stage 3 Instruments: condensed matter experiment to do *ultra*-high energy physics

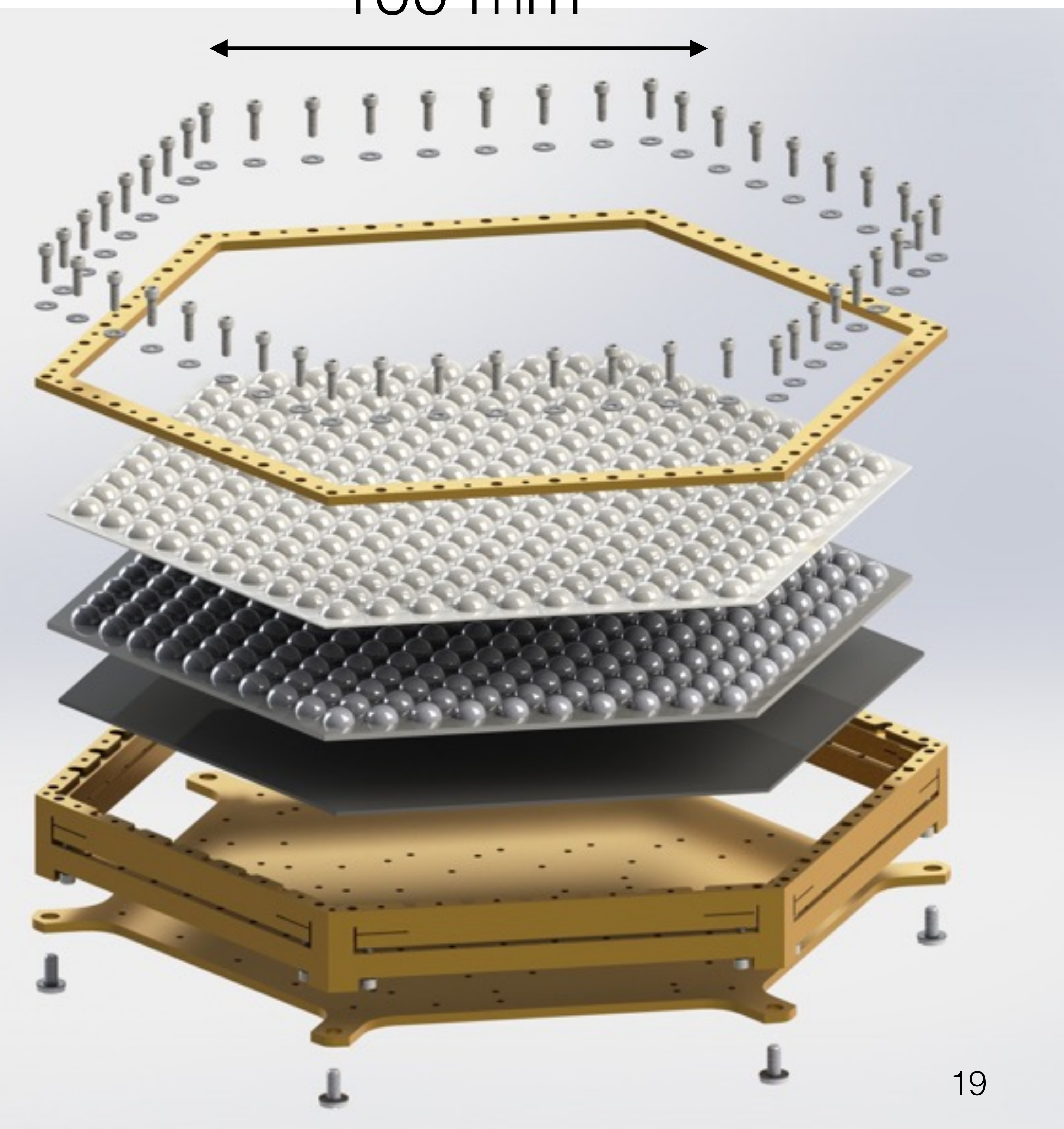


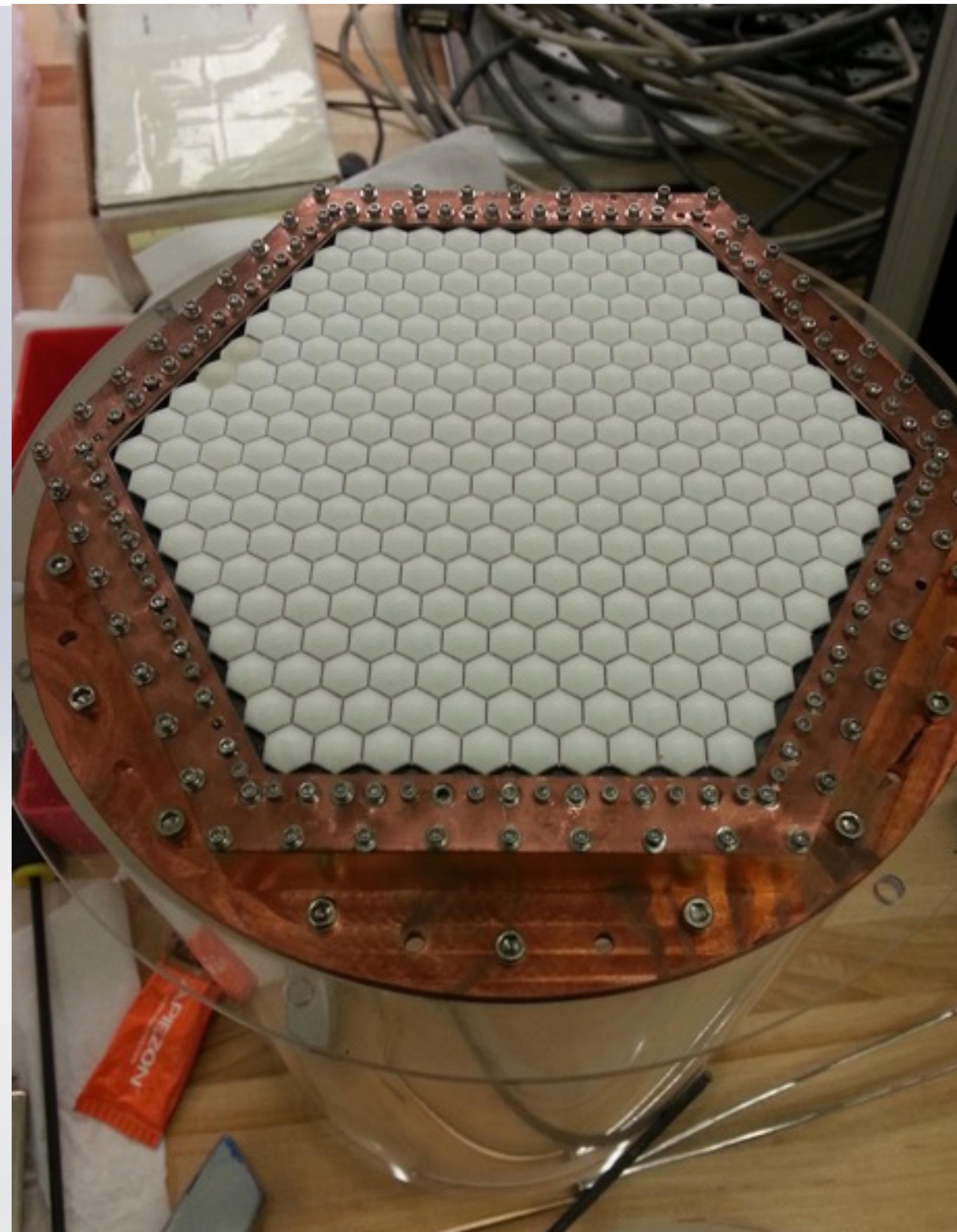
SPT-3G focal plane



SPT-3G detector module

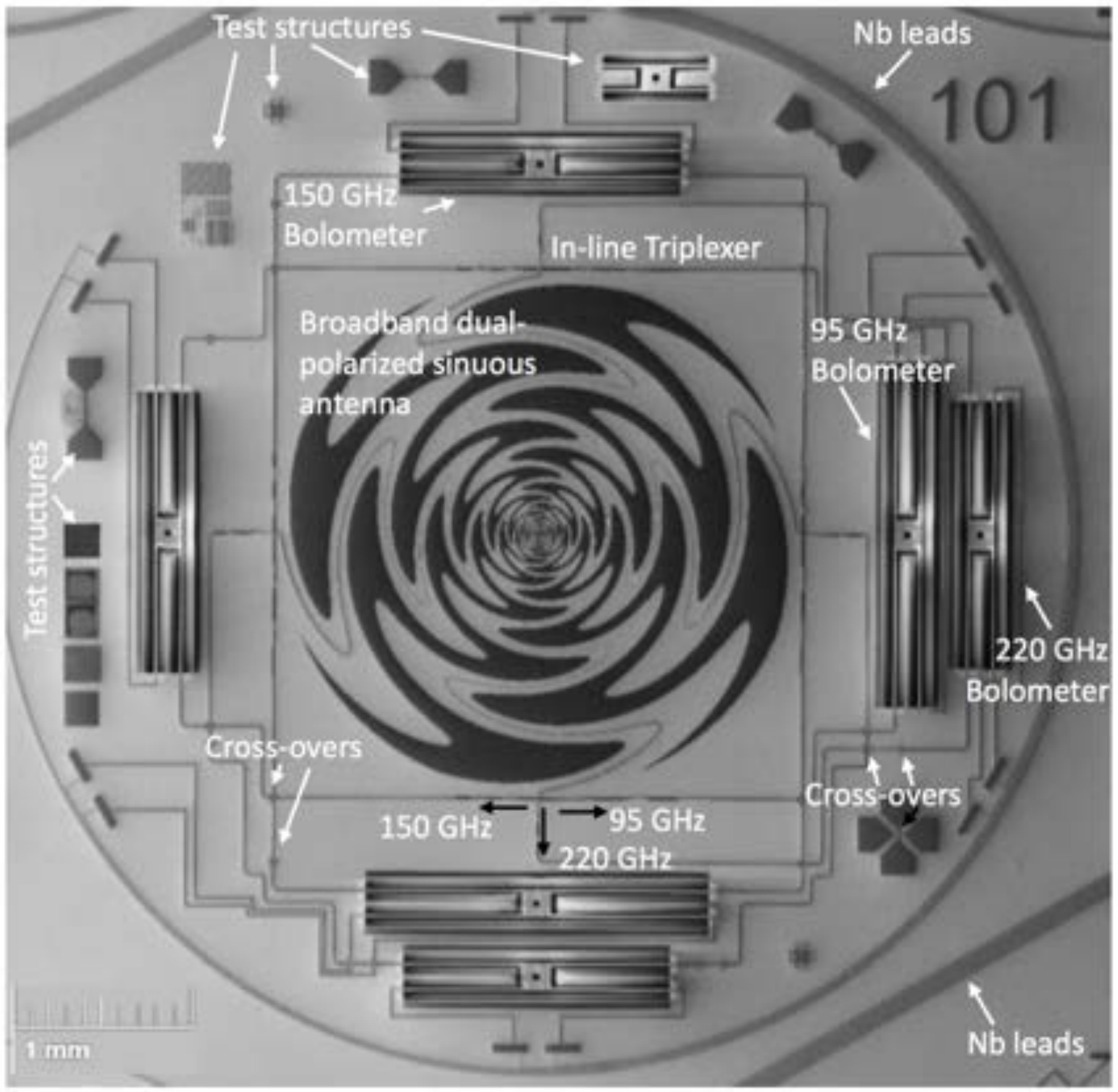
Detector fabrication at Argonne National Lab
Lenslet array fabrication at Illinois
Detector module assembly at Fermilab
Final integration at Pole

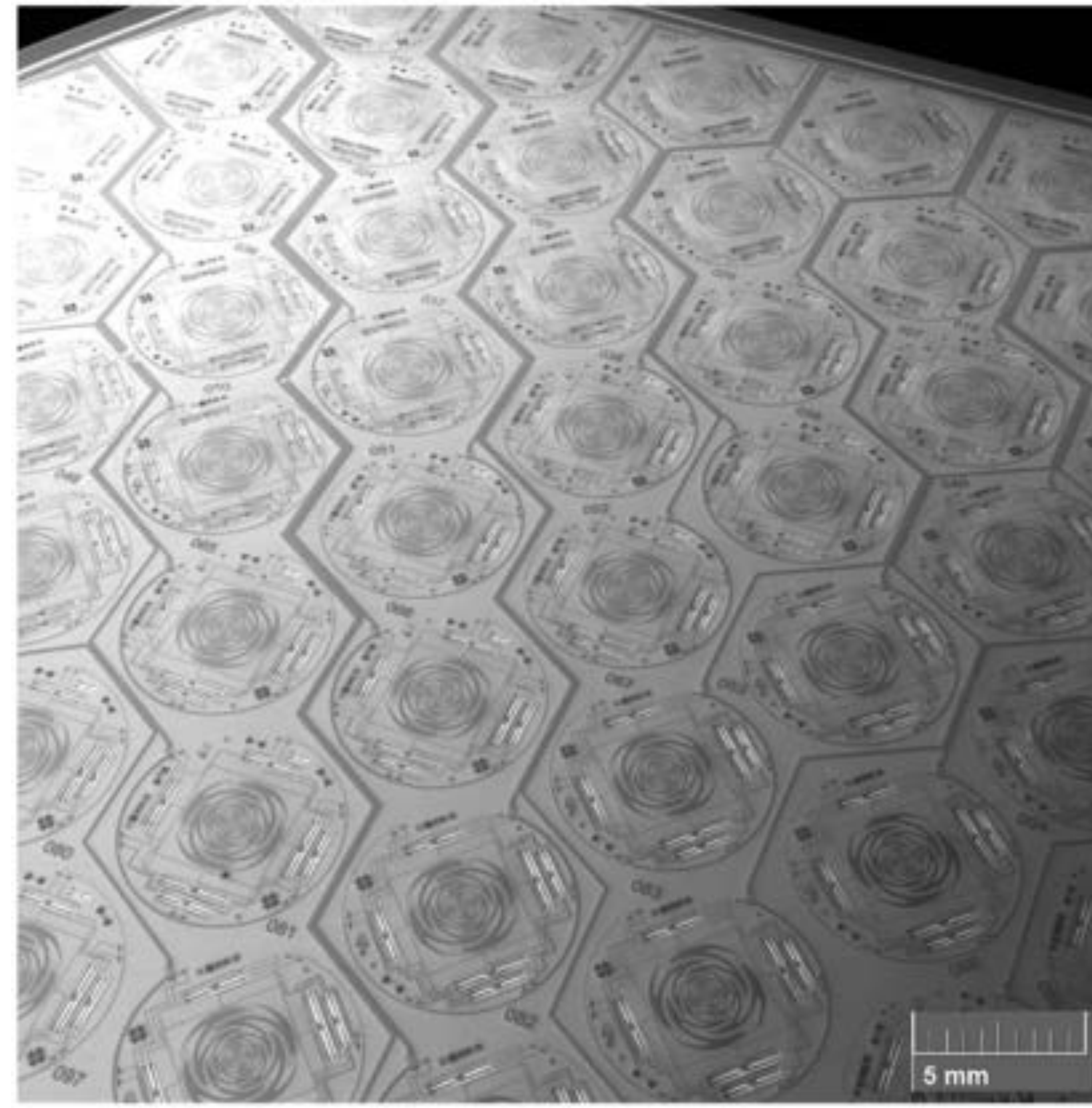




State of the Art Bolometers circa 2015

Micro-machined at Argonne National Laboratory





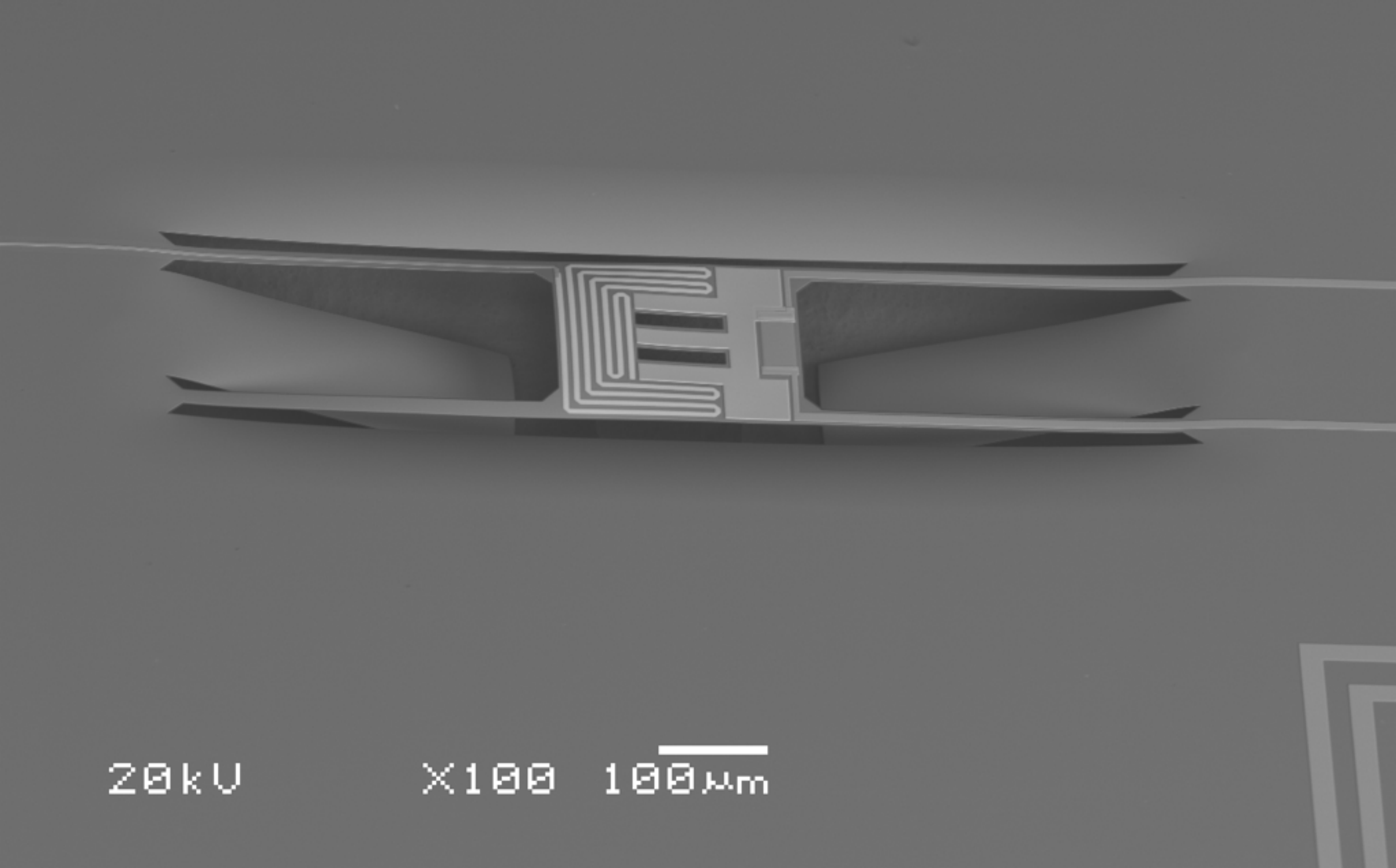
antenna-coupled **multi-chroic** polarization sensitive TES bolometers

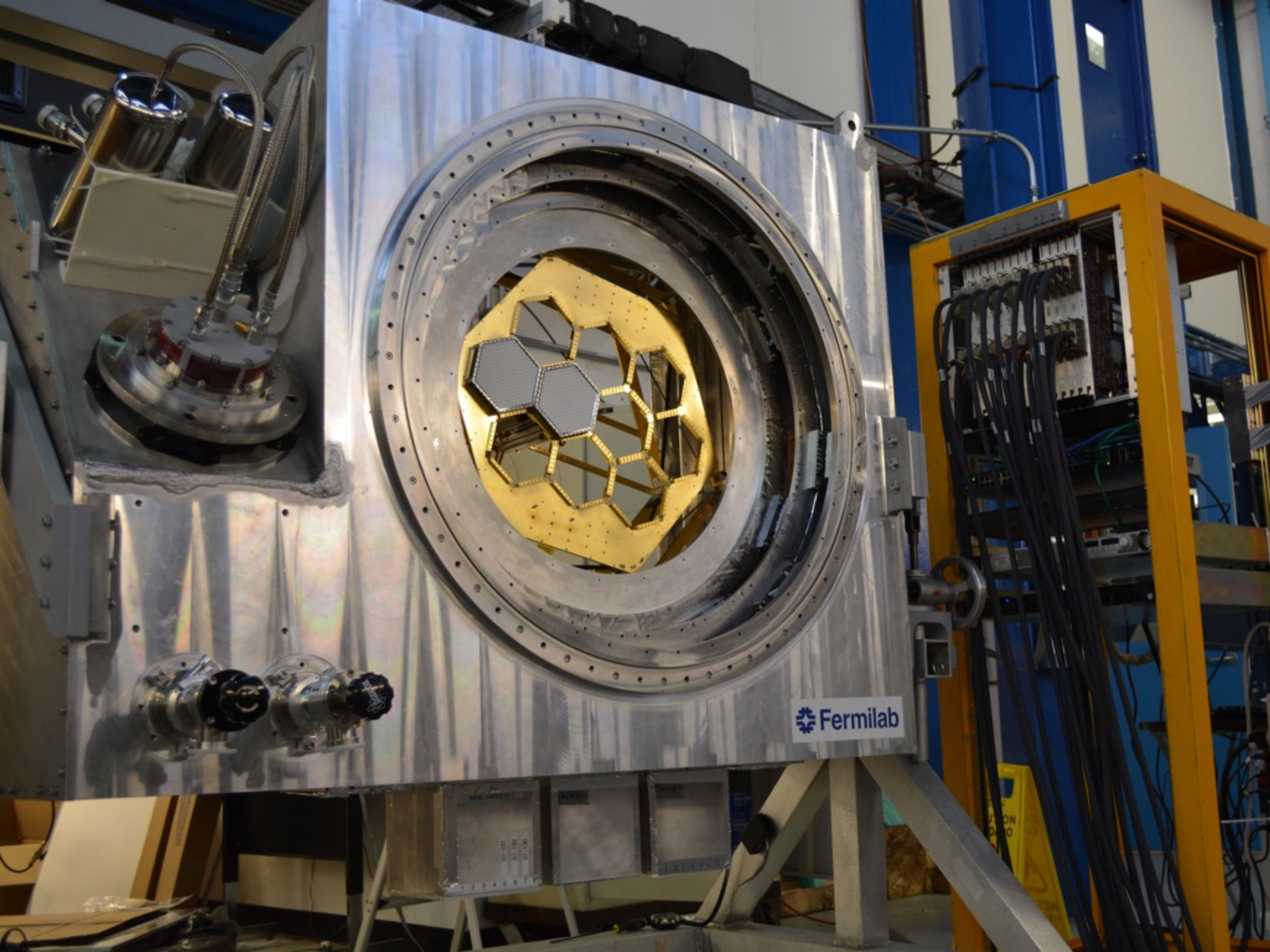
typical camera consists of ~2500 pixels

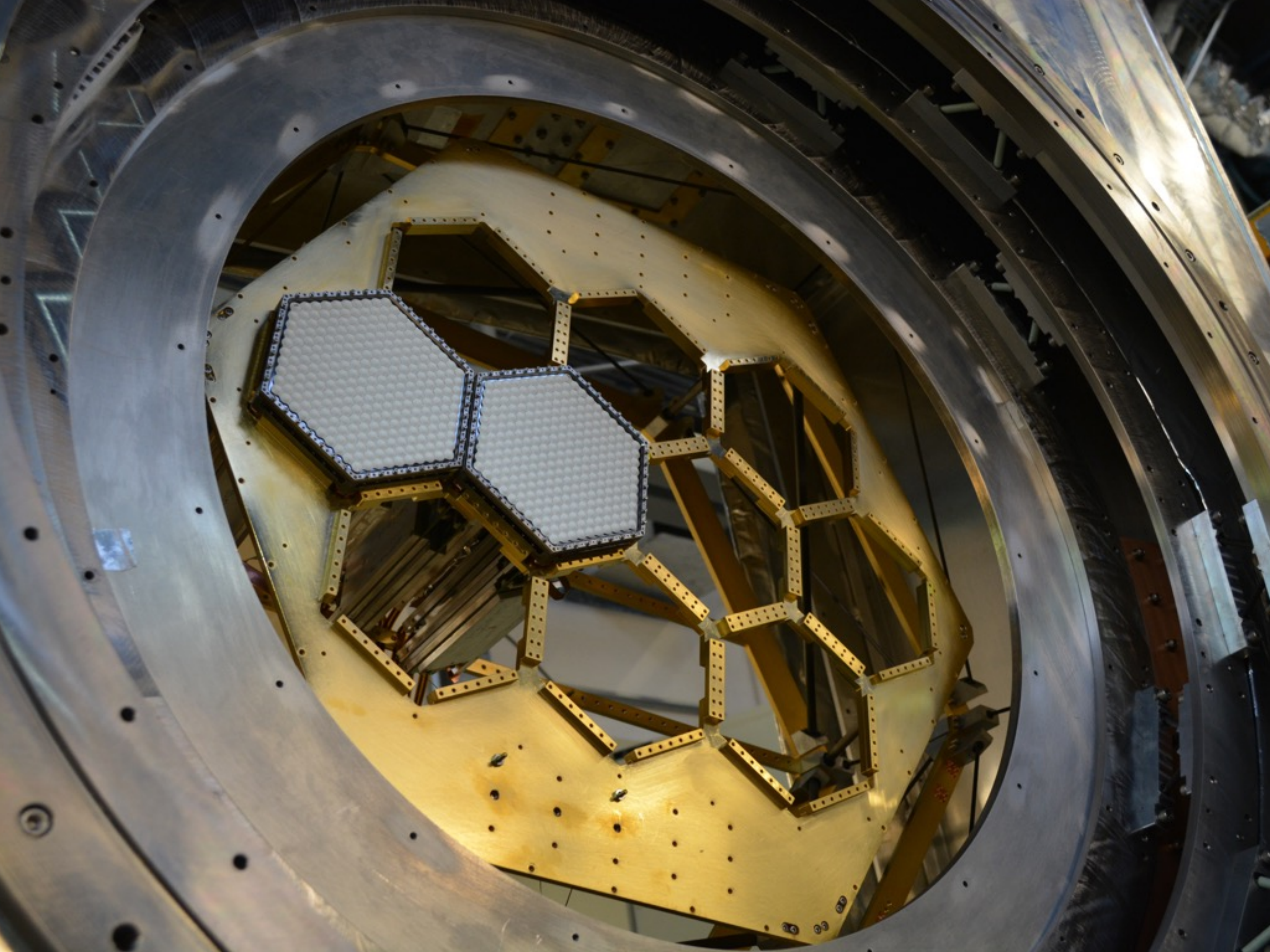
(x2 polarizations x3 colors = 15k detectors)

used in SPT-3G

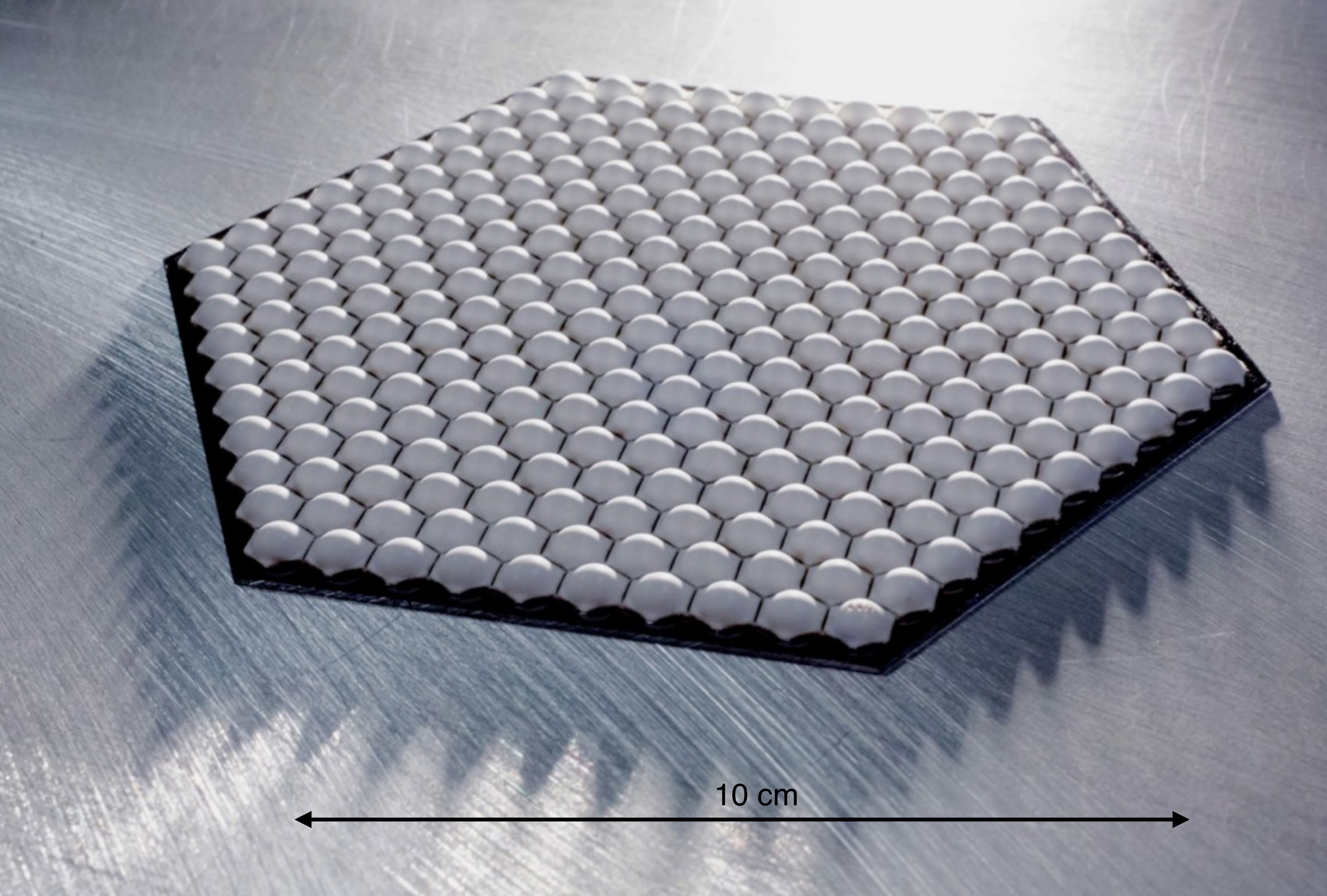
One single bolometer element
seen in a scanning electron microscope



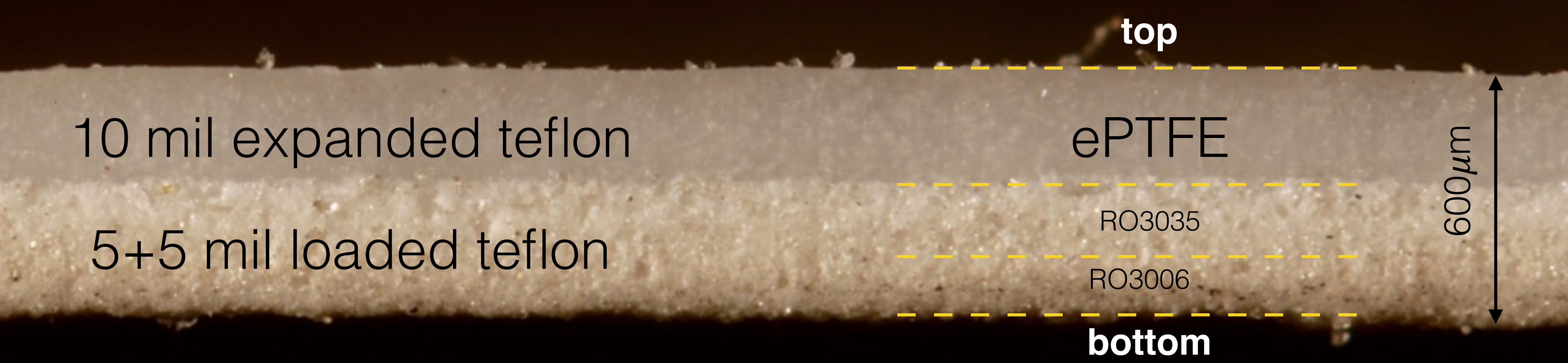

Fermilab



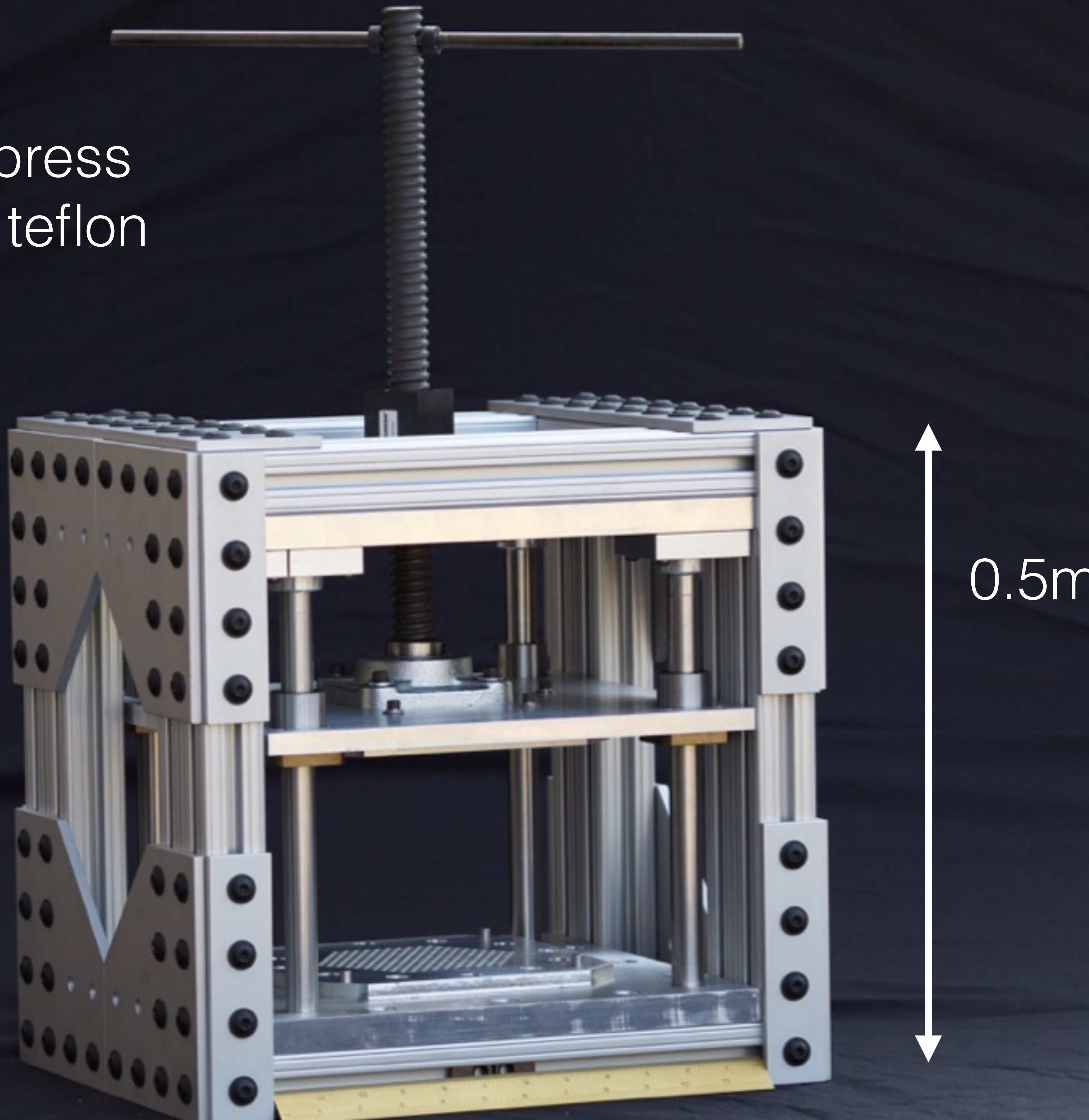
Lenslet arrays for SPT-3G designed and fabricated at Illinois

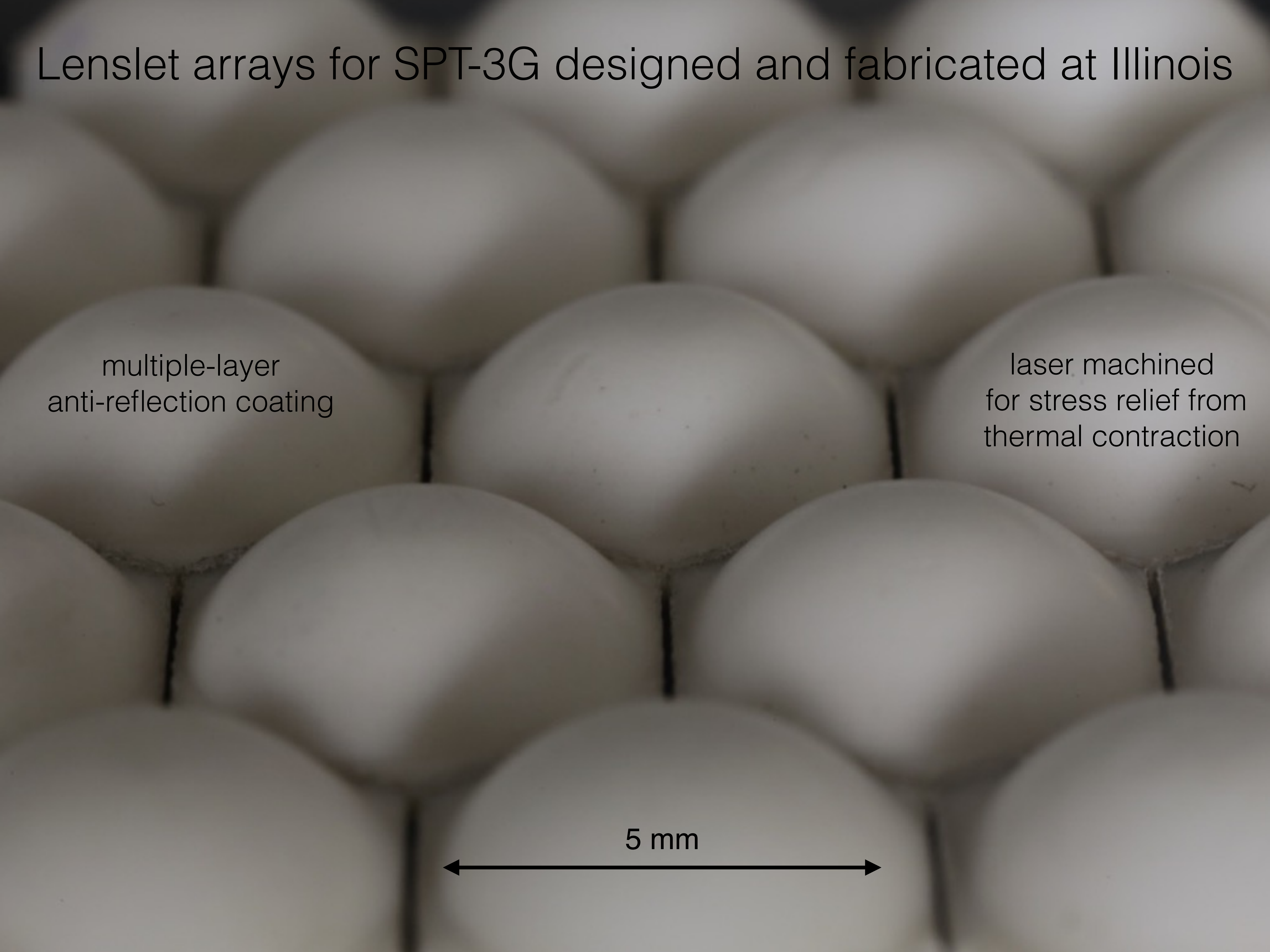


Cross section view

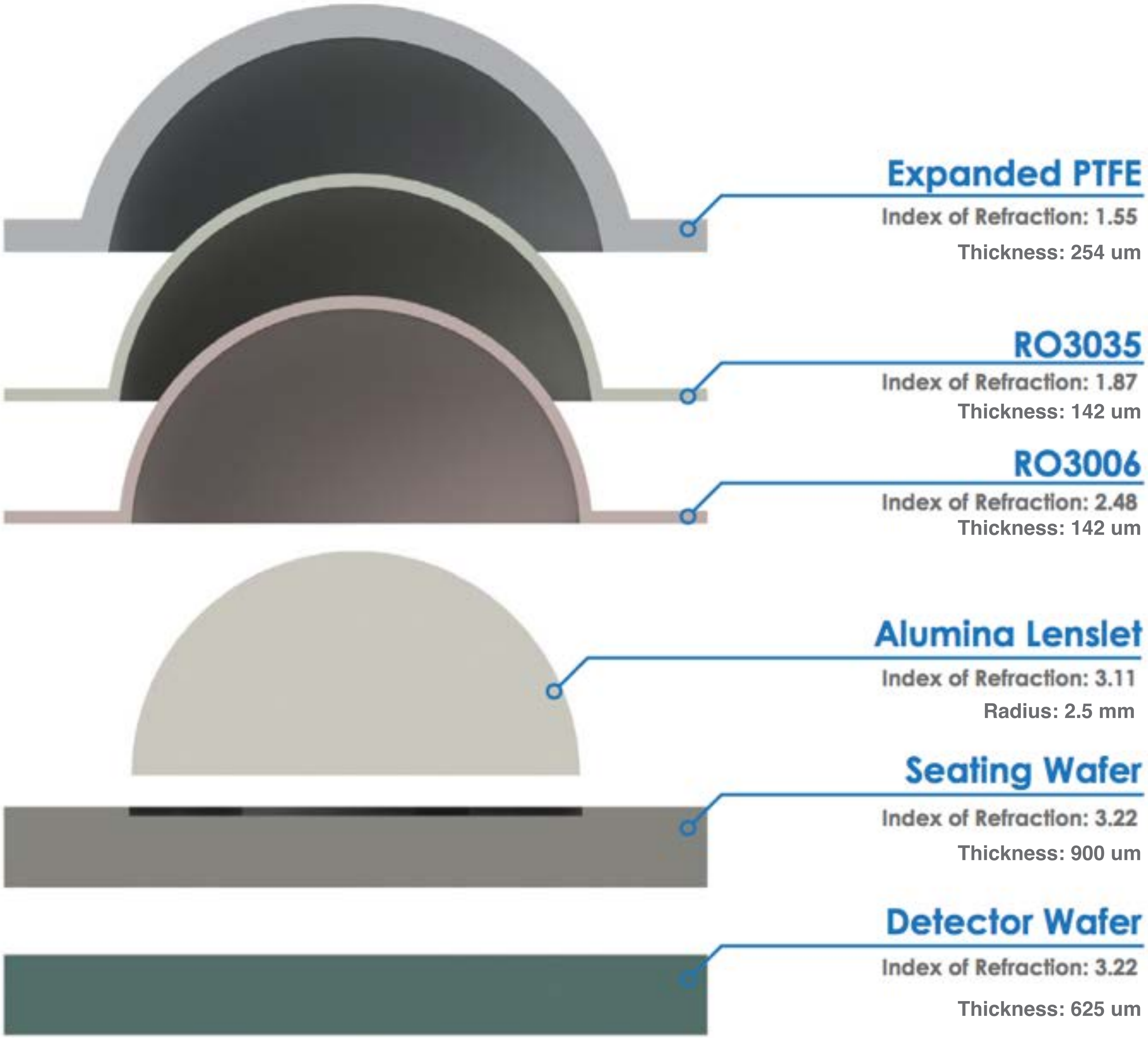


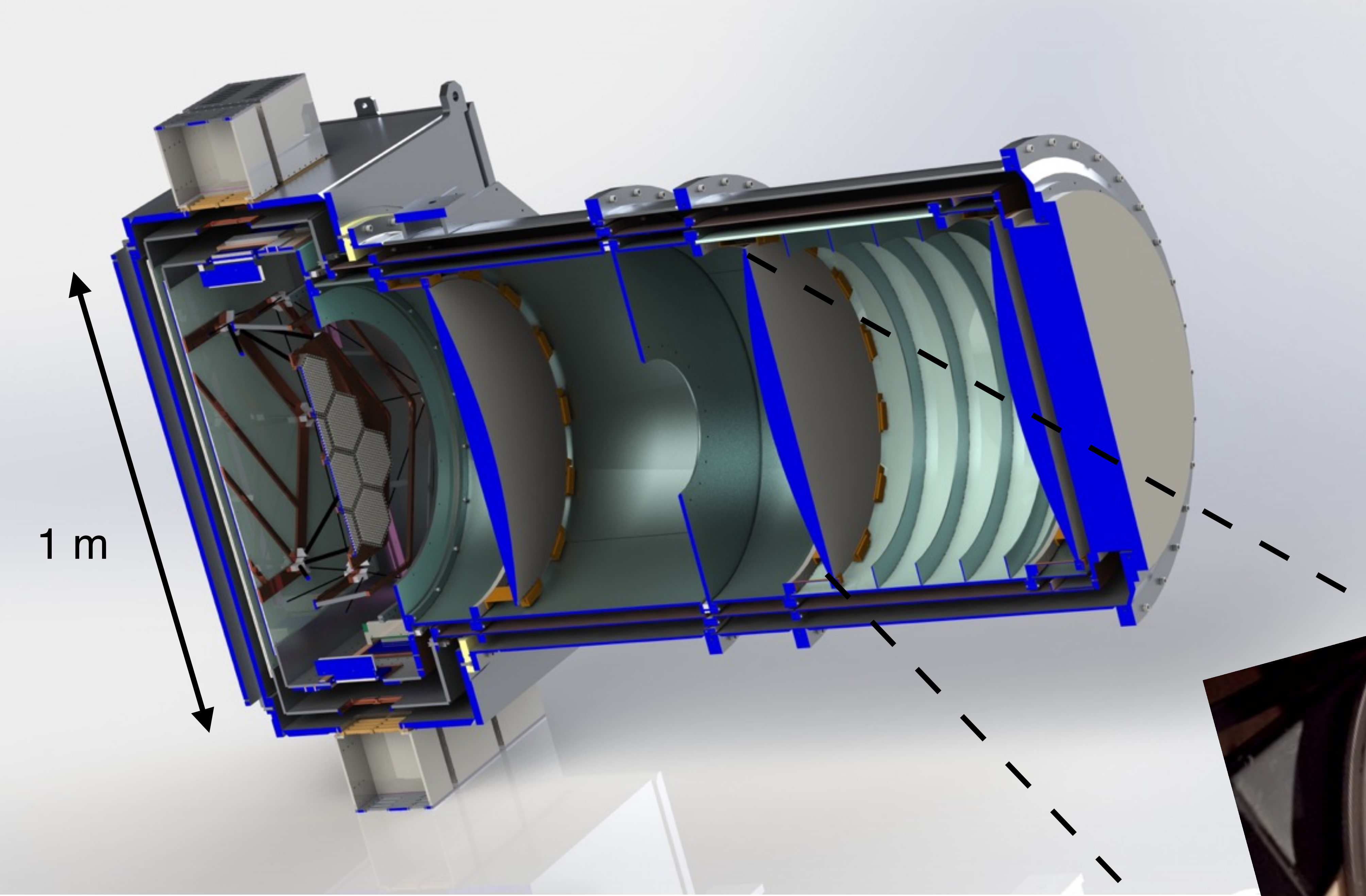
this is our press
for forming teflon



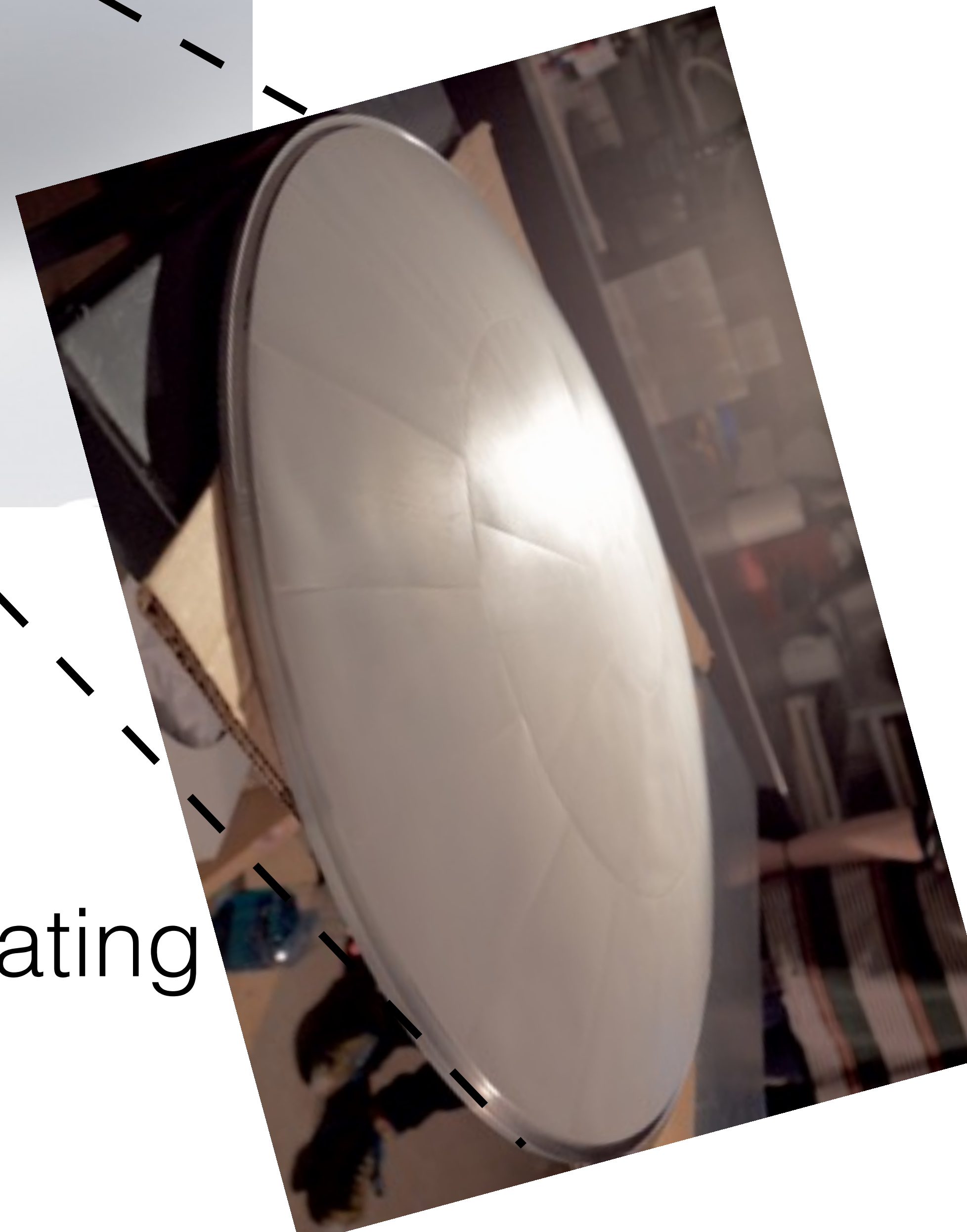

Lenslet arrays for SPT-3G designed and fabricated at Illinois
multiple-layer
anti-reflection coating
laser machined
for stress relief from
thermal contraction
5 mm

exploded view



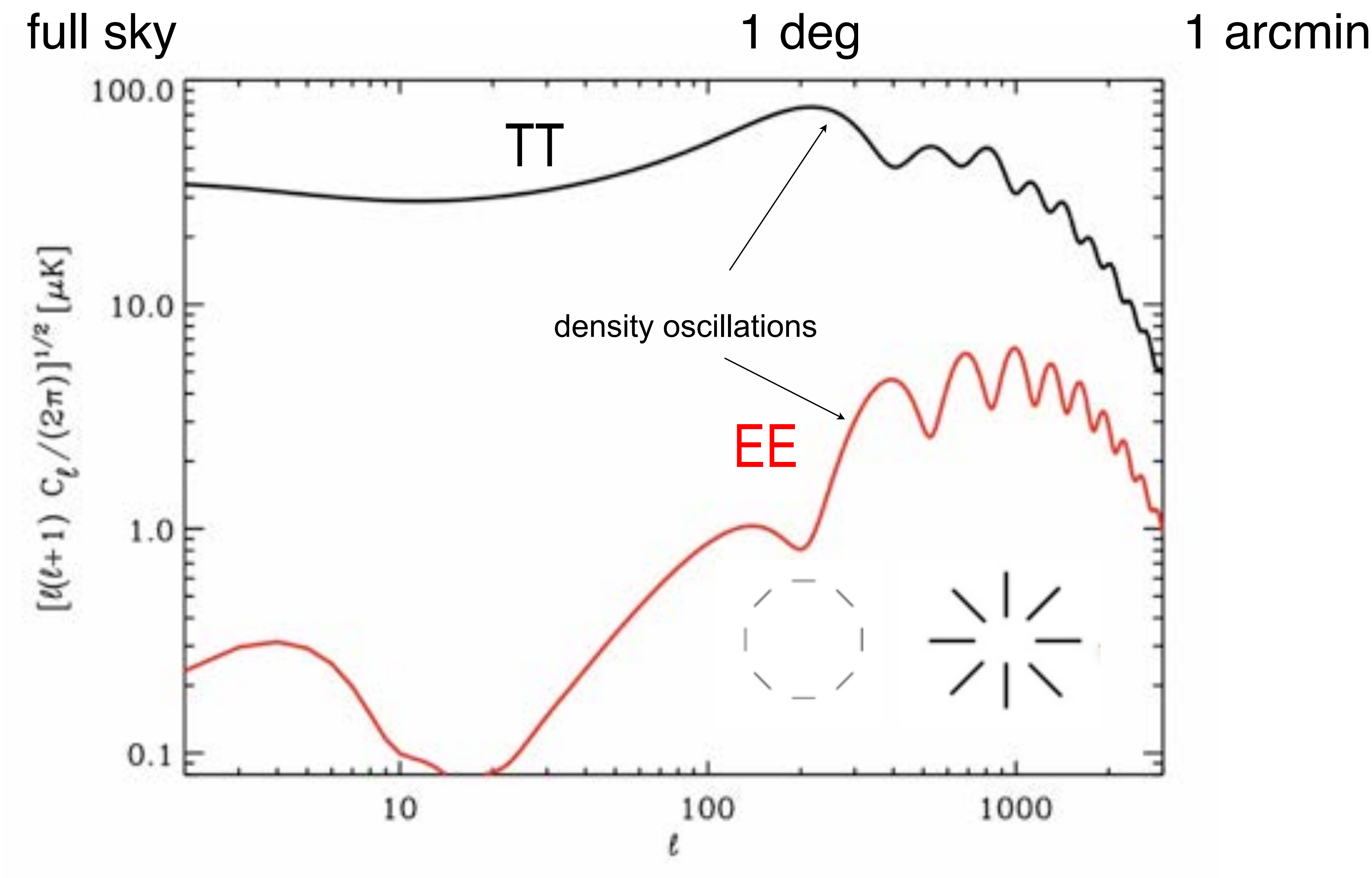


Cryostat design and commissioning at Fermilab

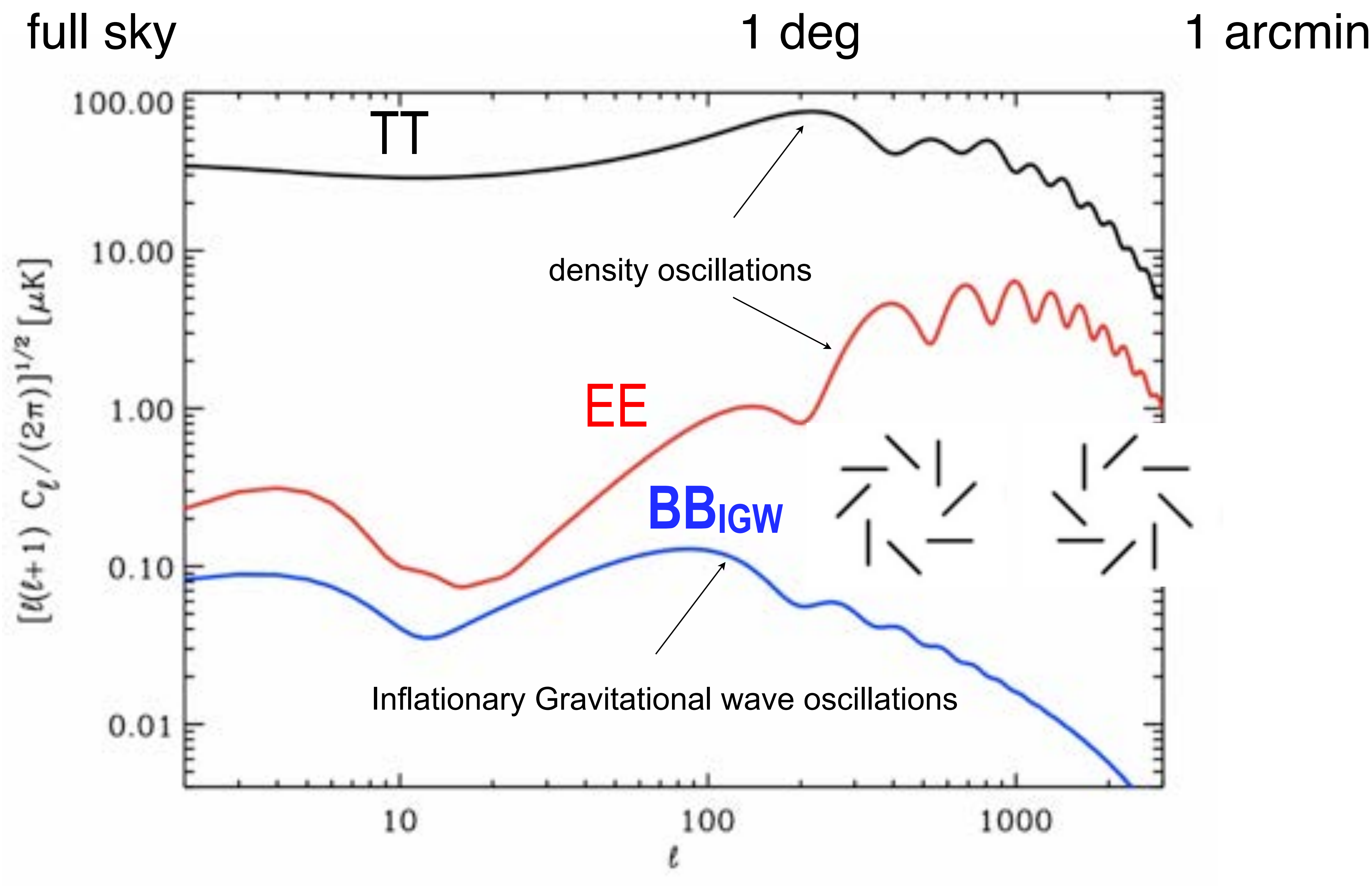


large format anti-reflection coating at Illinois

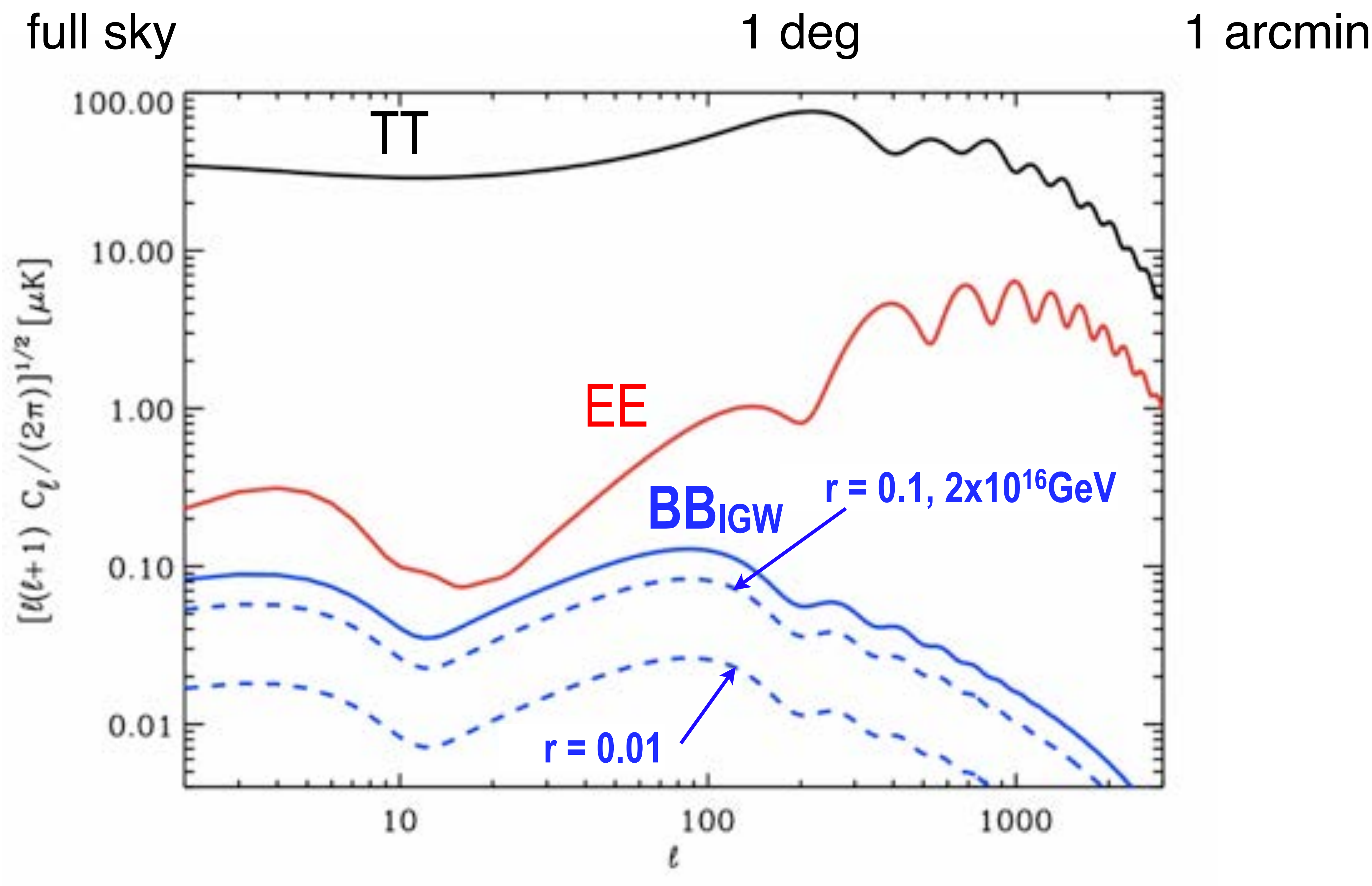
CMB polarization:
the next frontier for lensing & inflation



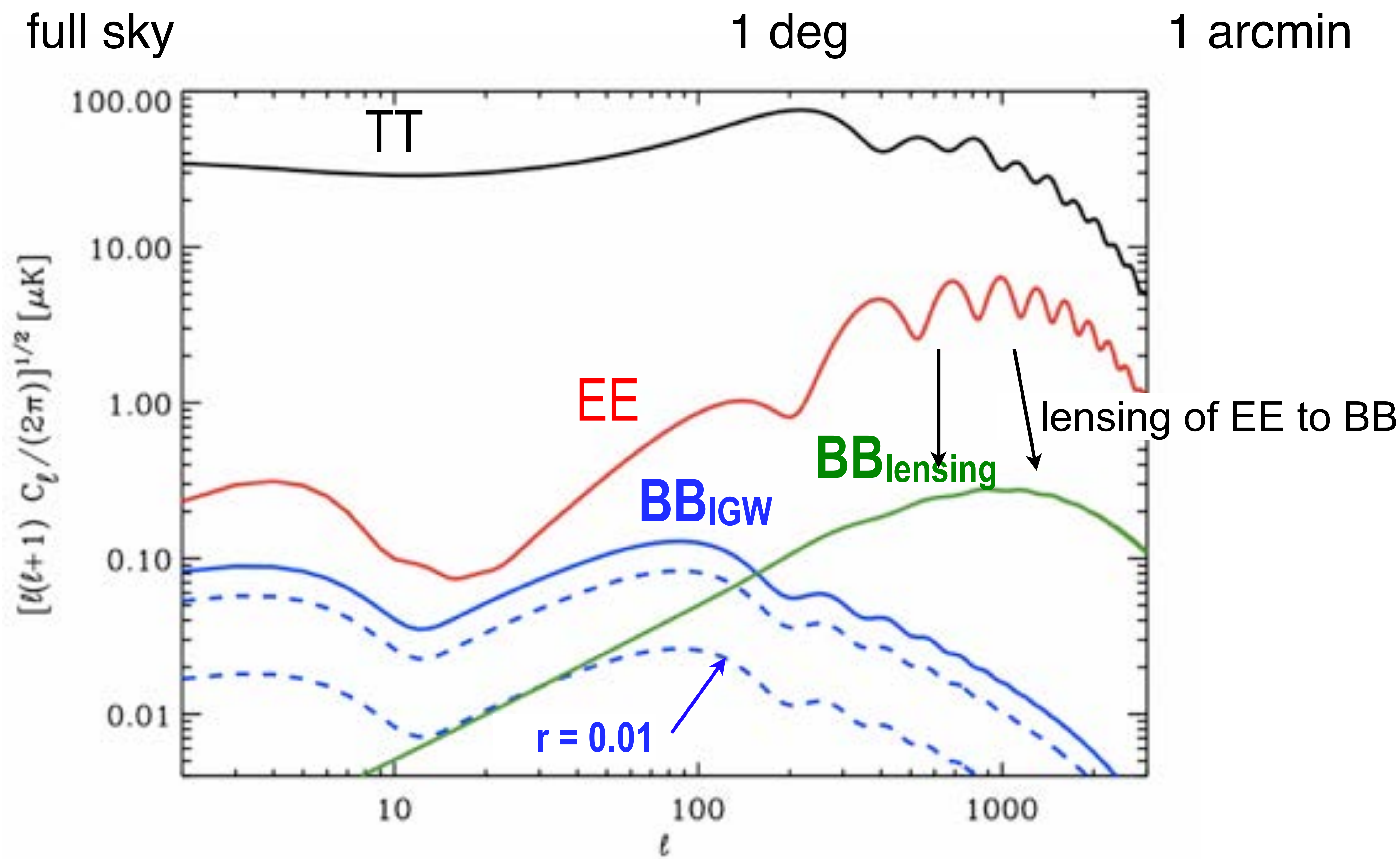
CMB polarization:
the next frontier for lensing & inflation



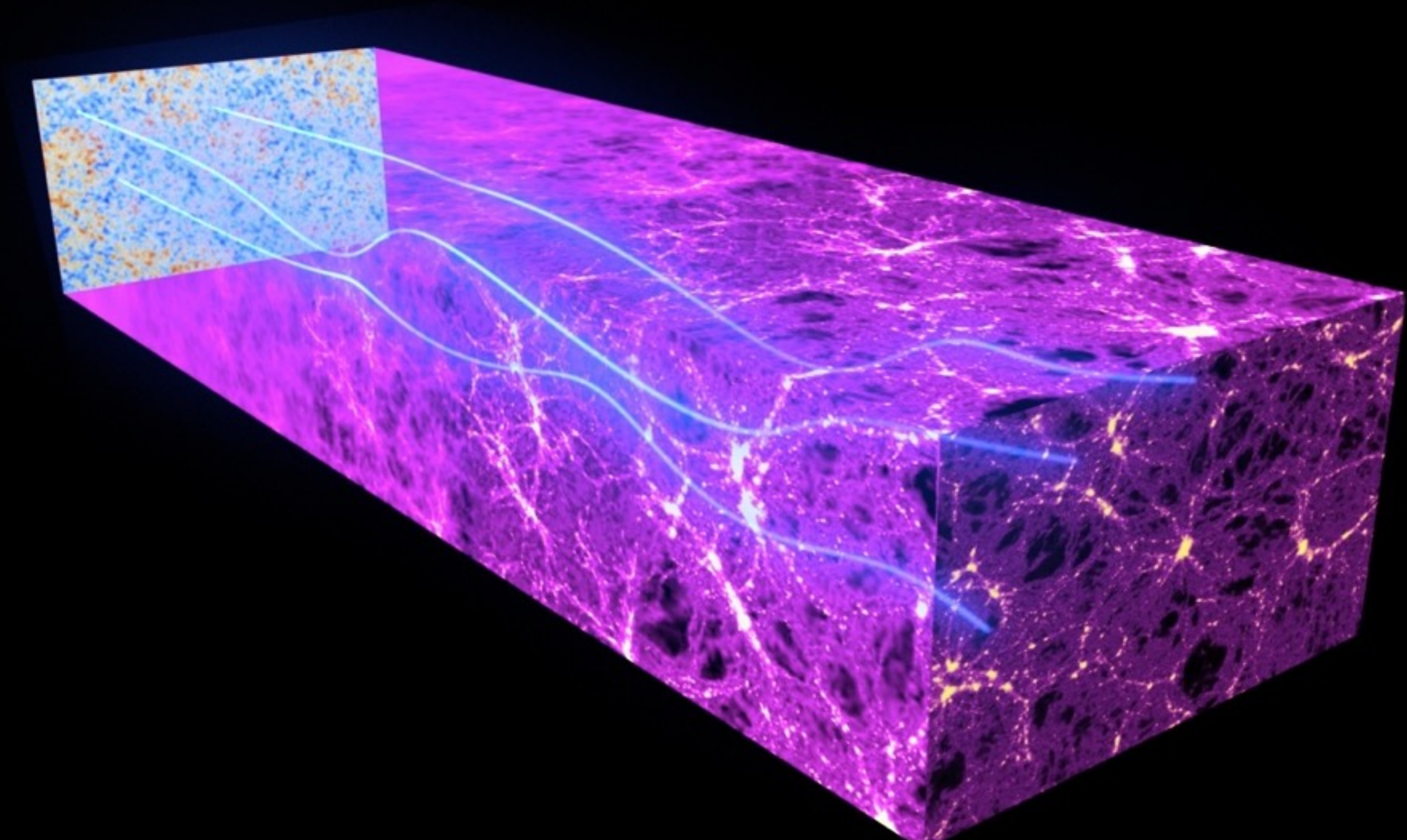
CMB polarization:
the next frontier for lensing & inflation



CMB polarization:
the next frontier for lensing & inflation

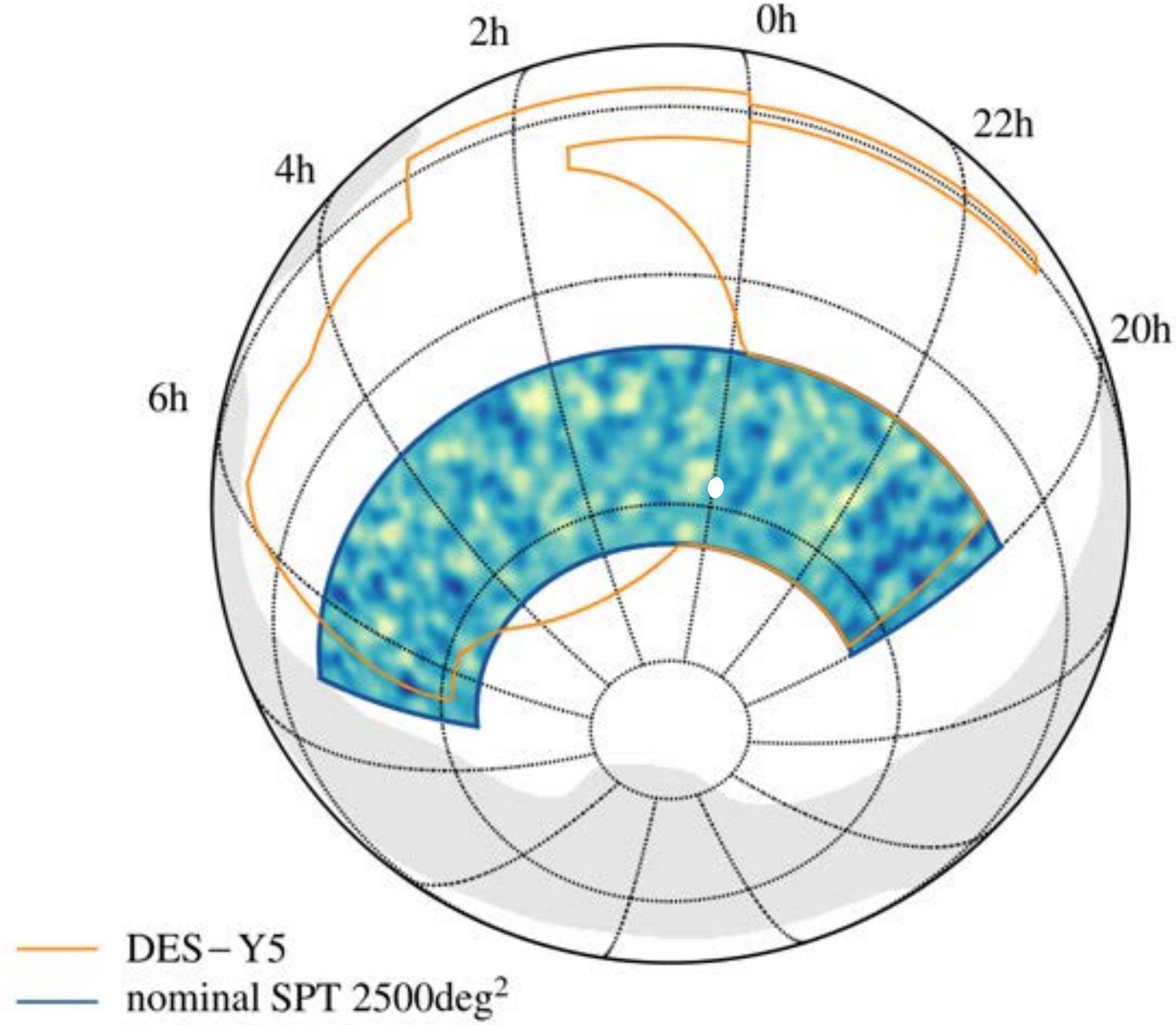


CMB lensing



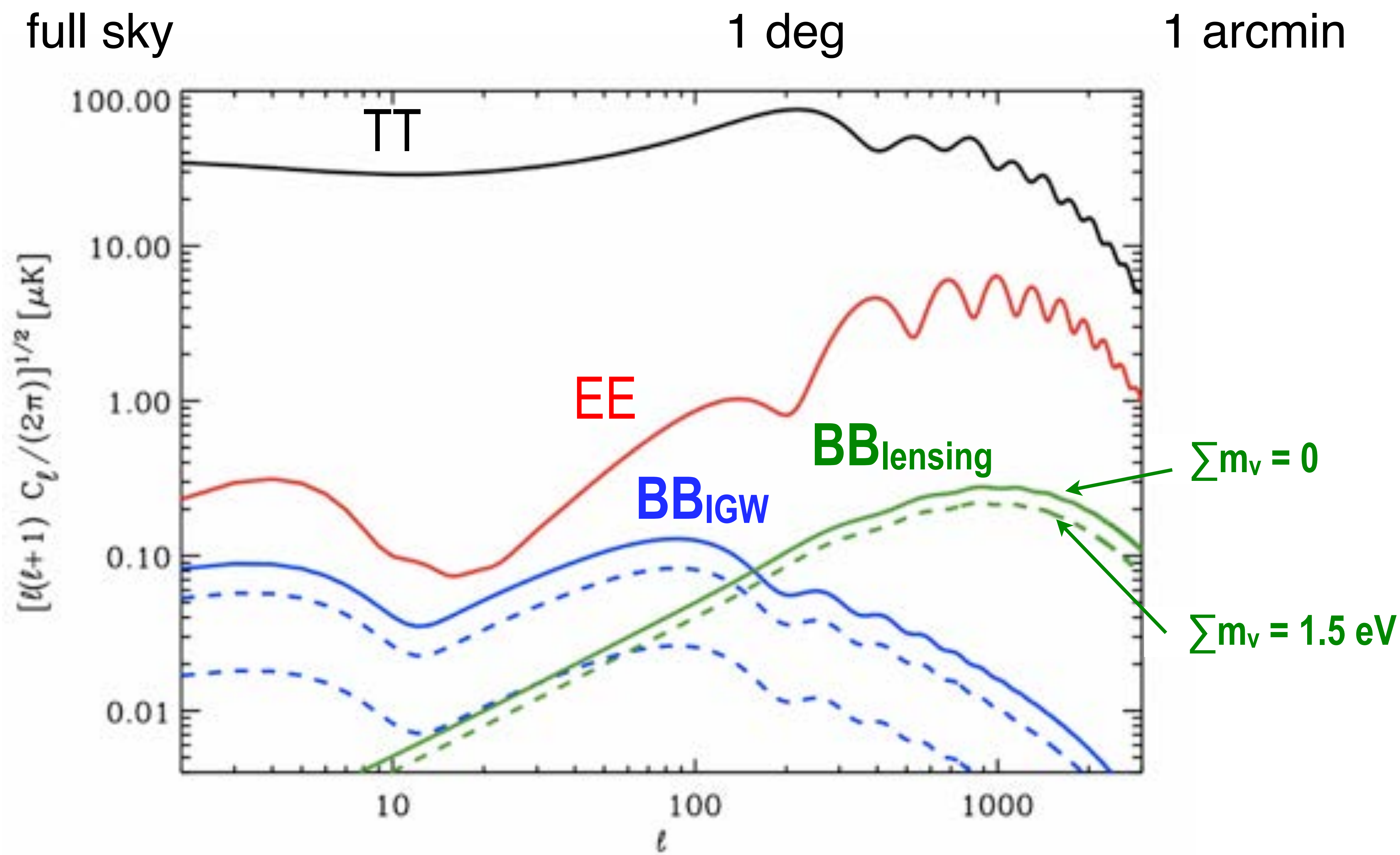
Gravitational Lensing of the CMB

- The CMB damping tail is sensitive to structure along the line of sight through gravitational lensing
- The CMB lensing redshift kernel peaks at $1<z<3$
- Basically gives a measure of σ_8 at $z\sim2$
- SPT has produced a map of the line-of-sight mean density with S/N~1 per square degree
- This can be cross correlated with catalogs of galaxies to directly measure the bias or mean halo mass in which the objects reside



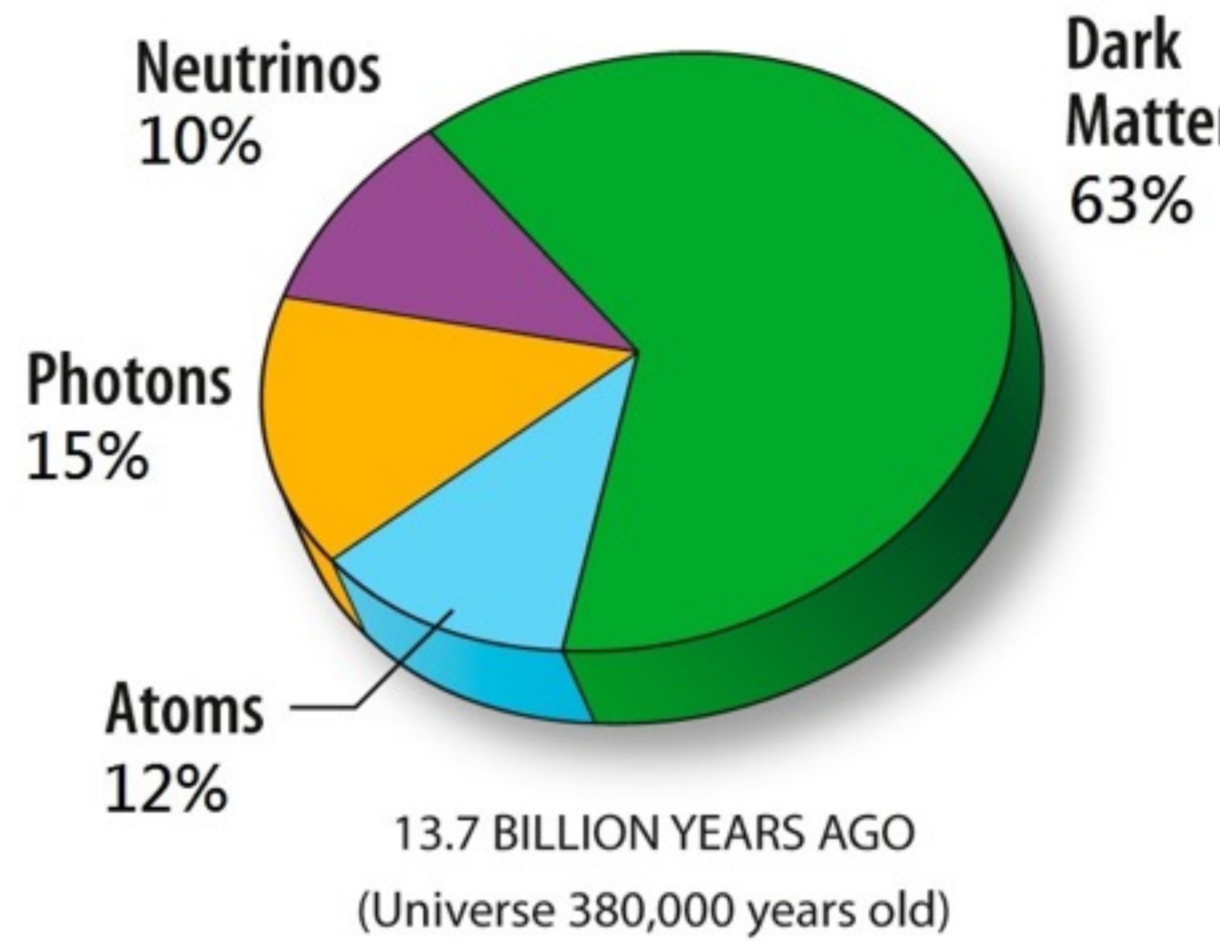
Van Engelen *et al.* 2012 ApJ
Bleem *et al.* 2012 ApJ
Holder *et al.* 2013 ApJ

CMB polarization:
the next frontier for lensing & inflation

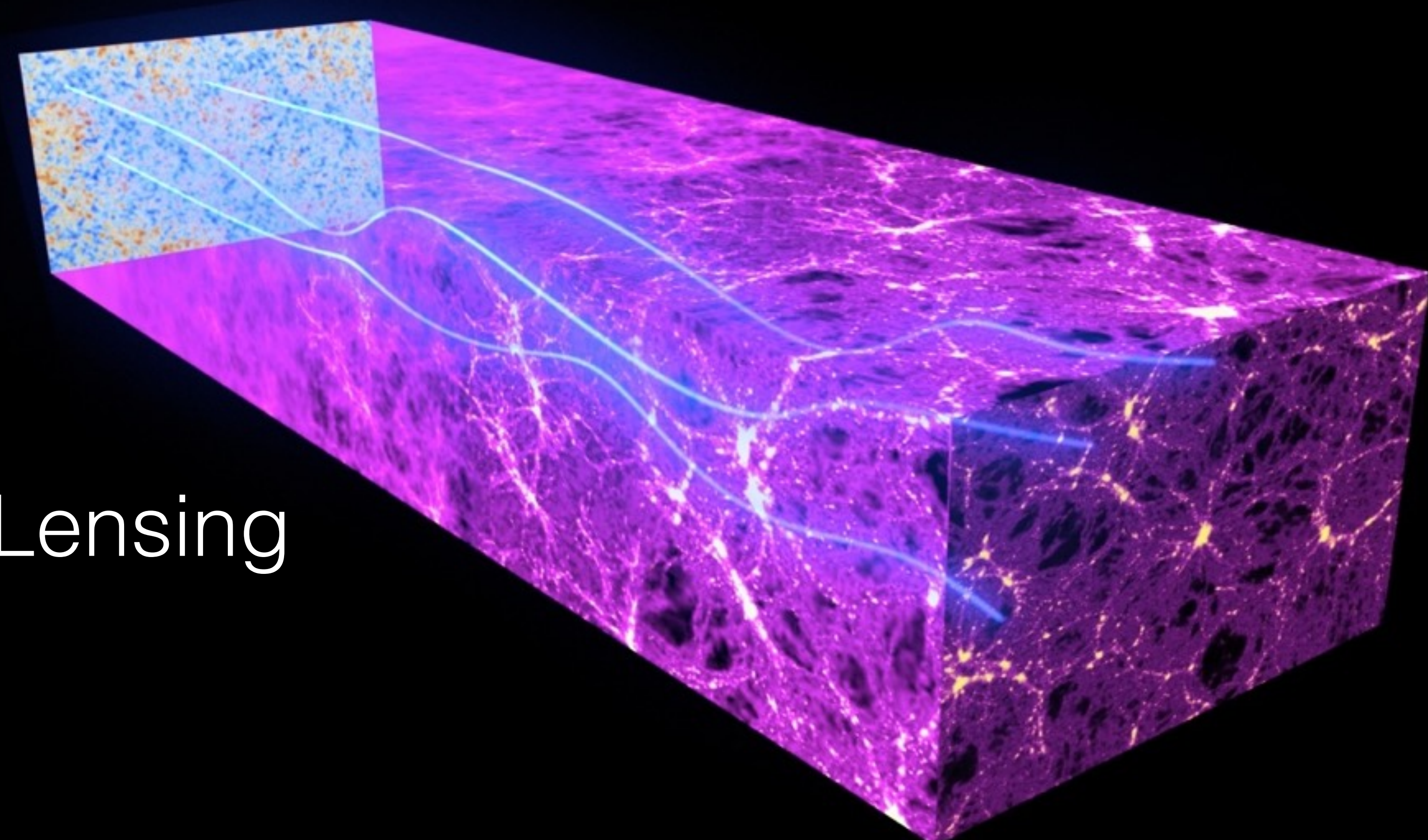


The Cosmic Neutrino Background

- Neutrinos decoupled from baryons ~1s after the end of inflation at ~1MeV and today they are ~10^{-4} eV ($T_\nu \approx 2K$)
- The total number of cosmic ν's is comparable to CMB γ's and the energy density of ν's is comparable to the baryons
- The effect of ν's on the growth of structure is different than baryons and cold dark matter and can be seen through their imprint on the CMB



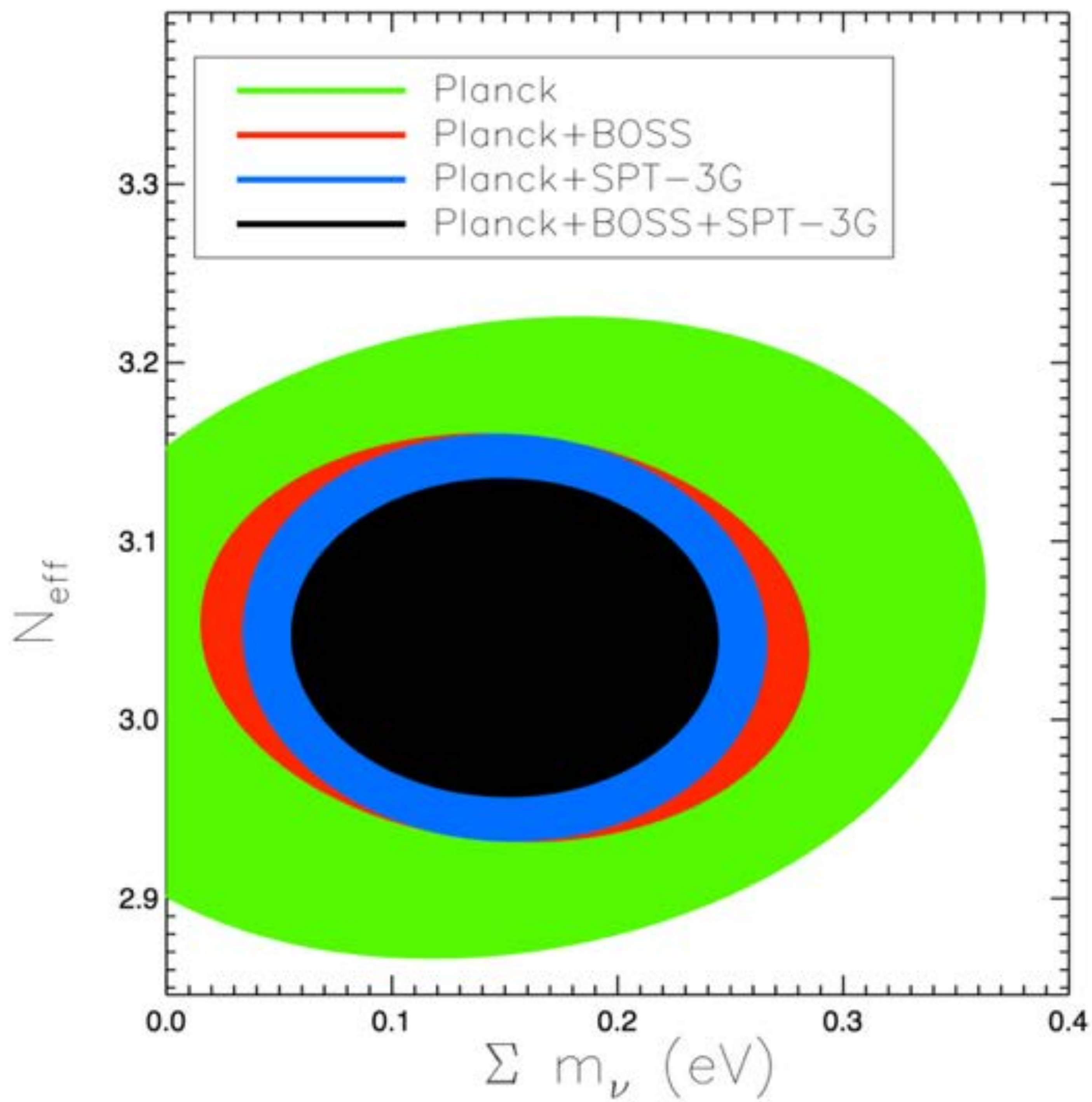
The Cosmic Neutrino Background



CMB Lensing

- Currently, CMB experiments have detected the CνB at ~10σ with N_{eff} = 3.15±0.23
- Cosmological measurements of ν's are highly complementary to the laboratory-based experimental effort.
- The cleanest astrophysical probe of neutrino mass is through gravitational lensing of the CMB

The cosmic neutrino background and mass of the neutrino



Σm_ν

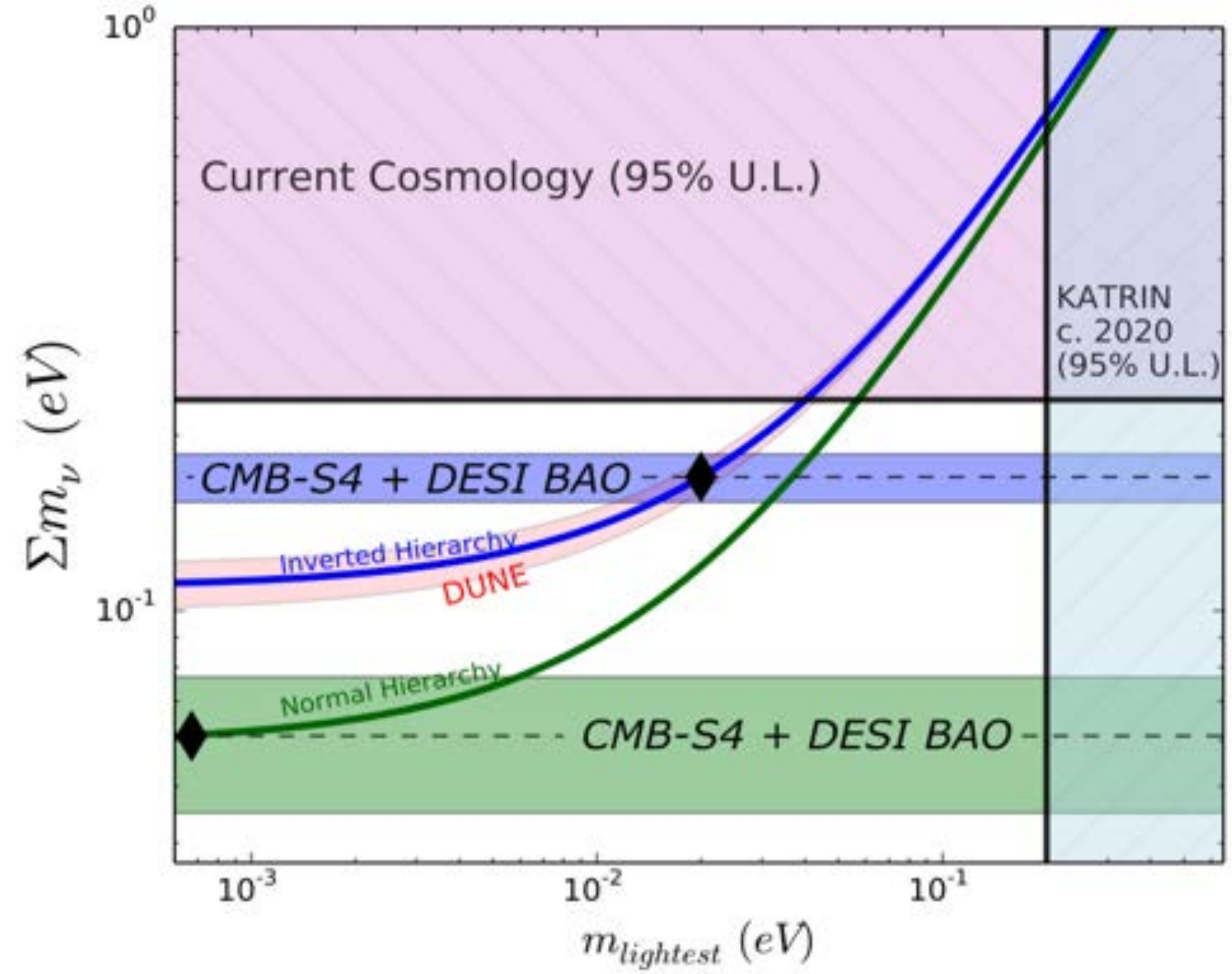
58 meV < Σm_ν < 194 meV

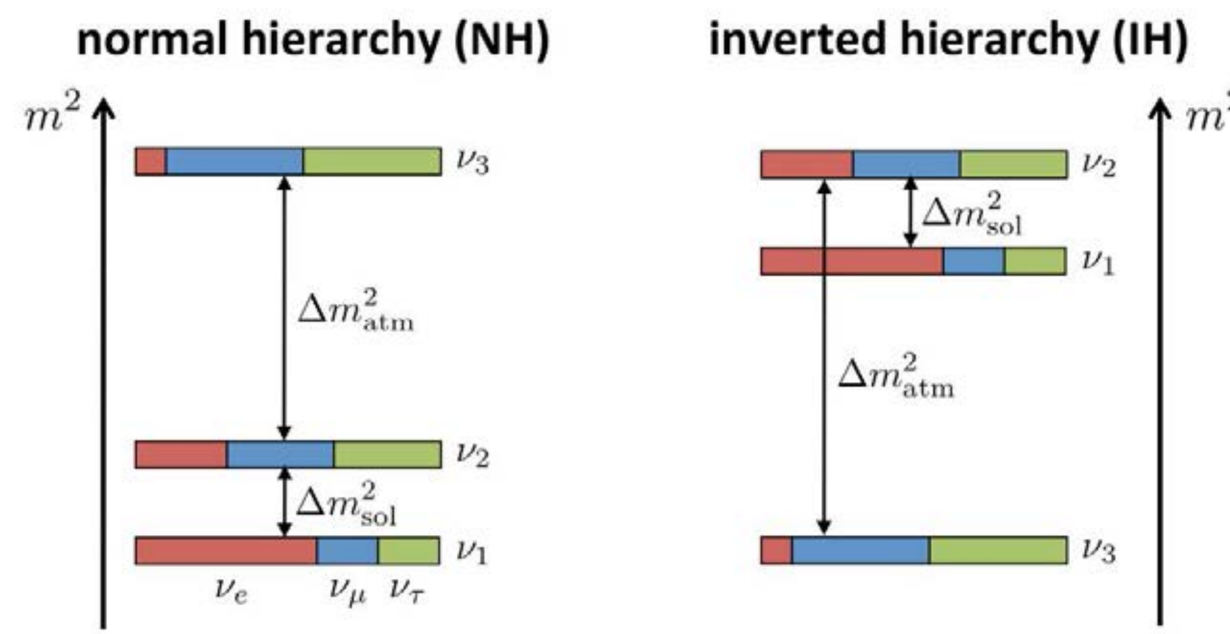
laboratory experiments

cosmological observations

Σm_ν is relevant to some of the most interesting open issues in neutrino and particle physics:

- mass hierarchy
- Majorana particles
- lepton number violation
- CP violation
- matter-anti-matter asymmetry



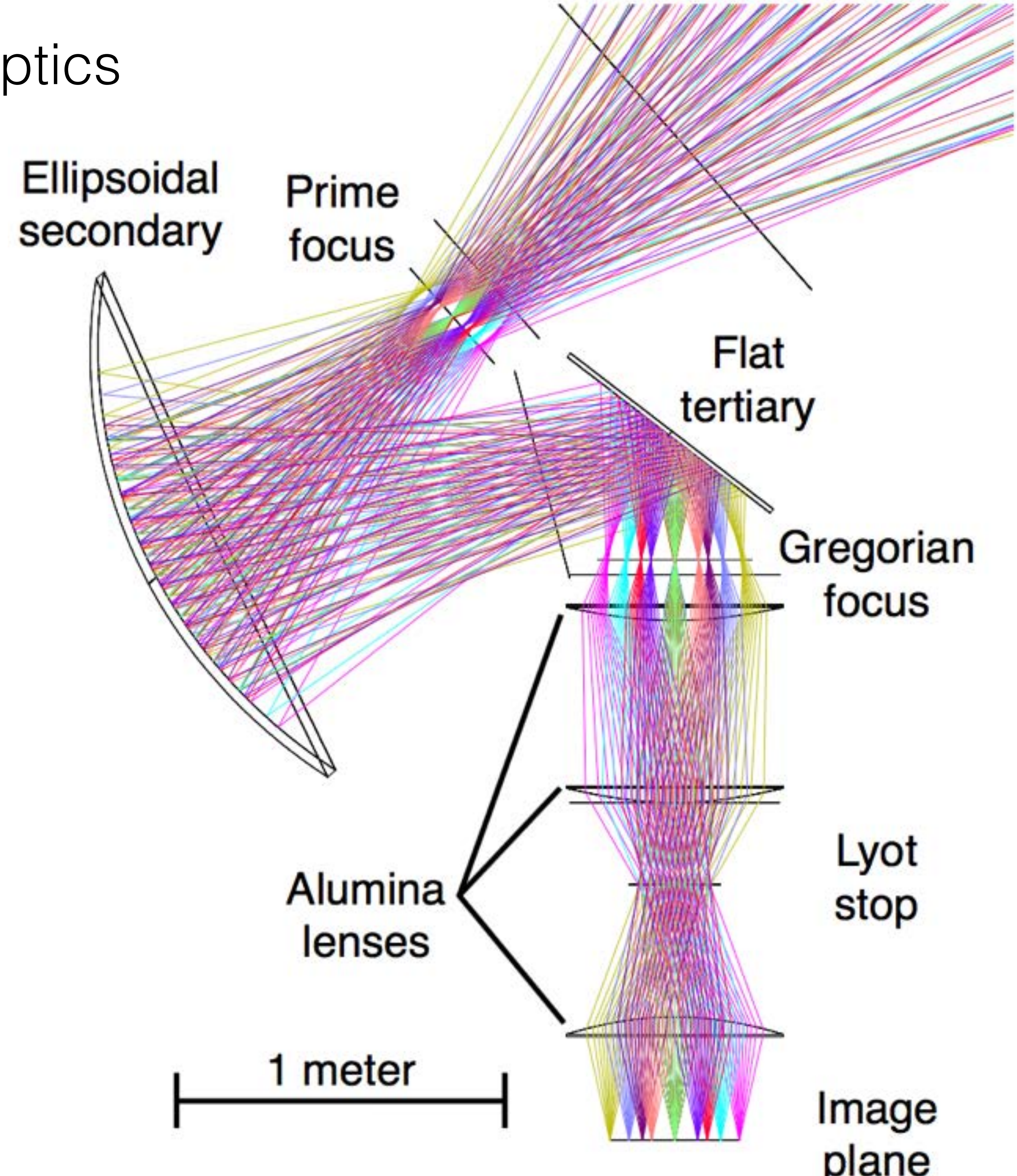


$\Sigma m_\nu \geq 58$ meV

$\Sigma m_\nu \geq 100$ meV


MANTIS

SPT-3G Optics

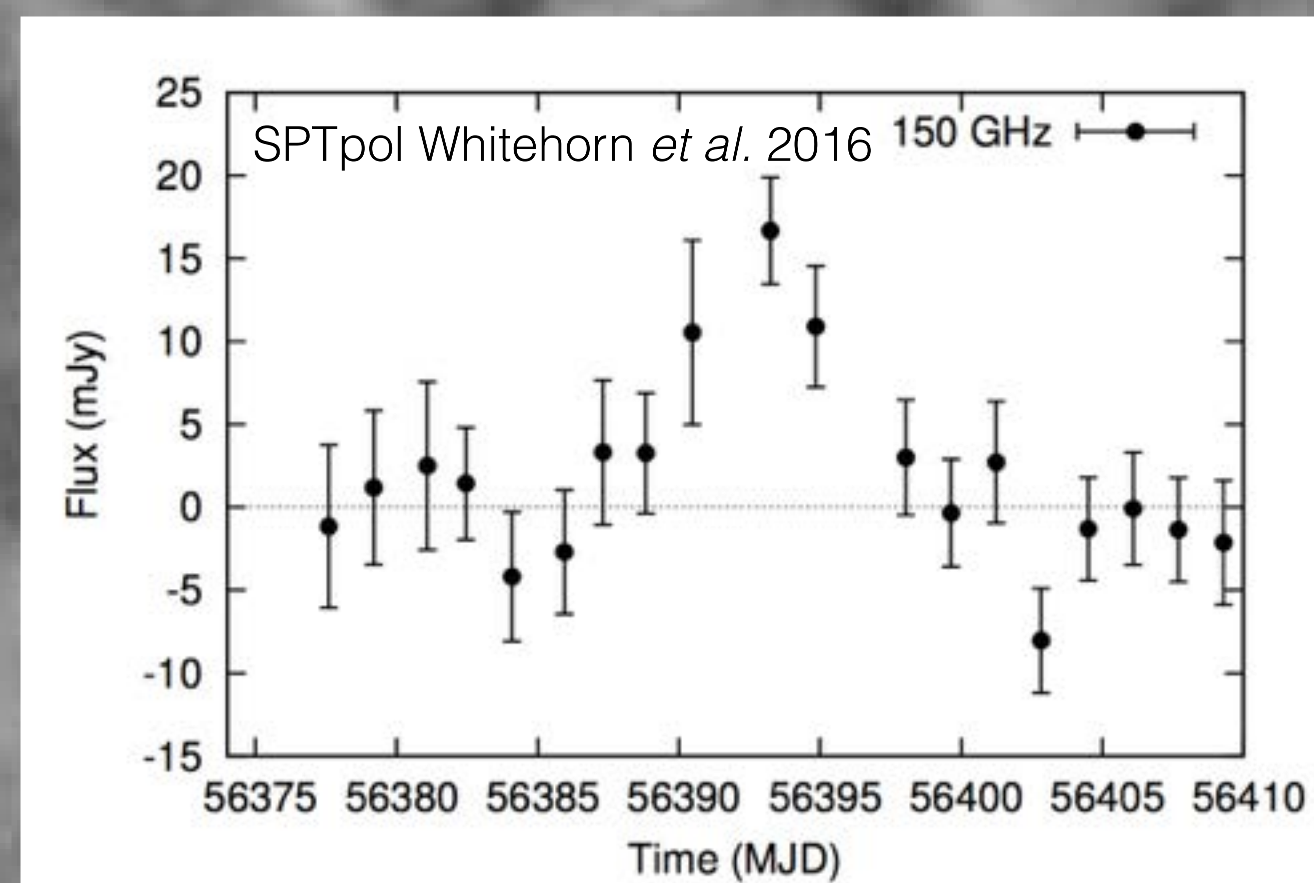



TCP-2
CRYOMECH
Done


WERNER

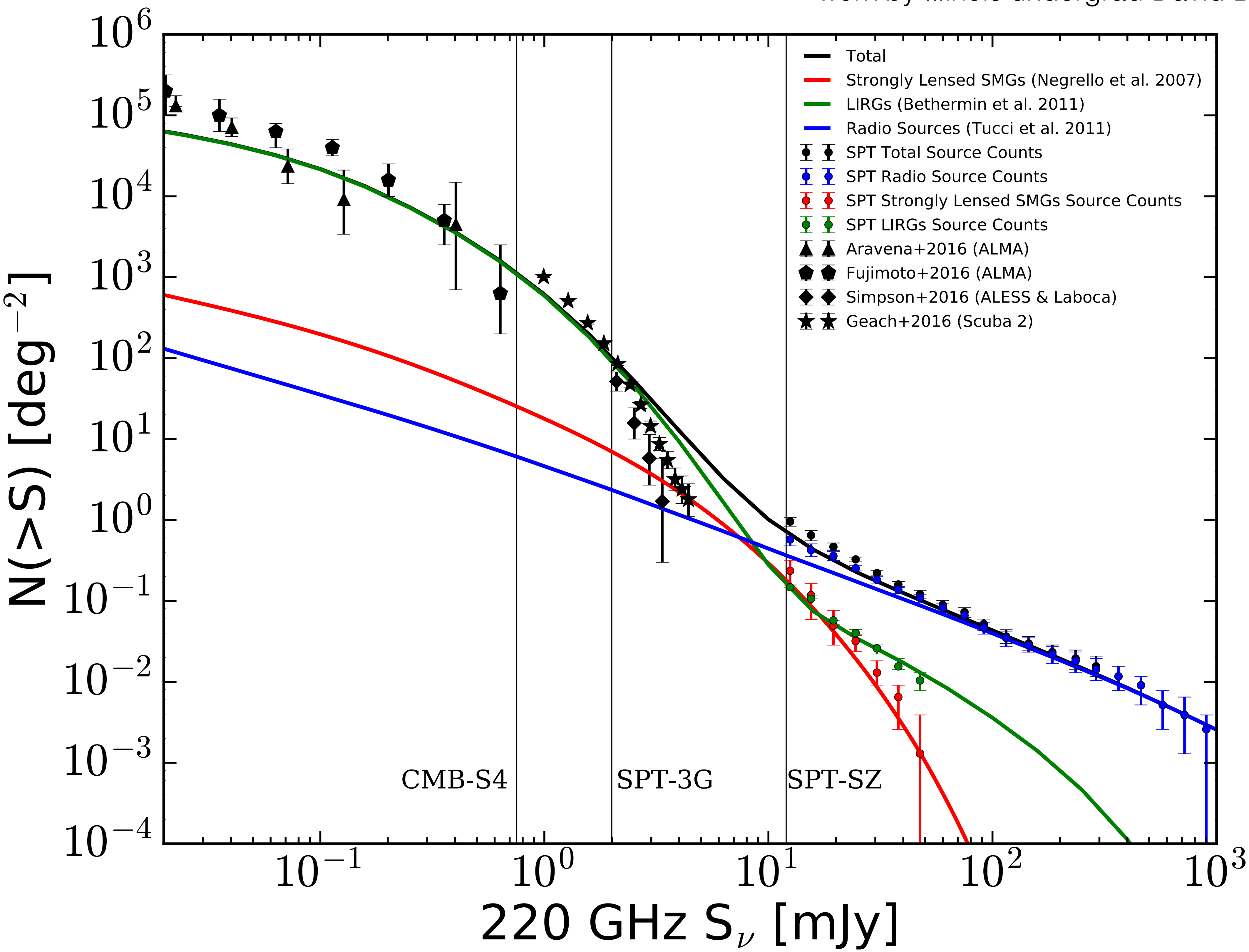
150 GHz SPT-SZ map

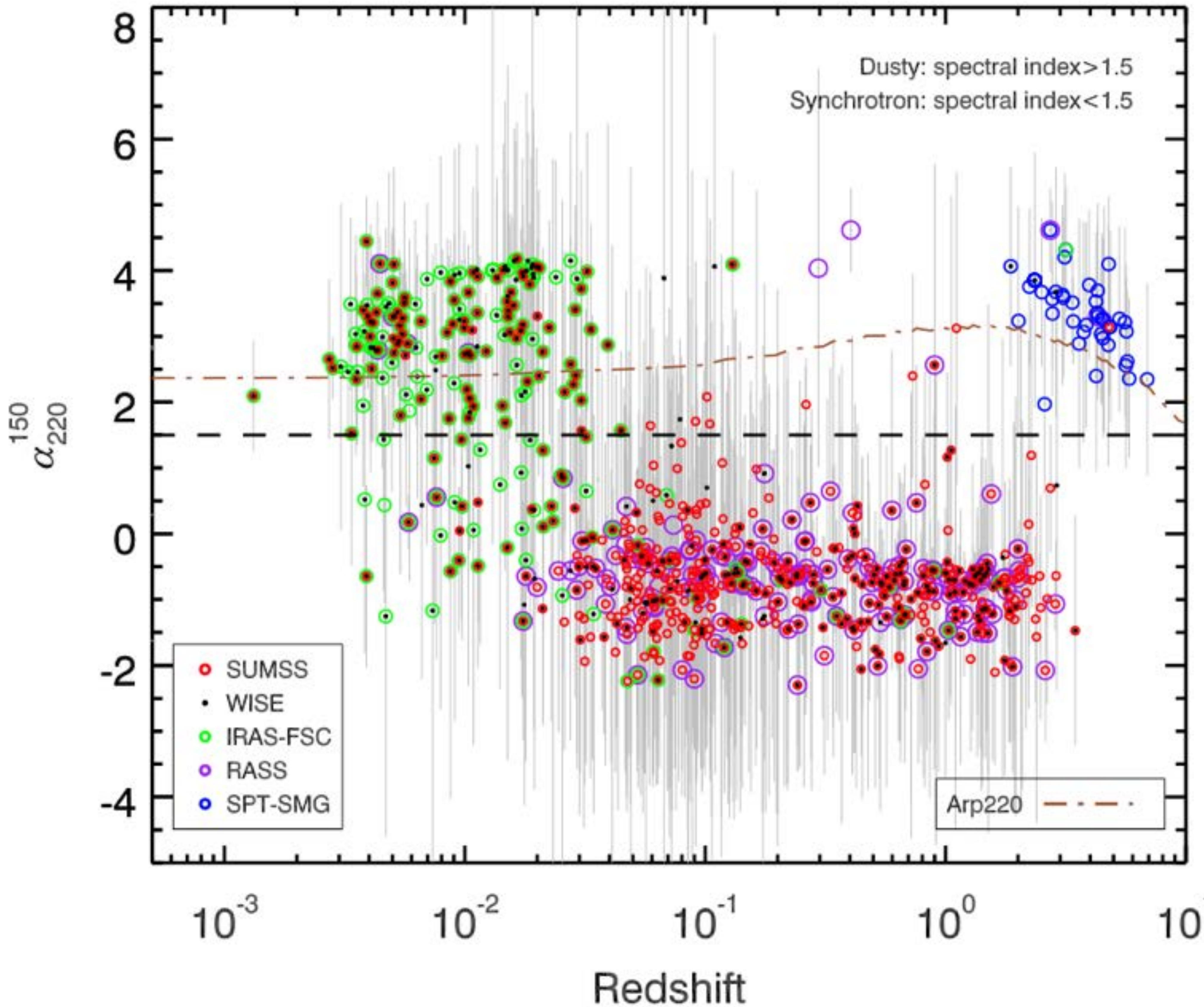
- For current CMB experiments, the dominant population of point sources are FSRQs
- ~2% of the SPT sources are strongly lensed dusty starforming galaxies at $2<z<7$
- For CMB-S4, the majority of sources will be luminous un-lensed dusty sources
- Any configuration of CMB-S4 will be confusion limited for point sources at 220 GHz
- We should think about synergies with other extragalactic surveys, e.g. LSST
- The time domain has been opened up for mm-wave transients.



CMB Point Sources by flux

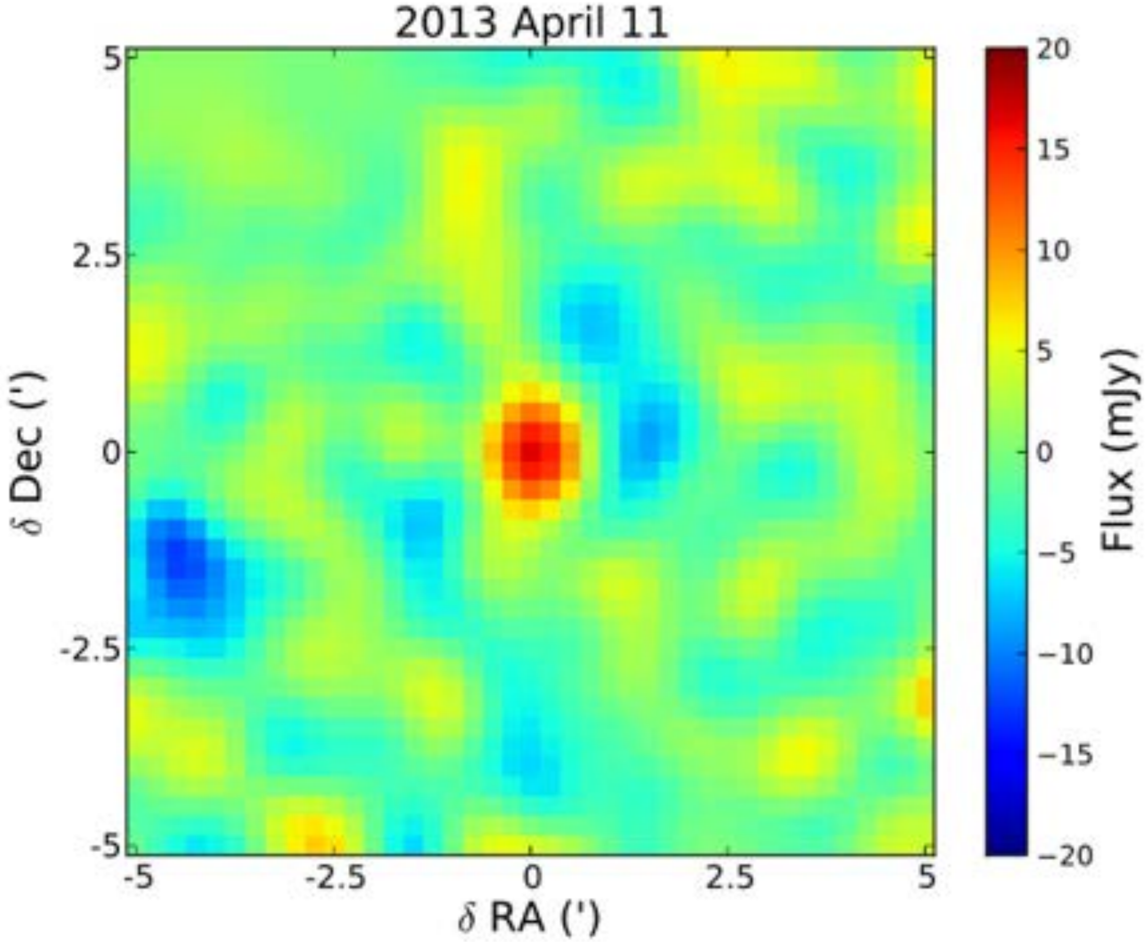
work by Illinois undergrad David Booke

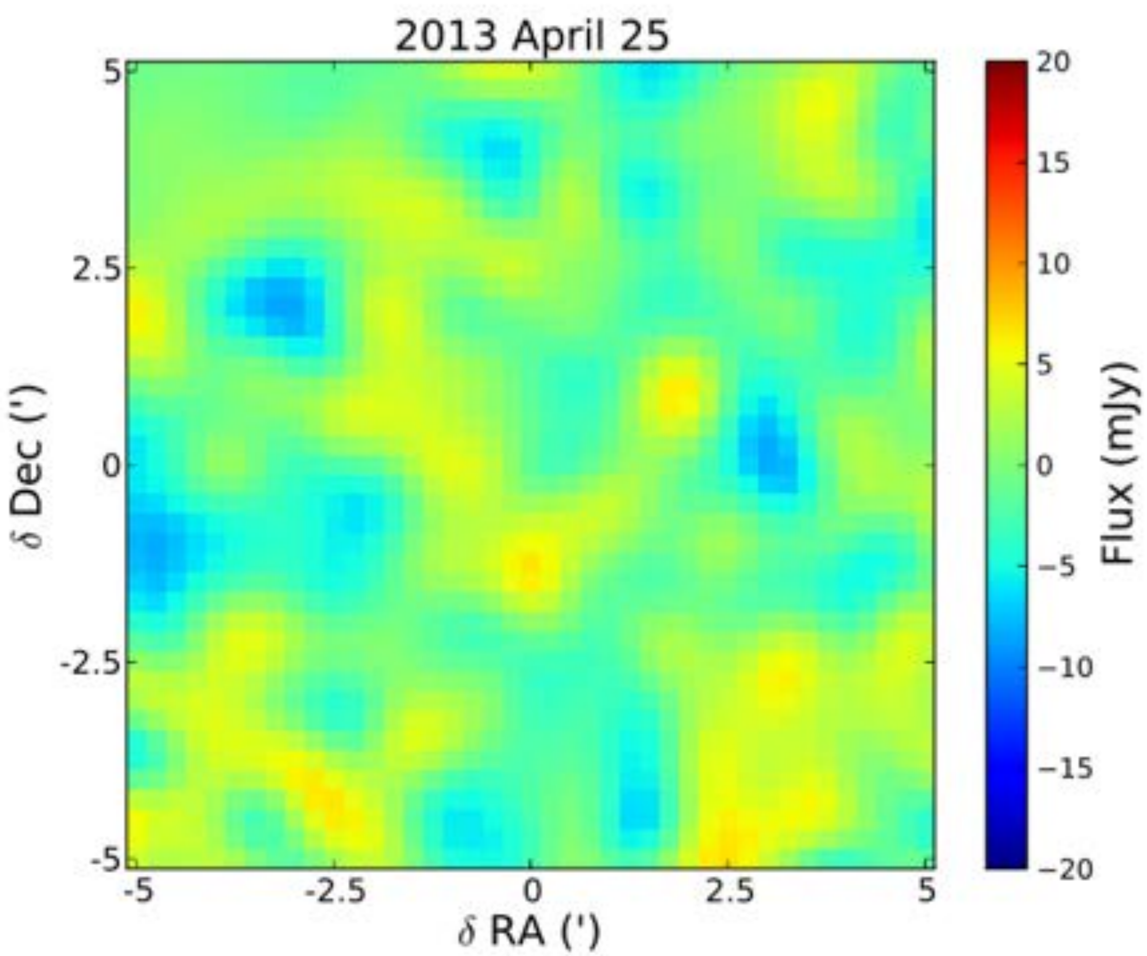


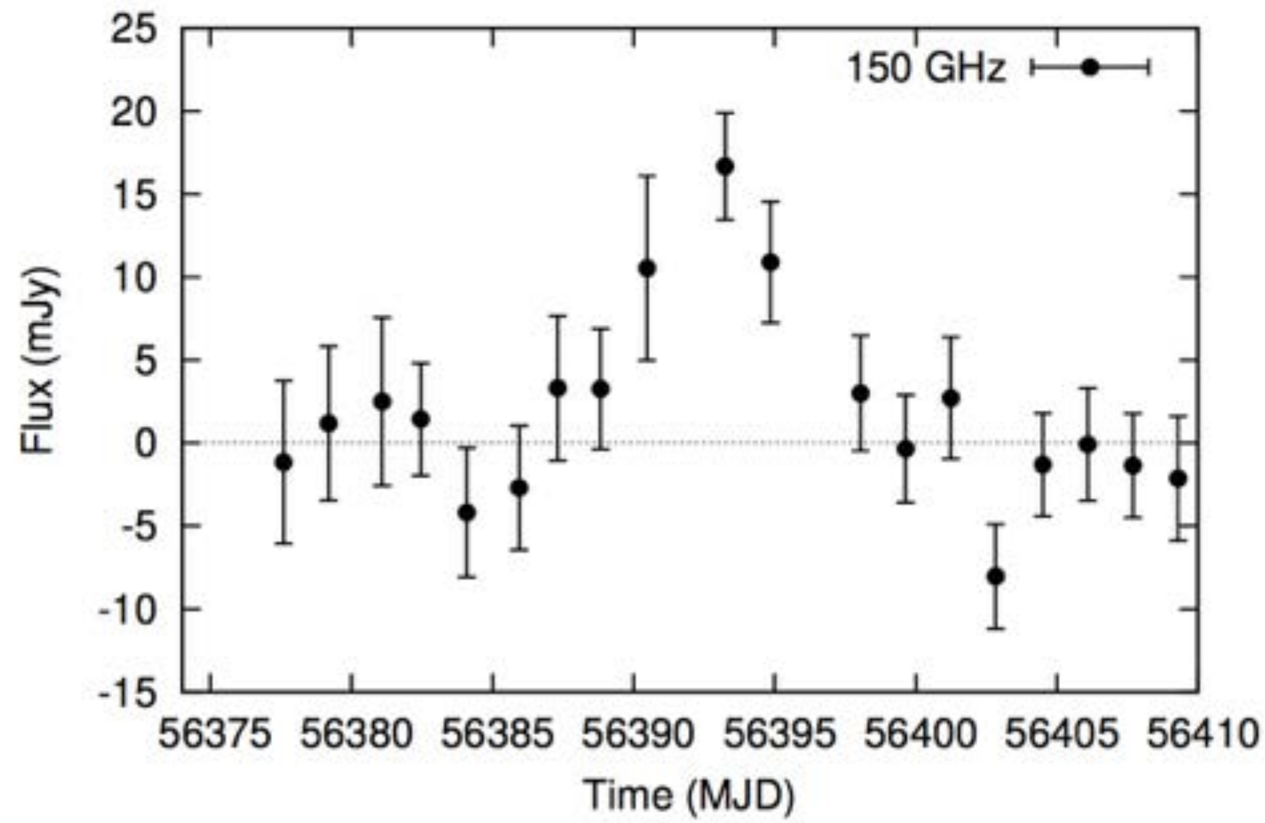


Dusty: spectral index>1.5
Synchrotron: spectral index<1.5
SUMSS
WISE
IRAS-FSC
RASS
SPT-SMG
Arp220
α_{220}^{150}
Redshift
8
6
4
2
0
-2
-4
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}

The mm transient sky

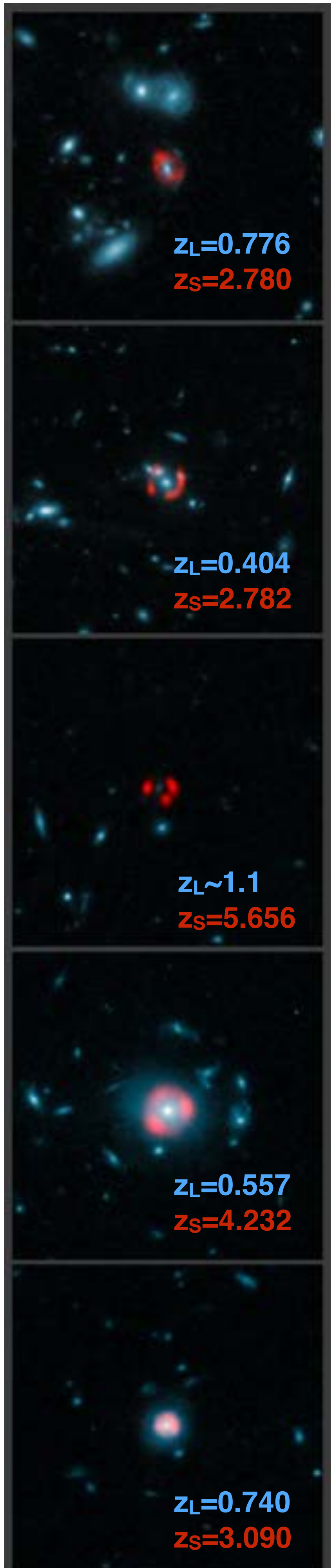


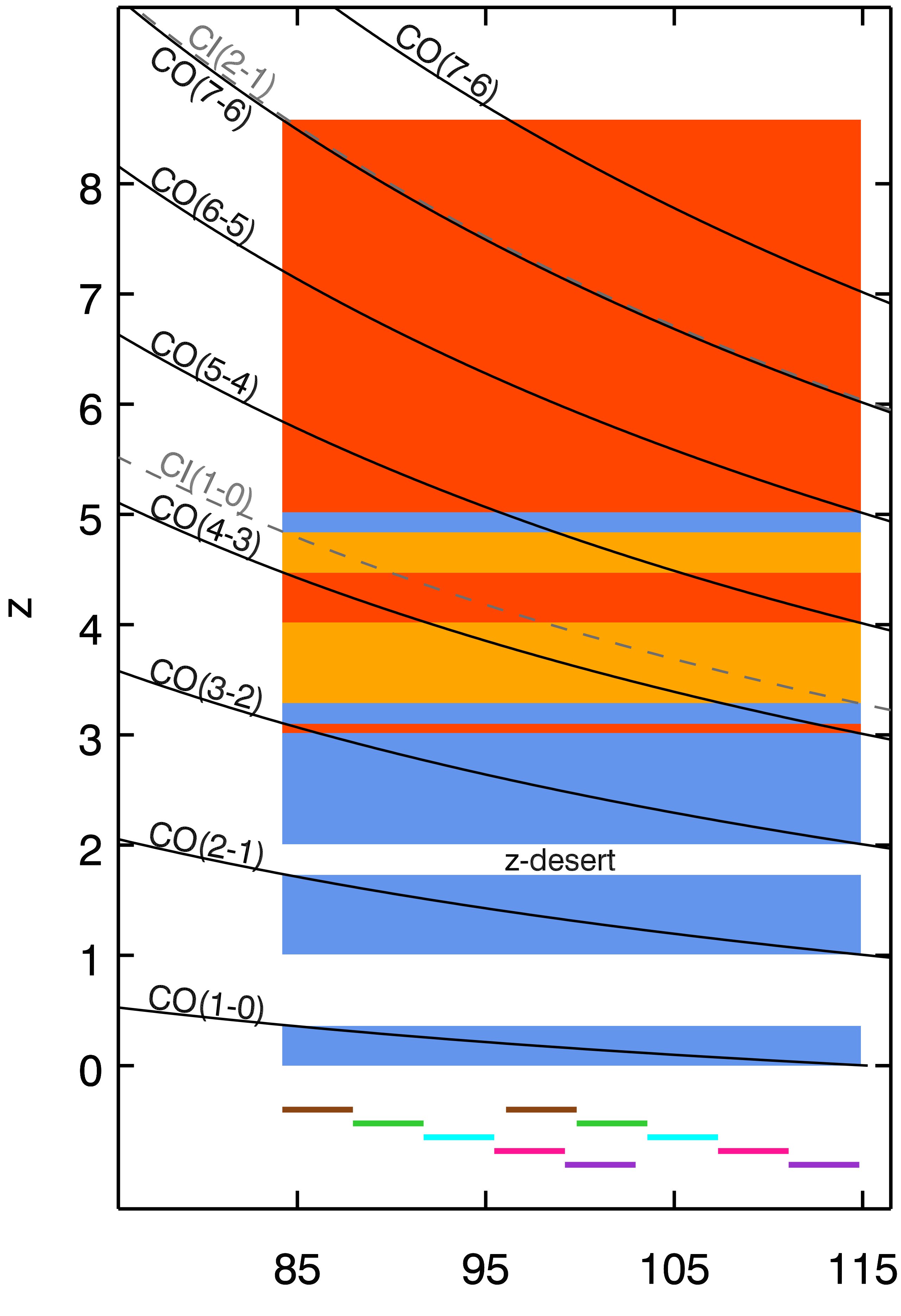


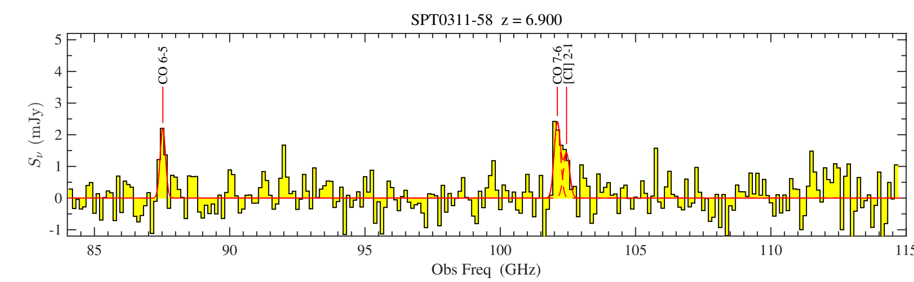


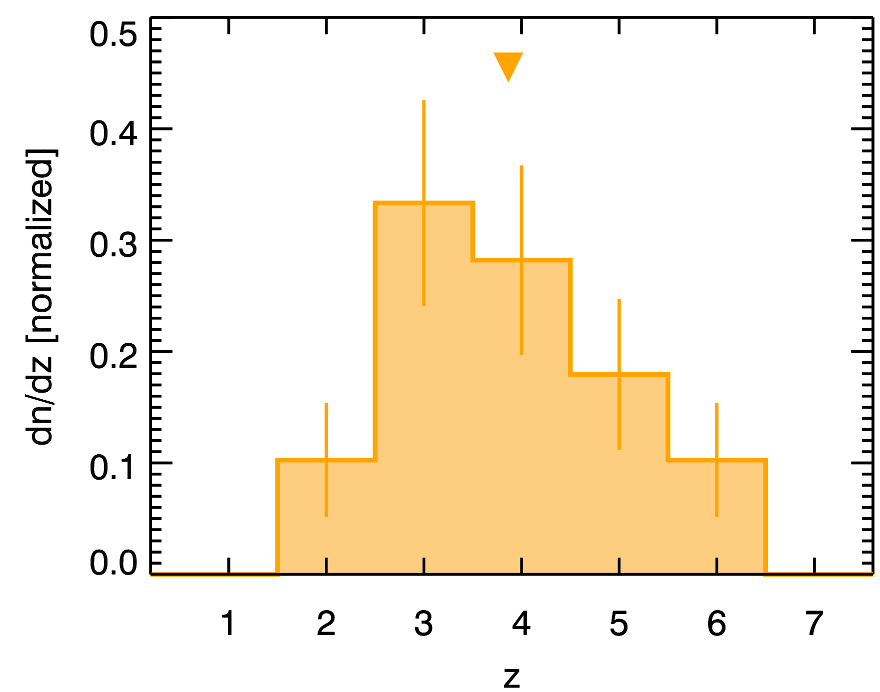
SPTpol Whitehorn *et al.* 2016

CO redshift searches with ALMA Band 3





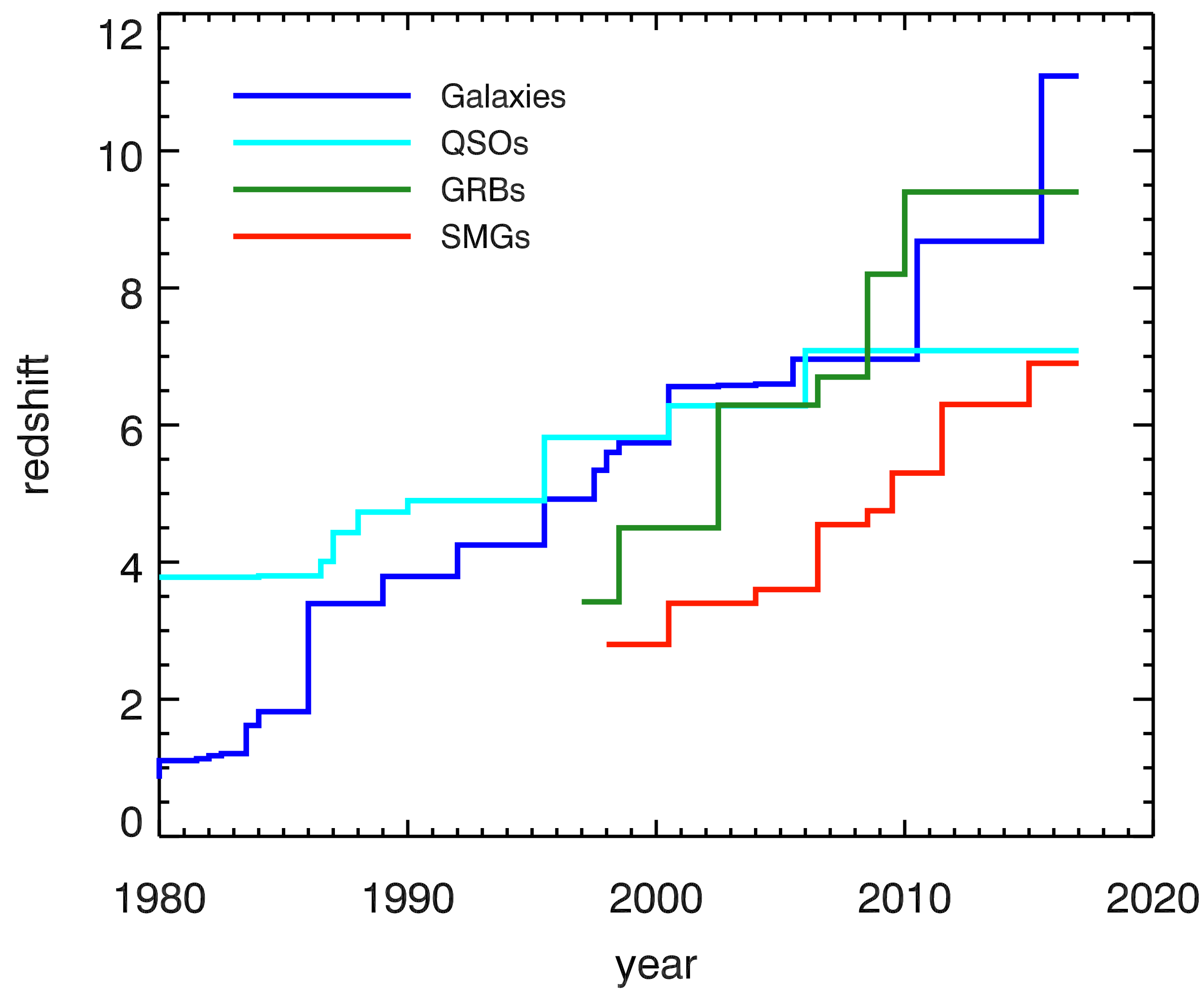




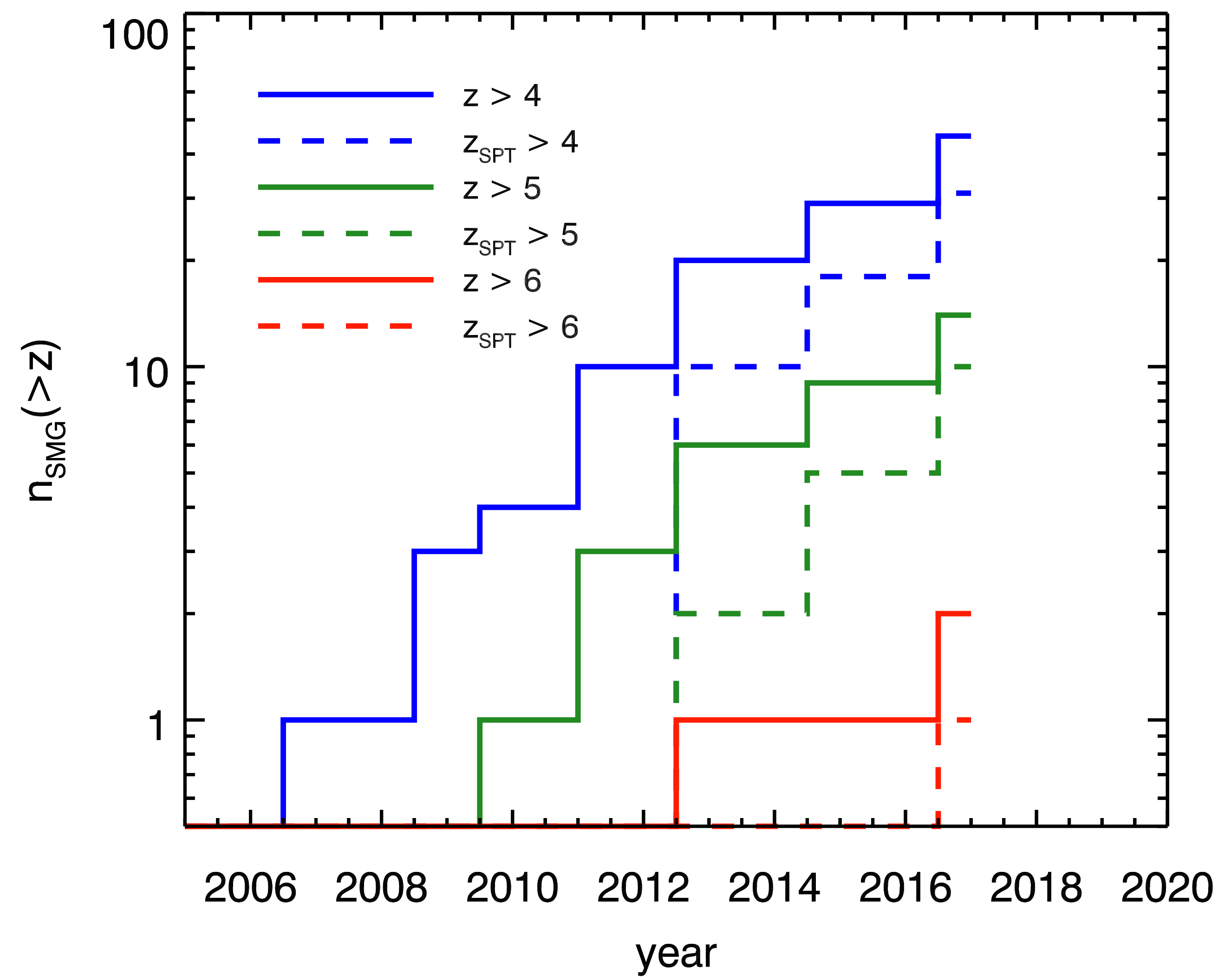
<z>=3.9±0.4

41 sources total
1.8<z<6.9

Most distant astronomical object

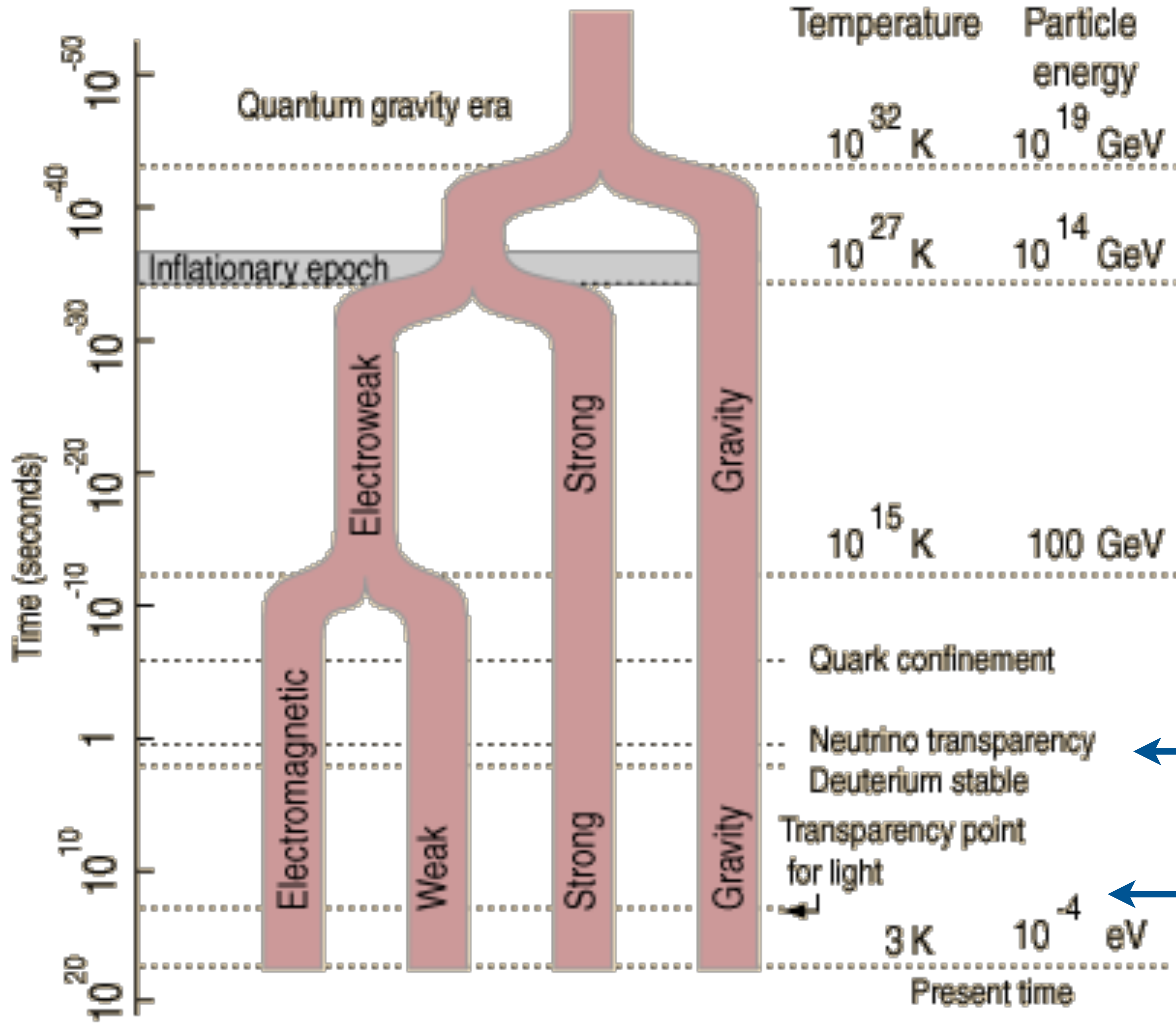


$N_{SMG}(>z)$ v. year



CMB surveys have discovered 70% of SMGs at z>4

The early Universe as a laboratory for high energy physics



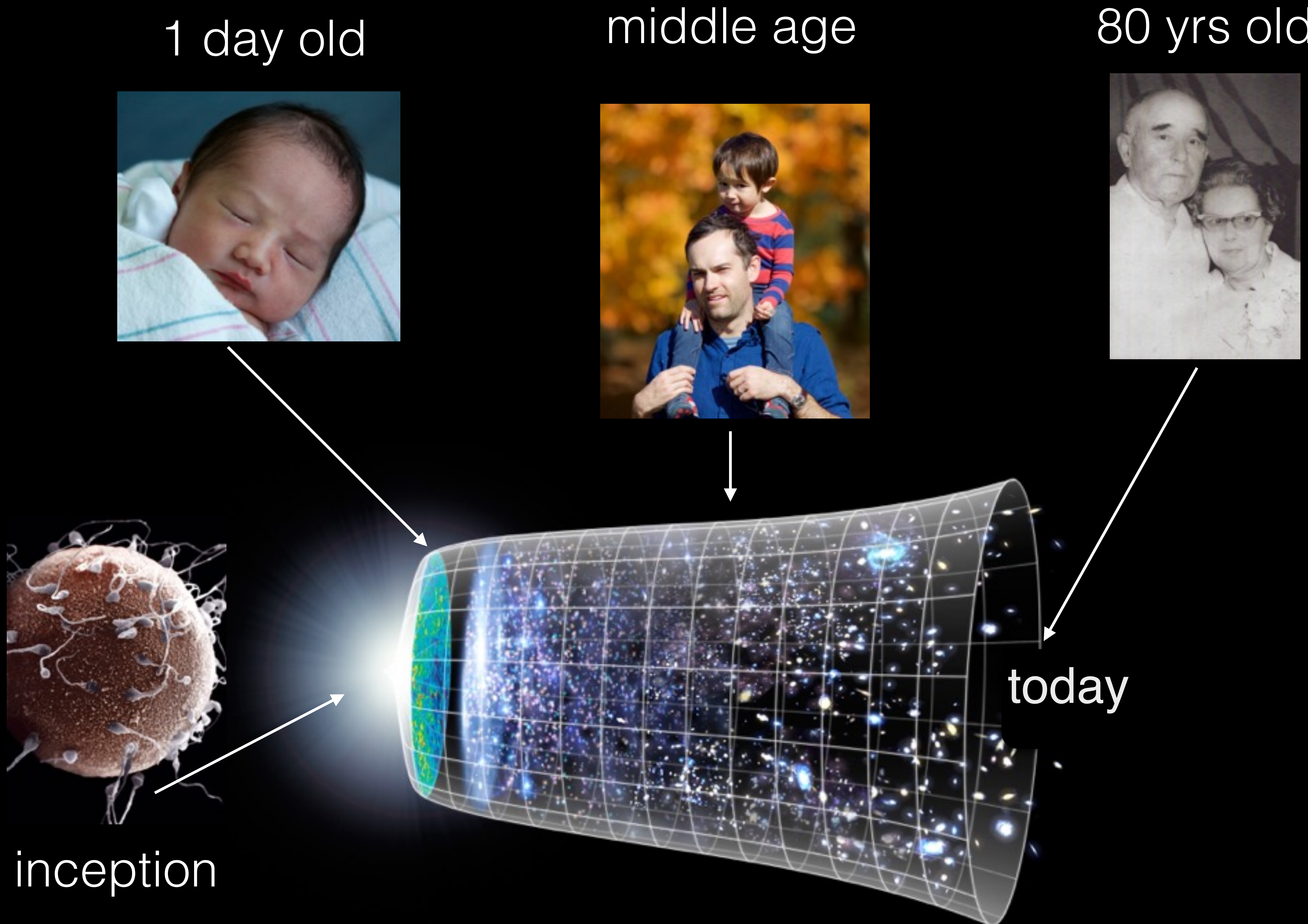
Inflation

$$V^{1/4} = 1.06 \times 10^{16}\ \mathrm{GeV} \left(\frac{r}{.01}\right)^{1/4}$$

energy scale probed by LHC

Cosmic neutrino background

Cosmic microwave background


1 day old
middle age
80 yrs old
inception
today

Funded by

Conclusions

- CMB experiments have made huge impacts in the field of cosmology and will continue to do so into the next decade.
- In addition to cosmology, CMB experiments are also making important measurements and discoveries in astrophysics and ultra high energy physics.
- Increases in superconducting detector arrays are the enabling technology.
- SPT-3G is currently deploying and will be on the sky in the next few weeks.
- The field is coming together to plan CMB-S4.
- CMB measurements in the next 5-10 years will constrain inflation, measure the mass of the neutrino and continue to become more useful to probe the cosmological and astrophysical evolution of the Universe.