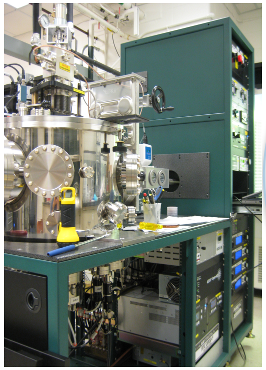
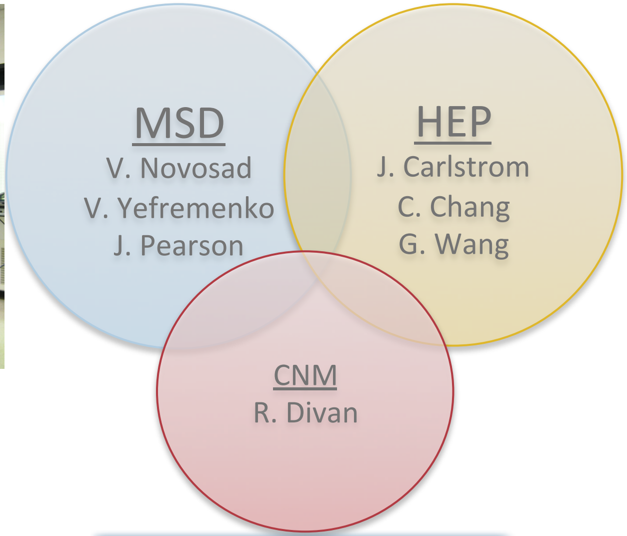
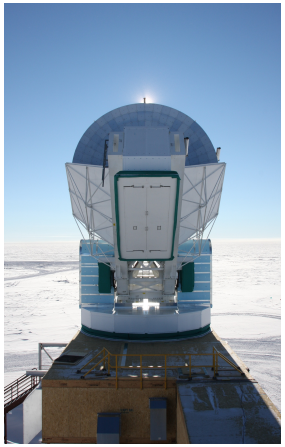
Transition Edge Sensors

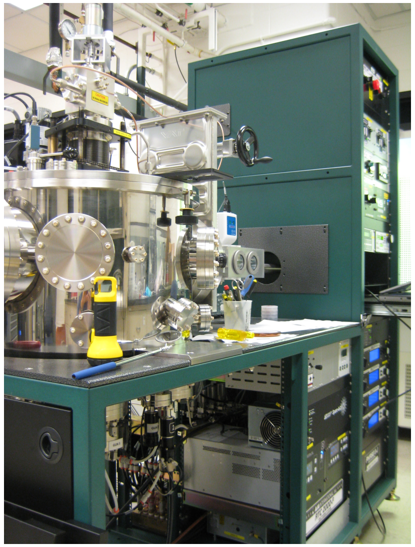
Clarence Chang
DOE HEP Site Visit
September 4, 2012

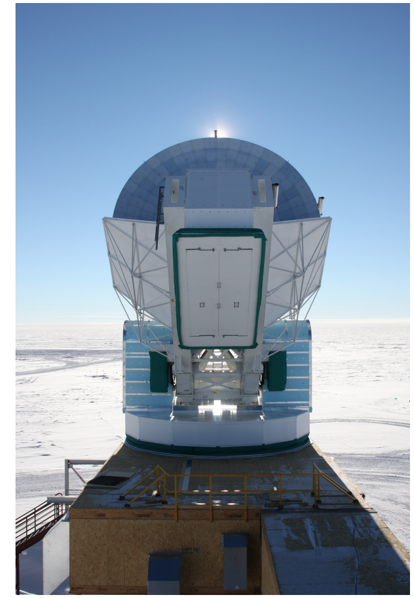






Unique multi-disciplinary program





MSD

- Thin film expertise
- Materials characterization
- Dedicated deposition equipment

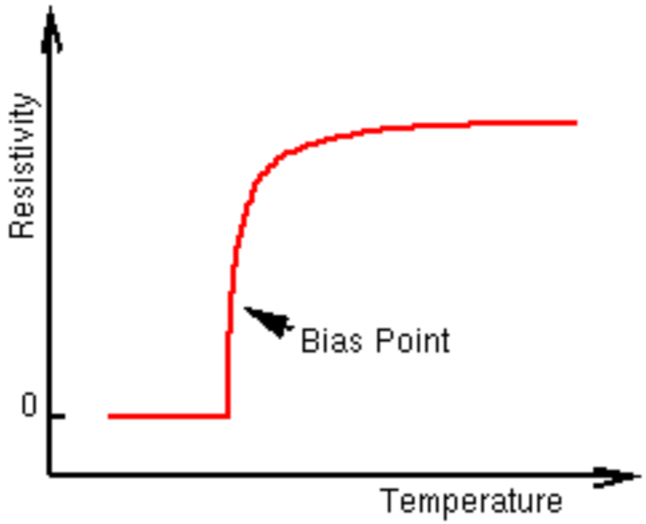
CNM

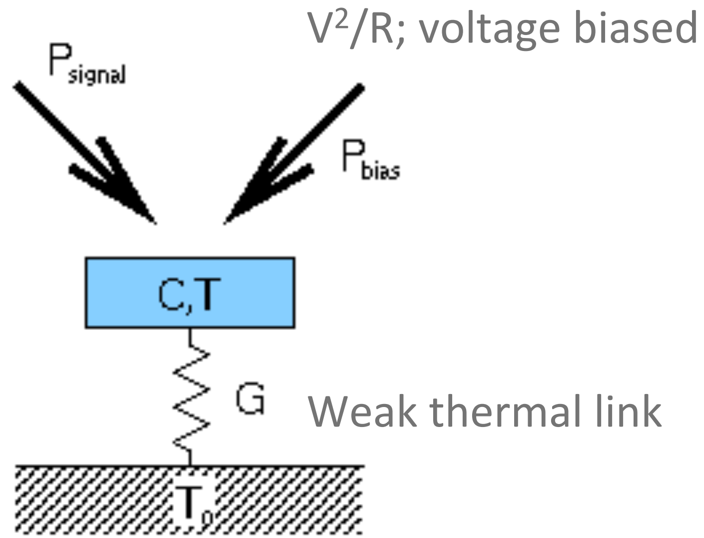
- Lithography & etching resources
- Scientific Users facilities

HEP

- Scientific context
- Detector testing & characterization
- Experiment delivery

Transition Edge Sensor

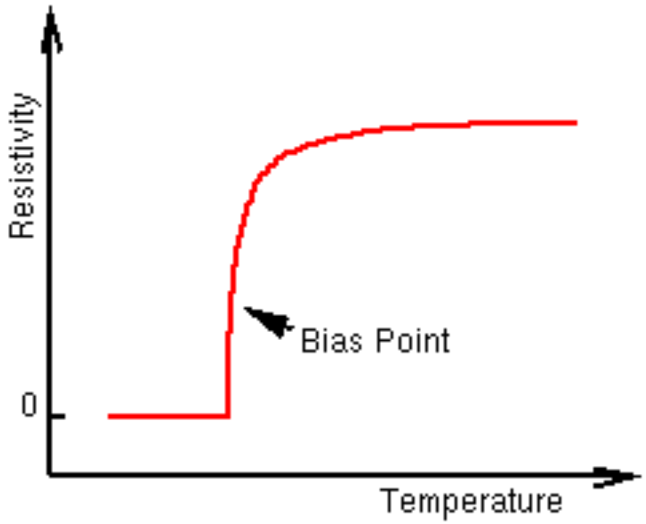




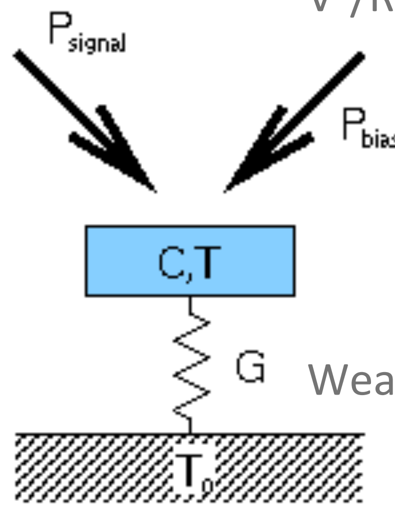
$\uparrow P_{signal}$ -> $\uparrow R$ -> $\downarrow P_{bias}$

- Negative feedback (good!)
- Multiplexable

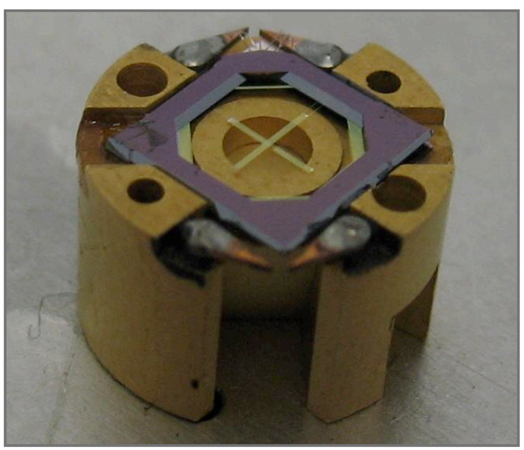
Transition Edge Sensor



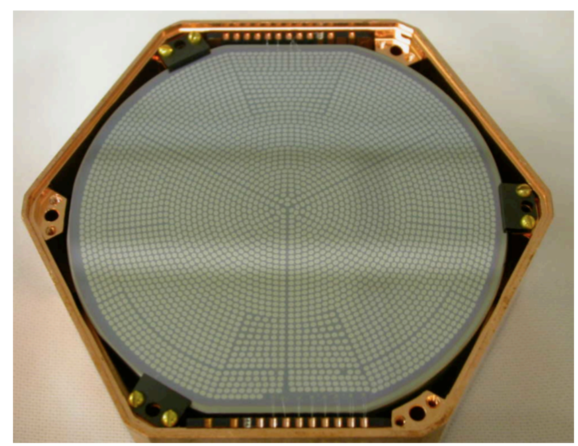
V^2/R; voltage biased



Weak thermal link



CMB bolometers, low energy, slow



Dark Matter detectors, higher energy, fast

From idea to "instrument ready"

- **Mm-wave bolometers**
- Optical/IR spectrophotometers
- X-ray microcalorimeters
- Gamma-ray spectrometers
- Alpha calorimeters
- **Heavy ion/particle detectors**
- Etc…

History of innovation

TES Array Technology

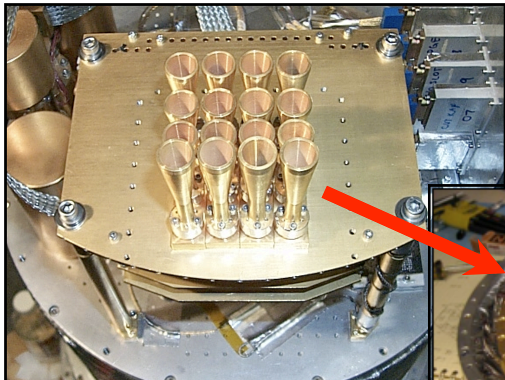
Science potential

- **CMB**
- **Dark Matter**
- Beta decay
- Synchrotron Light Source
- Nuclear Non-proliferation
- Heavy Ion Physics
- National Security
- Quantum Information
- Astrophysics & Astronomy
- Etc …

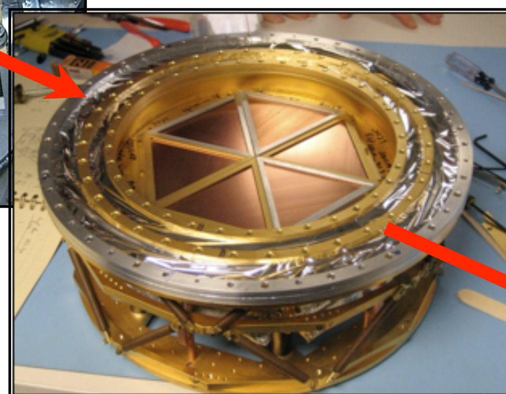
Evolution of CMB focal plane technology

2001: ACBAR
16 detectors

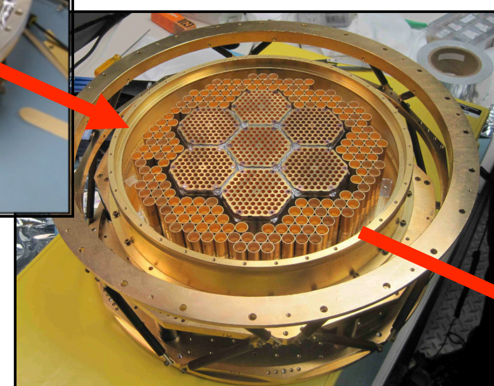
Detectors are background limited.
More sensitivity = more detectors!



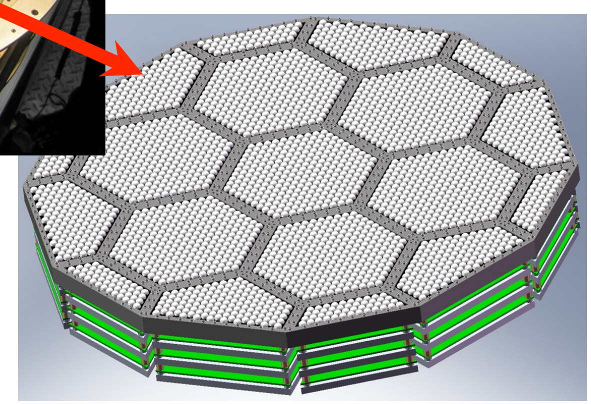
2007: SPT
960 detectors



2012: SPTpol
~1600 detectors



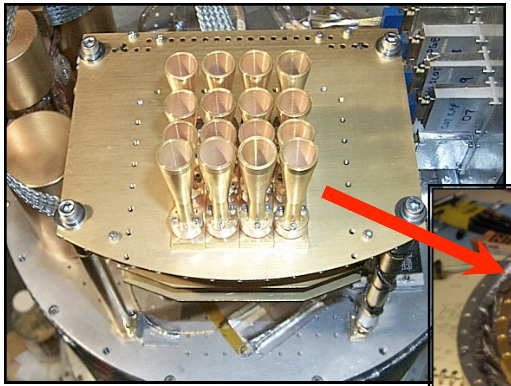
2016: SPT-3G
~15,200 detectors



Requires new technology for higher focal plane density.

Past 5 years: LDRD seeded; KA13 supported

2001: ACBAR
16 detectors



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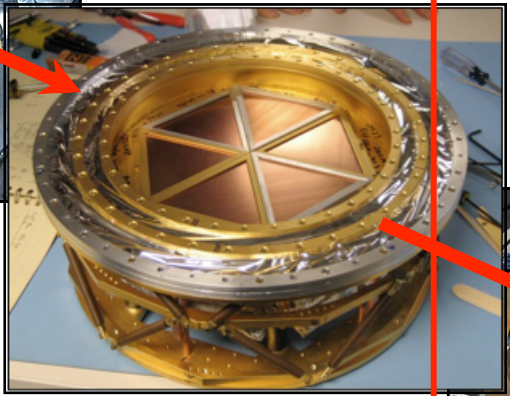
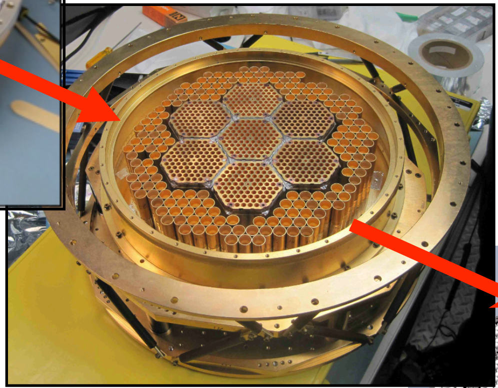


ANL 90 GHz &
NIST 150 GHz;
Built from scratch

2012: SPTpol
~1600 detectors



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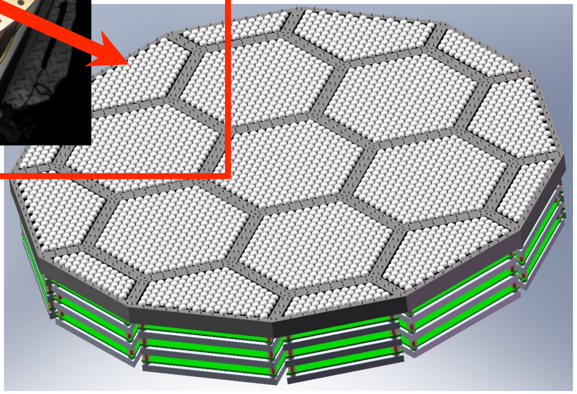
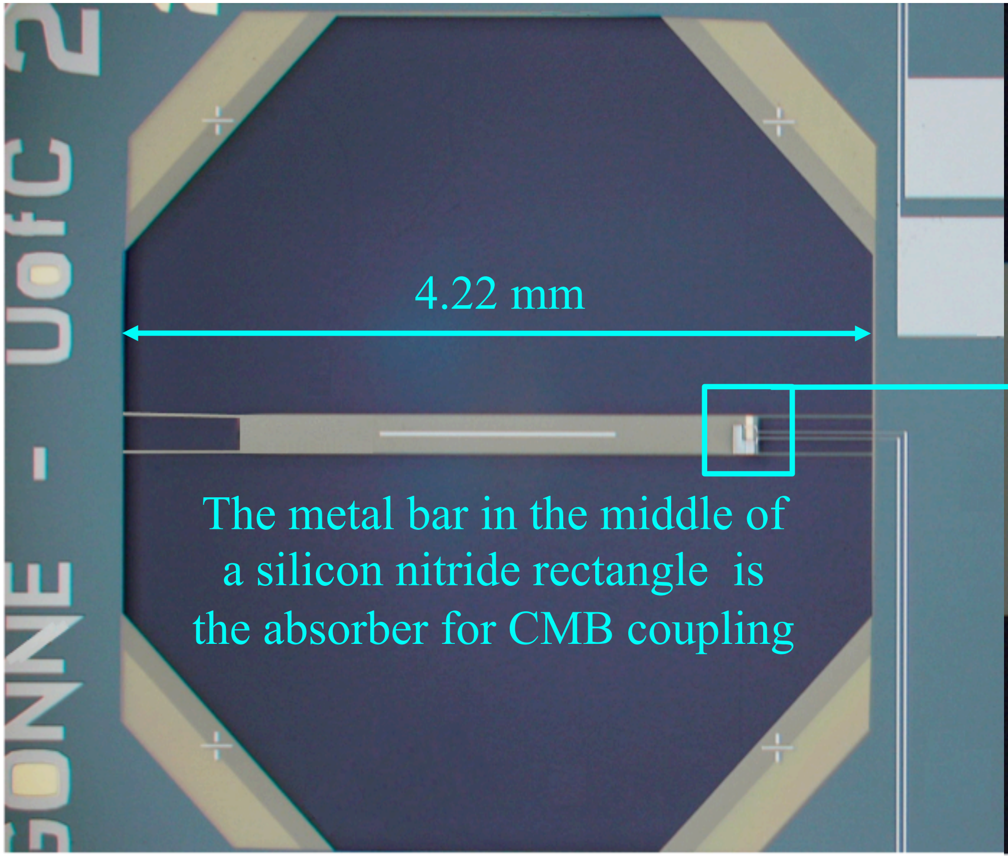
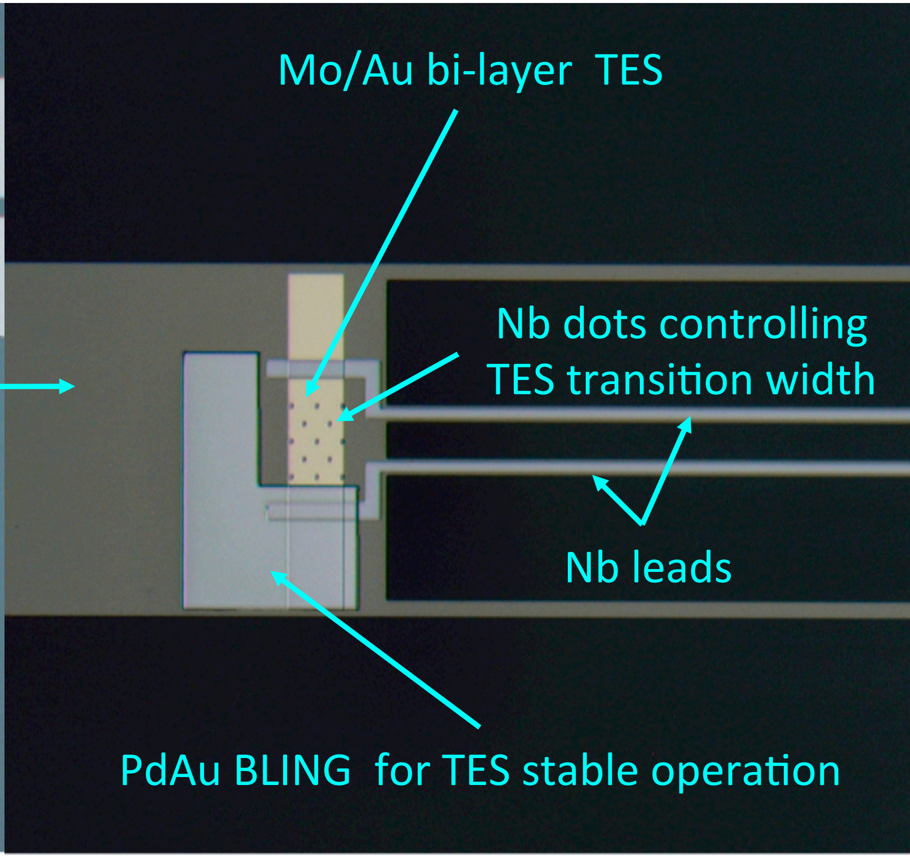


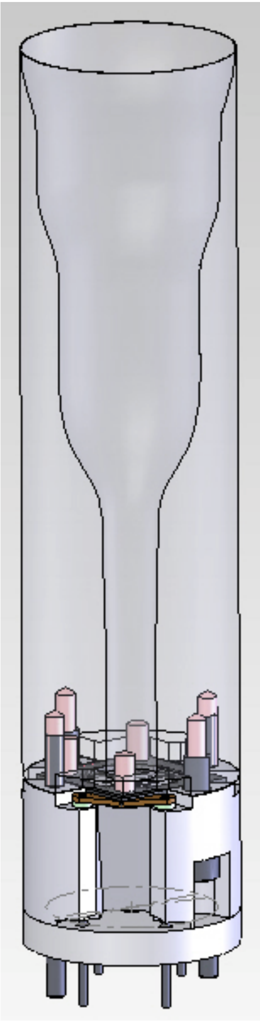
SPTpol: upgrade for
polarization sensitivity

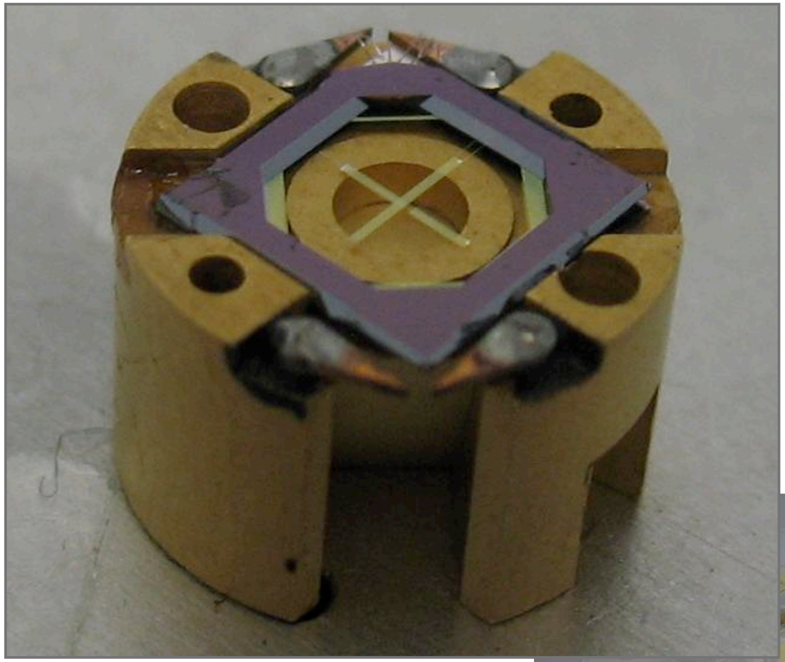
ANL TES bolometers: built from scratch

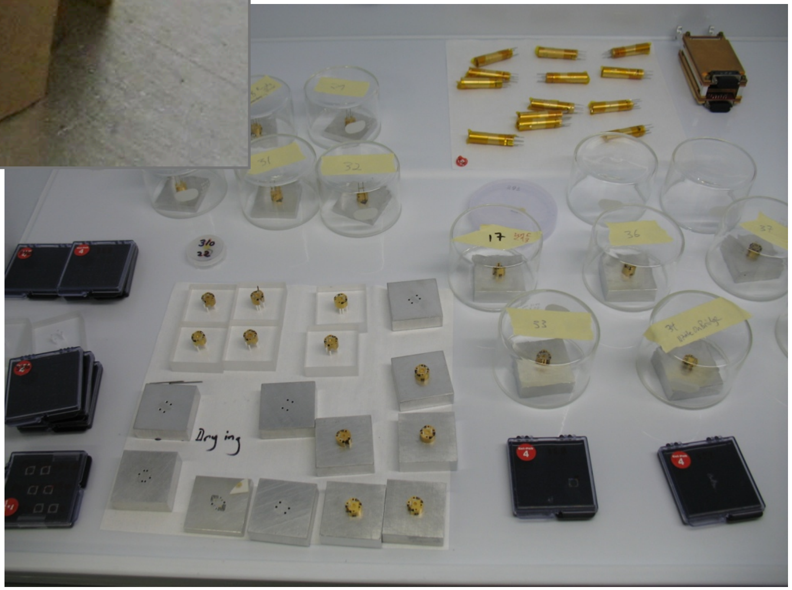


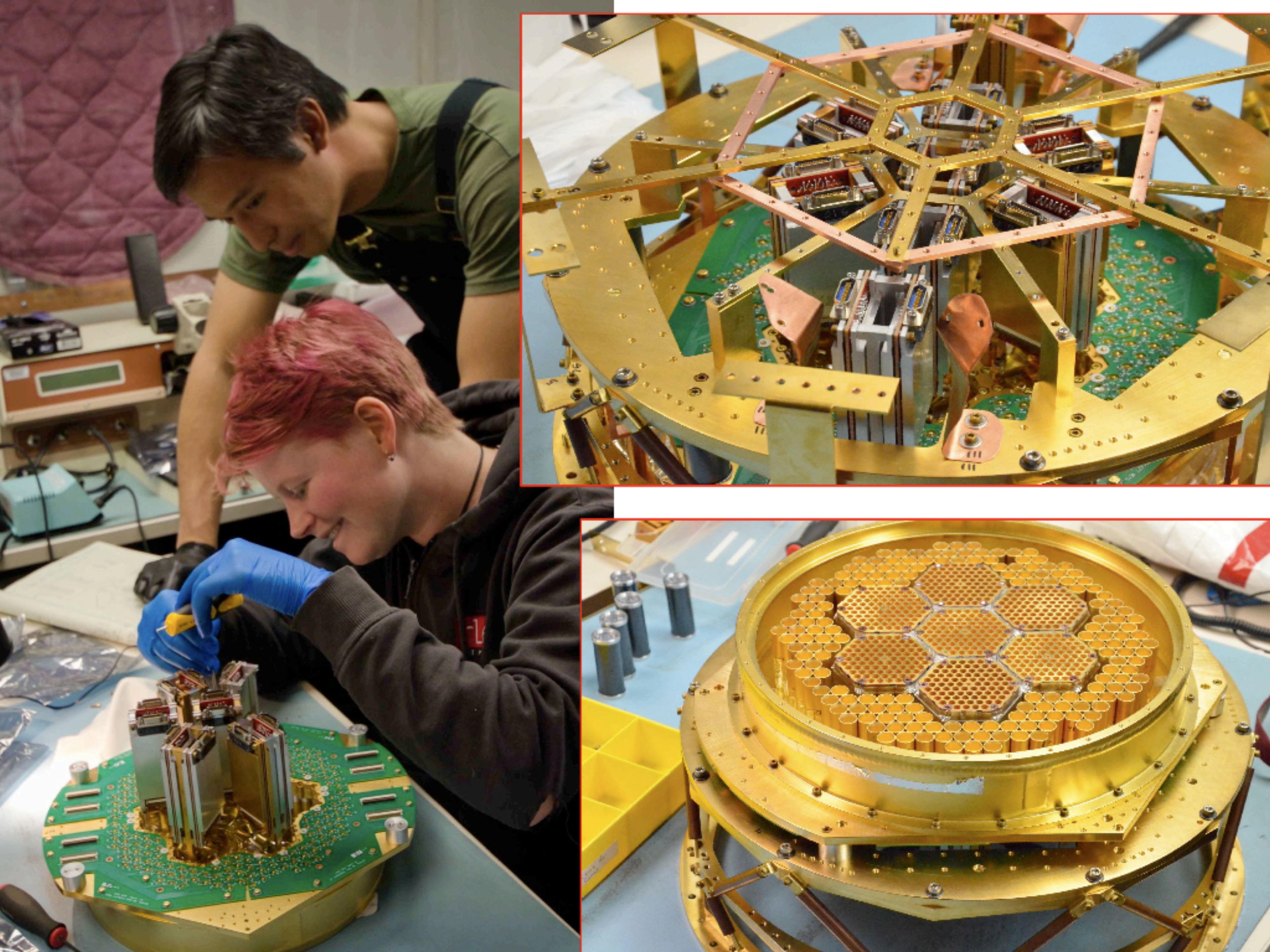


Detector production and assembly





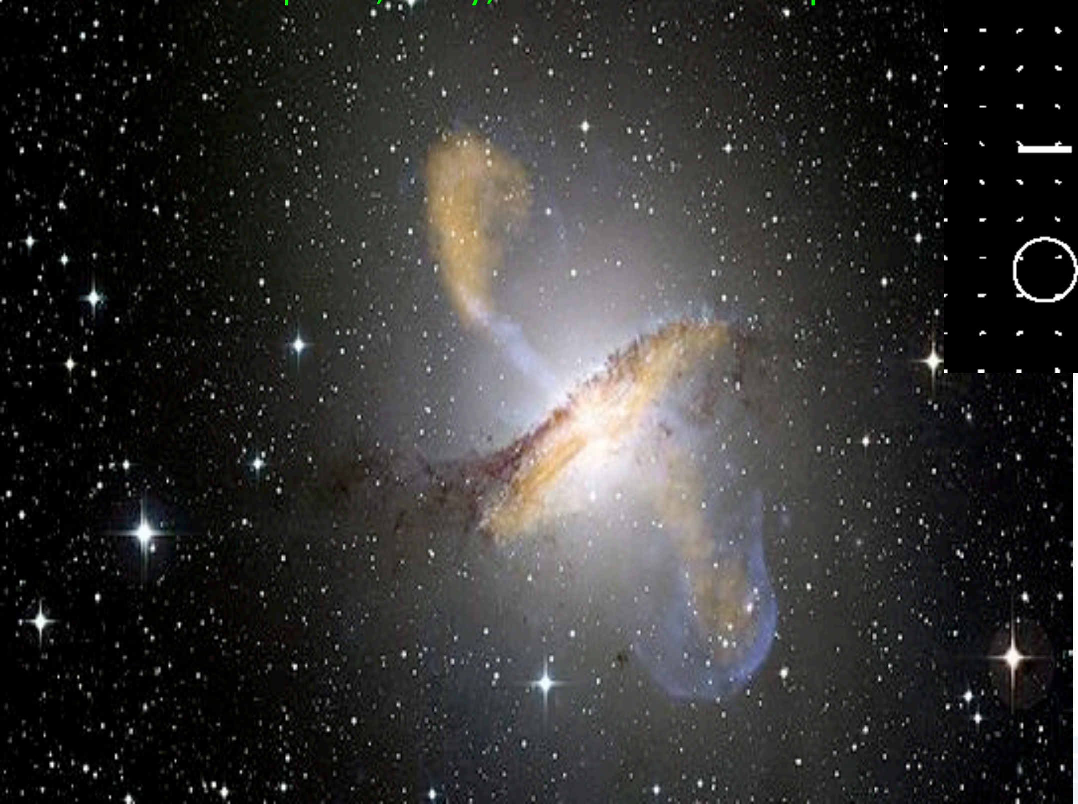


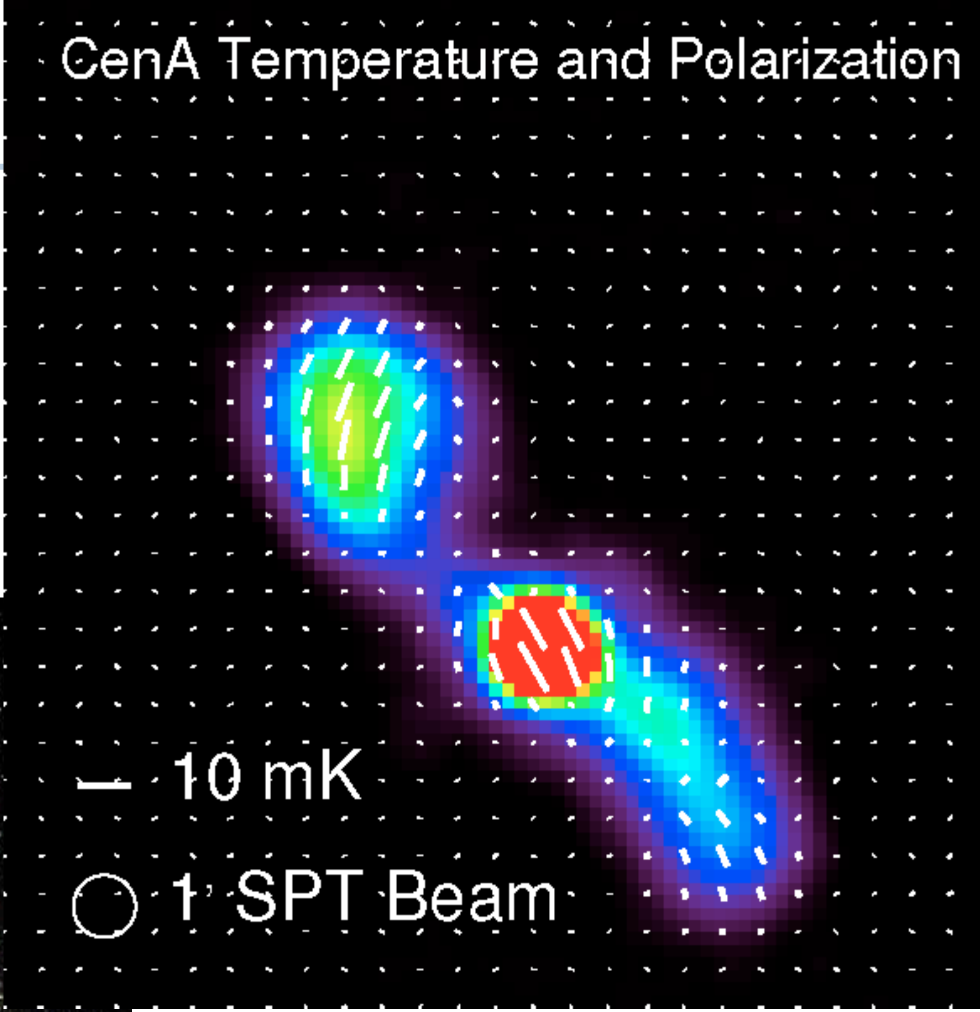


Data from commissioning

- Commissioning observations (40 mins) of highly polarized radio loud galaxy, CenA.

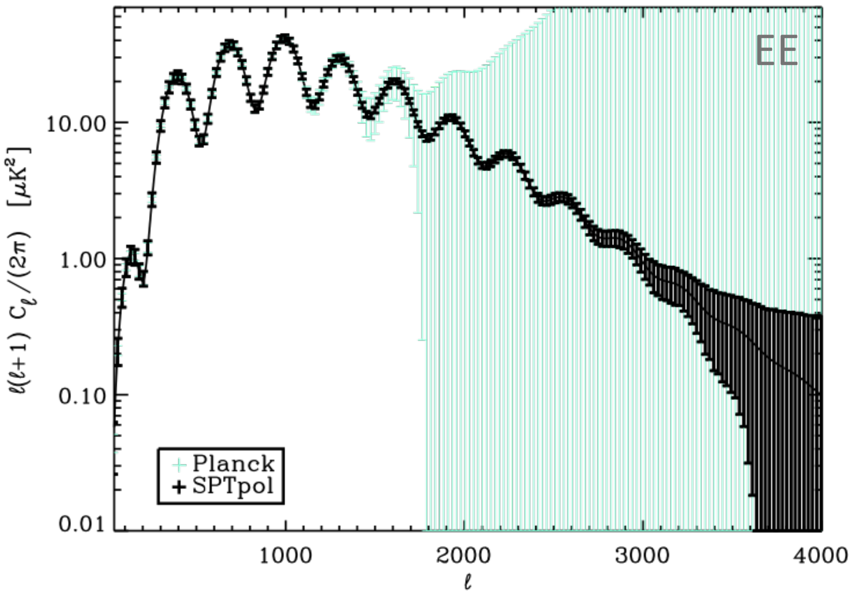
Centaurus A: Optical, X-ray, and sub-mm composite

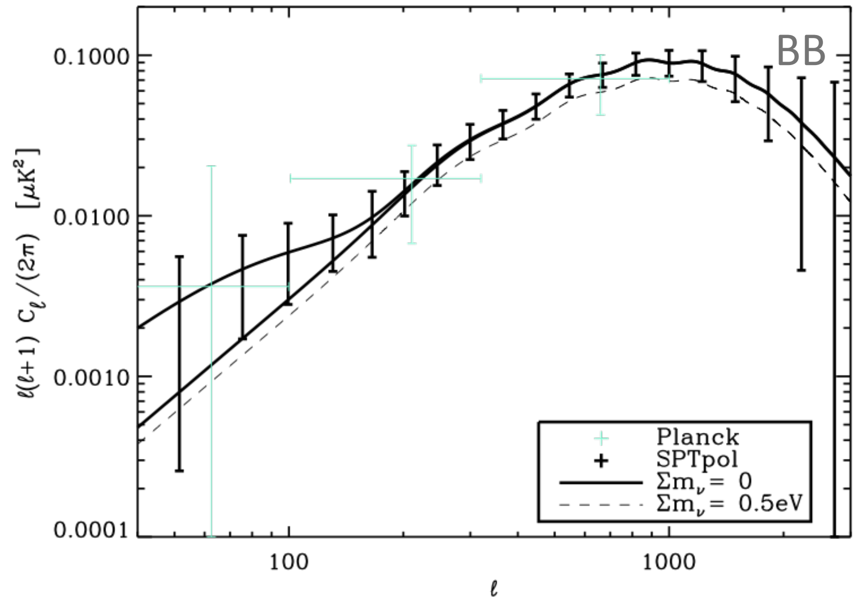




SPT-POL Polarization Map

SPTpol: Enabling and delivering new physics





Beyond SPT-SZE (& Planck):

- # neutrino-like species, N_{eff} (pol cross check)
- Σm_ν (pol cross check)
- Dark Energy, w
- Inflation (10^{16} GeV)

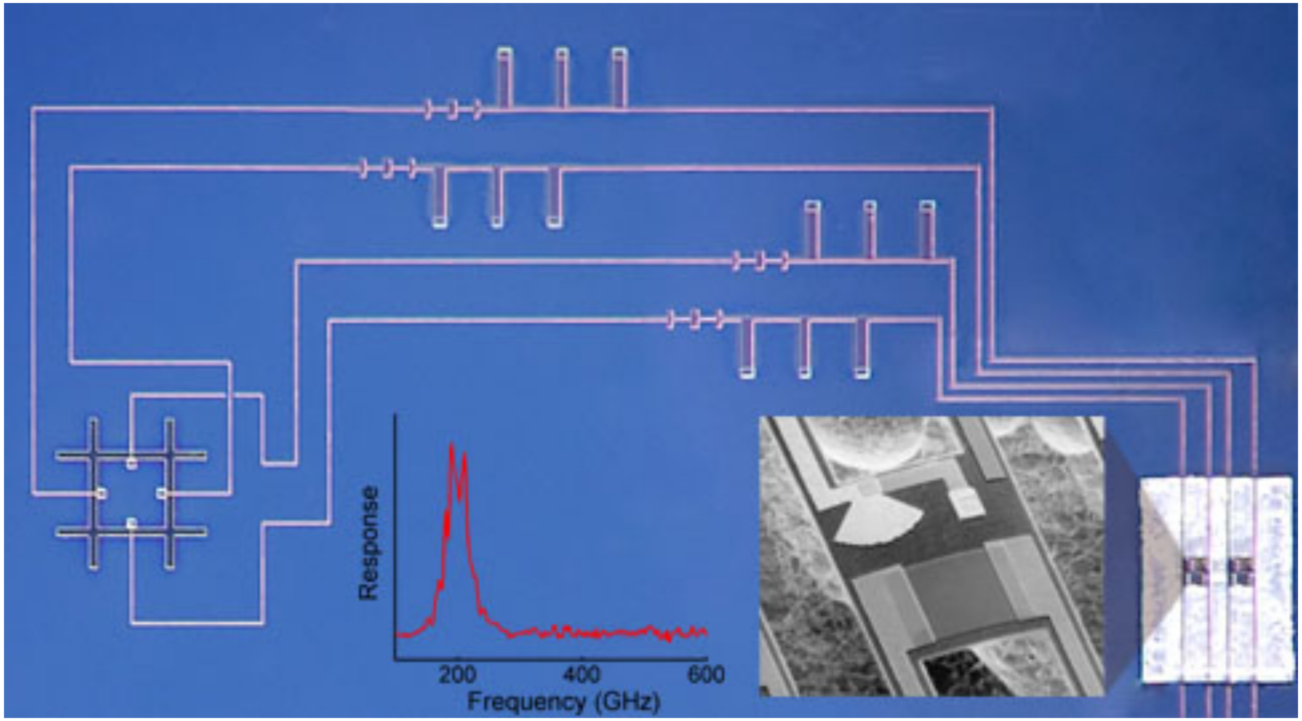
ANL delivered 90 GHz detectors. Targeting the first BB detection in 1 year!

Looking ahead: program funding

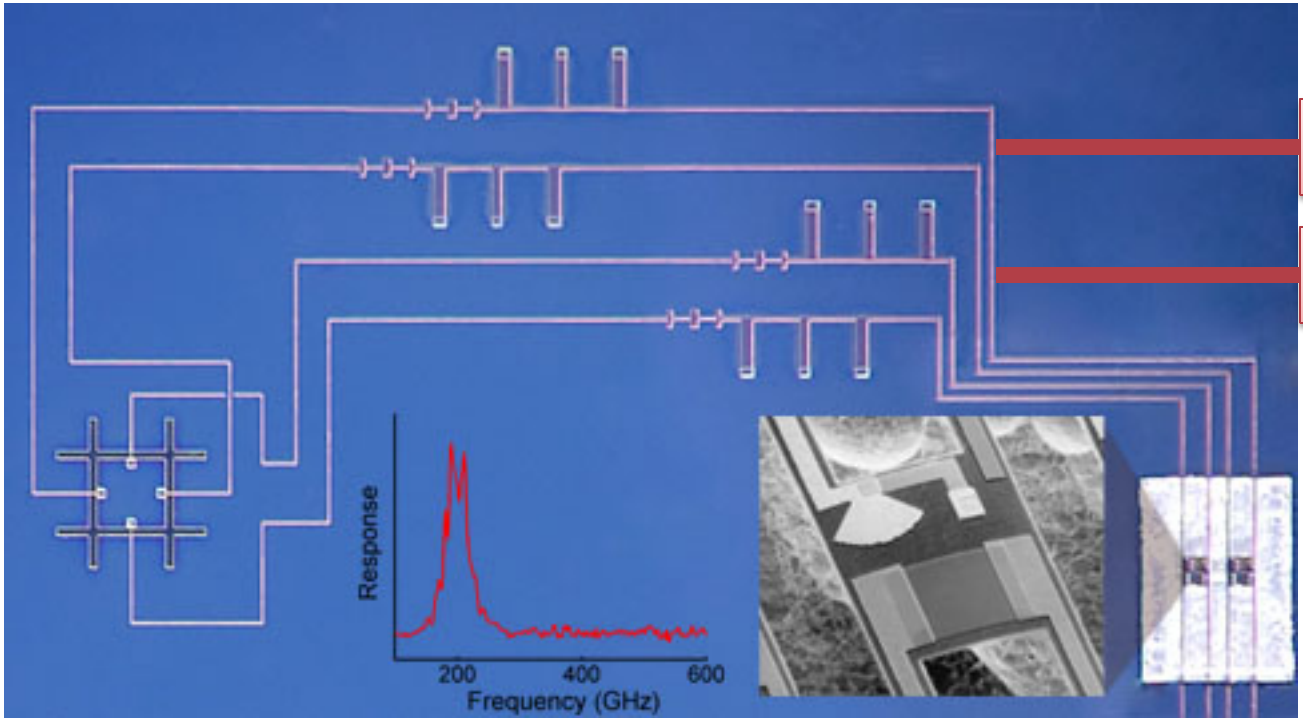
- CMB: Develop low-loss microstrip for mm-wave radiation coupling
- Dark Matter: Demonstrate proof-of-concept new TES multiplexer

- Leverages unique multi-disciplinary resources at ANL
  - MSD, CNM, HEP
- Strong history and collaborations with experts in the field
  - NIST, Berkeley, UC-Boulder, McGill, CWRU
- Local support
  - KICP Detector initiative (including Berkeley, ANL, JPL)
  - opportunities for launching/exporting technologies into science applications

CMB: Low-loss microstrip detectors



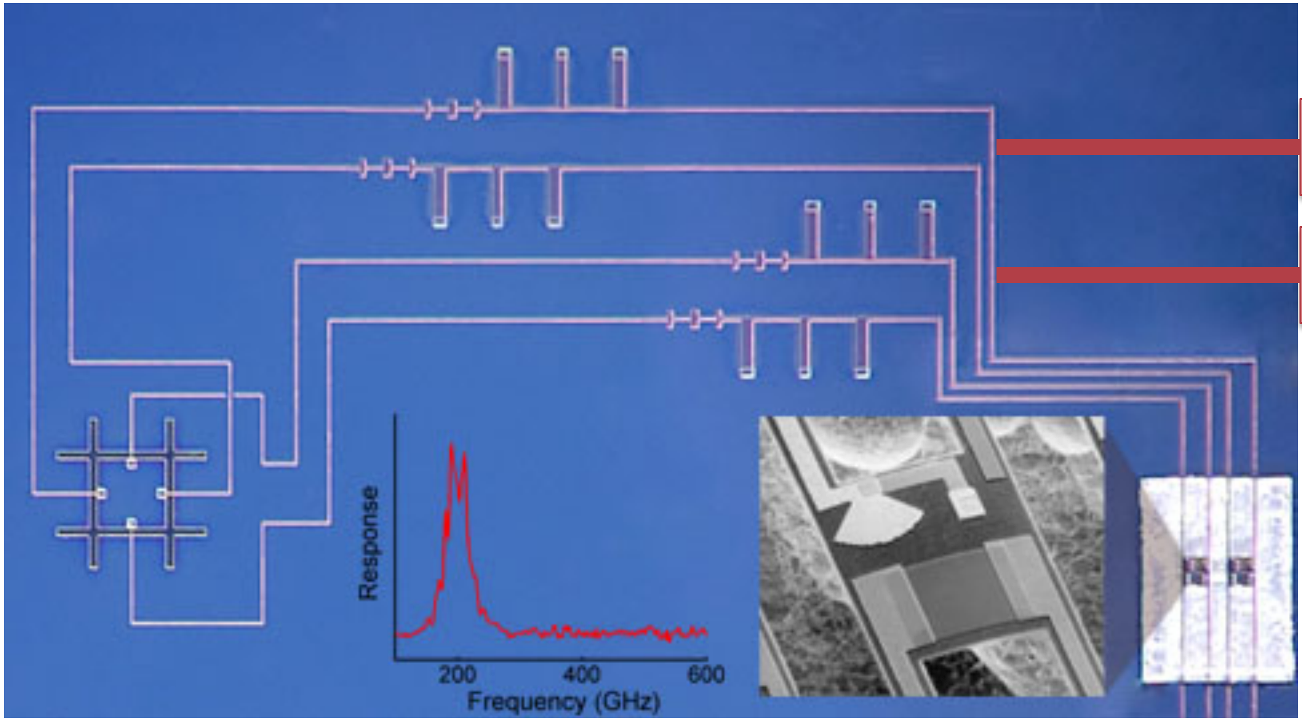
CMB: Low-loss microstrip detectors



Detector

Detector

CMB: Low-loss microstrip detectors



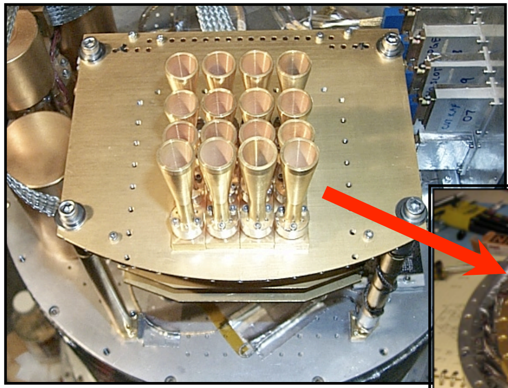
Detector

Detector

More detectors on one pixel

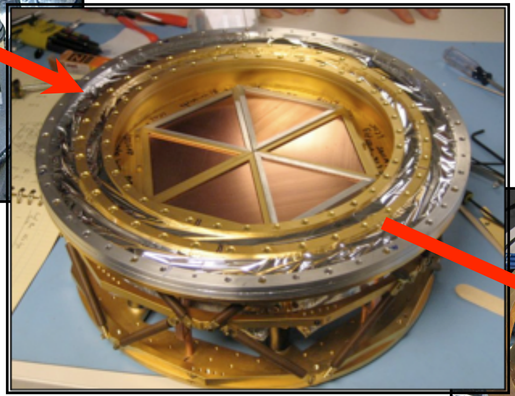
Impact: high-density focal plane arrays

2001: ACBAR
16 detectors

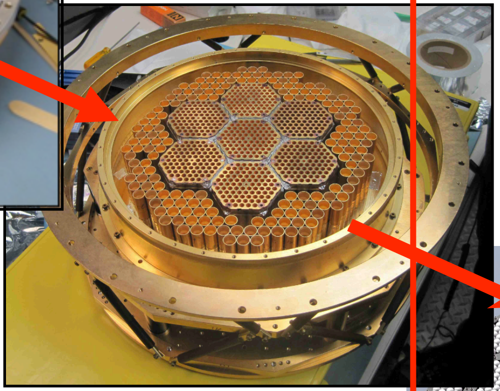


Detector performance governed by material properites

2007: SPT
960 detectors

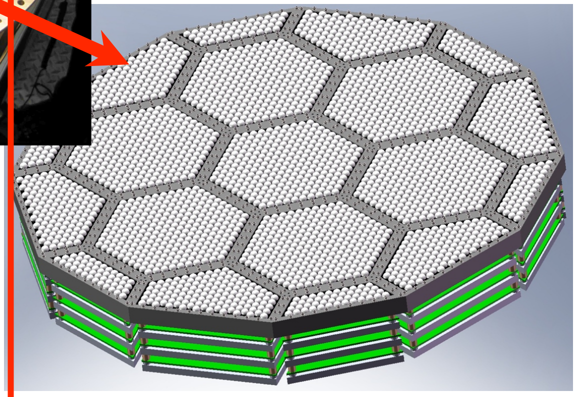


2012: SPTpol
~1600 detectors
+pol



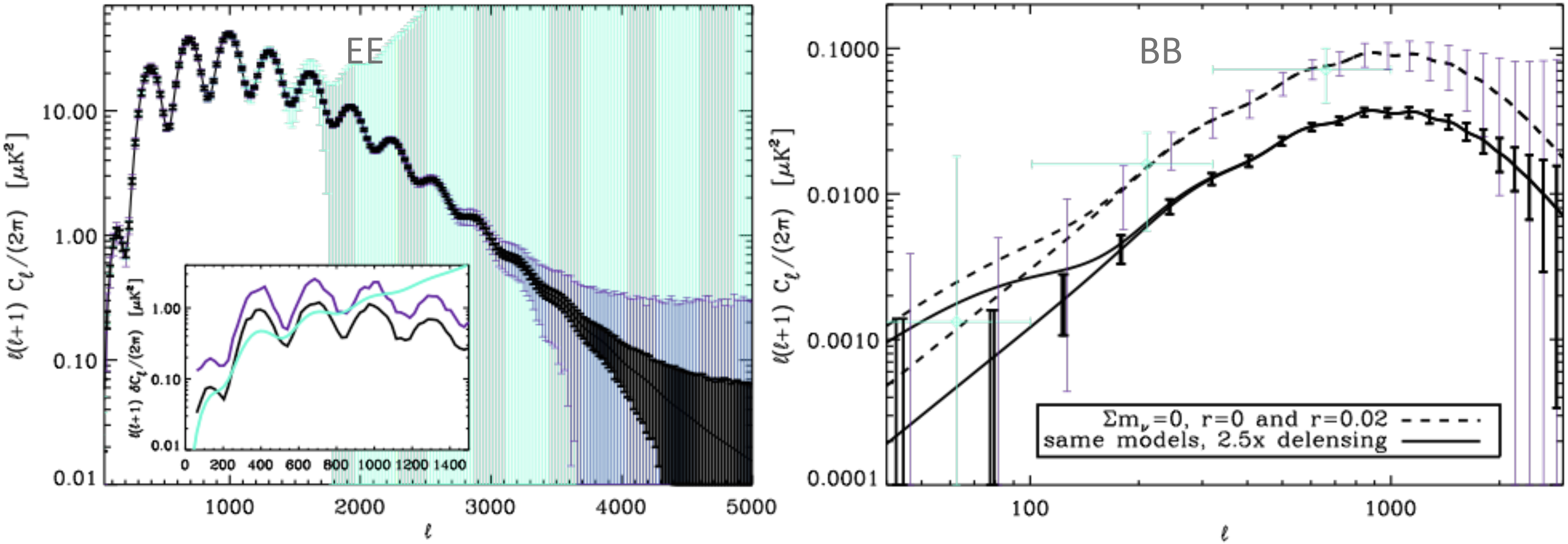
FY13-15 R&D

2016: SPT-3G
~15,200 detectors
+pol, multichroic



Requires high-throughput production

Impact: Beyond Planck (4 yrs w/ 3G)



Planck SPTpol **SPT-3G**

Dataset	$\sigma(N_{eff})$	$\sigma(\Sigma m_\nu)$	$\sigma(r)$
Planck	0.14	117 meV	0.06
+SPT-3G	0.076	74 meV*	0.01

*61 meV including BOSS

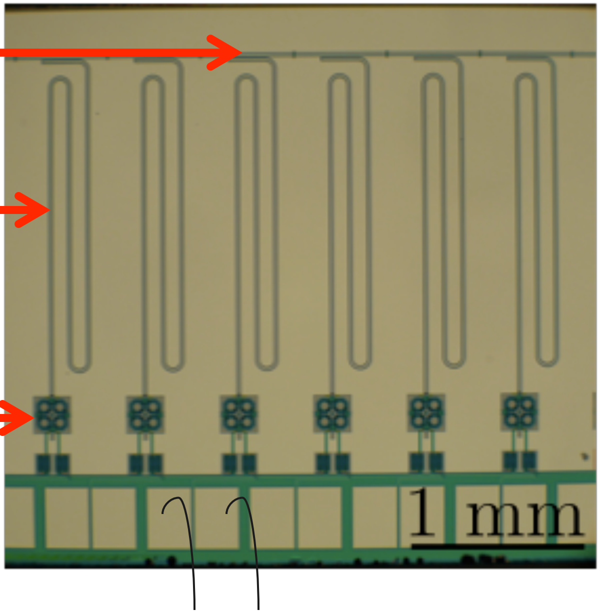
TES multiplexer on a chip

"Blue sky" multiplexer technology:

- New high speed digital electronics
- New superconducting resonators

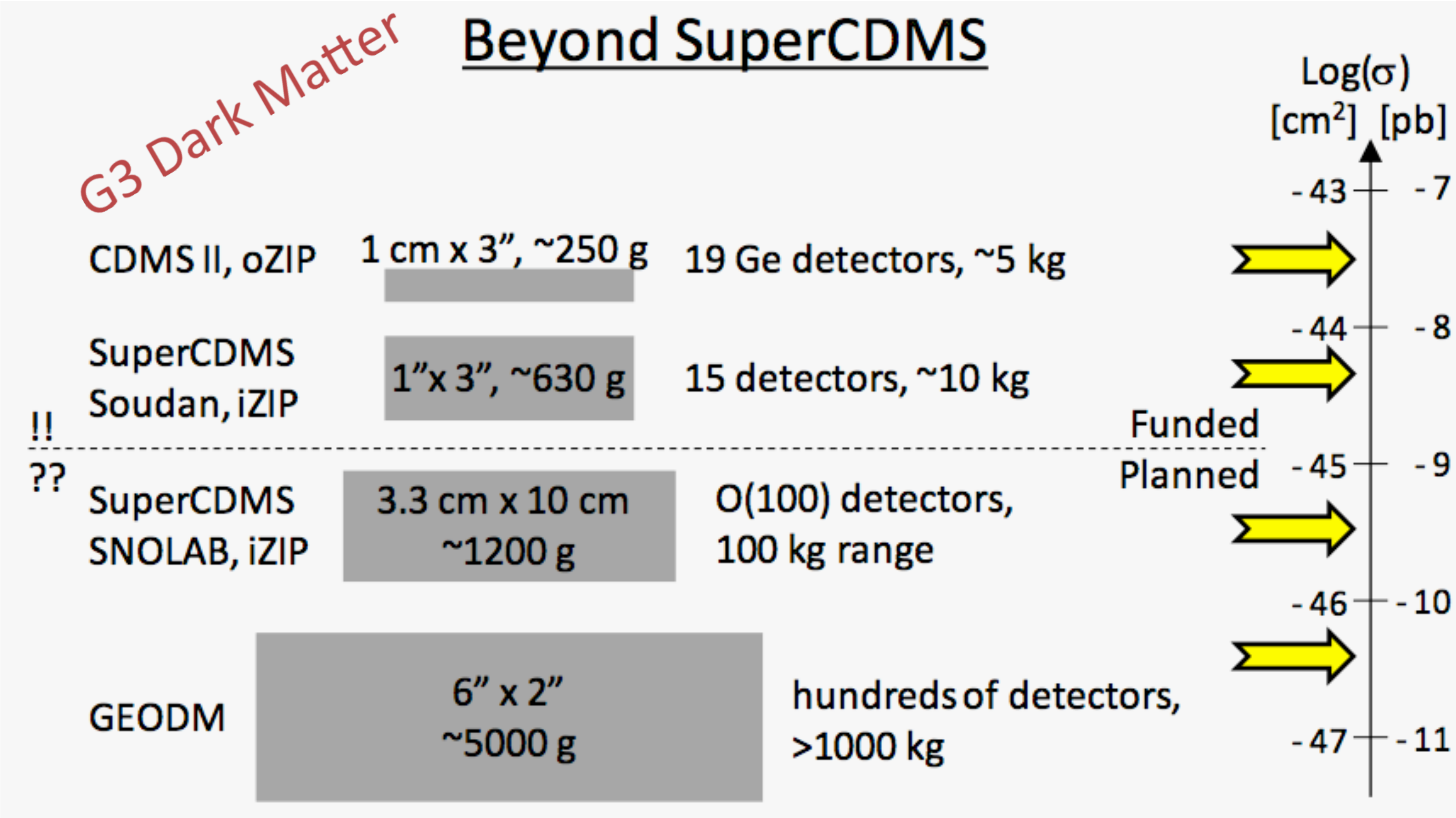
G3 DM Gateway technology:

- **1000s** of detectors on a single readout line
- **~1 MHz** of bandwidth (required for DM background rejection)



Different approach to tonne-scale DM

Working Technology	R&D
Scalable detector (eg: LAr)	Dark Matter detector?
Dark Matter detector (CDMS)	Scalable via Multiplexing



Multiplexer scales from SuperCDMS SNOLAB (G2) to tonne-scale GEODM (G3)

From idea to "instrument ready"

- Mm-wave bolometers
- Optical/IR spectrophotometers
- X-ray microcalorimeters
- Gamma-ray spectrometers
- Alpha calorimete
- Heavy ion/parti detectors
- Etc…

History of inno

Unique ANL resources
- MSD
- CNM

TES Array Technology

TES expertise
- Expert collaborators
- Development history

Scientific connections
- ANL
- KICP
- FNAL

Science potential

- CMB
- Dark Matter
- Beta decay
- Synchrotron Light Source
- Nuclear Non-proliferation
- on Physics
- ecurity
- nformation
- s & Astronomy

Summary

Capability Gap

Take from ideas to "instrument ready" technology

- Global TES R&D effort w/ strong history
- Broadly applicable
- Lots of good ideas ready to move to the next step

Approach

Unique resources & relationships

- Multi-disciplinary resources via MSD, CNM, HEP
- Strong collaborative structure w/ TES experts (KICP Detector initiative)
- Significant scientific interest at ANL, FNAL, and UofC (both HEP and beyond)
- History of successful delivery

Benefit

CMB beyond WMAP (& Planck)

- N_{eff} : # neutrino-like species
- Σm_{ν} : energy scale of neutrino mass
- w: Dark Energy equation of state (growth based)
- r: Inflation (unique window into 10^{16} GeV physics)

Ton-scale Cryogenic Dark Matter experiment

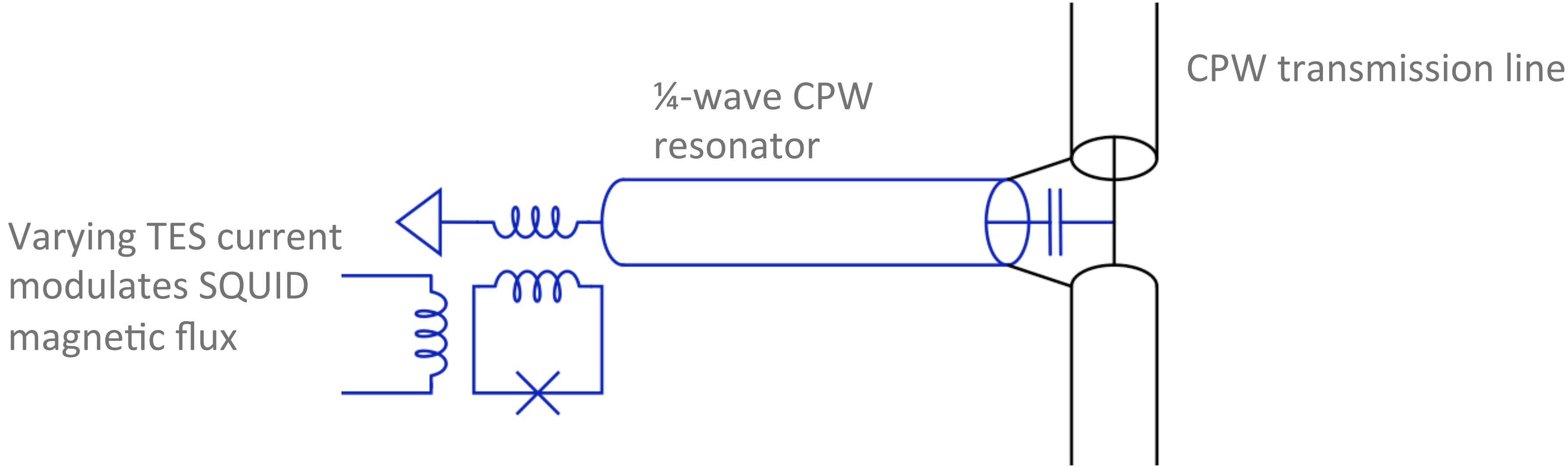
Technology relevant outside of HEP

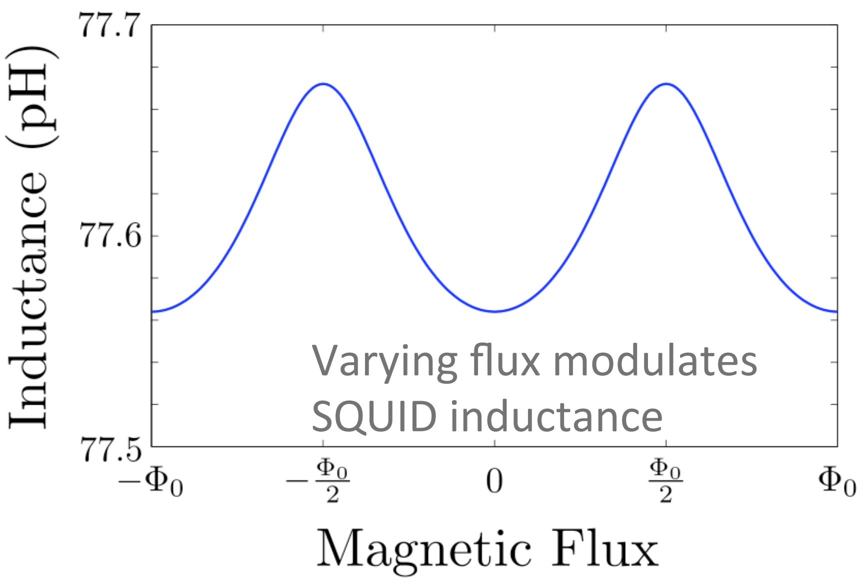
Results and Deliverables

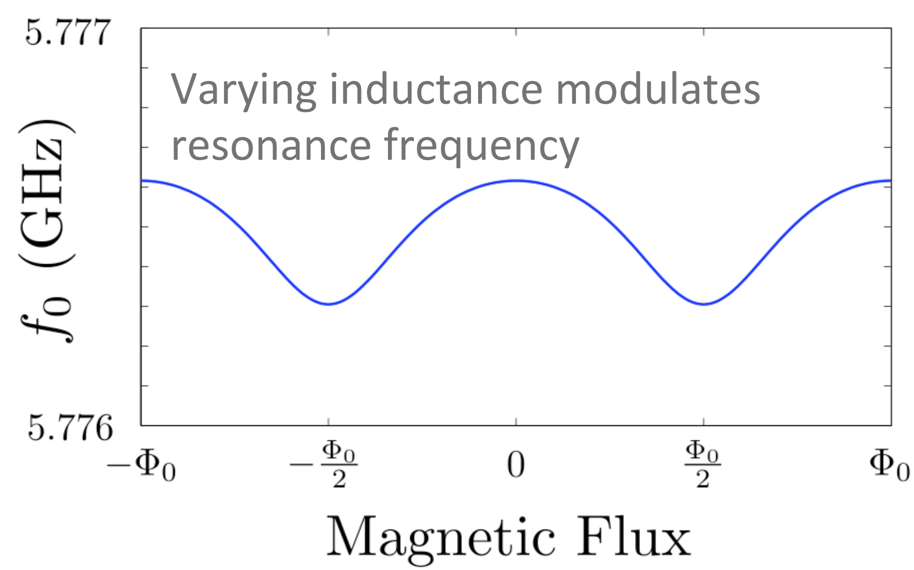
- Develop low loss microstrip technology for array fabrication
- Demonstrate proof-of-concept multiplexer

Extra slides

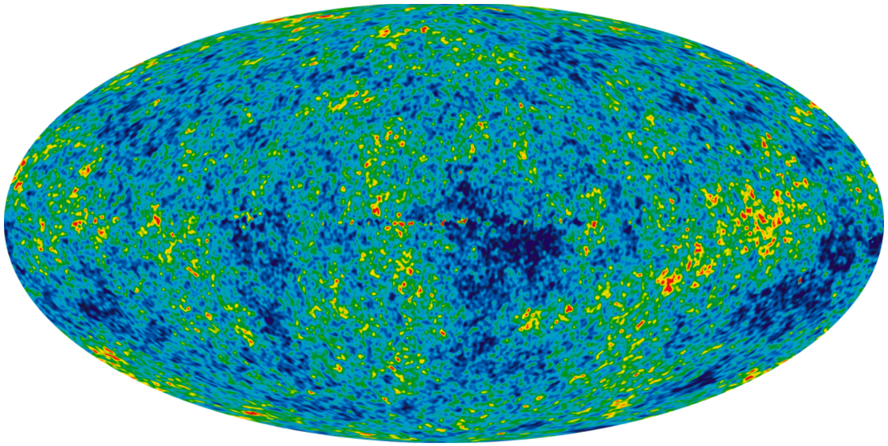
MUX: SQUID coupled microwave resonators

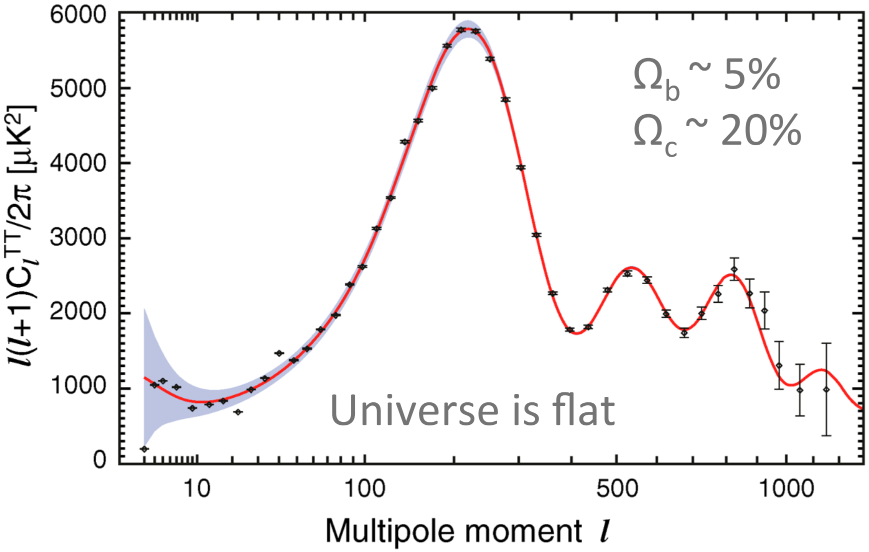






Frontier of CMB





well understood physics permits accurate calculation of features

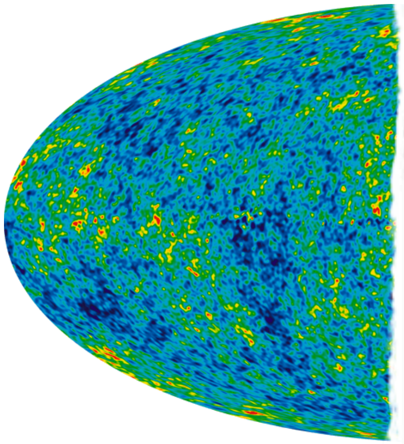
Depends on energy density and expansion during the early Universe

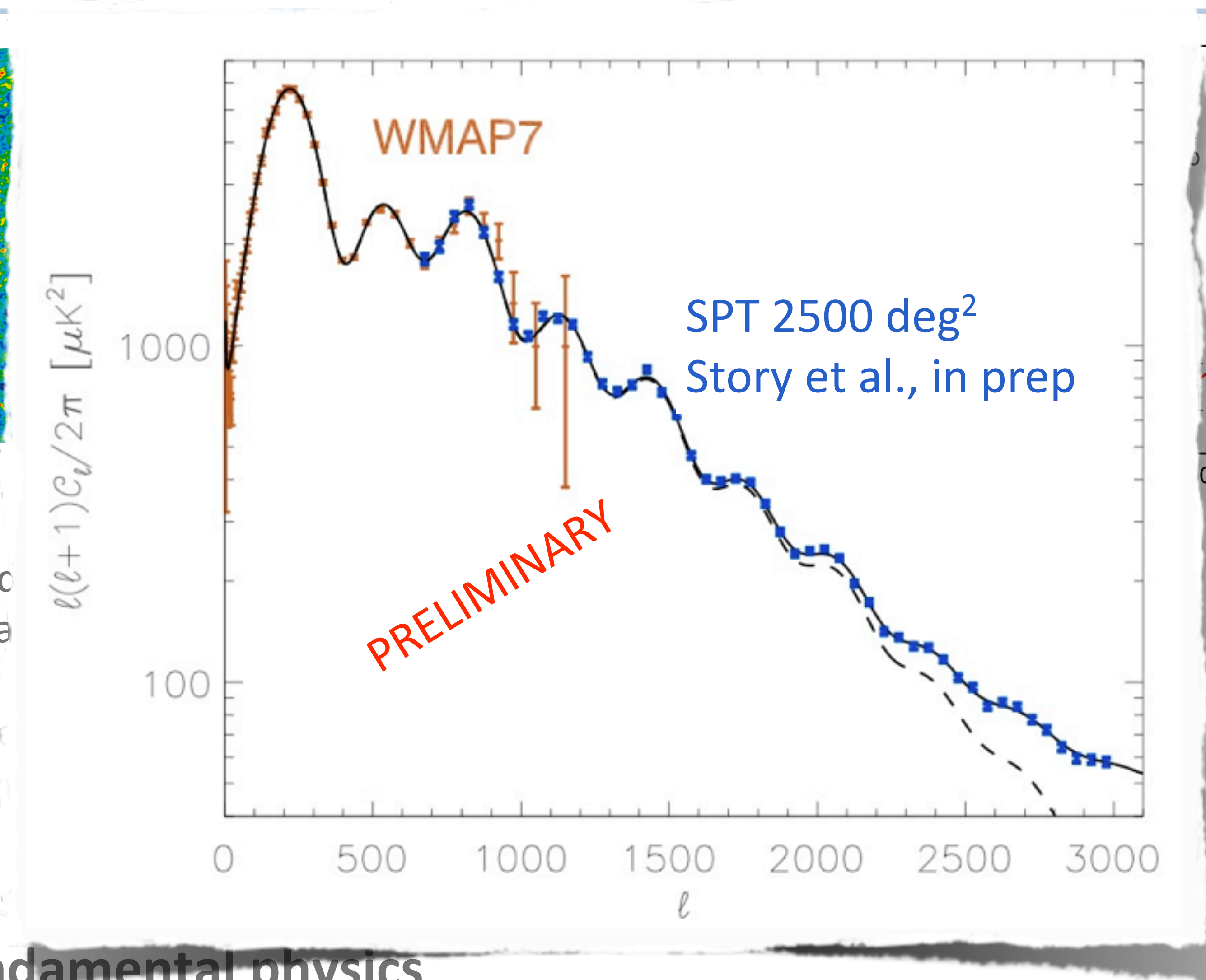
Better measurements explore fundamental physics

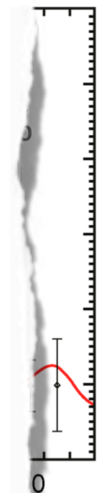
Beyond WMAP:

- N_{eff}
- Σm_ν
- Dark Energy, w
- Inflation & GUT scale physics

Frontier of CMB







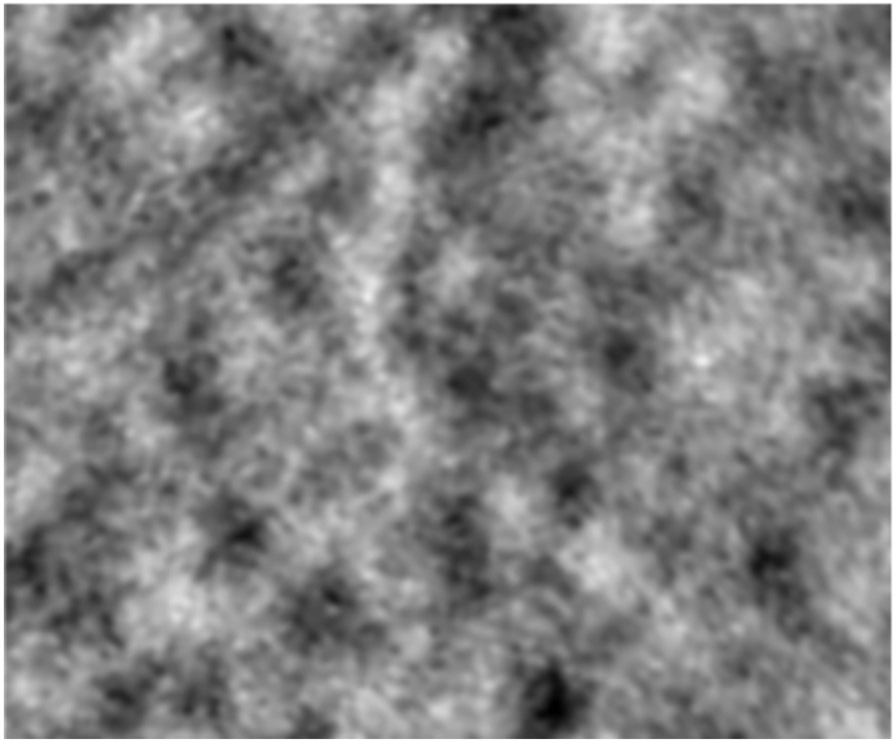
well understood
accurate calcula

Depends on en
expansion durin

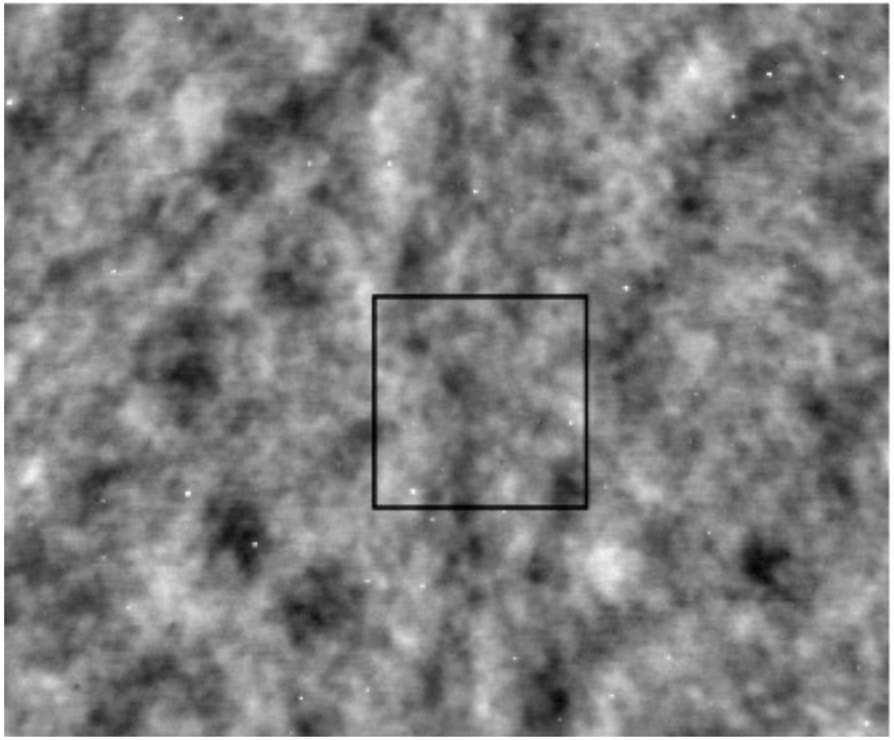
Better meas **sics**
explore fundamental physics

CMB ca. today (150 deg^2 of WMAP vs SPT)

WMAP



SPT



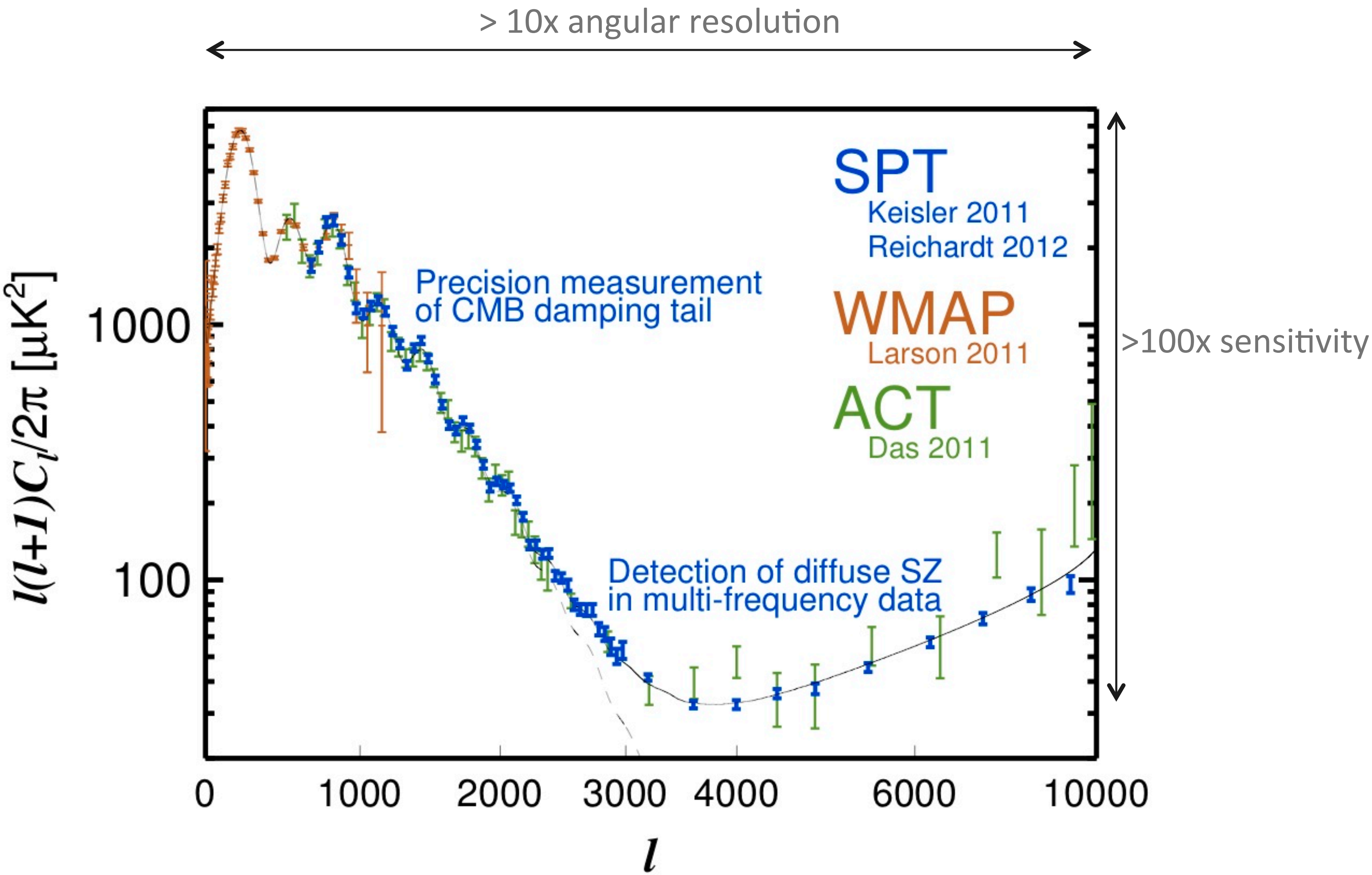
13x resolution and 17x deeper than WMAP

5x higher resolution and 3x deeper than Planck blue book

Shows structure from degrees to arc minutes:

from large-scale CMB to SZ & unresolved sources.

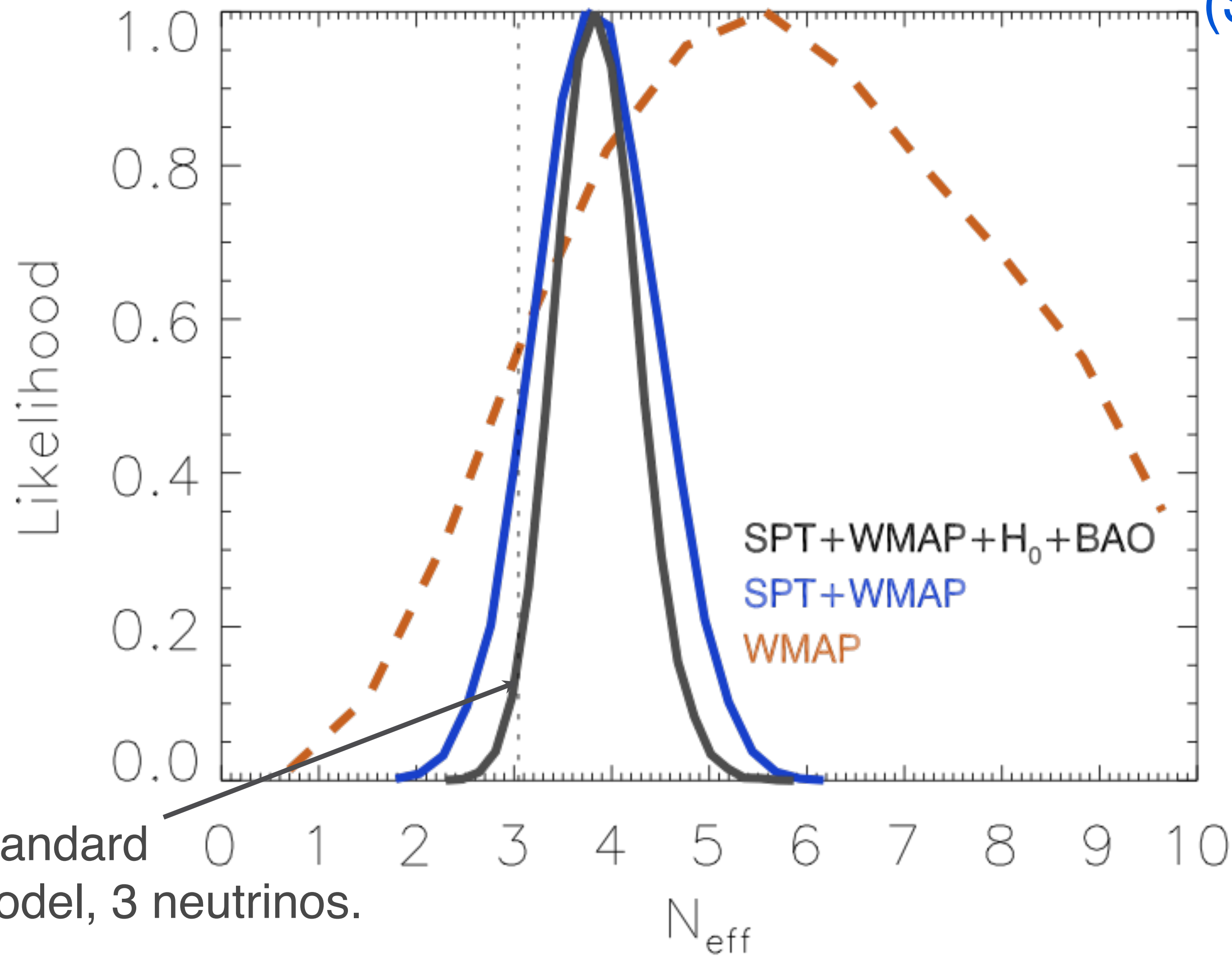
Increased sensitivity and resolution



Primordial relativistic degrees of freedom

Keisler et al 2011, ApJ, 743, 28

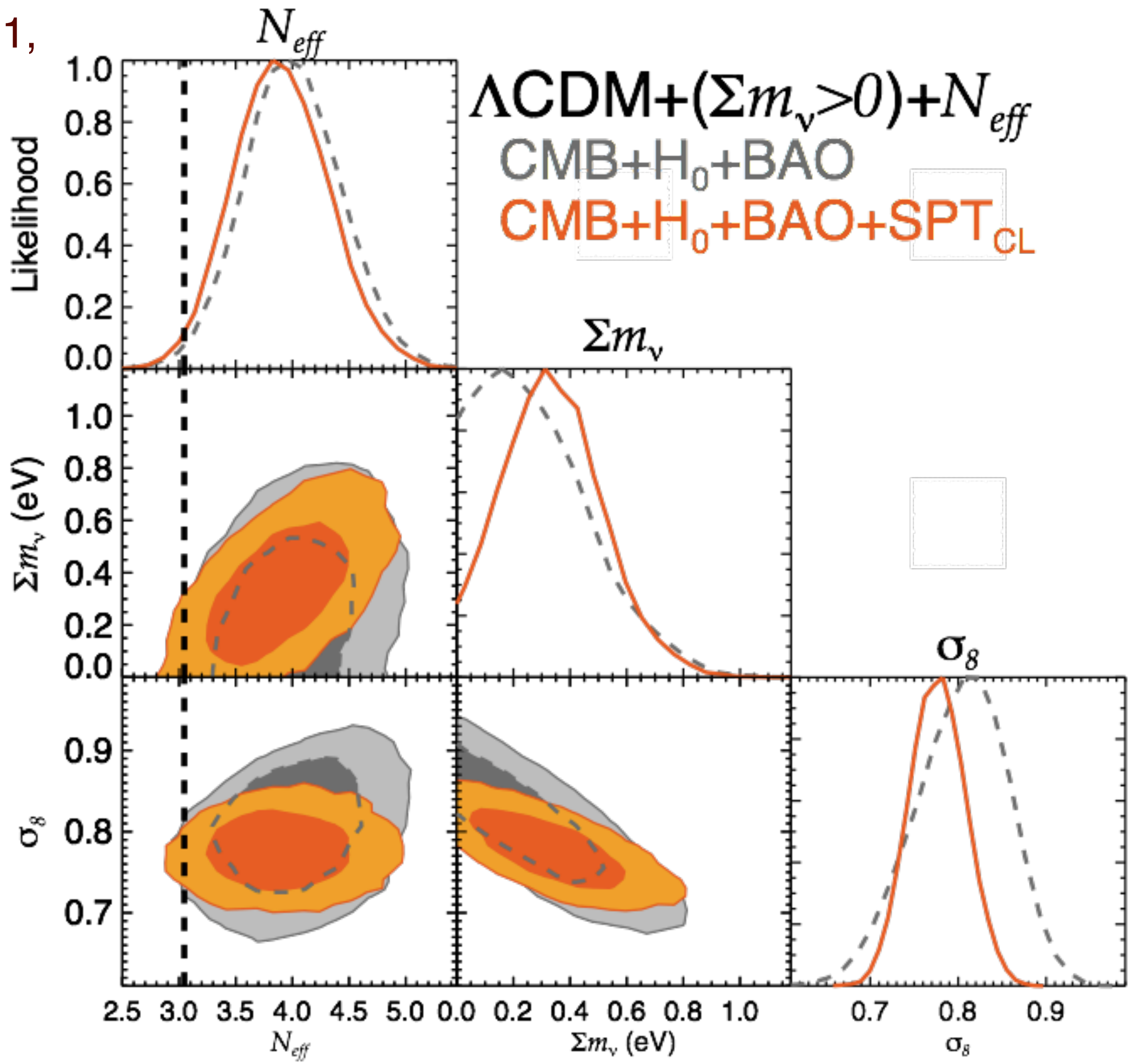
$N_{\mathrm{eff}} = \mathbf{3.86 \pm 0.42}$
(SPT+WMAP
+H_0+BAO)



Standard
Model, 3 neutrinos.

Measuring neutrino mass

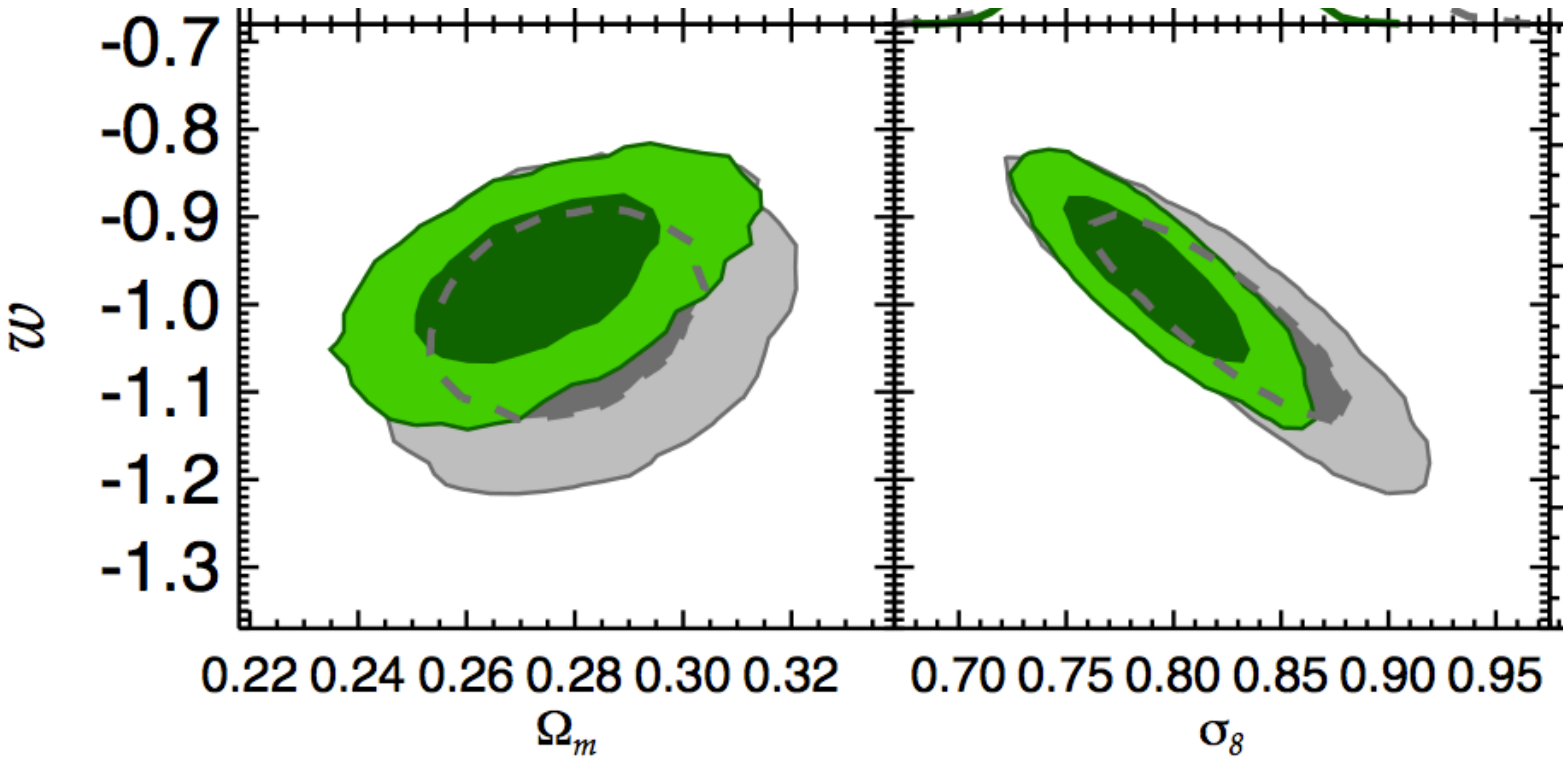
Benson et al 2011,
arXiv: 1112.5435



Probing Dark Energy

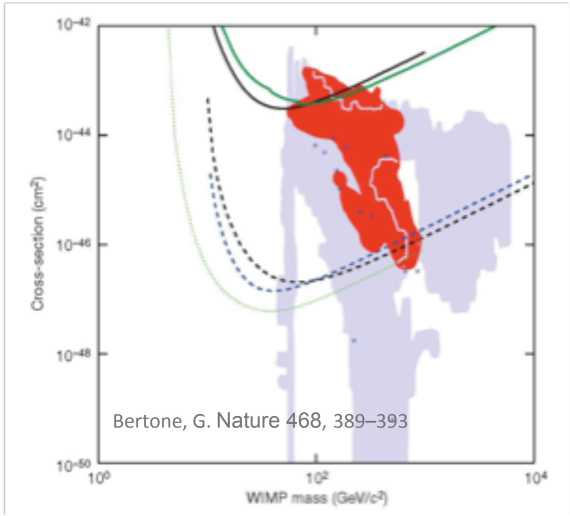
Benson et al 2011,
arXiv: 1112.5435

w= -0.97 +/- 0.06



wCDM
CMB+BAO+SNe
CMB+BAO+SNe+SPT_{CL}

1 ton cryogenic Dark Matter detector?



- Current MUX operate at 300 kHz - 2 MHz
  - 1 ms resolution per channel
- Develop high frequency MUX at 1-10 GHz
  - 1 µs per channel
  - High speed digital electronics + superconducting microwave resonators
  - Required for background rejection
- Makes existing SuperCDMS detector technology scalable to 1-ton