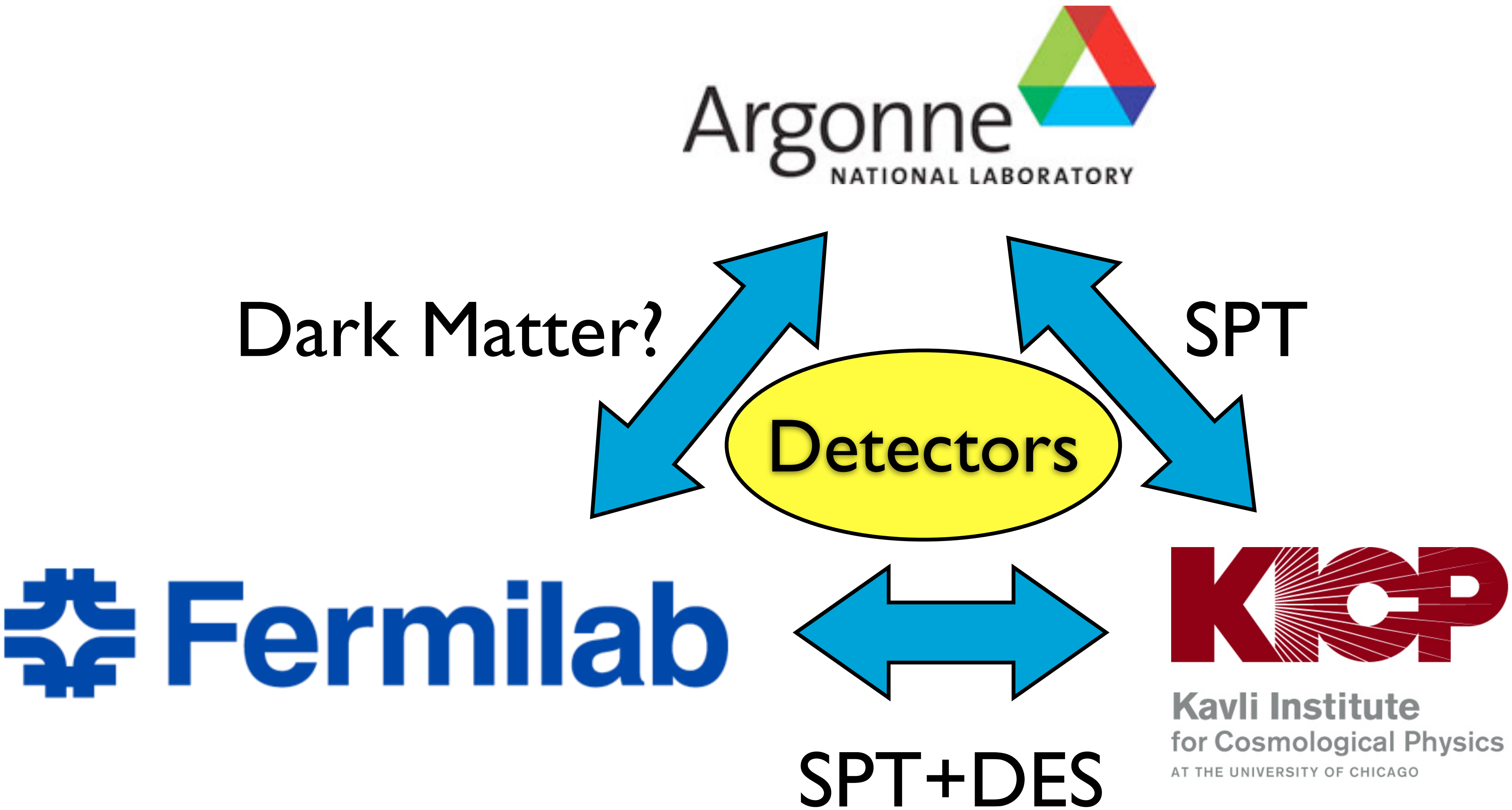
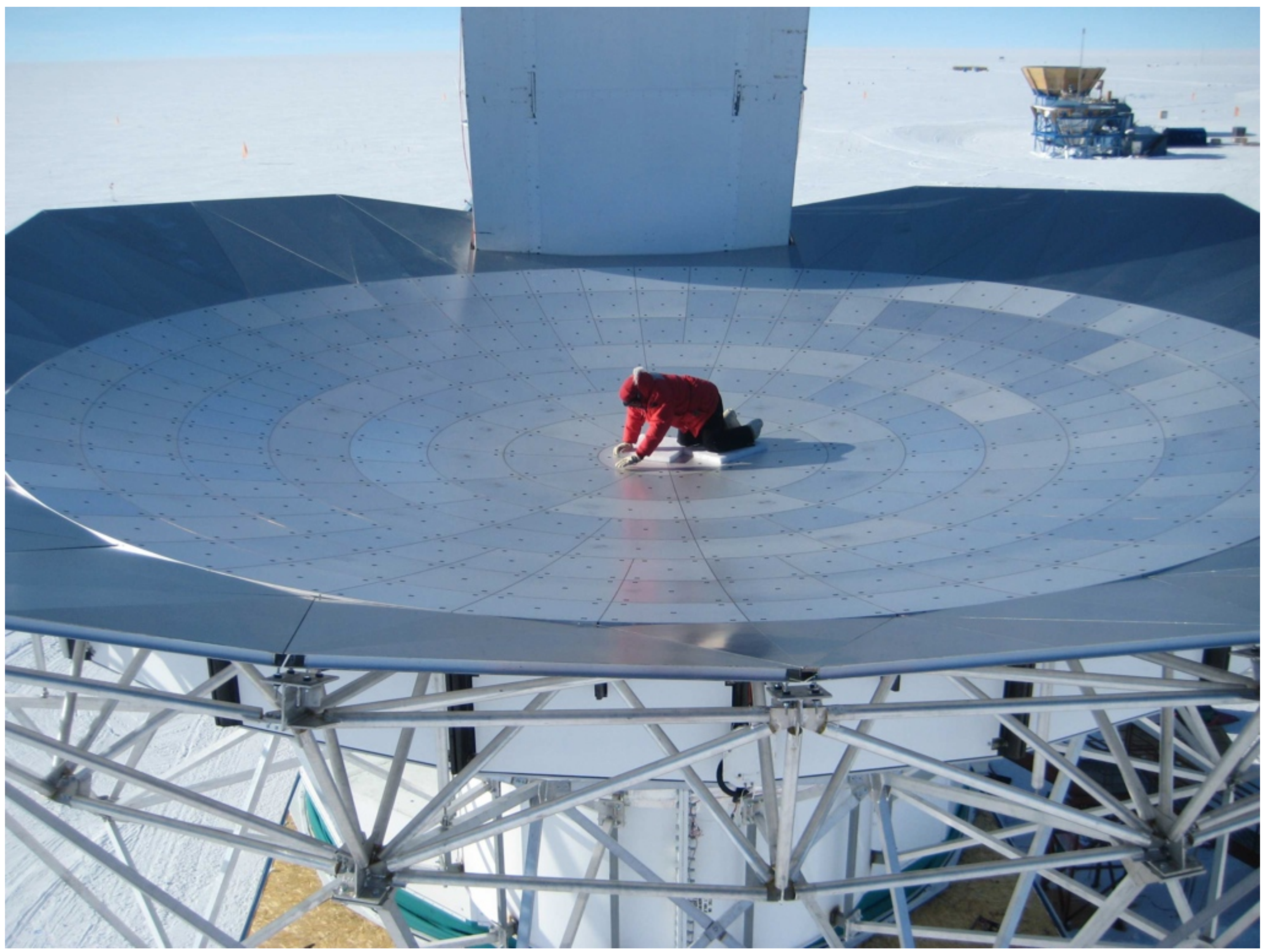
CMB and Dark Matter Detector initiatives at ANL

Clarence Chang
FCPA/KICP/ANL Retreat
June 5, 2012
Fermilab – Kuehn Barn

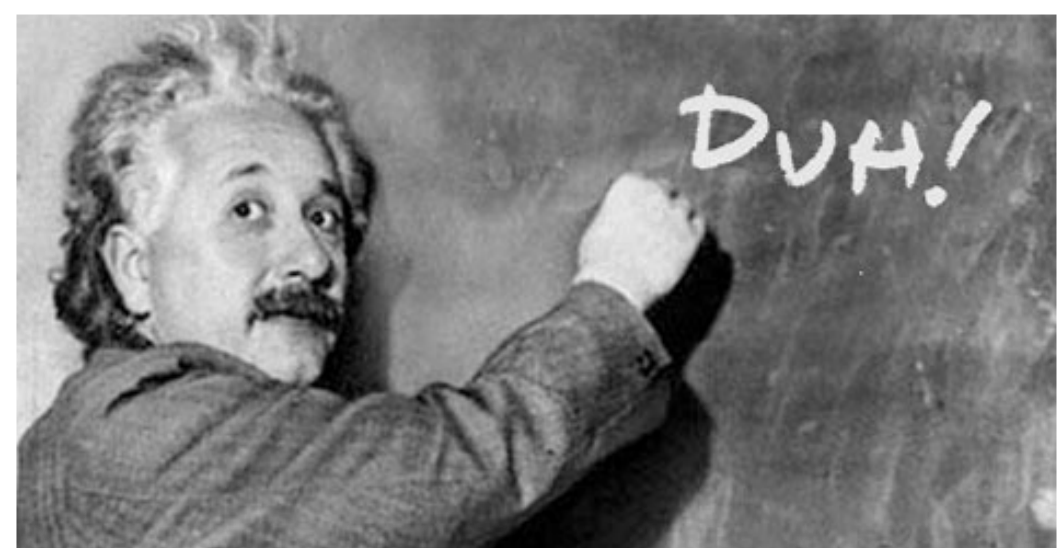

Argonne
NATIONAL LABORATORY
Dark Matter?
SPT
Detectors
Fermilab
KICP
Kavli Institute
for Cosmological Physics
AT THE UNIVERSITY OF CHICAGO
SPT+DES

The South Pole Telescope

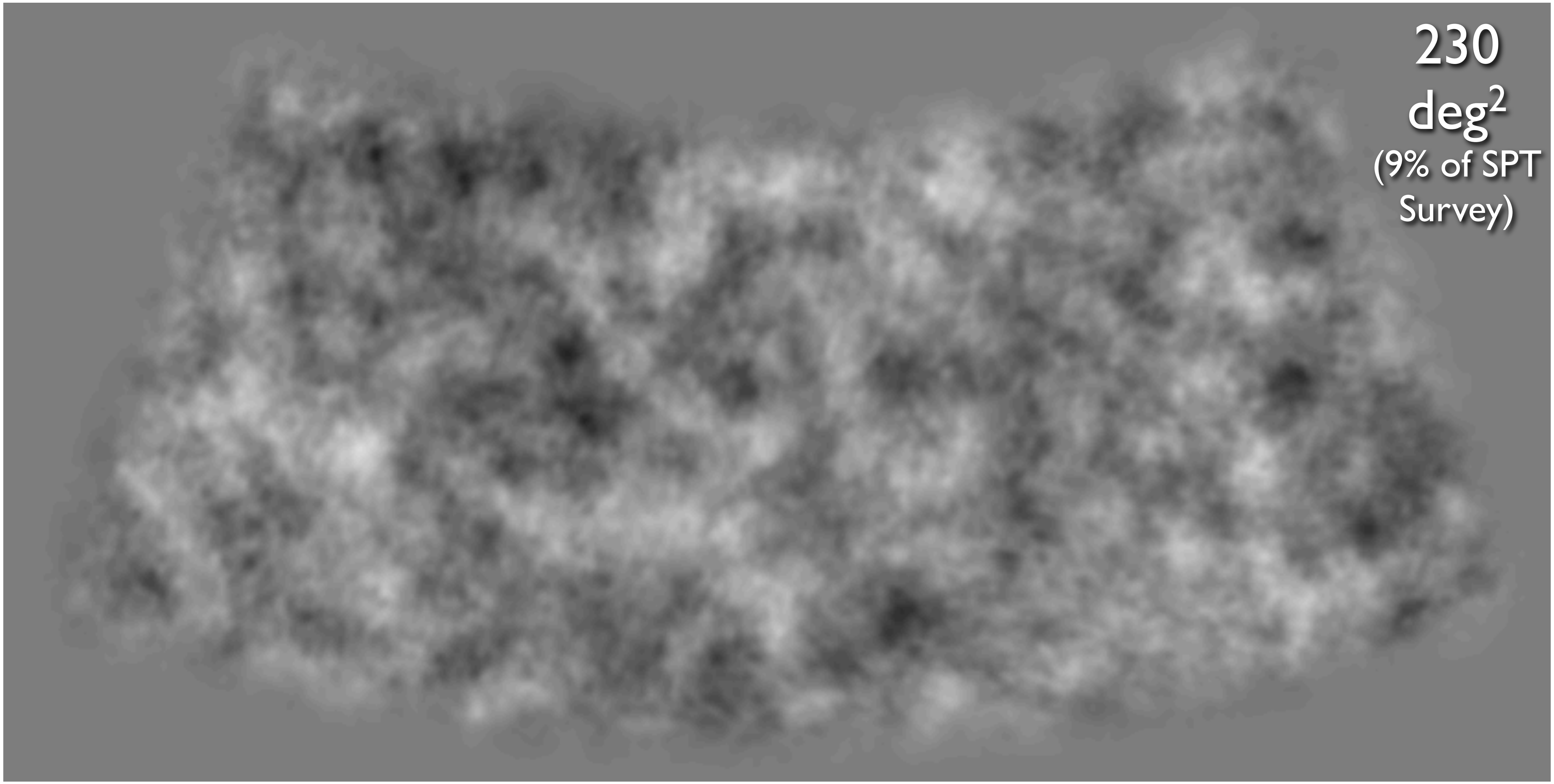
10-m dish gives 1-arcmin resolution at 2 mm



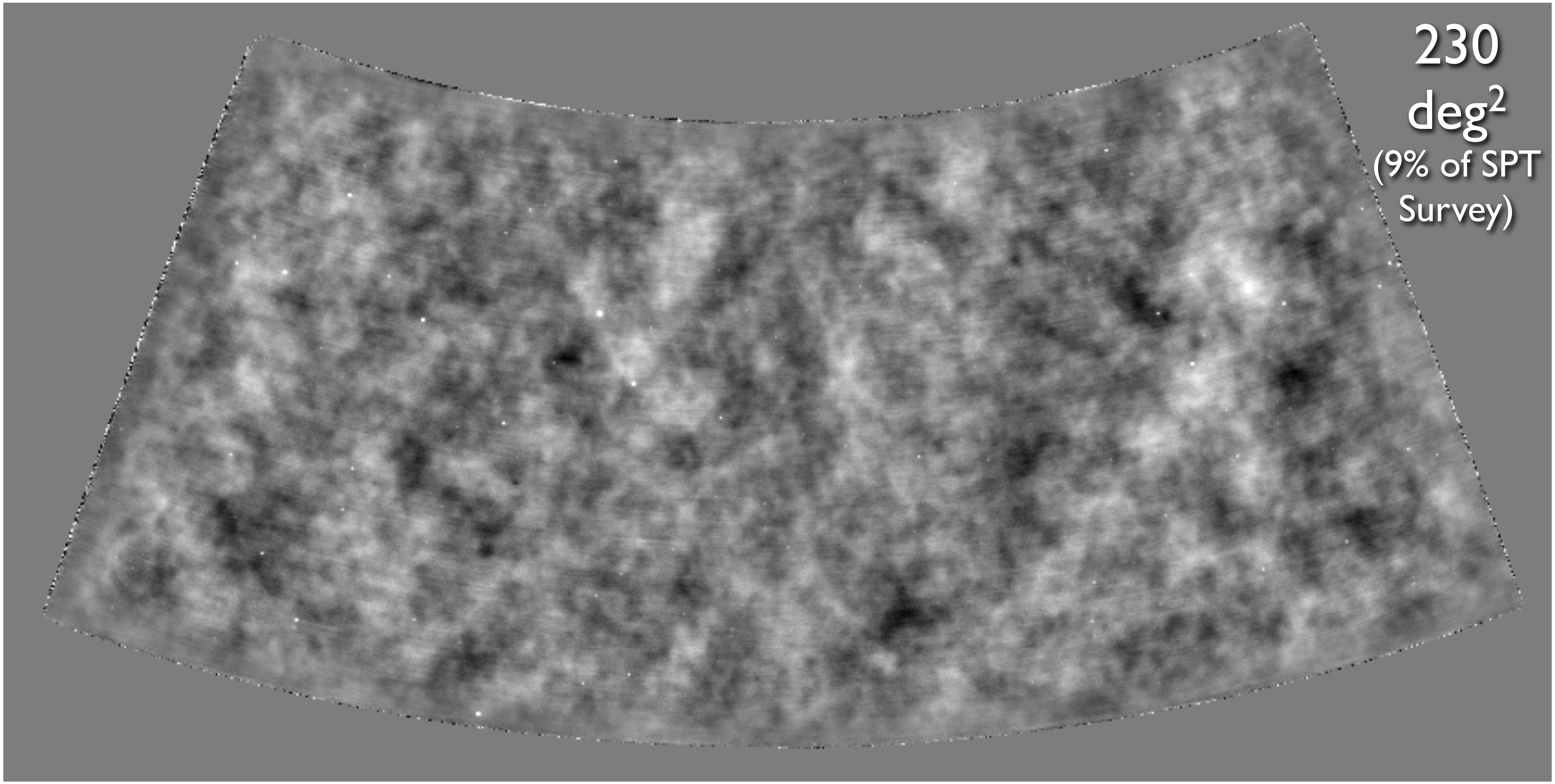
Located at the South Pole



WMAP



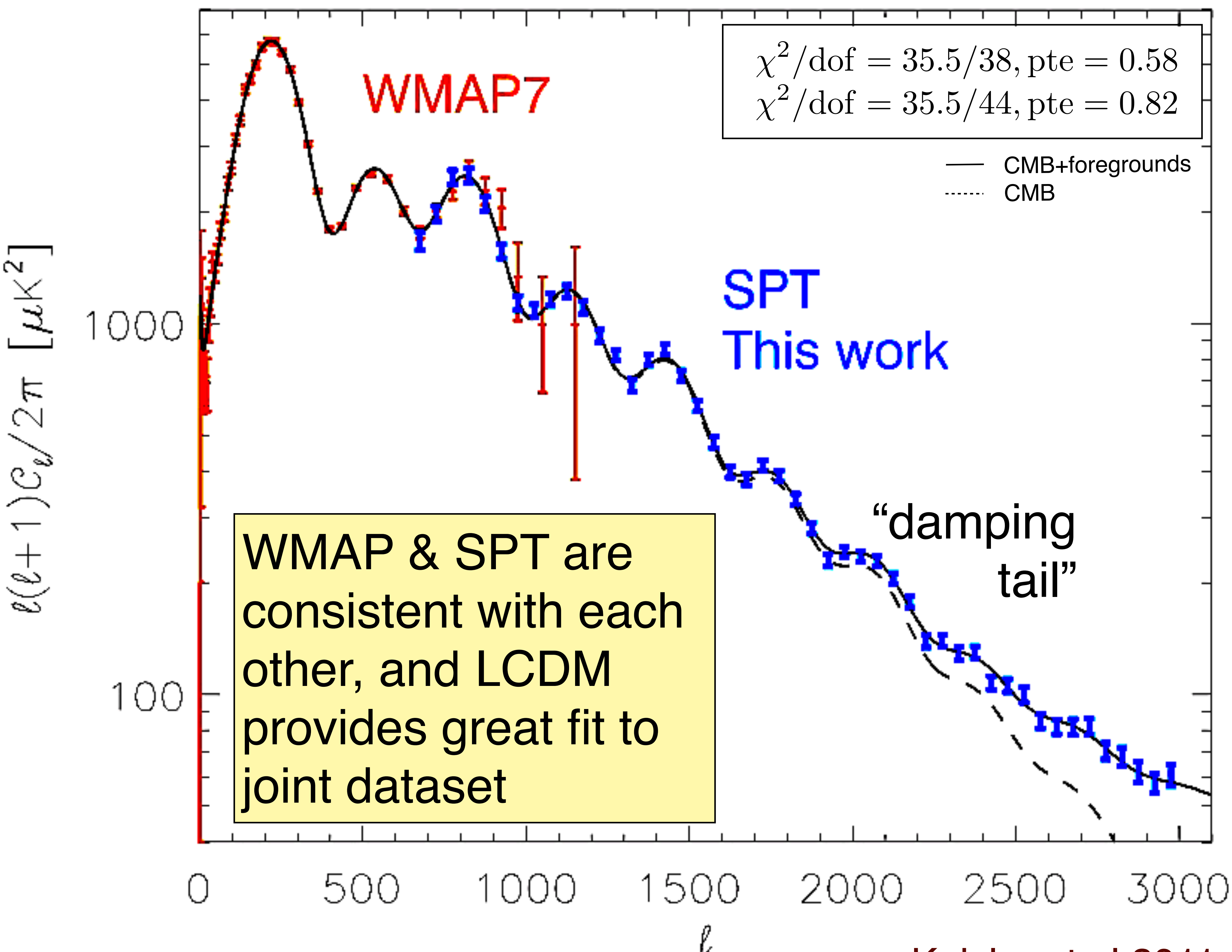
SPT



13x smaller beam (13' vs 1')

17x deeper (300 uK-arcmin vs 18 uK-arcmin)

CMB Power Spectrum: WMAP and SPT



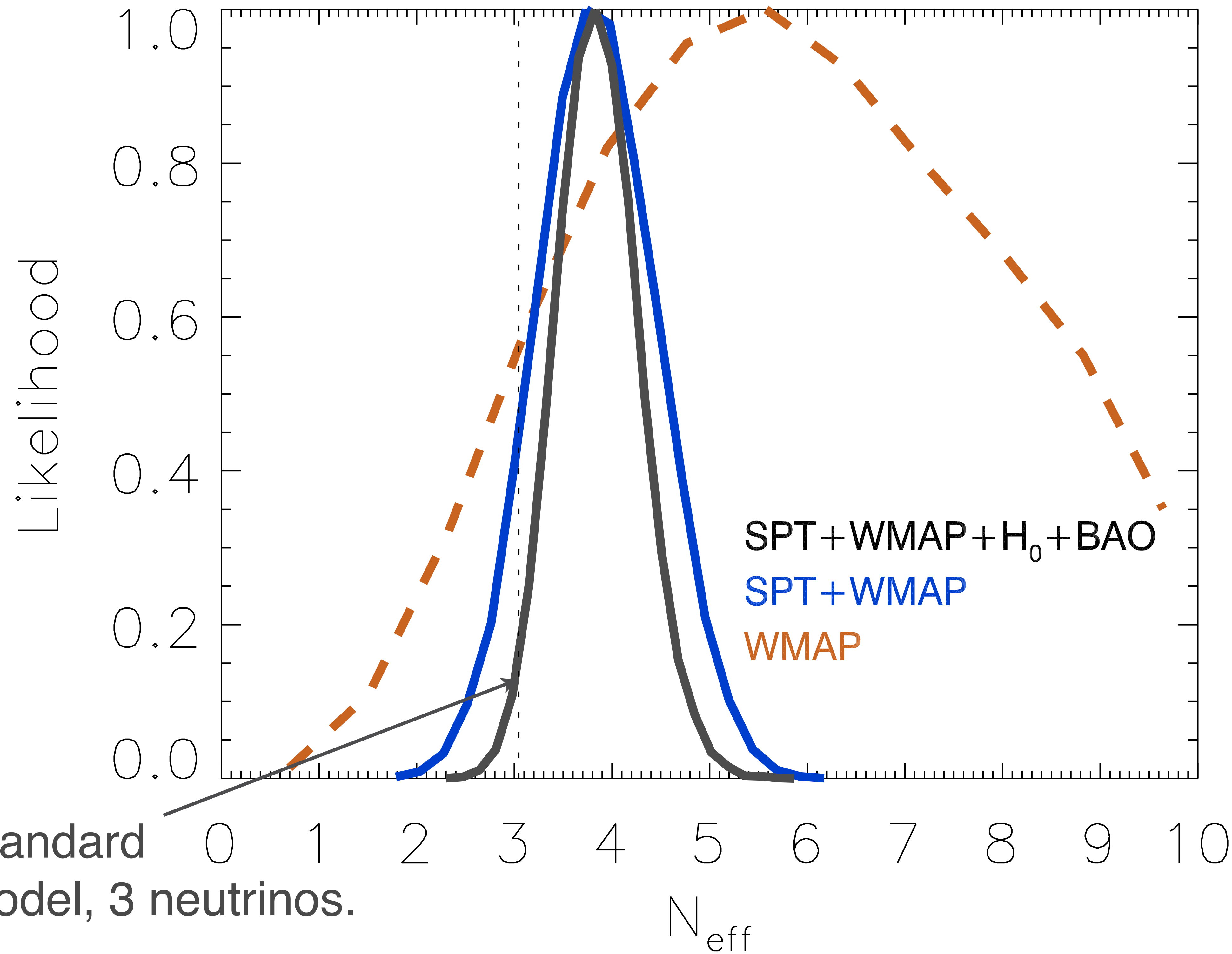
WMAP & SPT are consistent with each other, and LCDM provides great fit to joint dataset

Keisler et al 2011, ApJ, 743, 28

Science Highlight 1:
Searching for new particles

Keisler et al 2011, ApJ, 743, 28

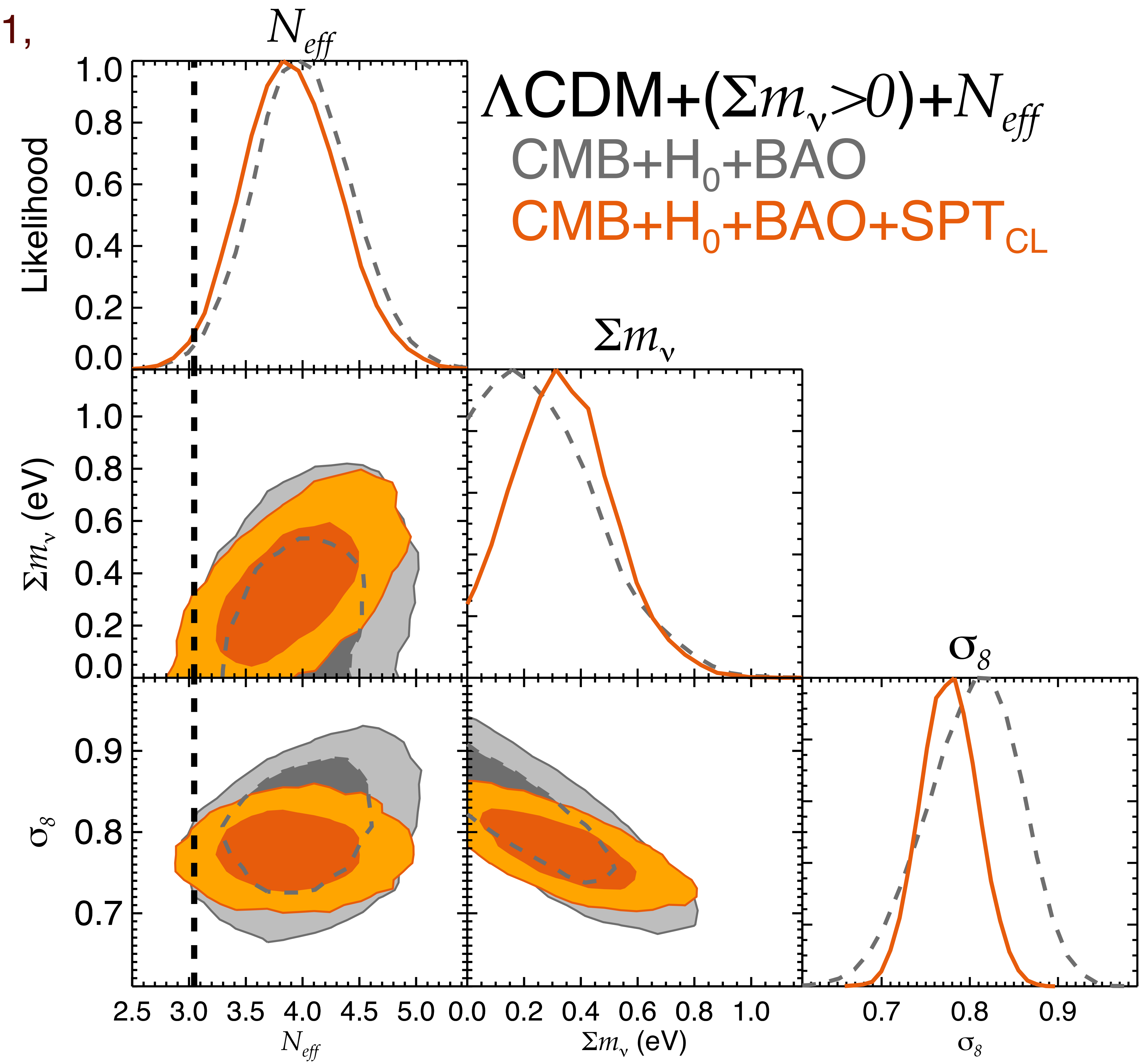
N_{eff} = 3.86 ± 0.42
($SPT+WMAP+H_0+BAO$)



Standard Model, 3 neutrinos.

Science Highlight 2: Measuring neutrino mass

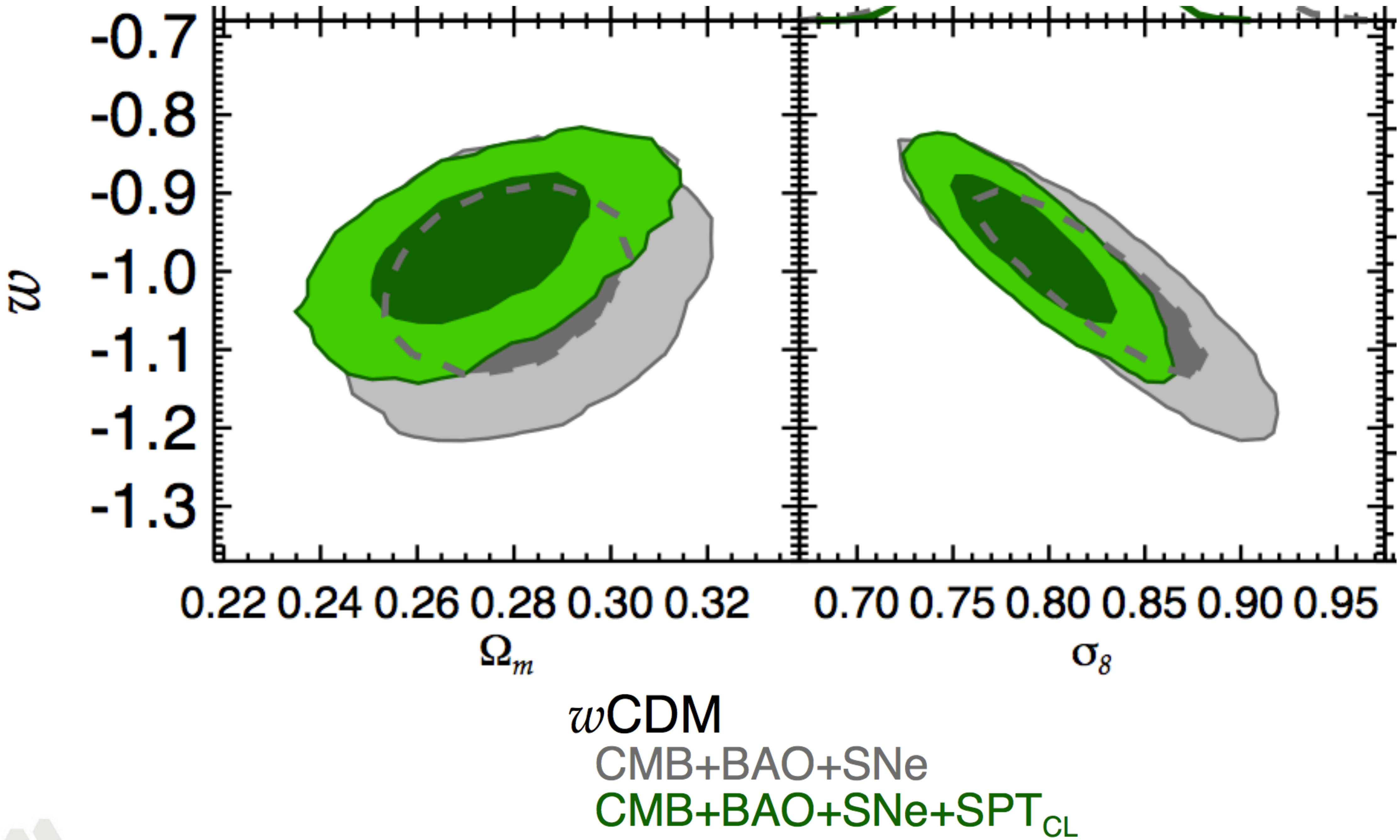
Benson et al 2011, arXiv: 1112.5435



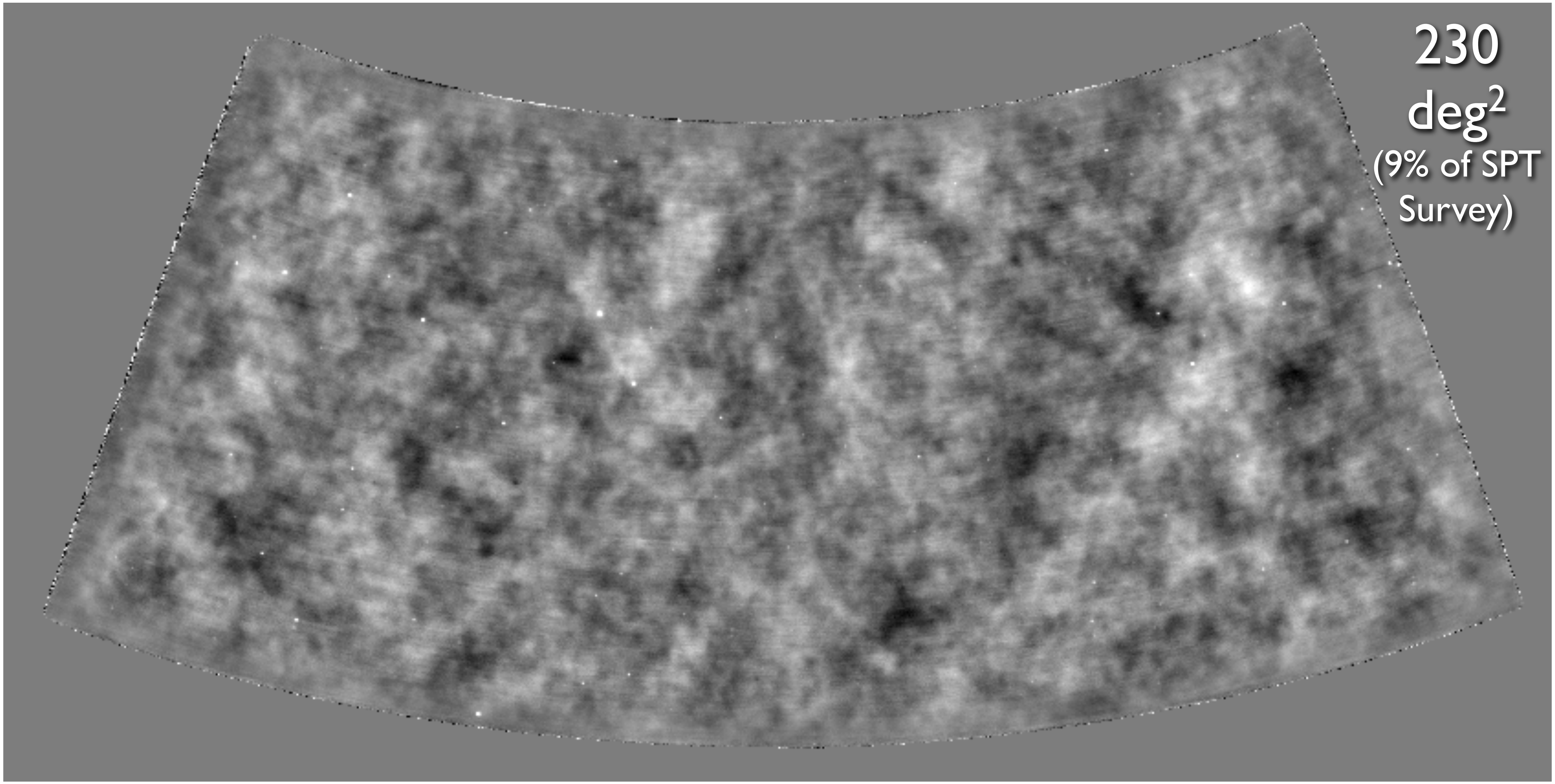
Science Highlight 3: Probing Dark Energy

Benson et al 2011, arXiv: 1112.5435

w= -0.97 +/- 0.06



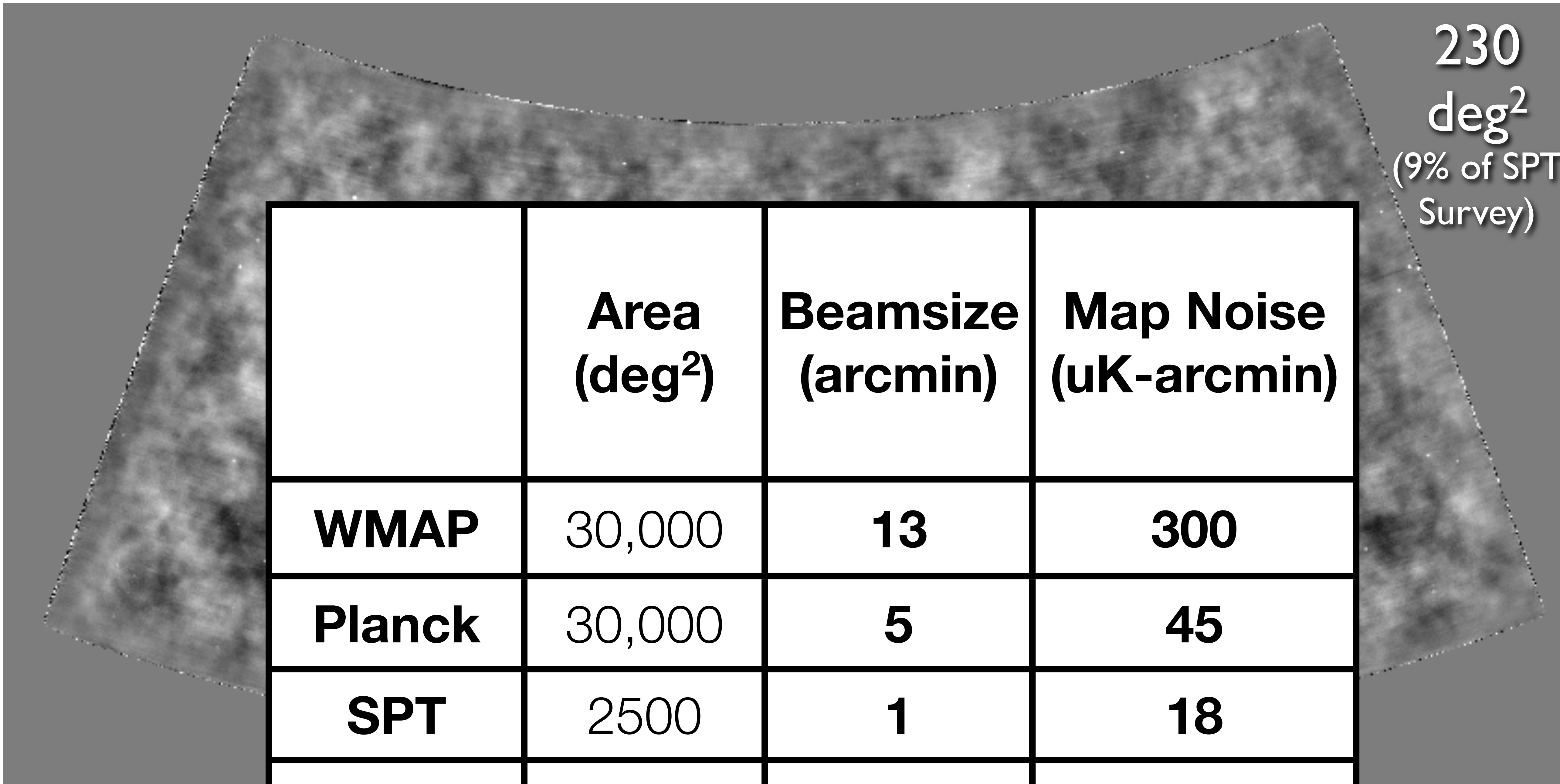
SPT



13x smaller beam (13’ vs 1’)

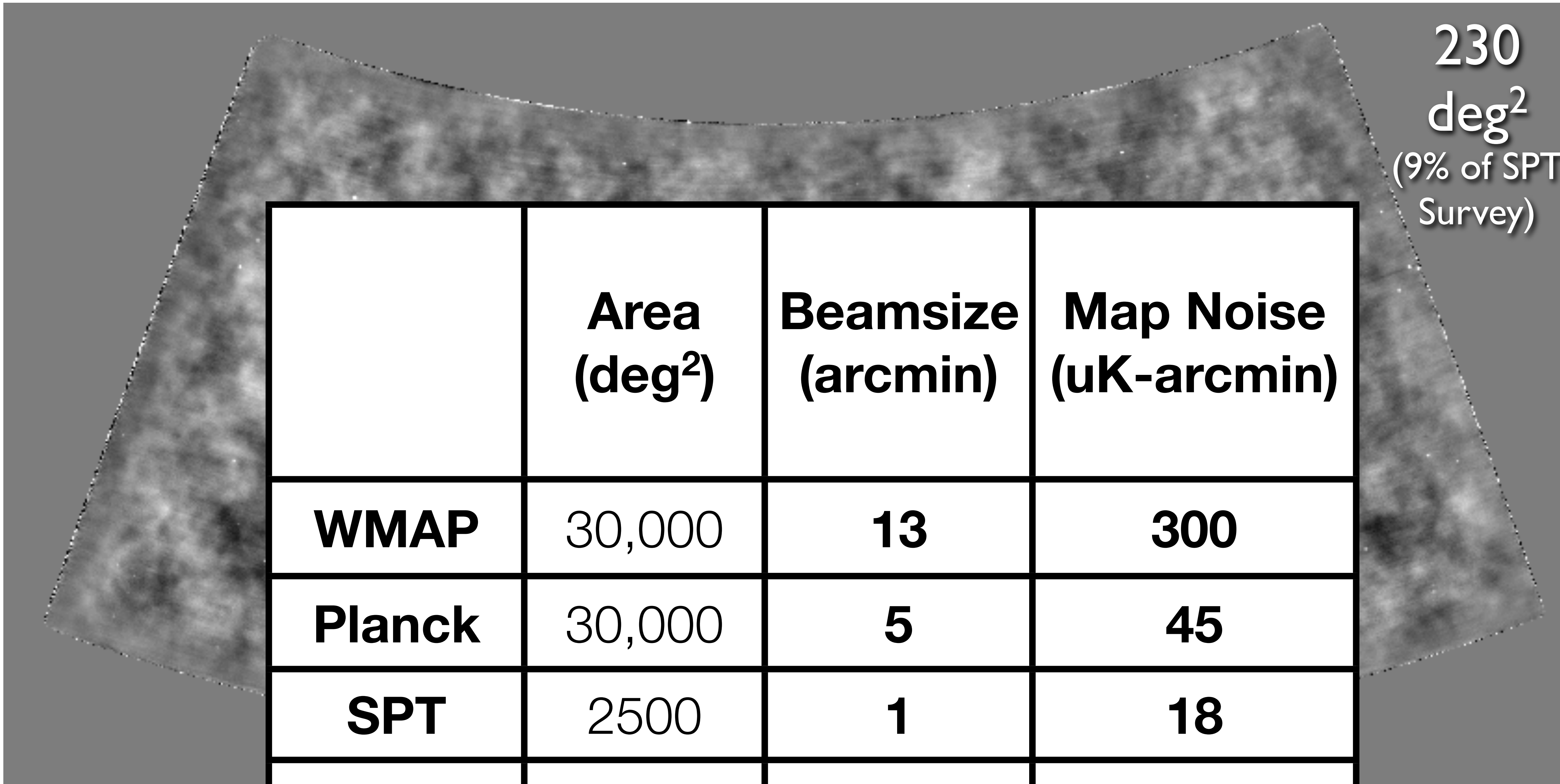
17x deeper (300 uK-arcmin vs 18 uK-arcmin)

SPT



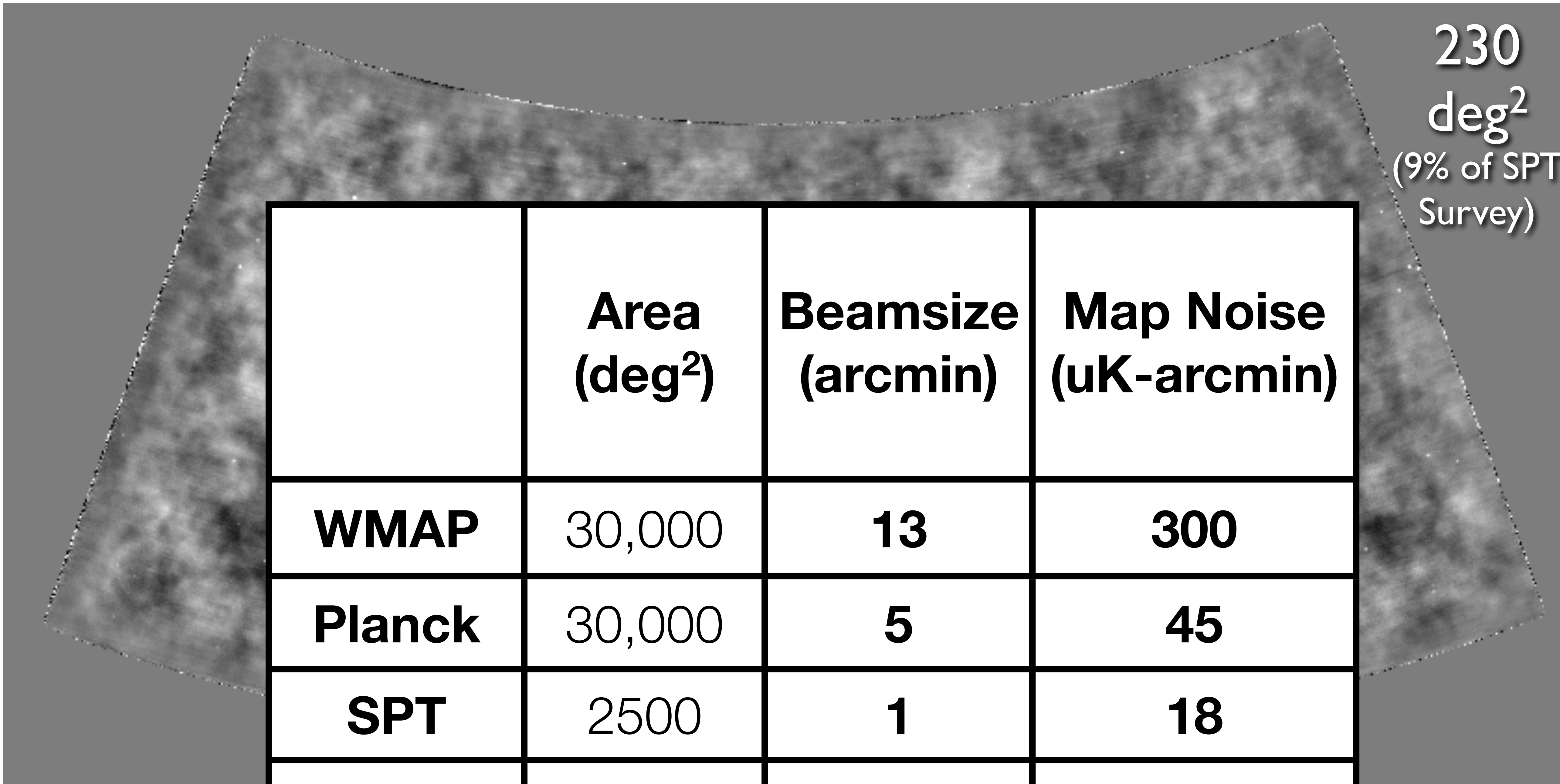
	Area (deg^2)	Beamsize (arcmin)	Map Noise (uK-arcmin)
WMAP	30,000	**13**	**300**
Planck	30,000	**5**	**45**
SPT	2500	**1**	**18**

SPT



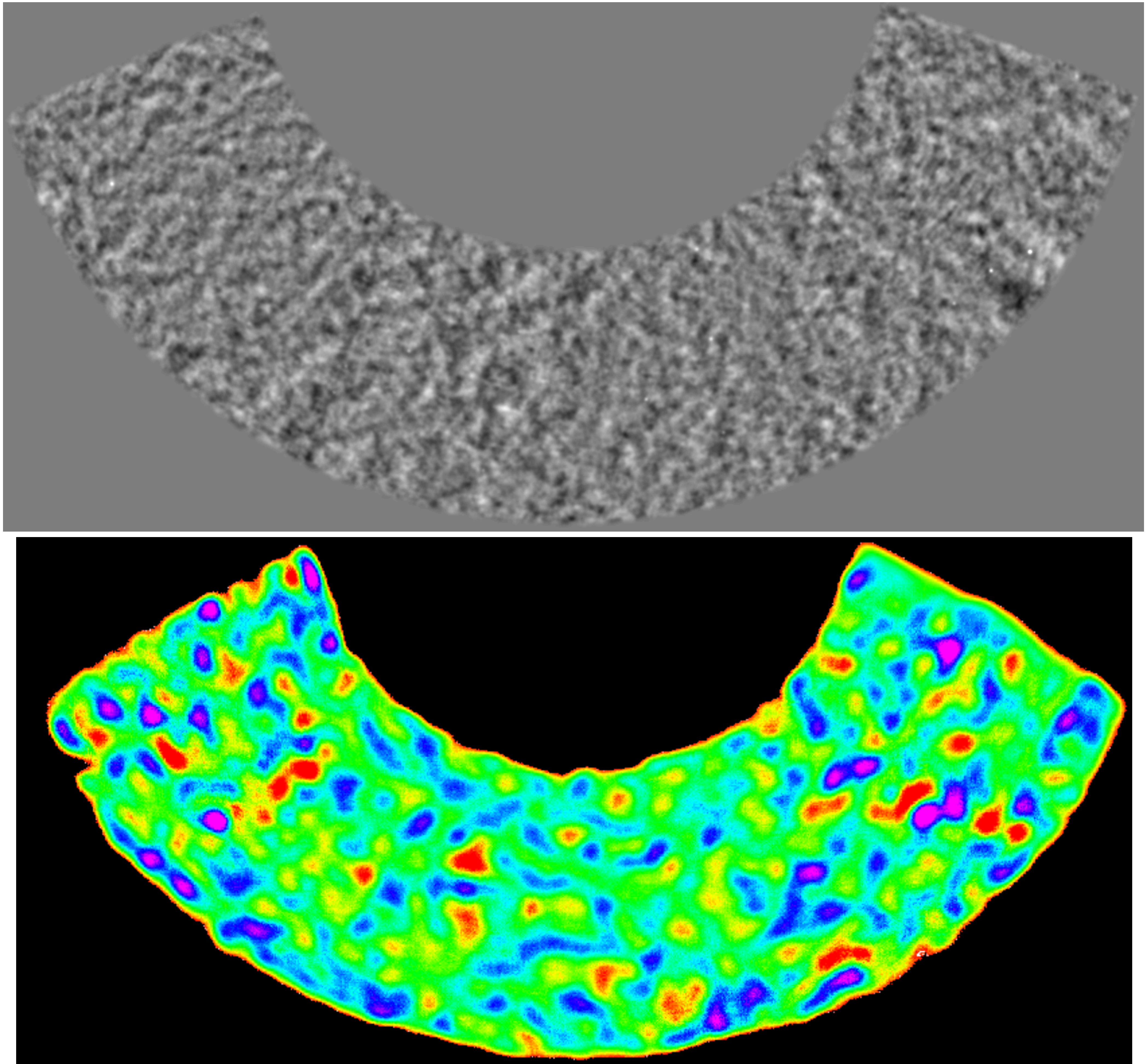
	Area (deg²)	Beamsize (arcmin)	Map Noise (uK-arcmin)
WMAP	30,000	**13**	**300**
Planck	30,000	**5**	**45**
SPT	2500	**1**	**18**
SPTpol	600	**1**	**5**

SPT

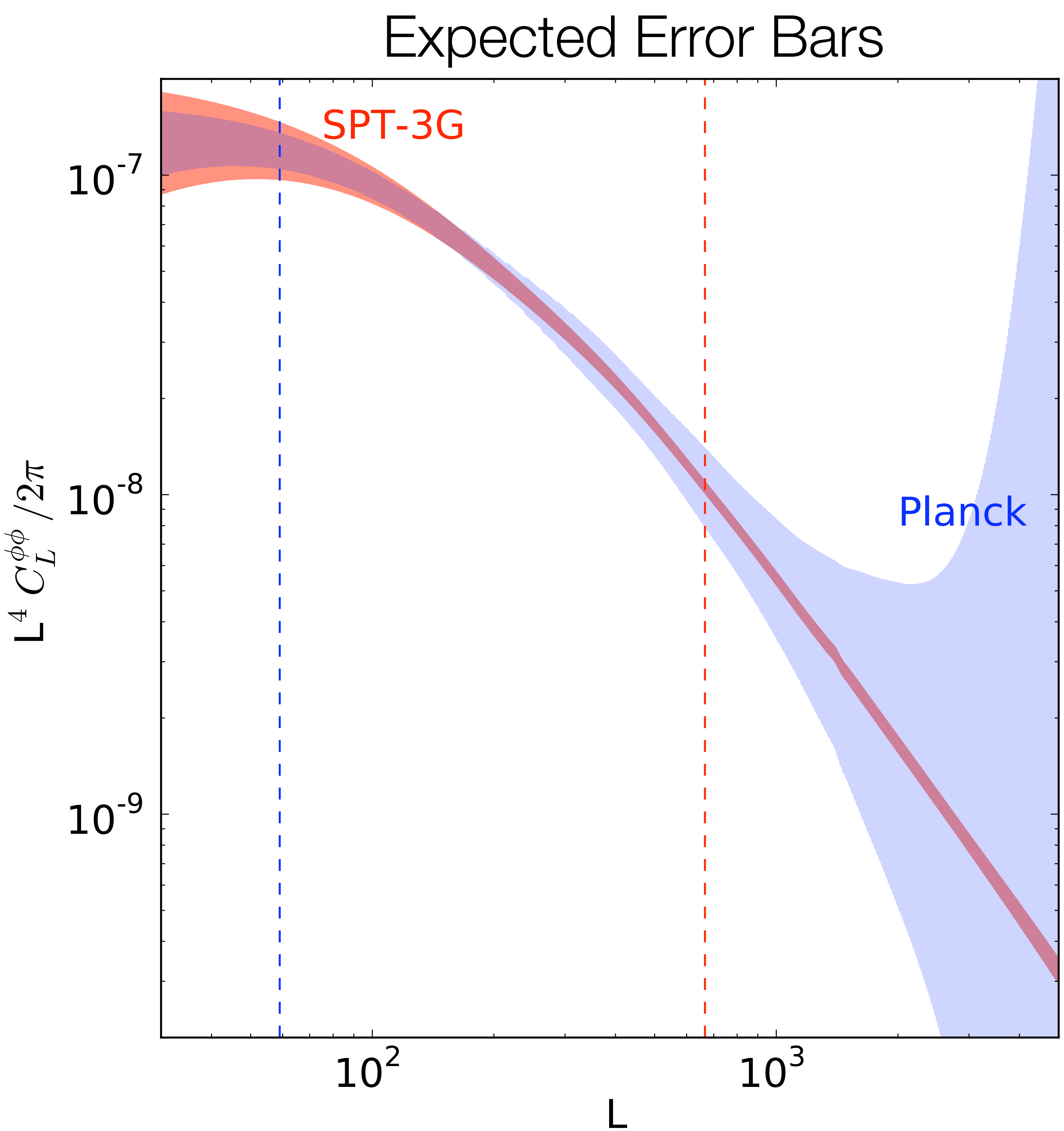


	Area (deg²)	Beamsize (arcmin)	Map Noise (uK-arcmin)
WMAP	30,000	**13**	**300**
Planck	30,000	**5**	**45**
SPT	2500	**1**	**18**
SPTpol	600	**1**	**5**
SPT-3G	2500	**1**	**2**

10x deeper than SPT!



SPT-3G:
CMB Lensing Power Spectrum



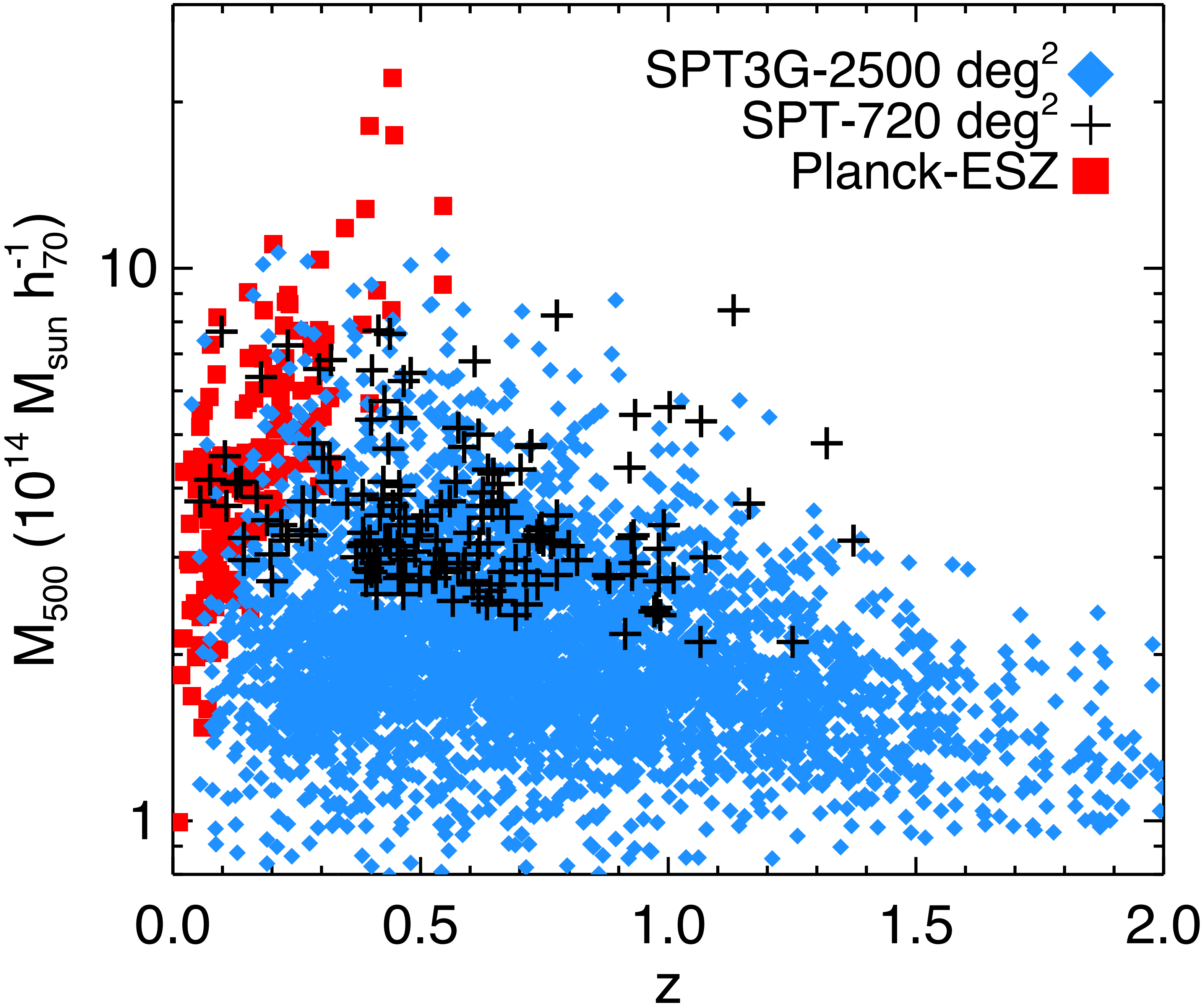
- CMB Lensing Detection Significance
  - -SPT-SZ=30-s
  - -Planck=30-s
  - **-SPT-3G=150-**s

- SPT-3G will measure individual lensing modes out to ell~1000 (Planck to ell~60)

- Cross-correlating with DES will measure galaxy bias to better than ~1%

Credit: G. Holder

SPT-3G:
Cluster Survey



- -10x increase in number of clusters over SPT
  - 4000 clusters at 99% purity threshold
- -Could improve DES dark energy figure of merit by ~4 by calibrating scatter in richness-mass relation (Wu et al. 2010)
- -CMB-cluster lensing should provide a 3% cluster mass calibration (per 4000 clusters)
  - competitive with mass calibration from stacked weak-lensing (Rozo et al. 2011)

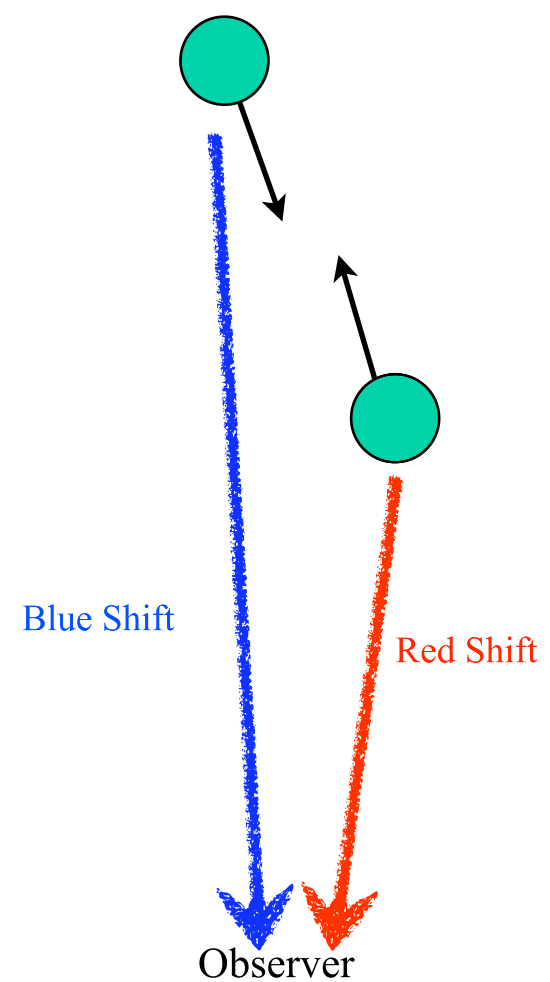
Credit: B. Benson

SPT-3G:
Testing Gravity on Large-scales

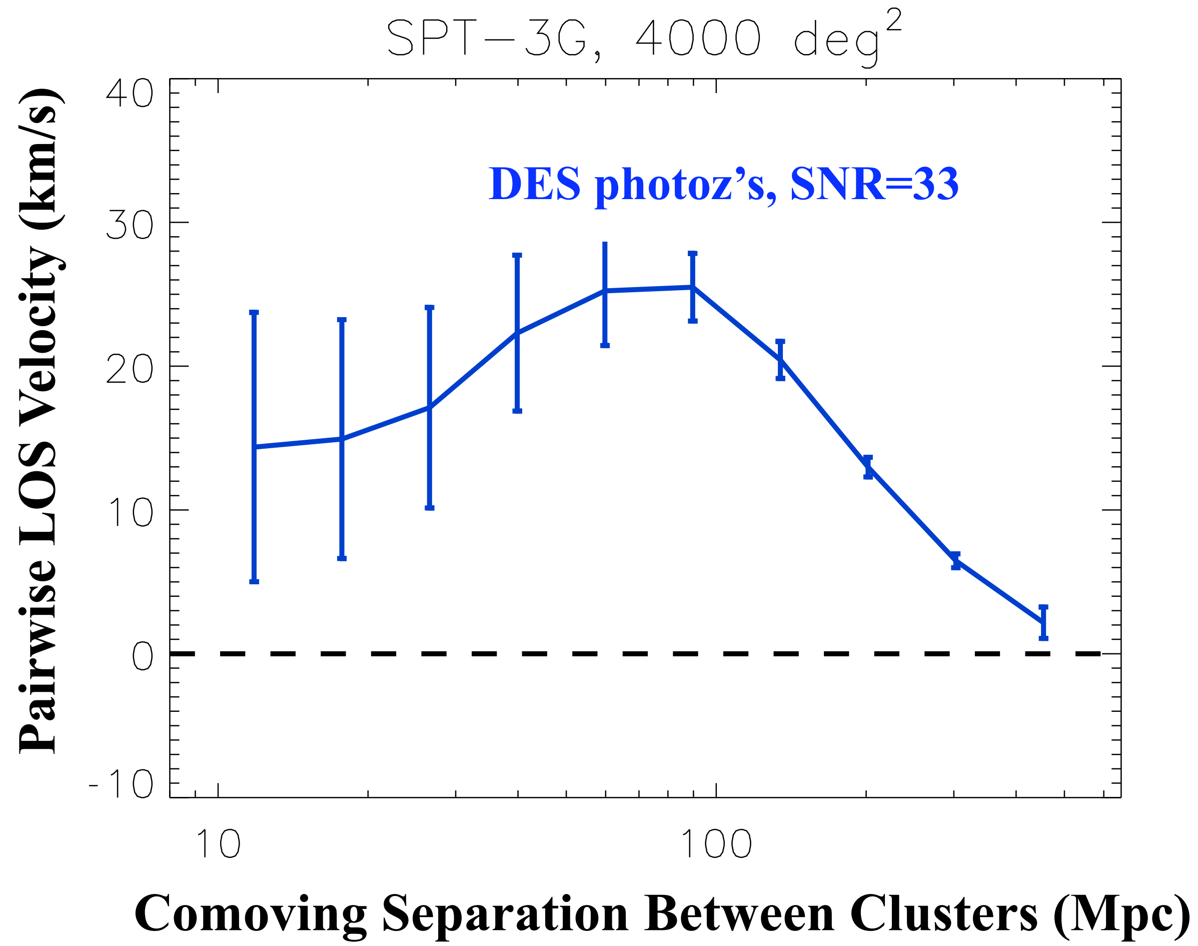
kSZ Pairwise Velocity Signal

Galaxy clusters tend to fall towards each other (w.r.t. Hubble flow).

For a given pair, the high-z (low-z) cluster tends to move towards (away from) us
=>
differential CMB signal from kSZ effect.



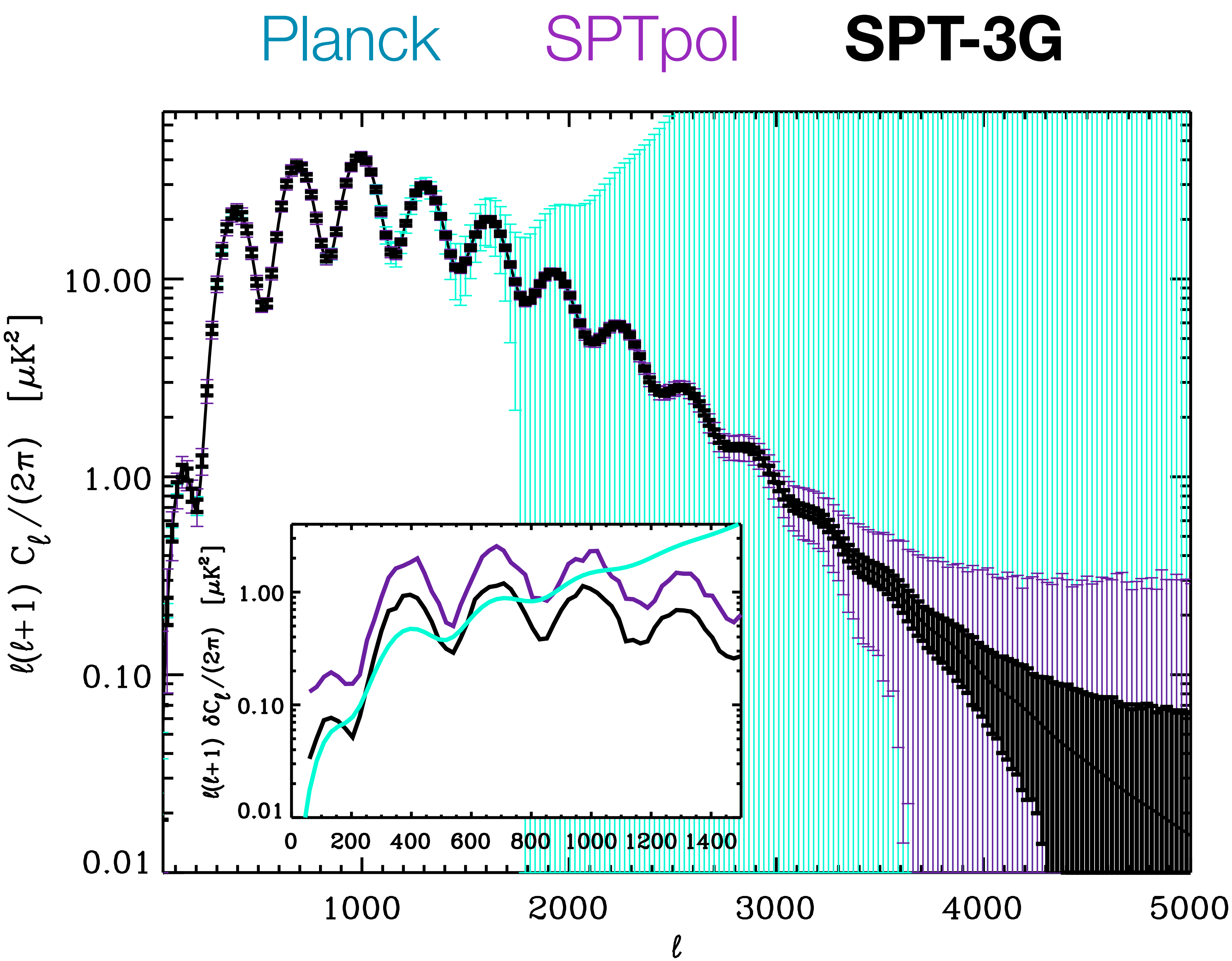
Project a **30-40-sigma** detection of the pairwise kSZ signal for SPT-3G and a DES-like cluster sample with photoz errors.



This provides a novel probe of gravity on **~50-200 Mpc** scales and competitively constrains modified theories of gravity (f(R)/chameleon and DGP) on very large length scales.

Credit: R. Keisler

SPT-3G:
Projected E-mode Power Spectrum



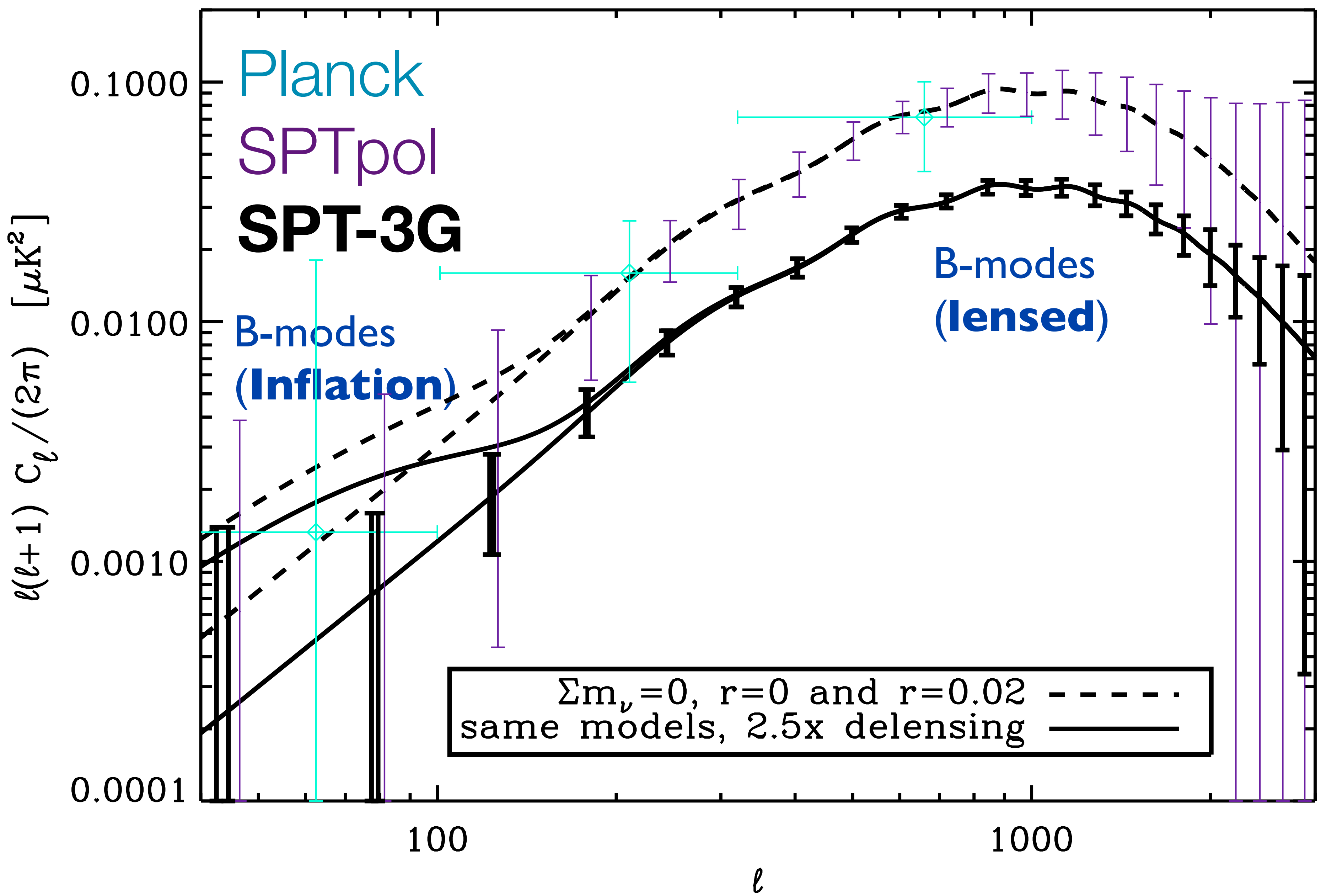
-SPT-3G competive with Planck at ell > ~200

-Significantly improve "damping tail" science from EE-spectrum

-(parameter constraints in a few slides)

Credit: T. Crawford

SPT-3G:
Projected B-mode Power Spectrum



-Planck realistically will not detect B-modes

-SPTpol will make pioneering B-mode measurements

-SPT-3G will be deep enough to:

- improve neutrino mass constraints (over Planck)
- "de-lens" at large-scales and improve "r" constraint

Credit: T. Crawford

SPT-3G:
Parameter Constraints

blue=big improvment
green=decent improvement

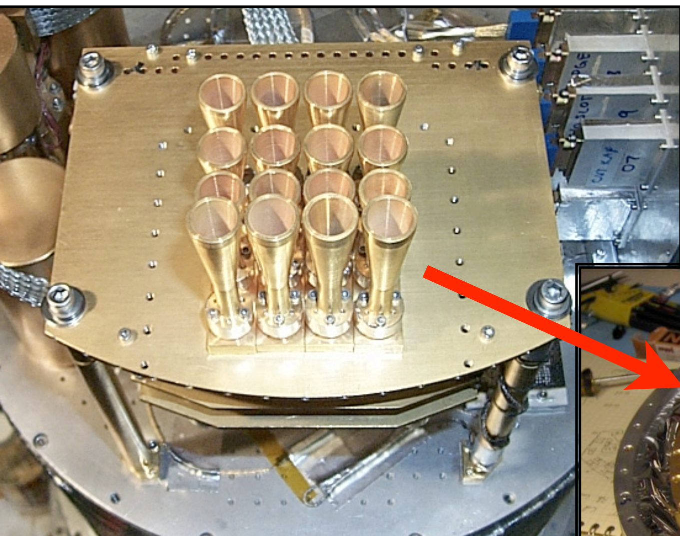
Dataset	Cosmological parameter constraints								
	$\sigma(\Omega_b h^2)$ $\times 10^4$	$\sigma(\Omega_c h^2)$ $\times 10^3$	$\sigma(A_s)$ $\times 10^{11}$	$\sigma(n_s)$ $\times 10^3$	$\sigma(h)$ $\times 10^2$	$\sigma(\tau)$ $\times 10^3$	$\sigma(N_{\rm eff})$ $\times 10^1$	$\sigma(\Sigma m_\nu)$ [meV]	$\sigma(r)$ $\times 10^2$
Planck	1.93	2.02	5.36	7.07	1.88	4.96	1.39	117	5.72
+SPT-3G	1.12	1.29	4.24	4.78	1.18	4.94	0.81	75	1.05
Planck+BAO	1.41	2.02	3.53	4.99	0.72	4.93	1.17	72	5.72
+SPT-3G	0.98	1.26	3.16	3.82	0.62	4.88	0.74	51	1.05

- Scalar-to-tensor constraint of **d**r=0.01
- Constrain sum-of neutrino masses **d**(Smn)=0.05 eV
- Constrain number of relativistic species to **d**($N_{\rm eff}$)=0.07
  - factor of 1.9x improvement, break degeneracies with other cosmological parameters

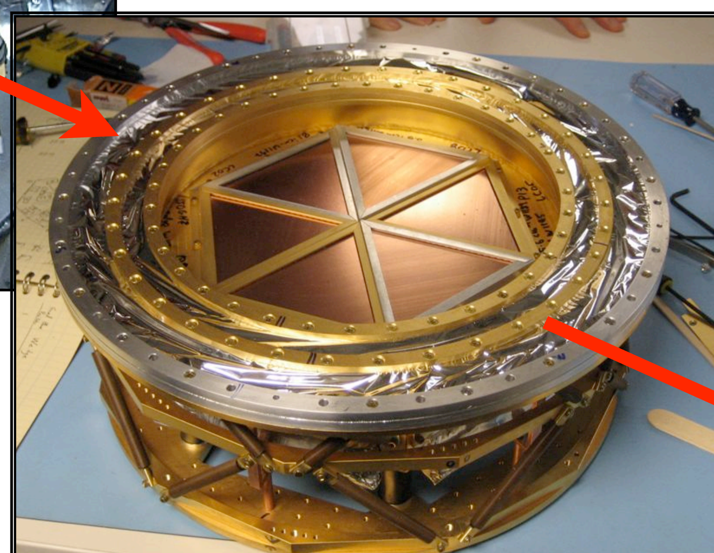
Credit: C. Reichardt, G. Holder, G. Simard

Evolution of Detector Focal Planes

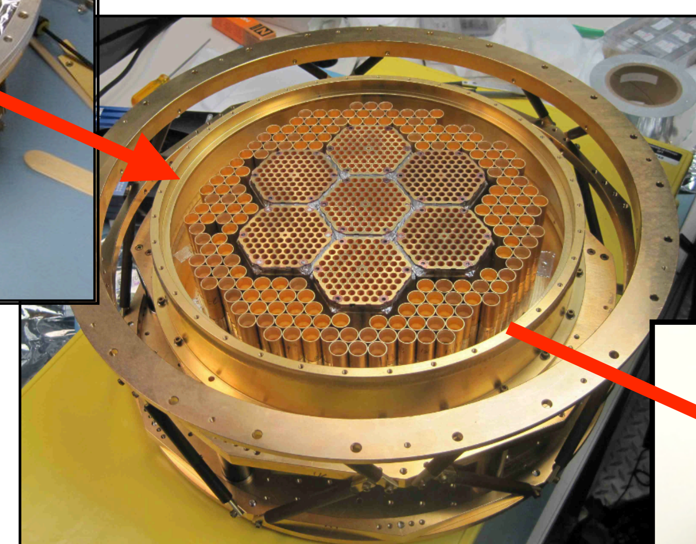
2001: ACBAR
16 detectors



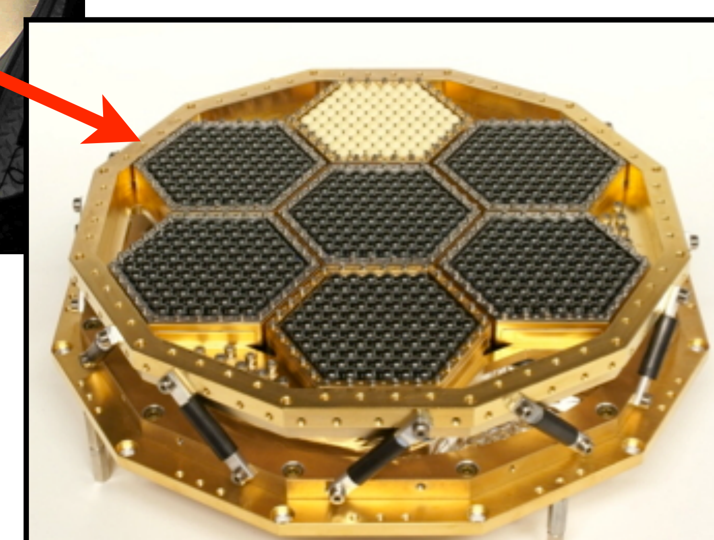
2007: SPT
960 detectors



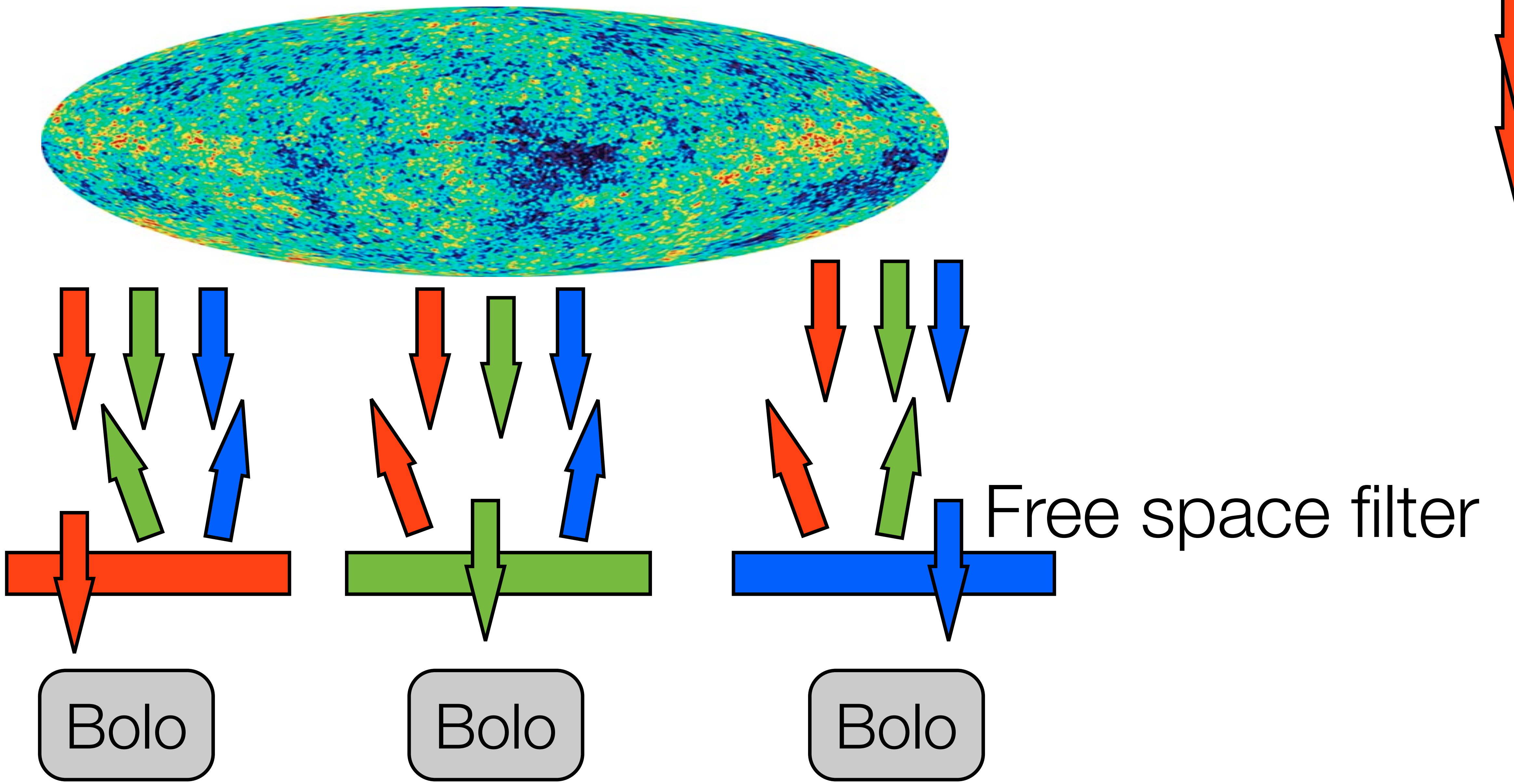
2012: SPTpol
~1600 detectors

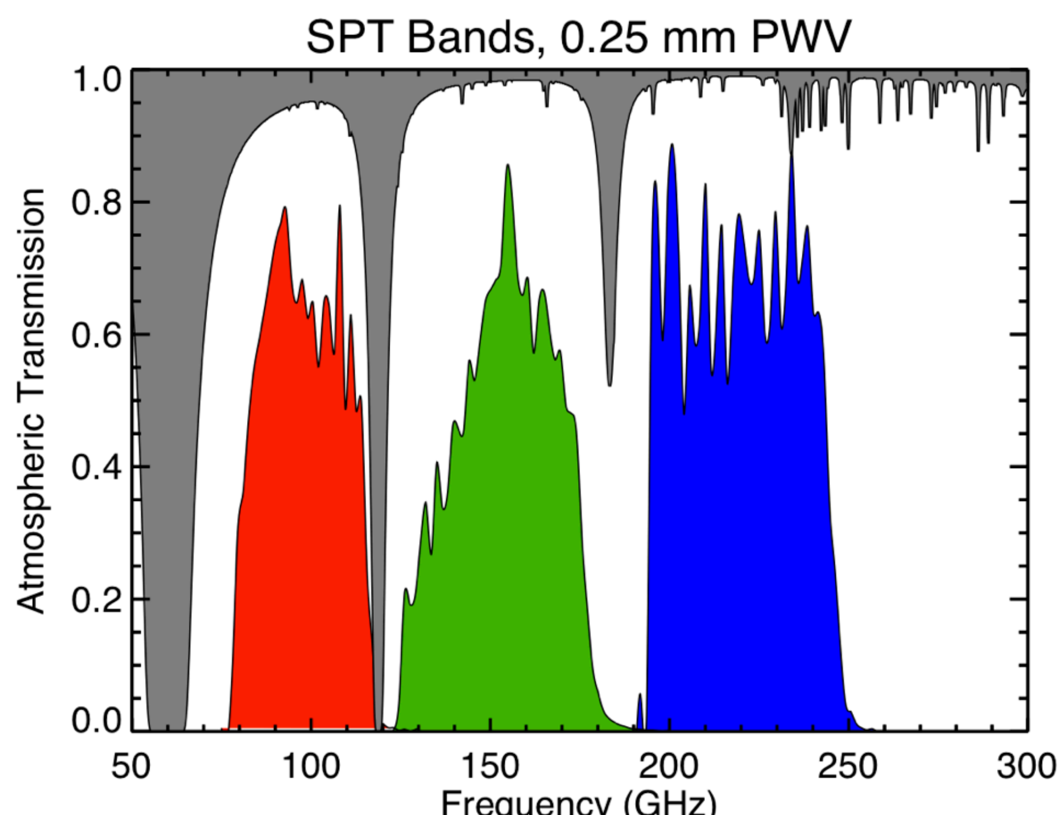


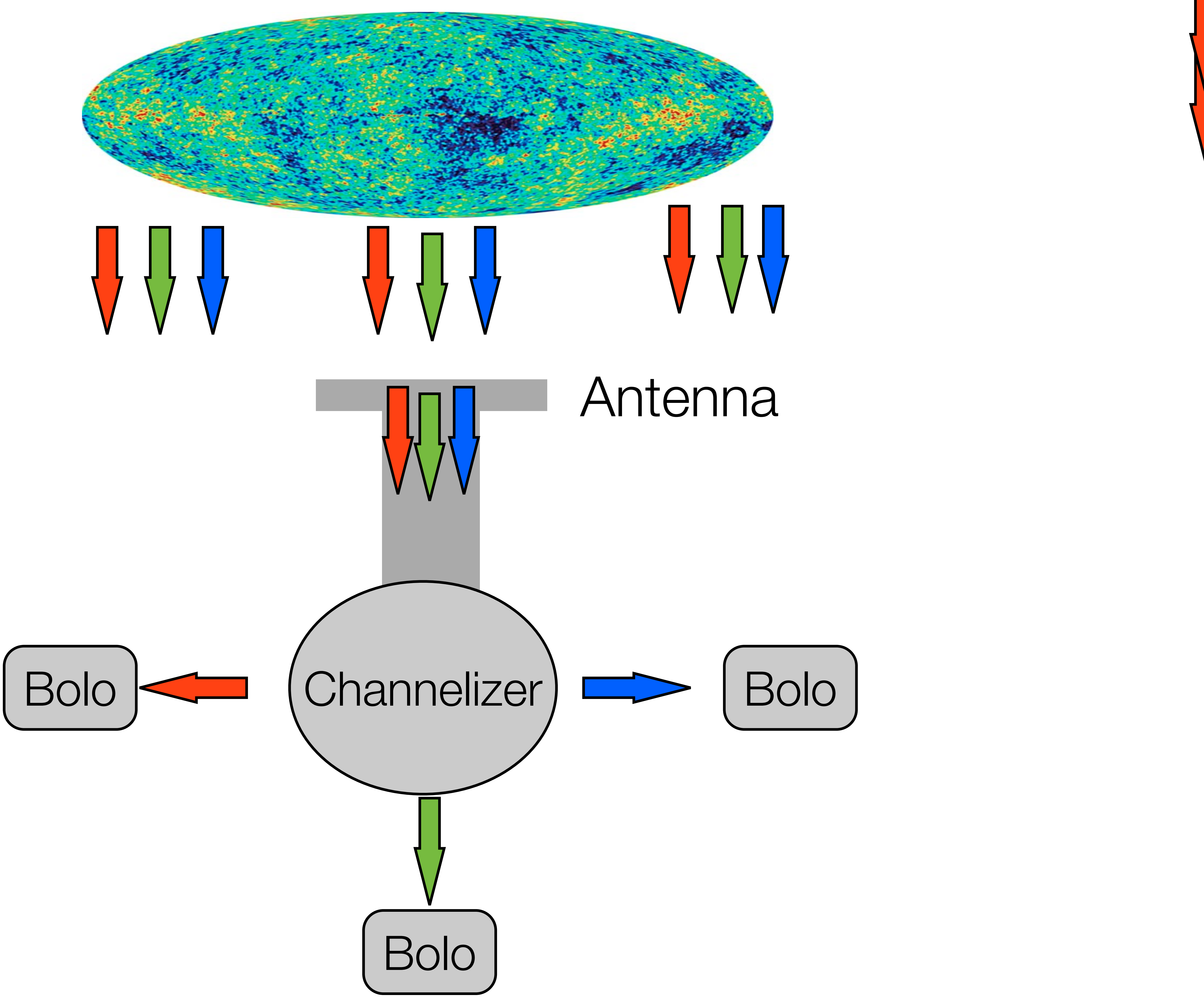
2016: SPT-3G
~15,200 detectors

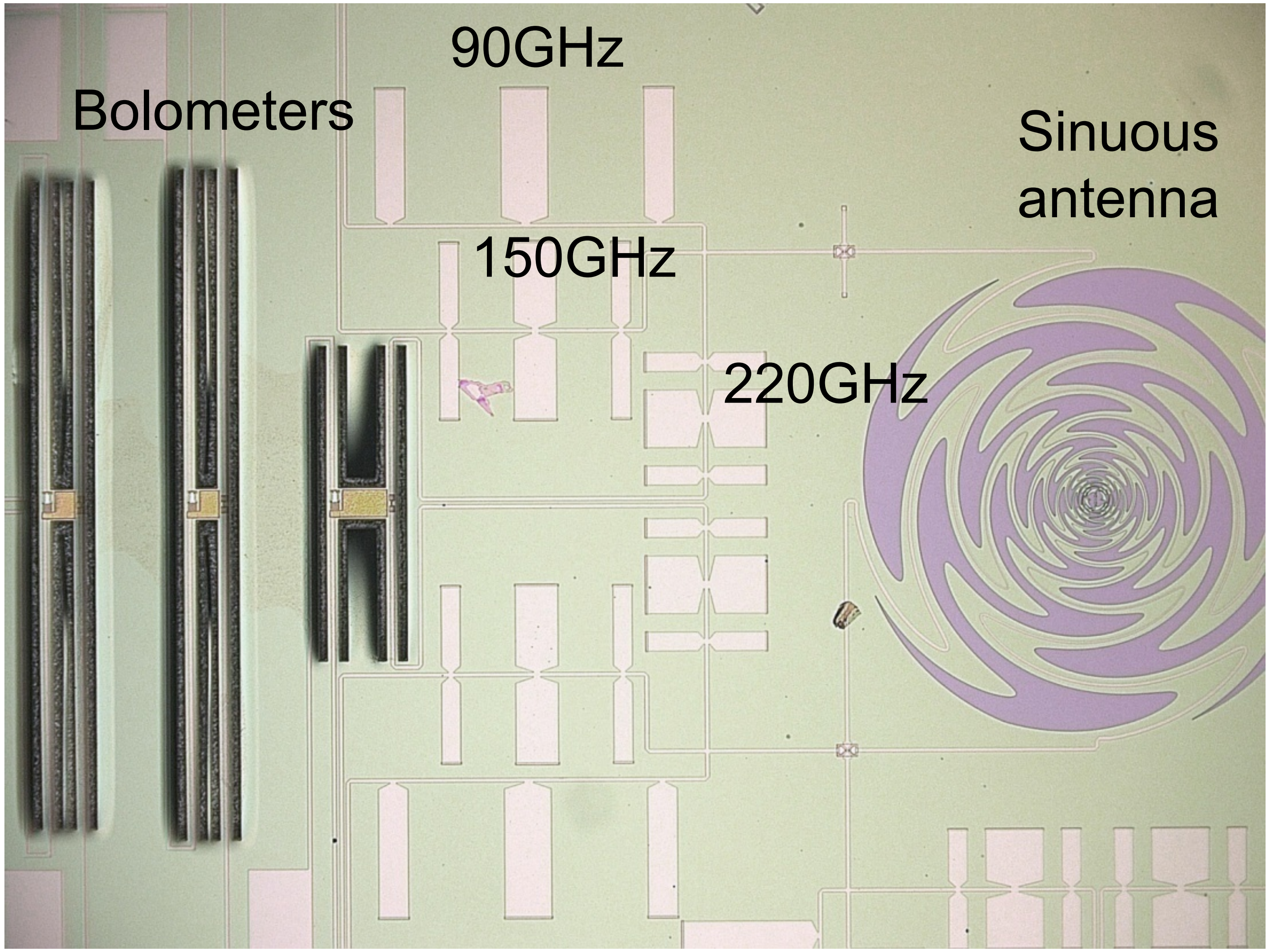


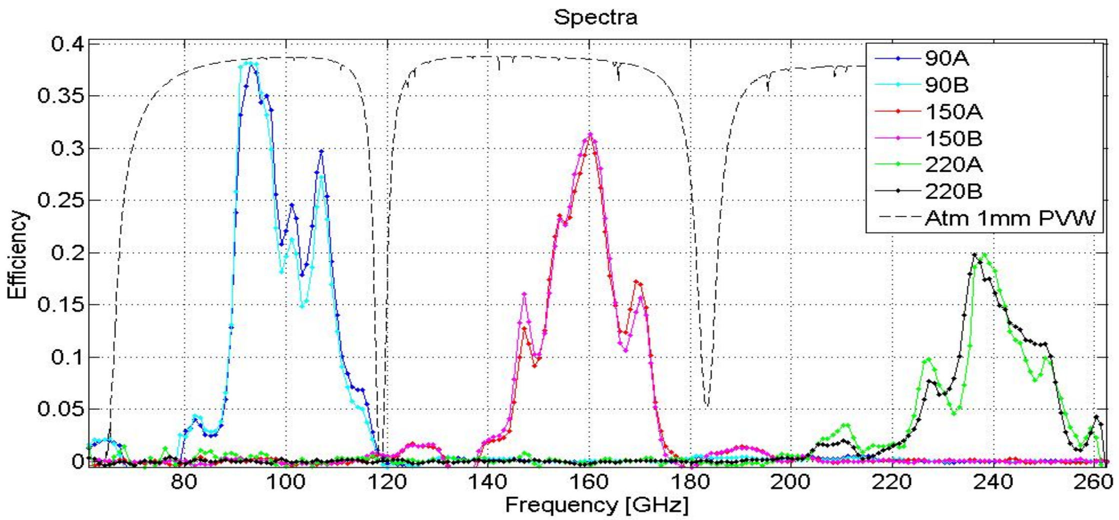
ACBAR was the first experiment to make a "background limited" detector, since then we've just been trying to make more of them


Free space filter
Bolo
Bolo
Bolo

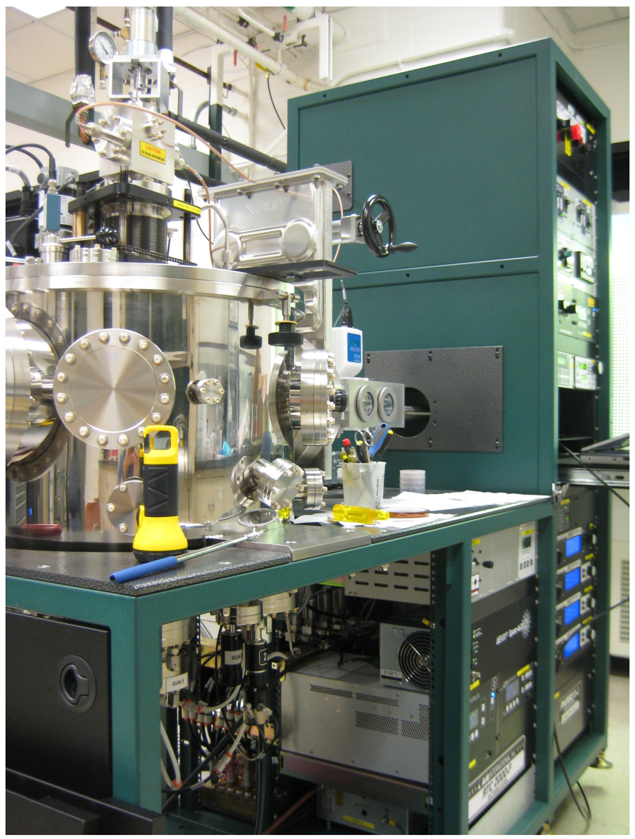

SPT Bands, 0.25 mm PWV
Atmospheric Transmission
Frequency (GHz)
0.0
0.2
0.4
0.6
0.8
1.0
50
100
150
200
250
300


Antenna
Channelizer
Bolo
Bolo
Bolo


90GHz
Bolometers
150GHz
220GHz
Sinuous
antenna


Spectra
Efficiency
Frequency [GHz]
90A
90B
150A
150B
220A
220B
Atm 1mm PVW

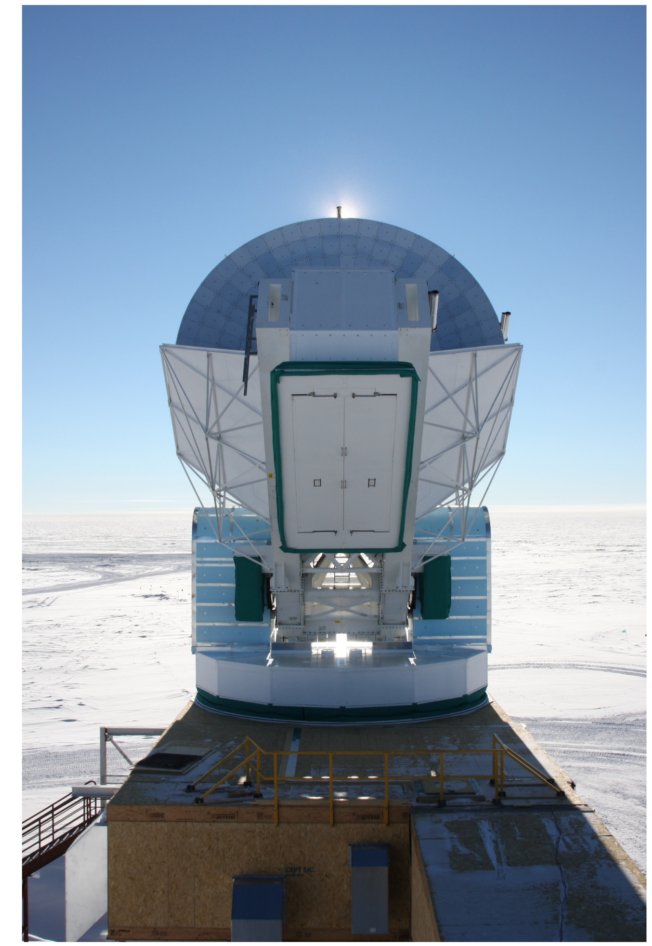
Superconducting Detectors at ANL

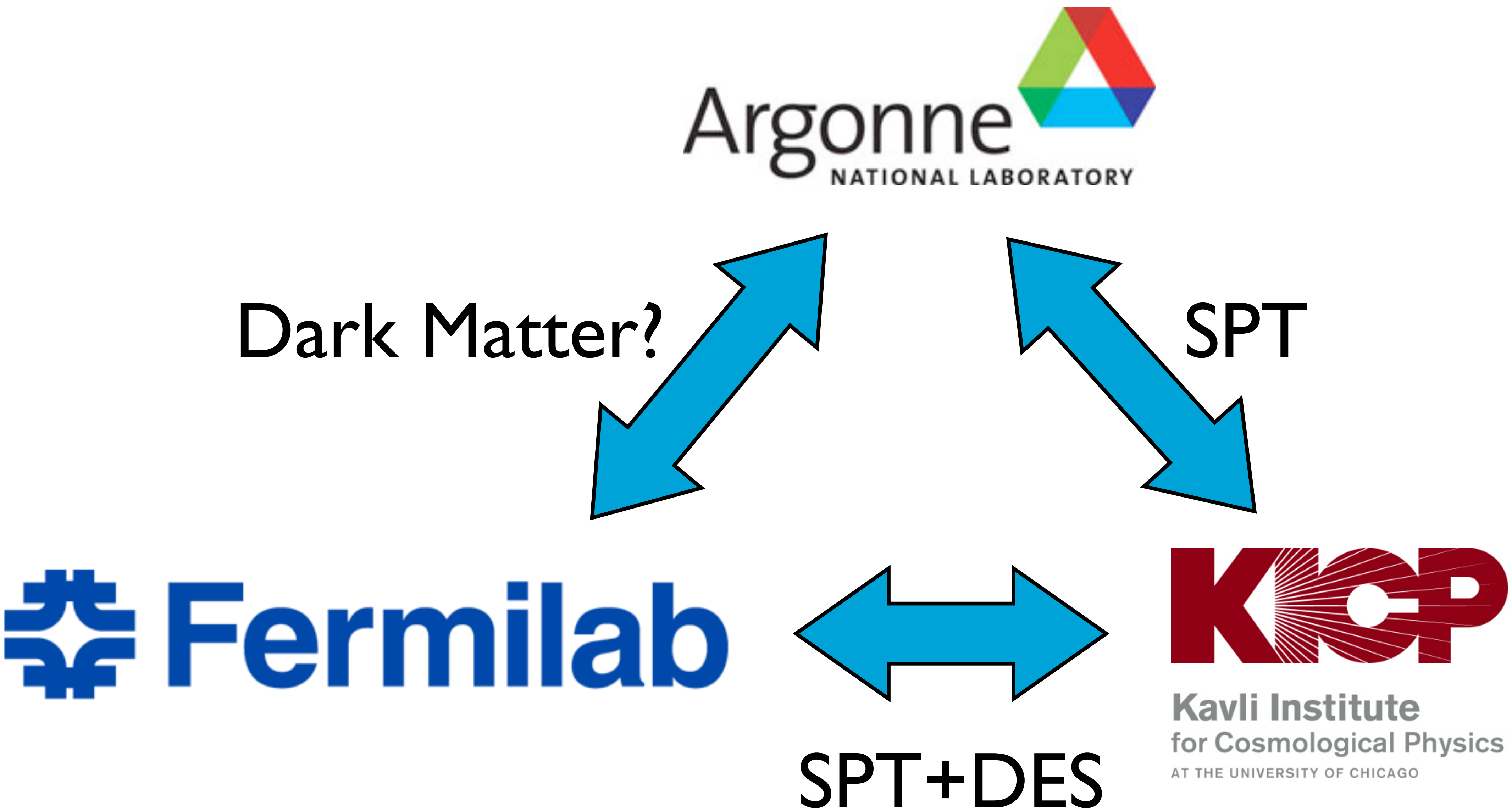


MSD
V. Novosad
V. Yefremenko
J. Pearson

HEP/UofC
J. Carlstrom
C. Chang
G. Wang

CNM
R. Divan

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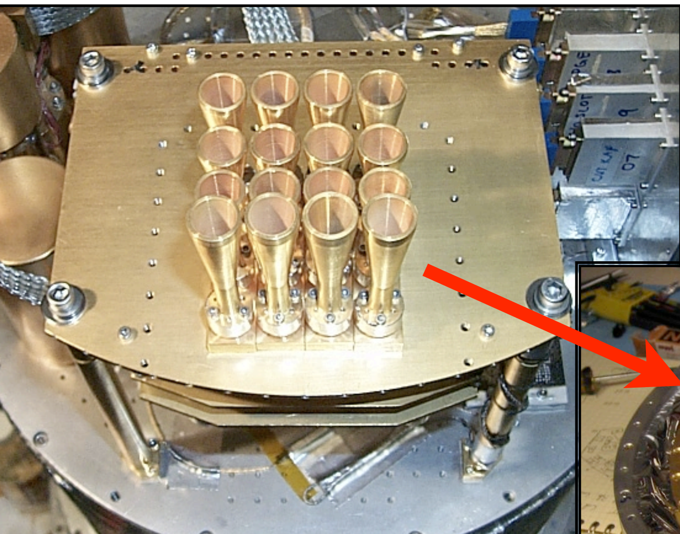
Role of multiplexing

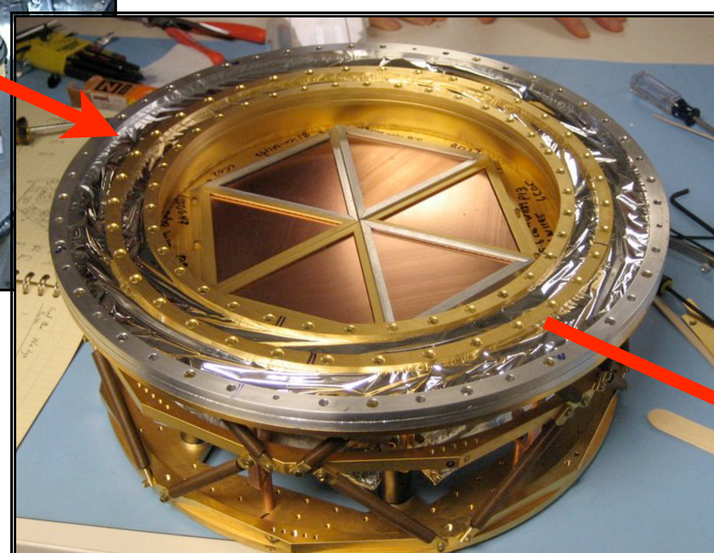
Cryogenic detectors - wiring is what matters

2001: ACBAR
16 detectors



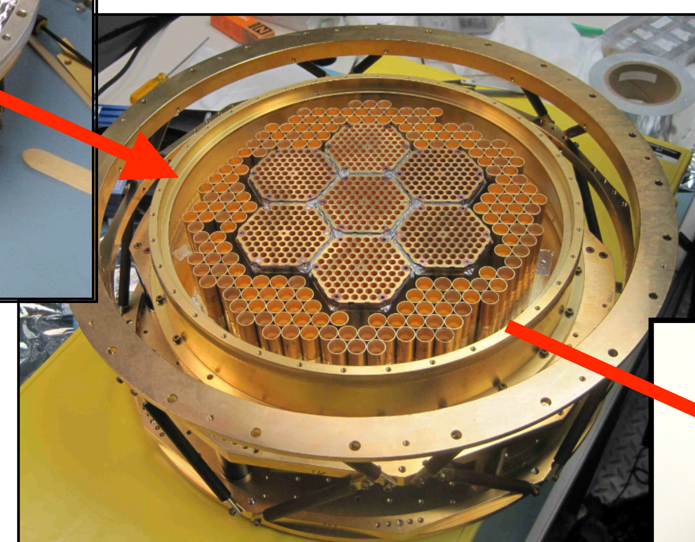
1x MUX

2007: SPT
960 detectors



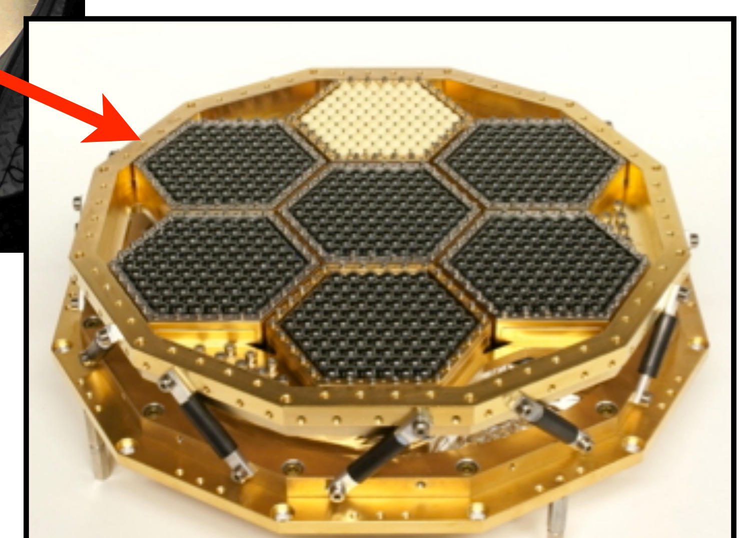
8x MUX

2012: SPTpol
~1600 detectors



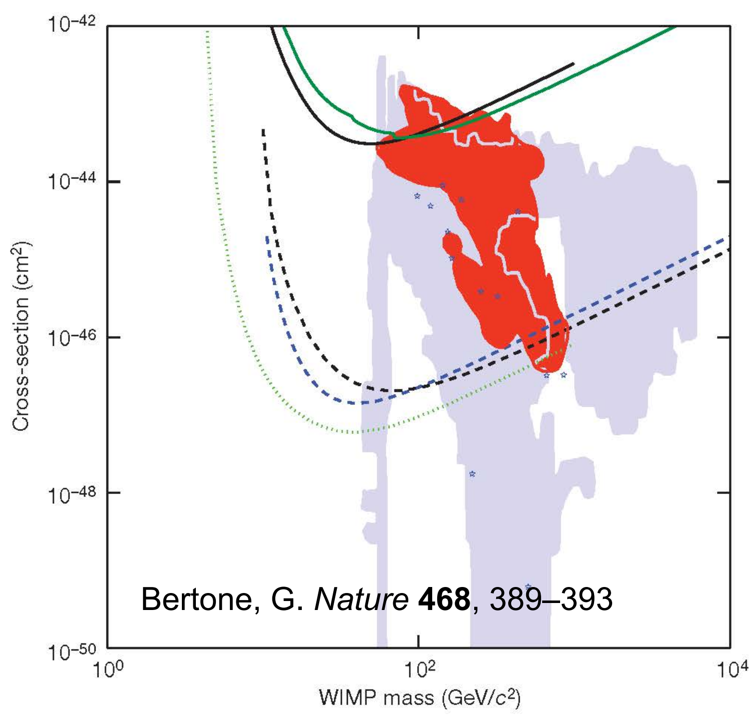
12x MUX

2016: SPT-3G
~15,200 detectors

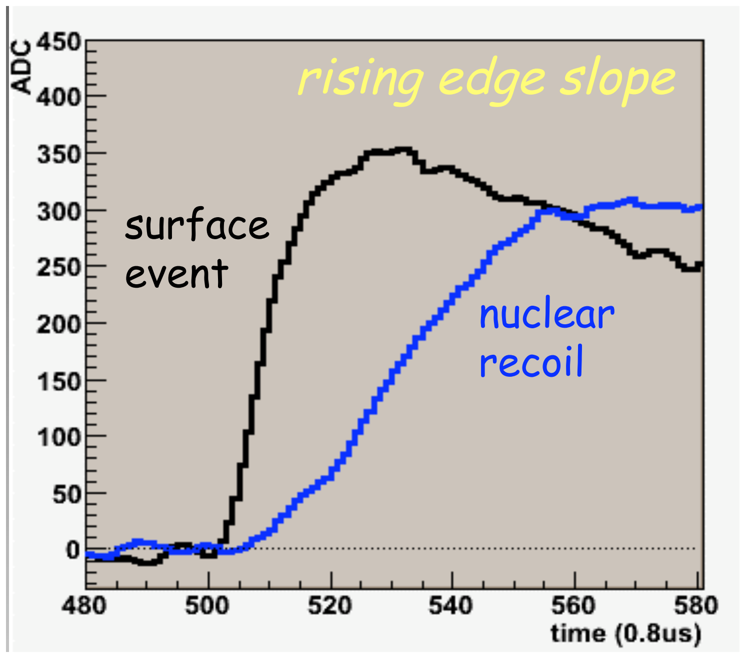


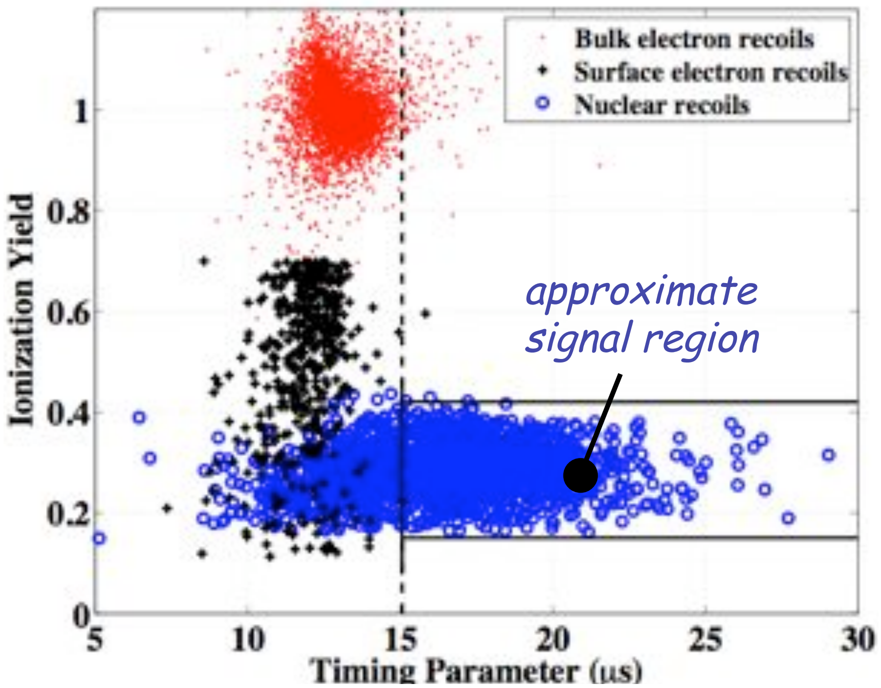
64x MUX

SuperCDMS -> 1 ton?



- Future DM direct detection experiments will be ton scale
- bandwidth requirements makes MUXing current SuperCDMS technology is challenging





Beyond SuperCDMS

CDMS II, oZIP — 1 cm x 3”, ~250 g — 19 Ge detectors, ~5 kg

SuperCDMS Soudan, iZIP — 1”x 3”, ~630 g — 15 detectors, ~10 kg

!!

Funded

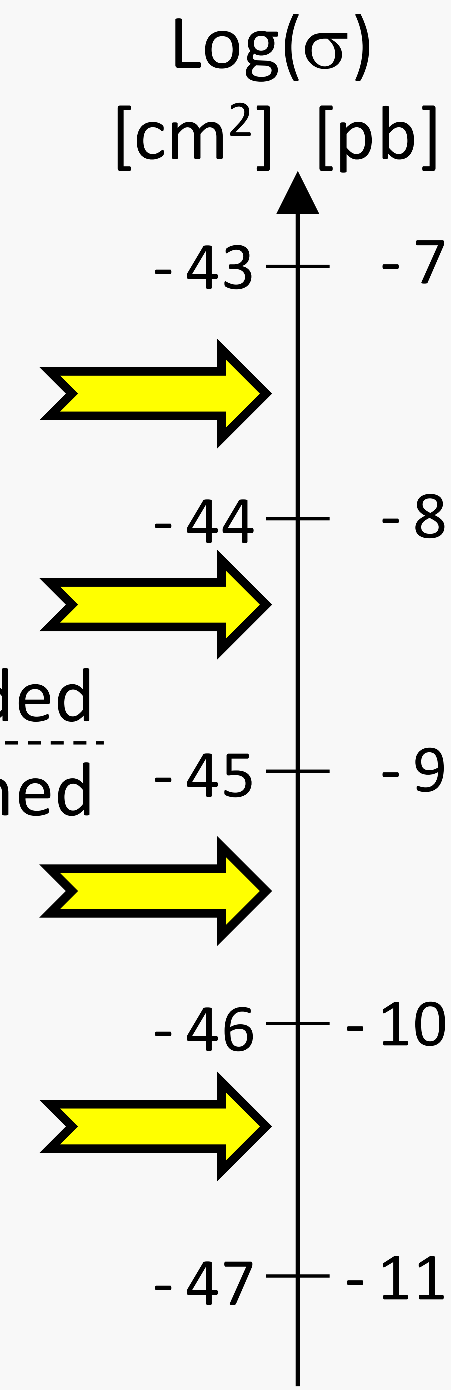
- - - - - - - - - - - - - - - - - - - -

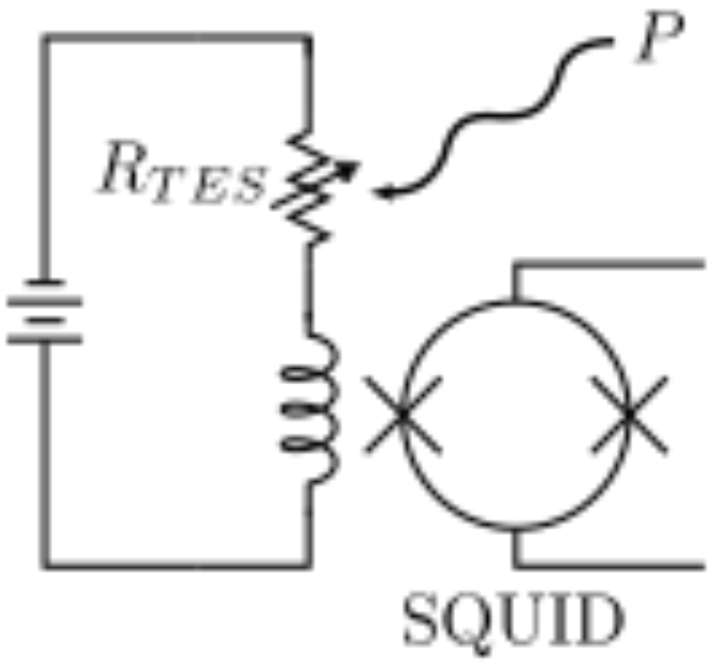
??

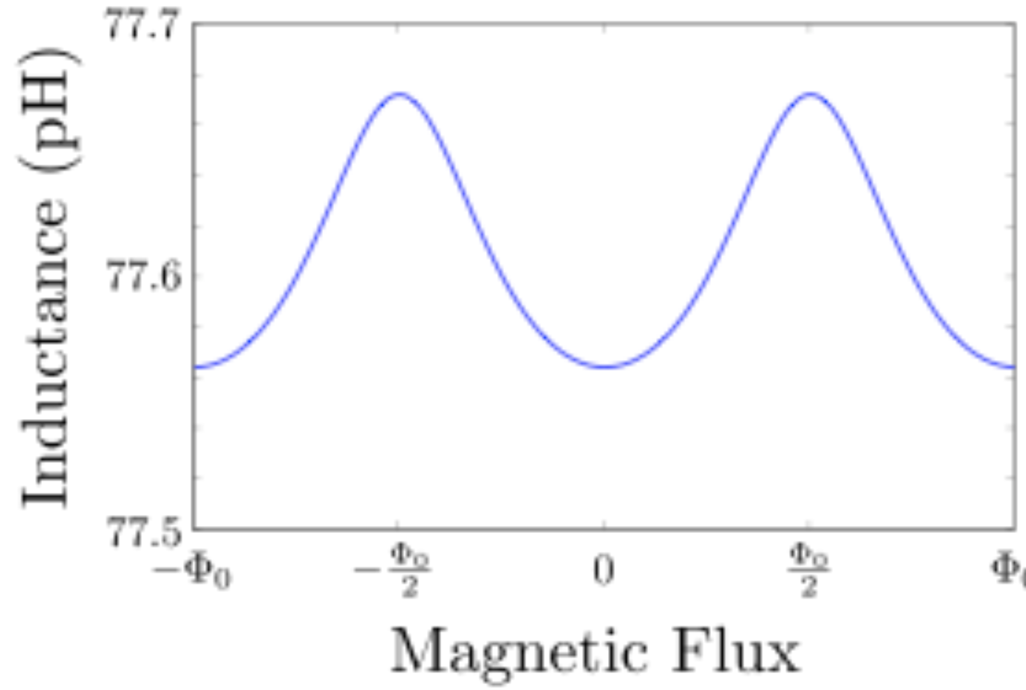
Planned

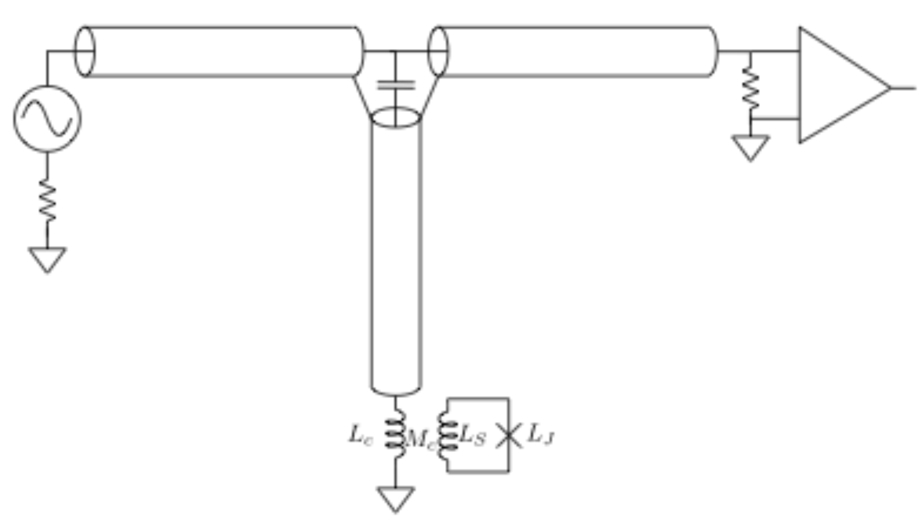
SuperCDMS SNOLAB, iZIP — 3.3 cm x 10 cm ~1200 g — O(100) detectors, 100 kg range

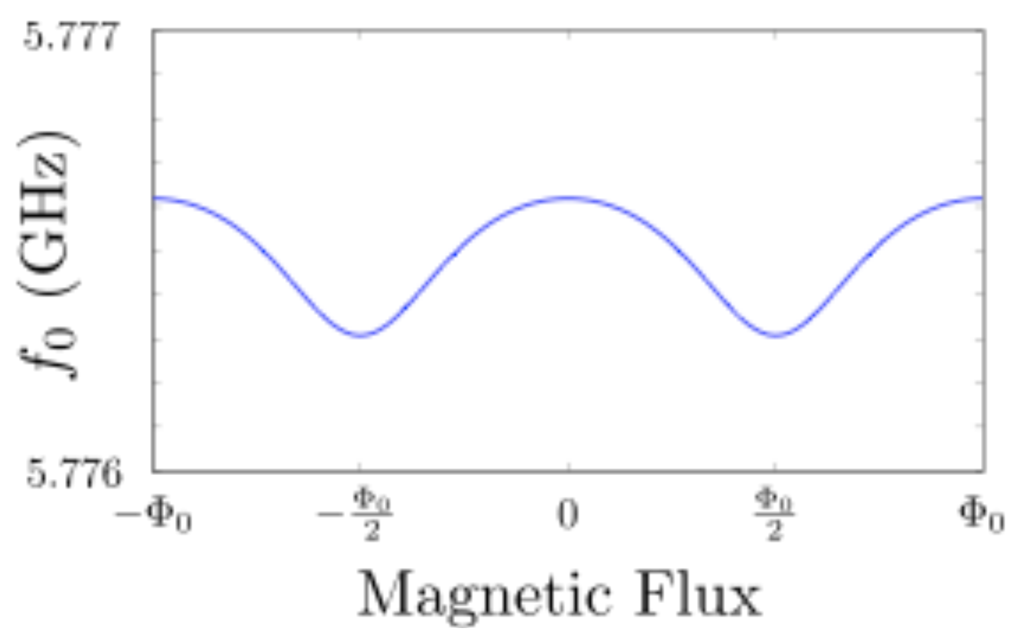
GEODM — 6” x 2” ~5000 g — hundreds of detectors, >1000 kg

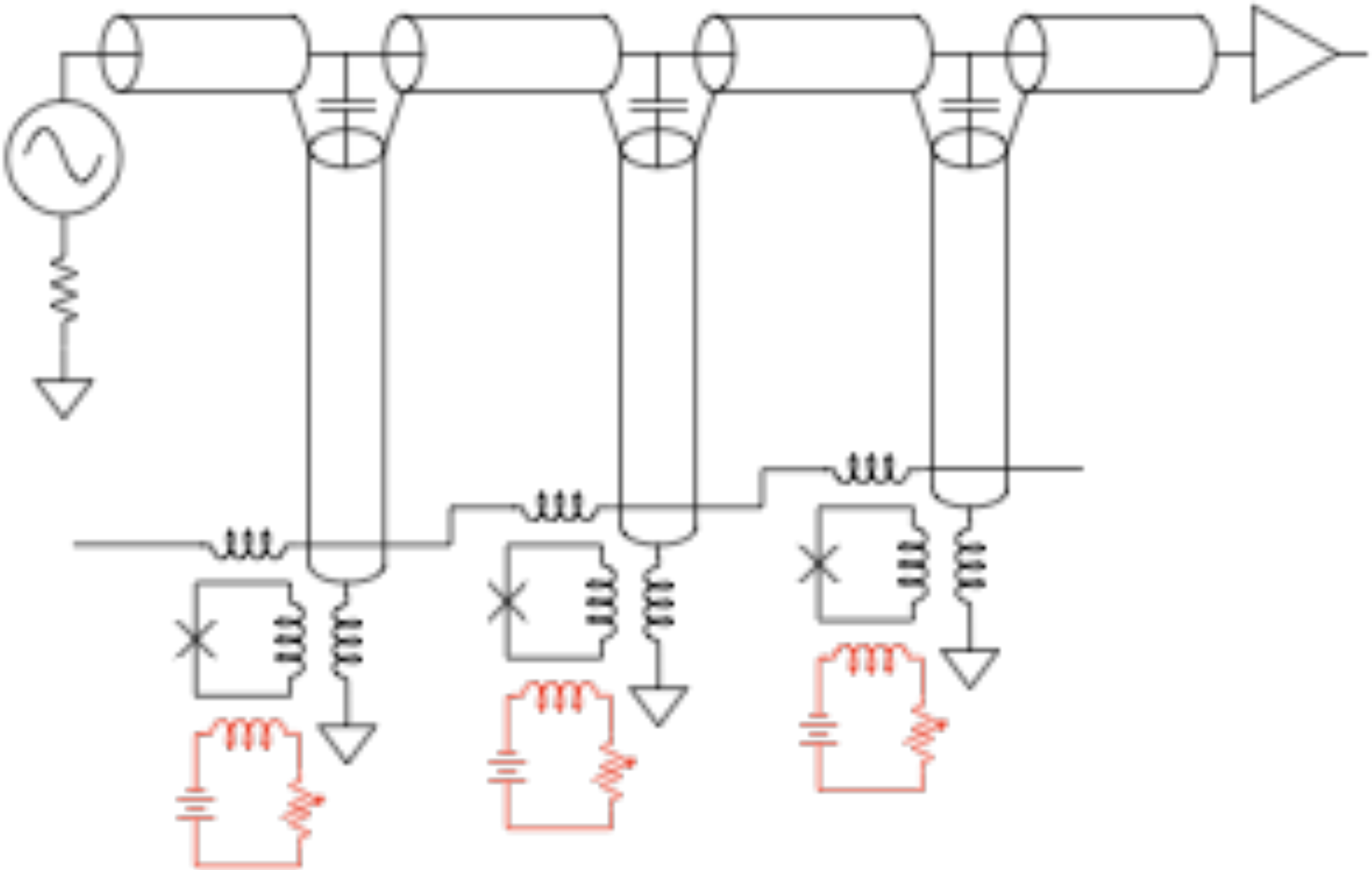



P
R_{TES}
SQUID


Inductance (pH)
77.7
77.6
77.5
$-\Phi_0$
$-\frac{\Phi_0}{2}$
0
$\frac{\Phi_0}{2}$
Φ_0
Magnetic Flux


L_c
M_c
L_S
L_J


f_0 (GHz)
5.777
5.776
$-\Phi_0$
$-\frac{\Phi_0}{2}$
0
$\frac{\Phi_0}{2}$
Φ_0
Magnetic Flux



New Multiplexing technology

- Current MUX operate at 300 kHz - 2 MHz (~5 kHz bandwidth per channel)

- Develop high frequency MUX at 1-10 GHz (~1 MHz bandwidth per channel)

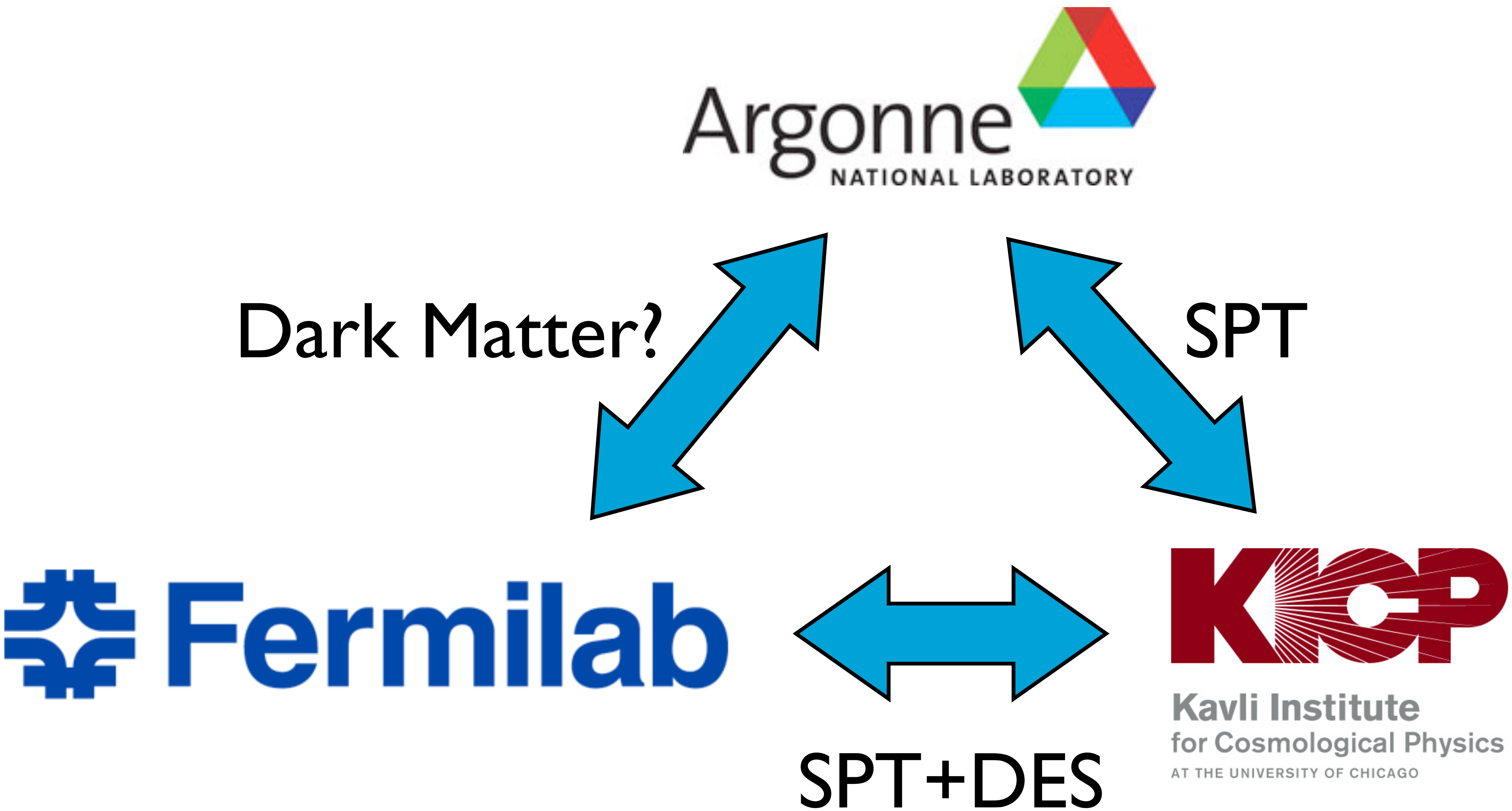
  - High speed digital electronics + superconducting microwave resonators

- Makes existing SuperCDMS detector technology scalable to 1-ton

- Broad applications elsewhere eg:

  - Mpixel X-ray micro-calorimeter arrays

  - Mpixel Optical/Near-IR spectrophotometer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