SKA x mm-wave: What can we do with that?

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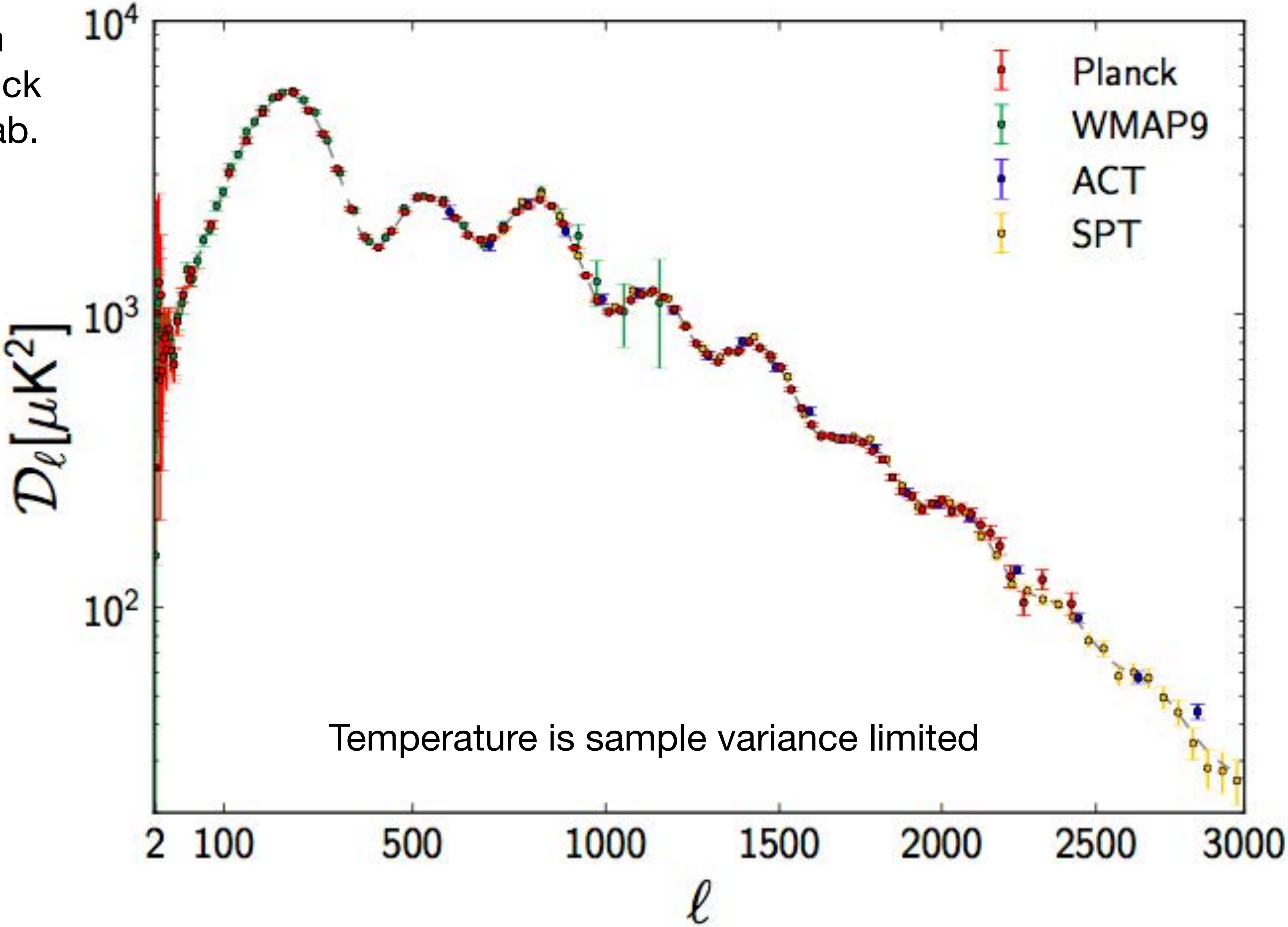
Outline

- What mm-wave data will be available?
- Maximizing science
  - Complementary constraints
  - Complementary data
  - Cross-correlations

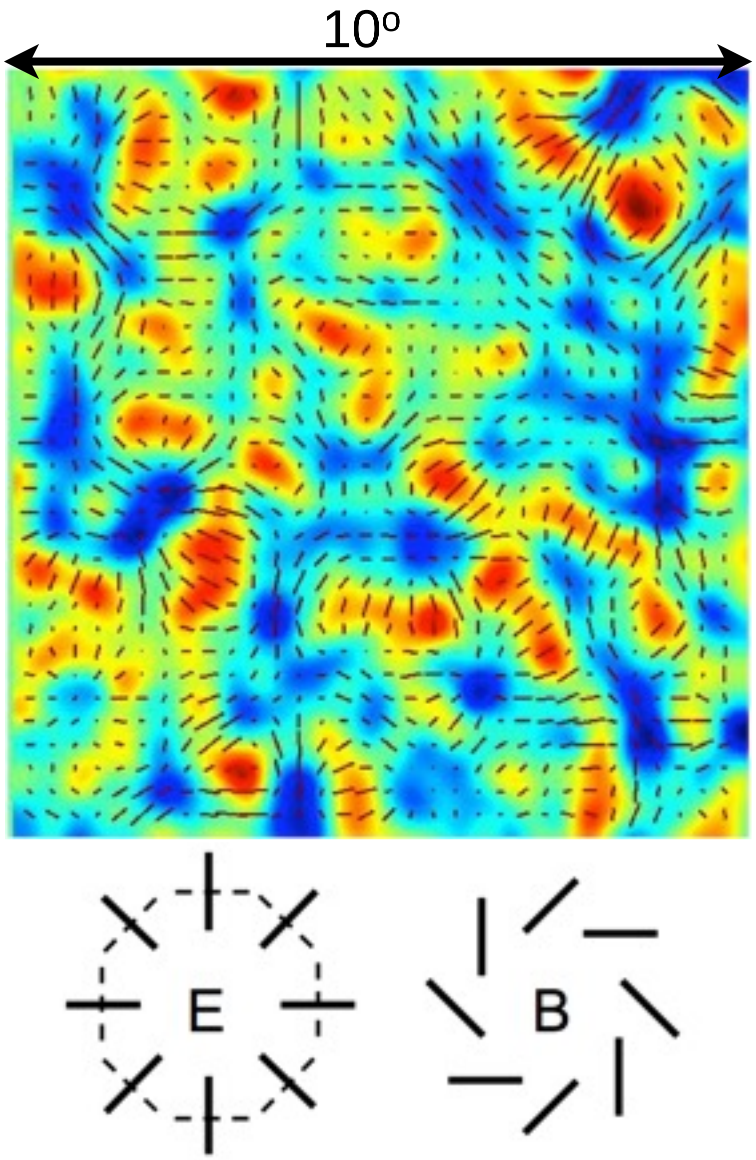
South Pole Telescope

Cosmic microwave power spectrum

from Planck collab.



The Next Frontier:
Polarization

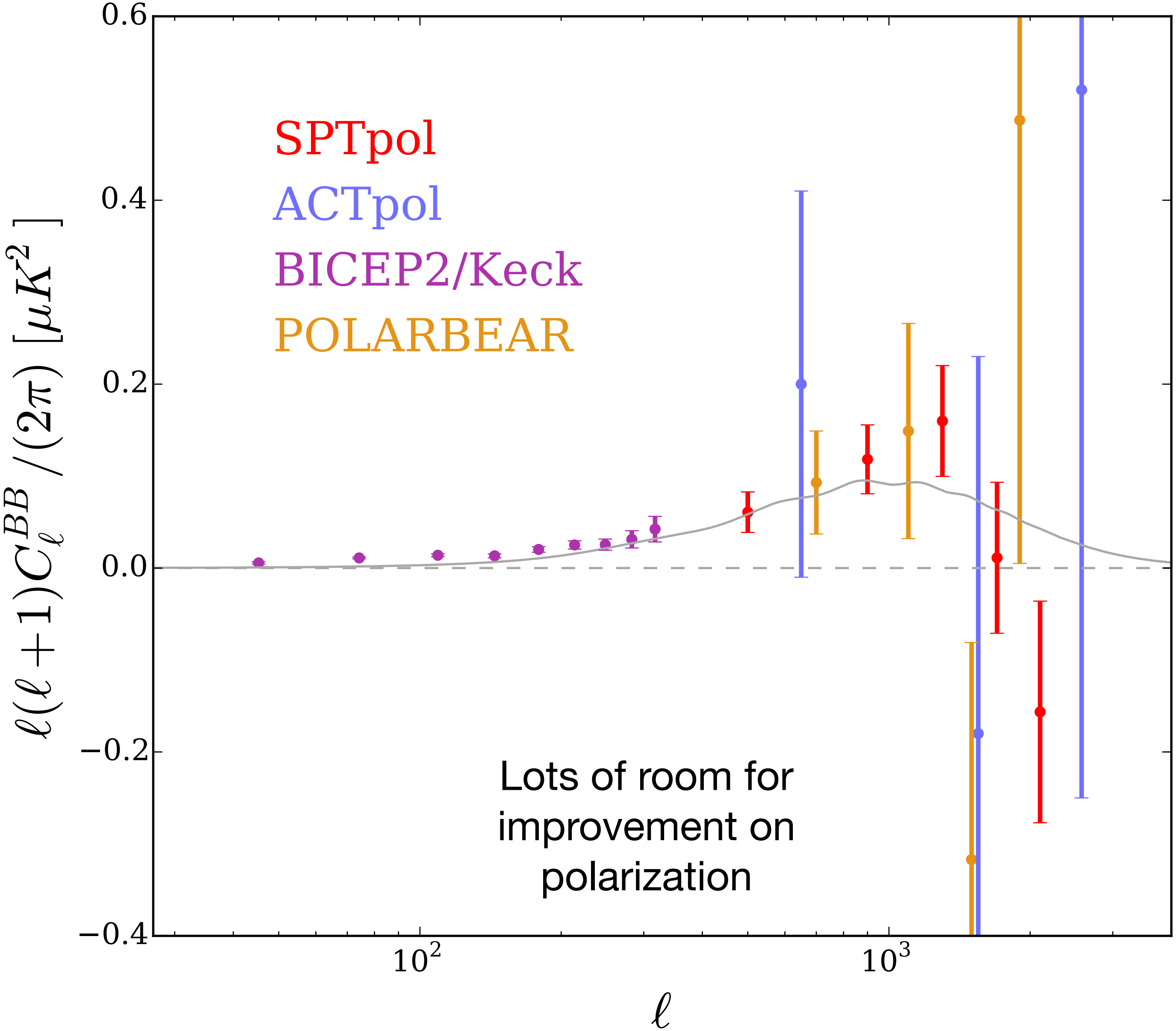


Smith et al 2008

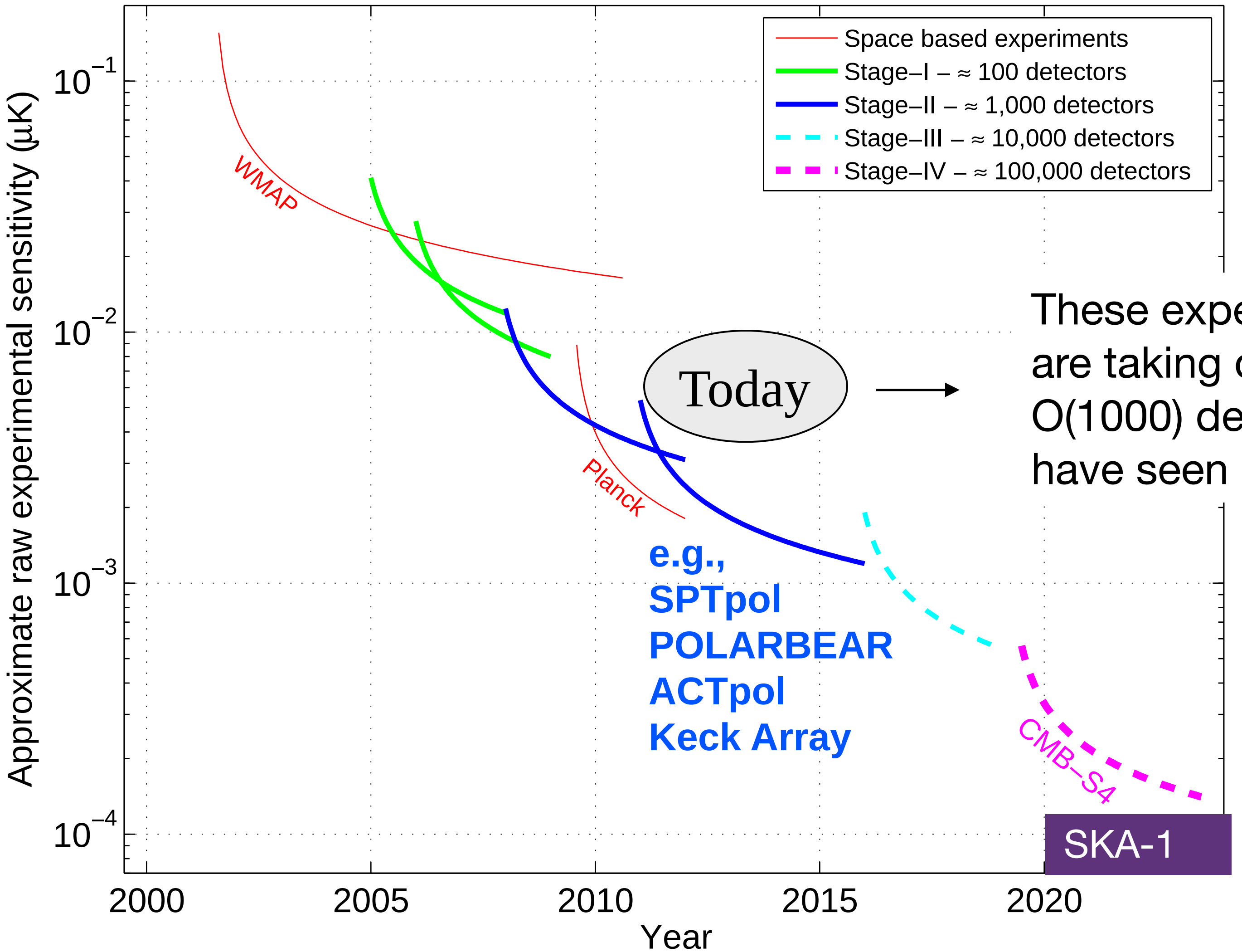
- Any polarization pattern can be decomposed into "E" (grad) and "B" (curl) modes
- Quadrupole anisotropy introduces polarization at surface of last scattering
- Density fluctuations do not produce "B" modes!
- "B" modes are created by:
  - On large scales: primordial gravity waves from Inflation
  - On small scales:
    - lensing of the CMB from large scale structure
    - anisotropic optical depth

Cosmic microwave power spectrum

from Keisler et al.



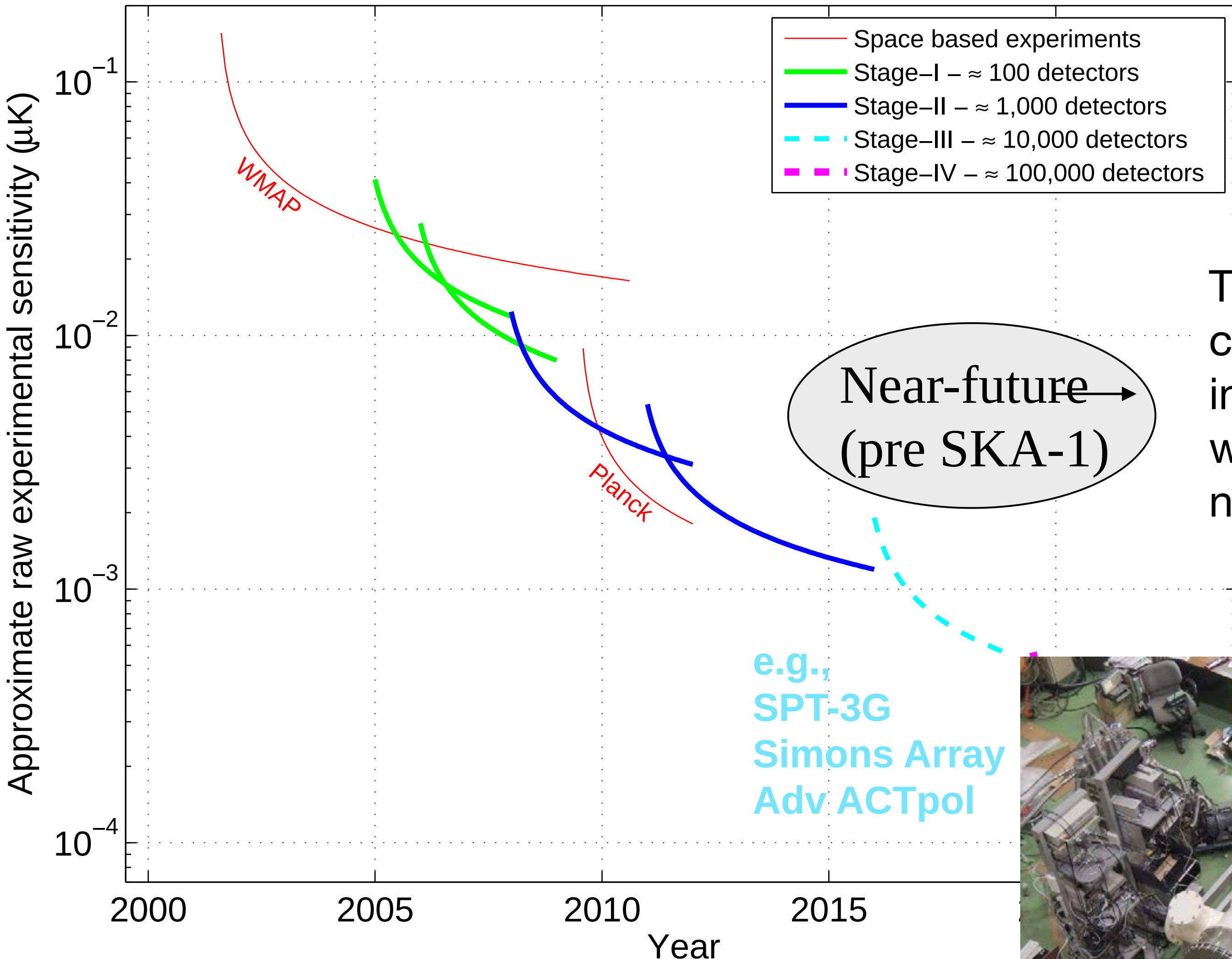
CMB Experimental Stages



These experiments are taking data with O(1000) detectors; have seen B-modes

Snowmass: CF5 Neutrinos Document
arxiv:1309.5383

CMB Experimental Stages



These experiments currently testing/ integrating hardware w. O(10k) detectors; no data yet

Snowmass: CF5 Neutrinos Document
arxiv:1309.5383

On the ground

from L Page

Chile

		Have data	Current or planned freqs
ABS			145 GHz
ACTPol/AdvACT	+Lens	2016	*30, 40*, 90, 150, 230 GHz
POLARBEAR/Simons	+Lens	2015	90, 150, *220* GHz
CLASS			40, 90, 150 GHz
GroundBIRD - *MKIDs*		2016	150 GHz

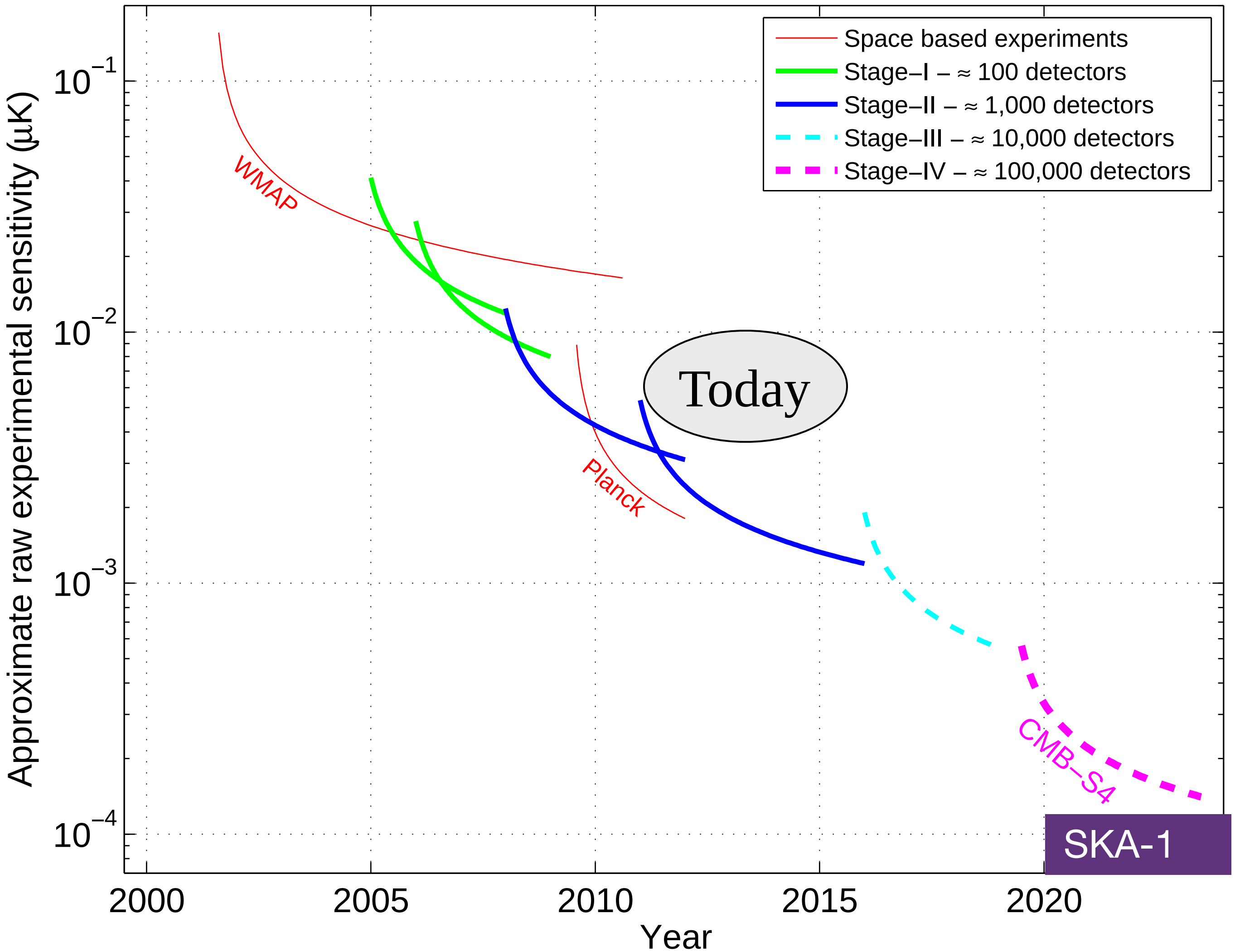
Antarctica

KECK/BICEP3			90, 150, 220 GHz
SPTPol/SPT-3G	+Lens	2016	90, 150, *220* GHz
QUBIC - *Bolo int.*		2016	90, 150, 220 GHz

Elsewhere (for now)

B-Machine –*WMRS*		40 GHz
GLP - *LEKIDs*	TBD	150, 210, 270 GHz
MuSE - *Multimoded*	TBD	44, 95, 145, 225, 275 GHz
QUIJOTE - *HEMPTS*		11-20, 30 GHz

CMB Experimental Stages



Stage-IV CMB experiment = **CMB-S4**

~200x faster than today's Stage 2 experiments

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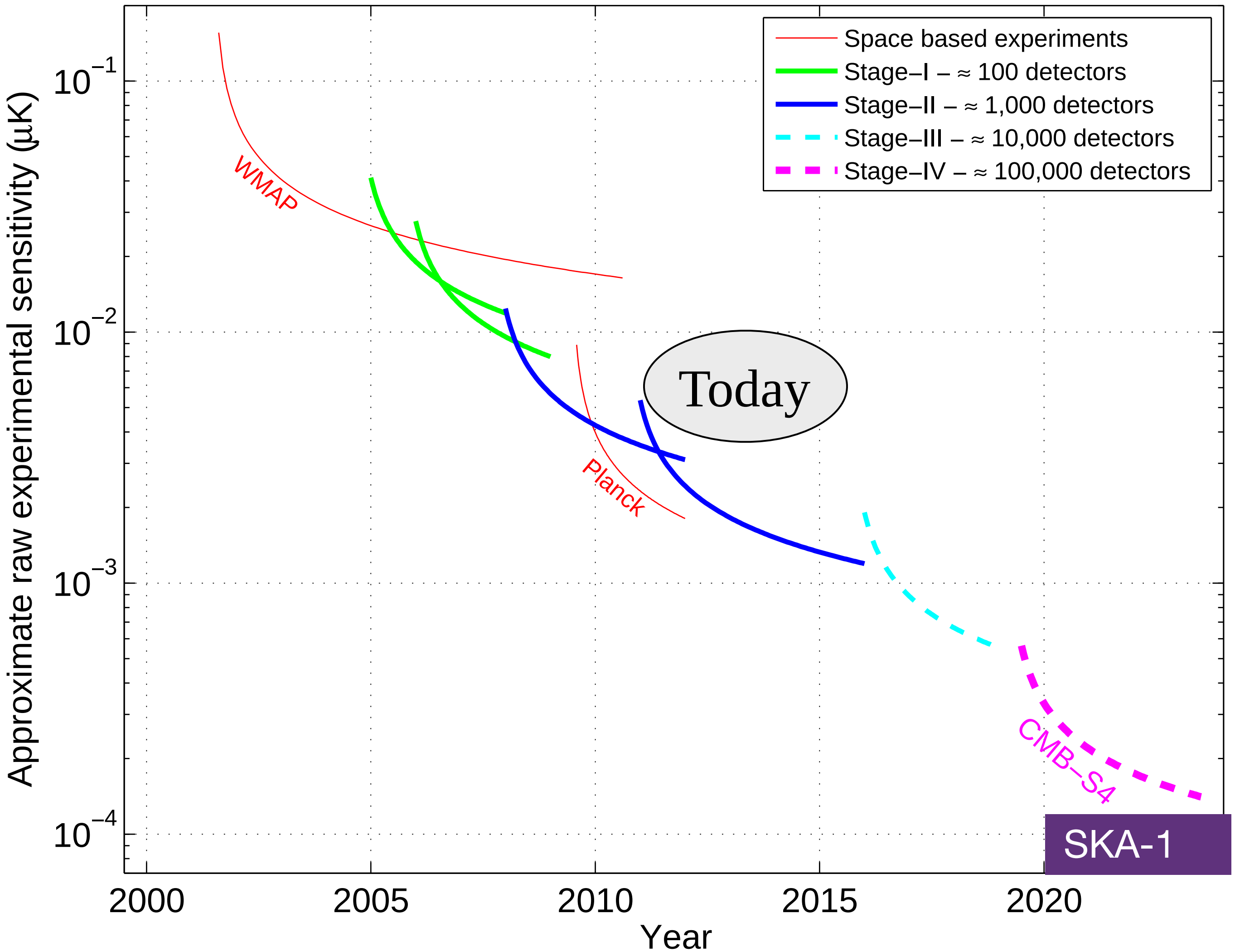
CMB Experimental Stages



Stage IV: Design/specs not finalized.

Expected timeline similar to SKA-1

Given highest priority in US particle physics decadal plan

Snowmass: CF5 Neutrinos Document
arxiv:1309.5383

Credit: C. Chang

Stage IV concept

- Large angular range (degrees to arcminutes) … minimum 3 arcmin resolution
- Half the sky: 20,000 deg^2
- Lots of detectors: ~500,000
- Broad frequency coverage (50-240 GHz)
- Target noise of 1 uK-arcmin over 50% sky, starting 2020 on a 5-year survey.

Primary technical challenge is one of scale

Credit: C. Chang

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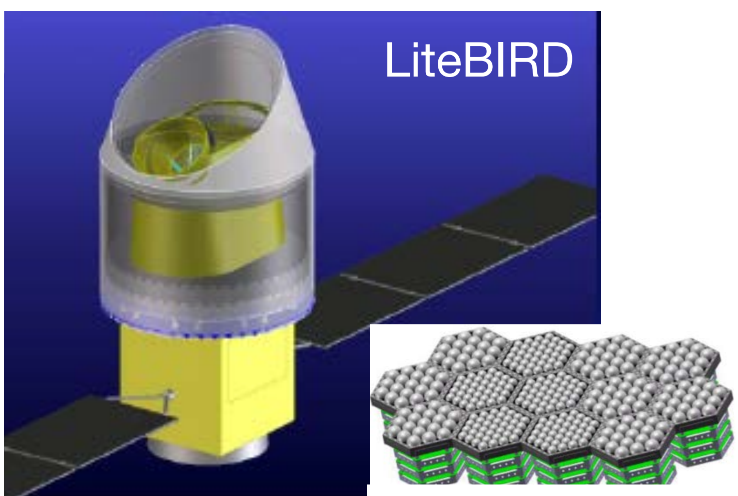
Almost certainly sited in Chile — complete overlap with SKA

Perfect to extend SKA1 mid frequencies

Satellites

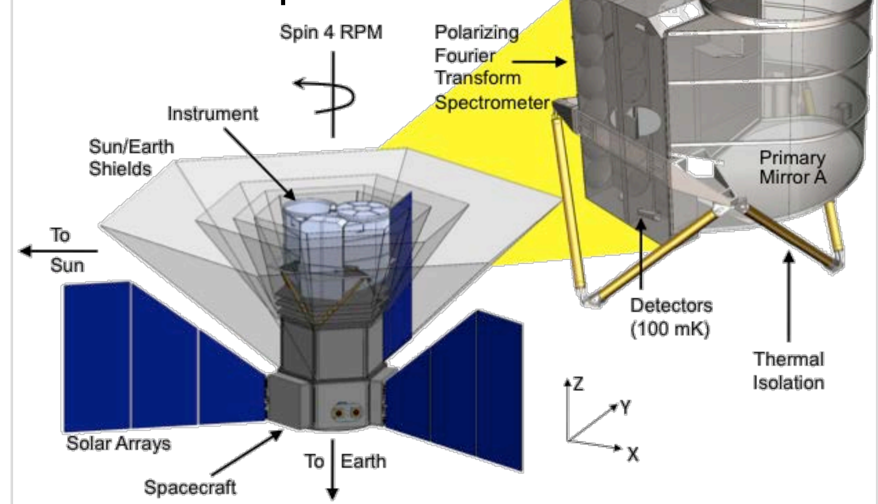
Possibilities:

- LiteBIRD (Japan concept)
- PIXIE (US concept)
- *COrE, PRISM, CMBpol (unlikely for SKA-1; EU, US concepts)*



2,022 Bolometers

PIXIE concept



Basic data product: a map

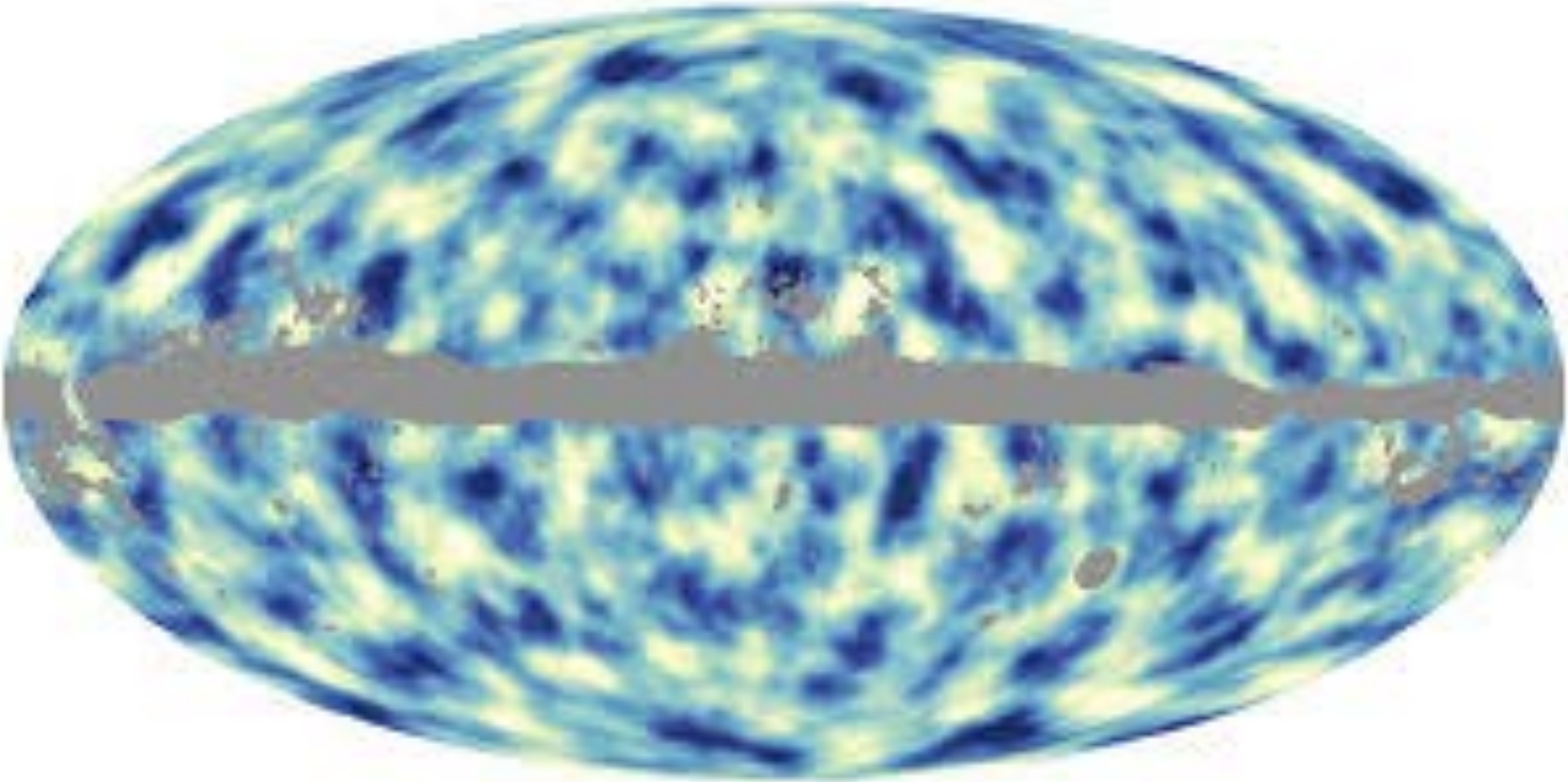
~50 deg^2 from the SPT-SZ
2500 deg^2 survey

No 3d information

A map per frequency band

Can look for time-varying sources,
although not optimized for it

Derived maps
eg Planck lensing map



- Can use multiple frequencies to separate out components, e.g., kinetic SZ map, thermal SZ map, …
- Can use higher-order correlations to get lensing mass maps (above), anisotropic optical depth maps

Outline

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- Maximizing science
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  - Complementary data
  - Cross-correlations

South Pole Telescope

Independent constraints

(possibly complementary?)

Constraints on "vanilla" cosmology

CMB and SKA data are both forecast to improve cosmological constraints
Combination *might* break degeneracies

SKA-side:
From Pritchard et al. 2015

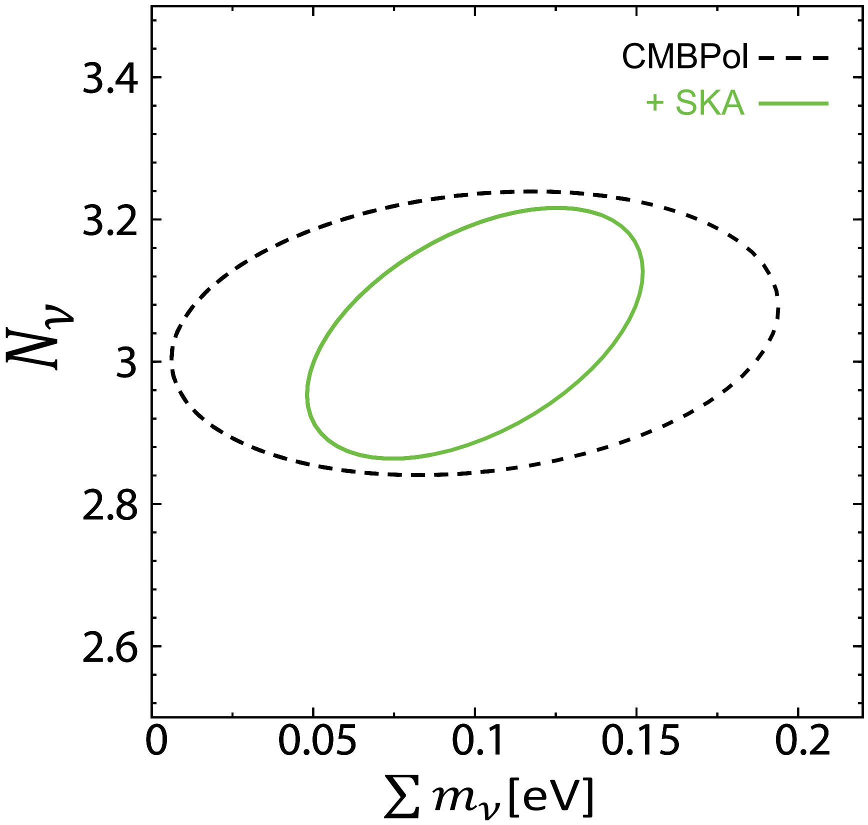
	$\log\Omega_m h^2$	$\log\Omega_b h^2$	Ω_Λ	n_s	$\log(A_s/10^{-10})$	Ω_k	$dn_s/d\log k$	M_ν (eV)
Value	-1.9	-3.8	0.7	0.95	-0.19	0	0	0.3
Planck	0.028	0.0068	0.038	0.0035	0.0097	0.0022	0.0047	0.35
Hera	0.0091	0.0055	0.011	0.003	0.0088	0.0021	0.0036	0.12
SKA0	0.017	0.0058	0.023	0.0032	0.009	0.0022	0.0034	0.22
SKA1	0.0083	0.0051	0.01	0.003	0.0084	0.002	0.0018	0.12

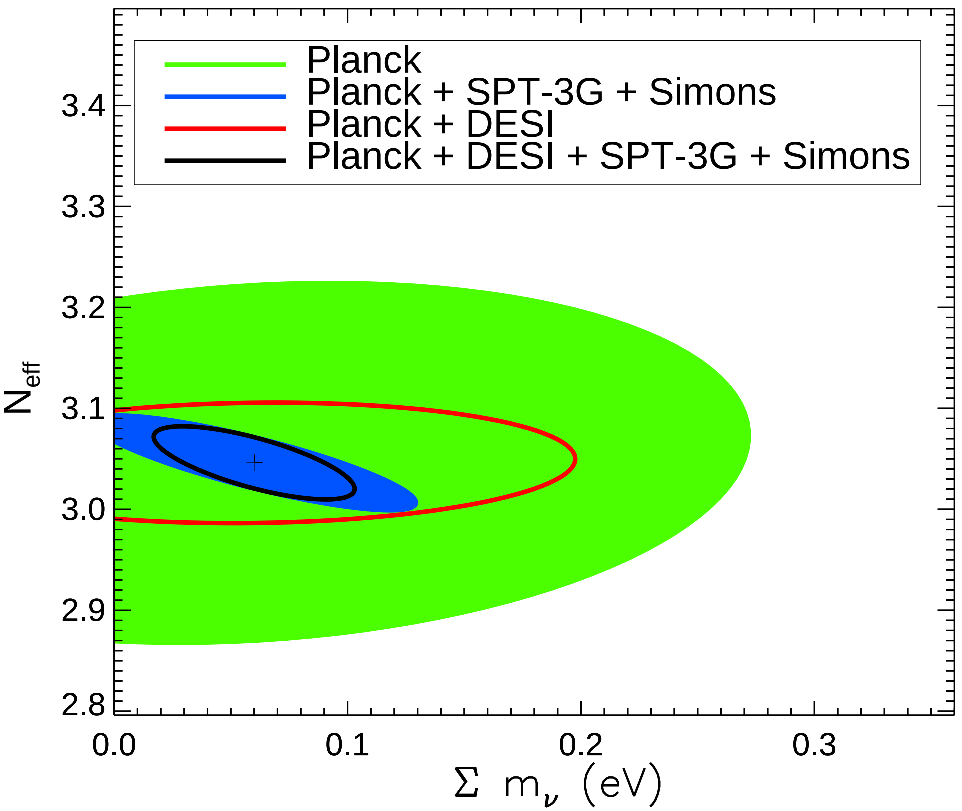
CMB-side (typical for Stage III):

Datasets	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 + DESI	1.17	0.97	3.75	3.66	1.12	4.92	0.39	91	5.72
+ SPT-3G + Simons-Wide	**0.63**	**0.61**	**2.35**	**2.18**	**0.078**	4.61	0.28	**24**	**1.31**

Example: neutrinos

Oyama et al. 2013





Detailed forecasts TBD, but ellipses appear somewhat orthogonal

Testing unusual models

Better CMB data and SKA data are both forecast to improve cosmological constraints
Unclear how much better the combination is…

e.g.,

- Primordial magnetic fields
- Early dark energy
- DM annihilation/decay
- Light DM models (~keV; only PIXIE)
- Cosmic strings

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Pogosian 2013: PRISM (CMB):
σ(PMF) = 0.05 nG
Sethi & Subrmanian: SKA
σ(PMF) = 0.1 nG

NASA/Swift

Complementary data

SKA-low
50-350 MHz

SKA-mid
350 MHz-14 GHz

CMB-IV
50 GHz-240 GHz

Map out SEDs
Gamma ray bursts
FRBs
New mystery objects

credit: N. Whitehorn

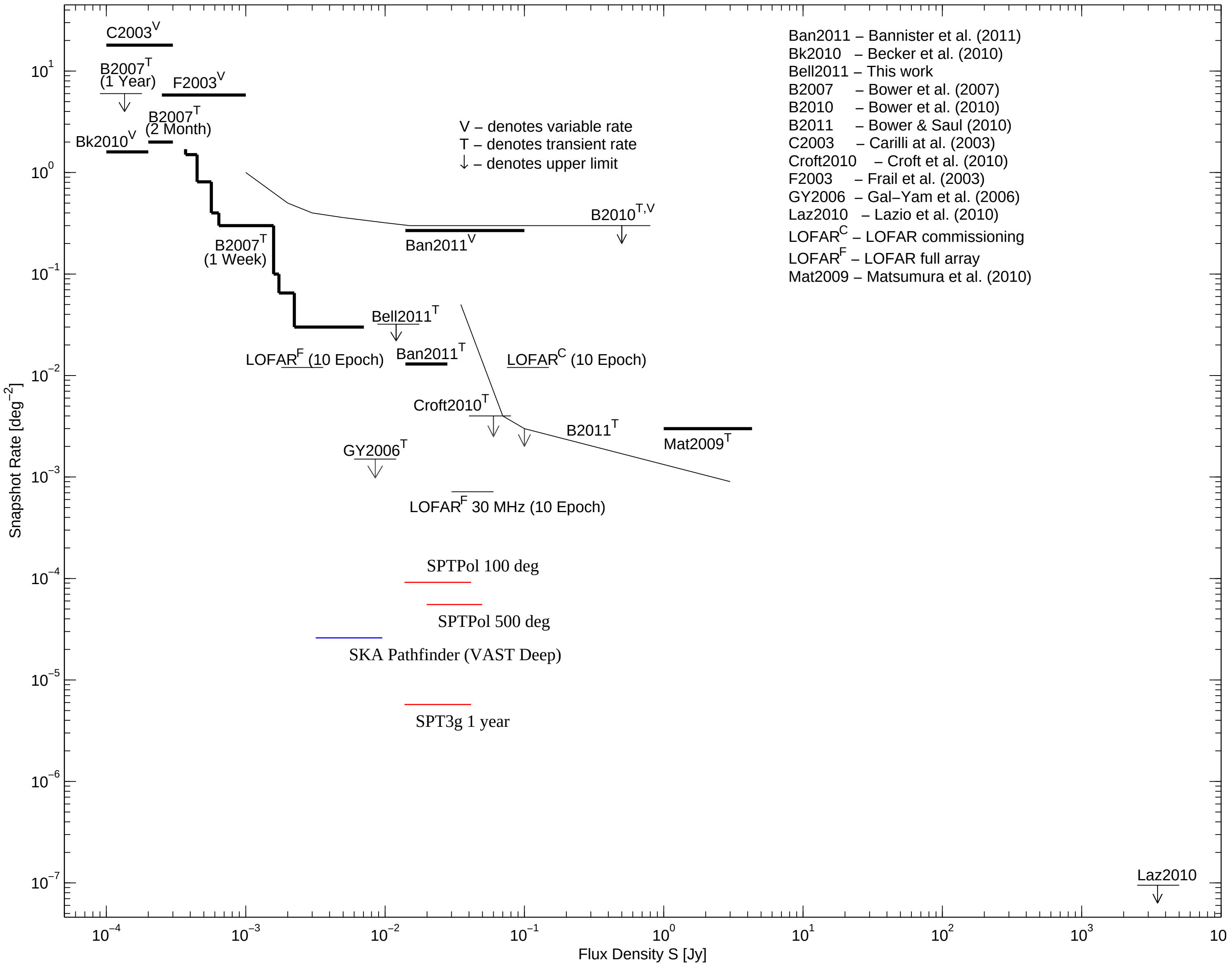
Why are these interesting for us?

- GRBs are highly beamed in gamma rays, since the jet (and Γ) are very high, with a poorly constrained opening angle
- As a result, it's not clear how many of them there are
- At longer wavelengths, the afterglows are less tightly beamed, allowing a rate comparison
- Also: possible class of "gamma-dark" bursts (especially interesting as cosmic ray accelerators)
- Measuring any of this requires the ability to discover bursts at long wavelengths, rather than doing followup
- Obsessive reobservation of a fixed patch of sky is the perfect way to detect these

credit: N. Whitehorn

Comparative sensitivity

An automated archival VLA transients survey.



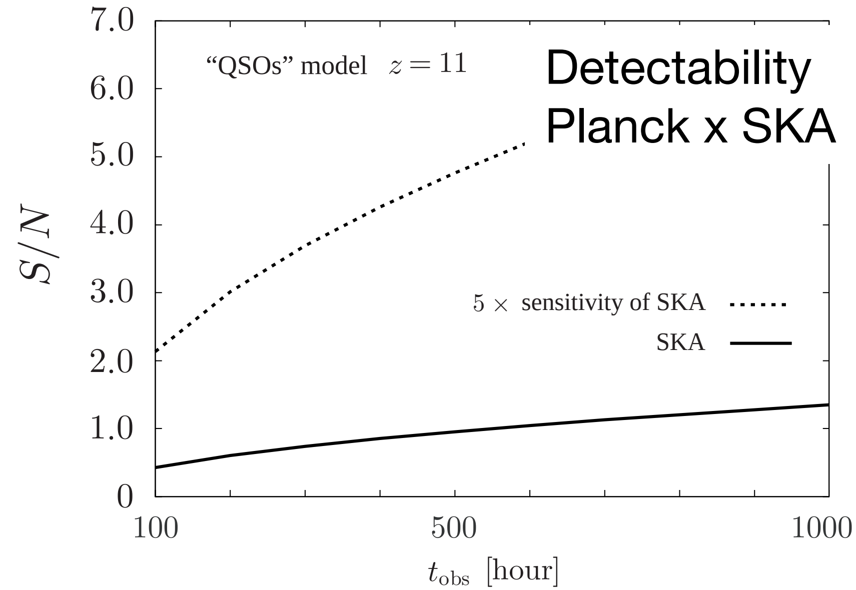
Cross-correlations

- lensing x low-redshift
- kSZ x EOR
- τ x EOR

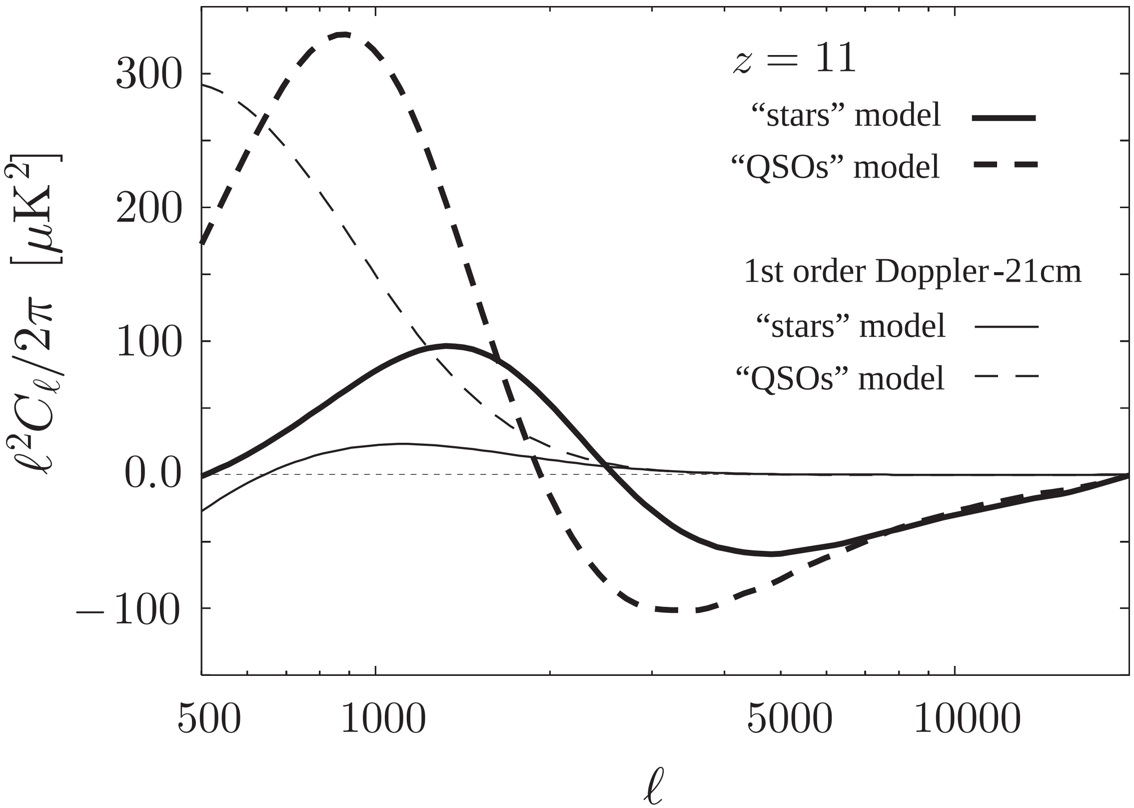
Tashiro et al. 2011

kSZ x 21 cm

(2-pt estimator)



Cross-correlation

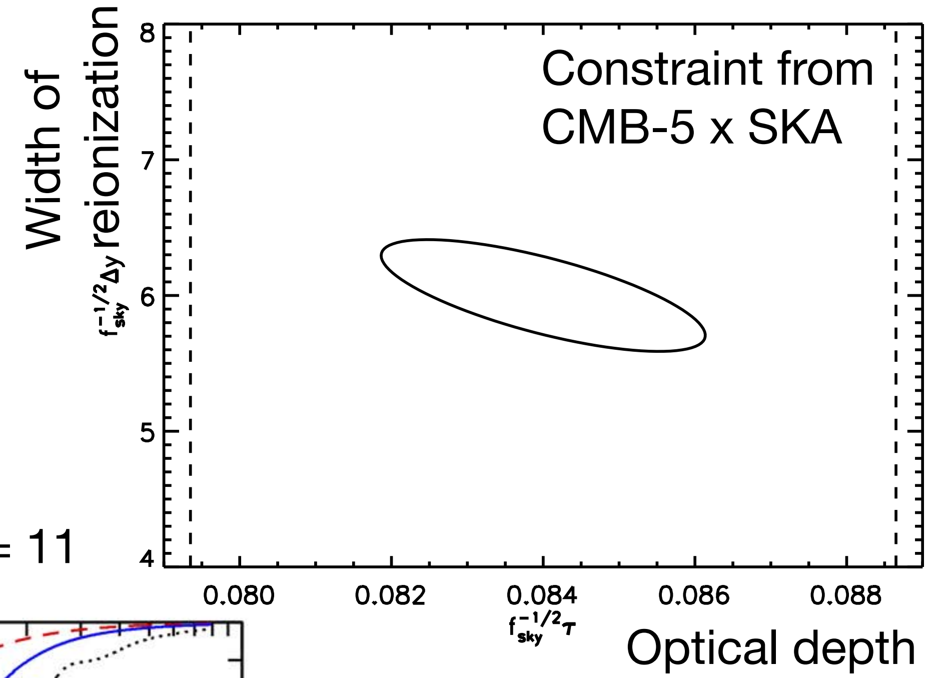


- Potentially interesting test of EoR
- but signal small
  - unlikely with Planck x SKA

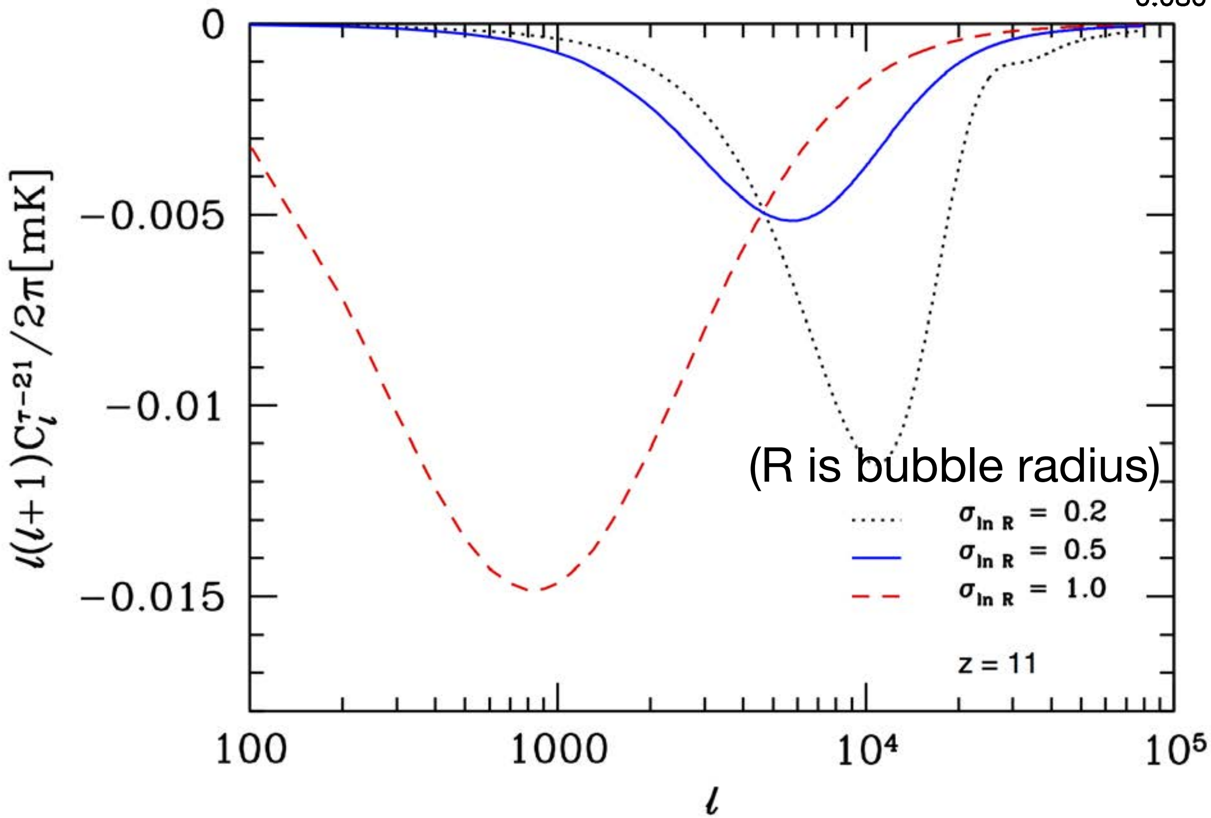
Meerburg et al. 2013

Tau x 21 cm

(3-pt estimator)



Cross-correlation at z = 11



- Avoid foregrounds
- Detectable w SKA - S/N ~16

In conclusion

- Expect extremely sensitive, broad-band CMB experiments on the timescale of SKA-1
- Broad overlap in sky coverage; complementary frequencies
- Cross-correlations are potentially interesting
  - Mitigate foregrounds
  - but Detectability is uncertain