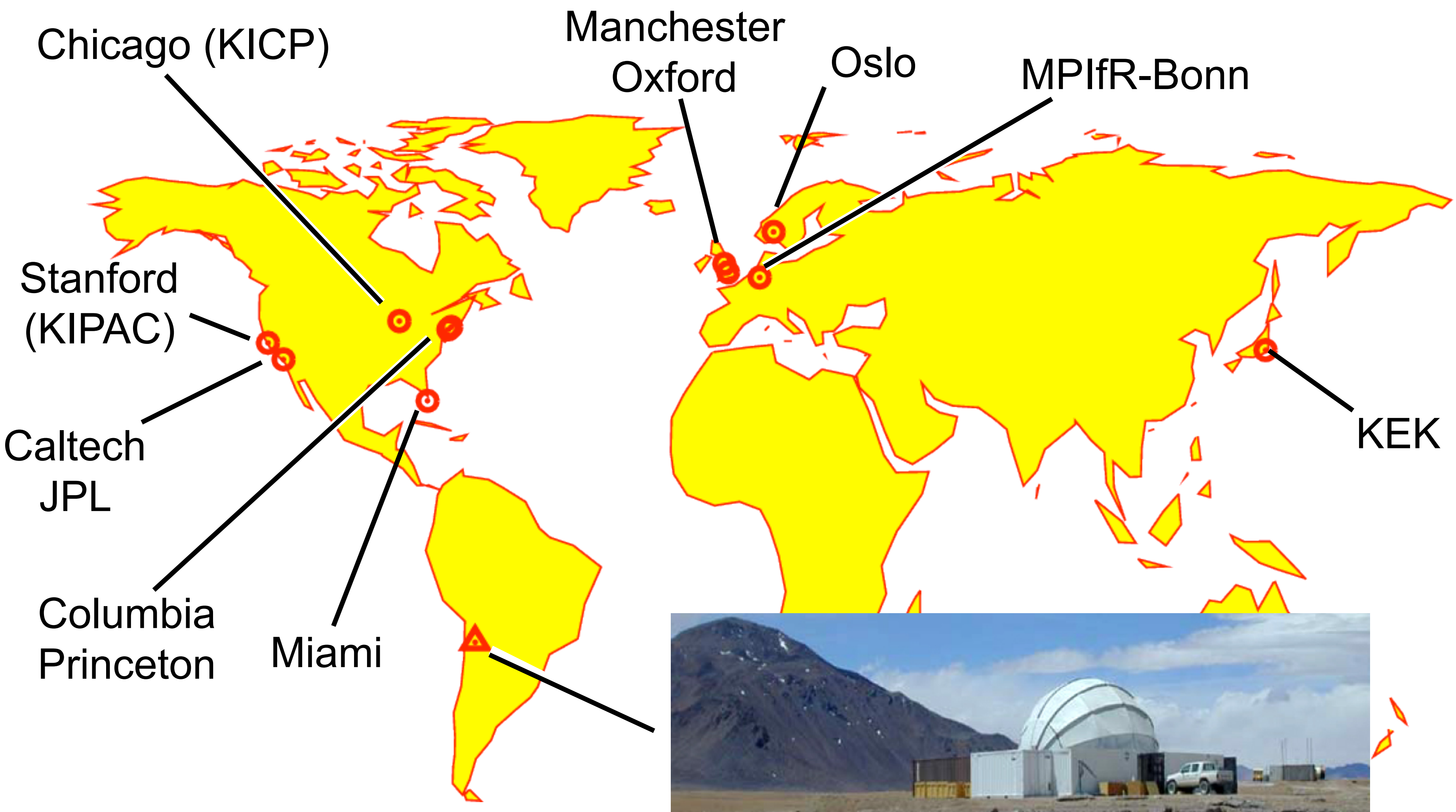
QUIET Collaboration Milestones

Formation	3/03	
Proposal	10/04	
Phase I Proposal (NSF)	6/05	100 detectors
Funding	7/06-7/09	3.7M
Data Taking (Q)	10/08 - 4/09	
Collab. Mtg at FNAL	6/09	
Data Taking (W)	6/09-~3/10	
Supplemental Funding (NSF)	Now	~0.74M
Private Funding	duration	~1.5M
Phase II Proposal	8/09	1600 detectors ~12M US Total
Phase II Approval	~3/10	
Phase II Data	9/11 - 9/15	

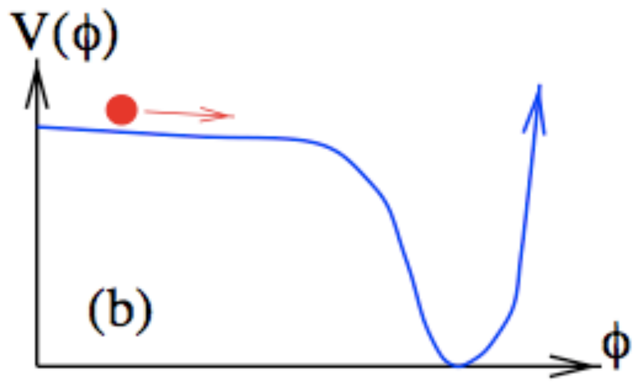
Q/U Imaging ExperimenT Collaboration



5 countries, 12 institutes, ~32 people

Optimism for Gravity Waves ?

(Pagano et al., astro-ph 0707.2560)

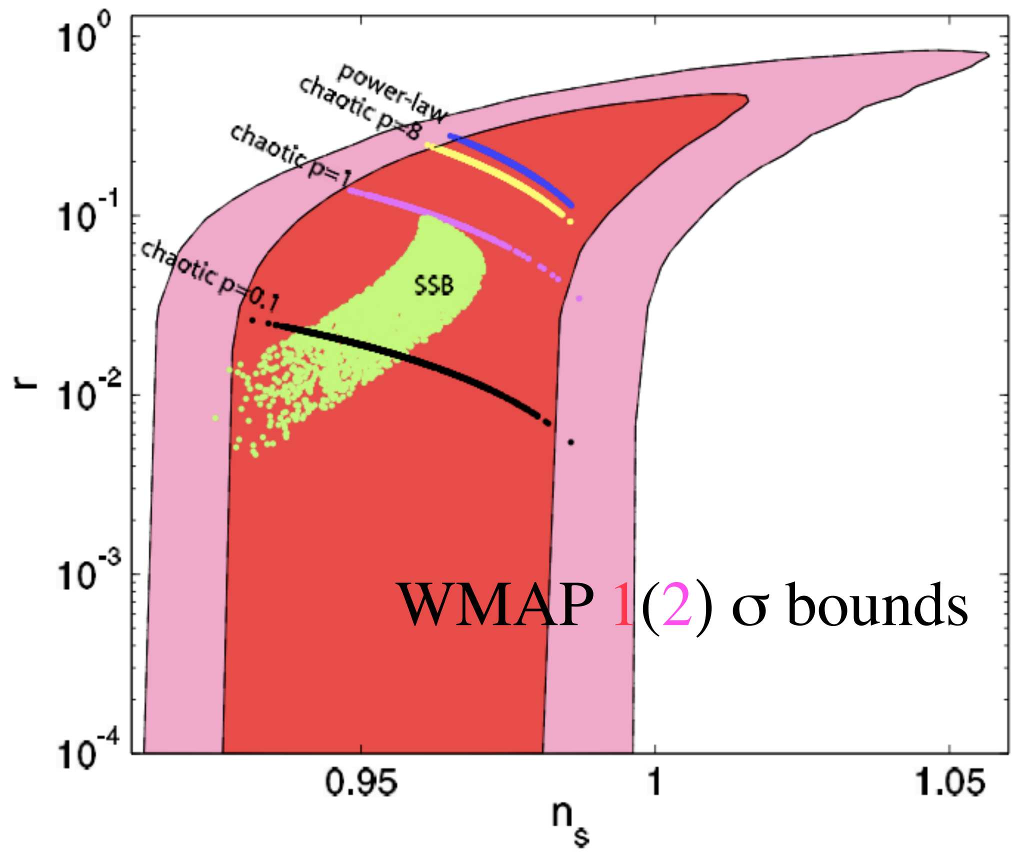


$$\varepsilon = \frac{m_{PL}^2}{16\pi}\left(\frac{V^{'}(\phi)}{V(\phi)}\right)^2 ; \eta = \frac{m_{PL}^2}{8\pi}\left(\frac{V^{''}(\phi)}{V(\phi)}\right)$$

$$n_S \approx 1 - 6\varepsilon + 2\eta$$

$$r \equiv T/S = 16\varepsilon$$

$$n_S \neq 1 \Rightarrow r \neq 0$$



Things that go bump in the CMB polarization: features from inflation versus reionization

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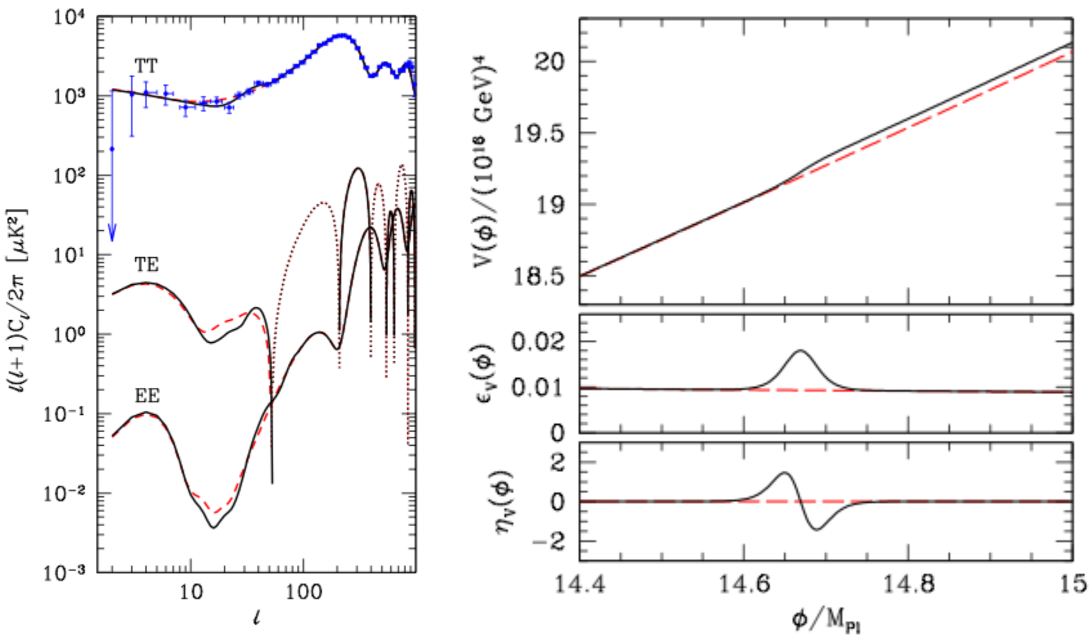
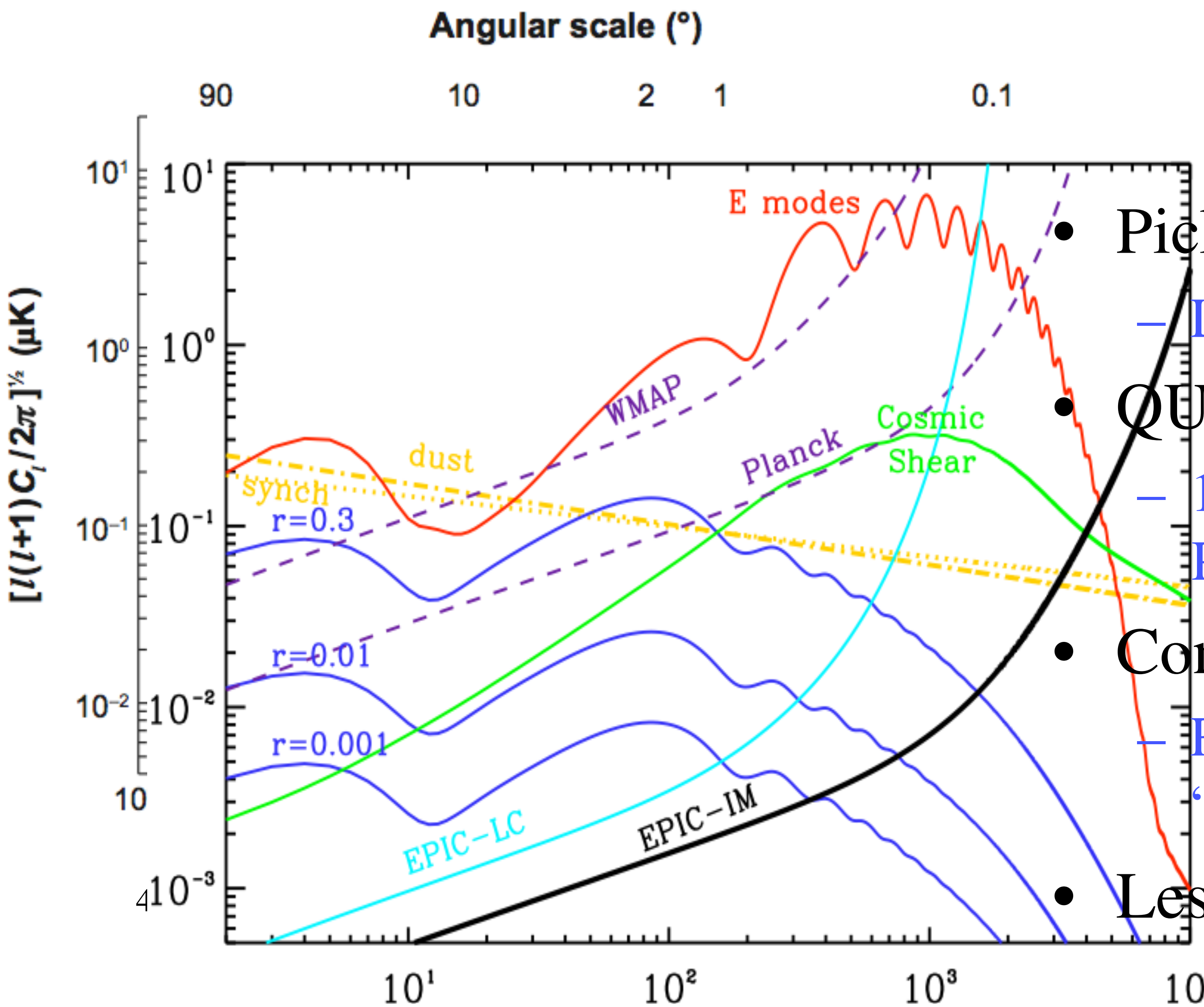
[1] *Department of Physics, University of Chicago, Chicago IL 60637*
[2] *Kavli Institute for Cosmological Physics and Enrico Fermi Institute,*



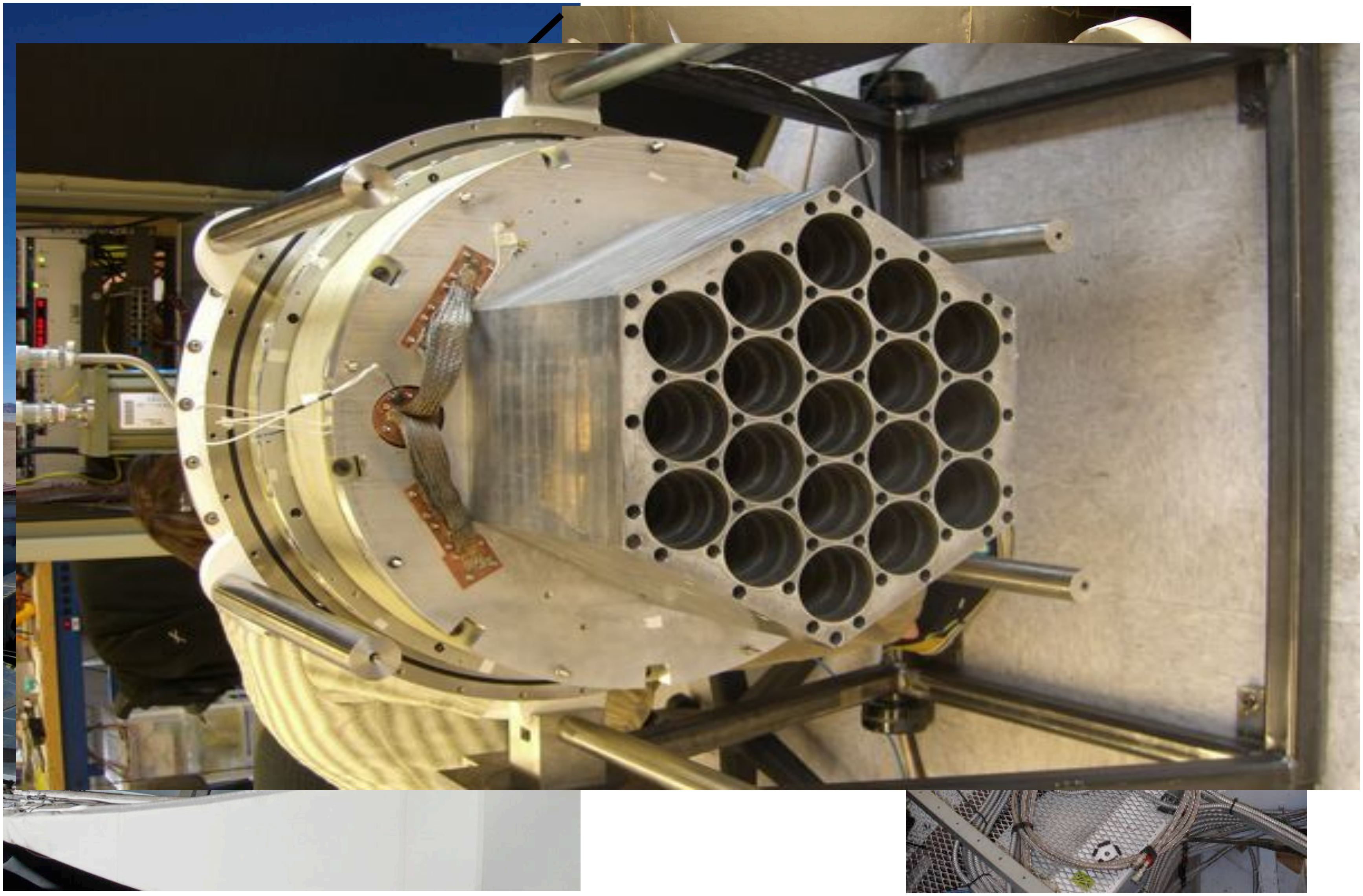
CMB Polarization Power Spectra



Ground based:

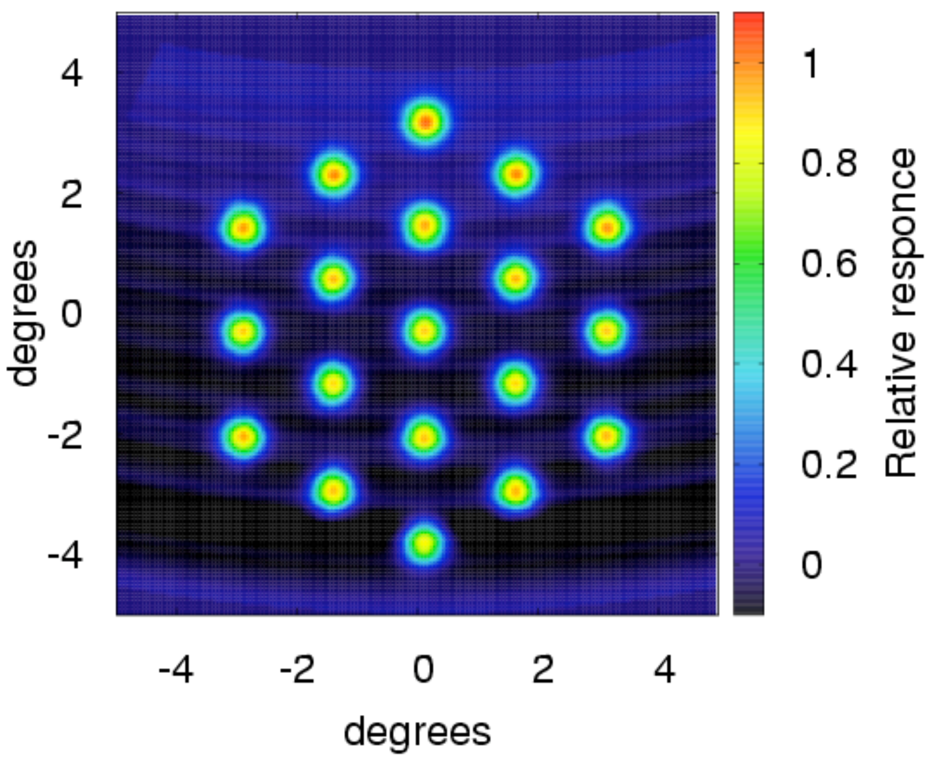
- Pick best sky patches
  - Little foreground
- QUIET integration:
  - 100 times deeper than Planck
- Concentrate on LSS
  - Reionization "impossible"
- Less risk

QUIET currently collecting data

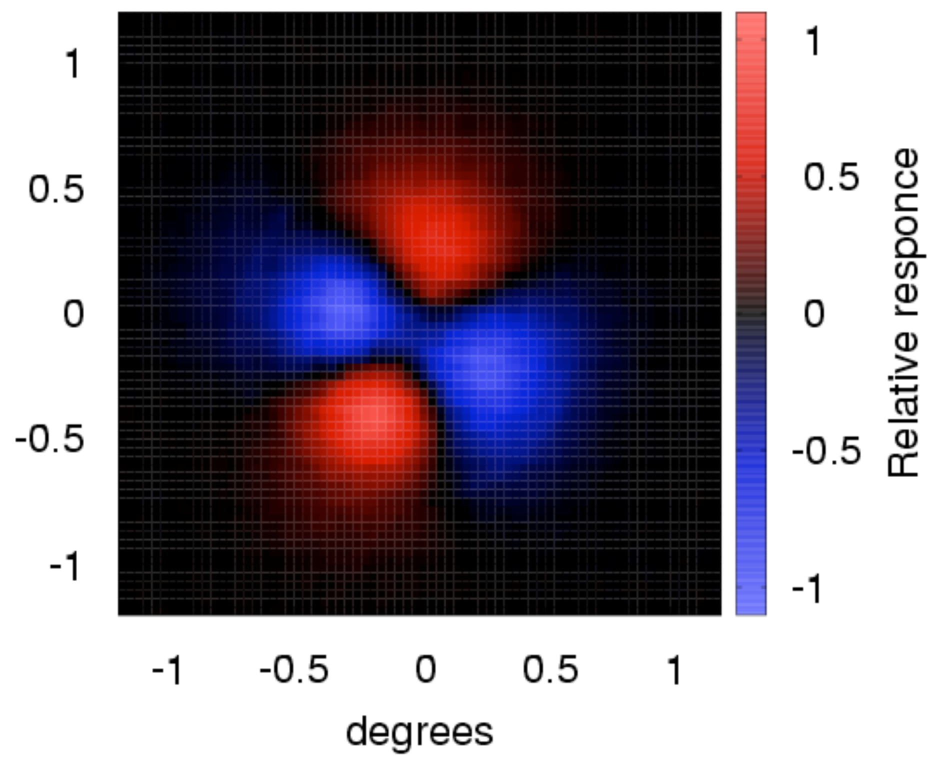


The Moon in Q-band

Total power

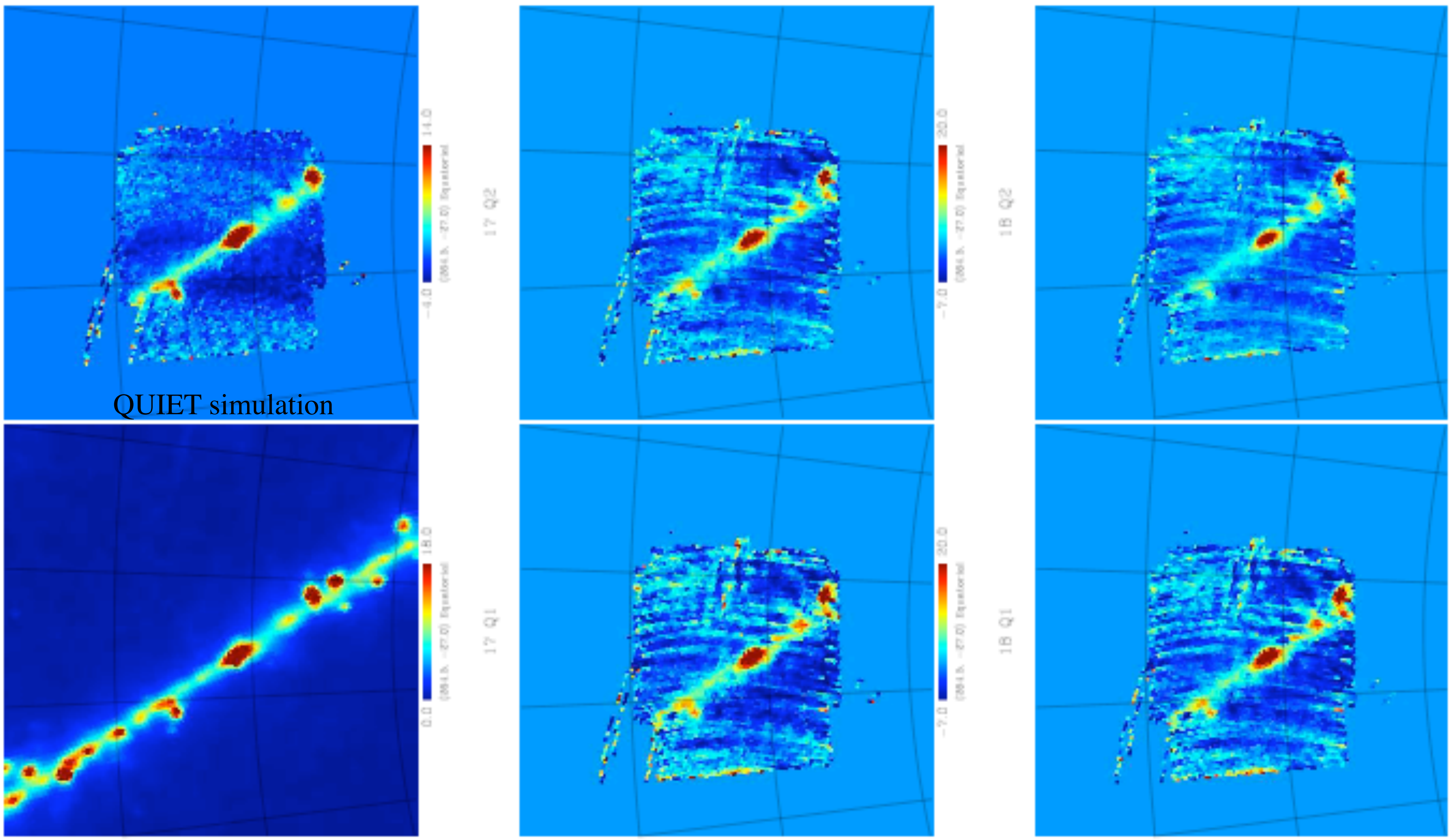


Polarization



The Galaxy in Q-band

(Hardware & Analysis: D. Samtleben, MPI)



WMAP

~5hrs of QUIET data

Preparing the 91-element W-band Array in the Chicago Lab

The Picture of the Field

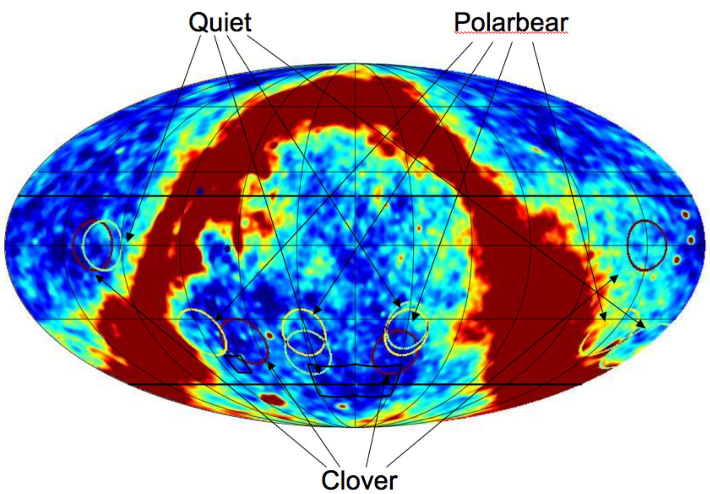
Table 1: Future Suborbital CMB Polarization Experiments.

	Technology	FWHM (arcmin)	Frequency (GHz)	Detector Pairs	Modulator
US-led balloon-borne:					
EBEX (Oxley et al., 2004)	TES	8	150/250/410	398/199/141	HWP
Spider (Montroy et al., 2006)	TES	60/40/30	96/145/225	288/512/512	HWP/Scan
PIPER I	TES	21/15	200/270	2560/2560	VPM
PIPER II	TES	14	350/600	2560/2560	VPM
US-led ground-based:					
ABS(Staggs et al., 2008)	TES	30	150	200	HWP
ACTpol(Fowler et al., 2007)	TES	2.2/1.4/1.1	90/145/217	$\sim$ 1000	Scan
BICEP 2(Nguyen et al., 2008)	TES	37	150	256	HWP/Scan
Keck Array(Nguyen et al., 2008)	TES	55/37/26	100/150/220	288/512/512	HWP/Scan
MBI(Korotkov et al., 2006)	NTD	60	100	4	Int.
Poincare(Chuss, 2008)	TES	84/30/24	40/90/150	36/300/60	VPM
PolarBeaR(Lee et al., 2008)	TES	7/3.5/2.4	90/150/220	637	HWP
QUIET I(Samtleben, 2008)	MMIC	20/10	44/90	$\sim$100/1000	ϕ-switch
SPTpol(Ruhl et al., 2004)	TES	1.5/1.2/1.1	90/150/225	$\sim$ 1000	Scan
European-led ground-based:					
BRAIN(Polenta et al., 2007)	TES	60	90/150	256/512	Int.
C_ℓOVER(Piccirillo et al., 2008)	TES	7.5/5.5/5.5	97/150/225	3x96	HWP
QUIJOTE(Rubino-Martin et al., 2008)	HEMT	54-24	10-30	34	HWP

This is most definitely NOT a race! (e.g. w measurement)

What Characterizes/Distinguishes QUIET?

- Unique RF technology
  - Different (likely better) systematics
  - 4 KHz modulation
- Modulation from sky rotation
- Q & U measured simultaneously
- ~6% of the sky mapped 100 times deeper than Planck
  - Sensitivity to r = 0.01
    - Based on <u>current</u> performance (noise, duty cycle)
- Alliance with (bolometric) POLARBEAR and ABS
  - Identical Patches
  - frequencies straddle WMAP "sweet spot"
- HEP-like
  - 800kHz digitization (FPGA demodulation)
  - simulations, data reduction
  - Systematics, systematics, systematics
- Upgrade Path:
  - Sharing ATACAMA telescopes
  - MMIC improvements: from 20 QL to 10 QL to 3QL
    - CIT/JPL Keck Institute Program



Workshop Overview

MMIC Array Receivers and Spectrographs Workshop 2

| overview | schedule

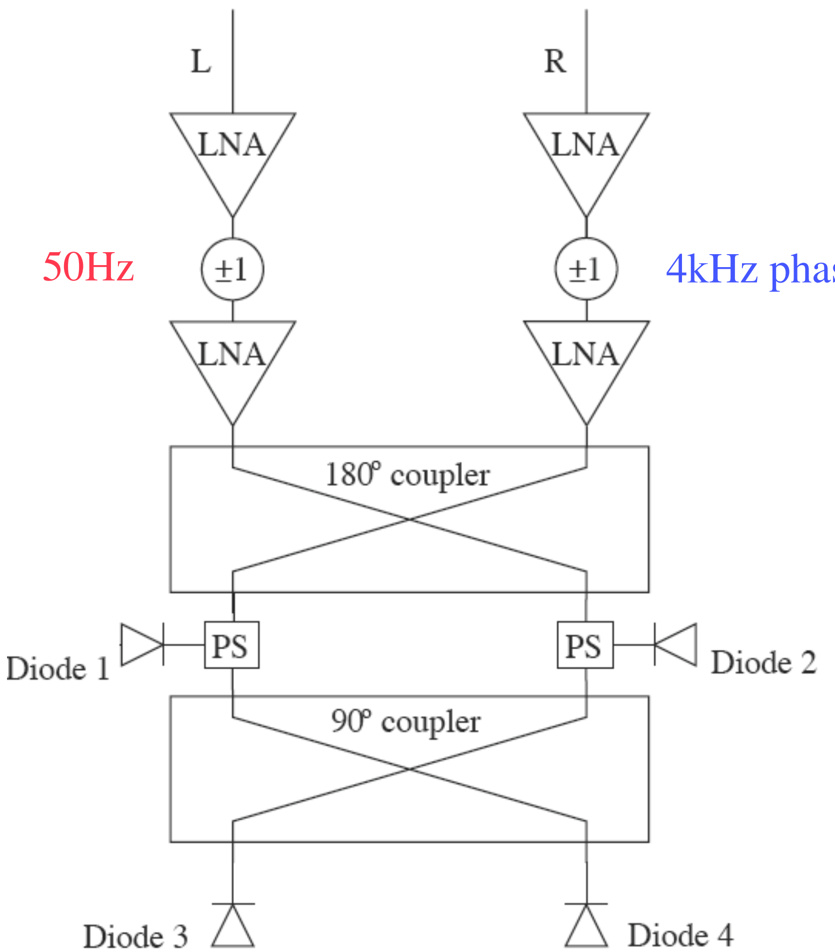
March 22 - 24, 2009
California Institute of Technology
Pasadena, CA 91125

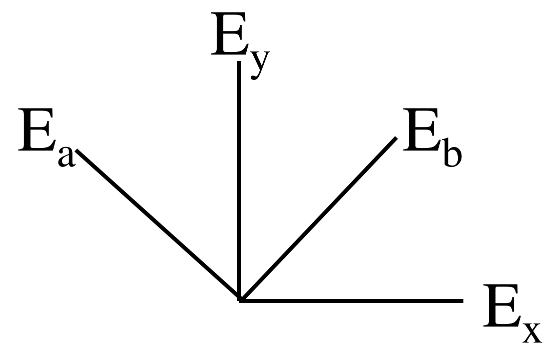
This study has the following objectives:

1. Explore the science that would be enabled by large MMIC arrays for cosmology, astrophysics, planetary science, atmospheric science, and remote sensing of the Earth. Would this be "transformational" science?
2. Explore the technical promise and projected capabilities of MMIC arrays over the next decade. What are the current limitations to their development? (funding?, shortage of groups working on this worldwide?, other?)
3. Determine the key technical developments that are needed both for MMIC arrays themselves and for digital backends. Identify prototypes that should be the subject of follow-on funding.
4. Devise a roadmap for MMIC arrays and MMIC array spectrograph development over the next decade, including the prototypes, the likely sources of funding, the principal instrumentalist groups and industries that should be involved, etc.
5. Recommend specific prototype development programs that should be funded over the next 2-3 years to ensure timely exploitation of this rapidly developing capability.

"The two highest priorities of the KISS program are improvement of the cryogenic performance of HEMT MMICs at frequencies up to 300 GHz, and realization of the full performance potential of the MMICs in complete radiometer/polarimeter modules. Work on improving module performance has already started. Work on improving the cryogenic performance of MMICs is expected to commence by the fall, after a new lab is set up that can make cryogenic measurements on-wafer."

QUIET L/R Correlator: Simultaneous Q/U measurements



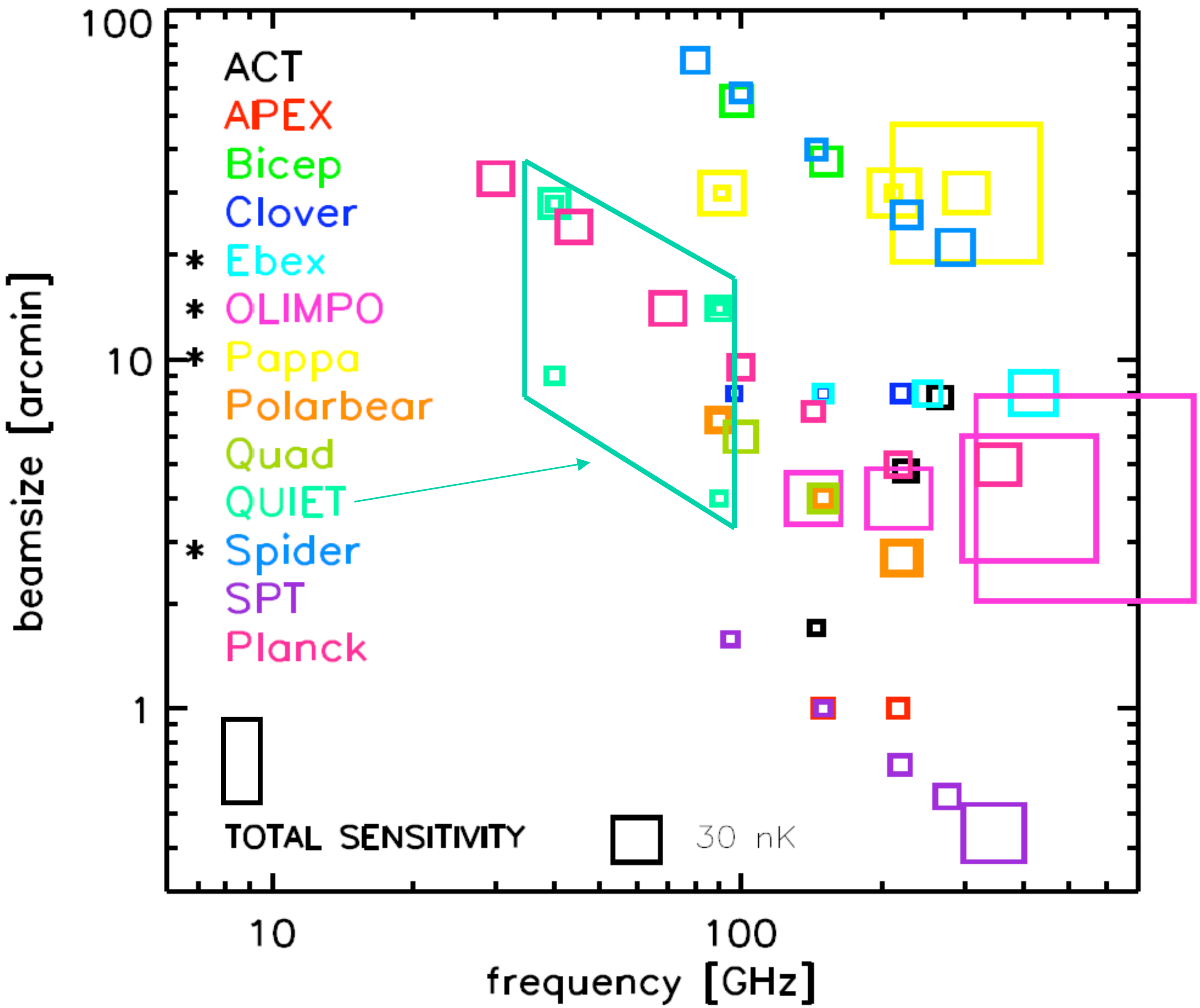


$$\left|L \pm R\right|^2 = \left|\left(E_x + iE_y\right) \pm \left(E_x - iE_y\right)\right|^2 = \underbrace{4E_x^2, 4E_y^2}_{Q}$$

$$\left|\left(L \pm R\right) + i\left(L \mp R\right)\right|^2 = \left|L \mp iR\right|^2 = \left|L\right|^2 + \left|R\right|^2 \mp 2\,\mathrm{Im}\left(RL^*\right)$$

$$\mathrm{Im}\left(RL^*\right) = \mathrm{Im}\left(E_x + iE_y\right)^2 = 2E_xE_y = \underbrace{E_a^2 - E_b^2}_{U}$$

Future CMB experiments
(D. Samtleben)



Why CMB Polarization?

V. CONCLUSION

Cosmic microwave background polarization offers an extraordinary opportunity to gain a

first glimpse into the physics that shaped our Universe. Experimentalists have demonstrated

that a coordinated attack on this problem over the coming decade will likely detect primordial gravity waves – thereby providing extensive information about new physics at ultra-high

energy scales – or severely constrain the scenario responsible for the origin of the Universe.

S. Dodelson et al., Decadal Survey White Paper

Why DOE?

"CMB research is another example of relatively small investments with big payoffs for particle physics and of fruitful cooperation between agencies: DOE supported Smoot's work on COBE, resulting in the recent shared Nobel Prize. In recent years, DOE has received requests for only very small amounts of support for CMB research, with the bulk of the funding coming from NSF and NASA, but DOE-funded technical contributions have been key. Both NSF and DOE should remain open regarding future investment in this area if the correct opportunity arises. In any case, small levels of continued support for detector development are certainly warranted."

(from the P5 report, 29 May 2008)

F=ma

Most Important Lessons Learned in Phase I

- Modules
  - "Need" to improve noise temperature and bandwidth
  - Want ~1600 Modules
    - Need to fabricate at ~100/month
      - cf ~10/month in Phase I
- Need L/R OMTs with better performance
- Cable Plant will need simplification
- Need to enlarge the collaboration
- Project Management
  - Need dedicated and experienced manager