The South Pole: Acbar and the SPT

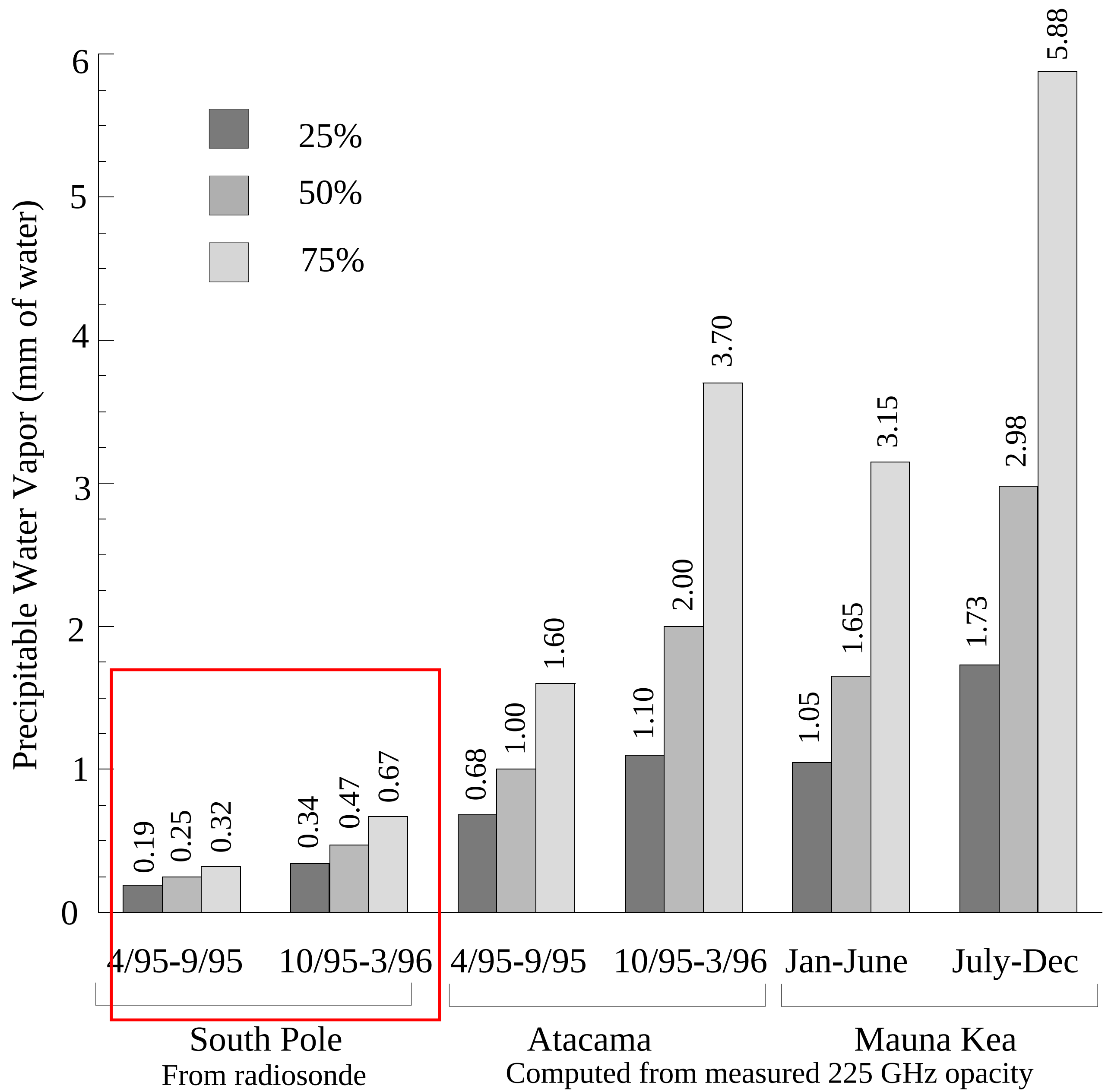
John Ruhl, Case Western Reserve University

Pressure Altitude ~ 12,000’

Very high and cold ⇒ very little water vapor

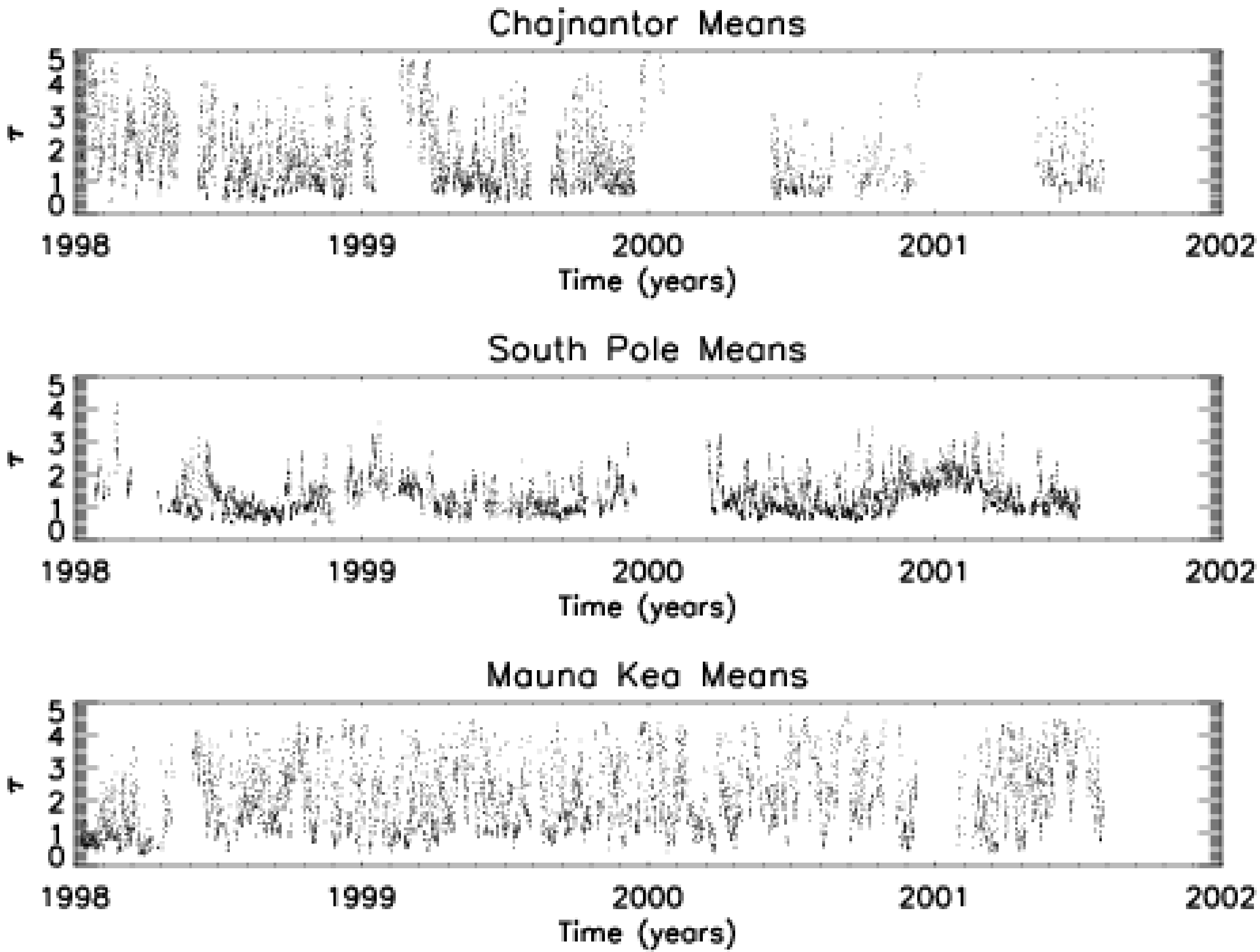
(the best observing this side of L2)

Quartiles of PWV at three Sites



L2

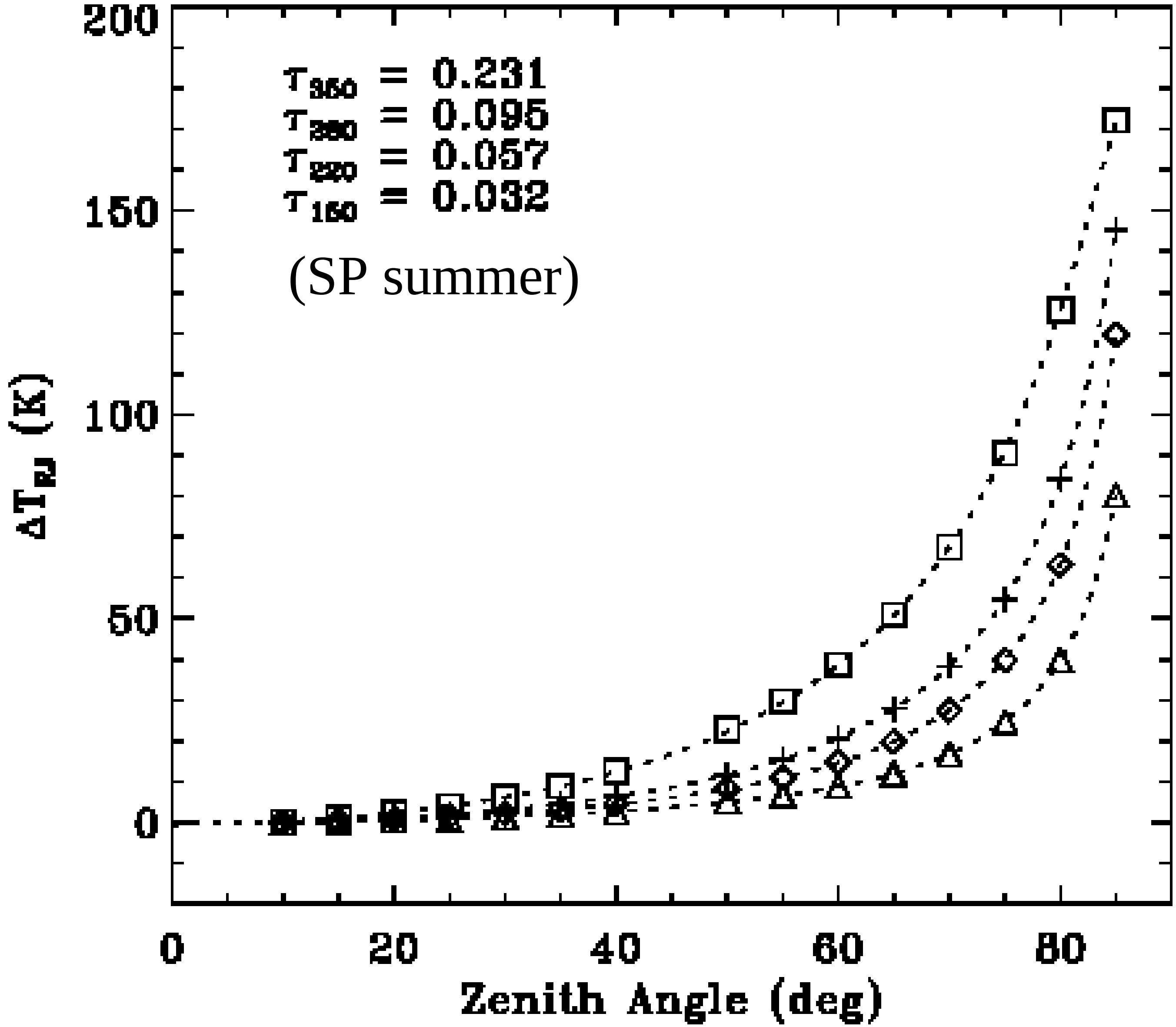
Atmospheric stability



860 GHz Zenith Optical Depth J.B. Peterson et al. 2002

Acbar skydips determine atmospheric opacity…

(and soon, Bussman etal 2004, atmospheric noise properties in Acbar's bands…)



The ACBAR Collaboration

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LBL:
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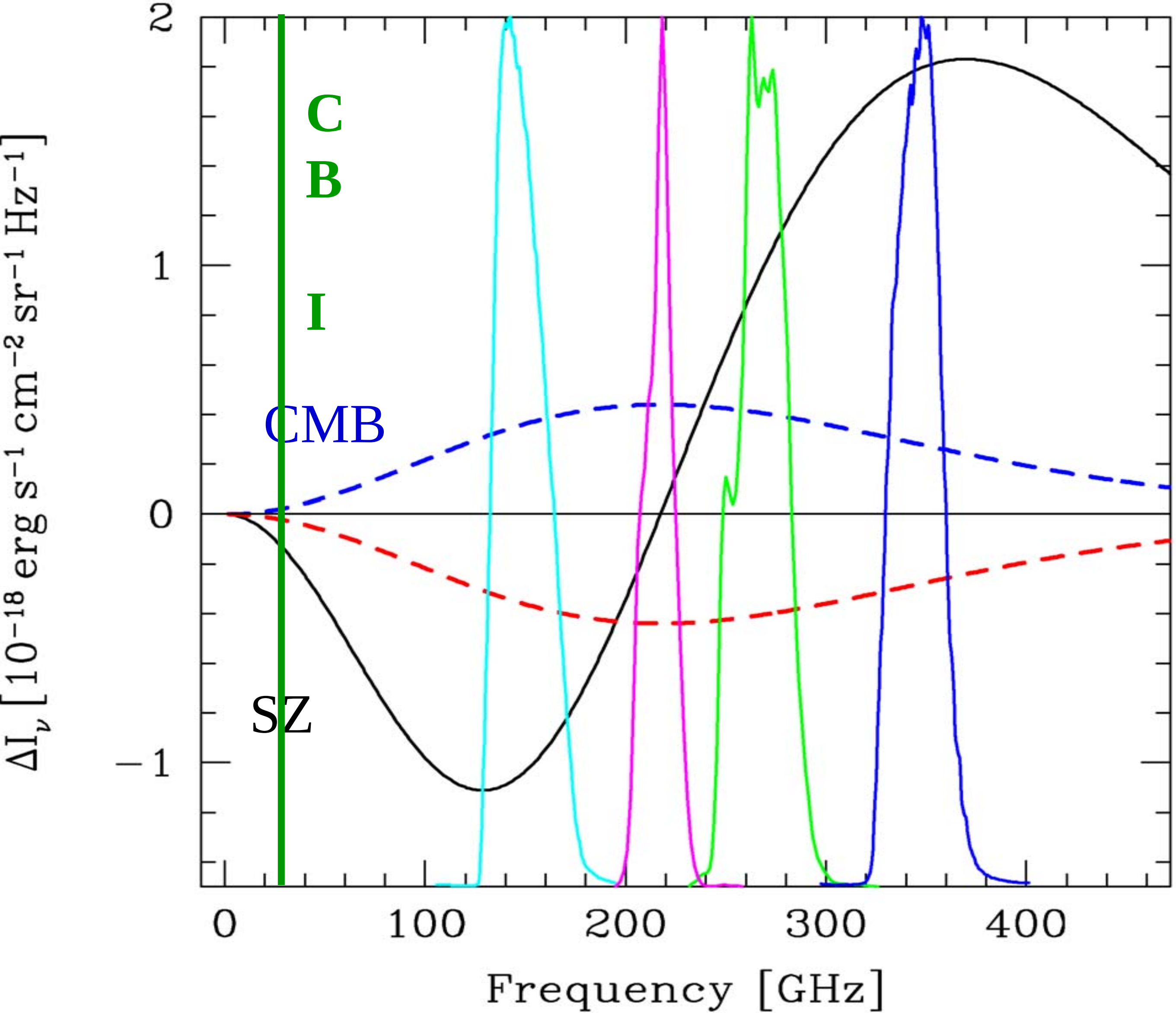
Funded by the NSF Office of Polar Programs

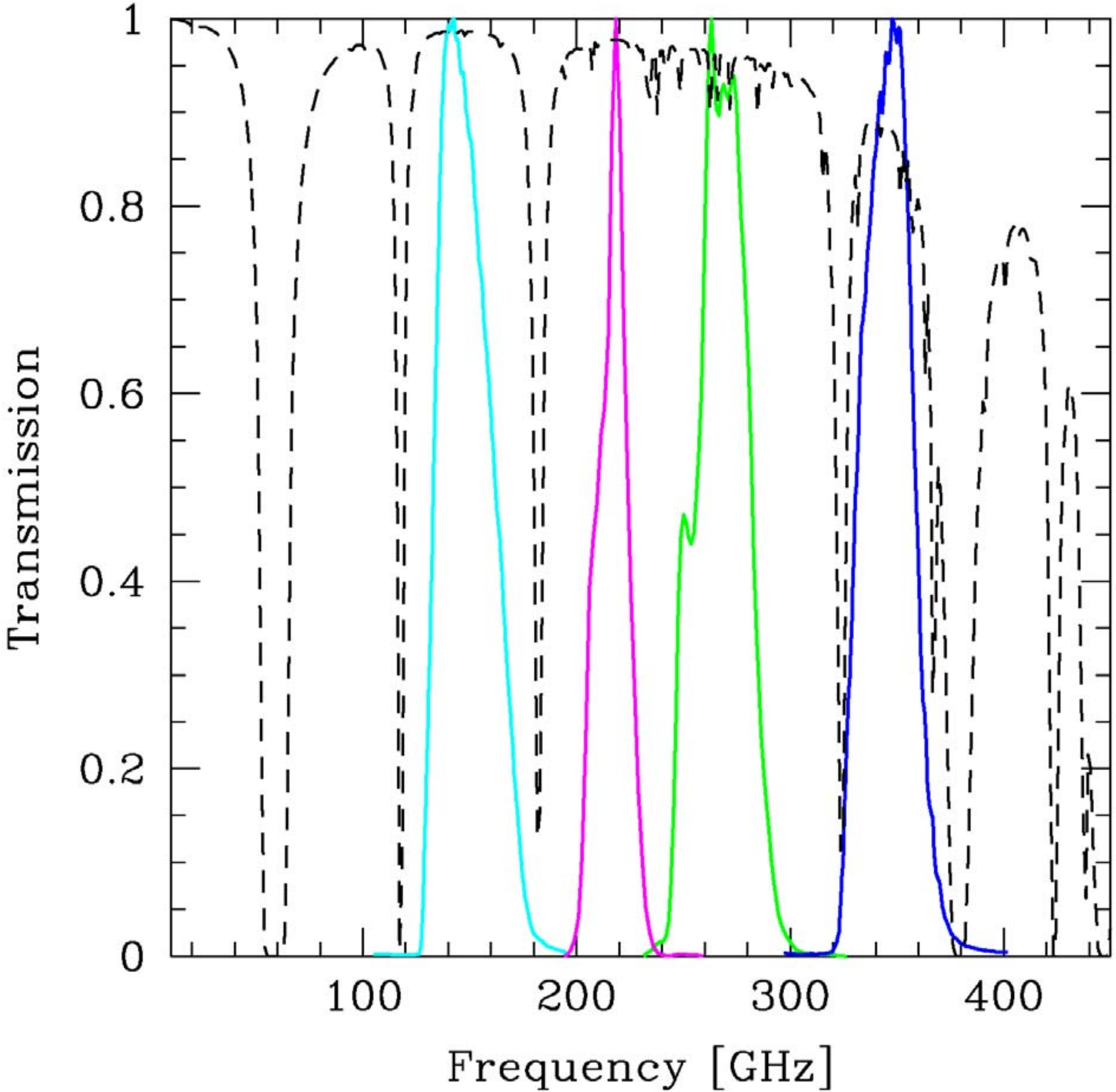
Winterovers:
Matt Newcomb (2001,2002)
Paolo Calisse (2003)
Justus Brevik (2004)

Acbar Bands vs. Cosmic Signals



Band	**Width**
150	20%
219	15%
274	18%
345	8%

Acbar Bands vs. Atmospheric Transmission

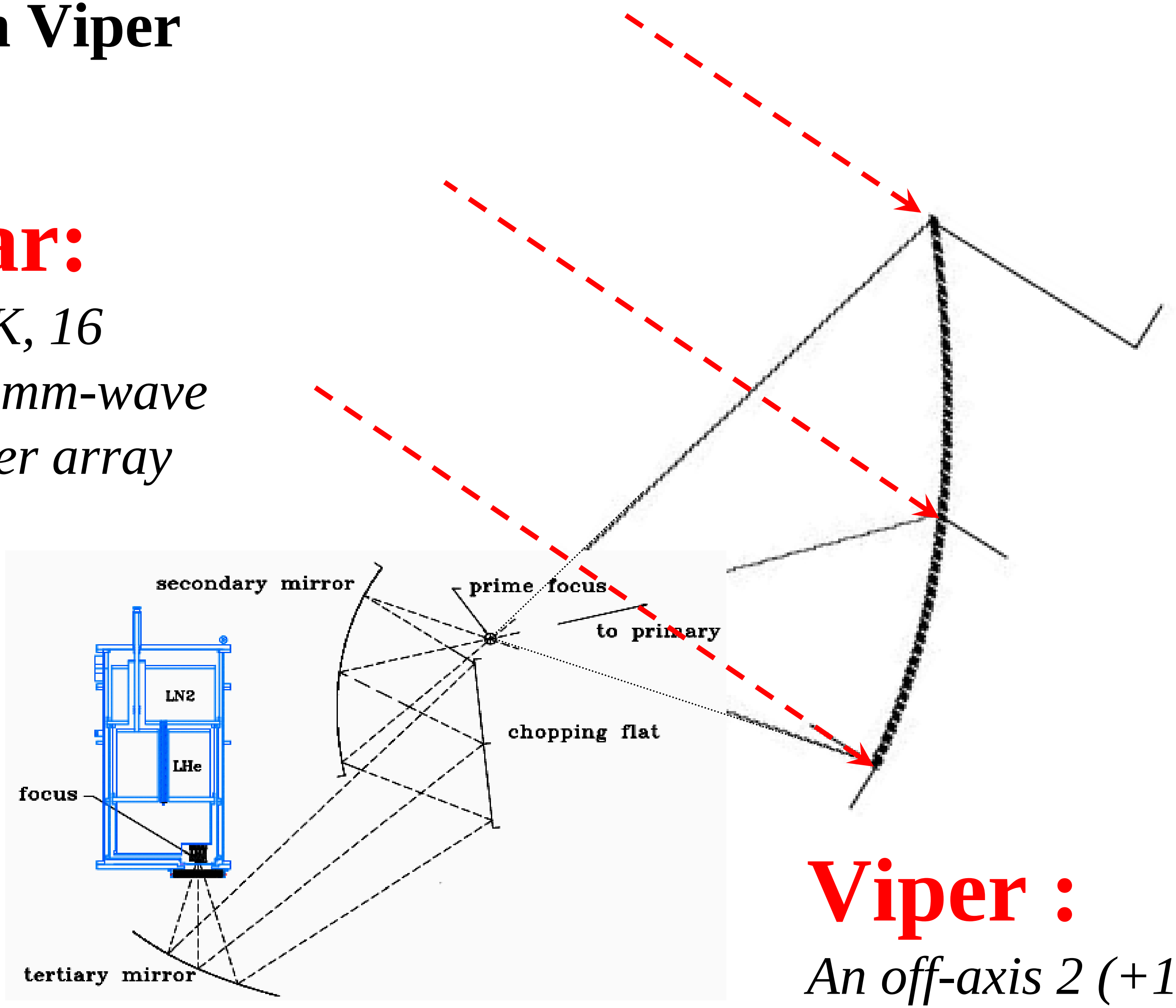


Band	Width
150	20%
219	15%
274	18%
345	8%

Acbar on Viper

Acbar:

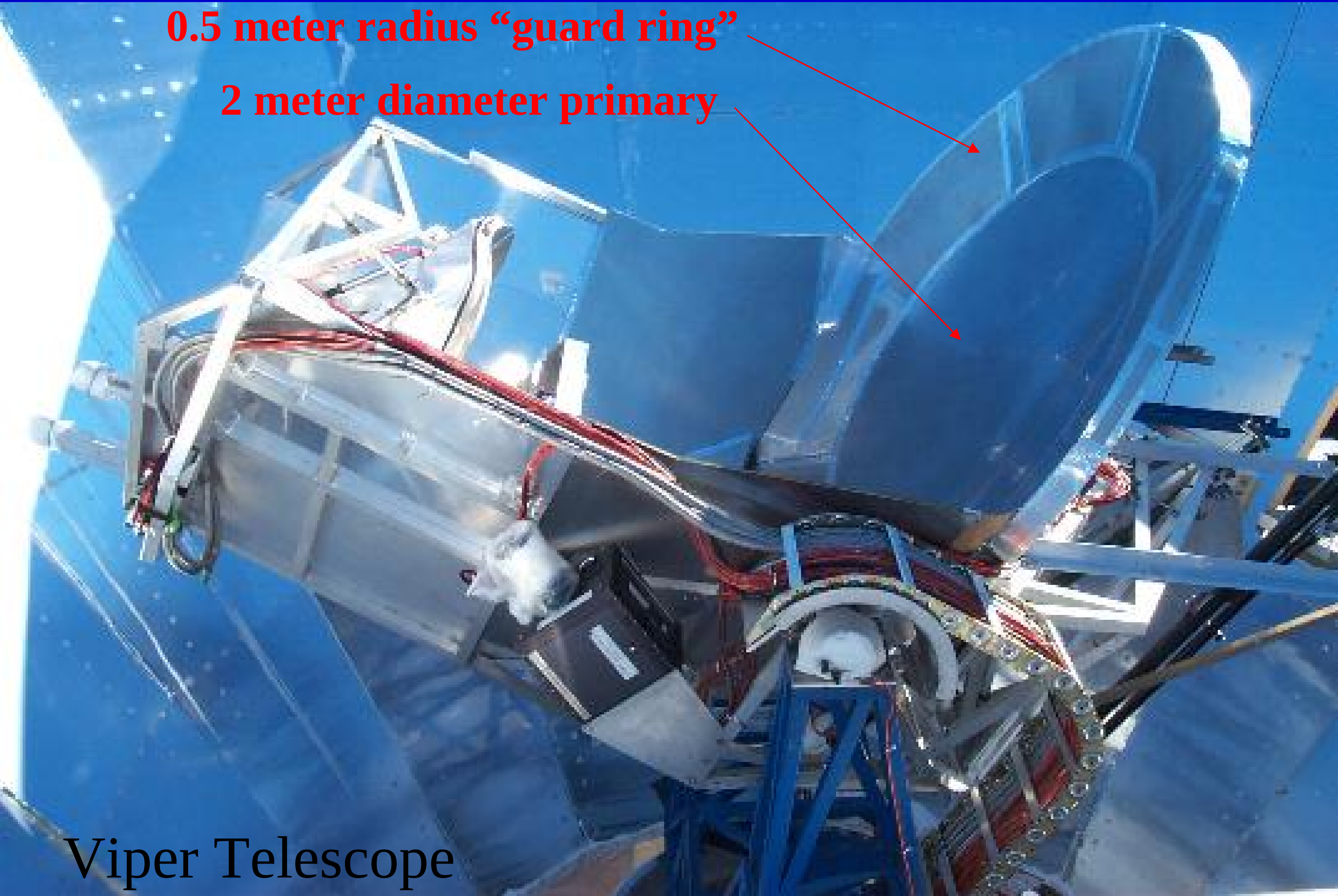
A 250mK, 16 element mm-wave bolometer array



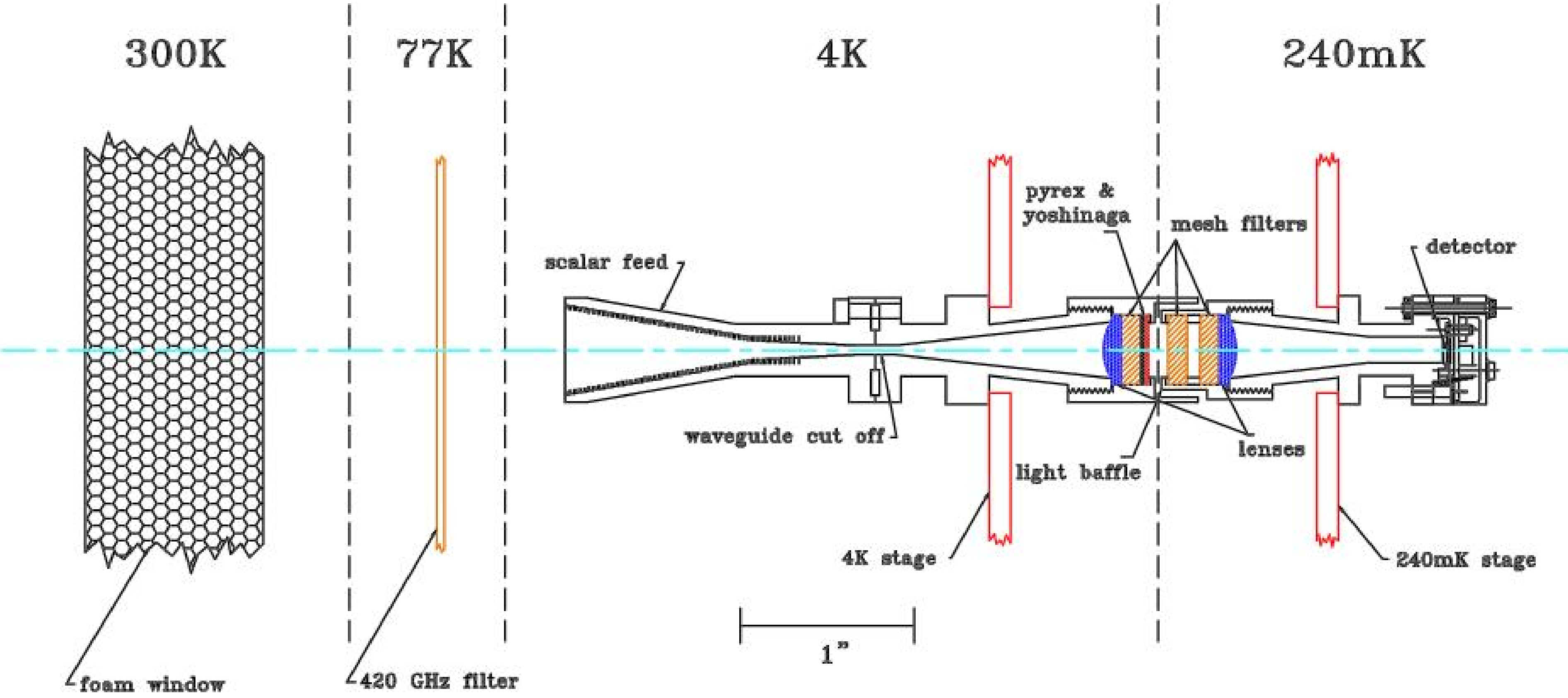
Viper :

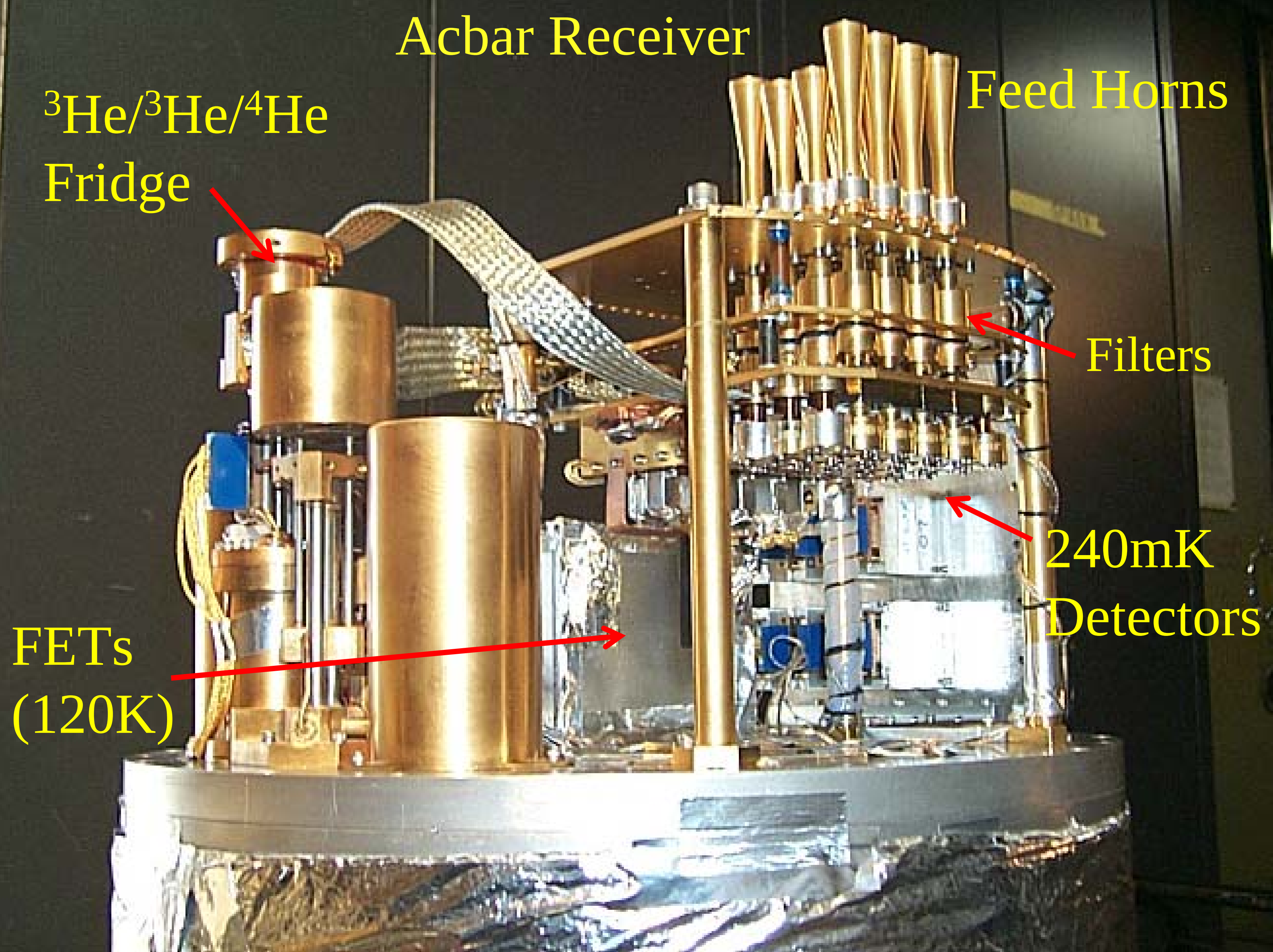
An off-axis 2 (+1) m diameter telescope

2 + 1 = 3m effective diameter



Feeds and filters
(very similar to Planck)

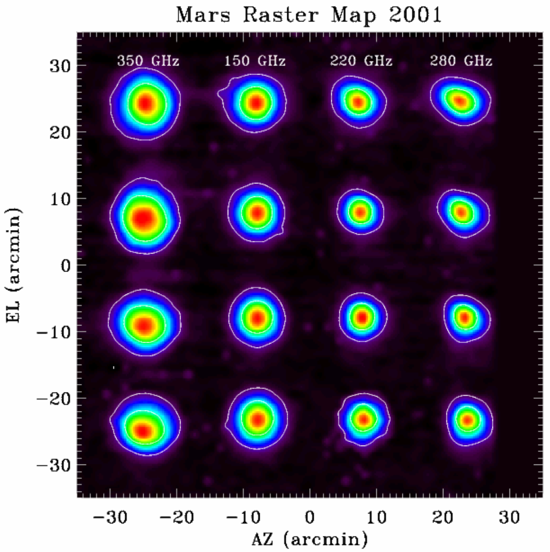



Acbar Receiver
$^3He/^3He/^4He$ Fridge
Feed Horns
Filters
240mK Detectors
FETs (120K)

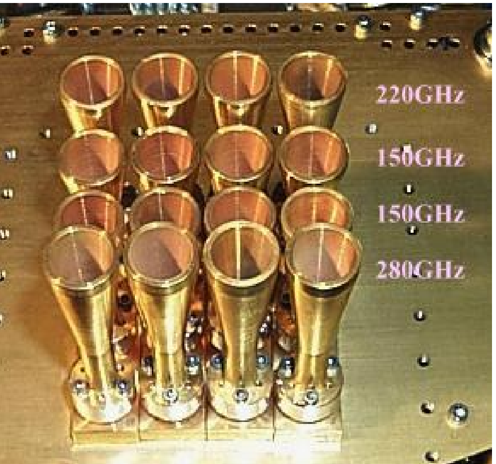
Beams and Calibration

2001: Mars

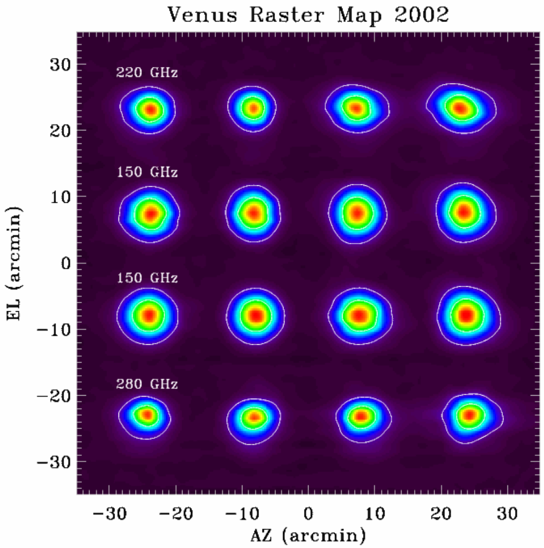
band	FWHM
150 GHz	4.8′
220 GHz	4.0′
280 GHz	4.0′
350 GHz	5.7′



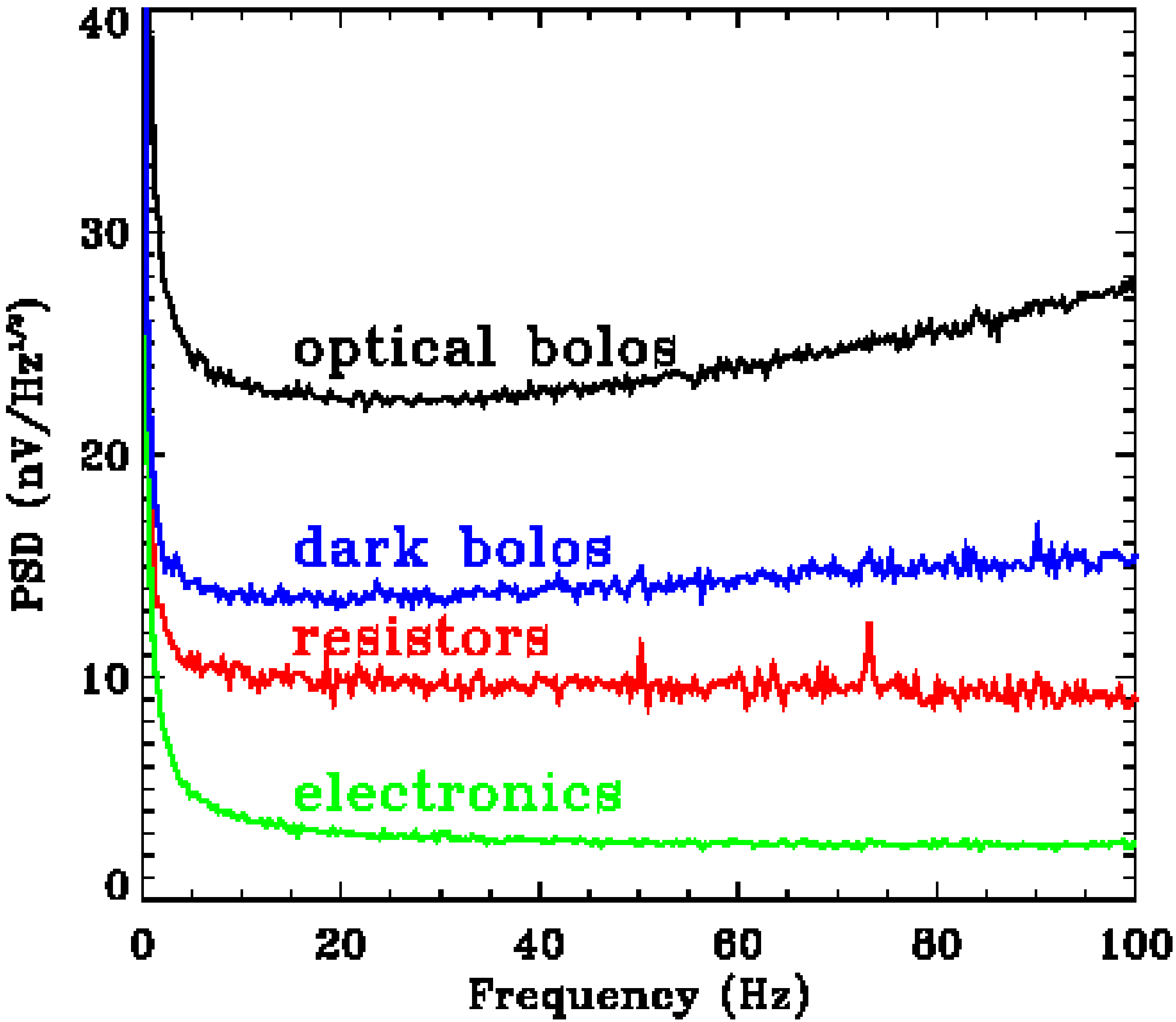
2002: Venus



band	FWHM
150 GHz	4.7′
220 GHz	4.2′
280 GHz	3.9′



Noise is background limited…



Measured Performance of ACBAR (2002 Season)

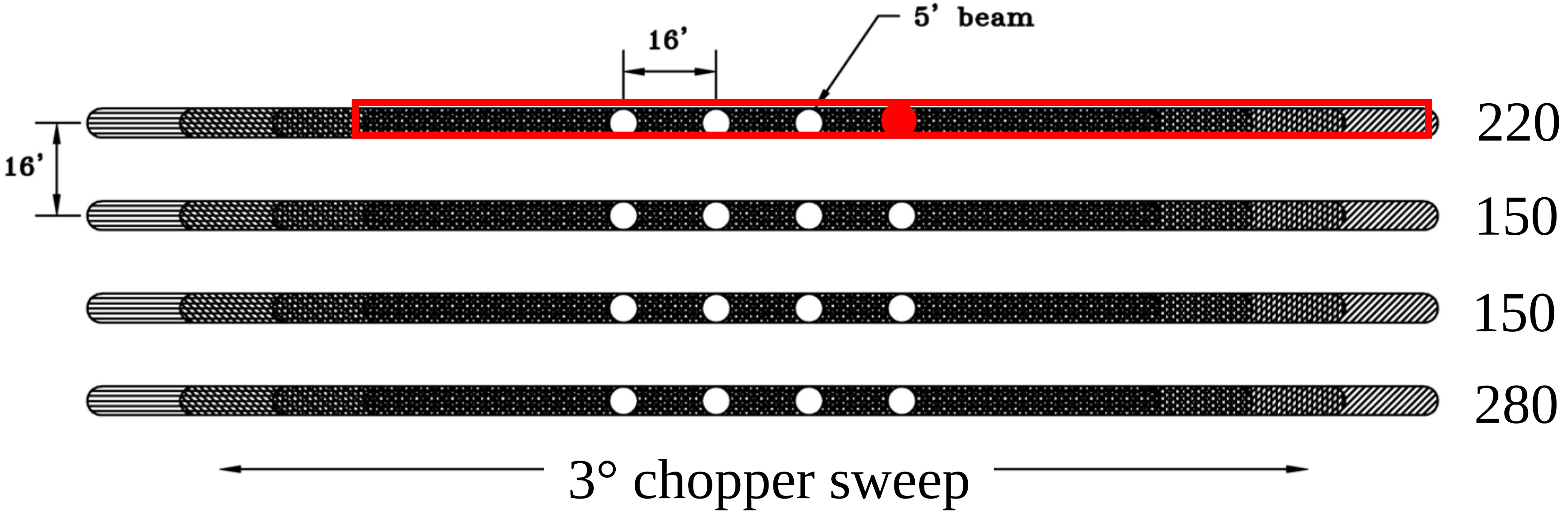
Frequency Band (GHz)	**150**	**220**	**280**
Bandwidth (GHz)	31	31	48
Number of Detectors	8	4	4
Optimal efficiency (%)	40	34	33
Beam Size (FWHM)	**4.7**	**4.2**	**3.9**
Detector NEP (10^{-17} W/√Hz)	9.4	9.5	14.8
NET_{RJ} (μK √s) *(1 detector)*	200	250	280
NET_{CMB} (μK √s) *(1 detector)*	**350**	**770**	**1550**

Sensitivity/sqrt(t_obs) at 150GHz comparable to LDB ballooning…

Scan Strategy

Chopping flat rotates to sweep the array "horizontally" by 3 deg on the sky

(triangle wave, 0.7 and 0.3 Hz used)



While tracking (to compensate for Earth rotation)

30s **L**ead | 60s **M**ain | 30s **T**rail

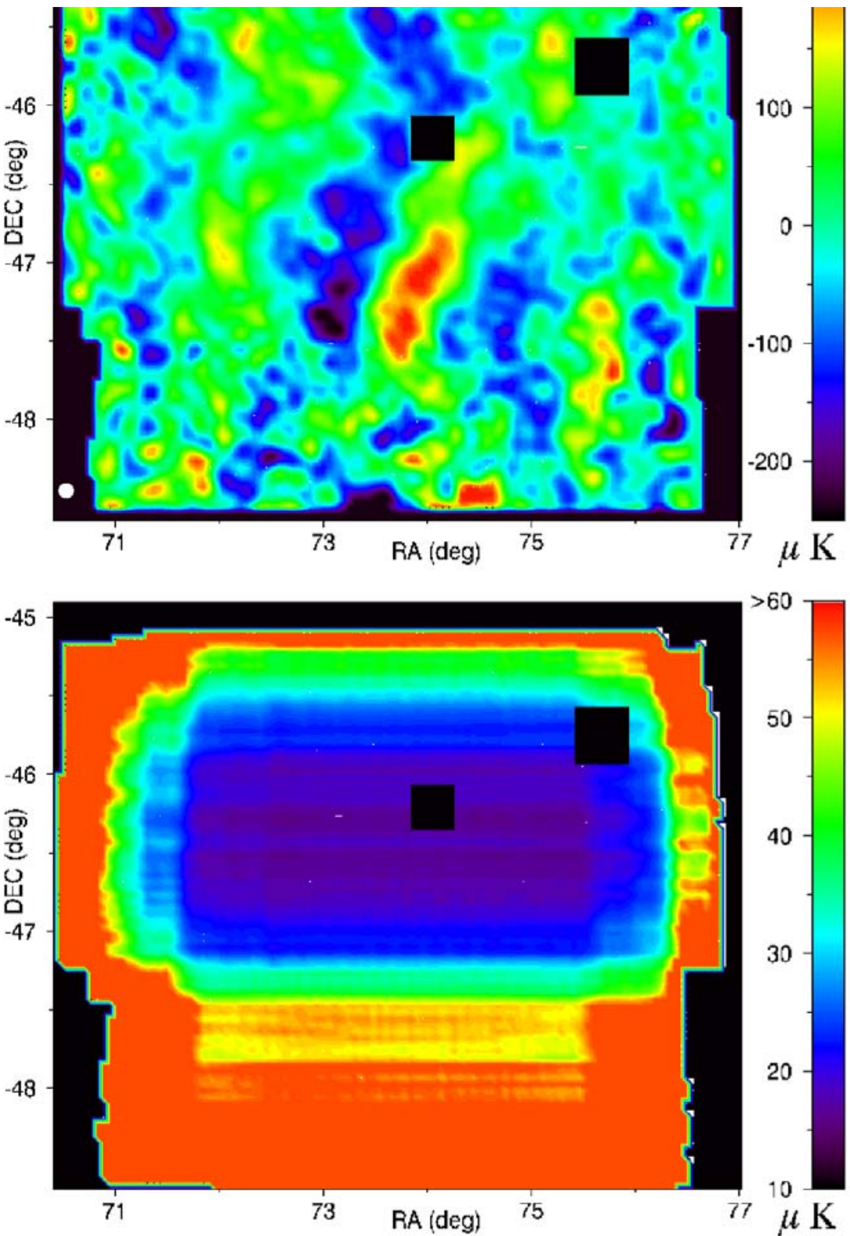
(Move down in elevation a fraction of a beam, repeat)

To remove stationary and linearly drifting chopped offsets, we did our first CMB analysis on the pseudo-map:

$$S = M - (L + T)/2$$

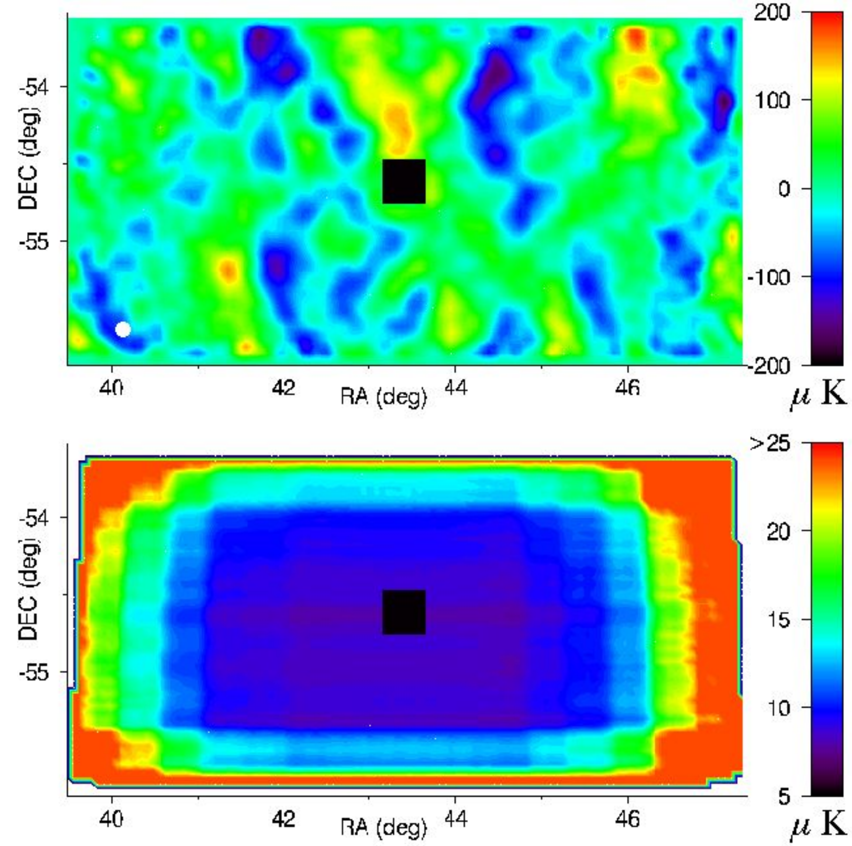
CMB2

(shallow field)



CMB5

(deep field)



These are maps of

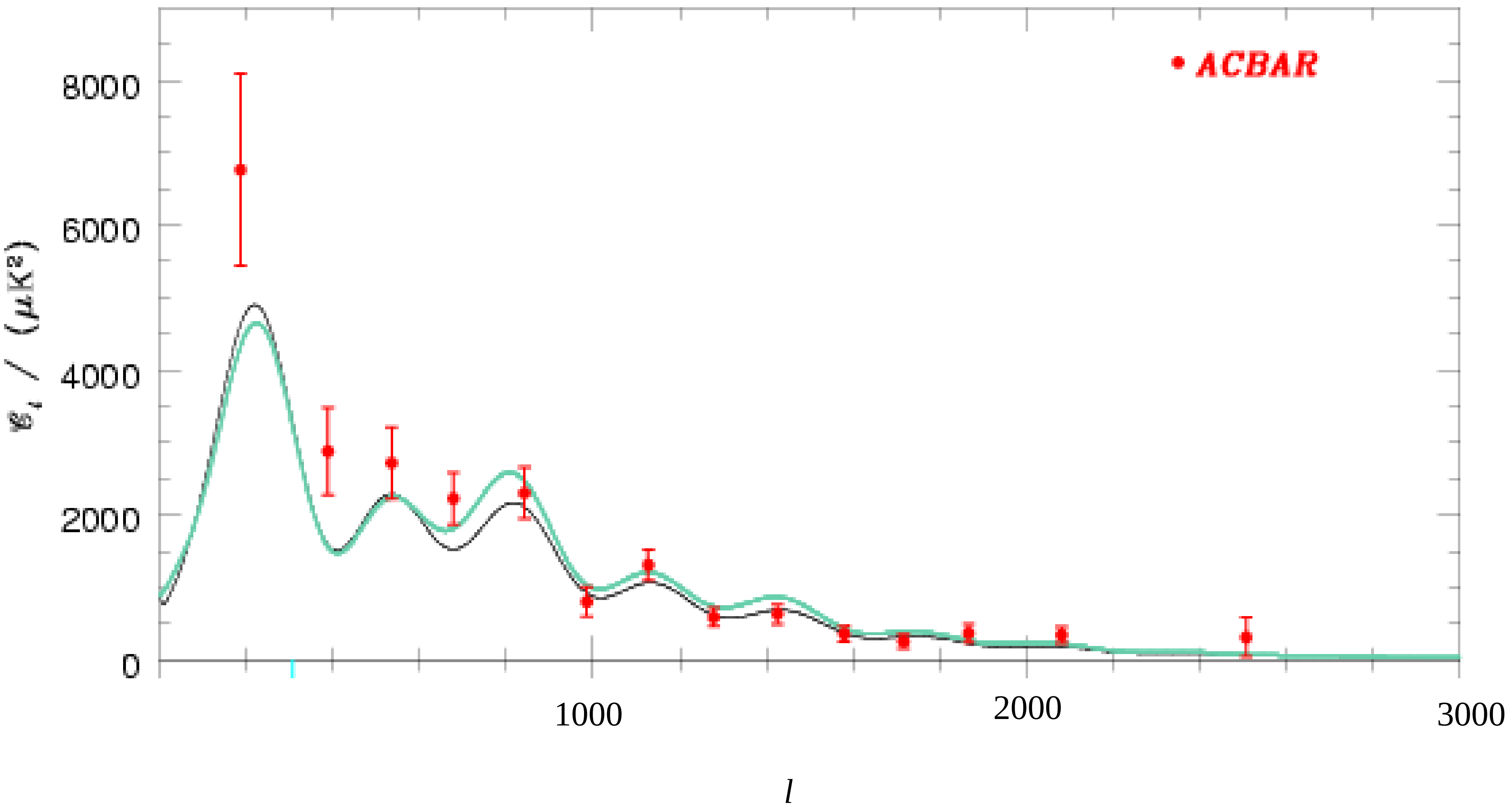
S = M – (L+T)/2

(with no crosslinking!)

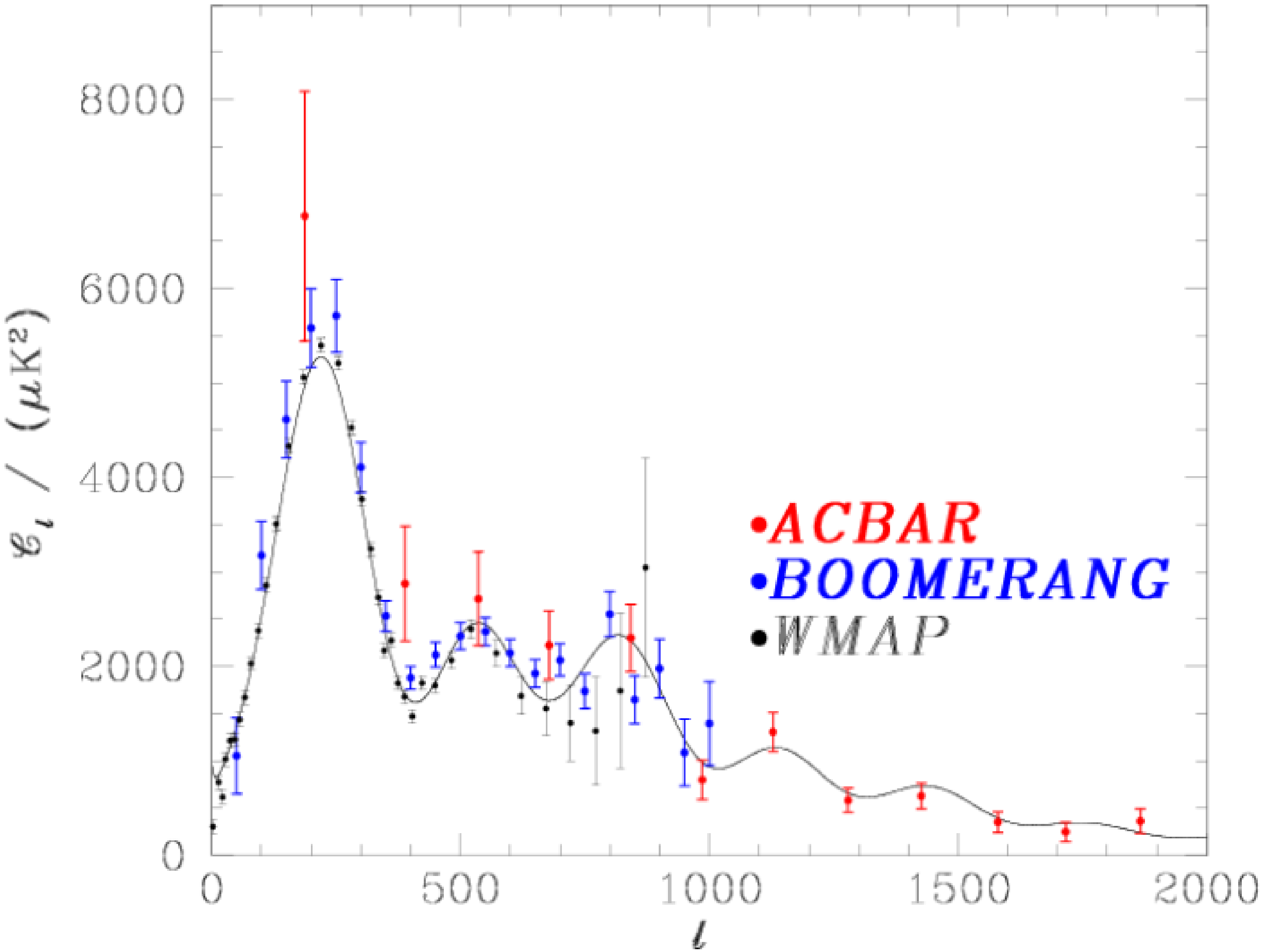
Acbar 2002 CMB Power Spectrum:

Using LMT analysis on CMB2 and CMB5 fields at 150GHz.

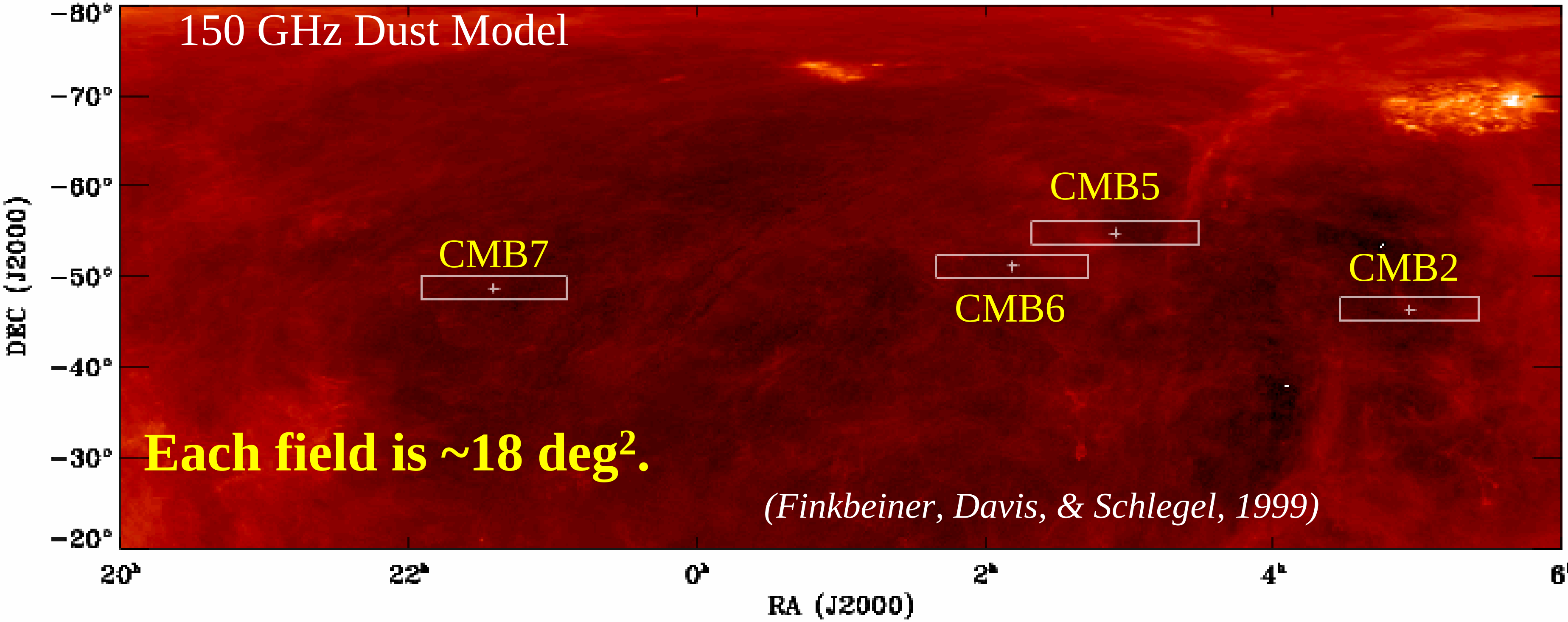
More results and more data are on the way!



The “Acbar-ext” CMB Power Spectrum



2001 & 2002 CMB Observations



Point source provides monitor of pointing and beams:
Coadded point source image includes beam size and pointing jitter.

FIELD (PMN object)	RA (J2000)	DEC	Time (d)	σ_{150}/beam
CMB2 (J0455-4616)	73.962	-46.266	39	~9μK
CMB5 (J0253-5441)	43.372	-54.698	109	~5μK
CMB6 (J0210-5101)	32.692	-51.017	23	—
CMB7 (J2235-4835)	338.805	-48.600	21	—

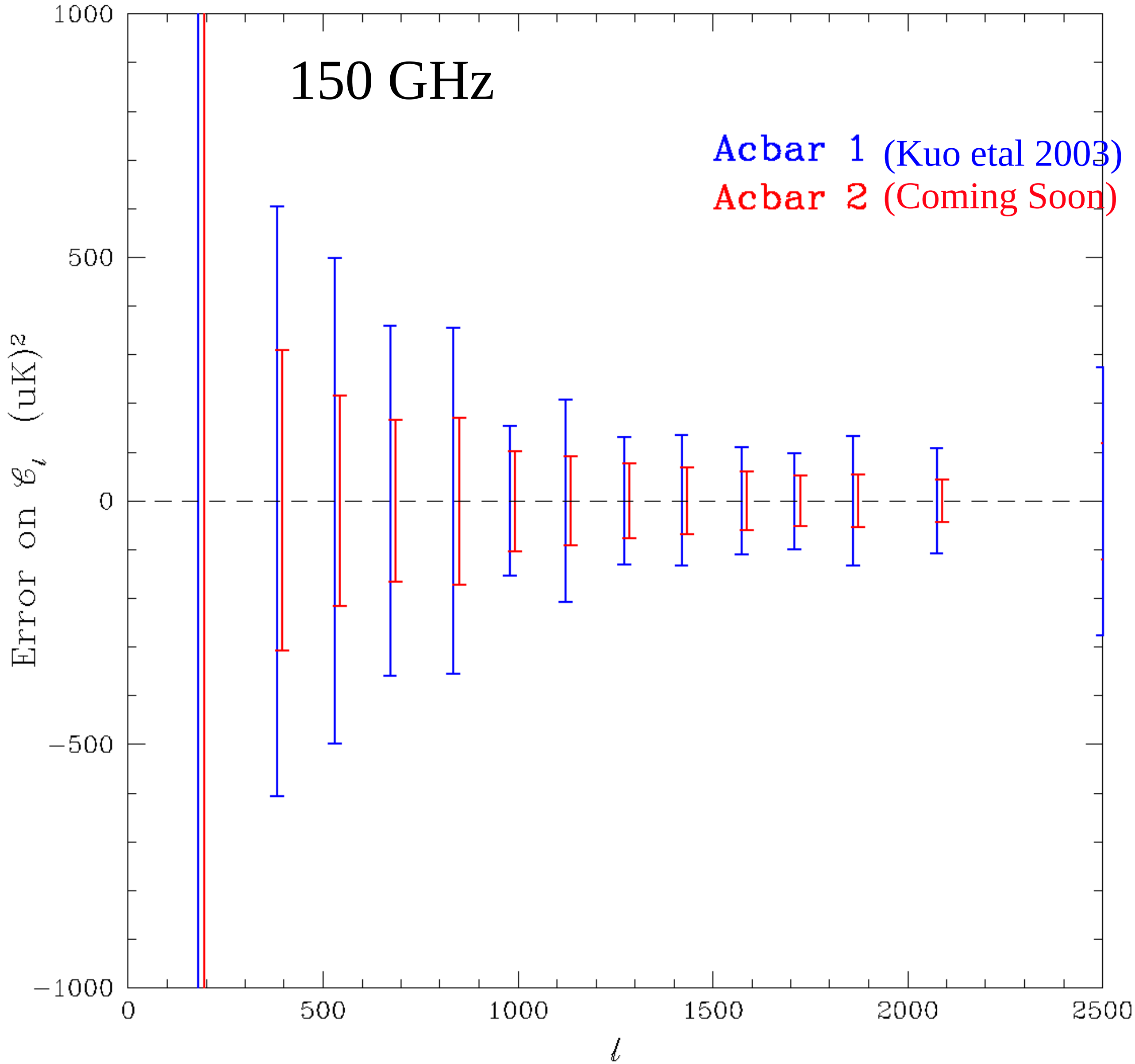
Acbar: New Analysis of 2001/02 data (to get better high-*l* errors)

• Two more fields: CMB (2,5), plus (6,7)

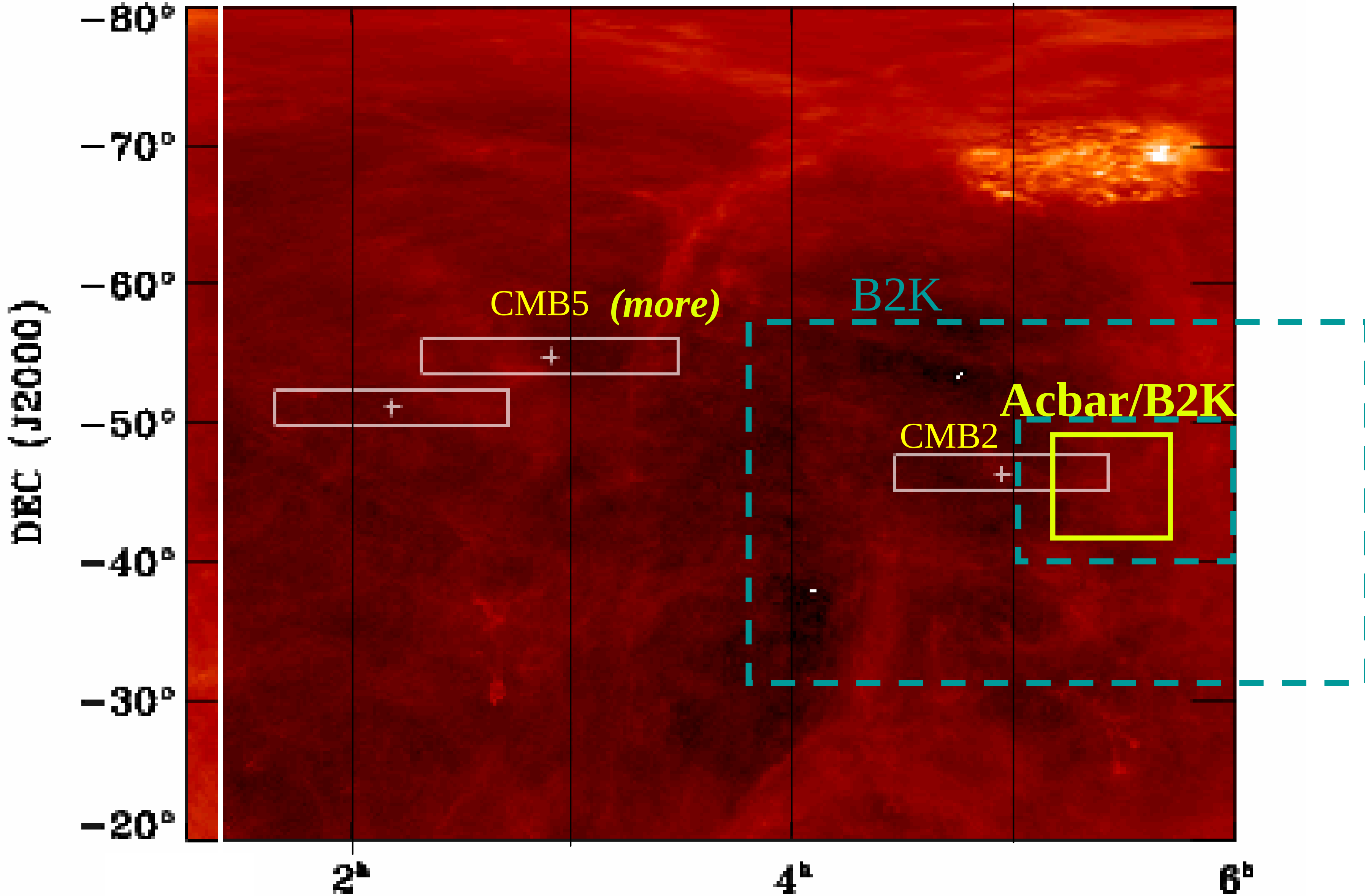
• No LMT field-subtraction… instead, remove a slowly varying (in elevation, time) offset from each field.
This loses some low-*l* signal, but does better at high-*l*

• A new calibration path: WMAP ⇒ B98 ⇒ Acbar

Acbar "upcoming errors"



2004: New B2K/Acbar overlap field



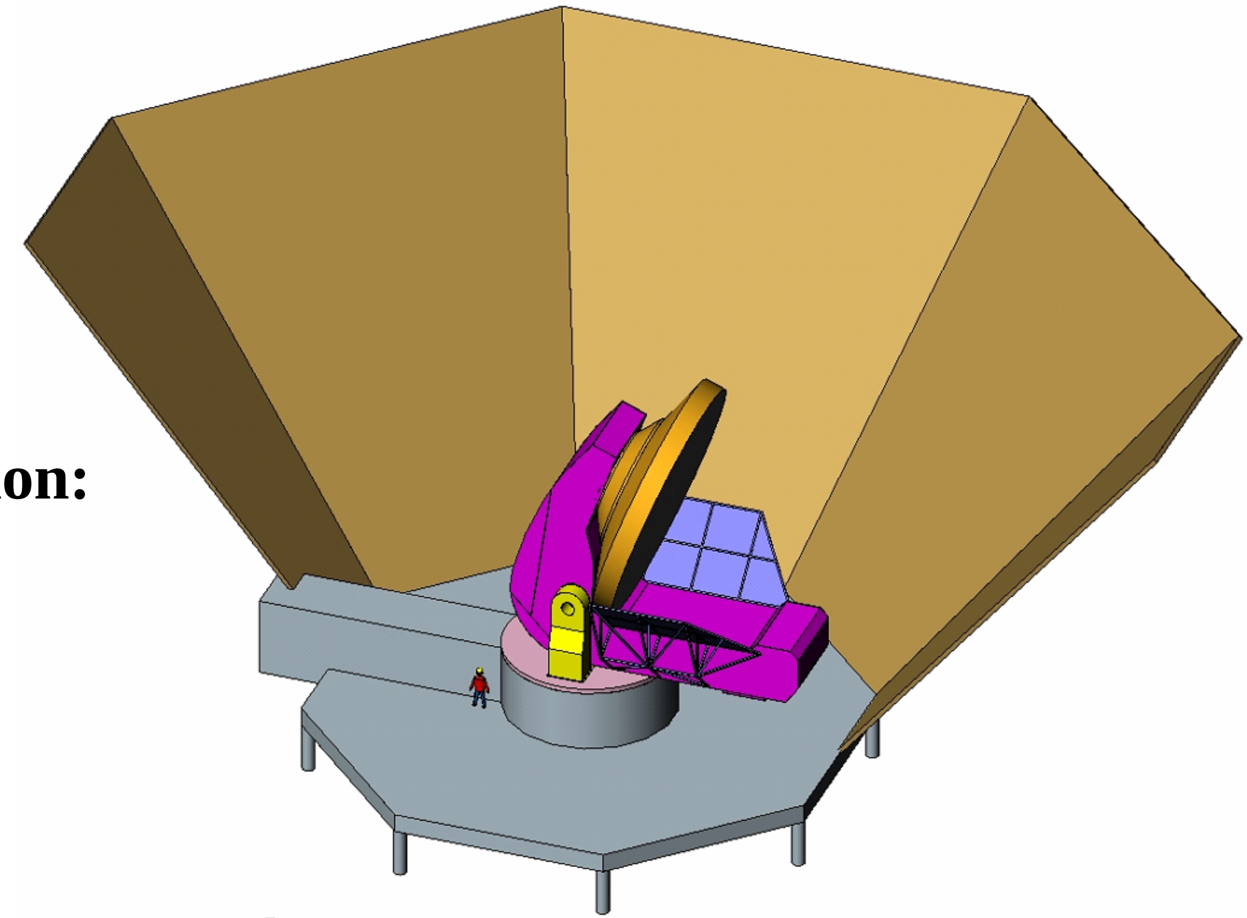
The South Pole Telescope

(A 10m diameter telescope for $\lambda > 200\mu$)

John Ruhl, Case Western Reserve University

Funding:
NSF Office of Polar Programs

SPT Collaboration:
U. Chicago
Cardiff Univ.
Case Western
Harvard CfA
LBNL
U. C. Berkeley
U. Illinois



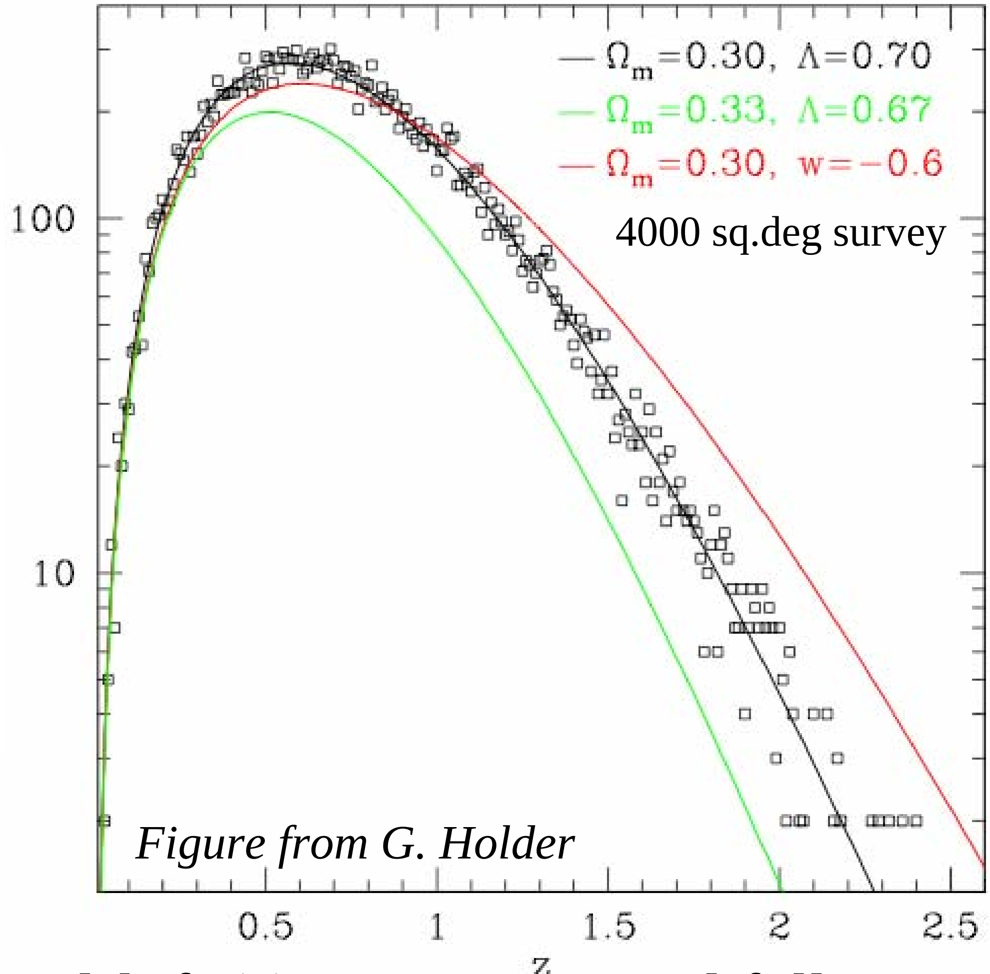
Telescope Design: Vertex/RSI
Other Structures: Raytheon Polar Services

Reference: SPIE paper, will be on astro-ph soon…

Science Goal #1:

Discover 10's of 1000's of SZ Clusters,

use them to trace the history of structure formation, and thus measure time dependence of Λ

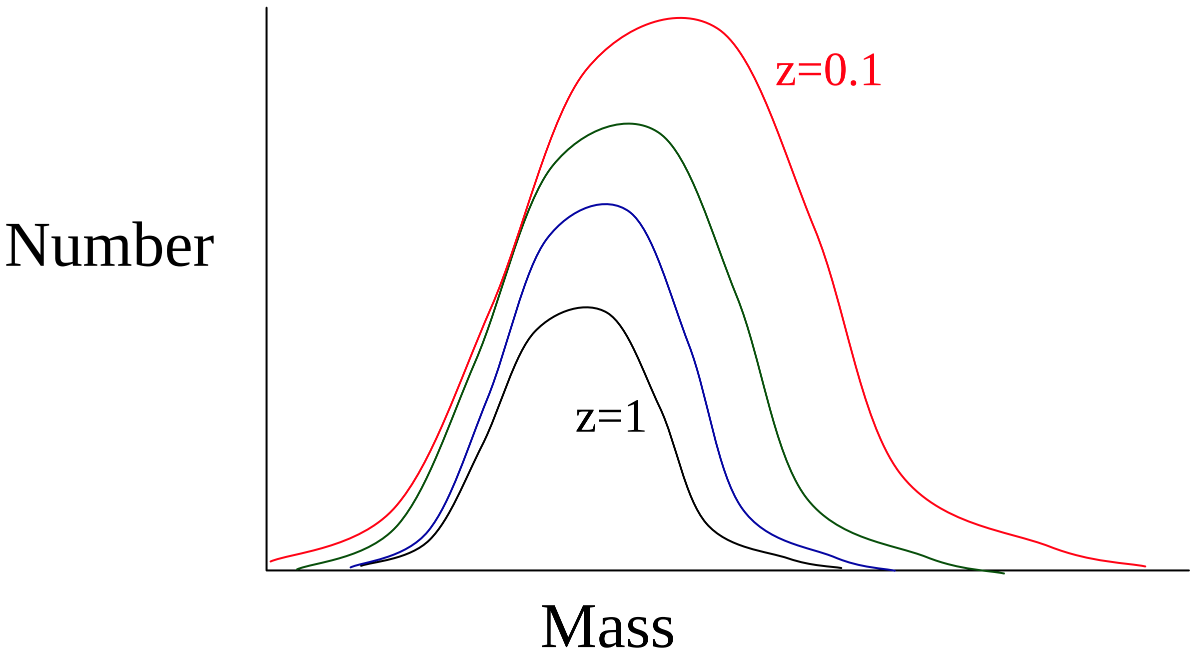


Counts per Δz = 0.01

Redshift (z), requires optical followup

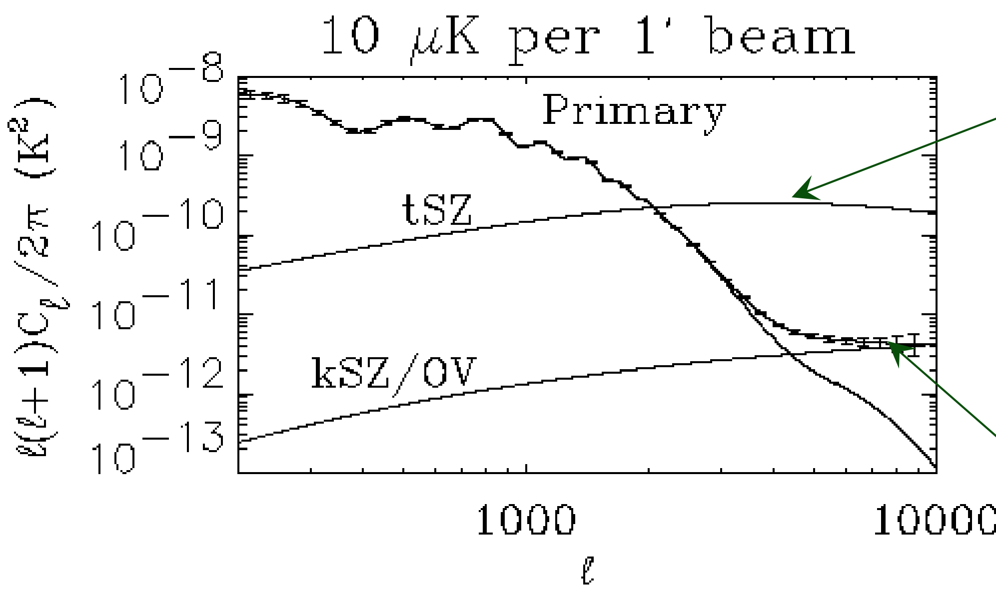
SZ will ***test*** Structure Formation Models

Watch the "mass histogram" evolve as f(z)… ie test N(M,z) and see whether it is consistent with (modified) Press-Schechter…



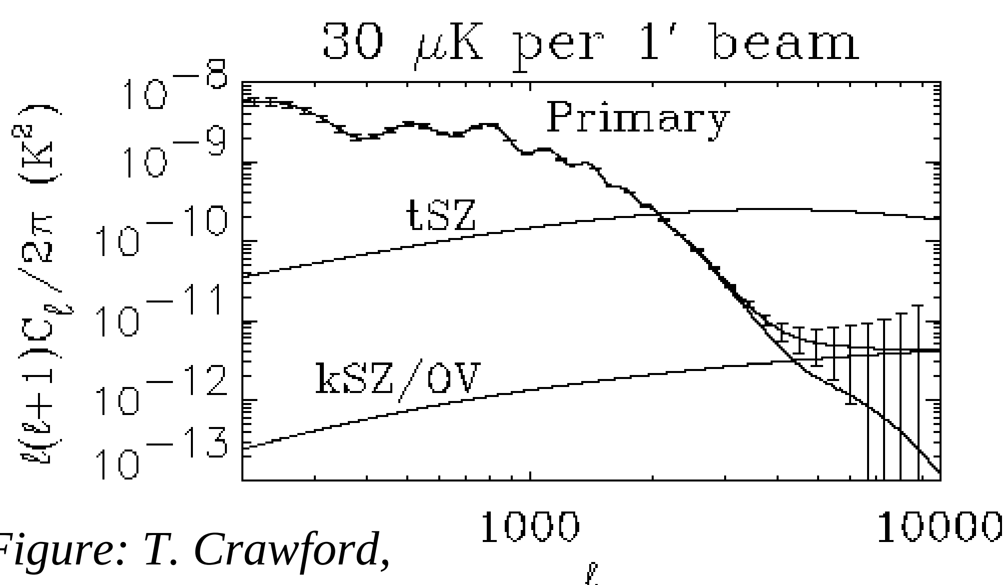
Getting the redshifts will be important…. and difficult.

Science Goal #2: Secondary CMB



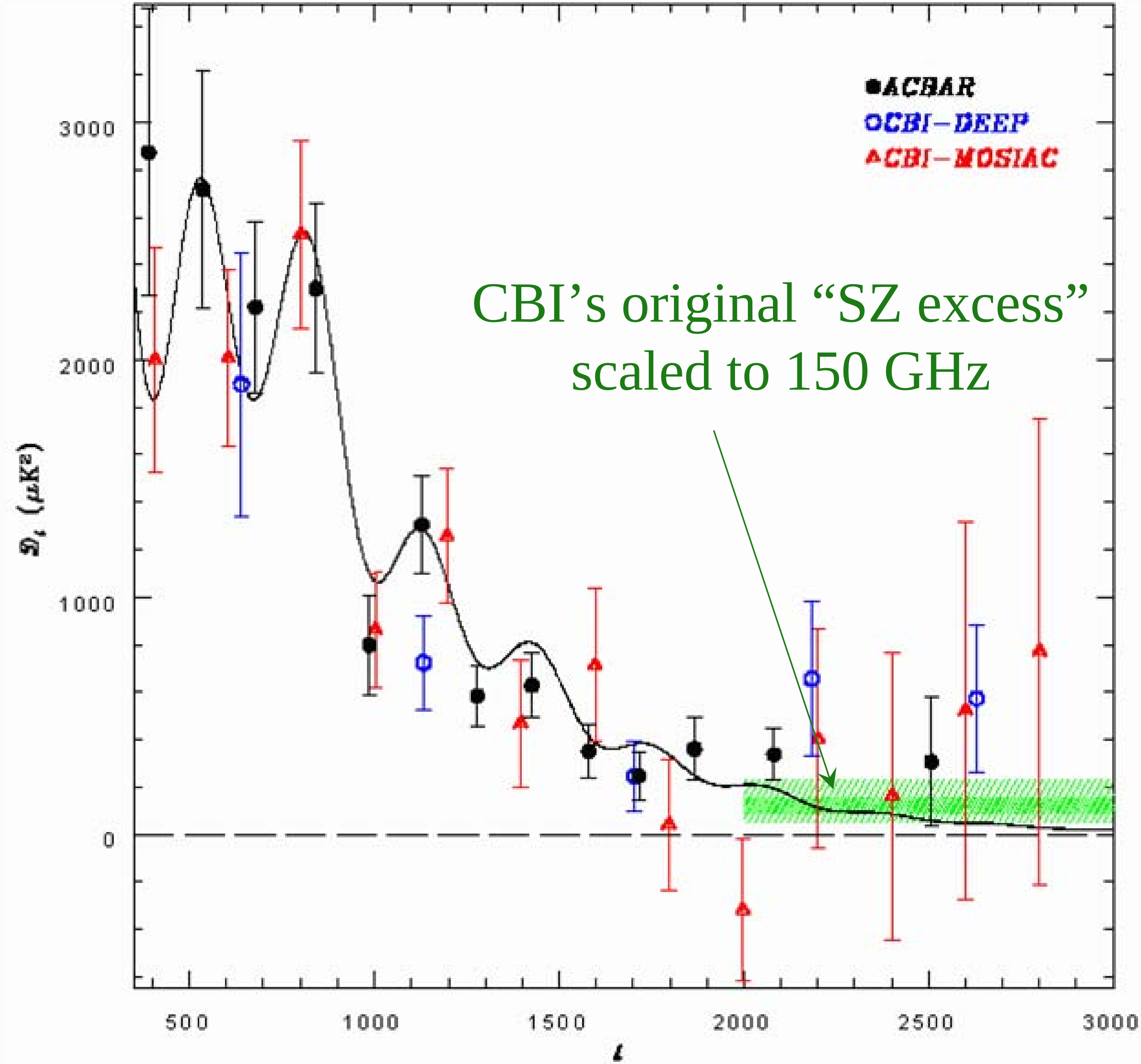
1. Measure the SZ power spectrum after removing obvious clusters…

2. Measure CMB-spectrum power spectrum at high l after removing thermal SZ signal… requires multiple colors.



500 sq. deg. surveys, Noise is on CMB-only after perfect tSZ subtraction.

Figure: T. Crawford, spectra from W. Hu

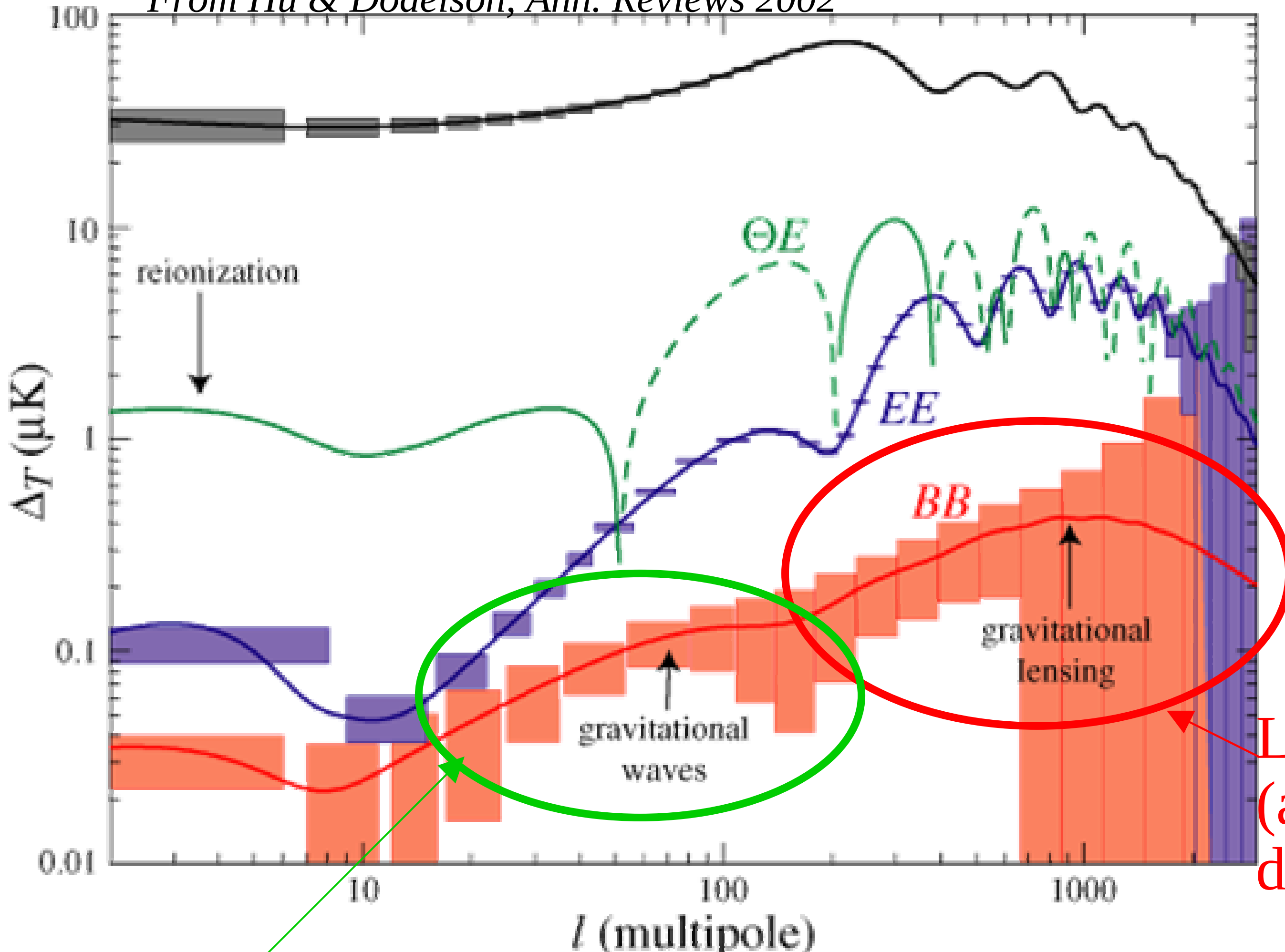


ACBAR
CBI−DEEP
CBI−MOSIAC
CBI's original "SZ excess"
scaled to 150 GHz
3000
2000
1000
0
500
1000
1500
2000
2500
3000

Science Goal #3: CMB polarization

(requires a polarimeter!)

From Hu & Dodelson, Ann. Reviews 2002



Errors shown are for Planck...

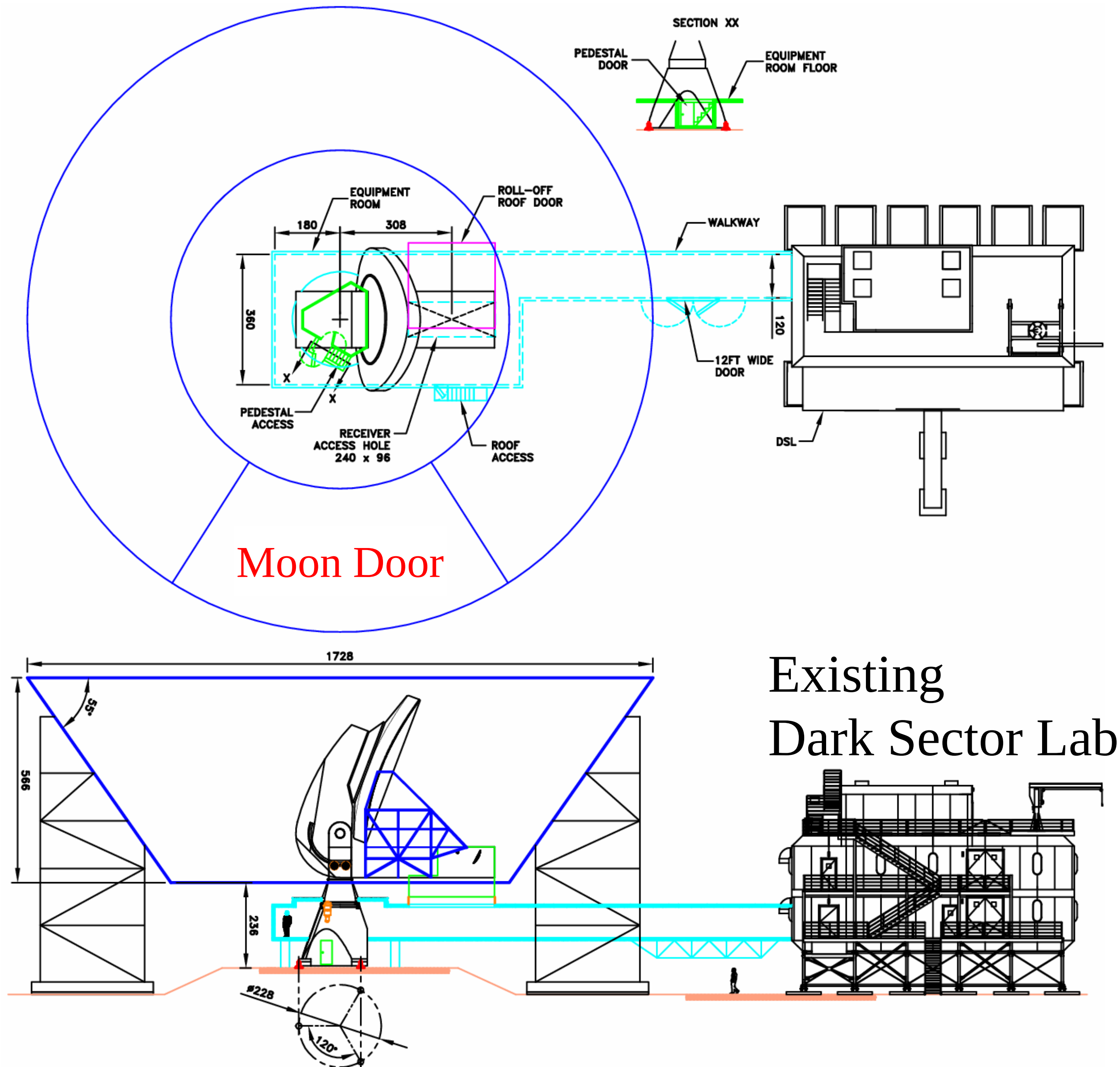
Lensing B-modes (a way to map the dark matter)

Primordial B-modes, fingerprint of Inflation.
(Shown for T/S = 0.1, a high value)

Telescope Design Goals

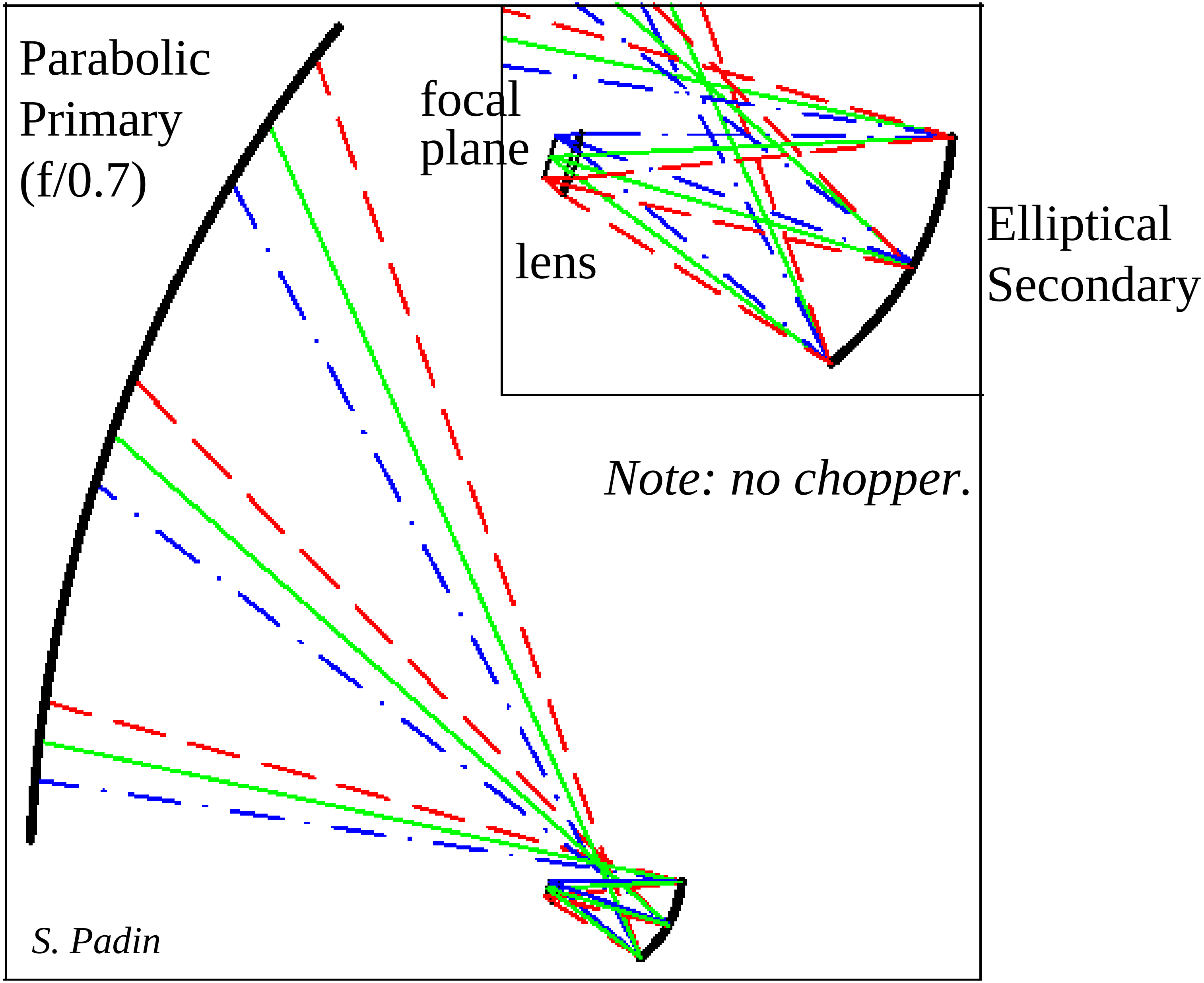
1. Angular resolution for clusters (~ 1') at 150 GHz:
   Originally 8m + (1m radius "guard ring"),
   now 10m precision surface, no "guard ring"
2. Observe CMB & foregrounds from 1-3mm
   rms < 1mm/100 = 10 microns on small scales,
   rms < 1mm/20 = 50 microns on large scales
   pointing reconstruction ~ 1 arcsecond rms
3. Surveys ⇒ 1° diameter field of view at 150 GHz
4. Low offsets, low loading, low sidelobes
   fixed Gregorian w/ cold secondary and stop,
   2 levels of ground shields.
5. Capable of sub-mm observations in the future
   rms < 20 microns overall (in future)
6. Flexibility for future use
   pure parabolic primary, large optics cabin

The Facility and Site

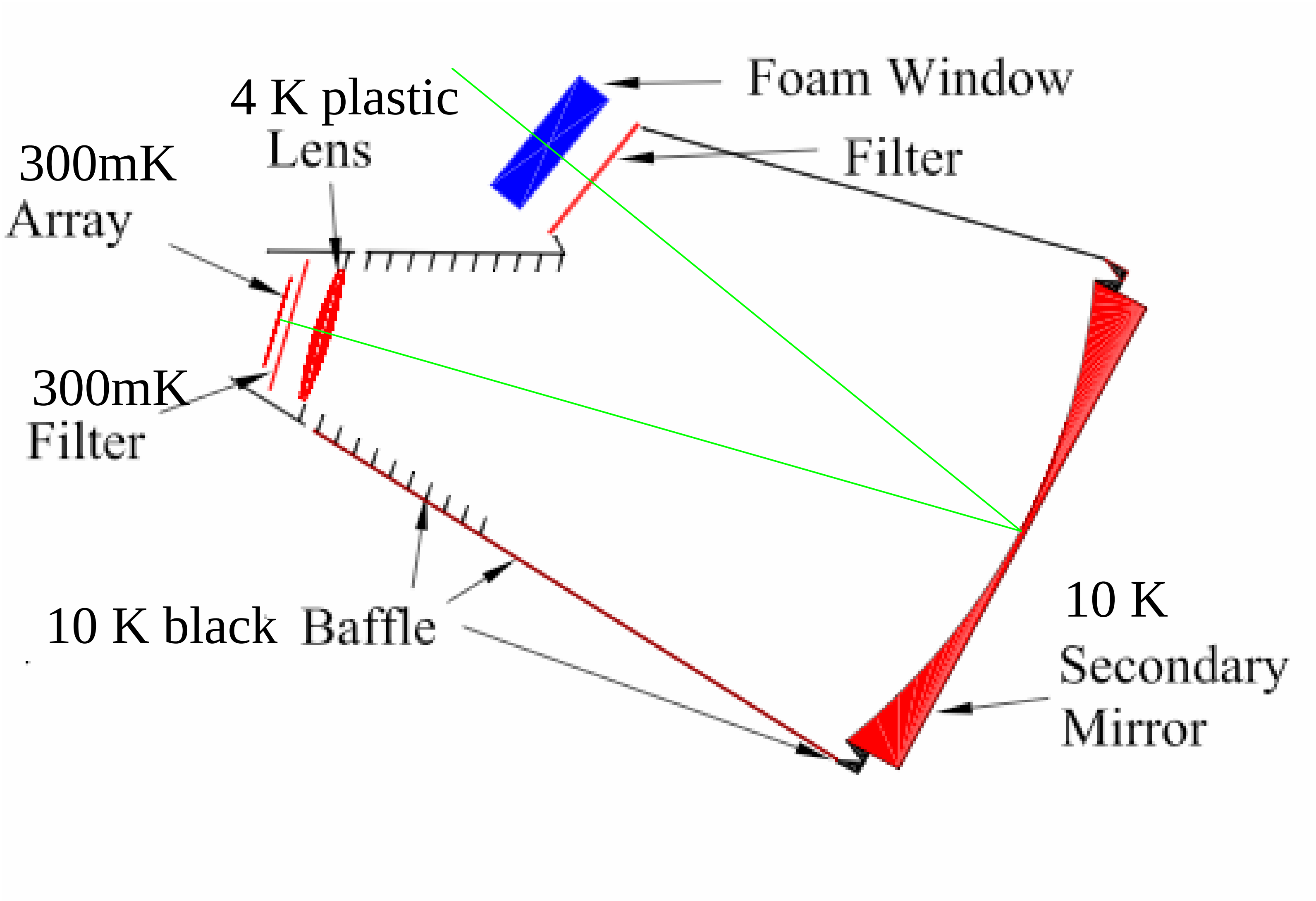


Existing
Dark Sector Laboratory

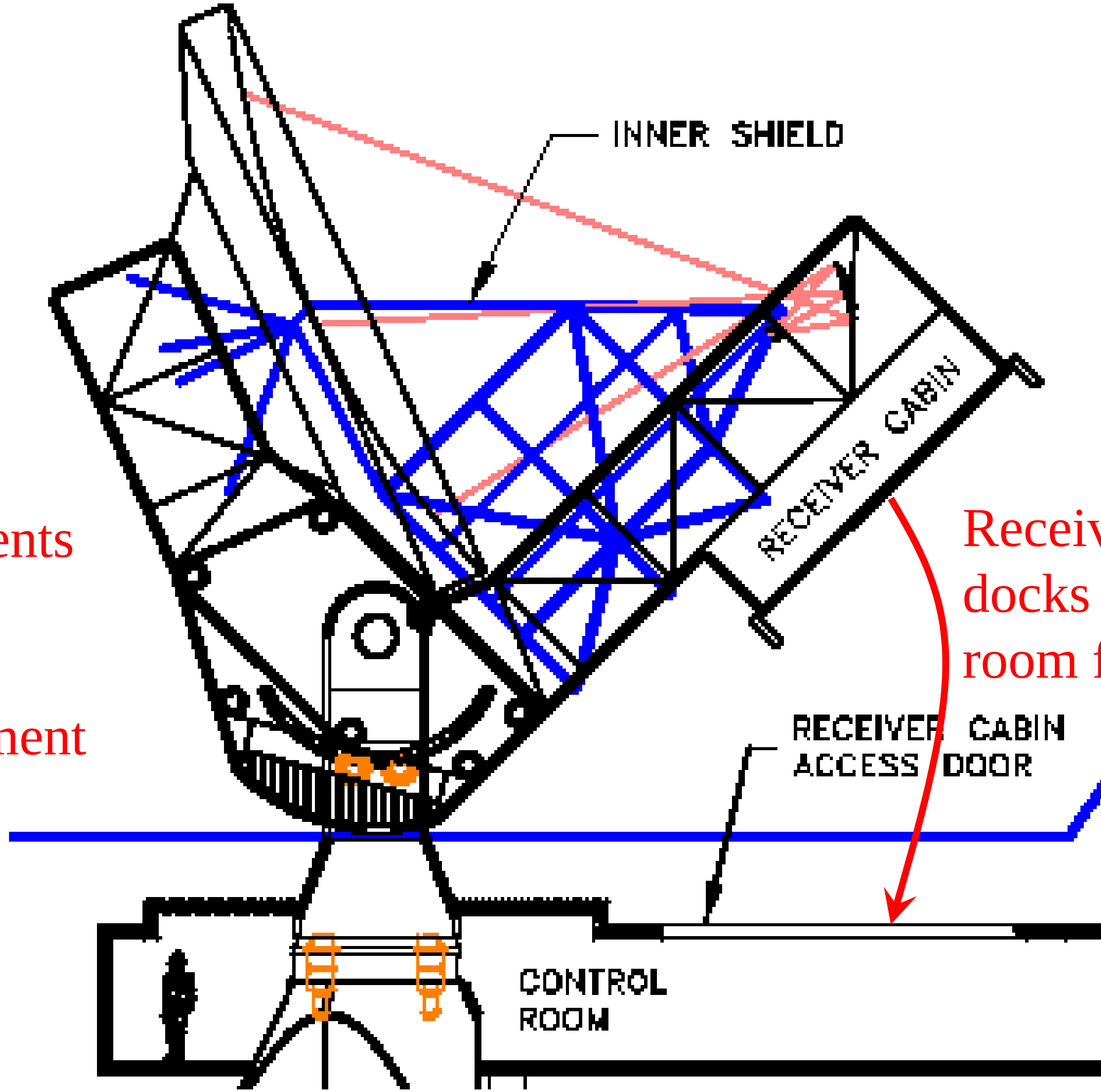
Optical Design: Off-axis Gregorian



10 Kelvin Secondary and Baffle



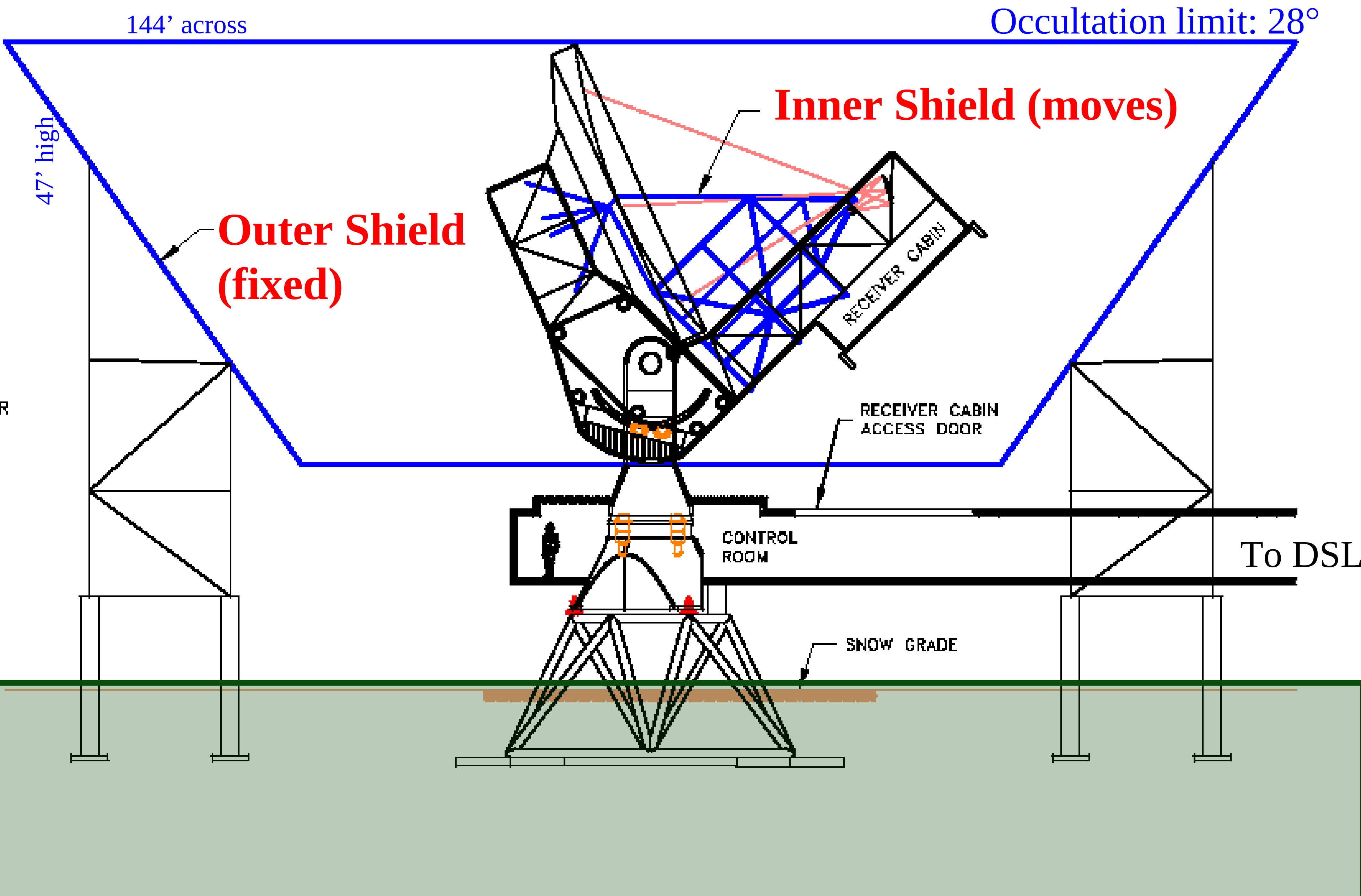
Telescope



Drive components are all in warm environment

Receiver cabin docks to control room for access

Structure and Shielding



SZ Focal Plane

2fλ Feedhorn Coupled, ~1000 elements

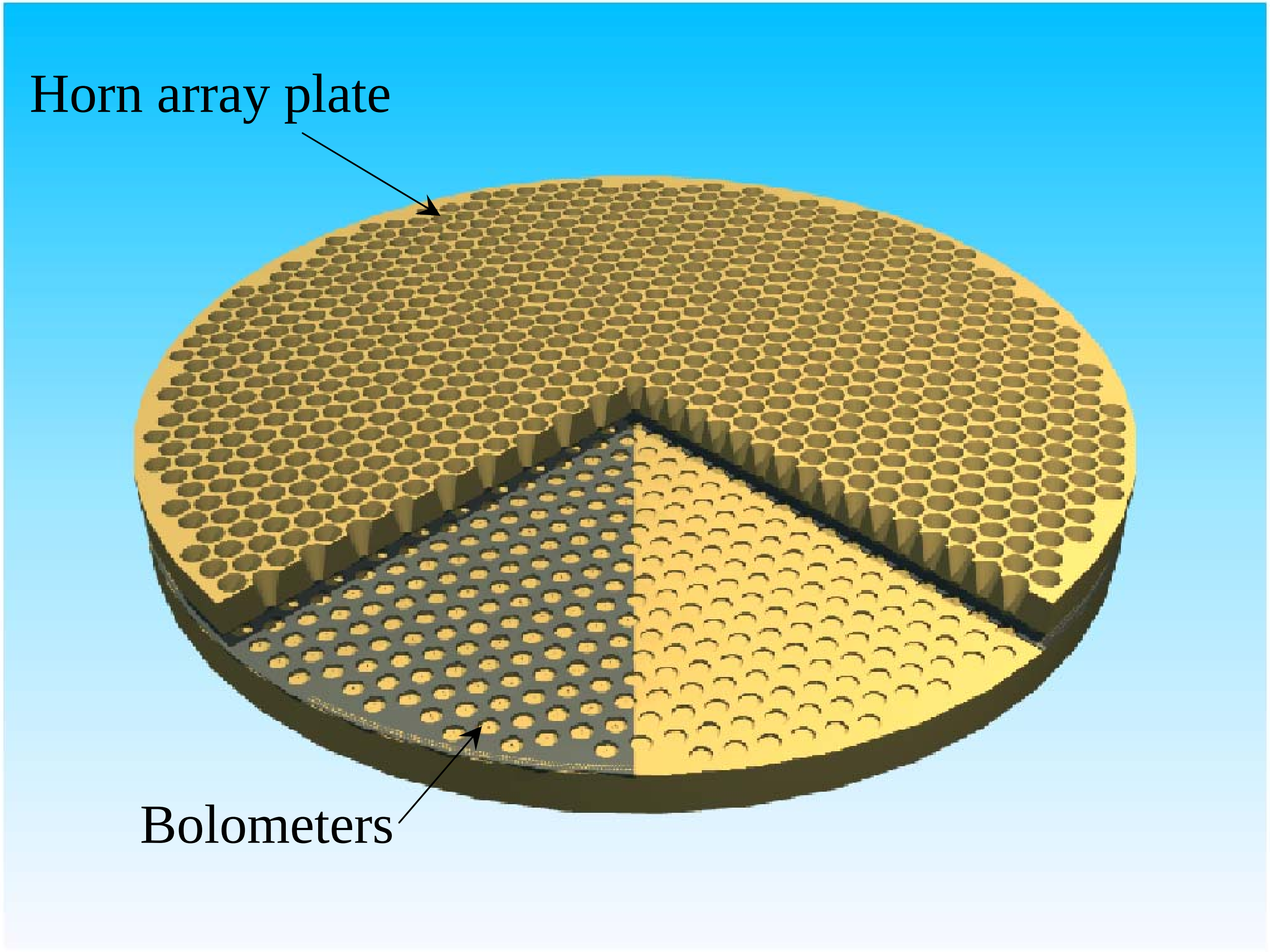
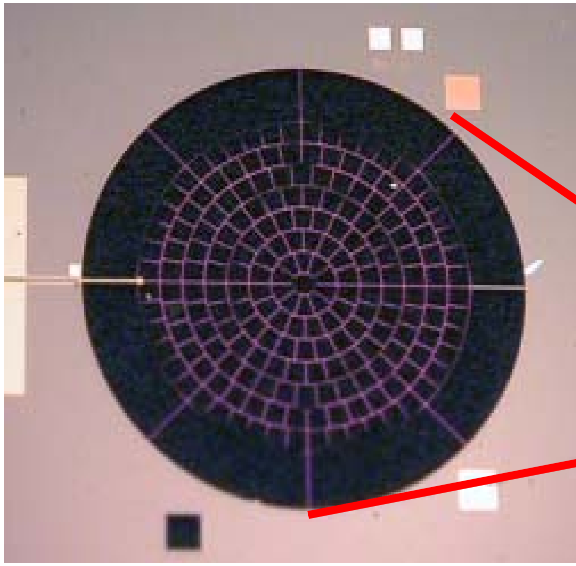
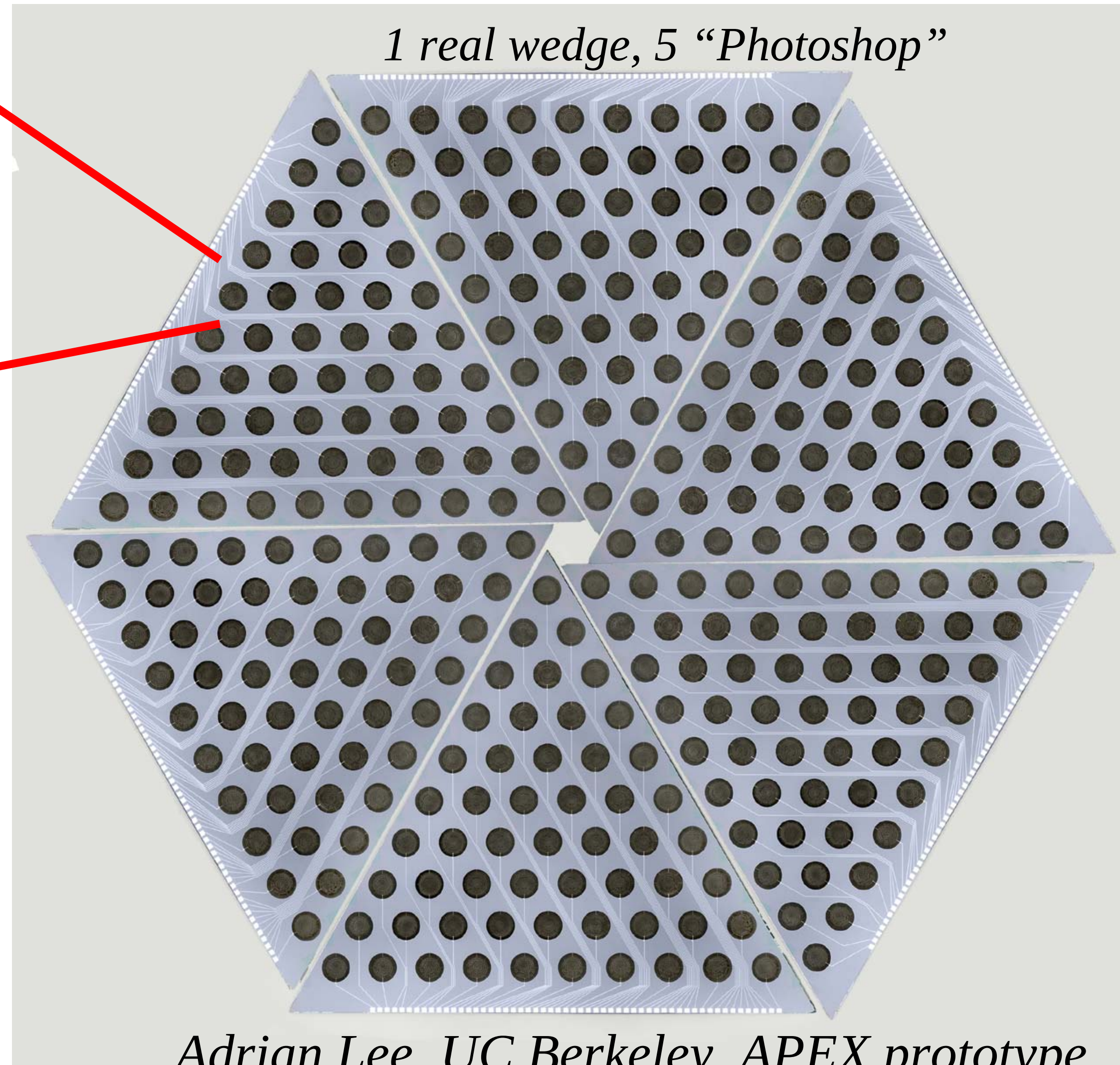


Figure: W. Holzapfel

TES Bolometer Array



SiN suspended web



Cryogenics:
Cooled with closed cycle 3He and pulse tubes, no LHe supply…

Observing Strategy: Atmospheric Noise and Filtering

(no chopper… can we succeed with telescope-scanning?)

Input:

- celestial signals (CMB, SZ)
- detector noise (with 1/f)
- Acbar-normalized atmospheric fluctuations
- SPT scan rate

Process:

- Do “fake” array observation to create timestream,
- use some method to filter 1/f + atmospheric noise

Output:

- naïvely “binned” maps
- cluster mass detection thresholds, etc

Pure Timestream filtering

Noise:

- 0.1 Hz 1/f
- "SP-Acbar Atmosphere"

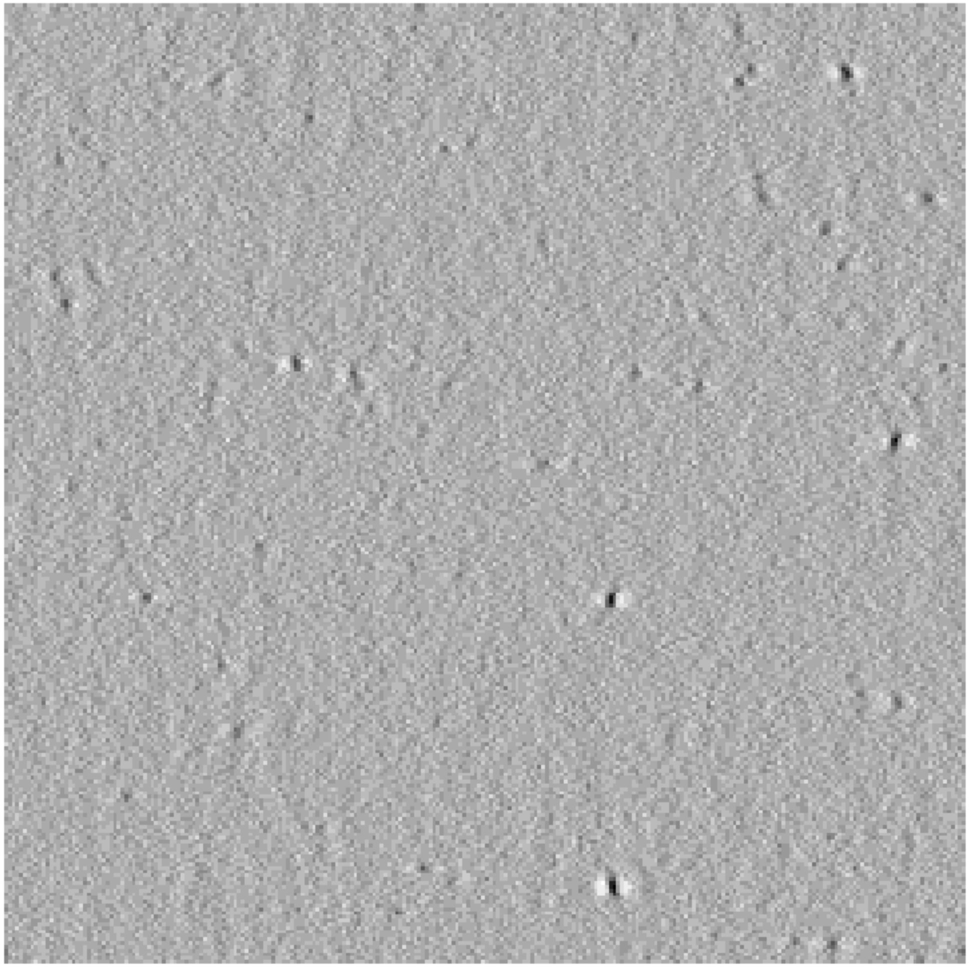
Scan rate:

2'/second

Filter:

0.3Hz HP

3°x 3°



Tom Crawford, U. Chicago

Array common-mode subtraction only

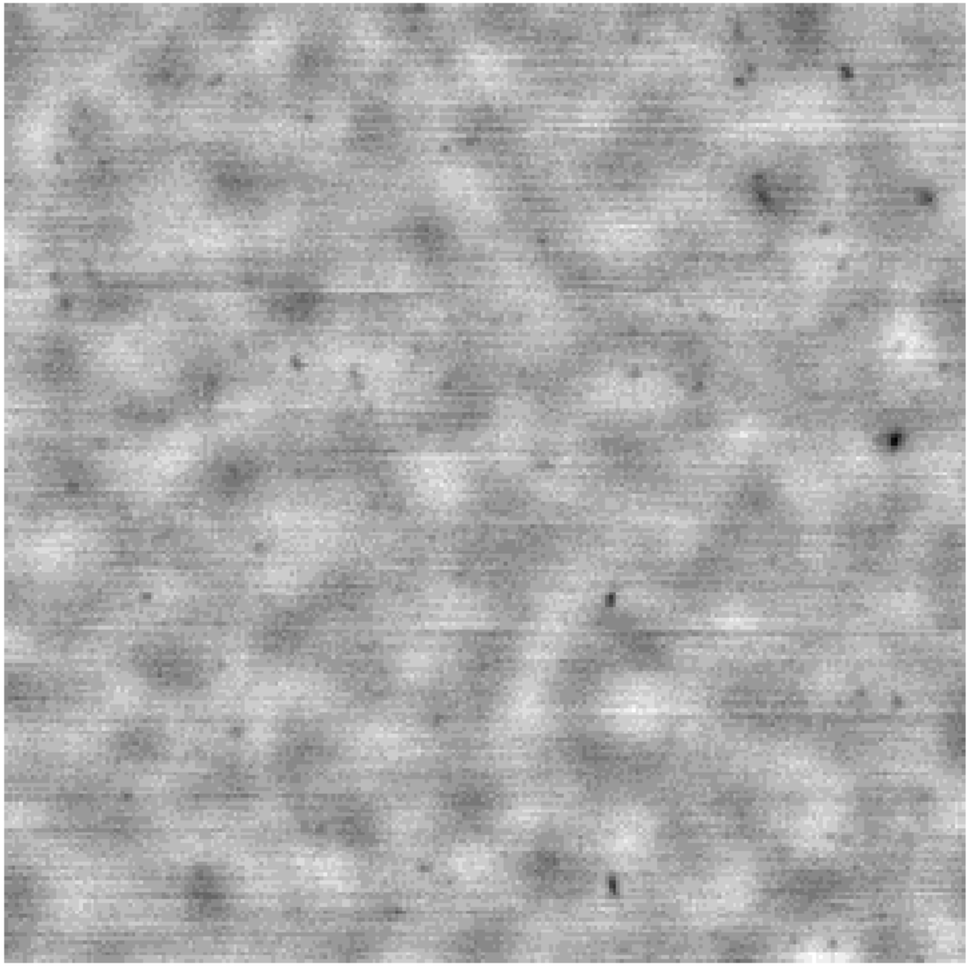
Noise:

- 0.1 Hz 1/f
- "SP-Acbar Atmosphere"

Scan rate:
2'/second

Filter:
16 spatial modes at each timestep

3°x 3°



Tom Crawford, U. Chicago

Band selection: which of 90, 150, 220, 270, 345 GHz ?

CMB
Thermal SZ } 150 + 220 GHz

IR point sources } 270 GHz

Radio point sources } 90 GHz ? (but resolution gets worse…)

Expected performance of these bands if used on the SPT

ν_0 (GHz)	$\Delta\nu$ (GHz)	T (trans)	P_o (pW)	G (pW/K)	NET_{RJ} ($\mu K\sqrt{s}$)	NET_{CMB} ($\mu K\sqrt{s}$)	θ_{fwhm} (arcmin)
95	24	0.964	8.1	2×10^{-10}	221	278	1.58
150	38	0.982	10.8	2×10^{-10}	150	259	1.00
219	35	0.969	11.0	2×10^{-10}	184	551	0.69
274	67	0.950	24.5	4×10^{-10}	159	774	0.56
345	27	0.844	22.3	4×10^{-10}	425	4975	0.44

Ongoing Work

Band selection: need more info on radio point sources populations, their correlations with clusters. Currently doing simulations to optimize bands and weighting…

Depth vs. Area: more simulations…

Scan speeds and patterns: more simulations with model atmosphere, elevation scanning, etc…

+ hardware, hardware, hardware…

Planned First Observing Season: Austral Winter 2007

END