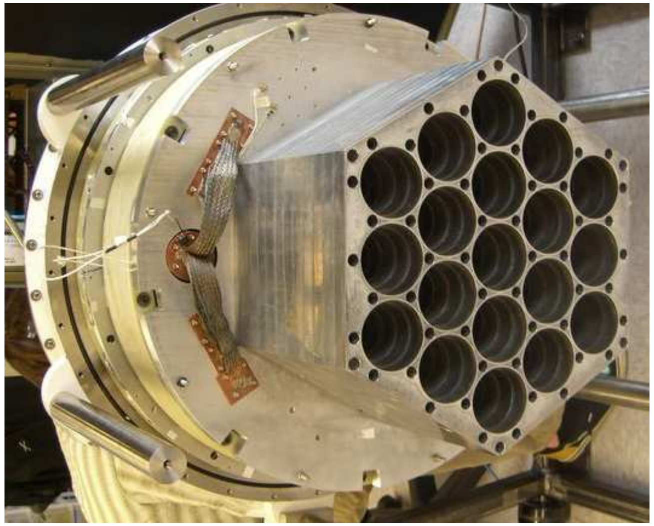
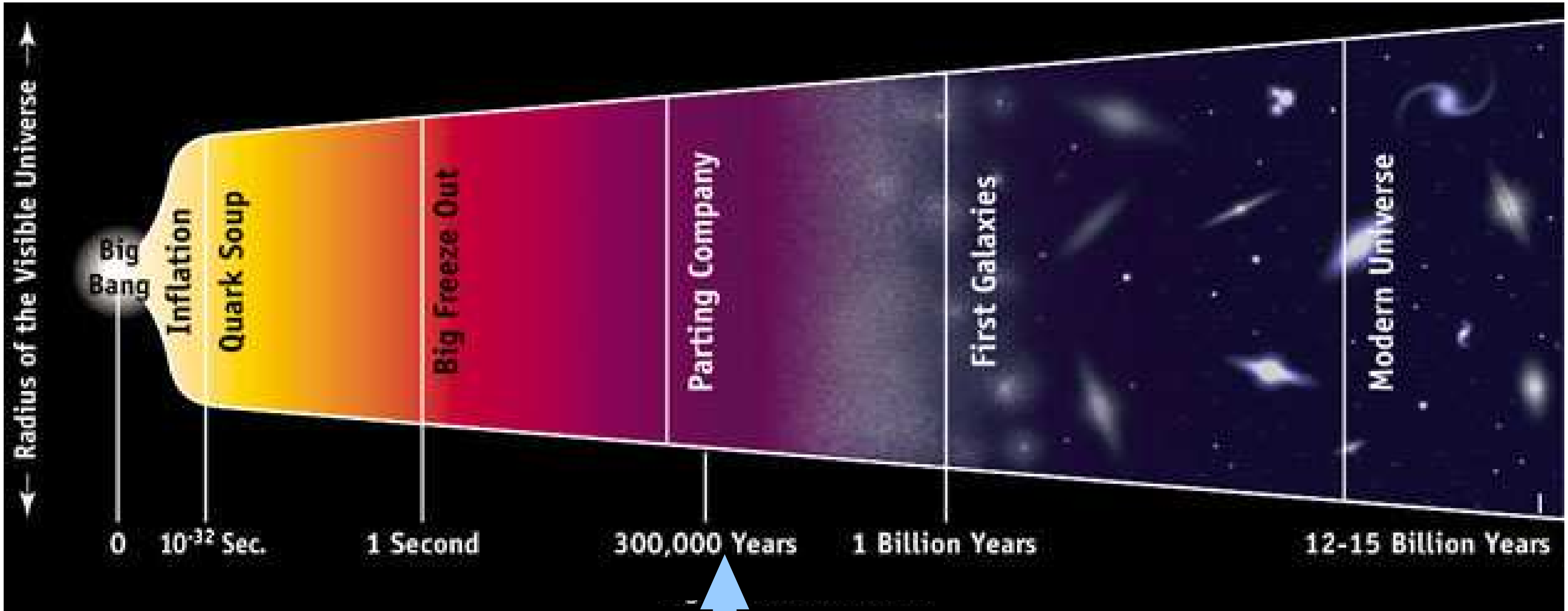


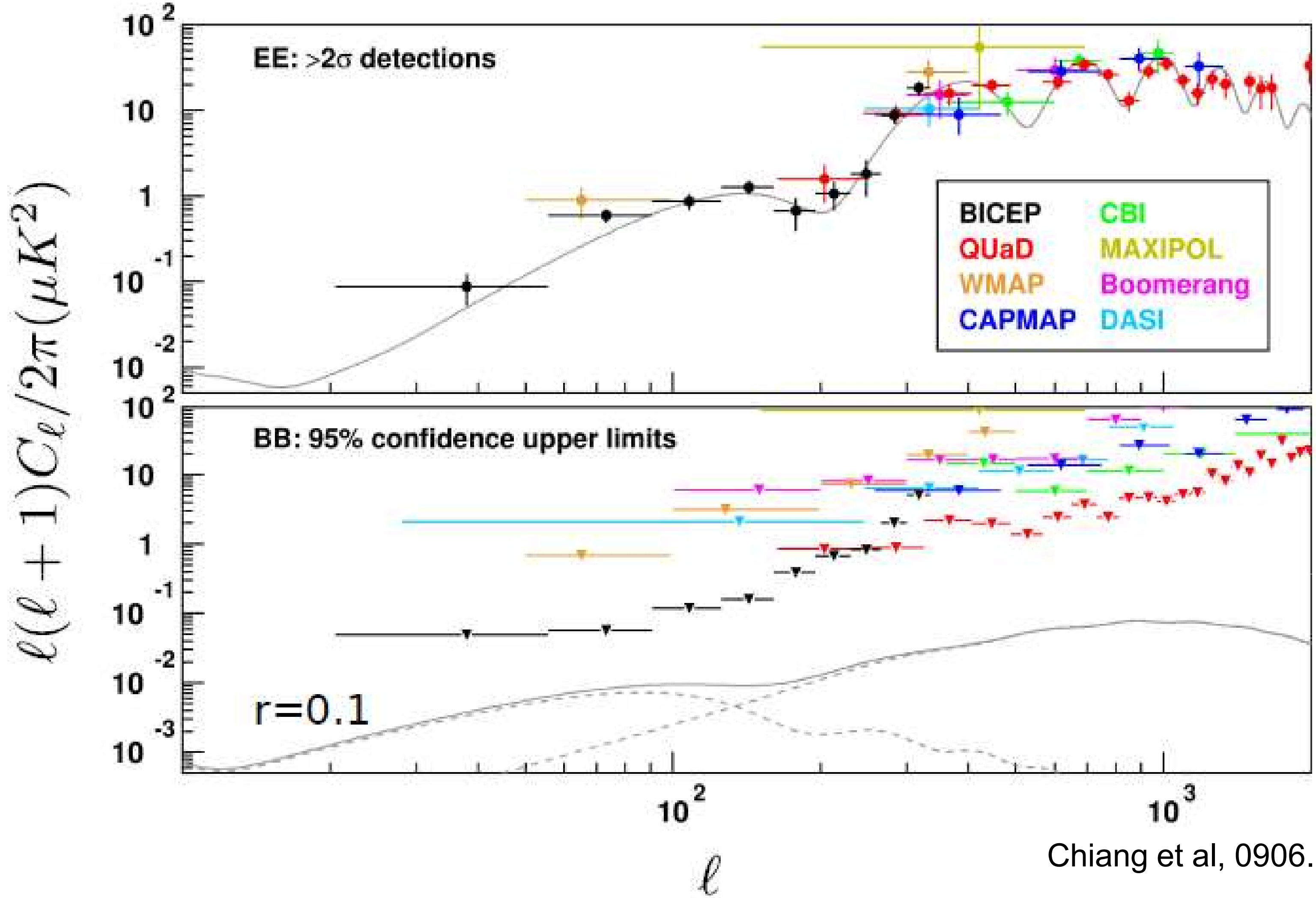
The Q/U Imaging ExperimenT (QUIET) receivers

Coherent Polarimeter Arrays at 40 and 90 GHz

Dorothea Samtleben,
Max-Planck-Institut für Radioastronomie,
Bonn



Universe becomes transparent
=> Release of Cosmic Microwave background Radiation



Chiang et al, 0906.1181

Density fluctuations produce E-modes,
B-modes derive from Lensing and Primordial Gravity Waves

Size of B-modes from Primordial Gravity Waves still unknown,
Parametrized by Tensor-to-Scalár Ratio *r*

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$_\ell$OVER(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

A Program of Technology Development and of Sub-Orbital Observations of the Cosmic Microwave Background Polarization Leading to and Including a Satellite Mission

ASTRO 2010 Decadal Survey White Paper

The QUIET Collaboration

14 institutes, 5 countries, ~30 people

Caltech, Chicago, Columbia, Fermilab,
JPL, KEK (Japan), Manchester, Miami, (Michigan),
MPIfR, Oslo, Oxford, Princeton, Stanford

QUIET Receiver Module

Radiometer on a chip:

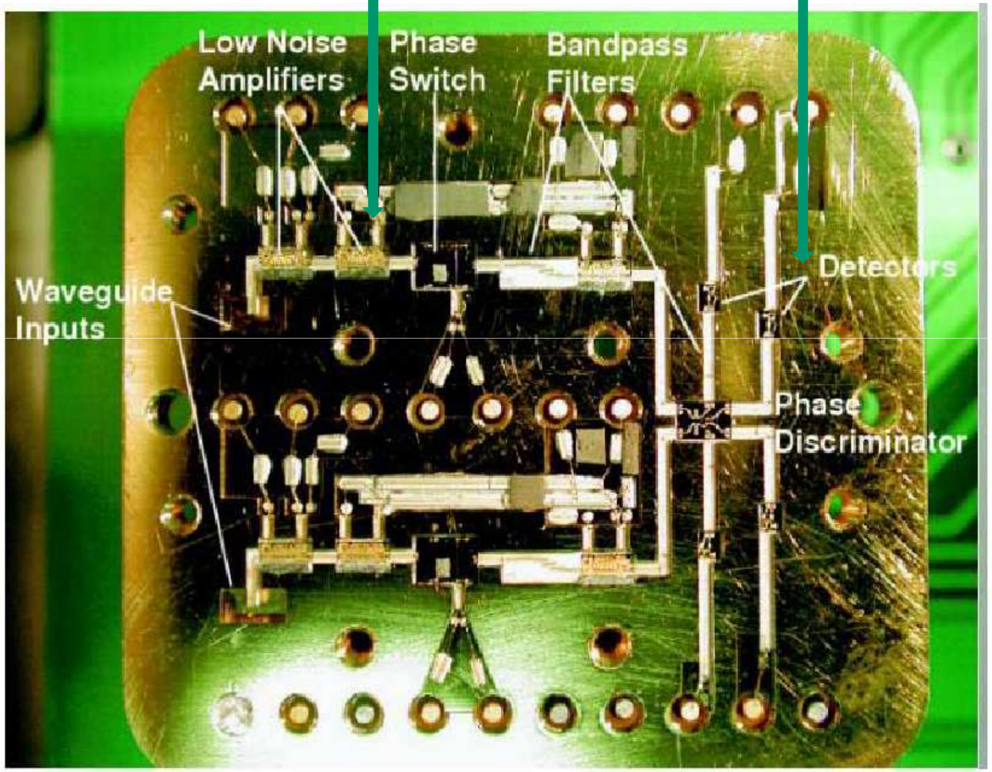
- Automated assembly and optimization
- Large array of correlation polarimeters

➢ Measuring Q/U simultaneously in each pixel

➢ Complementing frequencies from other experiments (bolometric experiments are >100 GHz)

InP MMIC

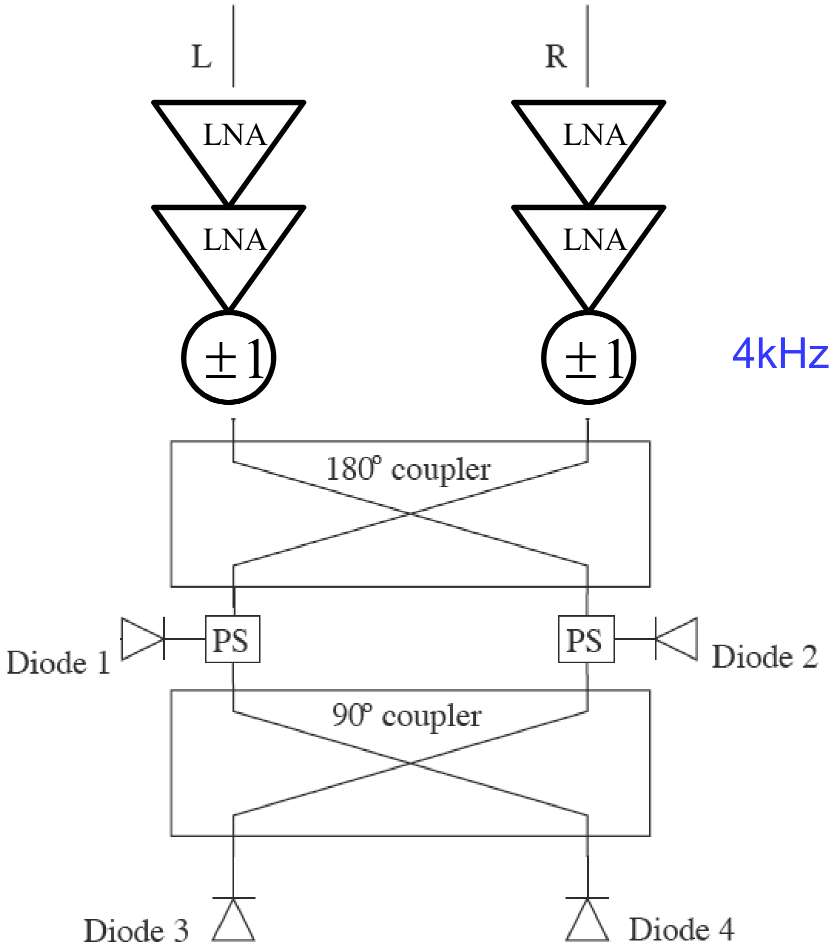
GaAs Schottky Diodes

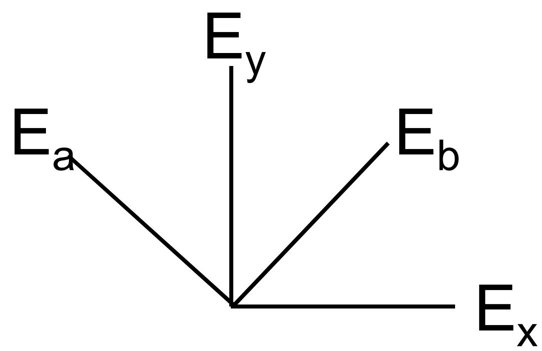


~1 inch

Produced by JPL based on developments for Planck LFI

QUIET L/R Correlator: Simultaneous Q/U measurements





4kHz phase switching

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

Q

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

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

U

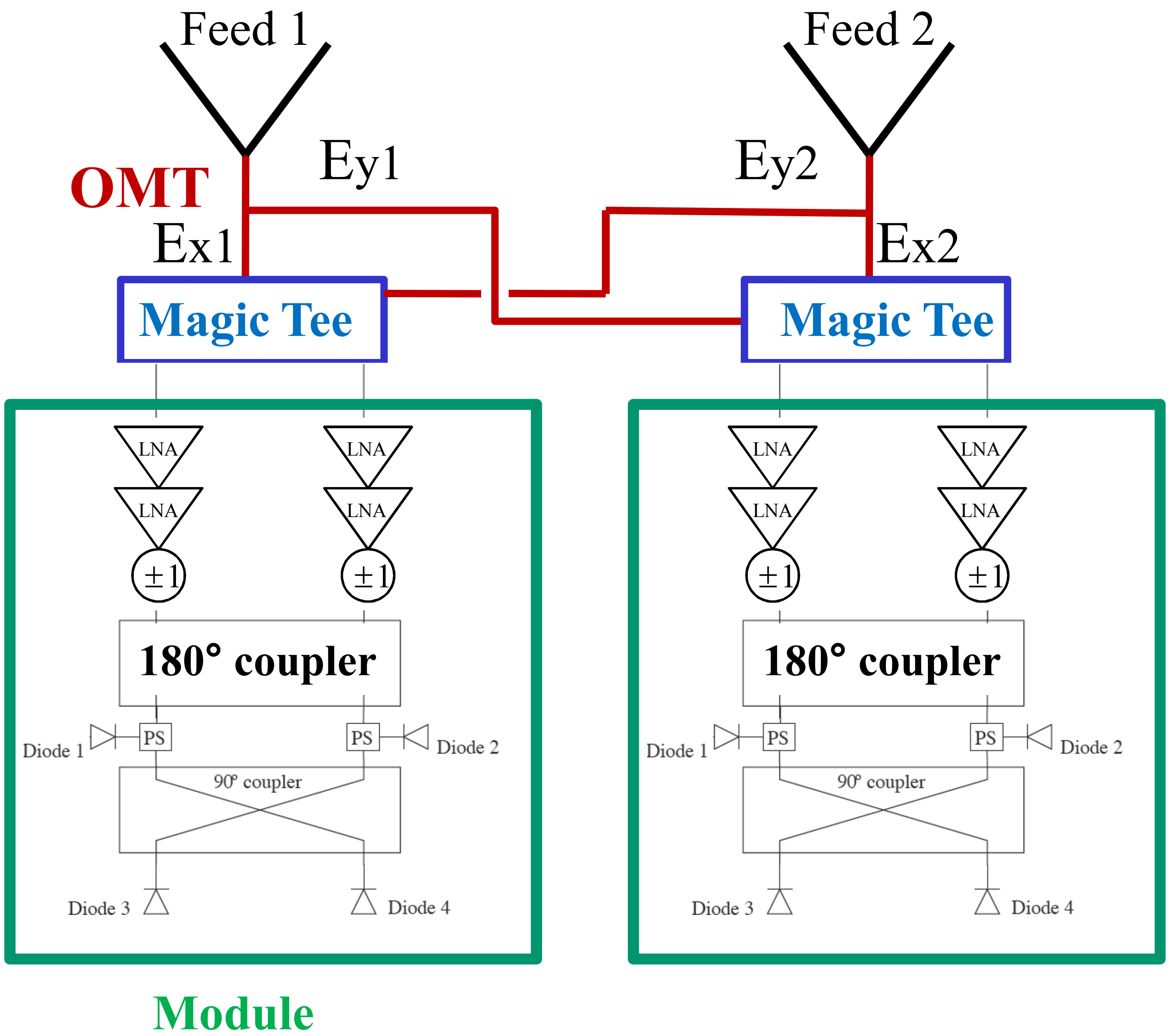
Differential Total Power Receivers (MPIfR)

Design and production of differential total power receivers:
2 Q-band, 6 W-band

Measuring ΔT between neighboured beams,
phase switching reduces 1/f of amplifiers

- Identification/characterization of unpolarized foregrounds
- Measurements of CMB Temperature and Temperature-Polarization correlations

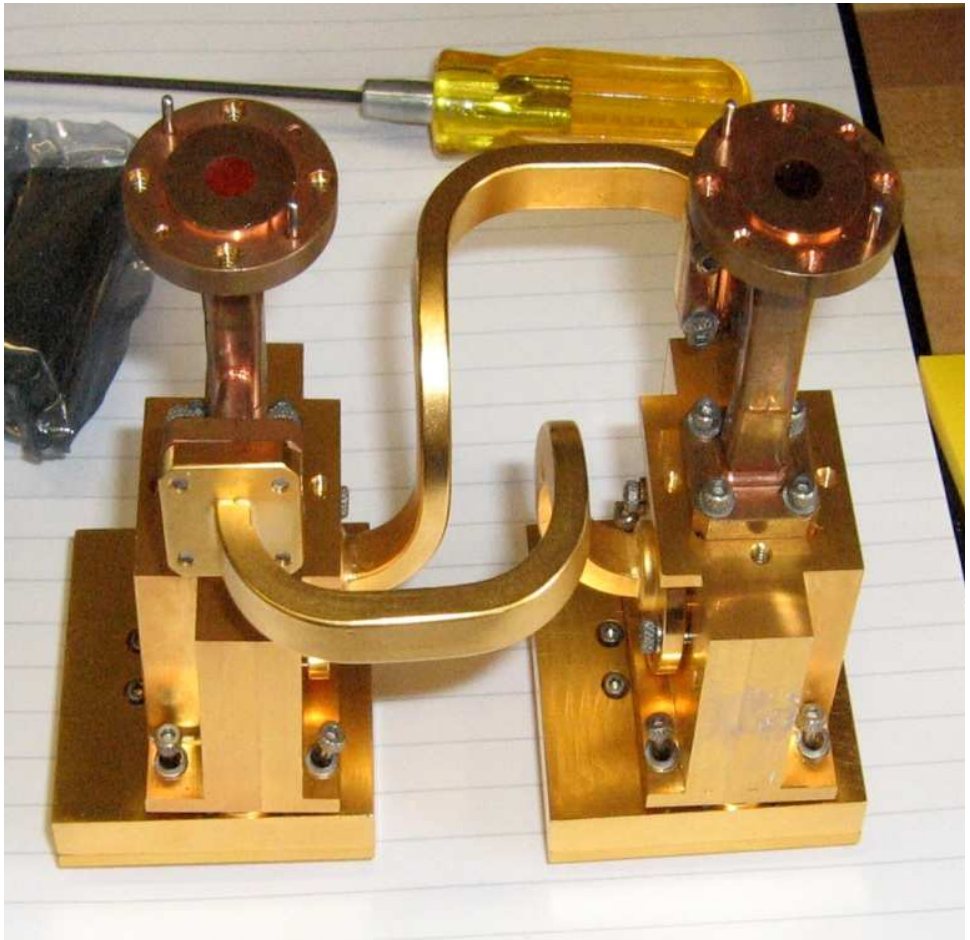
Differential Total Power Receivers (MPIfR)



=> Tx1 - Ty2

- Temperature difference
- Sensitive to polarization

Differential Total Power Receivers (MPIfR)

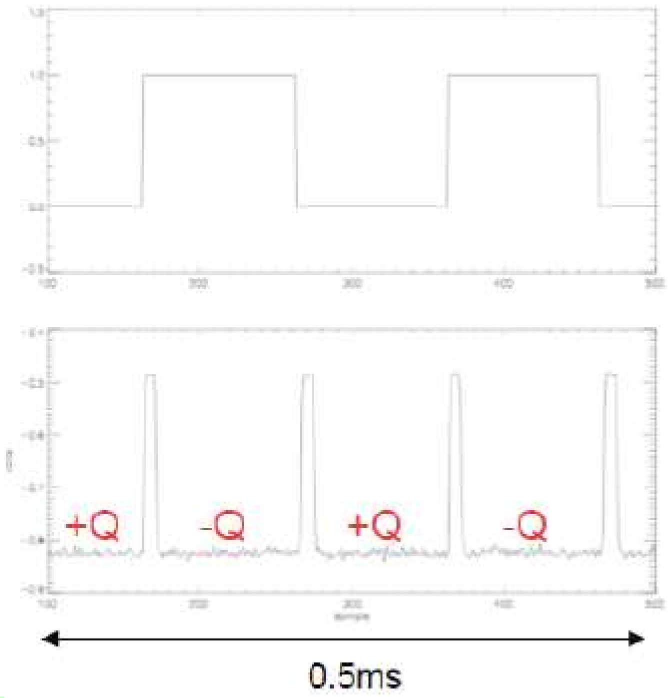


Q-band

W-band

2 of the JPL modules for the TT assemblies were assembled and tested at MPIfR with Frank Schäfer, Sener Türk

(Double) Demodulation



- Sampling at 800 kHz
- Switching at 4 kHz
- Blanking of 10%
- Combining to 100 Hz

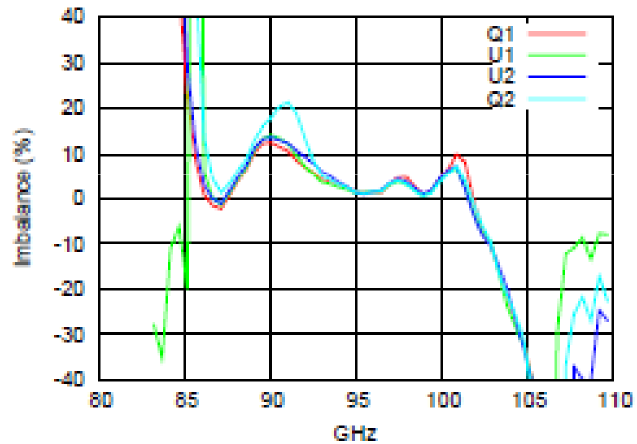
- Large phase switch imbalance (mainly W-band)
- Slightly different frequency dependences of the diode responsivities

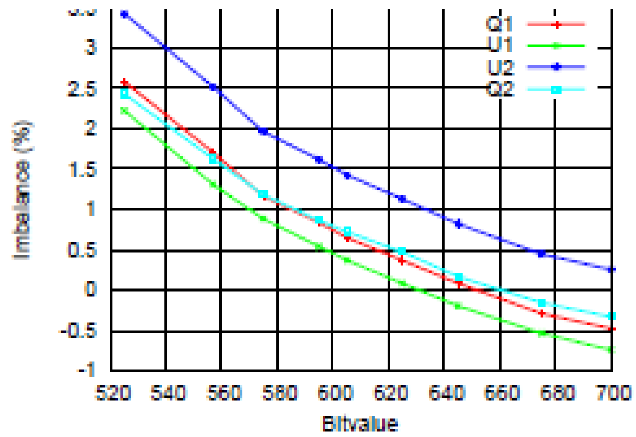
=> not all diodes simultaneously balanced

=> Use new demodulation scheme which eliminates phase switch imbalances:

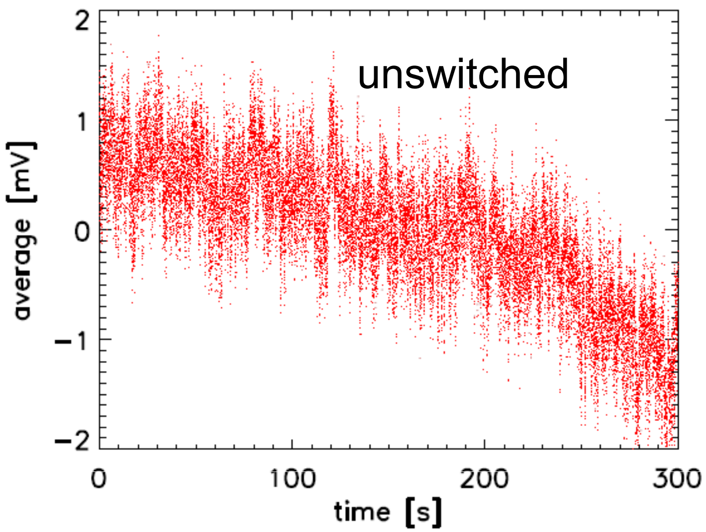
Leg A: +-+-+-+-+-+-+-+-+-+-+-+-+ 4kHz

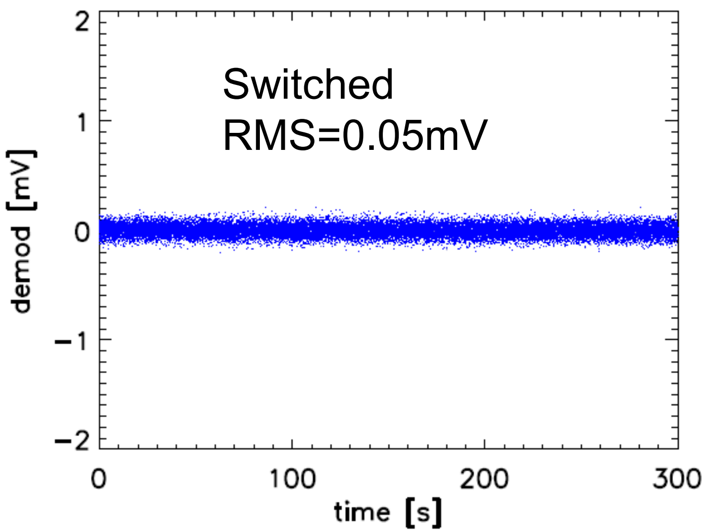
Leg B: +++++++++--------------- 50 Hz

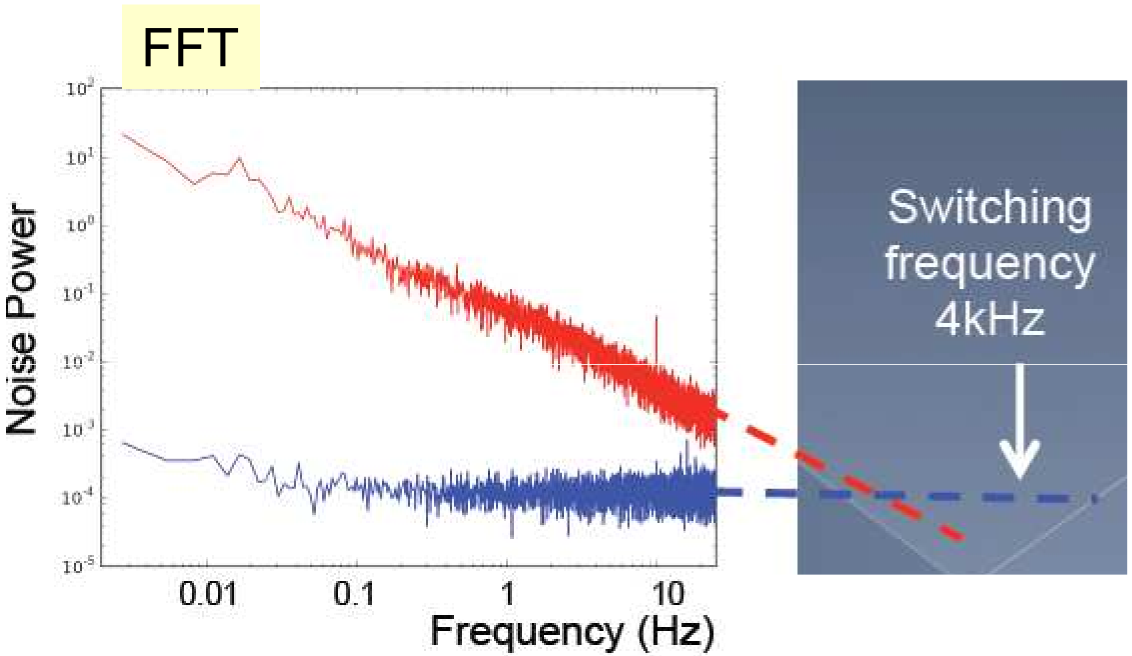


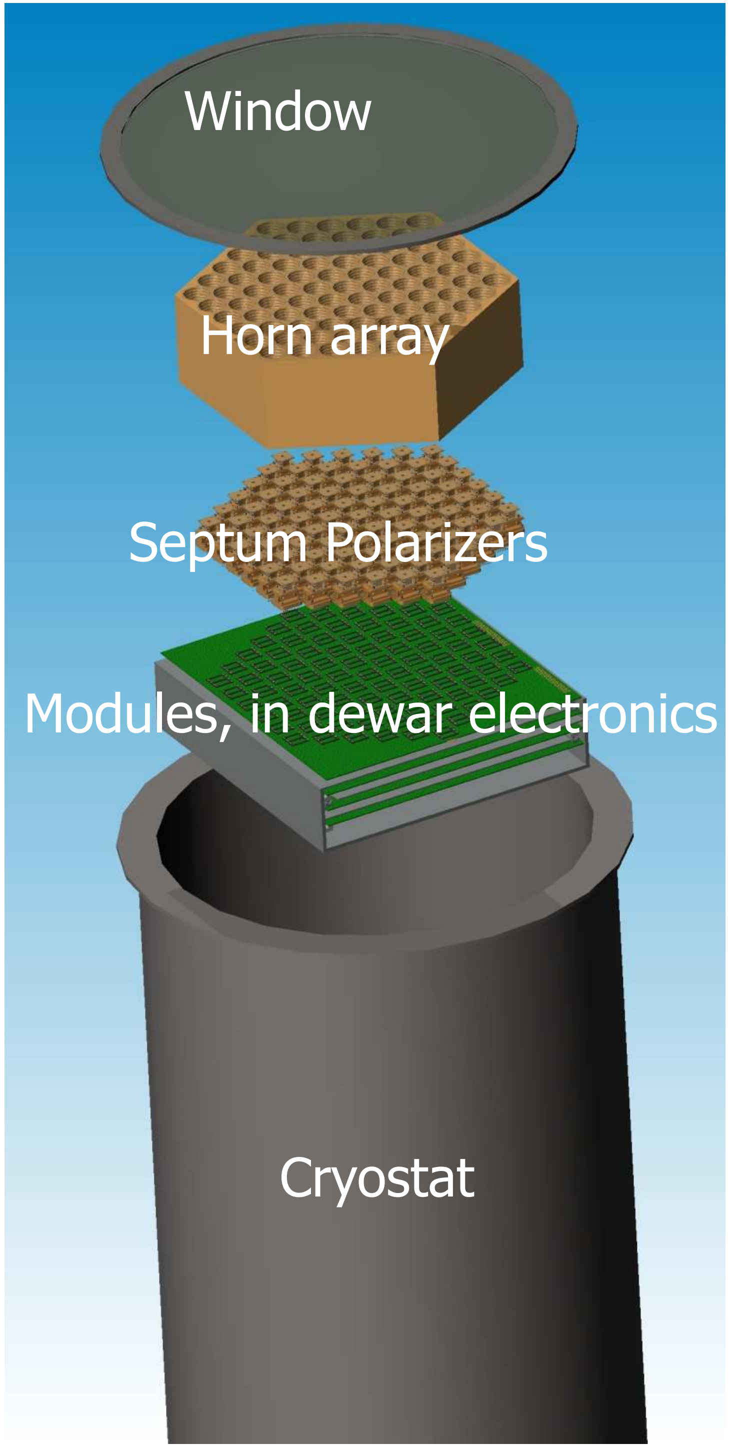


50 Hz Time streams (in Chile, azimuthal scan, constant elevation)









Receivers for QUIET

- Build large receiver arrays in cryostats
- Install up to 3 telescopes (1.4m) in the Atacama Desert

84+6* pixel 90 GHz
FWHM 12'
array sensitivity: 55 $\mu K\sqrt{s}$

17+2* pixel 40 GHz
FWHM 28'
array sensitivity: 65 $\mu K\sqrt{s}$

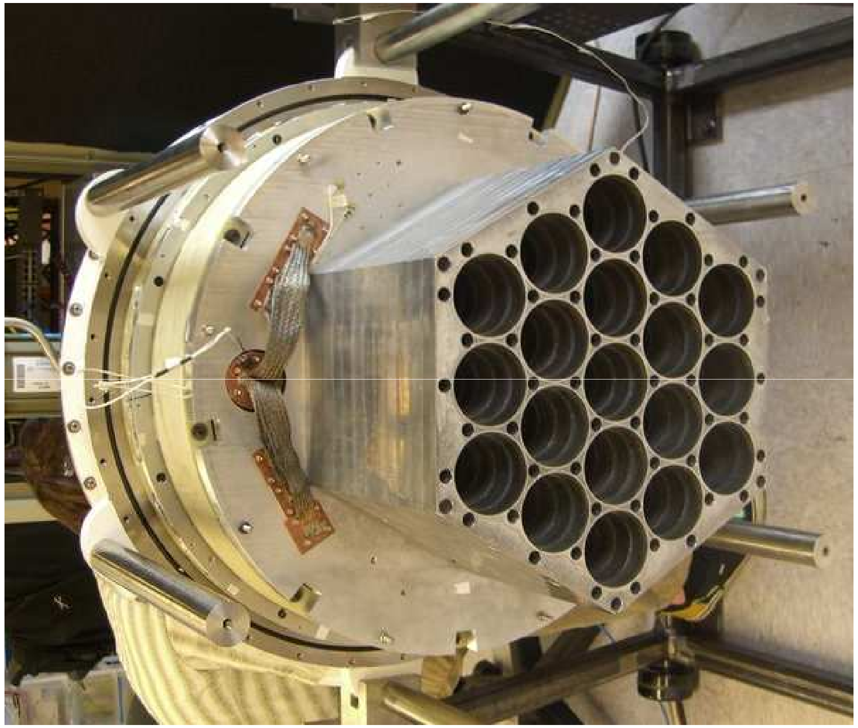
* 6 (2) pixels are Total Power Pixels in the W (Q) band array

Phase I,
in Chile 2008/09

3 x 499 pixel 90 GHz
61 pixel 40 GHz
18 pixel 30 GHz

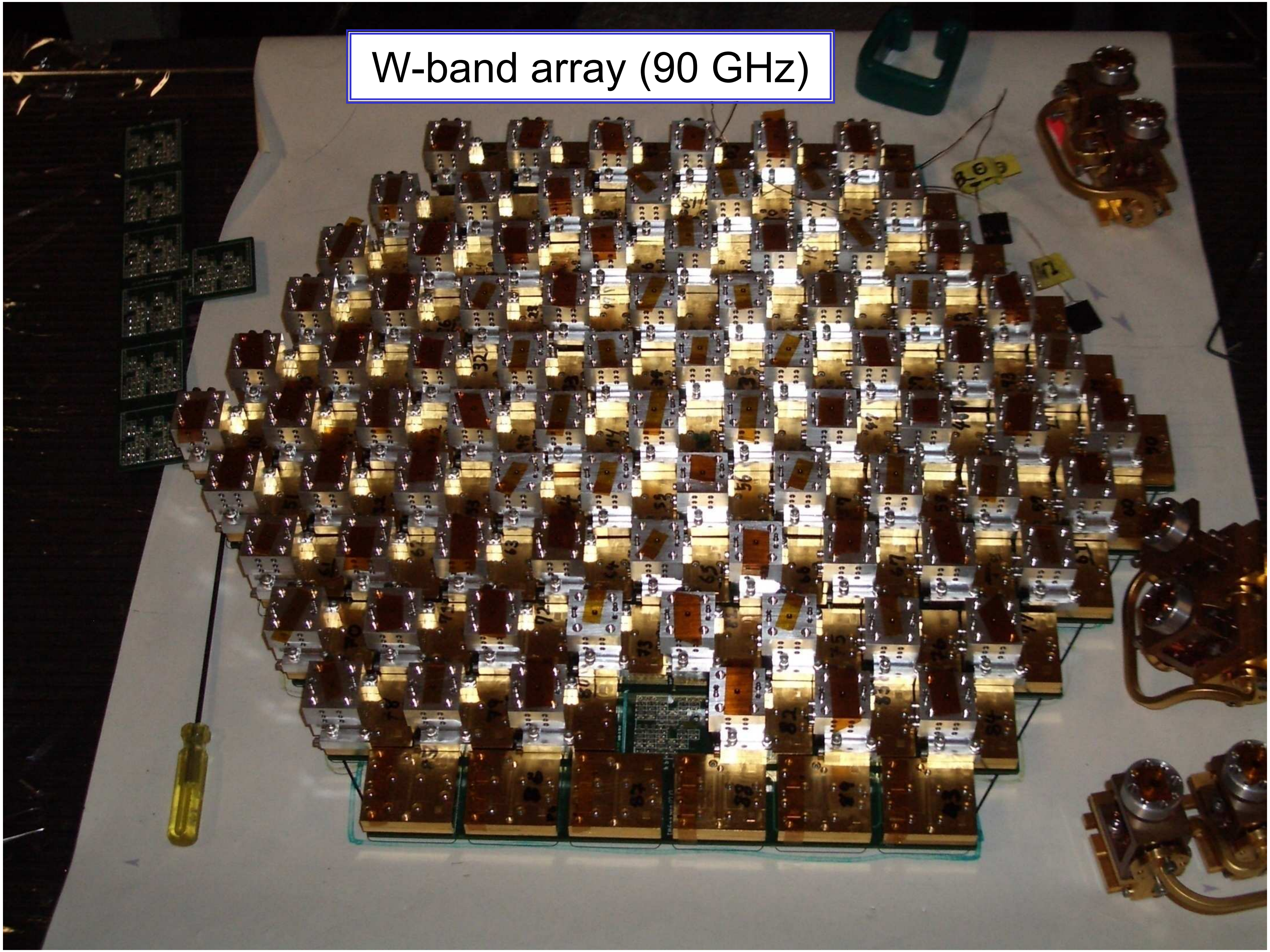
Phase II
2010++

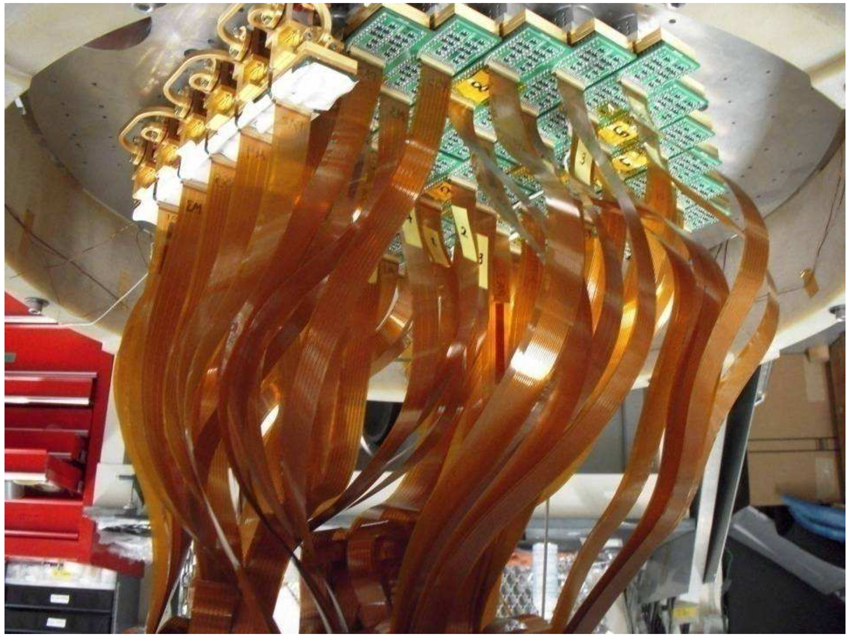
Q-band array (40 GHz)

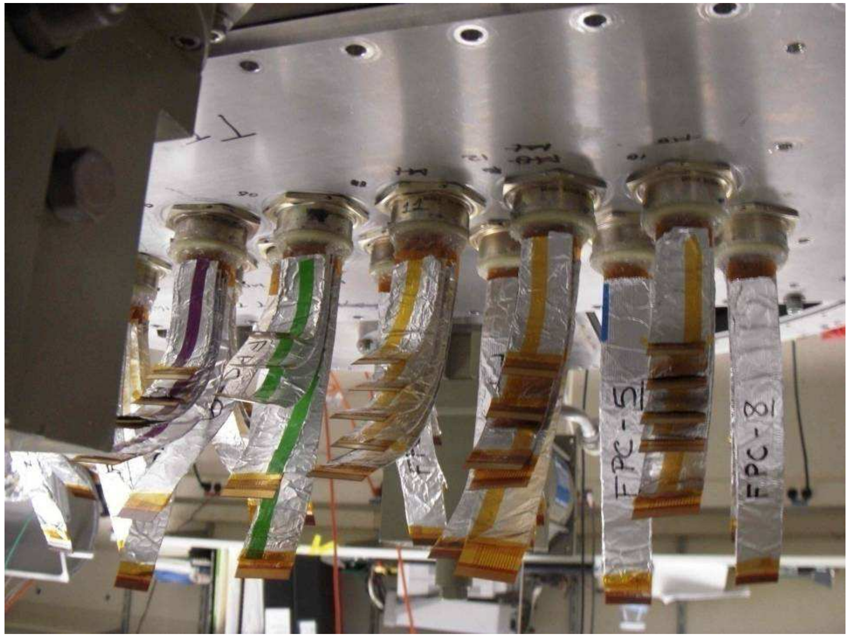


Horn arrays from 100 platelets combined by diffusion bonding

W-band array (90 GHz)



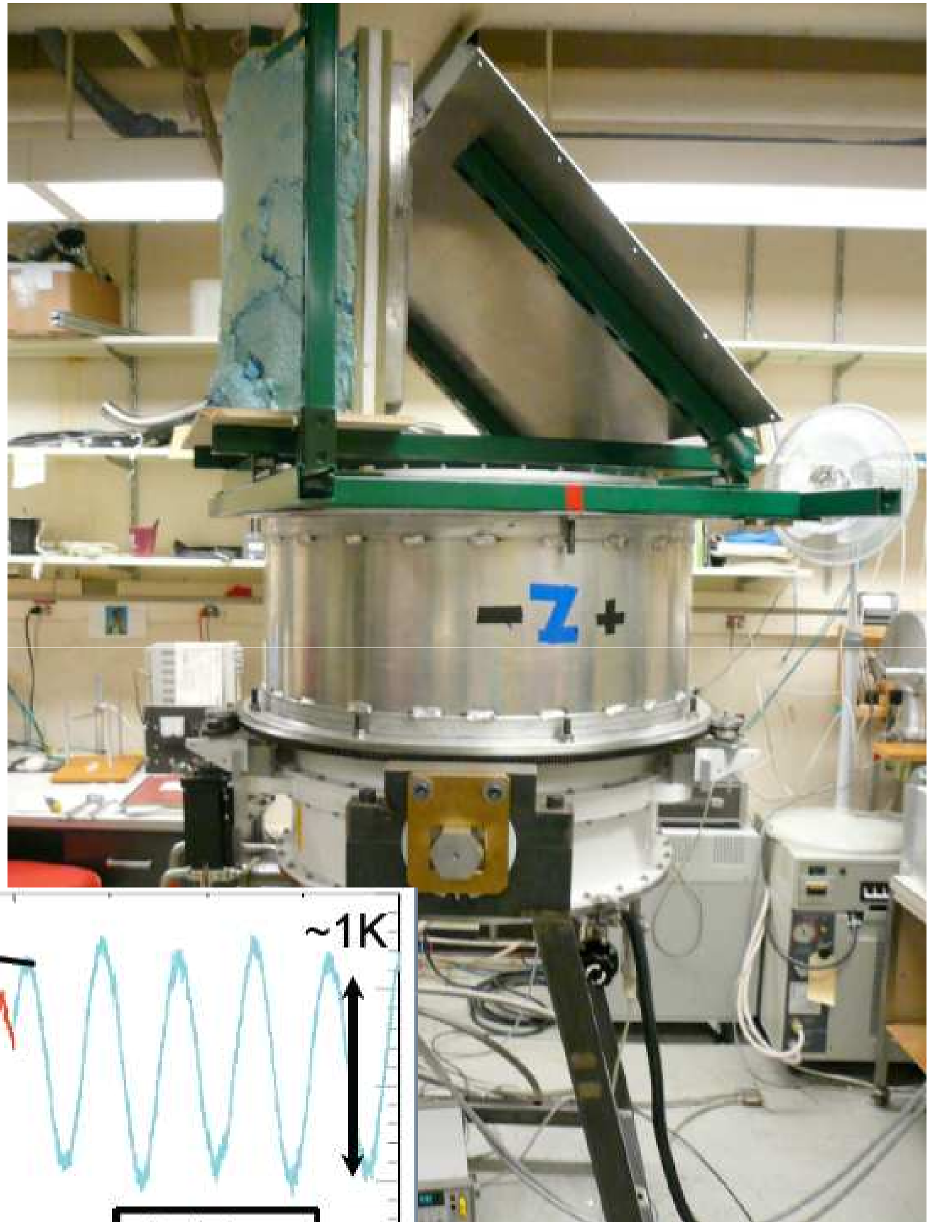


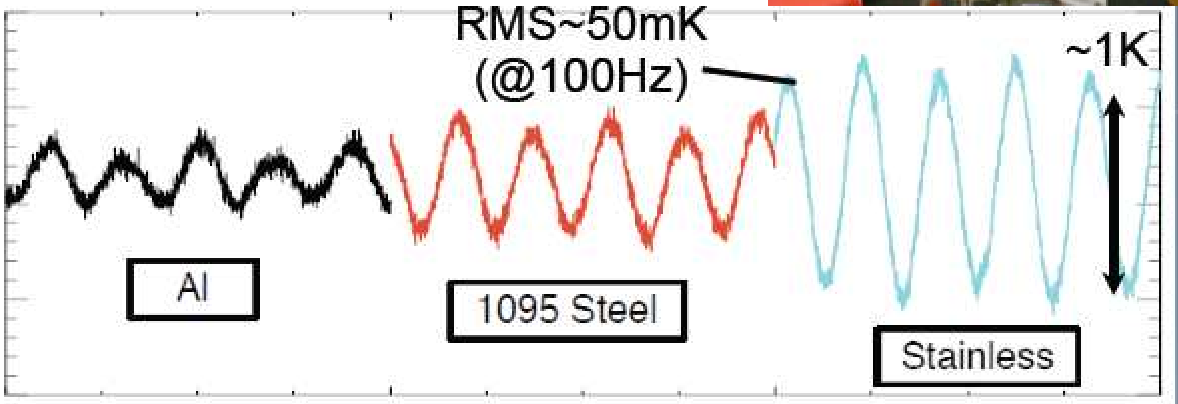

FPC-5
FPC-8

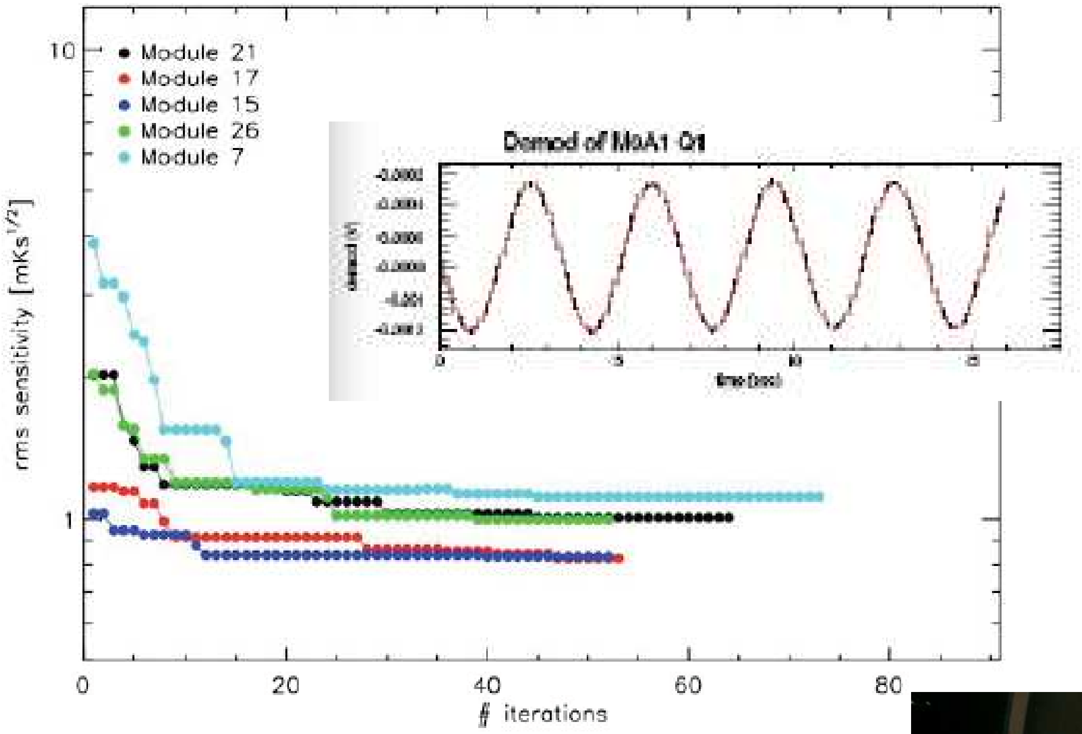
Characterization

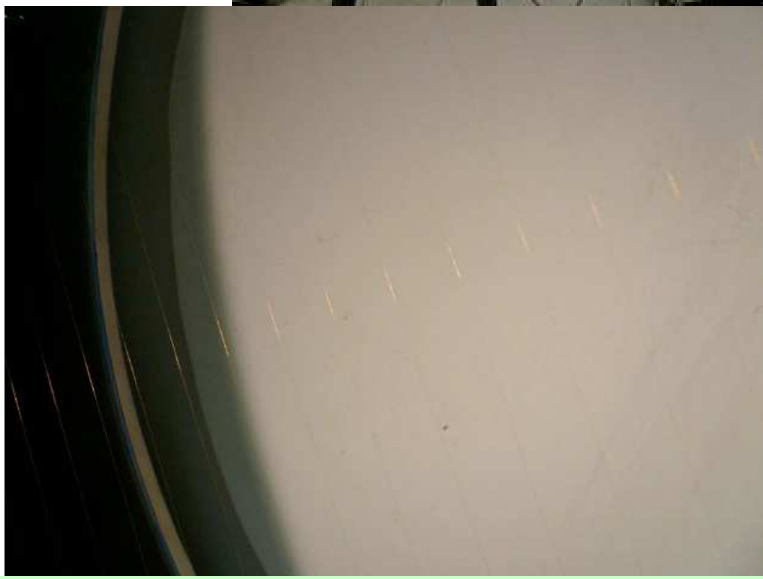
Assembly and Integration of the arrays in Columbia (Q-band) and Chicago (W-band)

- Two-load tests
  (liquid Nitrogen, Argon, Oxygen and 300K eccosorb)
- Band Sweeps
- Gain determination
  and optimization with rotating metal plate reflected from cold load







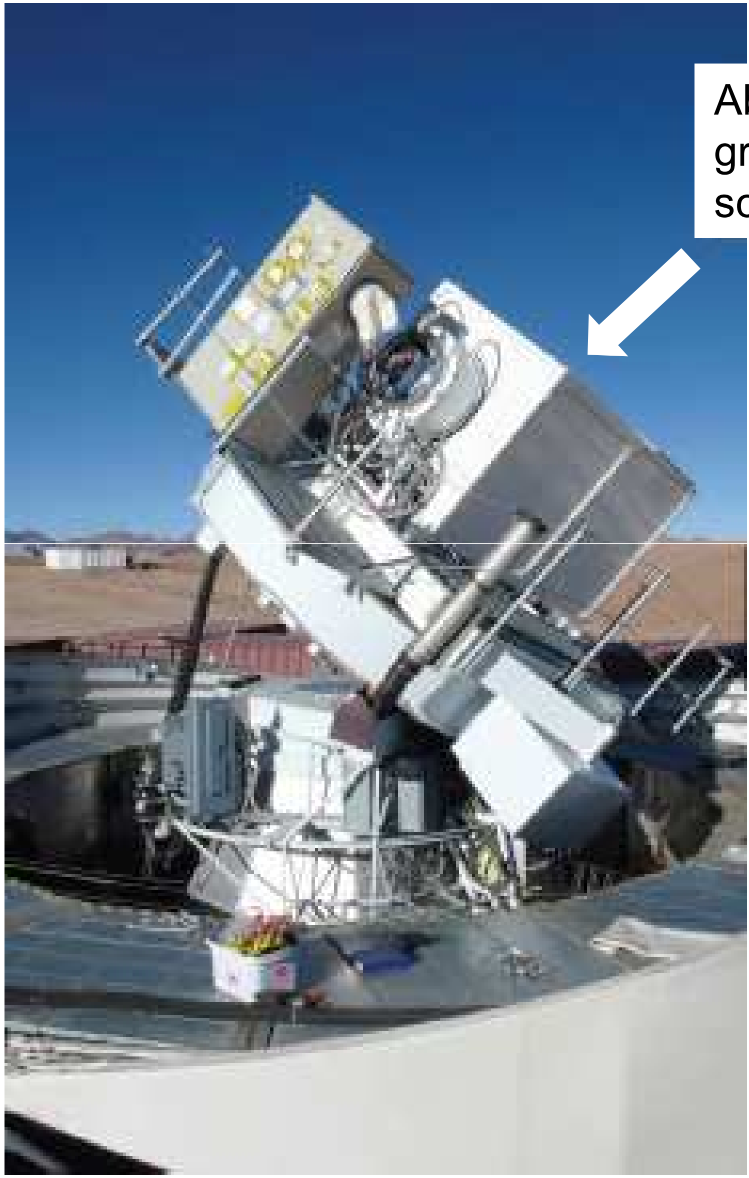


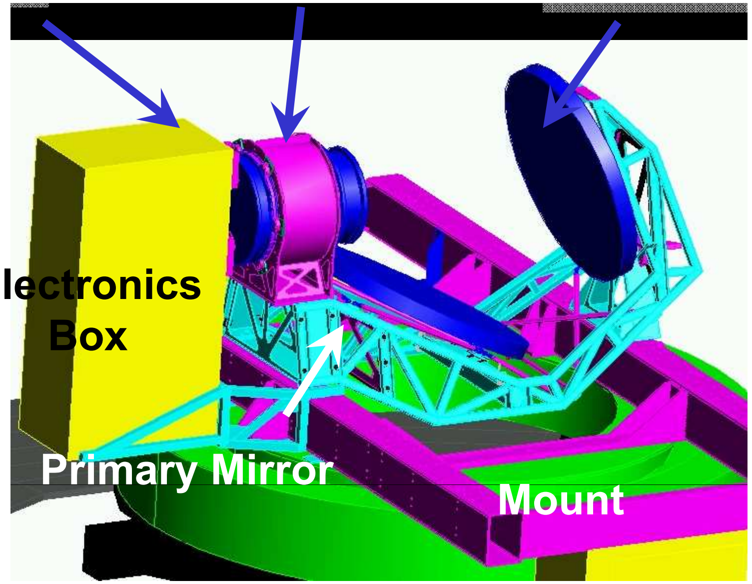
Sparse wire grids with 0.5-1 inch spacing

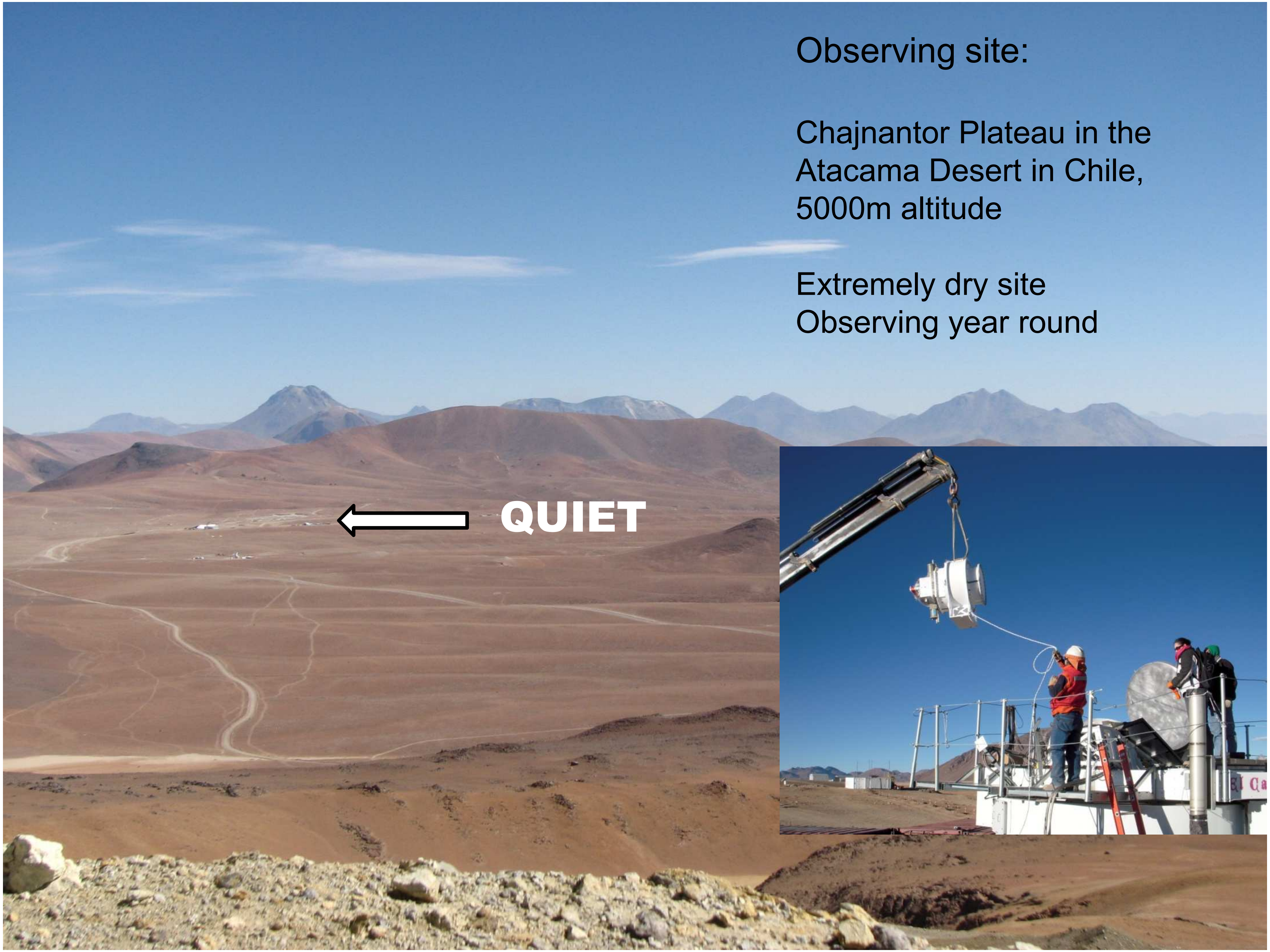
Automatic optimization

- Per module10 gate/drain voltages
- starting with JPL values
- Downhill-simplex optimization
- 50-150 iterations (coarse)
- ~50 iterations (fine)

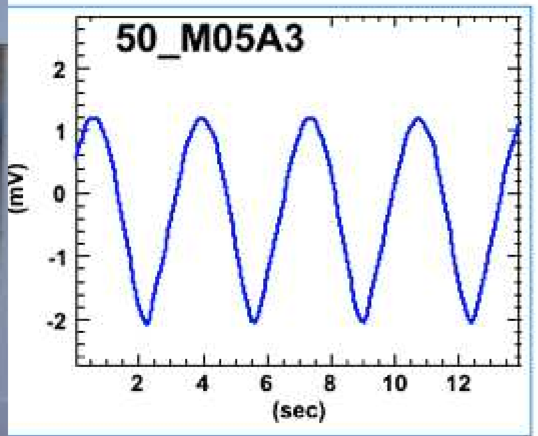
Whole array optimized in 10 hours

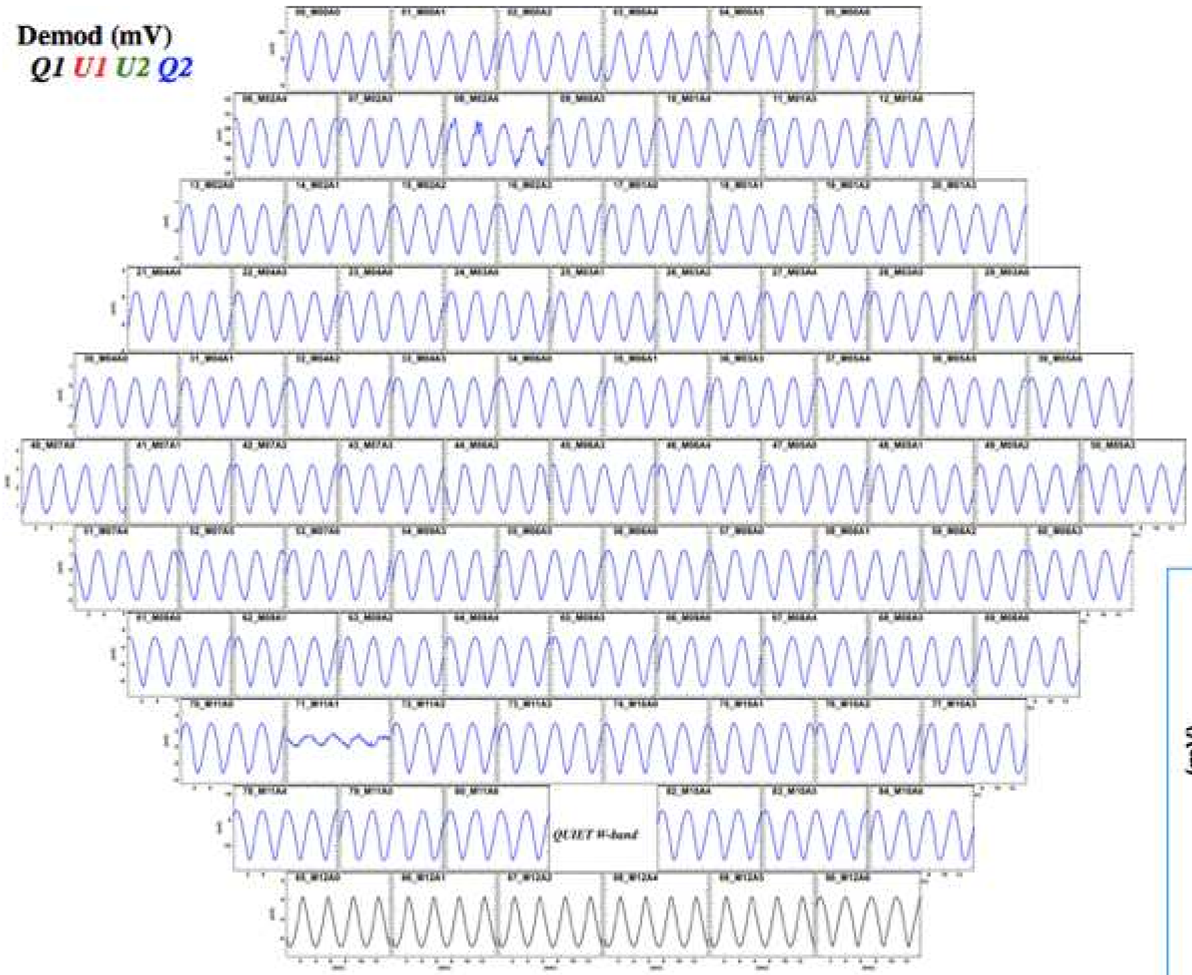

Absorptive ground screen


Focal Plane (Receiver)
Platelet Array
2nd Mirror
Electronics Box
Primary Mirror
Mount

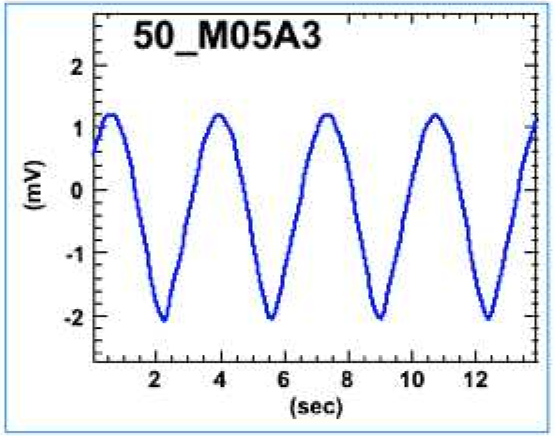

Observing site:
Chajnantor Plateau in the Atacama Desert in Chile, 5000m altitude
Extremely dry site
Observing year round
QUIET

Rotating wiregrid
at the site looking
at the sky (via metal plate)

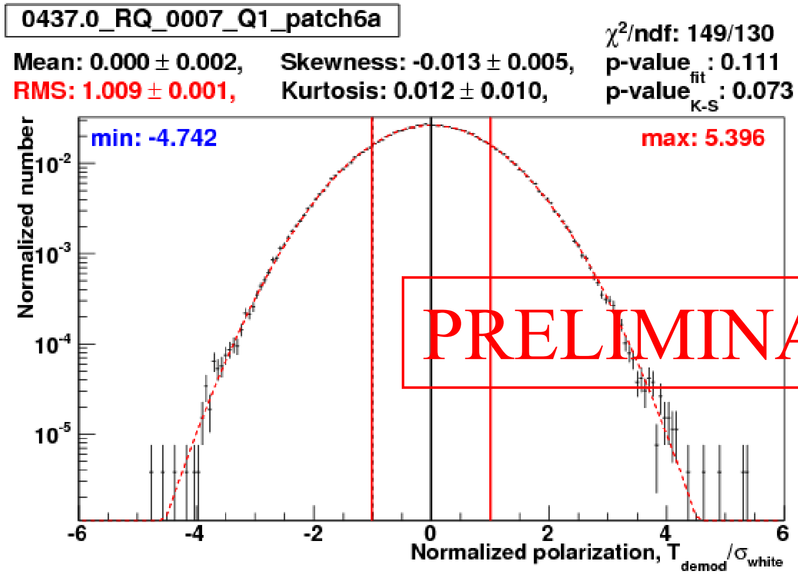


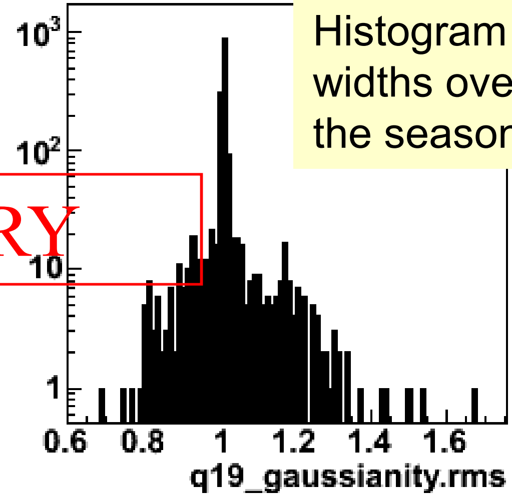


Rotating wiregrid
at the site looking
at the sky (via metal plate)

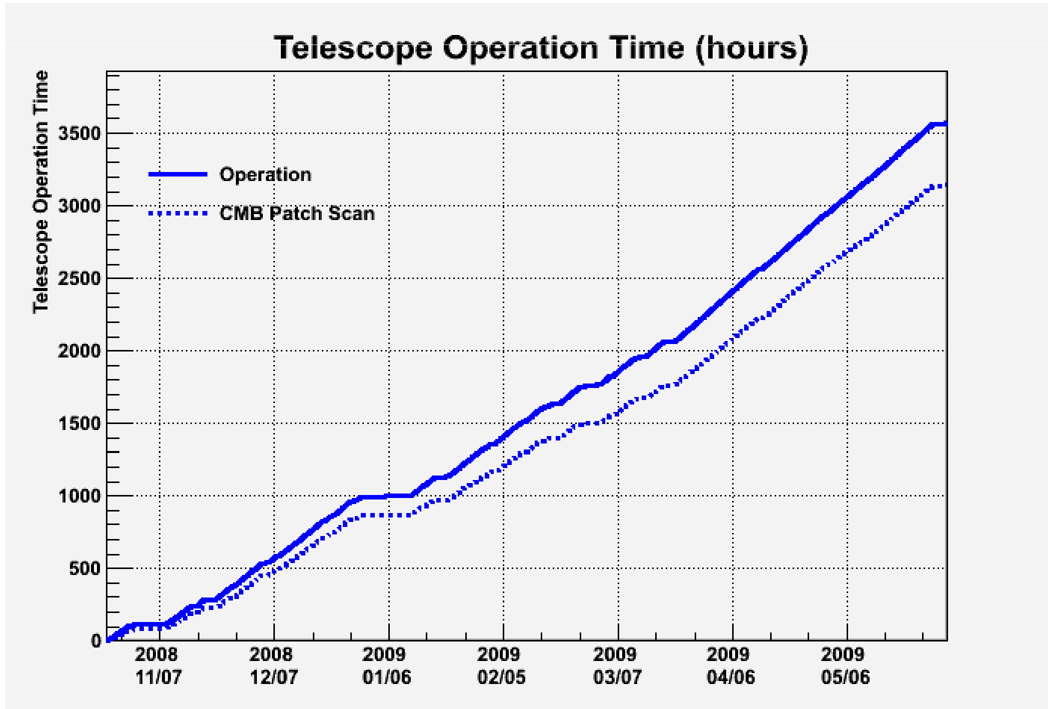


Histogram of data/white noise error for one channel





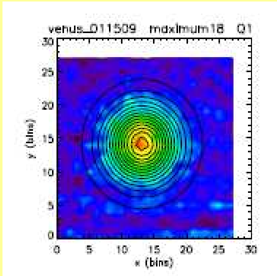
Histogram of widths over the season



70% observing efficiency
90% of observing time for CMB data

Calibration

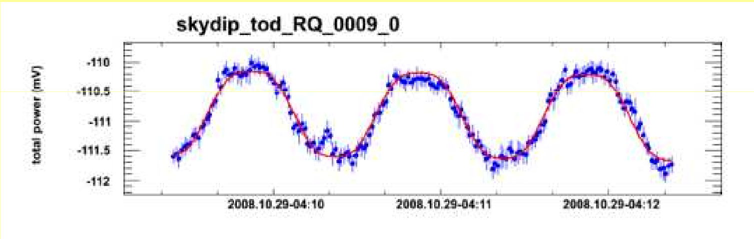
Jupiter in Total Power Receivers



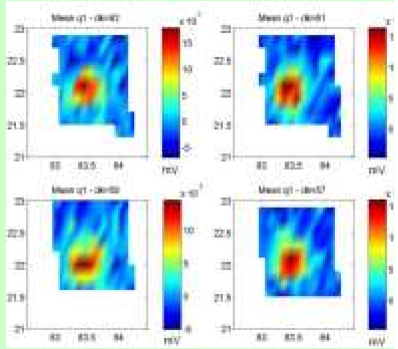
Temperature:

- Elevation nods (10% error)
- Jupiter/Venus/RCW38 (5% error)

Elevation nod in unswitched Total Power channels



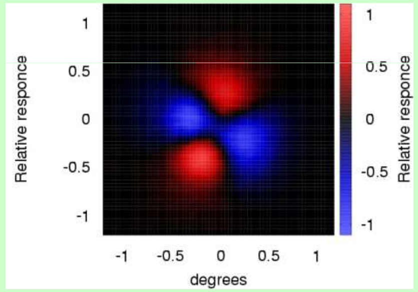
Tau A in Polarization



Polarization:

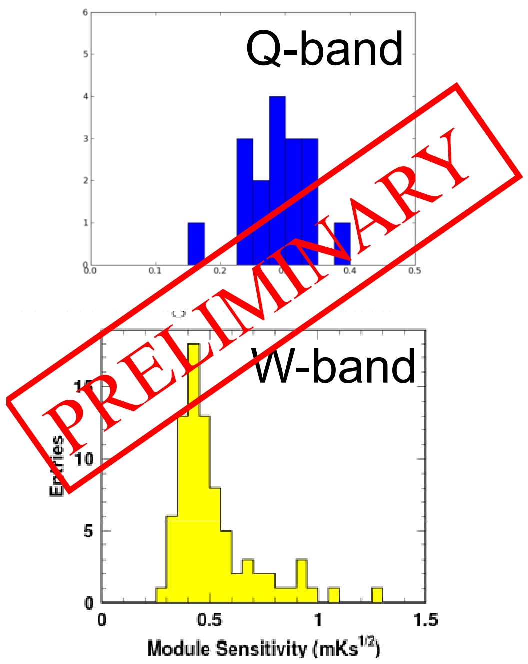
- Tau A (10% error)
- Elevation nods (I->Qleakage to 0.1%)
- Moon (angle uncertainty 2°)
- Noise Source (<5% error)
- Wire Grid (1% error on relative gain)

Moon in Polarization



Preliminary sensitivities/element

Performance/Improvements



	Q / W	
Sensitivity/element	0.27 / 0.5	$mK\sqrt{s}$
/array	65 / 55	$\mu K\sqrt{s}$
Noise temperatures:	30 / 90 K	
Bandwidth:	8 / 12 GHz	
1/f knees:	20 / 20 mHz	

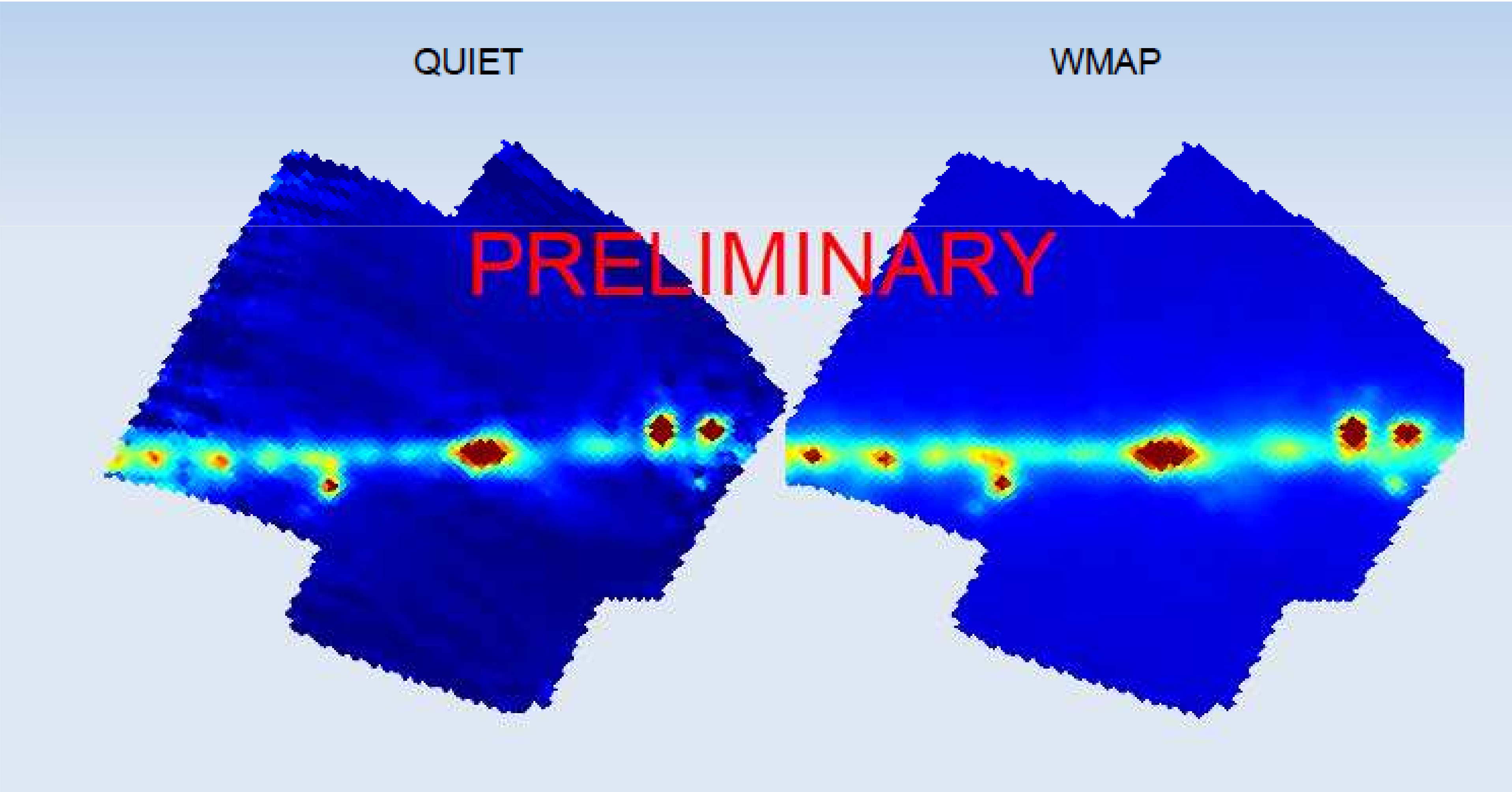
Issues:

- ~5% channels dead/unusable
- 1-2% Leakage (septum polarizer)
- Small bandwidth (hybrid)
- Higher noise temperatures than expected from LNAs

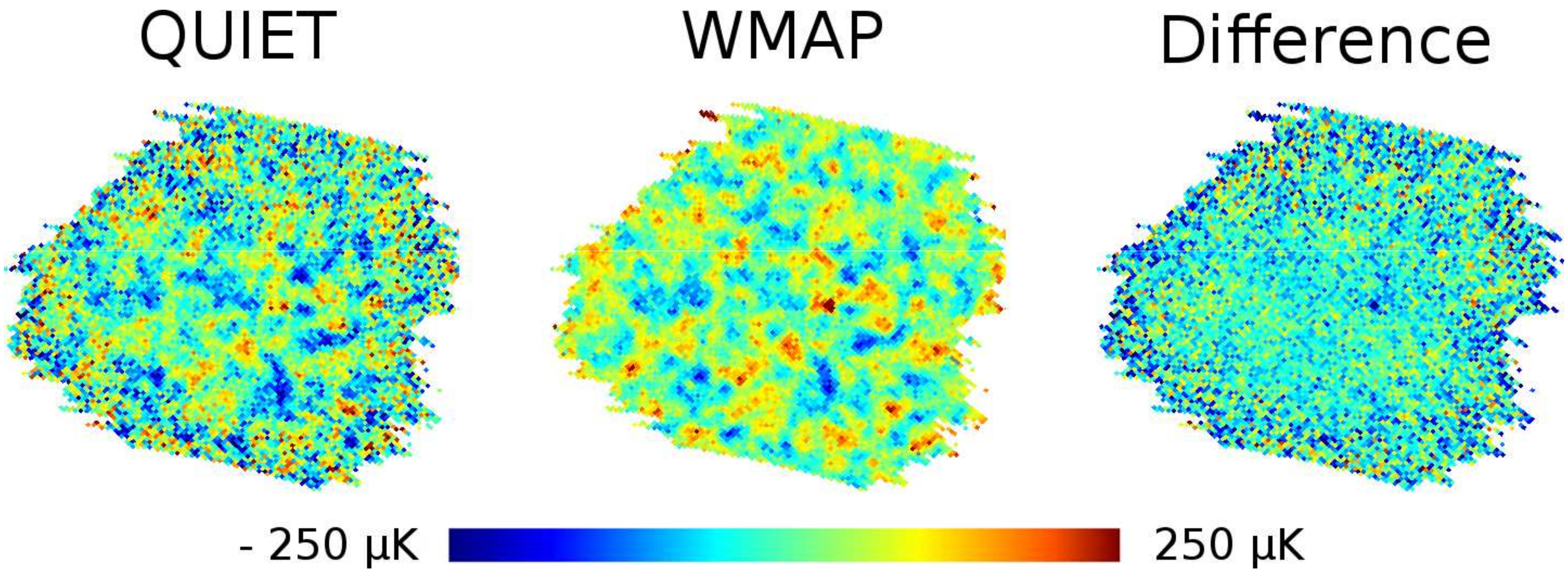
Improvements for phase II:

- Automatic assembly (automatically assembled modules needed less rework)
- Selection of chips from cryogenic testing (before warm selection)
- Changing from 100nm to 35nm gates (for W-band noise temperatures of ~30K were measured)
- Adapt W-band hybrid design to Q-band design for larger bandwidth
- Exchange detector diodes with ones that require no bias when cold

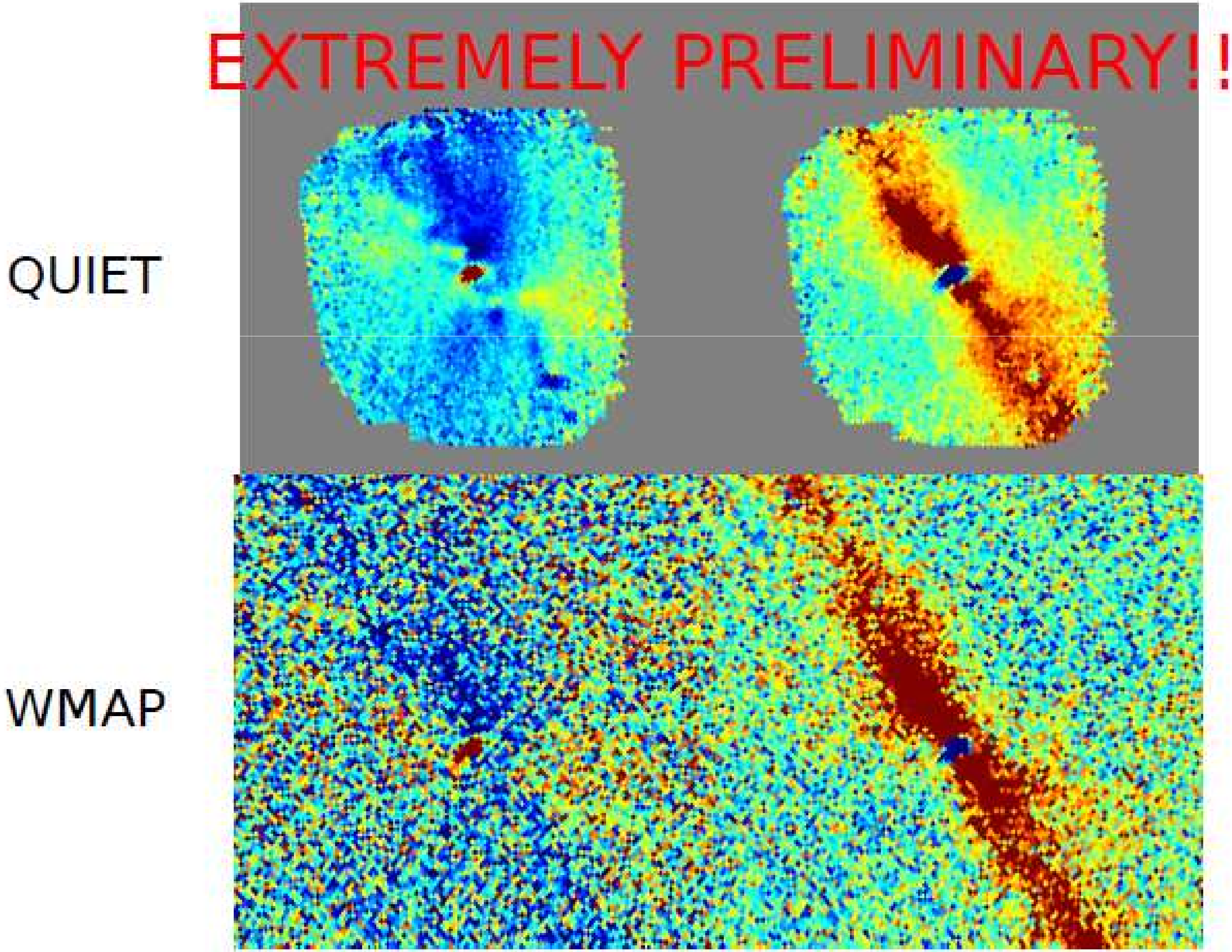
Galactic center map from
Total Power Receivers
(2 Q band receivers)



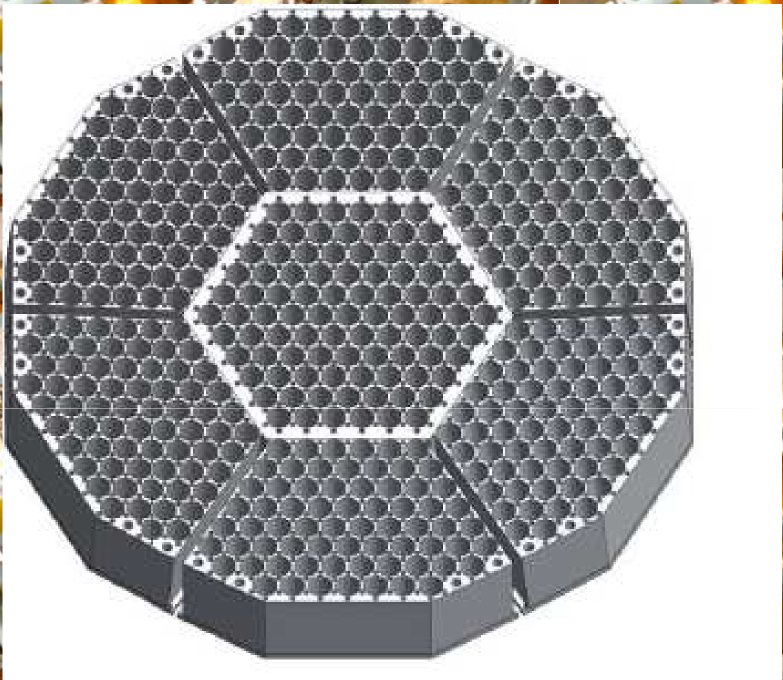
CMB Field (Total Power)



Galactic center map from
Polarization Receivers
(17 Q band receivers)



Outlook 2010++



Production of
3x499 W-band elements
61 Q-band elements
18 Ka-band elements

Module mass production at
Fermilab (W-band) and
Stanford (Q/Ka-band)

Cryostat window diameter 42 inch
4 coldheads/cryostat