QUIET

The Search for B-Mode Polarization in the Cosmic Microwave Background Using Coherent HEMT Detectors

A Proposed New Initiative for Fermilab

August 11th 2009

FCPA-PPD Review

Fritz DeJongh, Scott Dodelson, Dave McGinnis,

Hogan Nguyen, Albert Stebbins

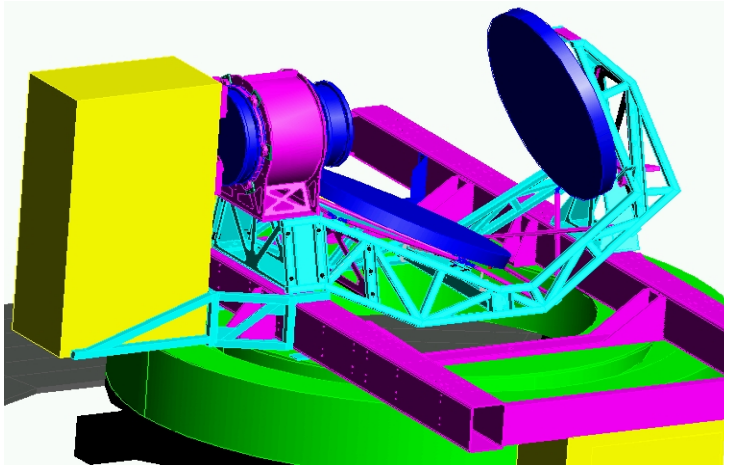
Outline

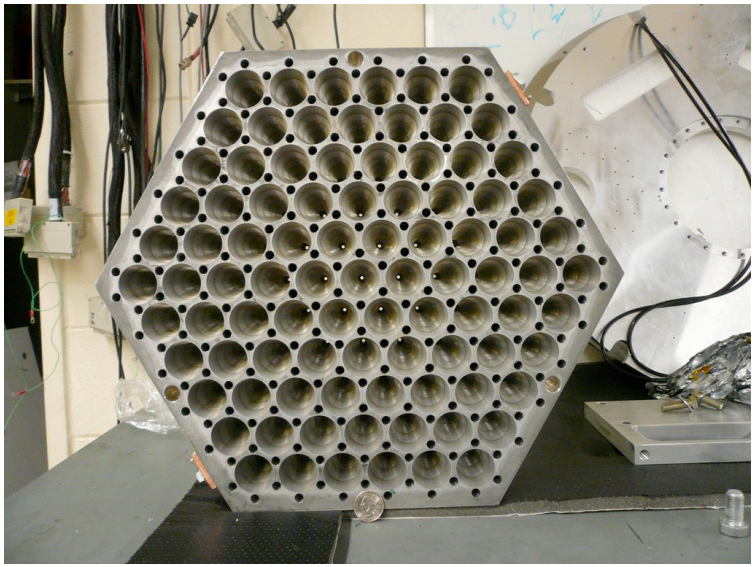
- Albert Stebbins - The Science of CMB Polarization
- Hogan Nguyen - The QUIET Experiment
  QUIET Phase 1 contribution
  The Proposed Phase 2 contribution
- Hogan Nguyen - W-band Assembly
- Fritz Dejongh - Production testing, Cryostat Assembly, Closing Remarks

The QUIET Experiment

Caltech, Chicago, Columbia, Fermilab, KEK, JPL, Manchester, Miami, MPI, Oslo, Oxford, Princeton, Stanford

Chajnantor Plateau (5612 m ASL), Chile

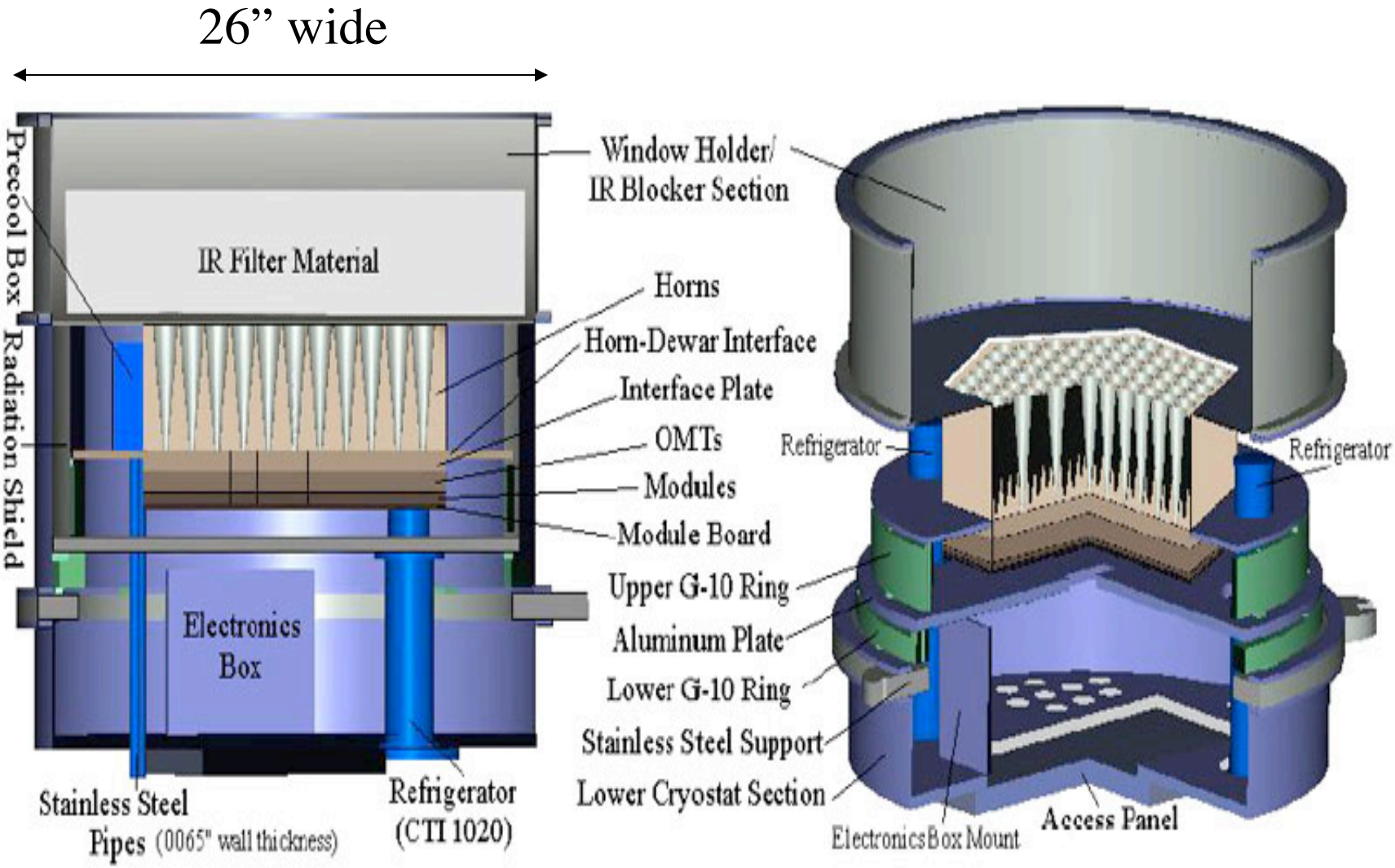




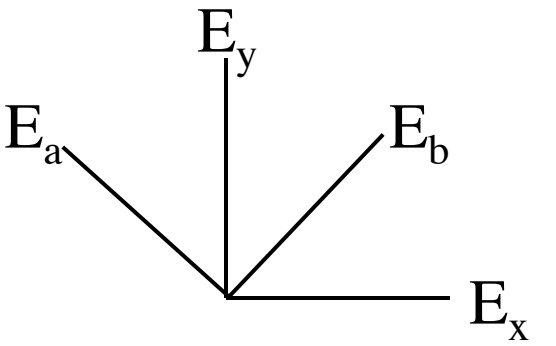
91-element W-band array
currently deployed at Site

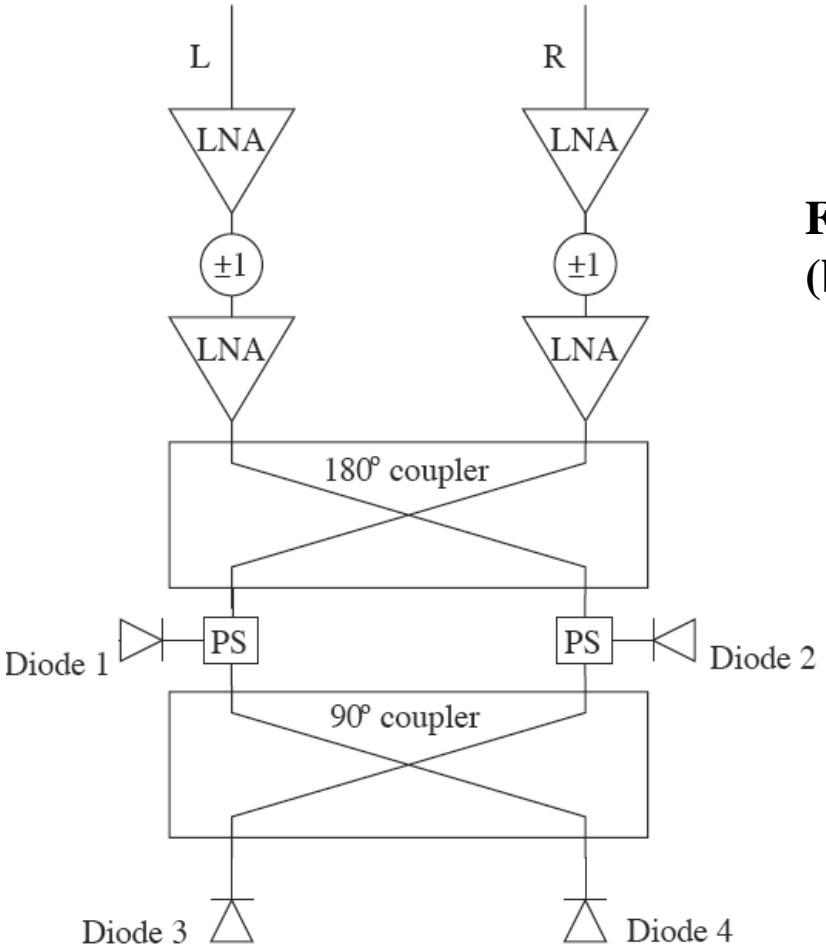
Currently the only experiment to employ HEMT-based technology on this scale

91 element W-band Cryostat



Simultaneous Q/U measurements in a single HEMT-based module operating at 20 Kelvin





Fundamentally very different than TES (bolometric) technology

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

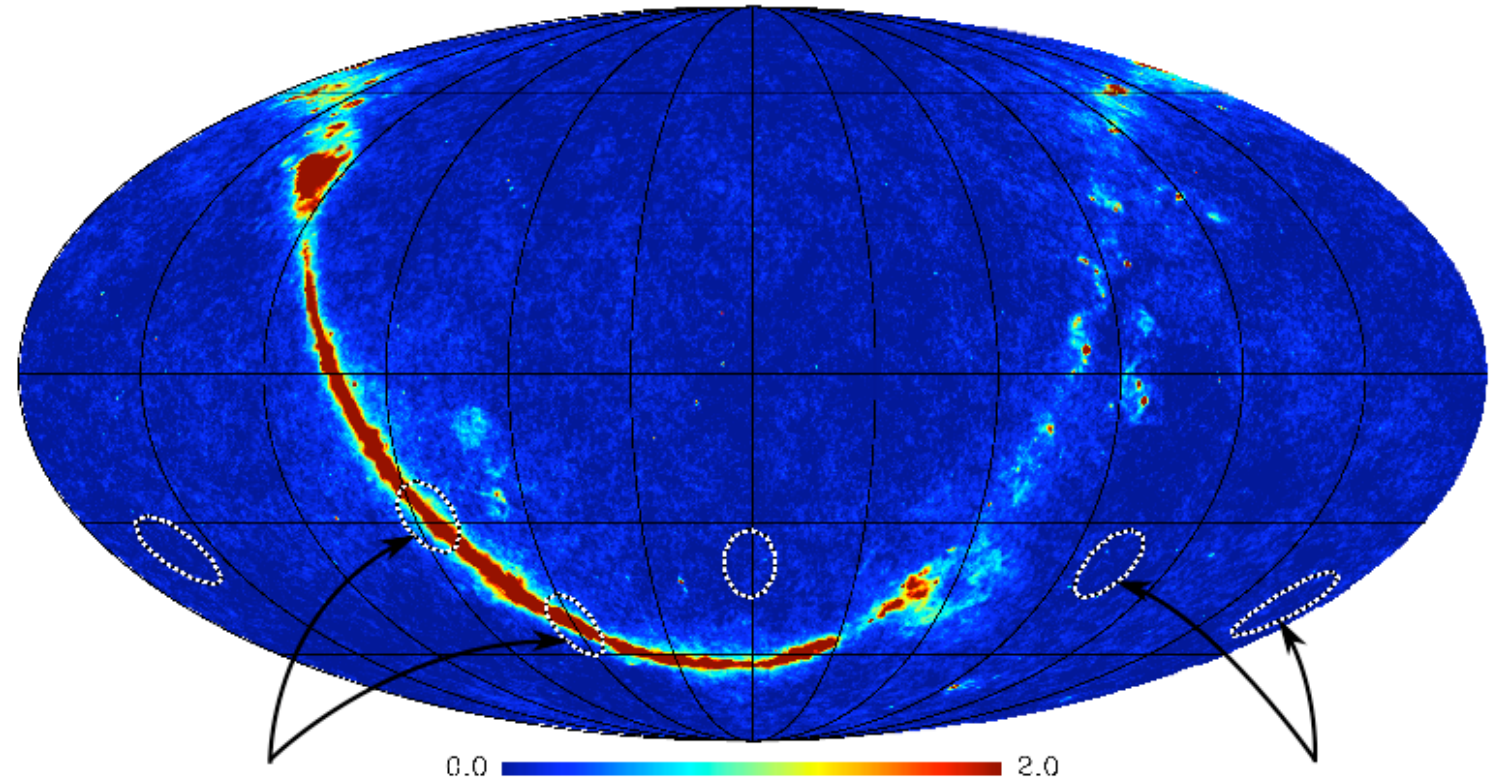
Q

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

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

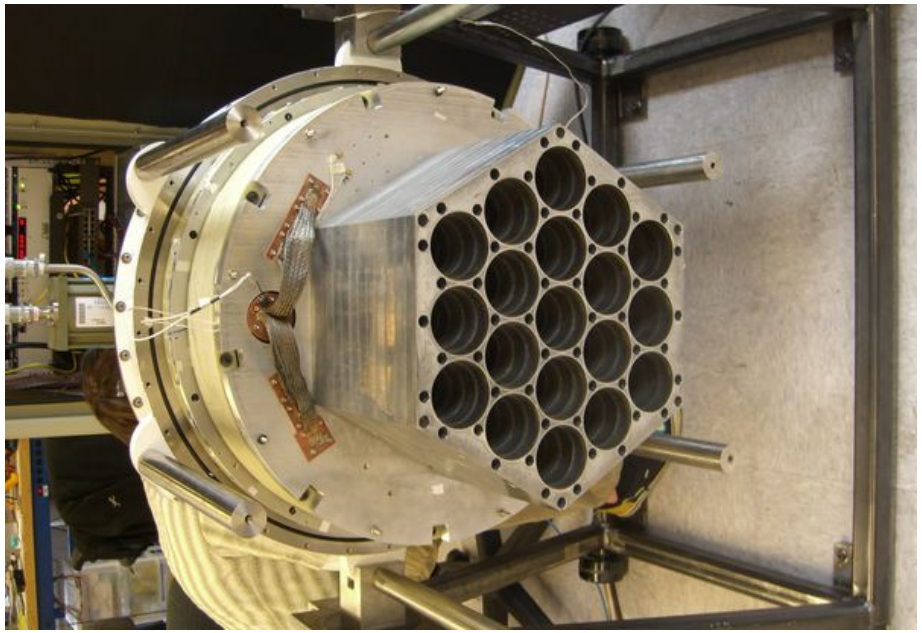
U

QUIET Observing Patches



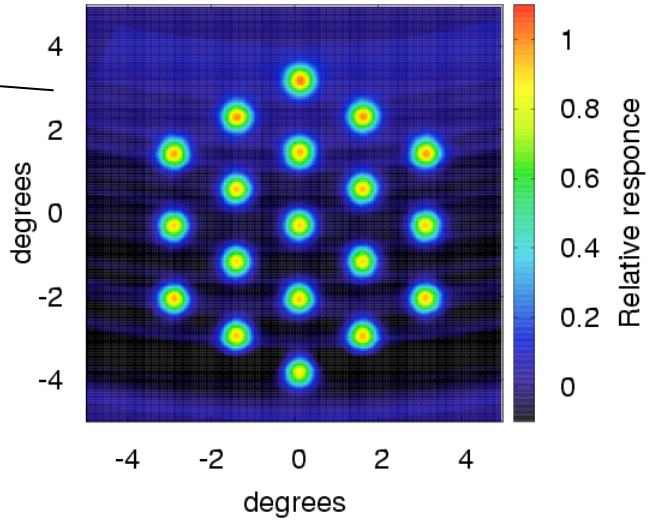
Map precision on 1x1 degree pixel:

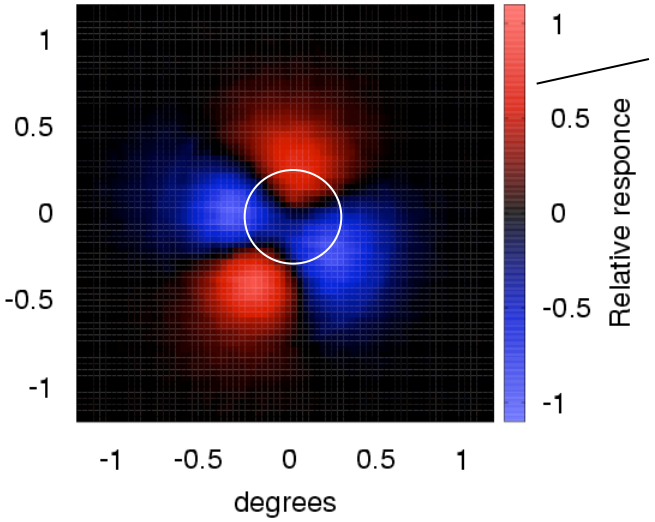
Planck: 1 μK (100 GHz)
QUIET: 10^{-1} μK (90 GHz)



Completed ~ 9 months of observations using the 19-element Q-band

Moon exposure over each element (preliminary)





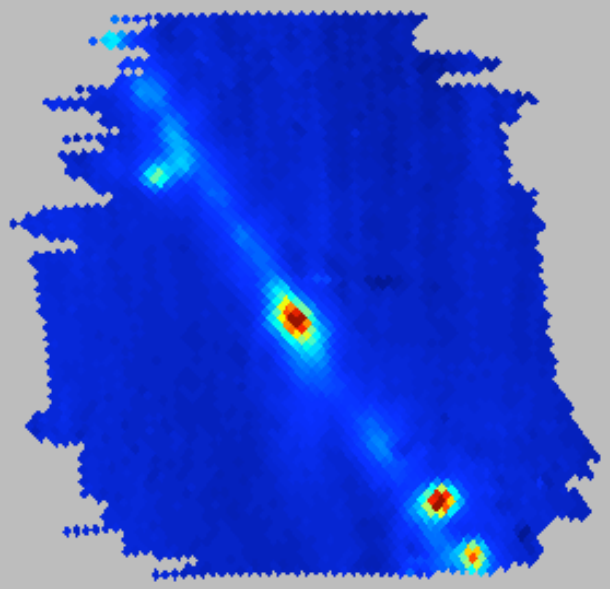
Moon polarization signal

Preliminary Data

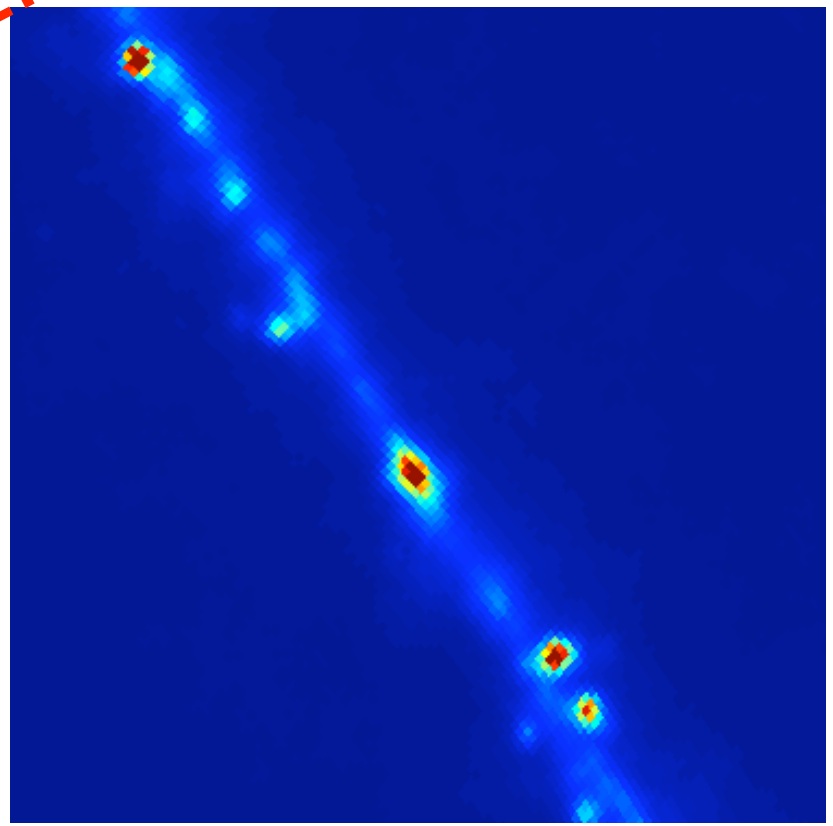
Galaxy
(TT, <100 hrs)

PRELIMINARY

QUIET

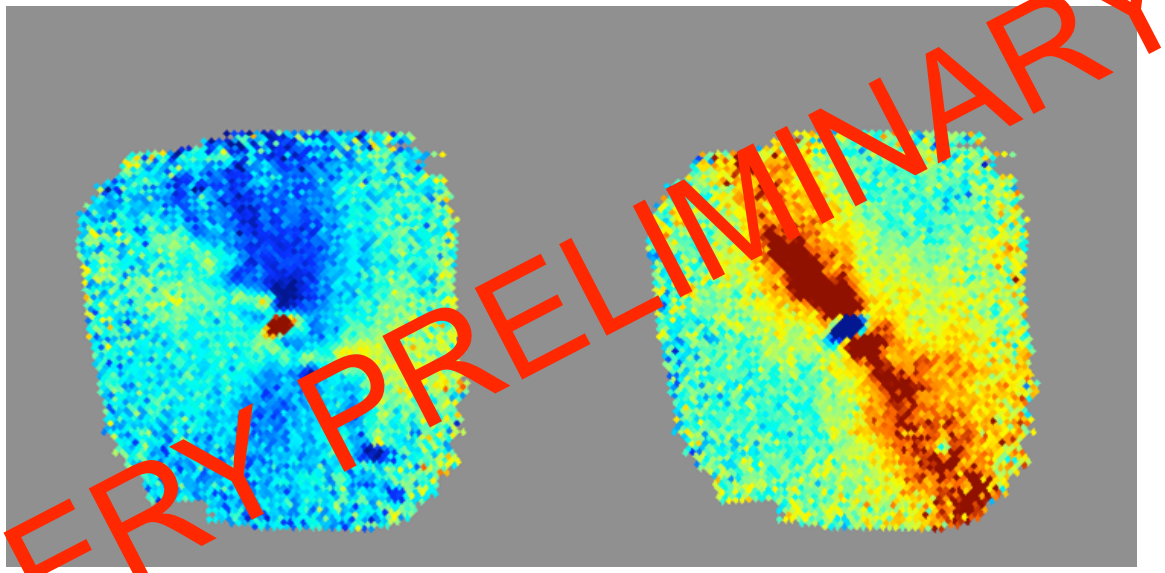


WMAP

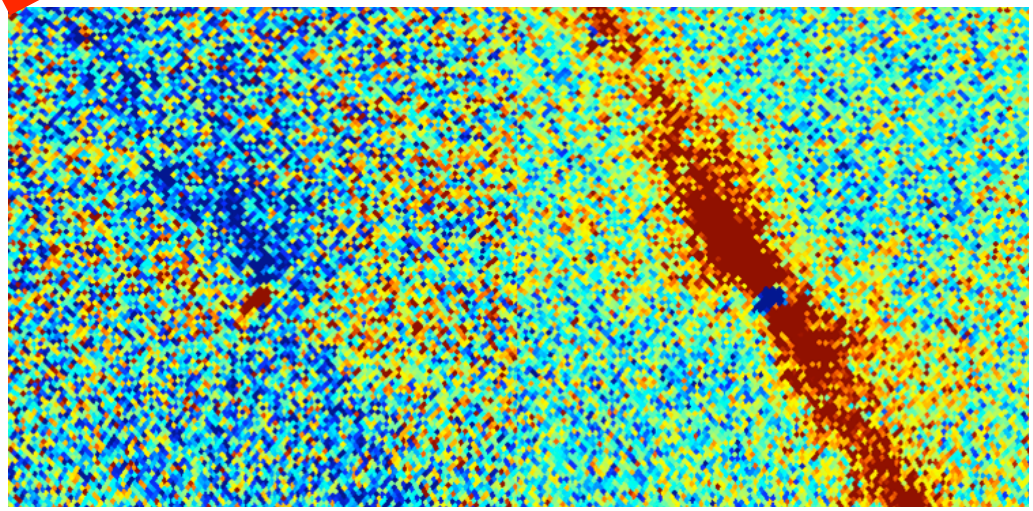


Preliminary Data (Cont'd)

Galaxy
(Pol., <100 hrs)
systematic efects
not considered yet



WMAP



Phase I

Oct 08- June 09	Completed 9 months of 19-element Q-band (40 GHz) operation.
June - July 09	Removed Q-band. Commissioned 91-element W-band.
August 09 -	W-band operation has started !

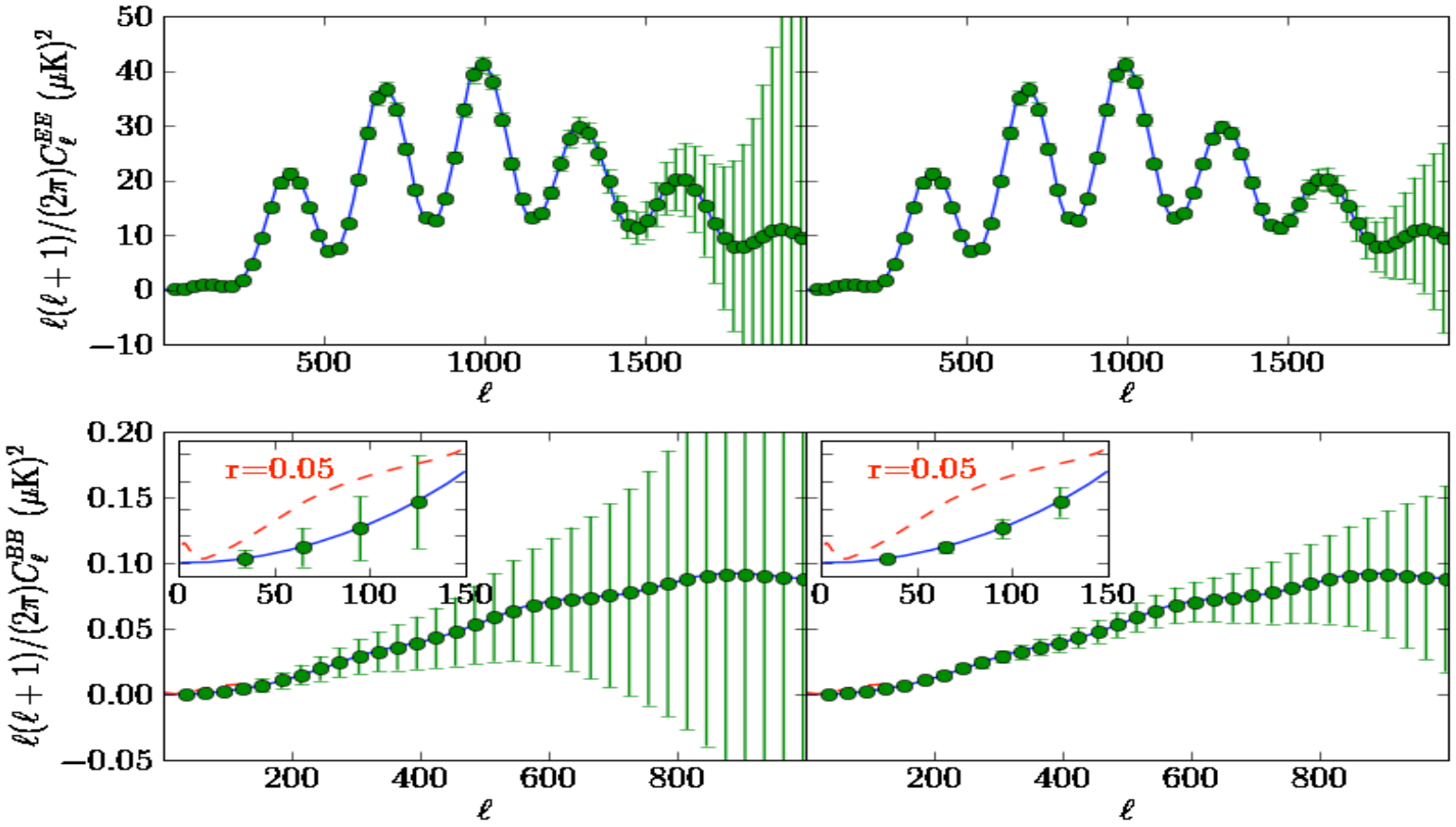
For Phase II (2012 start of operation)

500-element	Q and Ka Band in 1 cryostat
1500-element	W-band in 3 cryostats

QUIET Phase-II (1600 pixels)

Current Performance
(noise, duty cycle, 1/f)

Likely Improvements

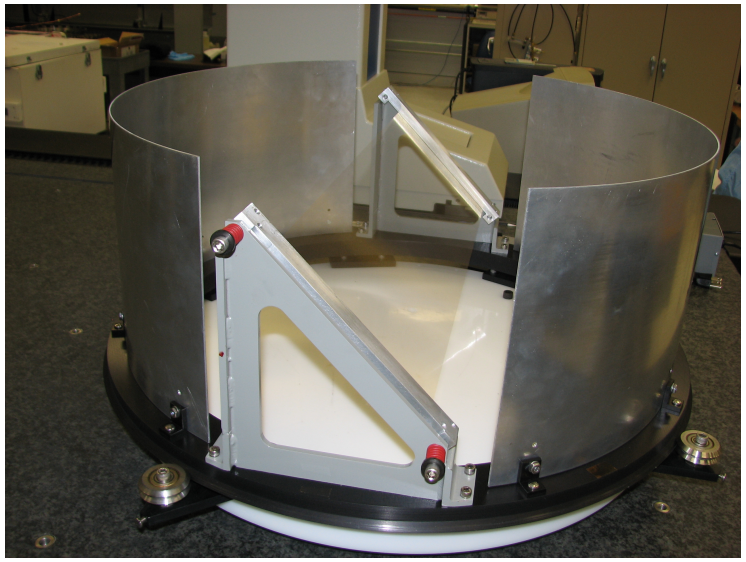


0.018
10σ

Δr
lensing

0.005
35σ

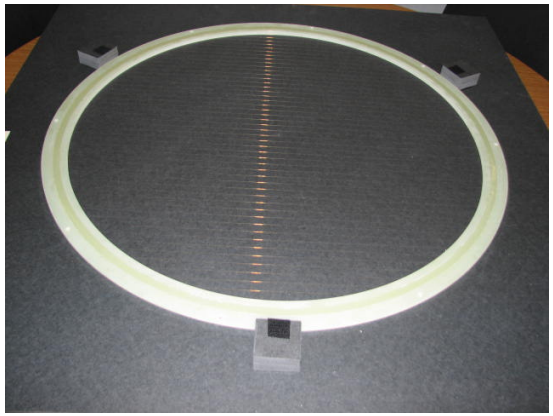
QUIET Phase 1 R&D at Fermilab



Large and accurate rotatable wire grids to produce and modulate polarized microwaves

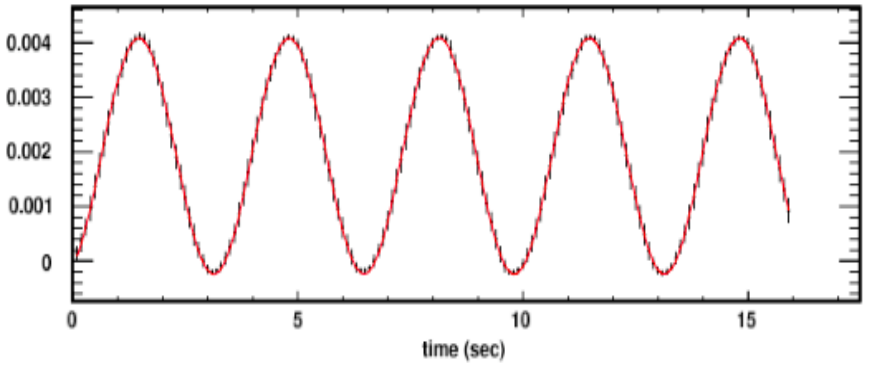
Made by PPD chamber winding group using HEP techniques

In use at KICP lab in Chicago since Feb 09 to optimize detector settings, calibrate relative "angles" of all modules, and provide absolute response to known input polarization signal



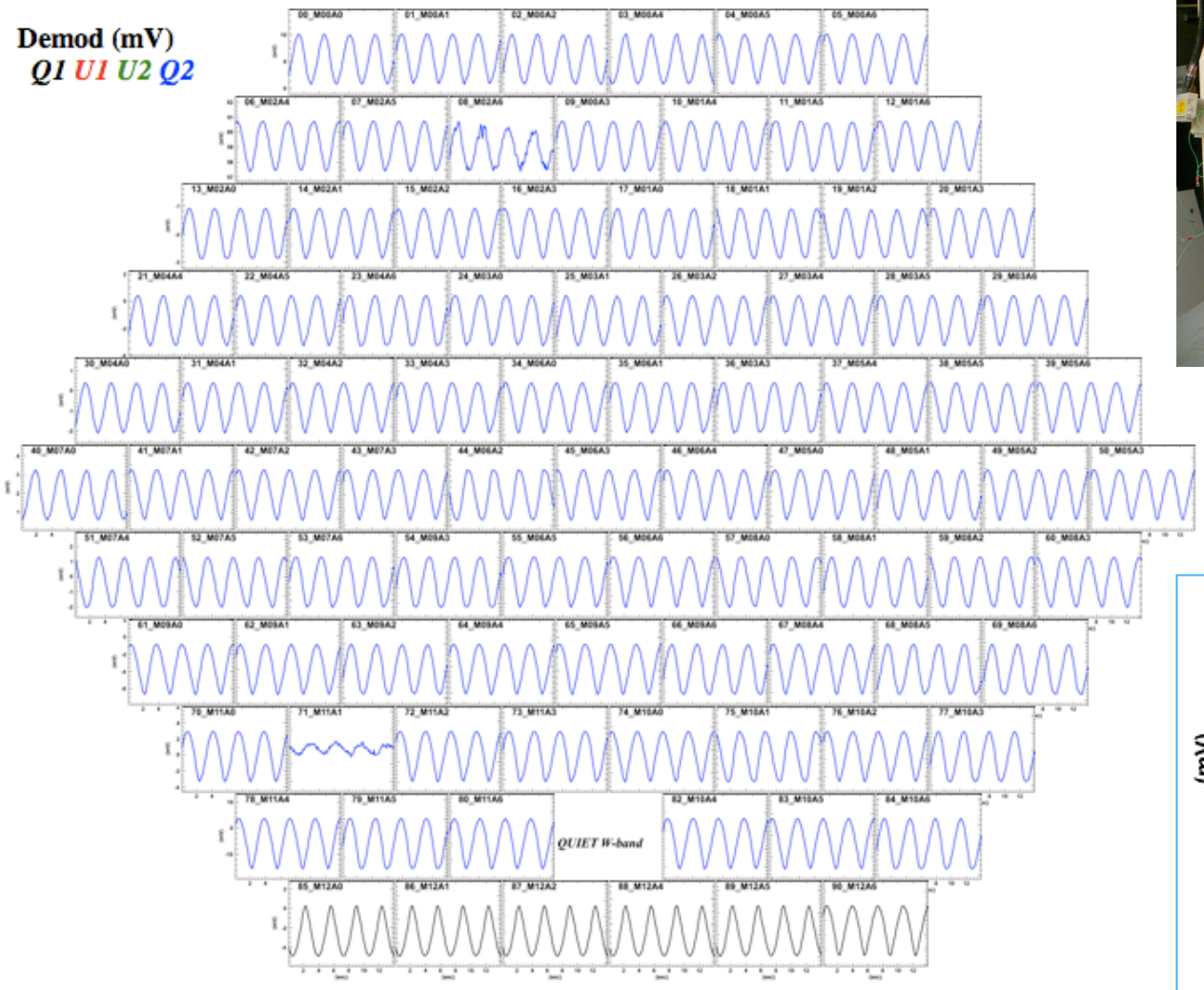
Typical Stokes-Q Response from a W-band Module

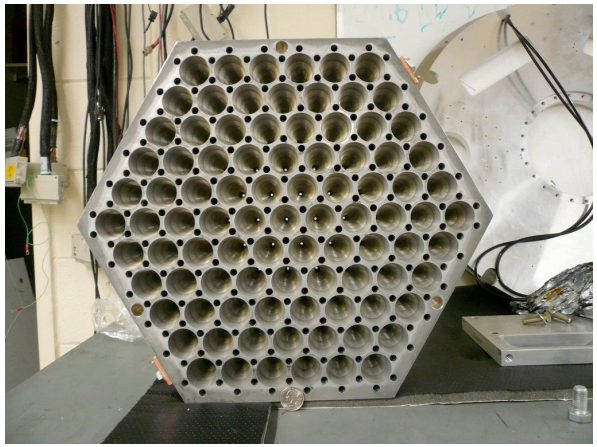
Grid rotates to modulate the polarization

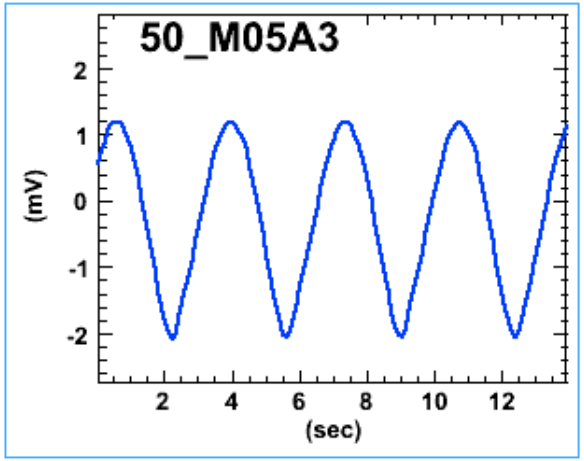


Deployed in Chile in June 09

91 Element W-band Optimized by Wiregrid and Ready for Observation

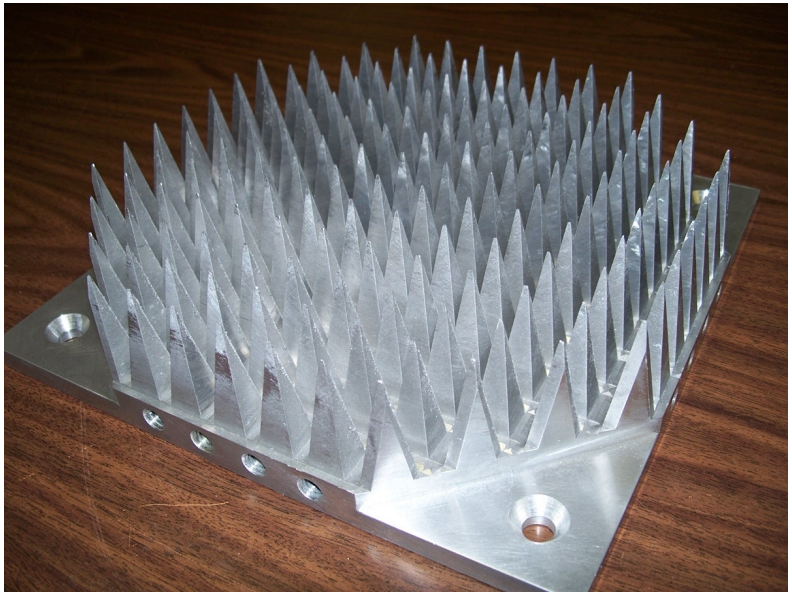






QUIET Phase 1 R&D at Fermilab

D. Butler, J. Korienek, C. Lindenmeyer, W. Newby, J. Wilson. Not pictured: J. Montes, R. Rucinski, K. Schultz



20 Kelvin Black Body Microwave Source For Full-System Characterization

A significant job carried out primarily by PPD Technical Staff:

A vacuum tank with a high-strength microwave-transparent vacuum window with anti-reflective coating.

A Microwave-absorbing epoxy cast over an aluminum core

A Commercial 5W@20K Cryocooler

Useful for characterizing large arrays of detectors of ANY technology.

Mimics the sky noise in Chile, while in a laboratory setting

20 Kelvin Black Body

A significant effort !

Goal

Deliver to Chicago in April 09 to study W-band before deployment of W-band to Chile

Would have learned about the detector noise in a lab setting. Would have been extremely valuable.

Did not meet this goal ! A huge disappointment to me !

Lab Cryo Safety Review Panel did not approve for operation.

Panel wanted more studies done of the ultra high molecular weight polyethylene window.

On track to complete this last step !

Cost For QUIET Phase 1: Oct 08 - May 09

	FY2009		PPD Std Rate in $K/yr	Labor Cost			
FCPA Equipment							
Dvision Equipment							
Total Equipment	0						
FCPA M&S	15						
Division M&S	15						
Total M&S	30						
FCPA Scientist FTE							
Division Scientist FTE	0.8						
Total Scientist FTE	0.8						
Mech Engineer FTE			218				
Elec Engineer FTE			211				
Other Engineer FTE	0.36		199	71.64			
Mech Technician FTE	1.42		123	174.66			
Elec Technician FTE			130				
Other Technician FTE							
Design FTE	0.14		143	20.02			
Total Technical FTE	1.92						
Total Labor Cost (K$)				266.32			

Our Proposed Involvement in QUIET Phase II

Robotic Assembly of ~1500 W-band Polarization Modules

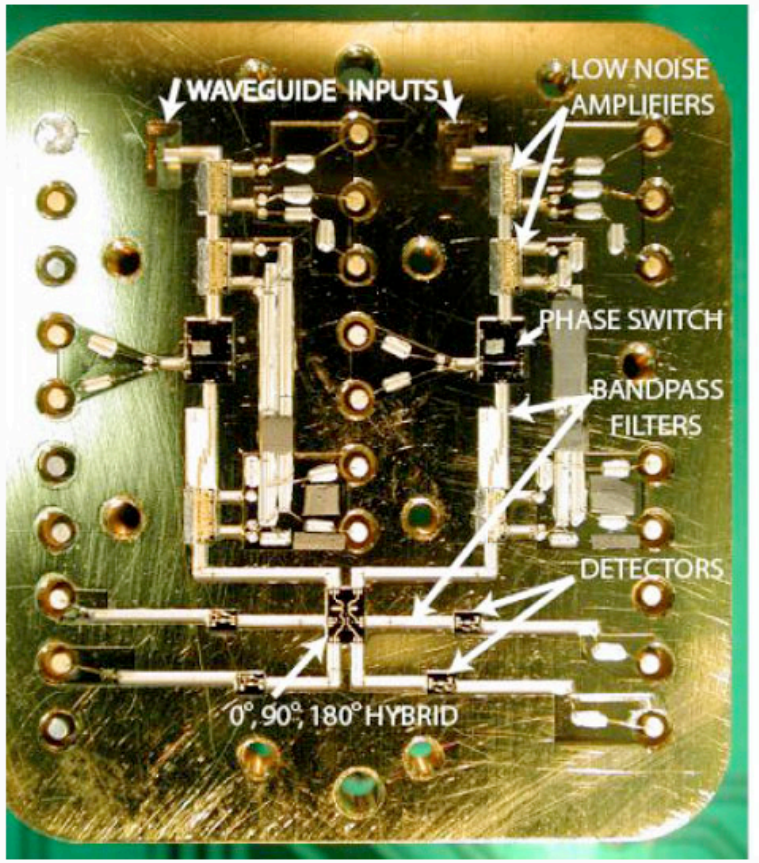
Covered in Hogan's talk

The collaboration invited us to take on this role.

A critical need within QUIET.

Involvement is Commensurate with our role as a National Laboratory.

1" W-band HEMT module

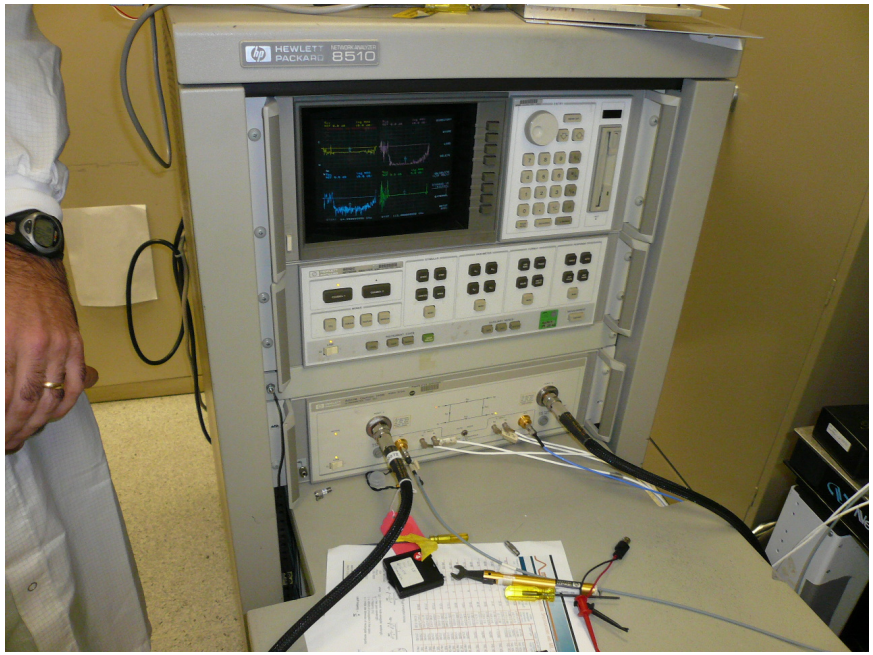


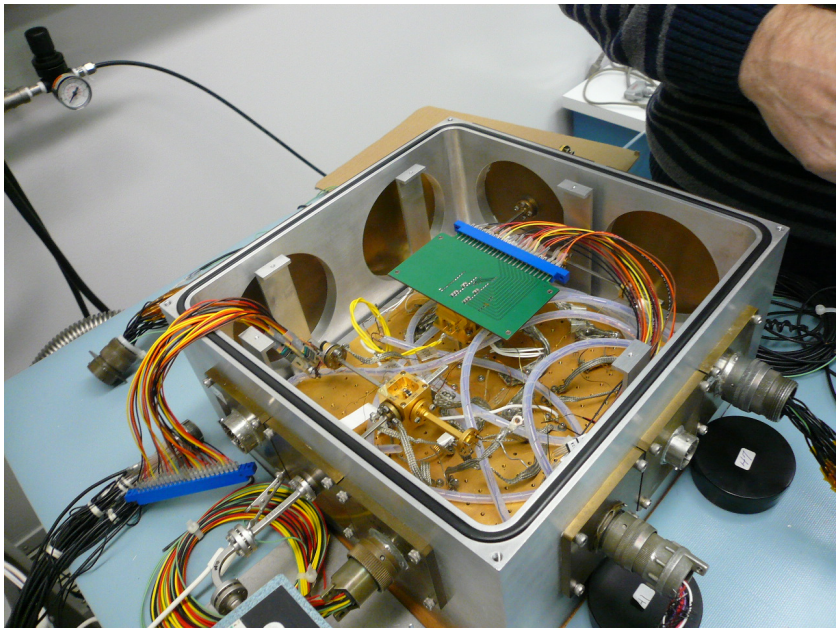
Quality Assurance is Critical

Inspection
Production Testing
Documentation
Management
Environment, Safety, and Health (ES&H)

Covered in Fritz's talk

We accounted for these in the time-and-effort estimate





VNA Teststands at NASA-JPL used for production testing and debugging of modules

We will replicate these stations at Fermilab.

We will utilize RF expertise at Fermilab.

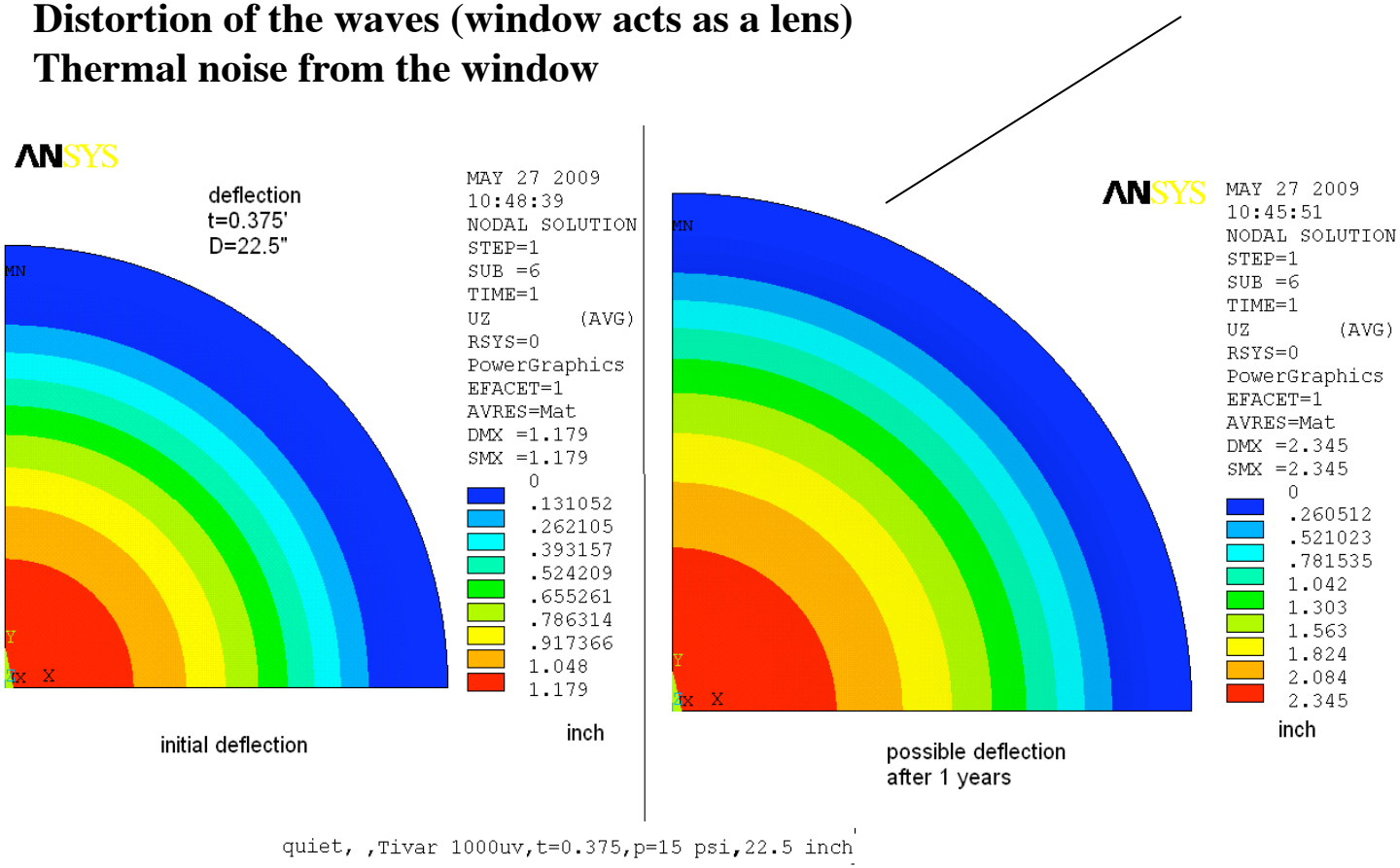
Our Proposed Involvement in QUIET Phase II

Wire Grid Assembly and Finite Element Analysis of Cryostat Vacuum Window.

Modest but really important contribution !

FEA of a QUIET Phase 1 Window,
done by Fermilab PPD Engineering Group

Mechanical Strength impacts the cryostat size
Distortion of the waves (window acts as a lens)
Thermal noise from the window



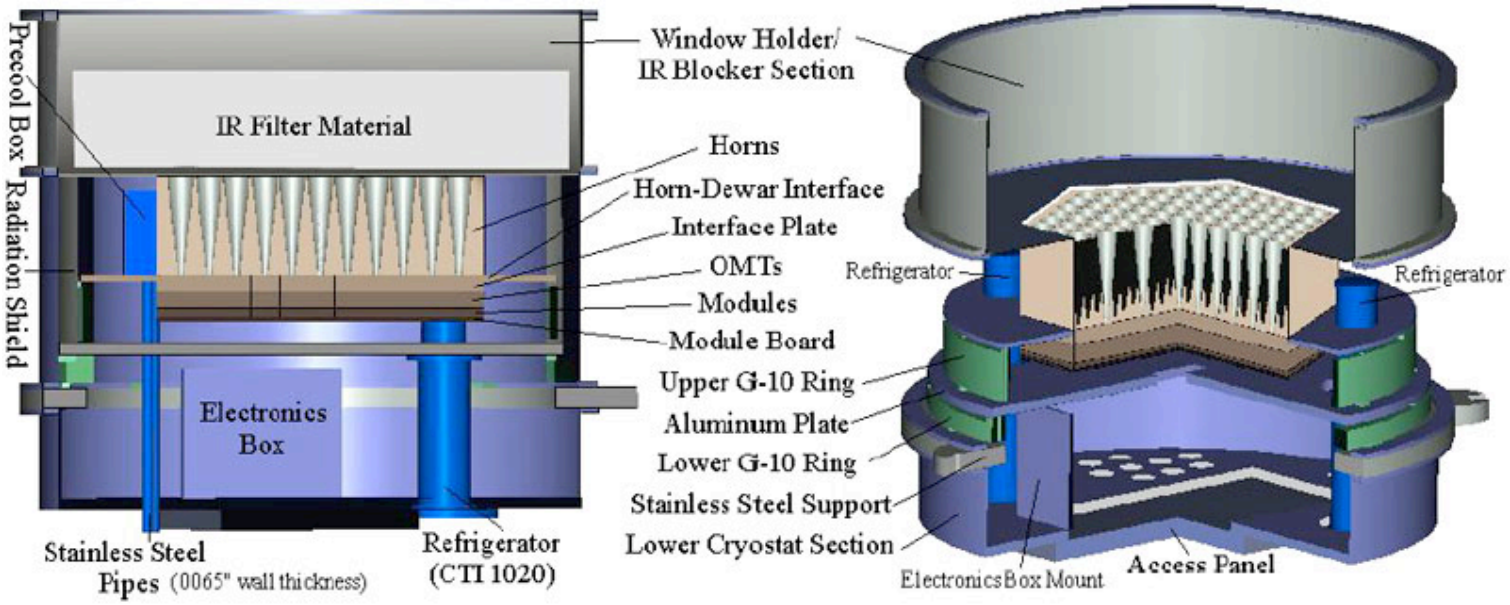
Our Proposed Involvement in QUIET Phase II

Final Cryostat Assembly and Characterization at Fermilab before deployment.

Covered in Fritz's Talk

An exciting possibility !

Key to attracting other scientists to the project, and enabling the staff to be at the center of the scientific activities



Time line of QUIET R&D at Fermilab

- DeJongh and Nguyen visited JPL in Dec 08, entered discussions with Winstein and JPL staff on QUIET.
- Rotatable Wire Grid delivered to collaboration in Feb 09
- Received W-band module fabrication notes from JPL in April 09
- Nguyen to take shifts in Atacama, Chile in May 09
- **Hosted a QUIET Collaboration and Phase II meeting at Fermilab in June 09**
- **B. Winstein presentation to PASAG in July 09**
- Fritz Dejongh visited JPL and SLAC in July 09 to discuss production module testing

Completed

- **Joint PPD/FCPA review of QUIET in August 09**
- **QUIET Collaboration submits Phase II proposal to NSF in mid August**

Our next Steps

- **Presentation to the laboratory PAC**
- **Recognition as a DOE project**

Our hope

Our Request

We'd like to propose a Fermilab/DOE partnership with QUIET

Project Construction Tasks

Assembly and QA of ~ 1500 W-band modules
Final assembly and commissioning of a cryostat
Calibration tools and window engineering analysis

Request to Fermilab/DOE:

Technical, Engineering, and Scientific Effort

Production tooling material costs
(*NSF would provide funds for detector material costs*)

Contribution to Chile site operations cost (~60 K$/year/institution)

Funds for Travel to Chile for Shifts and Installation. Travel to JPL.

Summary

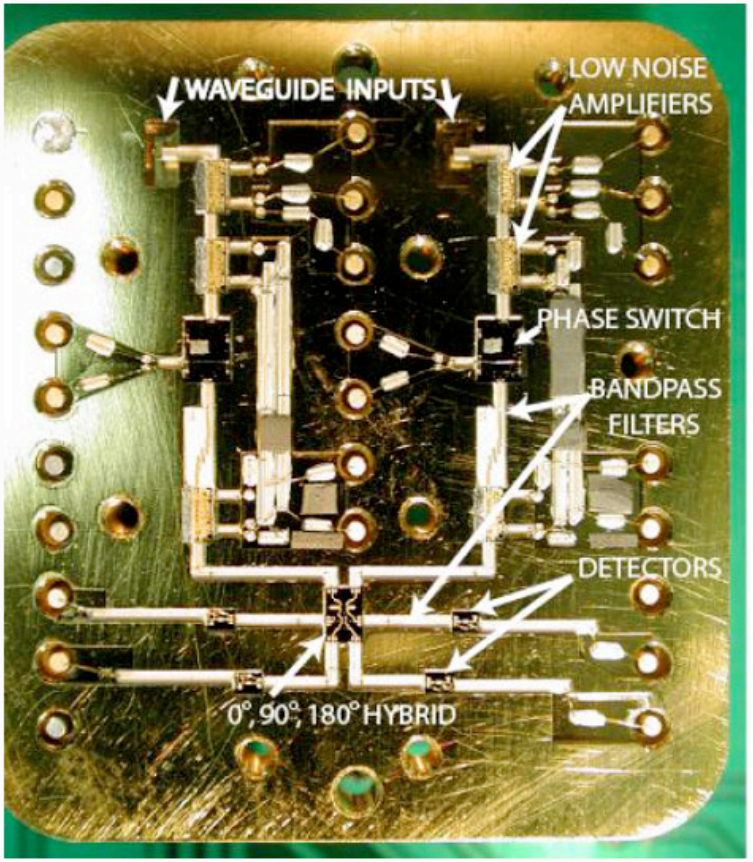
History and Strong Tradition of Intellectual Leadership

Dodelson and Stebbins were among the first to understand the importance of primordial CMB polarization.

A core for a strong Fermilab scientific team

Dodelson, Stebbins:	theory, analysis, scan strategy
DeJongh, Nguyen:	Detector fabrication, cryogenics
McGinnis:	RF/microwave circuit design and technology

The QUIET Collaboration is inviting us to take a central role.



Backup Slides