# Review of Plans to Participate in the QUIET Phase 2 Experiment

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The FCPA commissioned a review of the FNAL QUIET team's plans to participate in the QUIET Phase 2 experiment. The review was held on August 11, 2009 at FNAL. The review charge was as follows.

## Charge

The committee is charged with reviewing the proposed participation of Fermilab in the QUIET II experiment to measure B mode polarization of the cosmic microwave background. Specifically, we would like the committee to evaluate:

1. Experience of QUIET 1
    a) What was the role in QUIET 1?
    b) What was built, and was it successful?
    c) What resources were required (both FTE/SWF and M&S)?
2. QUIET II Science and Fermilab role
    a) Is the science case strong and aligned with Fermilab goals?
    b) Does QUIET II have a reasonable chance to achieve the science goals?
    c) What role will Fermilab have in the science of QUIET II?
3. What is the proposed Fermilab role in QUIET II construction/R&D?
    a) What will we construct? What R&D is required for that construction? How does this fit in with the technical expertise at Fermilab?
    b) What resources (FTEs, M&S) will be needed for the R&D? Similarly, what resources will be need for the actual construction? What is the schedule for this work?
    c) What synergies or conflicts are there with the rest of the program (e.g. CMS silicon upgrade)?
    d) What role would Fermilab play in the management of QUIET II and what resources will be available from outside Fermilab?
    e) Are there significant technical or management risks? What is the plan for mitigating those risks?

We ask that the committee provide a written report to FCPA and PPD within one week after the August 11 review.

## Review Agenda

We heard the following presentations.

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| Hogan Nguyen | - Introduction | 5m |
| Albert Stebbins | - The Science of CMBR | 30m |
| Hogan Nguyen | - Intro to QUIET, QUIET Phase 1, and our QUIET Phase 2 request | 30m |
| Hogan Nguyen | - W-band assembly | 30m |
| Fritz DeJongh | - Production testing, Cryostat Assembly | 30m |
| Committee | - Closing Remarks | |

## Summary of Findings and Comments

In this Section we present findings and comments based on the material presented at the review and some subsequent correspondence from Hogan Nguyen.

### Introduction

**Findings**

From the Introduction and opening remarks we learned that Fermilab has been approached by the QUIET collaboration to play a major role in the preparations for Phase 2 construction. The proposal is for FNAL to assemble and test 1500 W-band Polarization modules. Fermilab would also assemble and test at least one cryostat. There are a few other minor but important proposed contributions: finite element analysis (FEA) of the cryostat window and fabrication of a calibration grid.

Fermilab has already played a significant role in the ongoing QUIET Phase 1 experiment. In conjunction with the upgrade proposal Fermilab would formally join the QUIET collaboration. This would lead to an institution charge of approximately $50k/year for operating the telescope(s).

Proponents at the Lab include Fritz DeJongh, Scott Dodelson, Dave McGinnis, Hogan Nguyen, and Albert Stebbins.

Members of the Fermilab team are listed as co-Investigators on a proposal that will be submitted to the NSF in the near future.

**Comments**

Historically, support for CMB research has come from NSF and not DOE; the QUIET Collaboration leadership is in the process of addressing this given the potential involvement of both Fermilab and SLAC.

### The Science of CMBR

**Findings**

Albert Stebbins gave an overview the science of QUIET and similar experiments. From his talk we learned that CMB data plays an important role in determining the cosmological parameters and that WMAP is a standard against which new initiatives can be compared. Albert also made the case that CMB research is well within the "Energy Frontier" mission of the Fermilab. The Fermilab Astrophysics group played a key role in the `90s in classifying the **E** and **B** polarization modes.

The QUIET collaboration has not presented preliminary results from the Phase 1 polarization analysis; the work is still in progress.

QUIET Phase 2 would measure in Q, Ka, and W bands. There are other experiments, notably SPT, that will perform W-band measurements, but there is no apparent competition in Q and Ka bands.

QUIET Phase 2 should have a very good chance of detecting primordial gravity waves through **B** mode angular variations and should easily observe **B** polarization due to lensing. It's possible that QUIET may be unique in its ability to *unambiguously* detect gravity wave through polarization measurements. The **B** mode has not been seen to date.

**Comments**

This CMB experiment would produce results consistent with Fermilab's mandate to study the "Cosmic Frontier".

For future reviews it would be helpful to show a table that illustrates how QUIET compares with other CMS surveys, both approved and proposed.

It would be easier to have confidence in the expectations of QUIET Phase 2 if the Phase 1 polarization analysis was at the point where results could be extrapolated to Phase 2.

## Introduction to QUIET, QUIET-I, & QUIET-II Request

**Findings**

Hogan Nguyen summarized the program of the QUIET collaboration. The impression is that the group has been following a well-conceived plan to go from 19 (Q-band) and 91 (W-band) element arrays in a single telescope to 500 element arrays in 4 telescopes. The survey location is in Chile and this along with the sealed and instrumentally delicate nature of the cryostats puts a premium on QA for the modules. The High Electron Mobility Transistor (HEMT)-based modules will operate at 20K and the plan is to test a fraction of the detectors at this temperature.

The 19-element array recently completed a 9 month run and impressive-looking preliminary data from the center of our galaxy was shown. However, the performance of the modules in the field is not completely understood and there may be some sources of noise that escaped earlier testing. As of August, QUIET has switched to the 91-element array.

For QUIET Phase 1 Fermilab had prepared a wire grid for calibrating modules in the cryostat. The grid polarizes the microwaves and the degree of polarization can be adjusted by rotating the grid relative to the cryostat window. The grid was used in the field in June 2009.

A team at Fermilab also prepared a 20K black body array for characterizing the Phase 1 cryostat. However, due to safety concerns with the polyethylene window, the black body simulator has not been released and probably won't be used in Phase 1. Perhaps it will be used in Phase 2. In the meantime, much was learned through an FEA of the window for the safety review process. The Fermi group expects to provide a second wire grid and more FEA as part of the Phase 2 contribution.

The main contribution of FNAL group for QUIET Phase 2, assuming the proposal is accepted, will be the assembly and testing of 1500 W band modules. SLAC will perform this work for the 500 Q/Ka band modules. This will require significant technical, engineering, and scientific resources. However, the SiDet groups have successfully built more extensive systems.

The Fermilab effort so far invested in QUIET in FY 2009 consists of: 0.8 FTE Scientific and 1.9 FTE technician plus engineering, corresponding to roughly 266K for the technical labor. M&S contributions are $15k from PPD and $15k from FCPA.

Hogan has taken shifts on QUIET Phase 1.

**Comments**

The team was enthusiastic and committed to the proposal.

Fermilab has not yet participated in the analysis of Phase 1 data.

A black body source, built at Fermilab, has not yet received FNAL operational readiness clearance due to safety concerns with the poly-vacuum window. If they had this at the University of Chicago, they might have been able to calibrate the W-band noise temperature. Perhaps the black body source will be deployed in Phase 2, but the fact that QUIET has managed to operate without it brings into question the need for the source.

The black body source experience is a good reminder that project schedules should always include some allowance for safety and other reviews.

## W-band Assembly

**Findings**

Module assembly steps include the placement of 5 MMICs per module, controlled dispensing of silver epoxy, wire bonding, and optical survey. Some of the components are as small as 0.2mm x 0.2mm and the most demanding placement accuracy is 12.5 microns. JPL will provide tested MMICS, so JPL could pace the assembly at Fermilab.

The plan is convert several of the Zeiss Coordinate Measuring Machines at SiDet into robotic assembly stations. The Zeiss machines have extremely precise X, Y, and Z motions and in principle can be controlled through a LabVIEW application. The LabVIEW Vision software would be used in conjunction with a camera to identify fiducial marks and corners of components. A separate motorized platform would need to be provided for theta rotations.

Up to 4 (out of 7) Zeiss machines would be used for the assembly. Each machine would perform the assembly step on 10 modules in a single pass. Assembly will be paced by the time required for testing.

A Technical Centers group stationed at Lab 8 would oversee the retrofitting of the Zeiss machines. This group has successfully handled similar projects, such as the CMS Magnetic Field mapper. The Lab 8 group currently has a few other responsibilities, but this has been factored into the 30 week estimate for retrofitting the Zeiss machines. The cost estimate is around $140k for the conversion.

It will also be necessary to develop tooling for picking and placing of components and dispensing epoxy. Fermilab would also be responsible for procuring the brass chassis and non-MMIC components and for the QA for these parts.

A total of 2.25 years is allowed for the assembly although once the process is fully debugged it would only take 1.2 years for the full assembly. The JPL delivery schedule for the MMICs is more closely matched to the longer schedule. The labor cost estimate for the W-band tooling preparation, assembly is around $0.5M, including contingency.

We note that the final design of the module is not yet complete; there is an ongoing R&D effort within the collaboration to improve the noise performance.

**Comments**

This is a moderately sized job on the scale of past silicon detector projects at SiDet.

There is some experience from QUIET Phase I that the yield for HEMT-based modules should be close to 100%. However, this was only after a fair amount of repair work and it would be useful to quantify the amount of time and effort spent on the repairs and retesting in Phase 1.

More information on the robotic assembly of modules in QUIET Phase I would have been useful. What was the cost per module? Who did the testing? Were the modules delivered on time? Where there QA issues during the construction, during testing, or in the field? This information may help the team better evaluate the project cost estimate.

The Fermilab QUIET team leader is head of PPD Technical Centers and has some leeway to put infrastructure resources into increasing the technical capabilities within the Division. We agree that robotic assembly in general is worthwhile for SiDet to pursue.

### Production Testing, Cryostat Assembly

**Findings**

All modules will be tested at room temperature and a subset will be completely characterized at 20K. In the beginning all of the modules will be tested at low temperature. JPL will help get the Fermilab group come up to speed in operating and testing modules. The test stands need to be developed but there are existing systems at JPL that could at least be used as starting points. Some PCB design and fabrication will be required for the module testing.

The plan has all testing at SiDet. However, some of the testing could be farmed out to universities or, alternatively, university personnel could help with the testing at Fermilab.

FNAL will assemble and test at least one cryostat. The cost estimate for the test stands is $100k; the test stand labor $757k; and the cryostat technician support $120k.

Hogan Nguyen expressed concern that the present Fermilab physicist team might not be enough to perform the work, especially if Fermilab will be responsible for assembling and testing all 3 W-band cryostat receivers.

**Comments**

The setup and commissioning of hardware and software for the test stands is likely to require substantially more effort than is provided for in the estimated cost. The estimate for programming the test stands in particular seems insufficient even with the quoted 100% contingency.

The competition within the collaboration to assemble and commission the three cryostat receivers is likely to be intense, and other groups have a head start. The Fermilab team may need to identify additional scientist resources for the cryostat work. The schedule for this work seems to be very tight and there is substantial schedule risk. On the other hand, this work is important and has a greater potential for a "leadership" role within the collaboration.

The total amount of work that the team proposes is likely to exceed $2M given the present uncertainties.

## Recommendations

Not applicable to this review.

## Answer to Charge

1. Experience of QUIET 1
    a) What was the role in QUIET 1?
    b) What was built, and was it successful?
    c) What resources were required (both FTE/SWF and M&S)?

    Fermilab built hardware for QUIET Phase 1. A polarizer was used successfully as part of the calibration. A microwave source was built but not delivered to the experiment. The effort to date on QUIET is 1.9 FTE technical labor and $30k for M&S.

2. QUIET II Science and Fermilab role
    a) Is the science case strong and aligned with Fermilab goals?
    b) Does QUIET II have a reasonable chance to achieve the science goals?
    c) What role will Fermilab have in the science of QUIET II?

    While Fermilab (and DOE) has not been involved in CMB experiments up to now, the reasons may be merely historical. The science is that of the "Cosmic Frontier" and is fundamental physics. Although our backgrounds are largely in particle physics, we do not see any fundamental reason why QUIET Phase 2 would not achieve its goals. However, we would be more convinced of Phase 2's chances if there were results from the Phase 1 polarization analysis at this time. The Fermilab group would be involved in the analysis of Phase 2 data, but would probably require one or two Research Associates to have a major impact on the analysis. Participation of the theorist team in data analysis would also increase Fermilab's visibility within the Collaboration.

3. What is the proposed Fermilab role in QUIET II construction/R&D?
    a) What will we construct? What R&D is required for that construction? How does this fit in with the technical expertise at Fermilab?

    The Fermilab QUIET Team proposes to build and test some 1500 W-band modules to be deployed in three cryostats. R&D is required to develop tools to perform robotic assembly, to develop test procedures for the receivers, to determine the expected yield, and to understand the required scope of repairs needed to produce acceptable receivers. Results from a trade study that compares the desire and capability of industry to perform any or all of the W-band module assembly steps should be gathered. All of the R&D work could be accomplished with Fermilab resources. Performing only the W-band module assembly and testing will be a major part of the QUIET Phase 2 preparations, but may not be sufficient to give Fermilab a leadership role in the project.

    The Team also proposes to assemble and test one to three of the W-band cryostats, the exact number to be negotiated with the collaboration. This job and these tests need to be better defined. This work is important and has more potential to lead to a leadership role in the experiment.

    b) What resources (FTEs, M&S) will be needed for the R&D? Similarly, what resources will be need for the actual construction? What is the schedule for this work?

    More resources are likely to be required than what has been specified for the module assembly. In particular, the estimate of effort needed to develop automated test procedures, both for the warm and cold module testing and for the testing of the W-band cryostats, seem to be optimistic. Both of these tasks would also probably require additional scientist resources.

The schedule, as presented, is based on the upcoming NSF grant. It starts almost immediately and parts would be delivered by 2012.

c) What synergies or conflicts are there with the rest of the program (e.g. CMS silicon upgrade)?

SiDet has the capability to perform multiple, concurrent construction projects. Examples include the simultaneous construction of CDF and DZero silicon detectors, where careful planning occurred at that time to distribute resources to both projects. While it is too soon to tell if there are going to be important resource conflicts, PPD should maintain a timeline of potential SiDet projects, paying attention to issues of space, key people, and technical staffing.

The development of robotic assembly capability may benefit other upcoming projects.Also, QUIET may benefit from the involvement of Donna Kubik, given her present involvement on the DECam CCDs and her past experience at Aricebo.

d) What role would Fermilab play in the management of QUIET II and what resources will be available from outside Fermilab?

If this is funded through the DOE, it is likely to be handled with appropriate Project Management techniques. The construction of 1500 W-band modules is, depending on the organization of the project, likely to be managed at 2$^{nd}$ or 3$^{rd}$ level with CAM responsibility. There is some chance that collaborating institutions on QUIET will send personnel to help with the testing.

e) Are there significant technical or management risks? What is the plan for mitigating those risks?

There are several risks. There is schedule risk in robotizing the Zeiss machines given that a clear strategy for interfacing LabVIEW has not yet been identified. We note that the final design of the W-band modules is not yet complete. The cost of the assembly and testing has high uncertainty because the yield and/or the repairs required aren't known very well. There will be significant resources required to develop automated warm and cold module assembly test procedures. The likelihood of performing any of the cryostat assembly depends on the early investment of scientific effort and the Team will be competing with other interests in the Collaboration. There is no guarantee that this effort will be successful in "winning" Fermilab the work.

Of course, the R&D should be aimed at mitigating risks. The Team has identified some important issues and is working on them.

The total amount of work that the team proposes could well exceed $2M given the present uncertainties. In addition QUIET Phase 2 would have a component at SLAC. This has implications within the DOE as to the funding and approval process, and therefore, the timeline and total resources required.

In summary, we feel that the science goals of QUIET are well aligned with the Lab's mission; that sufficient capabilities exist within the Lab for doing the proposed main task; and that the FCPA and PPD should support the R&D required to get the project to the point of production.