External review of the 21 cm R&D initiative at Fermilab

June 23, 2010

1 Introduction

The external review of the 21 cm R&D initiative at FermiLab was held on June 3, 2010 with a panel consisting of Stephan Meyer (Chair), Gustavo Cancelo, Rich Kron, Huan Lin, and Miguel Morales. Also present were Dan Bauer and Craig Hogan representing the Center for Particle Astrophysics at Fermilab.

The committee was charged with reviewing "the progress of the R&D effort at Fermilab to develop a 21 cm radio telescope experiment." The complete charge to the panel is included in Appendix A. The panel reviewed the charge and sent a set of topics to be covered in the presentations to the collaboration. The list reached the collaboration too late to be included in some of the presentations. The topics list is shown in Appendix B.

This external review follows an FNAL internal review in April, 2010 that included members of this panel (Gustavo Cancelo, Rich Kron, Huan Lin). This panel is in agreement with the findings and recommendations of the internal review. Because of the overlap in membership, the panel was able to see the technical progress made in the past two months.

The review agenda is shown in Appendix C. There were several members of the collaboration present who did not give presentations but were part of discussions and question and answer sessions. They included Jeff Peterson, Peter Timbie, Reza Ansari, Scott Dodelson, among others.

A closeout with the experiment collaboration is planned by telecon following the disbursement of this report.

2 Panel Recommendation

The panel was impressed with the progress made by the collaboration in designing and optimizing the ideas for a 21 cm BAO experiment in the past half year. The group has shown that the BAO signal is likely to be detectable in the presence of astrophysical foregrounds. The case was properly made for the importance of the measurement and where it fits into the development of the understanding of Dark Energy using astrophysical measurement. In addition, progress with the deployment of a prototype antenna and using it to validate both the electronics development and the instrument simulations has been made.

The panel felt that the collaboration has demonstrated both the scientific potential of the 21 cm measurements and its own potential for evaluating different experiment configurations and planning the experiment. The panel has developed a specific recommendation to maximize the probability of converting the evident promise of this collaboration into a viable funded project. The recommendations take the form of suggesting five prerequisites for serious FNAL funding. These prerequisites will require the participation of the entire collaboration, not only the FNAL contingent. They are designed to be easy to document and are formulated to position the collaboration for the next step: convincing the scientific community and the funding agencies that it is ready to move forward.

The prerequisites are:

1. **Select an instrument baseline.** Generate a design based on the simulations and optimization programs developed, freeze the design and generate a top level Work Breakdown Structure (WBS) or equivalent.

2. **Build the collaboration.** Ensure that the collaboration can cover all parts of the WBS. This may require bringing in new people.

3. **Task the collaboration.** Assign a lead collaborator to each part of the WBS. Name associate collaborators and ensure that all collaborators have a charge. Each lead for each WBS element should be tasked to add detail, develop a zeroth order design, and from that, derive a cost estimate and schedule for each piece of the WBS. Find a way to internally review the WBS and personnel. Document the review.

4. **Develop the Experiment.** Continue the experimental efforts with the prototype, electronics, and simulation. Plan and document the R&D effort needed to be able to complete each element of the WBS. Continue to enhance the scientific case for the experiment in particular, broaden the case for the ancillary science. Connect with other groups working in the field. Broaden the interest and backing of a larger segment of the US astronomical community by continuing to publicize the experiment by writing papers and giving talks.

5. **Select a baseline site.** Develop the cost model for deployment to the site.

6. **Develop a funding model.** For each potential source of funding, write a proposal, or generate an agreement or document requesting the funding, as appropriate. The total of the funding model must be close to the cost model derived in Item 3.

The panel endorses a program to achieve these prerequisites. The panel recommends that support from FNAL continue at least at the current level to help with this work but stresses that the undertaking must be carried out by the collaboration as a whole. The panel also endorses the generation of the pre-conceptual design report that the collaboration has committed itself to completing in 2010.

For its part, FNAL should plan that the collaboration will develop an experiment and a road map for its development that will make serious FNAL support extremely compelling.

3 Panel Response to Charge

3.1 Science

The science requirements for this experiment is to provide a 3D map (two angular dimensions and one redshift dimension) of the HI distribution from $.5 < z < 2.0$ to map the statistics and evolution of matter in the universe. One of the main observables for probing dark energy properties is to detect and measure the Baryon Acoustic Oscillations (BAO). The BAO provides a physics-based standard ruler over a broad range of redshift, calibrated with CMB observations. Because of this, BAO observations can provide an observational constraint on the equation of state of Dark Energy (DE) and its time evolution provided the surveys have sufficient volume to provide good statistics, resolution in angle and redshift to see the BAO scale, control of astrophysical bias, and immunity from galactic and terrestrial foregrounds. The strongest constraints on DE will come from a combination of BAO studies together with supernova and weak lensing observations. There is a strong case for pursuing all three DE probes.

Optical and spectroscopic surveys are both competitive with and complementary to 21 cm intensity mapping for making use of the BAO yard stick to constrain cosmological models. Optical surveys have better angular resolution, but without spectroscopy, much lower redshift resolution. 21cm surveys extend to higher redshift. This provides a larger observed volume to reduce sample variance errors, and a longer redshift lever arm for detecting evolution in the equation of state of DE.

At the moment the CRT effort is as far along in development as any of the intensity mapping post-reionization experiments. This group and others contemplating 21cm intensity mapping will be the ones who must garner the necessary community support to attract sufficient funding for the project.

The scientific risk of 21 cm BAO observations is relatively low. The BAO have been observed in optical surveys. 21 cm emission in galaxies is a conventional tool for their study. The primary risks usually cited are galactic foregrounds and terrestrial interference – and this team has gone a long way towards retiring the former with their instrument optimization and observation simulations.

3.2 Technical approach

There has been progress on several of the technical questions facing the team. Simulation of the instrument and the sky have been combined along with detailed analysis of the extraction of the signal from a noisy, foreground contaminated map.

3.2.1 Straw man design and technical specification

The presentations showed good progress in simulation of various antenna configurations. The team can now calculate the Dark Energy Figure of Merit (FoM) given a potential antenna configuration and can therefore directly evaluate the scientific reach of a given antenna configuration for a range of parameter and measurement priors. The tools for this analysis have been made publicly available.

Missing from the straw man design is a link to the hardware. How are the panels made? How is the cabling run? How is the electronics housed, powered, synchronized, controlled? Is phasing an issue? Is computing the correlation a problem and how will it be done? While it is obviously early in the design of this instrument, a top down view of *all* the technical issues is needed.

Both costing and schedule exercises depend directly on having a good top level assessment of the project as a whole. Many of the hard costing questions do not need detailed engineering. How many cables go to each electronics box? Is there an electronics box for each antenna? The presentations did not make it clear that this level of planning is being carried out or is on a list of tasks. In that sense the straw man design is lacking and the path to schedule design or costing is uncharted.

3.2.2 Site selection

Several sites have been looked at in the past but no new information was presented in the review.

3.2.3 Role of FNAL

The role of FNAL has so far been limited to developing to a set of instrument design tools, contributing to the conceptual design report and documenting the science motivation. No plans for expanding this role were presented.

3.2.4 Instrument Calibration

The collaboration used a set of prototype CRT cylinders setup at CMU along with electronics developed by the IRU/SPP collaborators. They have demonstrated a digitally developed interferometer beam and used Cas A to determine the complex gain of each antenna. Using these gains they have shown the ability to form a 2D beam. These are good first steps to developing a model of the instrument and learning how to calibrate. A calibration procedure using multiple celestial sources to determine the long-term gain model was discussed. These models will be further tested in the fall of 2010 using the CMU prototype cylinders. The connection between the instrument simulation being developed at FNAL, the prototype development carried out at CMU, and the French data taking system is one of the most promising examples of the collaboration functioning.

3.2.5 Progress on simulation of 21 cm BAO signal

The panel was shown a simulation program consisting of a sky and foreground simulation along with a model of the instrument that simulates the cylinder visibilities. The resulting simulated instrument signal was analyzed using a frequency-smooth foreground model that was subtracted from each sky pixel. At the moment the full telescope model with all visibilities has not been implement on the FNAL-KICP cluster but it should be possible to do so.

3.3 Collaboration and funding

Collaboration, planning and the development of a funding model are the areas needing the most work at this time.

3.3.1 Collaboration development

The group appears to operate in a manner similar to a small research group where task assignment hinges on collaborators following their own current interests. For small groups this is an ideal way of operating, there is little management overhead and people naturally gravitate towards their talents. The problem is that no schedule nor cost estimate beyond a back of the envelope calculation is possible with this method. Such estimates are also likely to be very optimistic.

At this stage in the 21 cm project, with a budget likely to easily exceed the current estimates put forward by the collaboration, much more formal organizational structures must be put in place. At the moment, the collaboration is not in a position to face the rigorous reviews of the schedule and cost models that will be demanded by funding agencies in the near future. The development of a more formal management structure should not be confined to the FNAL part of the collaboration. The leadership of the experiment needs to play a proactive role in taking the experiment to a new level of organization in order to garner community support and agency funding.

As enumerated in Section 2, it is essential that a baseline experiment be chosen, that all tasks needed to complete baseline experiment be itemized, that first guess technical solutions be documented, and that the tasks be assigned to members of the collaboration to develop a cost and schedule model. If this collaboration is to be ready with a detailed design, complete with schedule, site, and project costing in the near future, it needs to begin to move immediately.

3.3.2 Schedule and budget plans

No plans for developing a schedule or budget were presented.

3.3.3 Project Cost

Project costs have been estimated at the back of the envelope level.

3.3.4 Funding model

No funding model currently exists. No funding agencies have been approached nor proposals written. Negotiations with private donors have been carried out in the past but no plan for future donor development was presented.

Appendix

A Charge to the Panel

The committee is charged with reviewing the progress of the R&D effort at Fermilab to develop a 21 cm radio telescope experiment. Such an experiment would make a 3-D map of 21 cm radiation from large red shifts in order to measure baryon acoustic oscillations (BAO) and thus study dark energy. We request that the committee assess and summarize the scientific, technical and management status of this project, and its relationship to other projects in the field. Specifically, we would like the panel to recommend whether this project is suitable to be the next dark energy experiment at FNAL beyond DES. To arrive at this recommendation, we suggest you consider the following:

1. Science
   (a) Evaluate the science requirements for this experiment, and the justifications for them. Compare to proposals for other experiments intended to study BAO, and dark energy in general. Is the dark energy 'reach' comparable to other proposals of similar scale, in a similar time frame? Will a single-purpose BAO experiment such as this produce compelling dark energy results? Will it be compelling enough to garner the necessary community support to be funded? How risky is this project compared to competing proposals of similar scale?
2. Technical approach
   (a) The collaboration should present a straw man design, with concise technical specifications. Evaluate whether this design is a reasonable starting point and examine their plan for developing this design into a full conceptual and technical design, paying particular attention to how R&D and prototype work feed into this plan.
   (b) Is a rigorous site selection process underway? Are there technical, cost, schedule, and collaboration factors that make a Morocco site better than other possibilities?
   (c) What role will FNAL play in the technical design and prototyping process. In particular, will FNAL have a significant role in antenna design or electronics? Does FNAL have people with sufficient expertise to do this work and, if so, are such people available? If the hardware design is mostly done by other institutions, do they have the technical resources and expertise to carry it out?
   (d) Evaluate the plans for calibration and monitoring of the radio telescope. Can these be done sufficiently well to extract the signal from the foreground?

(e) Assess progress on simulations and algorithms being developed to extract the 21 cm signal. Are these mature enough to proceed with technical design of the instrument, or do they need substantial further development?

3. Collaboration and funding

   (a) Has a coherent collaboration emerged, capable of moving this concept towards an experiment? Are there well-defined institutional roles during the design and R&D phase? What are the institutional commitments? Does the collaboration have the credibility and expertise to carry this project to completion?

   (b) Is there a realistic schedule and budget for completing R&D and moving forward with a project? Is there a realistic plan to obtain funding for R&D?

   (c) What is the total project cost projected to be, including realistic estimates for labor, overhead, contingency? How much do the construction and operations costs depend on the site chosen? Have these issues been folded into the overall project planning?

   (d) Is there a viable funding model for this project as a whole? Does the radio astronomy community expect to support it, through funding and participation?

We ask that the committee provide a written report, with comments, findings and recommendations, to FCPA within one week after the June 3 review.

B List of questions to the collaboration before the review

The collaboration was given the following list of topics by the panel shortly before the review.

1. Science

   (a) Motivation - What are the science questions to be address by this project? Is it just Dark Energy?

   (b) Observables - What is to be measured and how is it related to the questions?

   (c) Signal - What are the predicted signals, what are the foregrounds and the strength? What are the sources of noise and interference?

   (d) Context - What other experiments are needed to achieve the science goals?

   (e) What are other complementary experiments, what are the other competitive experiments and what is their status? Where will they be on your time scale?

2. Responses to the April 26 internal Review

3. Technical Approach

    (a) Straw man Design - Telescope, electronics data quantity, data handling, analysis challenges.
    (b) Instrument optimization
    (c) Path to validate requirements
        i. Prototype Development?
        ii. R&D plans?
    (d) Experiment simulation and development - How complete is the model of the sources, strength of the signal and the instrument.
    (e) Site Selection

4. Schedule, collaboration and funding:

    (a) Collaboration - personnel commitments
    (b) Collaboration organization
    (c) Role of FNAL - institutional commitment
    (d) Other needed areas of expertise
    (e) Plan for Schedule development
    (f) Plan for Budget development

C Agenda

June 3, 2010

13:00 - 14:00	Executive Session	Panel
14:00 - 14:20	Introduction and Science Motivation	Albert Stebbins
14:20 - 14:40	Telescope Design and Requirements	Dave McGinnis
14:40 - 15:00	A Ground Based 21cm Survey	Hee-jong Seo
15:00 - 15:20	Instrument Calibration	Christophe Magneville
15:20 - 15:40	Break	
15:40 - 16:00	Simulation	Dave McGinnis
16:20 - 16:40	Collaboration and Management	John Marriner
16:40 - 17:00	Summary	Nick Gnedin
17:00 - 18:30	Executive Session	Panel