Report
IceCube Science Advisory Committee Meeting
Sept 11-12, 2017

Introduction

The IceCube Science Advisory Committee met at Caltech on September 11-12, 2017. The members in attendance were: Lothar Bauerdick, Karol Lang, Steven Ritz, Hank Sobel, Jennifer Thomas, Dave Wark, Jim Yeck, and Barry Barish (Chair). Roger Blandford, Edward (Rocky) Kolb were unable to attend. The agenda and two questions posed to the committee are in Attachment A.

The SAC meeting consisted of a review of the various aspects of Ice Cube program in a set of very informative talks. We discuss those talks briefly below, and we thank all the presenters for these updates.

The special focus of this meeting was the NSF requested 'White Paper,' that followed from the reviews of the midscale upgrade proposal, "IceCube Gen2 Phase 1 upgrade." The proposal received five excellent and one very good reviews." Despite the five out of six outstanding reviews, the NSF officials stated that R&D toward Gen2 should not be part of a mid-scale proposal. As a result, before proceeding further with the proposal, the NSF has asked for a White Paper on the science goals of the midscale proposal, excluding the Gen2 R&D.

The committee primarily concentrated on a critique of the draft White Paper, and have a series of suggested improvements in a rewrite. The White Paper will be critical to moving forward toward approval and funding at the NSF. Therefore, we have tried to be strategic in how we suggest it be rewritten, not just removing the Gen2 R&D, but making the best case for an upgrade to the NSF and possible panel reviewers.

General Remarks

Neutrino physics is becoming one of the central pillars of particle physics, and neutrino astrophysics experiments are crucial to the emergence of multi-messenger astronomy. IceCube and its potential future evolution promises to be a major contributor to both areas.

There are many neutrino projects underway and/or planned with goals to better determine oscillation parameters, measure the mass hierarchy and eventually observe CP violation for neutrinos. The IceCube midscale proposal will address discrepancies in the oscillation parameters from low energy experiments in a very different energy regime, and has unique abilities to pursue tau neutrino mixing and tests of the unitarity matrix. In addition, the technical improvements employed will establish improved technologies for a future next generation high energy expansion of Ice Cube.

Since our last meeting, WIPAC was awarded the renewal M&O cooperative agreement, which is a continuation of the present program with similar scope. The combination of an effective M&O organization, a strong international collaboration and an outstanding scientific track record combine to position IceCube very well for pursuing and evolving their scientific capabilities.

At the time of our last meeting there was tension between pursuing the ambitious PINGU MREFC proposal, which was aimed at resolving the hierarchy and determining neutrino oscillation parameters, as against moving more directly toward an MREFC Gen-2 upgrade to pursue neutrino astronomy for very high energy neutrinos. We are pleased to see that this was resolved by proposing a more modest but well-motivated "midscale" upgrade proposal with significant neutrino oscillation goals.

The submitted midscale proposal was sent for review and received five "excellent" and one "very good review." We also note that the "very good" review was very positive and also contained very constructive comments. As stated above, despite the high quality of the reviews, the NSF monitors have stated that midscale proposals are not to contain R&D toward possible future projects. Consequently the NSF has requested a new 'White Paper' that specifically addresses the mid-scale upgrade science.

At this SAC meeting, we focused our discussions mostly on the early draft of the White Paper. Below, we make a specific set of suggestions to help guide the rewrite, which is being undertaken by WIPAC at this time.

Questions to the SAC

Question #1: *Does our current white paper make a compelling science case for the Phase 1 upgrade? What areas could be improved?*

SAC Answers:

- We recommend changing the title of the proposal in the White Paper. A simple descriptive title is suggested, maybe "Scientific Justification for an Upgrade to the IceCube Detector."
- The report should begin with a concise statement of the science goals.
- The proposal is likely to be read by non-experts and therefore should be more pedagogical, making clear the science case.
- Emphasize that this is a small incremental upgrade, giving significant new scientific capability, to an existing large-scale highly successful experiment.
- Although more pedagogical, the report should include a balance of some hard numbers, etc. to make clear it is not a hand-waving report.
- The figures should be simplified and carry clear messages that can be easily understood by the reader.
- Try to reduce the length to ~ 5 pages, encouraging the reader to read all the way through the report.
- Use the most critical parts of peer reviews to clarify and better define the upgrade's goals
- Science Case
    - The complementarity of the oscillation measurements to the existing experiments should be a key point. The higher energy avoids cross-section complications, and the enhanced matter

effects give access to the octant which is superior to any existing experiment.

- Point out the importance of the neutrino oscillation measurements, especially that the distinguishing maximal mixing from, say, the NOvA solution, is more than just precisely measuring a number we cannot predict. Maximal mixing is clearly a very special result, and probably would point to some underlying symmetry. So resolving this tension is important.

- Tau neutrino measurements are presently the main particle physics motivation in this document and therefore you need to be careful how they are described and why the new phase 1 configuration is necessary to accomplish this measurement. The current discussion on atmospheric tau neutrinos needs to be changed to emphasize how much better the parameters can be determined, rather than the larger number of events that phase 1 would see relative to deep core.

- The very high energy of the events should make them more sensitive to some BSM neutrino models. The White Paper mentions this but gives no examples. You might want to look around for a few such cases, as this is once again a unique capability

- The key point on the neutrino astronomy is the greatly enhanced pointing accuracy. The case there should be made (if it can be made) a bit more quantitative. As we understand it, the improved systematics arise because the ability to put the light pulser close enough to the PMT's to see direct light as well as scattered light, and thus to be better able to distinguish the various sources of scattering. This should be better described and, if possible, quantified.

- Make a big point of the fact that the improved knowledge resulting on the ice will enable re-analysis of large body of existing data.

- The White Paper states the need to reach 10% on the tau appearance, but does not explain of how Phase I will allow an improvement. The ability to measure the mass-squared difference is better than any existing, so should be a world-leading measurement at least until DUNE has been running for many years.

- For the purposes of describing the importance of the neutrino oscillation measurements to the neutrino astronomers, it would probably be useful to point out that distinguishing maximal mixing from, say, the NOvA solution, is more than just precisely measuring a number we cannot predict. Maximal mixing is clearly a very special result, and probably points to some underlying symmetry that could be a key in understanding the underlying mechanisms determining the pattern of neutrino masses and mixing. The current NOvA number, on the other hand, makes the three angles look like just three angles taken randomly in the range $0 – 2\pi$. So, resolving this tension is important.

- The key point on the neutrino astronomy is the greatly enhanced pointing accuracy. The case there should be made (if it can be made) a bit more quantitative. As I understand it, the improved systematics arise because the ability to put the light pulser close enough to the PMT's to see direct light as well as scattered light, and thus to be better able to distinguish the various sources of scattering. This should be better described and, if possible, quantified.

- Translate how the hardware for the upgrade will enable better physics and argue that it is a cost-effective and reasonable step based on your so-far experience, but do not imply an entitlement. Point out opportunities for other measurements (e.q., DM-Ice, etc..)

- The discussion on optical properties is very important but complicated. We found it hard to understand how the detailed measurements of the optical properties in the restricted volume of the

7 strings can be reliably extrapolated to the entire array. Certainly there will be systematic errors associated with this extrapolation and the size of these errors is not discussed…will they be small enough that the extrapolation is useful?

- Should write a paragraph on the drill, recognizing it as the cost driver, but pointing out that it is based on expert past experience and will be a tool useful beyond this project.

- Point out the international contributions and strengths in carrying out the project.

- Remove all references to Gen2 detector R&D, although a careful sentence or paragraph indicating that any future large scale project will benefit from the improved Ice studies, technology used, etc. But, do not imply any future requests.

- The SAC committee members are willing to read a draft of the revised report, before submission.

Question #2: *"How would including some aspects of the full Gen2 array (radio detectors and surface scintillator arrays) into the scope of Phase 1 impact the current mid-scale proposal?"*

SAC Answer:

- The SAC recommends all references to Gen2 be removed (radio, scintillator, etc). Only a general statement of the value of this midscale upgrade to the future should be made.

Presentations to the SAC

"IceCube Science" (Dawn Williams)

Dawn Williams' presentation summarized the excellent scientific productivity of IceCube. Highlights of the presentation included:

- New efforts to increase the acceptance for lower energy events (Medium Energy Starting Events, MESE);
- New direct (“double-bang”) searches for tau neutrinos;
- Improved analysis strategies for the highest energy events (resulting in an additional event);
- New upper limits on GZK neutrinos;
- Recently published neutrino mixing parameter measurements that are competitive with, and complementary to, accelerator-based experiments;
- Recently published limits on spin-dependent dark matter;
- A new inclusive tau-neutrino appearance analysis.

Surprisingly, there is still no evidence for point sources, which further reinforces the importance of detector upgrades to resolve this mystery. The SAC commends the current attention to detector effects, such as hole ice non-uniformity, cable shadowing, and DOM saturation.

“Gen 2 Science” (Halzen)

It is clear that IceCube has seen cosmic neutrinos. The flux and shape of the events measured with the long up-going tracks and with the contained cascade events are consistent.

The atmospheric neutrino background spectra for both muon and electron neutrinos has now been measured with a combination of Super-K at the lower energies and IceCube at the higher energies. These results are consistent and smoothly connect. This is a great accomplishment!

Measurements of the light transmission length in the ice show an absorption length of well over 100 meters. This implies that the string spacing of a next generation IceCube could be twice that of the existing array. The threshold will increase, but this is not considered important as atmospheric neutrino background dominates in the lower energies.

The observed events currently are consistent with a diffuse source of cosmic neutrinos, but a galactic component currently cannot be excluded at the 3-sigma level.

The same sources that produce neutrinos must also produce gamma rays. The measured gammas from Fermi seen at the lower energies seem to be consistent with the flux and spectral shape seen by IceCube in its higher energy range, which could imply that the energy density of neutrinos (in the non thermal Universe) is similar to that in gamma-rays.

Given the IceCube results, IceCube Gen-2, is projected to have sufficient sensitivity to identify which of the many possible galactic components are responsible for the observed cosmic neutrinos.

The different neutrino flavors produce different event signatures in IceCube allowing clean separation. When the neutrinos propagate over cosmic distances, all of the possible production mechanisms eventually end up with a 1:1:1 flavor ratio. If a different ratio is observed this would imply exciting new physics

"Gen 2 – Wideband Neutrino Astronomy" (Albrecht Karle)

This presentation was a comprehensive view of the opportunities for the next generation of IceCube (Gen2), defined as a wide band neutrino observatory (MeV to EeV) using several detector technologies – optical, radio and surface veto. It could also have a low energy core, similar to the PINGU concept.

The present thinking regarding Gen2 has intriguing possibilities as to expand IceCube in the future. For this SAC meeting, we mainly concentrated on the mid-scale upgrade proposal and were not able to have substantive discussions of the long range future. We should do that, once the mid-scale upgrade is approved, especially to establish long-range R&D needs and preliminary work needed to establish an MREFC proposal in a timely manner.

"Better Ice / Better Astronomy" (Albrecht Karle)

The "Better Ice - Better Astronomy" talk describes a broad program to better understand the detector, which includes bulk ice, hole ice and DOM angular response functions. The significant progress in understanding the detector is on-going, but the upgrade will maximize the gain from the proposed re-analysis of all the IceCube data. Understanding the dead areas caused by the cable position in the string hole is ongoing with the present LED calibration data and information of where the cables were during deployment. These constants are already being added to the data base, including the orientation of the DOM with respect to the ice hole. But, in order to have full confidence in what happened after the ice melted, the new LED hardware associated with the upgrade will be able to check these values with high precision for the nearby 7 strings.

At present, the pointing accuracy for the HE muons is 0.5 degrees at 100TeV. With ideal conditions it could be reduced to 0.1 degree. This will only be achievable with the additional hardware of the upgrade. There might be an improvement to 0.3 degrees without it, but the final step to 0.1 degree will need to use the developments coming from the upgrade.

The impact of this improvement is potentially very large. Above 100TeV, the significance of a point source would improve by factor of 5, which is 25 x area (or running time) at .1 degree. It is clear that the upgrade is a critical component of this huge potential improvement.

It is very important for multi-messenger astronomy to have better pointing from the muons and this cannot be overstated.

"Phase 1 Science Goals" Ty de Young

The presentation on the Science Goals of the Phase I project first described the enhanced sensitivity which Phase I would enable for neutrino oscillation measurements, in particular for tau appearance measurements and to precision determinations of the 2-3 sector oscillation parameters. The very high energy atmospheric neutrino events available in IceCube greatly increase the tau appearance rate relative to other experiments, enabling high statistical precision just from event rates on an energy-angle plot.

The Phase I upgrades would produce a very large number of these events, which would enable a test of the unitarity of the PMNS matrix to high precision. The committee notes that the measurement of tau appearance, however, is and will remain systematics limited, so it would be good to make a clearer statement how Phase I would lead directly to reduced systematic uncertainties in this measurement.

In addition, Phase I would lead to improved measurements of the mixing parameters. The advantages are the higher energy of the oscillating neutrinos, which mean that reactions are dominated by DIS events, where the cross-sections are better understood and matter effects are more significant, coupled to the very high rates (which allow subtle three-flavour effects to be seen in disappearance). The sensitivity to Δm_{23}^2 will be better than any current experiment, and the sensitivity to $\sin^2\theta_{23}$ with different systematics, may be valuable, considering the current tension between the T2K and NOvA results.

The octant sensitivity of Phase I would far exceed any current experiment. The higher-energy of the IceCube events should also increase sensitivity to various BSM neutrino models, and there are also advantages in searching for sterile neutrinos. Taken together this seems a very strong science case for the upgrade.

Phase I will support the enhanced high-energy neutrino astronomy program, from measurements of ice properties that will improve reconstruction. The benefits include better identifying high-energy tau events from the "double bang" signature and improved angular reconstruction. Improved angular reconstruction will allow very significant enhancements in the science program for multi-messenger astronomy and for searches for point source.

Very importantly, the ability to apply this retroactively to the existing data is a major selling point for the upgrade.

"Phase 1: Project and Technical" Kael Hanson

The plan for the Gen2 Phase 1 upgrade is to deploy additional strings in the middle of the existing IceCube array, with closer spacing and much improved instrumentation. The new optical sensors would increase low energy performance to sub-GeV neutrinos and much improve angular resolution.

As proposed, the upgrade project has a \$35M TPC, of which \$22.7M is proposed to come from NSF, mainly to provide the large cost of the drill and South Pole infrastructure (~\$13M). The remainder will come from international partners (mostly Germany, other European countries and a pending proposal to Canada) for extras strings to a total of seven.

International partners are looking to an NSF signal or commitment to move forward with the project. The main features are:

- The project cost driver is the enhanced hot water drill, at $12.8M estimated, capable of delivering 4.6MW thermal energy to drill faster, would allow improving optical quality of holes (avoiding bubbles). The new drill design includes lessons learned and experience gained from the earlier drill.   It would be mobile on a sled arrangement, and would be an investment for other potential deep ice deployments at the pole.
- The detector upgrade comprises of new strings in a denser configuration and the inclusion of new calibration devices, that would provide significant progress in understanding ice optics (cable shadowing, tilt, etc.); includes POCAMs (uniform light sources), precision LED flashers, and imaging cameras
- R&D has proceeded towards upgraded DOM, with updated electronics board, proof-of-concept integration into IceCube system; also segmented photo detectors are being investigated that would provide 2x better angular resolution for HE, and would bring angular/energy reconstruction down to 100 MeV for LE; there is also R&D into cables
- R&D and planning is such that they are ready to start the 5 year project plan immediately

ATTACHMENT A

2017 IceCube Science Advisory Committee Meeting Agenda

September 11 & 12, 2017

Caltech
West Bridge Building Room 351
1165 E. California Boulevard
Pasadena, CA

This meeting will focus on future upgrades to the IceCube Neutrino Observatory, in particular the IceCube Gen2 Phase 1 upgrade for which a proposal has been submitted Fall 2016. The proposal reviewed extremely favorably (see reviews in SAC directory). Nevertheless, our NSF program officers are holding the proposal in an indeterminate state pending the submission of a brief white paper that details the Phase1 science program independent of any future Gen2 observatory.

Question #1: Does our current white paper make a compelling science case for the Phase 1 upgrade? What areas could be improved?

Question #2: How would including some aspects of the full Gen2 array (radio detectors and surface scintillator arrays) into the scope of Phase 1 impact the current mid-scale proposal?

Agenda

Monday September 11		
8.30 – 9.00	SAC Closed Session	
9.00 – 9.40	IceCube Science	Dawn Williams
10.00 – 10.40	Gen2 Science	Francis Halzen
11.00 – 11.30	Break	
11.30 – 12.30	The Gen2 Wideband Neutrino Observatory	Albrecht Karle
13.00 – 14.30	Lunch	
14.30 – 15.00	Better Ice Better Neutrino Astronomy	Albrecht Karle
15.00 – 15.40	Phase 1 Science Goals	Ty deYoung
16.00 – 16.30	Break	
16.30 – 17.00	Phase 1 Project and Technical	Kael Hanson
18.30 – 21.00	Dinner at Faculty Club	
Tuesday September 12		
8.30 – 9.15	SAC Closed Session	
9.15 – 10.00	Open Discussion	
10.00 – 12.00	SAC draft report writing	
12.00 – 12.30	Closeout	

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