The IceCube-Gen2 Neutrino Observatory

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Very Large Volume Neutrino Telescopes
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“Valencia”
Open Questions

What we know about the flux of high-energy neutrinos:

- Roughly power law in shape
- Seemingly flavor democratic
- Isotropic in arrival direction

But...

- No definitive sources yet (some tantalizing evidence)
- No UHE neutrinos (>10 PeV)
Driving Goals

A next generation observatory must enable...

• Improved precision on the spectrum and composition of the diffuse flux
• The identification of more point sources
• Better cross-correlations with astronomical catalogs

Which requires...

• Higher event rates, over a broader energy range
• Improved angular resolution
The IceCube-Gen2 Facility
A broadband neutrino observatory

Four new elements, leveraging complimentary technologies, to achieve sensitivity to MeV-EeV neutrinos

1. IceCube Upgrade
2. Enlarged deep optical array
3. Surface array extension
4. Shallow radio array
The IceCube-Gen2 Facility

- Gen2-Radio
- Gen2-Optical
- IceCube
- IceCube Upgrade

5 km
1 km
250 m
25 m

EeV  PeV  TeV  GeV
IceCube Upgrade

GeV Neutrinos

- 7 new strings, ~100 sensors/string
- 5 year construction project underway
- Key goals: ice calibration, sensitivity to GeV neutrinos
- R&D Platform: pixelated detectors, wavelength shifting sensors

See talk by M. Rongen (94)
Gen2-Optical
TeV-EeV neutrinos

• Enlarged, 8 km$^3$ optical array in a “Sunflower” layout
  ○ 122 strings, 240m lateral spacing
  ○ 80 OMs/string, 17m vertical spacing
• ~10x the contained volume of IceCube
Gen2-Surface

Cosmic rays

- Extension of IceTop, with a station atop each new optical string
- Dual technologies enable separation of muon and electromagnetic shower components
- CR detectors also provide a veto to the in-ice array
  - Gen2: 10 km$^2$sr
  - IceCube: 0.25 km$^2$sr

May 19, 2021

IceCube-Gen2 (B. A. Clark)
Gen2-Radio

EeV Neutrinos

• $\mathcal{O}(200)$ stations over 500 km$^2$
• Combination of “deep” and “surface” technology
  - Dipole antennas at $\sim$200m depth (like RICE, ARA)
  - LPDAs at surface (like ARIANNA)
• Final design still being optimized
Gen2-Optical Performance

Event Topologies

Like IceCube (and many other telescopes!) two primary detection channels:

**Tracks**
Mostly $\nu_\mu/\bar{\nu}_\mu$ charged current

**Cascades**
$v_e/\bar{v}_e, v_\tau/\bar{v}_\tau$ charged current
All flavors neutral current
Gen2-Optical Performance

Through-going tracks

5x the effective area of IceCube
2x improvement in angular resolution
Study Cosmic Particle Acceleration

Constrain the Sources and Propagation of Cosmic Rays

Probe Fundamental Physics on Cosmic Baselines

Resolve the TeV-EeV Neutrino Sky
Cosmic Particle Acceleration

Astrophysical Neutrinos

- Improved and extended measurement of the diffuse flux of neutrinos
- What is the flux at high energies? Is there a cutoff?

Mock measured spectrum, assuming 10 years of livetime, an \( E^{-2.5} \) astrophysical flux, and a mixed-composition cosmogenic flux.
Sources and Propagation of Cosmic Rays

Cosmogenic Neutrinos

- 500 km$^2$ radio array enables unprecedented sensitivity to UHE neutrinos
- Probes the makeup of cosmic ray primaries, even to very heavy (iron rich) compositions

![Graph showing the distribution of neutrino energy versus energy squared for different sources and detectors.](image)
Resolving the Neutrino Sky

Steady Sources

IceCube-Gen2 will be sensitive to sources 5x fainter than IceCube

5x fainter sources $\rightarrow$ 11x more sources total
Resolving the Neutrino Sky

Steady Sources

10-year mock TS skymap and differential sensitivities (assuming an $E^{-2}$ spectrum)
Resolving the Neutrino Sky

Transients

- IceCube-Gen2 has larger effective areas and improved pointing resolution
- Sensitivity to broad range of accelerators
  - Blazars/AGN flares
  - GRBs
  - Neutron star mergers
- “Hidden” sources
  - A TXS0506+056-like event would be discovered at high significance, without a gamma ray counterpart
IceCube-Gen2 will probe neutrino propagation over cosmic baselines.
Drilling

• Hot water drill for optical component is modified from IceCube for enhanced performance
  o Large sled modules – delivered by traverse, easy to move
  o “Degassed” holes to reduce bubble column
• Drill for radio component, “BigRAID,” is designed by the British Antarctic Survey
  o ”Dry” drill—removes ice as chips
  o Reach 200m in ~20 hours
Technology Development
Optical and Surface

• Gen2 will have pixelated OMs
  o 3x photocathode area → more photons
  o Directional information per-OM
  o A combined multi-PMT sensor for Gen2 is envisioned
• Surface technology being developed and deployed in the existing IceTop footprint
• Other sensors in development: wavelength shifting modules, etc.

See talks by V. Basu (67), A. Pollmann (95), J. Kelley (90)
Technology Development

Radio Array

• Radio array builds on heritage from RICE, ARIANNA, and ARA
  o Shallow antennas
  o Deep antennas
  o Autonomous power solutions
  o Phased array triggering

• Some new technology will be tested this summer in RNO-G, e.g. LTE-comms

See talk by A. Vieregg (this session!)
Timeline

- IceCube Upgrade ("Gen2 Phase 1") is under construction
- Gen2 design is well underway

We are here.
Radio array has completed first internal design review, with Surface array imminent.
Conclusions

- Gen2 will be a broadband neutrino observatory with unprecedented capabilities
- New detector technologies—pixelated detectors, radio arrays, scintillators, etc.—drive this progress
- Please see recent white paper for more information!