IceCube-Gen2

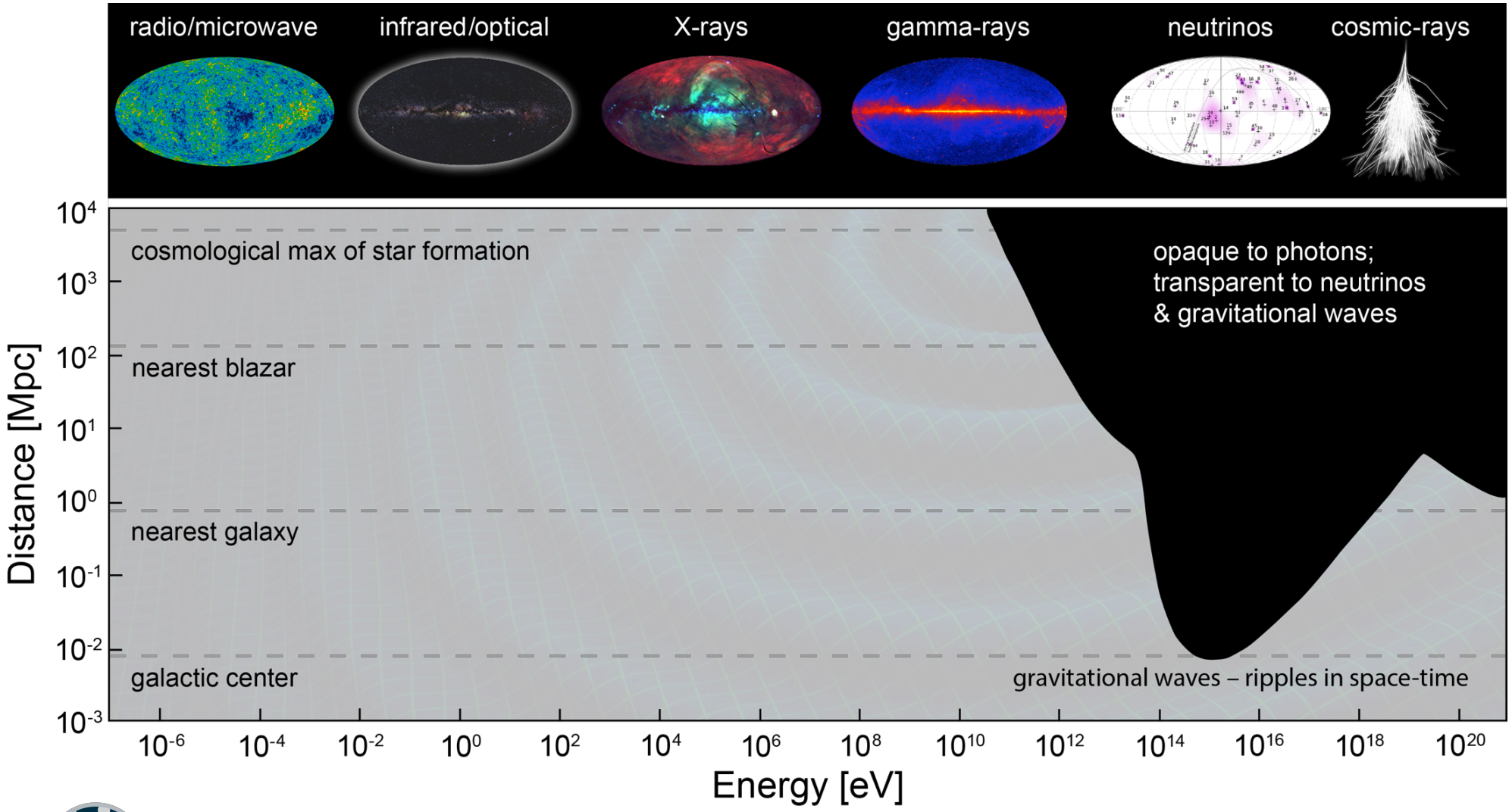
Notes on construction on ice

The IceCube-Gen2 Collaboration

Albrecht Karle (Univ. Wisconsin-Madison)

IceCube GEN2

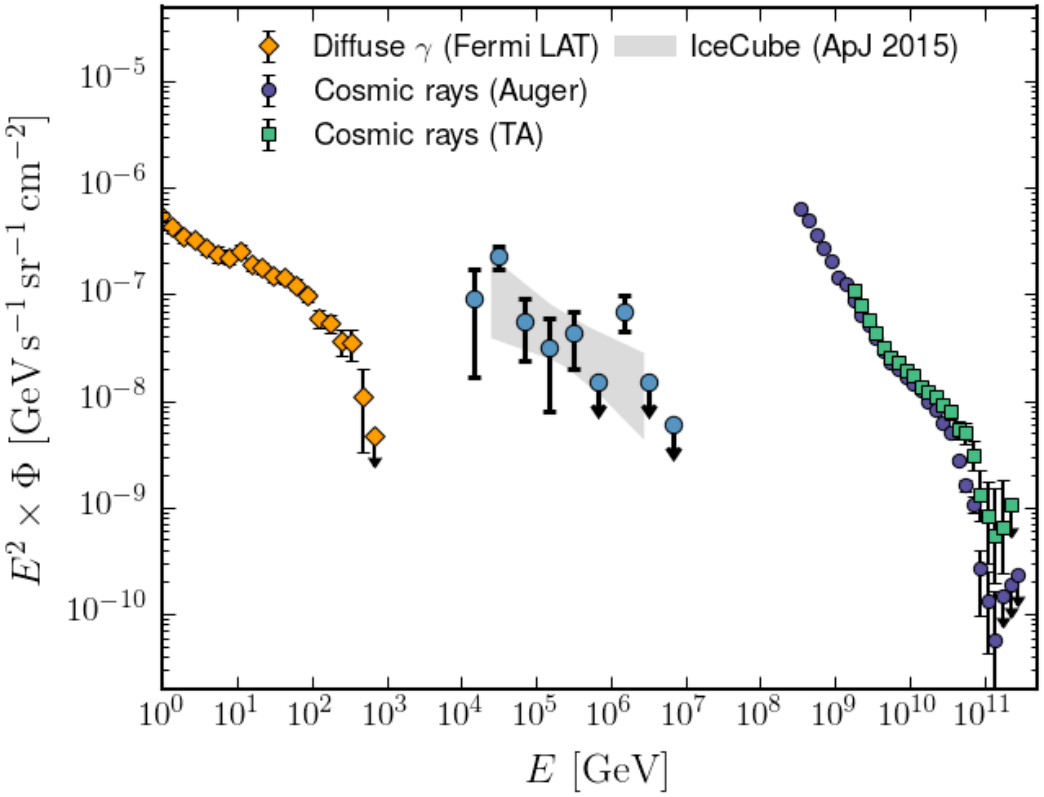
The energy frontier in astronomy



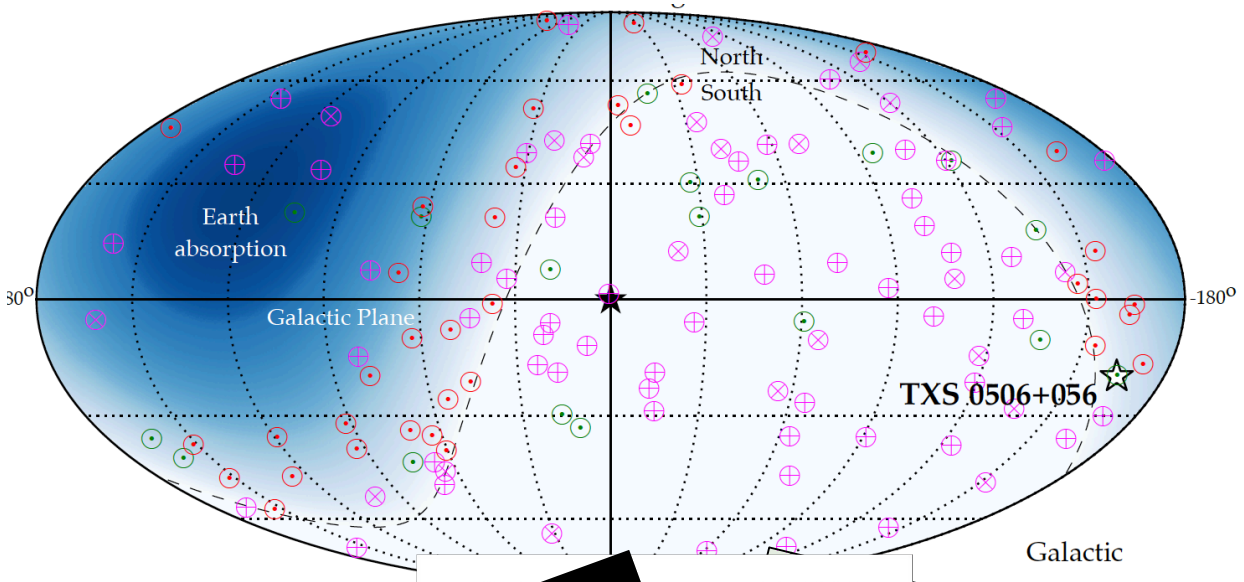
Universe opaque to photons for ¼ of the spectrum

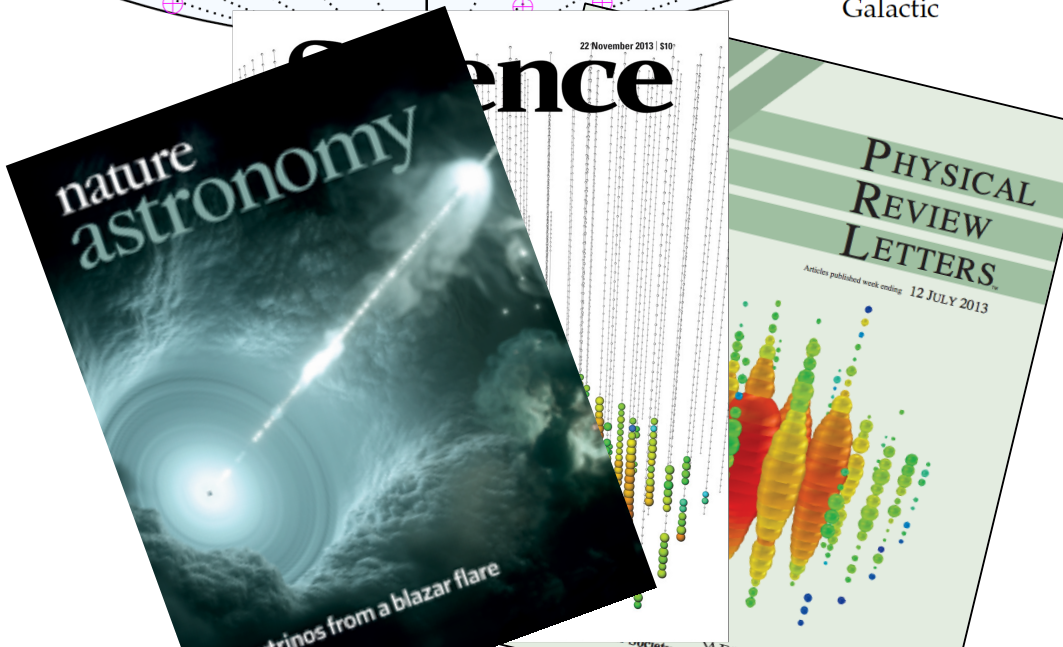
10 yrs of IceCube - a first view on the PeV Universe

Multimessenger spectroscopy



First sky map of cosmic neutrinos





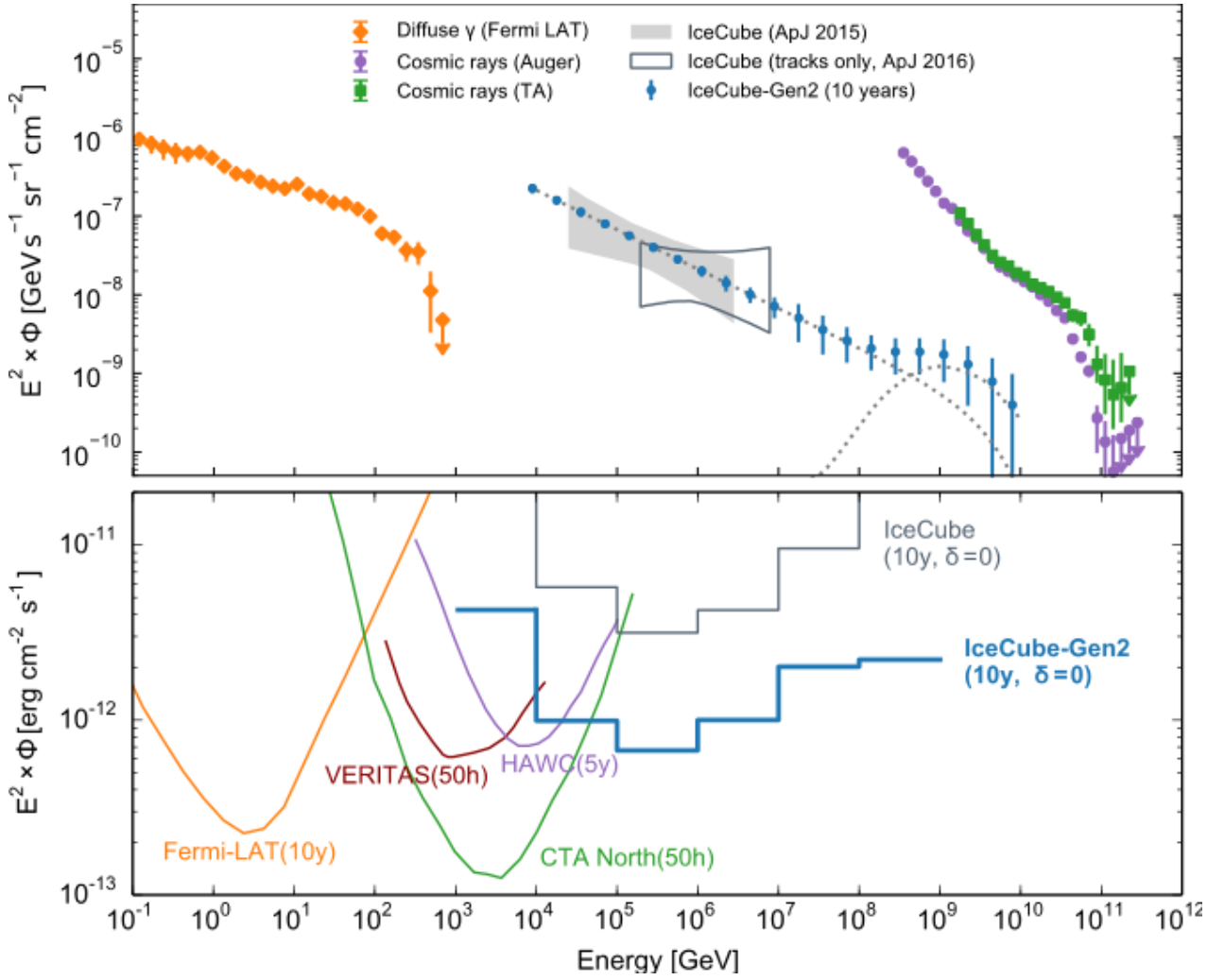
Some highlights:

2013: Discovery of cosmic PeV neutrino flux
2018: Evidence for Blazars as neutrino sources
2019: Observation of first tau neutrino

IceCube GEN2

Scientific objectives: building on 10 yrs of IceCube

1. Resolving the high-energy sky from TeV to EeV energies
2. **Understanding cosmic particle acceleration through multimessenger observation**
3. Revealing the sources and propagation of the highest energy particles in the universe
4. Probing fundamental physics with high-energy neutrinos



Completing the multi-wavelength view of the Universe

IceCube GEN2

Scientific objectives: building on 10 yrs of IceCube

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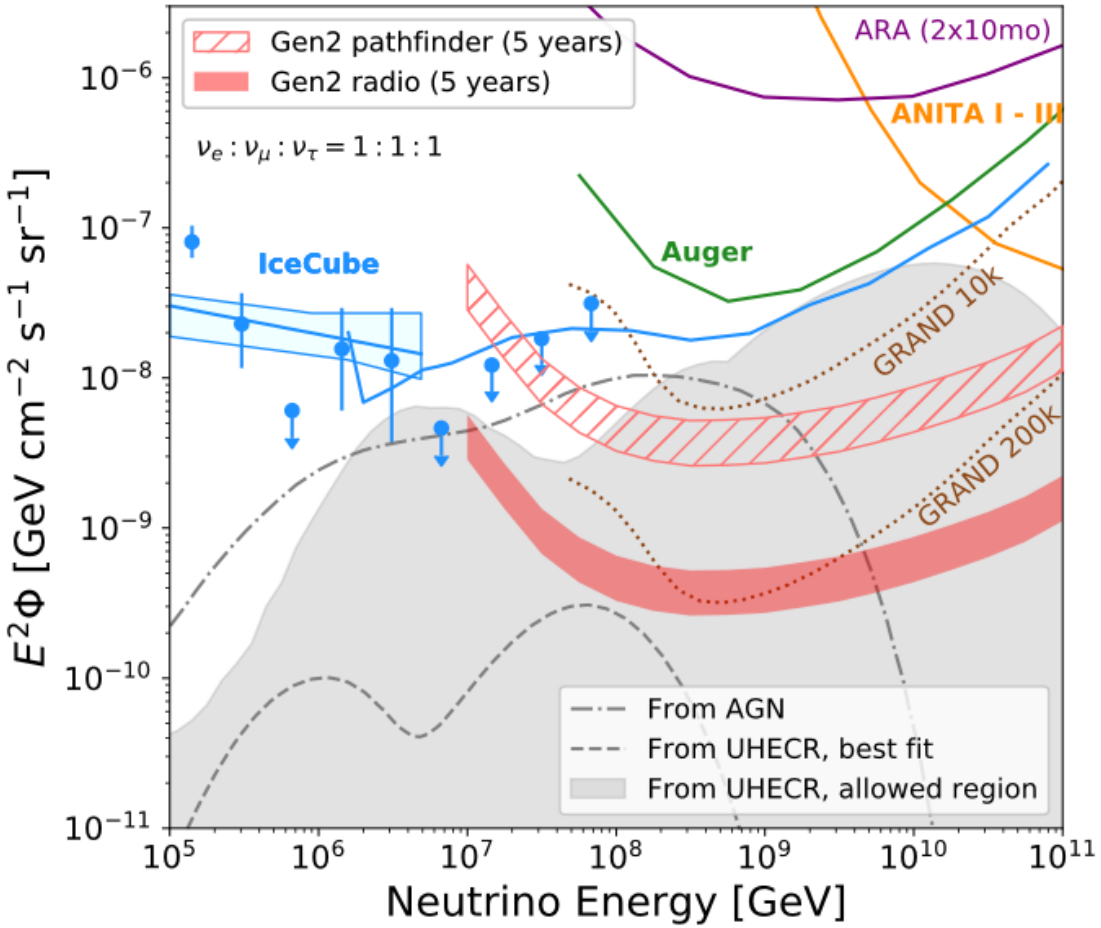

Probing source populations and composition of highest energy cosmic rays

IceCube GEN2

Scientific objectives: building on 10 yrs of IceCube

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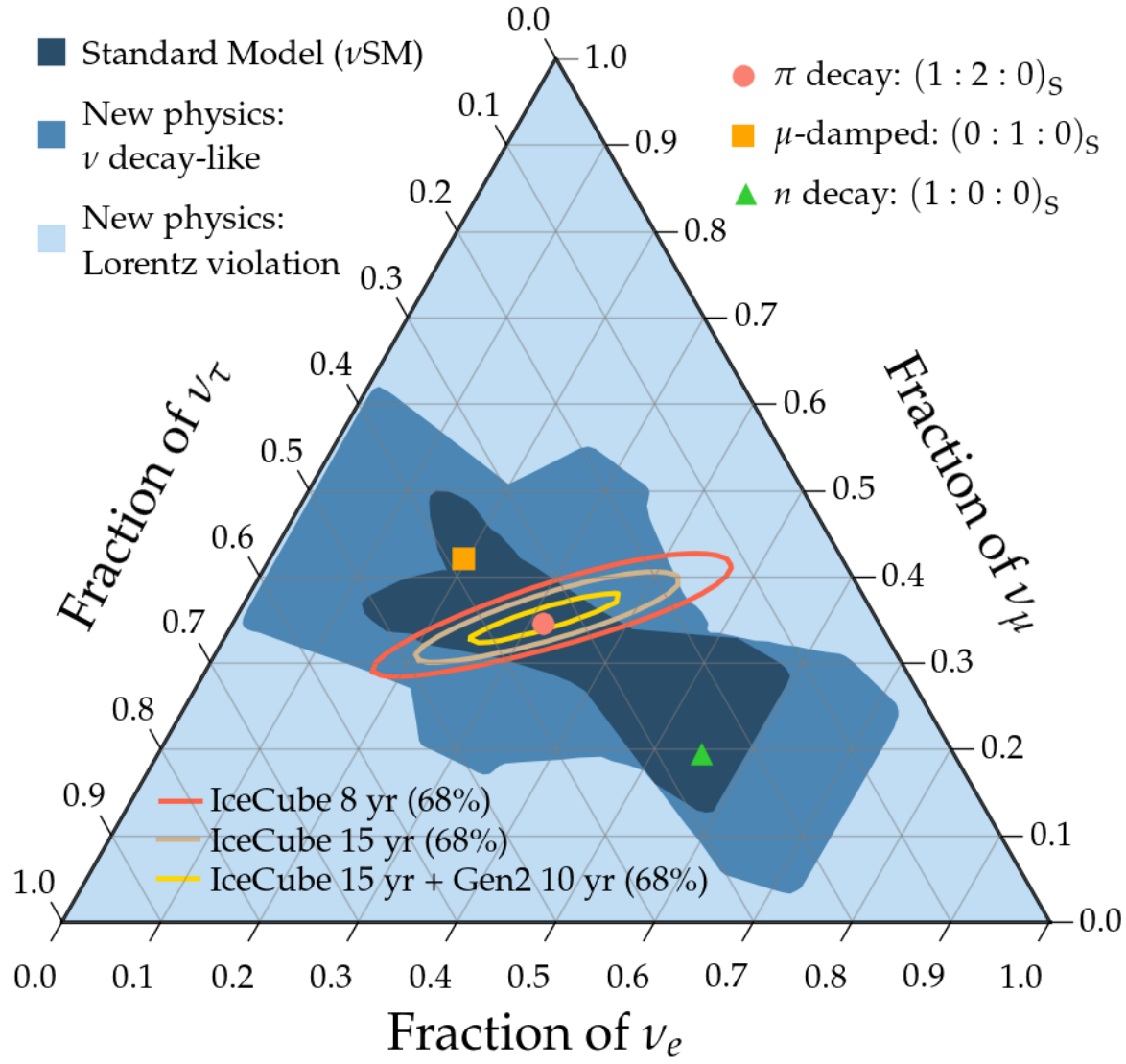
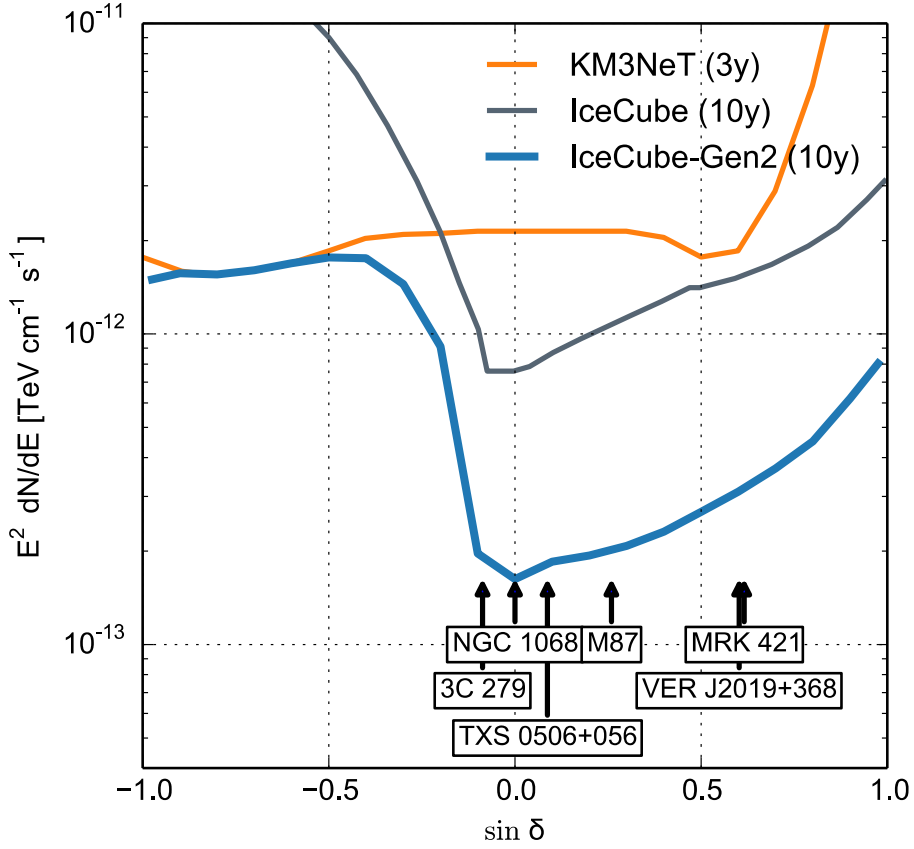


Probing neutrino oscillations over cosmic baselines

IceCube GEN2

Requirements for IceCube-Gen2

1. **Increase the neutrino point source sensitivity at least 5 times over the current IceCube array**
2. Enable multimessenger astronomy with individual, high-energy neutrinos
3. Collect 10 times more neutrinos per year than the current IceCube array in the energy range 100 TeV to 10 PeV
4. Expand energy range to beyond 10^{18} eV with sensitivity improved by two orders of magnitude
5. Enhanced sensitivity to neutrino flavors and the ability for flavor identification



Sensitivity to all realistic source populations (steady and transient) explaining the diffuse flux

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IceCube GEN2

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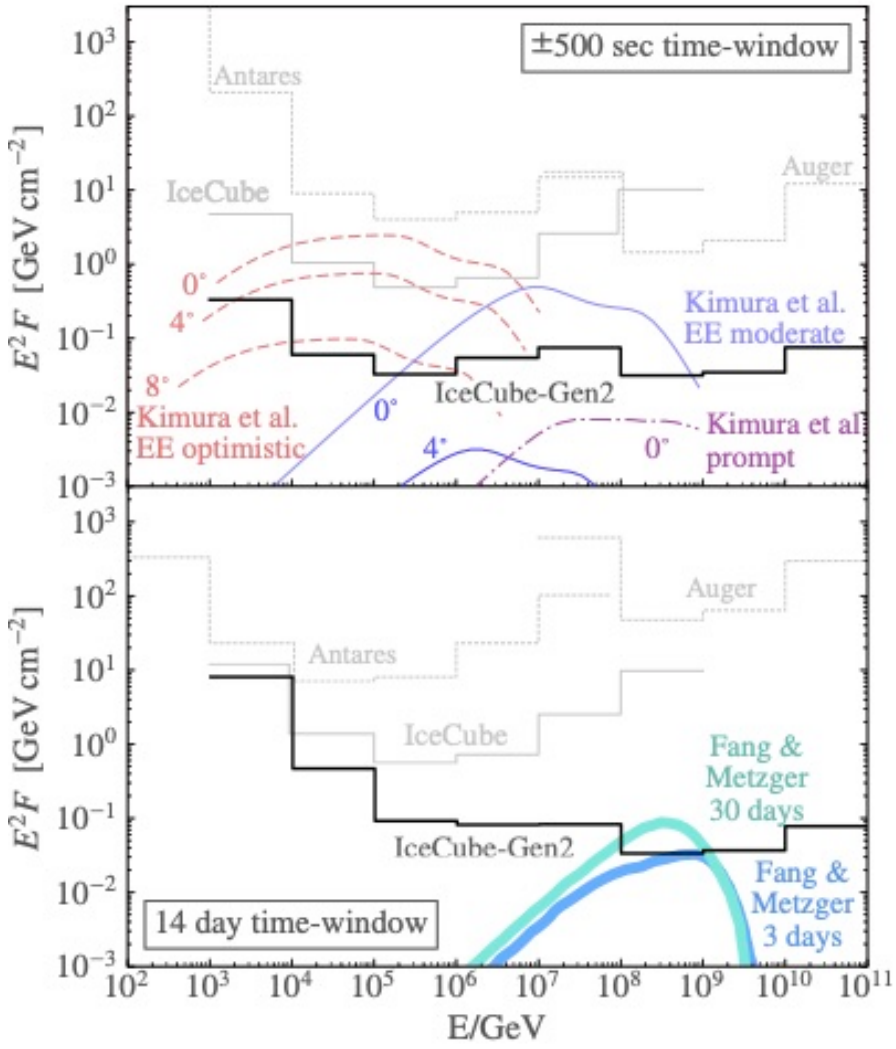
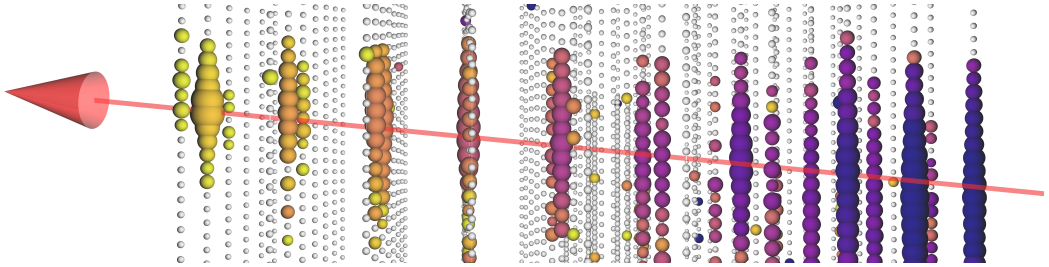
Gen2 sensitivity to NS-NS mergers



Neutrino alert IC170922A pointing to TXS 0506+056



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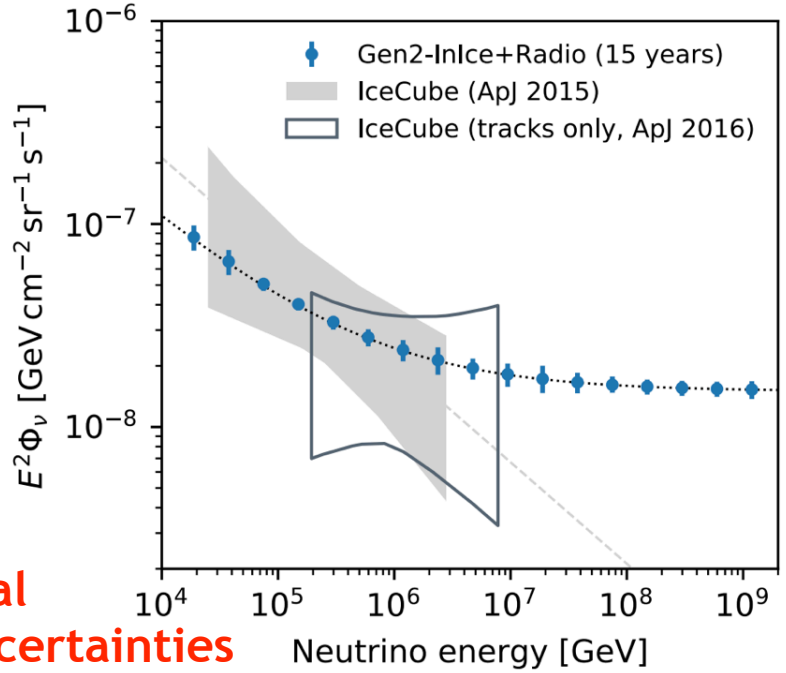
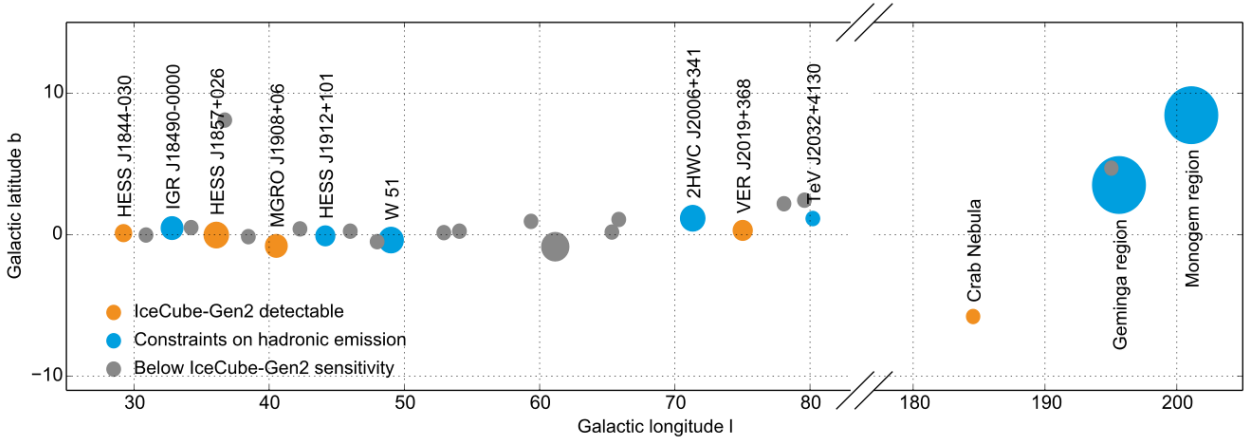


Projected spectral measurement uncertainties



Sensitivity to galactic sources

IceCube GEN2

Requirements for IceCube-Gen2

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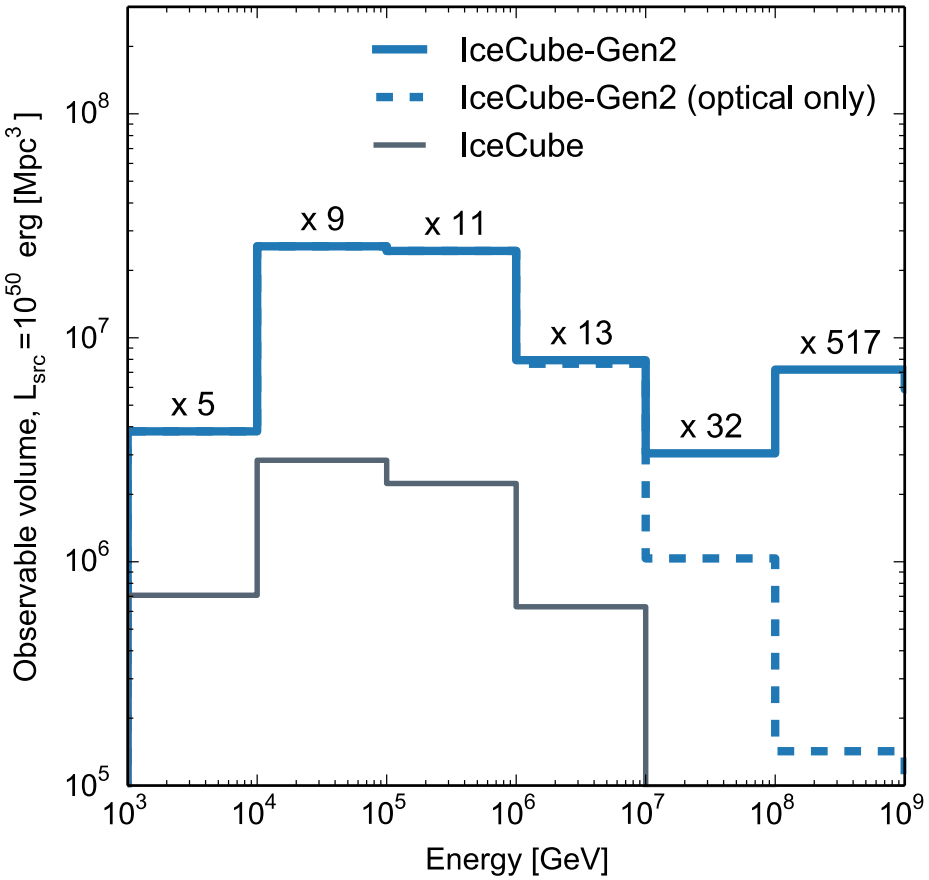

Uniform sensitivity over large energy range over more than 6 orders of mag energies.

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Requirements for IceCube-Gen2

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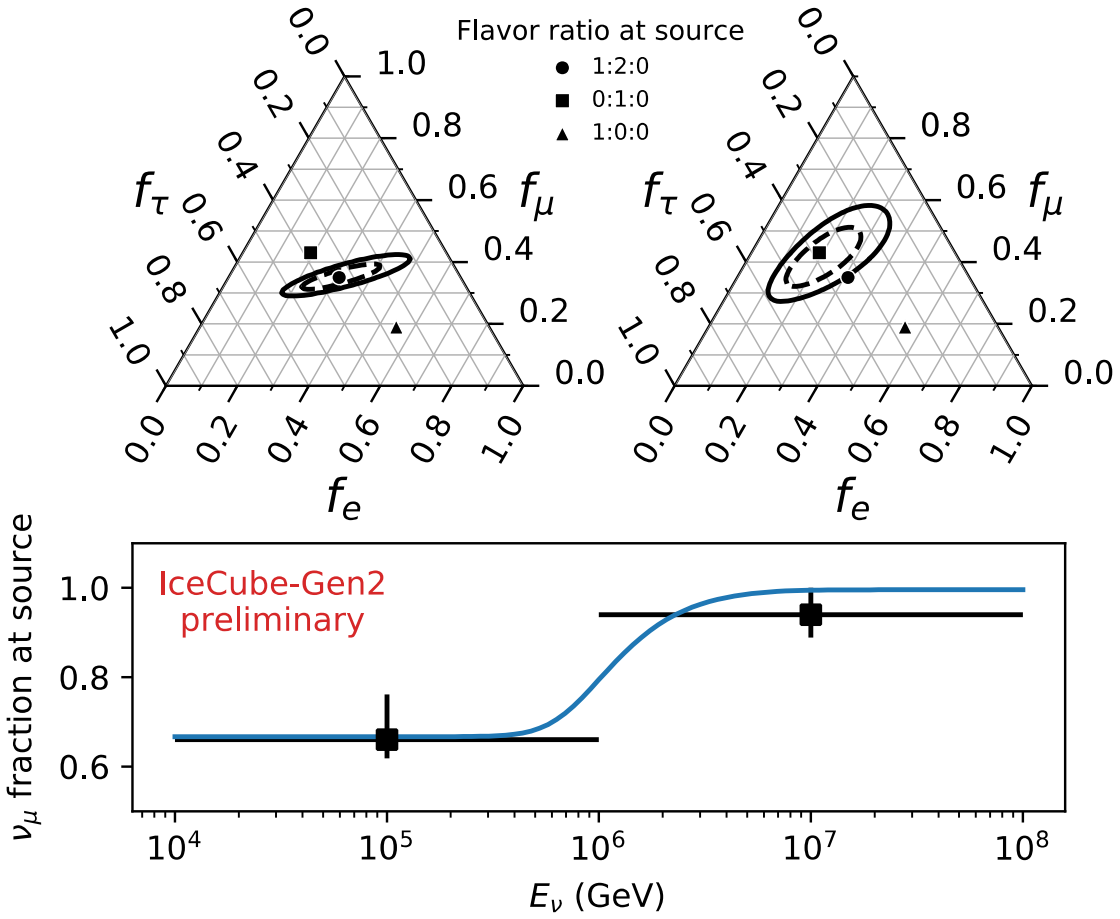
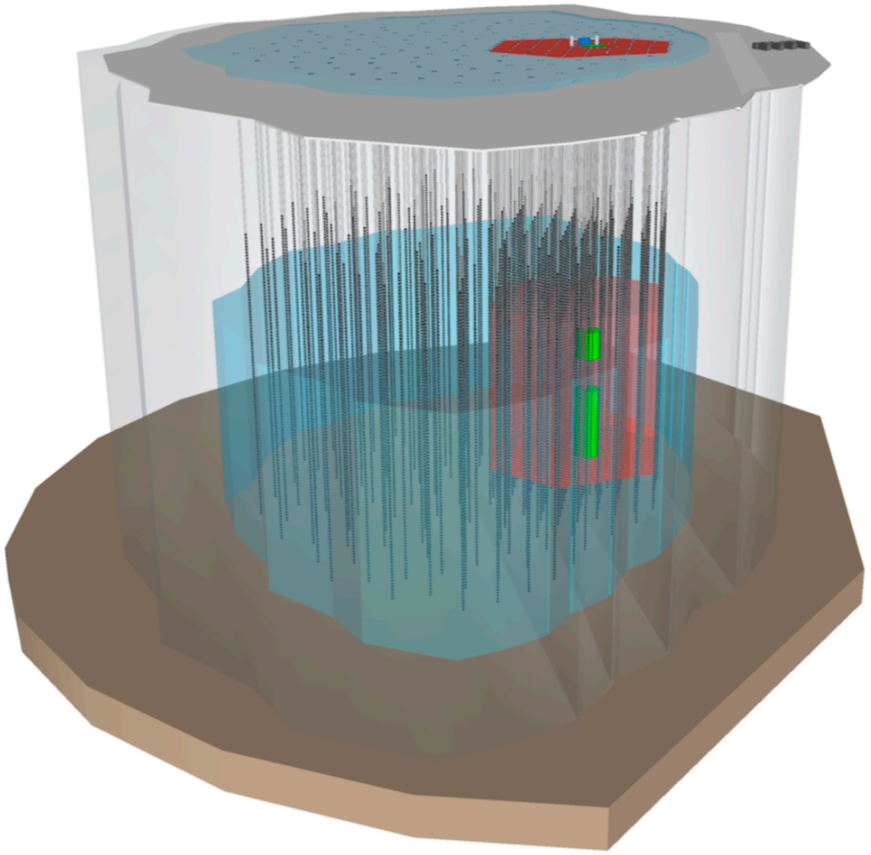


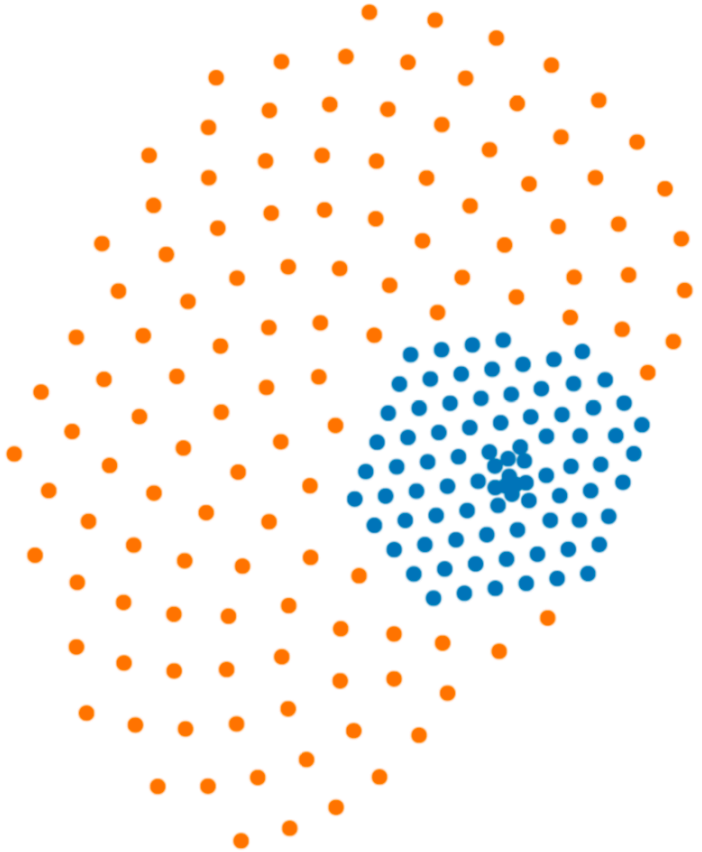
Measuring energy dependent neutrino flavor ratios (→BSM physics and nature of source)

IceCube GEN2

IceCube-Gen2

A Vision for the Future of Neutrino Astronomy in Antarctica (arXiv:1412.5106)





Artist's conception
120 strings at 240 m spacing

ICECUBE GEN2

The next-generation IceCube: from discovery to astronomy

THE ICECUBE-GEN2 COLLABORATION

AUSTRALIA
University of Adelaide

BELGIUM
Université libre de Bruxelles
Universiteit Gent
Vrije Universiteit Brussel

CANADA
Queen's University
University of Alberta–Edmonton

DENMARK
University of Copenhagen

GERMANY
Deutsches Elektronen-Synchrotron
ECAP, Universität Erlangen-Nürnberg
Humboldt–Universität zu Berlin
Karlsruhe Institute of Technology
Max-Planck-Institut für Physik
Ruhr-Universität Bochum
RWTH Aachen University
Technische Universität Dortmund
Technische Universität München
Universität Mainz
Universität Wuppertal
Westfälische Wilhelms-Universität Münster

JAPAN
Chiba University
University of Tokyo

NEW ZEALAND
University of Canterbury

REPUBLIC OF KOREA
Sungkyunkwan University

SWEDEN
Stockholms universitet
Uppsala universitet

SWITZERLAND
Université de Genève

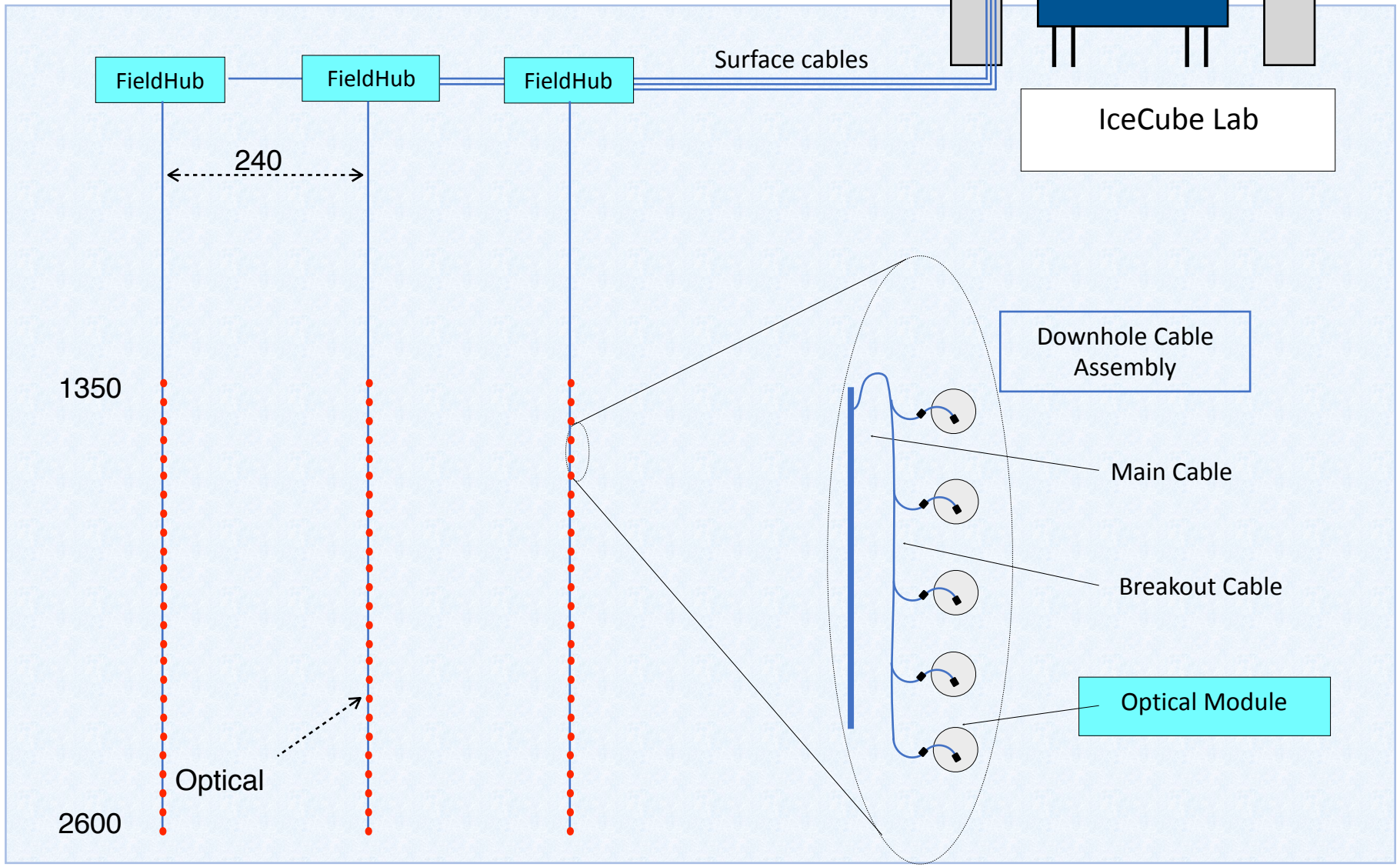
TAIWAN
National Taiwan University

UNITED KINGDOM
King's College London
University of Oxford
University of Manchester
Queen Mary University of London

UNITED STATES
California Polytechnical State University
Clark Atlanta University
Columbia University
Drexel University
Georgia Institute of Technology
Lawrence Berkeley National Lab
Loyola University Chicago
Marquette University
Massachusetts Institute of Technology
Mercer University
Michigan State University
Ohio State University
Pennsylvania State University
South Dakota School of Mines and Technology
Southern University and A&M College
Stony Brook University
University of Alabama
University of Alaska Anchorage
University of California, Berkeley
University of California, Irvine
University of California, Los Angeles
University of Chicago
University of Delaware
University of Kansas
University of Maryland
University of Notre Dame du Lac
University of Rochester
University of Texas at Arlington
University of Wisconsin–Madison
University of Wisconsin–River Falls
Yale University

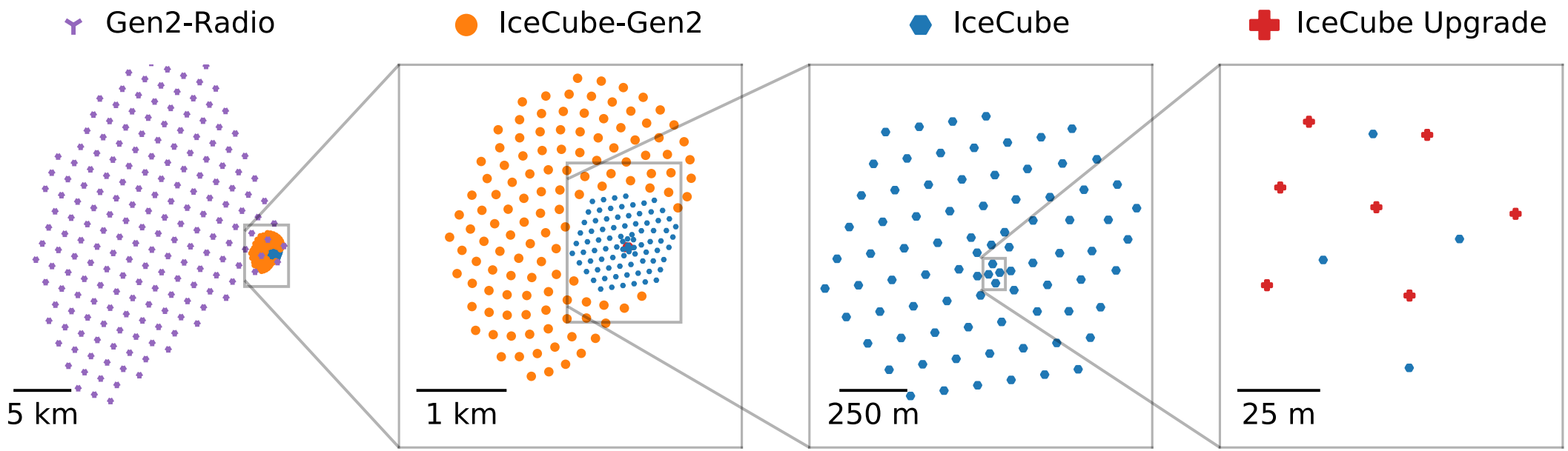
Architecture

- Power and communications architecture: simplified requirements for cable hardware.



IceCube-Gen2 — scope

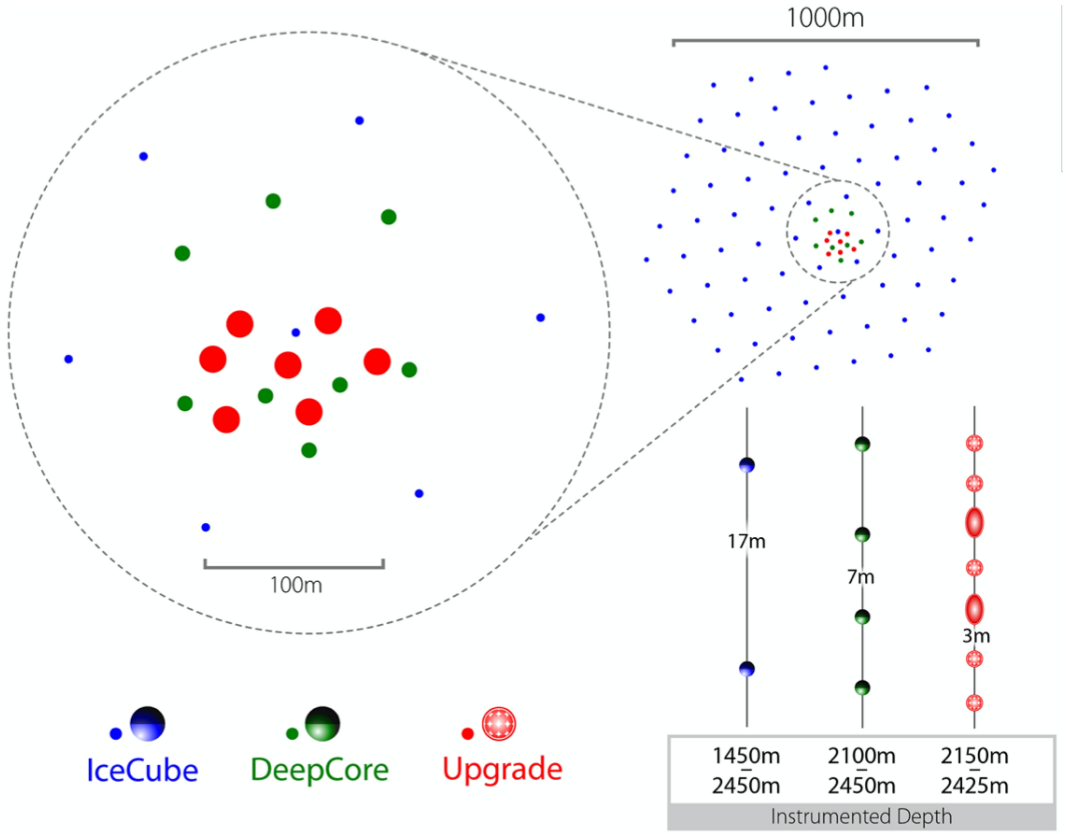
IceCube and Gen2 on different scales reflecting different energies



IceCube GEN2

IceCube-Upgrade (Gen2 Phase 1)

- 7 new strings instrumented with more than 700 advanced sensors
- Improvements to precision measurements of neutrino properties at low energies - O(10 GeV); extensive calibration program is expected to more than double the current IceCube high-energy neutrino sample
- Fully funded $36M project (~65% NSF/35% partner agencies and institution)
- Deployment completion January 2023.



ICECUBE GEN2

Optical sensors

IceCube DOM

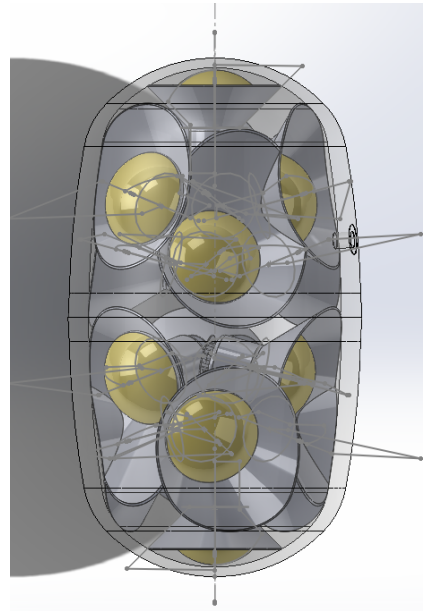
Diameter 33 cm
10 inch PMT

IceCube Upgrade (under construction) primary sensors

Directional information
24 x 3 inch PMT
Diameter 36 cm

2 x 8 inch PMT
Smaller diameter 30 cm

Gen2 sensor design studies: MDOM with smaller diameter.



12 x 4 inch PMT
Smaller diameter 30 cm

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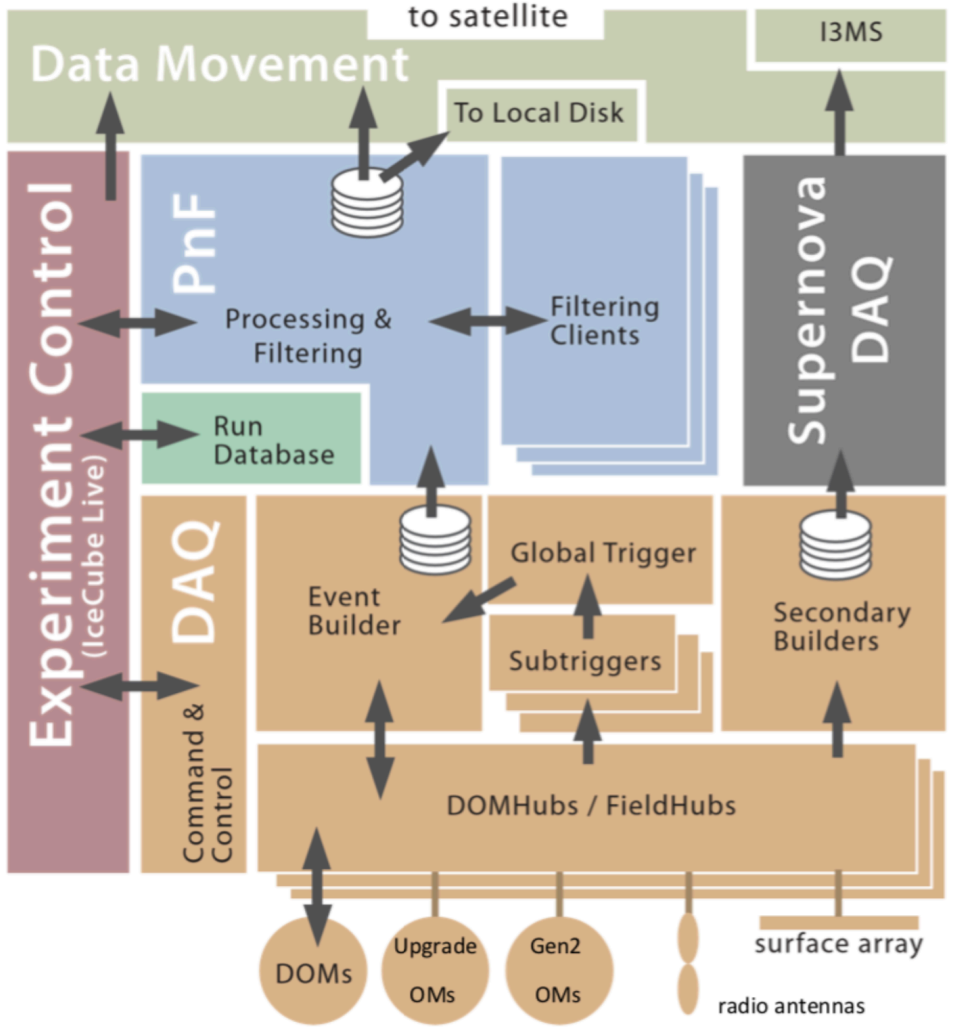
ICECUBE GEN2

IceCube(-Gen2) integration

IceCube will be an integral part of Gen2.

- This is possible for two reasons:
- IceCube is highly reliable: lost only a few sensors in the last 5 years.
- The fully digital architecture of IceCube allows integrating new strings/Gen2 into the system with only moderate adjustments.
- For comparison: AMANDA was turned off due to high burden of maintenance and operation, and challenges of integration.

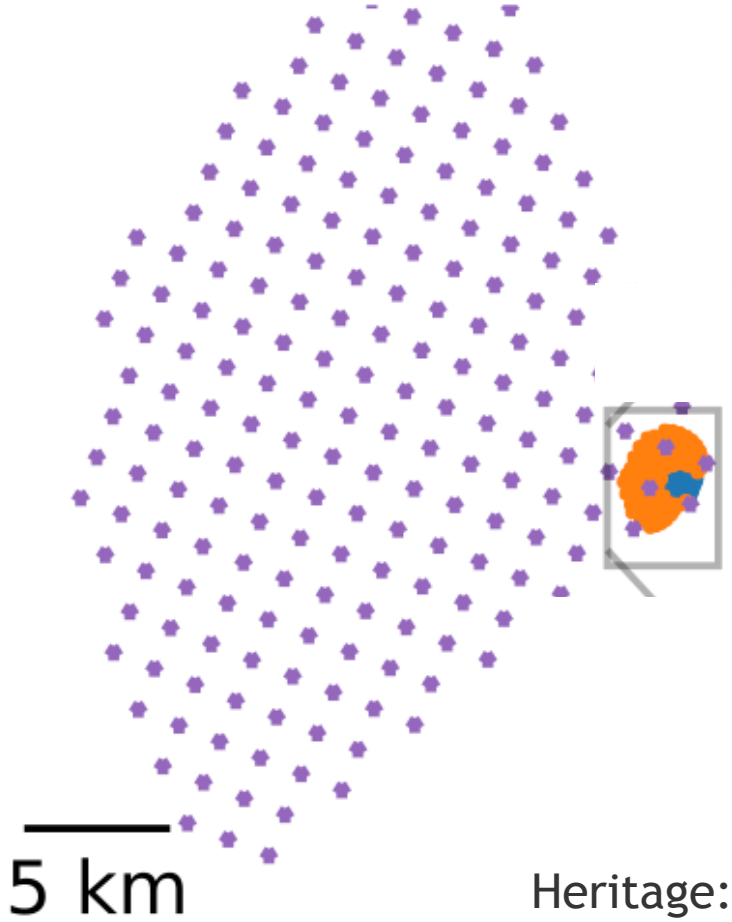


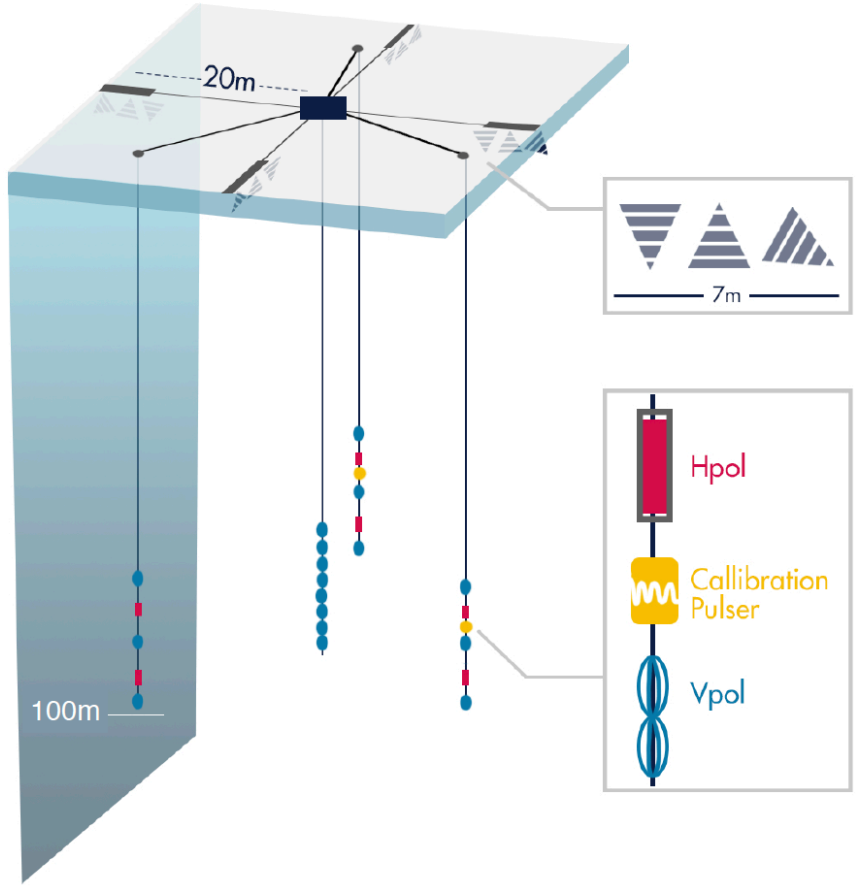
IceCube GEN2

The Gen2 radio array

200 stations
~500 km^2

- A daunting scale! Impact on Gen2 deployment.
- Highly efficient deployment will be critical.





Heritage:
RICE, ARA, ARIANNA

RNO-G (Greenland) first deployment summer 2020

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IceCube GEN2

EHWD-Gen1

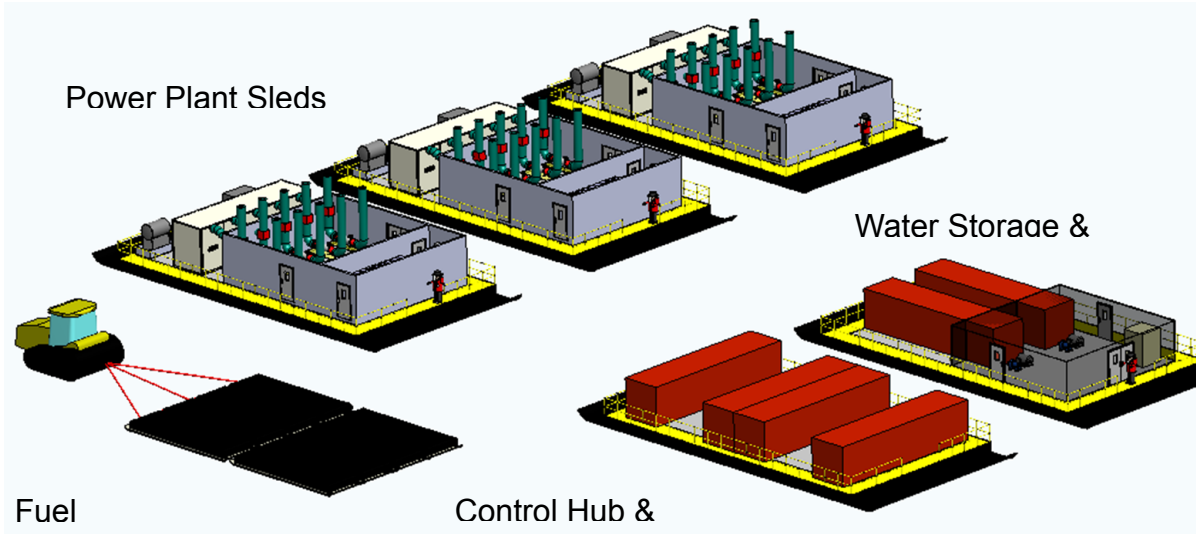
Hose reel

Mobile drill/deployment towers

EHWD heating plant: stationary
—> Gen2: mobile

Gen2 hot water drill - changes in requirements

- Mobility: IceCube drill was stationary per season. Gen2 string spacing requires a mobile drill. WDrill will be moved multiple times per season.
- Improved efficiency and lower maintenance technology
- Aim for higher drill speed. (Gen1: 2.1 m/min, Gen2 target close to 3 m/min)



IceCube GEN2

Logistical Support

1. Logistical Support: IceCube Gen1 had 9.5 million lb of cargo + fuel delivered by plane, more than 300 LC 130 missions. Construction took place simultaneously with South Pole station completion and SPT construction.
2. In recent years logistical support has dropped compared to 10 years ago. This is primarily funding driven. However, funding for logistical support is provided by the project.
3. Strategies for logistical support exist and have been discussed with ASC.
    1. Population of 60 people: —> separate field camp.
    2. Cargo: Traverse is scalable and can take care of fuel (2/3) and possibly cargo but this is not current practice.
4. Successful support will require high level prioritization and strategic planning at NSF's Polar Program.

—> Question 1

IceCube, and IceCube-Gen2 - numbers

Item	IceCube actual	IceCube-Gen2 projected
Deep ice strings	86	120
Drill and install seasons at Pole	7 (started 2004)	8 (start 2025)
Sensors/ strings	60	100
Hole depth (m)	2450	2600
Drilled hole diameter (cm)	60	55
Surface detector stations	81	120
Radio stations	none	200
Peak season total population	50	60
Population for radio	0	10
Typical total deployments	90	100
Typical yearly support from contractor (labor hours)	21000	21000
Total cargo delivered including fuel (lbs)	9.5M	9.5M
Fuel only (lbs)	4.1M	4.7M
Drill (lbs)	1.4M	1M
Instrumentation (lbs)	4M	2.75M
Instrumentation, radio (lbs)	0	0.2M
Operating power (kW)	70	150 (including Gen1)
'Dedicated' Herc flights per season	60	≤30 (use of traverse)
Total fuel used (gal)	572k	660k (drilling and camp)
Typical season length	Early November to late January	Early November to early February
Daily data transfer to north via satellite (GB)	105	150 (including Gen1)
Primary method of fuel delivery to Pole	Herc LC-130 aircraft fuel tanker	South Pole Traverse (tractors with sleds)
Population housing method	Station, summer camp	Station, field camp
Field camp	N/A	Housing for up to 60 people
Other large projects during construction	South Pole Station, South Pole Telescope	AIMS, potentially CMB-S4
Work schedule at Pole	3 shifts, 24 hours per day, 6 days per week	3 shifts, 24 hours per day, 6 days per week
Heavy equipment dedicated to project	Loader, skidsteer	Caterpillar Challenger or D8 dozer, 953 loader, skidsteer, transport van

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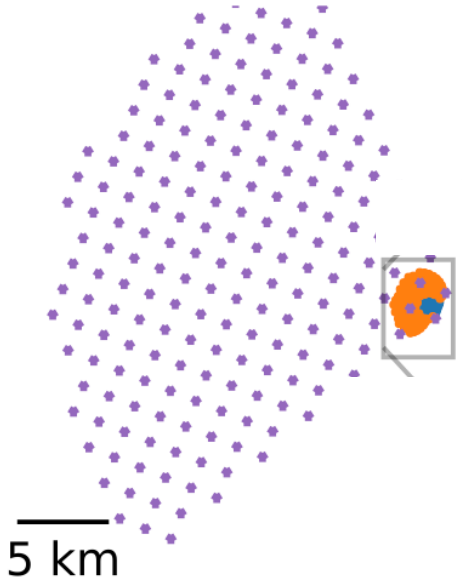
ICECUBE GEN2

IceCube-Gen2 Challenges: Radio array deployment

Drilling 120 holes: IceCube drilling required 7 seasons for 86 strings. Gen2 is planning 8 seasons for 120 strings.



Measures:

1. Drill speed. R&D underway to increase drill speed for Gen2. This can be achieved by increasing water pressure at the drill head from 1000 to ~1500 psi. Note that this will result in fuel savings of order 20 to 30%.
2. Investigate to increase season length by 1 or 2 weeks in February.

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IceCube-Gen2 - Challenges: Radio array deployment

Drilling

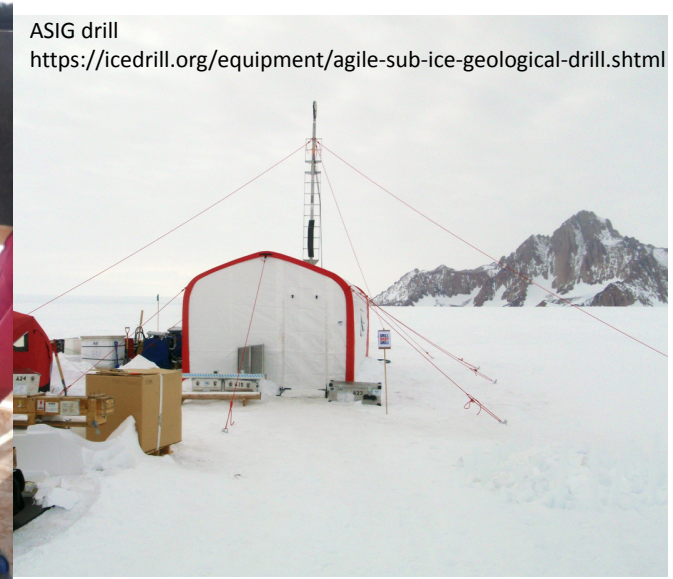
1. Drilling 600 holes for radio while a challenge, is conceptually straightforward.
2. Scalable solutions exist. ASIG drill is current reference. Requires to people to operate. can be turned on and off.
3. For production, a conceptually similar but more automated design of the British Antarctic Survey is envisioned.

Population: 2 - 3 people/hole/day

Reminder, why drilling:
the same detector at 100m depth collects about 3 times more events than at the surface.

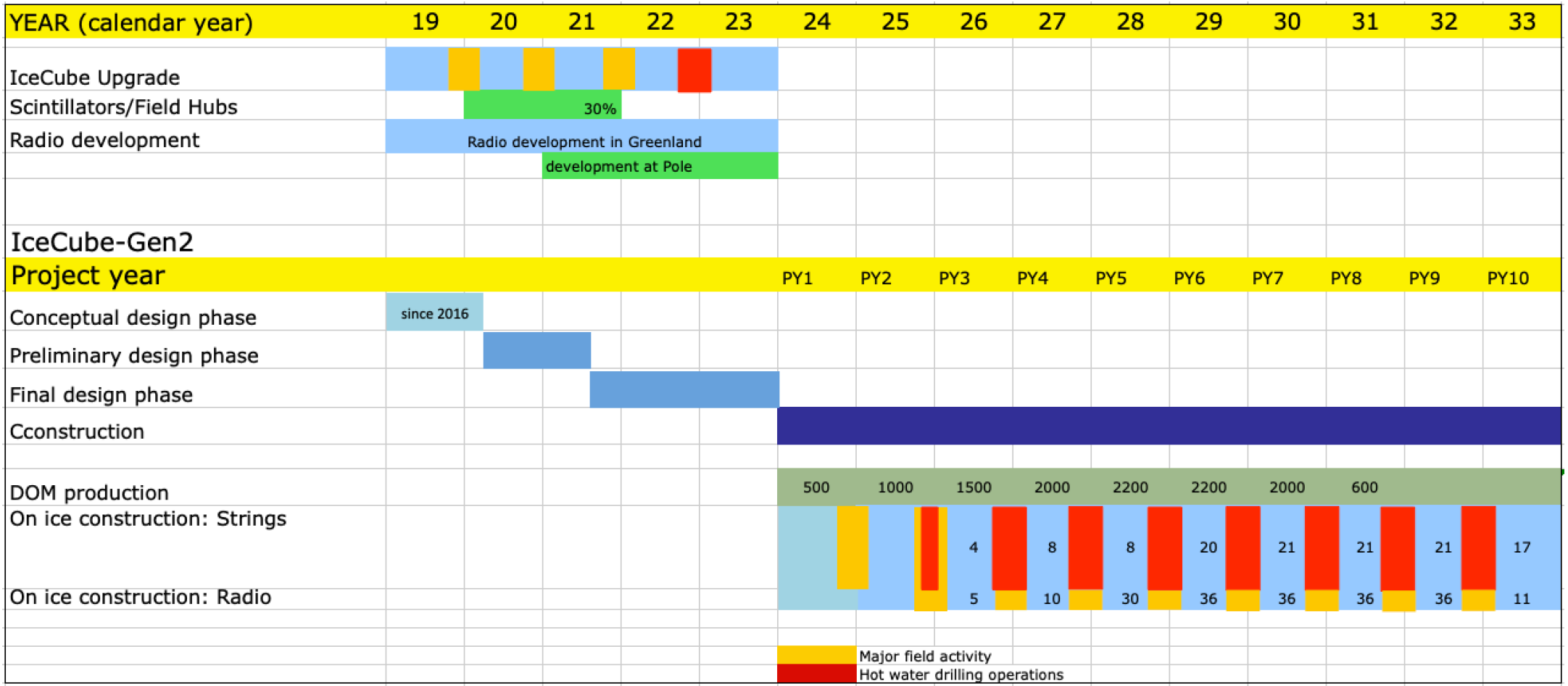
Deployment

1. Deployment takes most of the labor. about 2/3 of the population will be needed for deployment.
2. Long distances require special safety considerations.
3. Good equipment for transportation: Field shelters, Arctic trucks.



ASIG drill
https://icedrill.org/equipment/agile-sub-ice-geological-drill.shtml

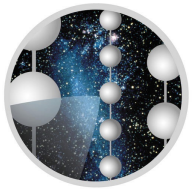
Timeline

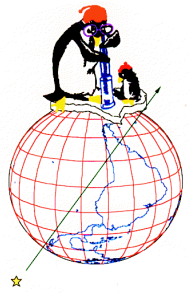


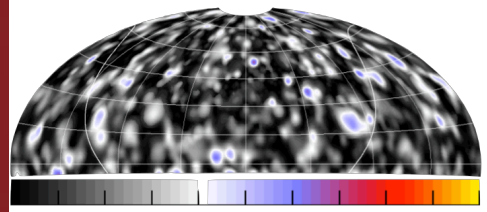
ICECUBE GEN2

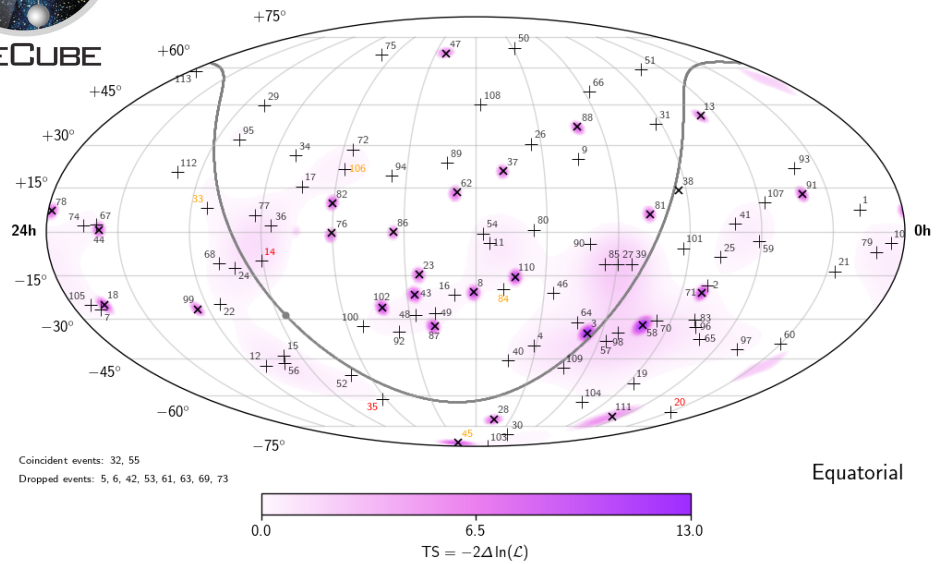
IceCube-Gen2: *From Discovery to Astronomy*

…building the future of a new field









Gen2 Phase 1 (Upgrade) drill camp; January 29, 2020

1st atmospheric neutrinos in ice

Discovery of astrophysical neutrino flux

$E < 300\,\text{TeV}$ | $300\,\text{TeV} < E < 1\,\text{PeV}$ | $1\,\text{PeV} < E$

First source identified

2002 AMANDA | 2004 IceCube | 2013 | 2018 | 2020 | 2023 | 2026 Gen2 Phase 1 (Upgrade) | 2032 IceCube-Gen2

First full Gen2 deployment season

Gen2 full detector completion

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IceCube GEN2

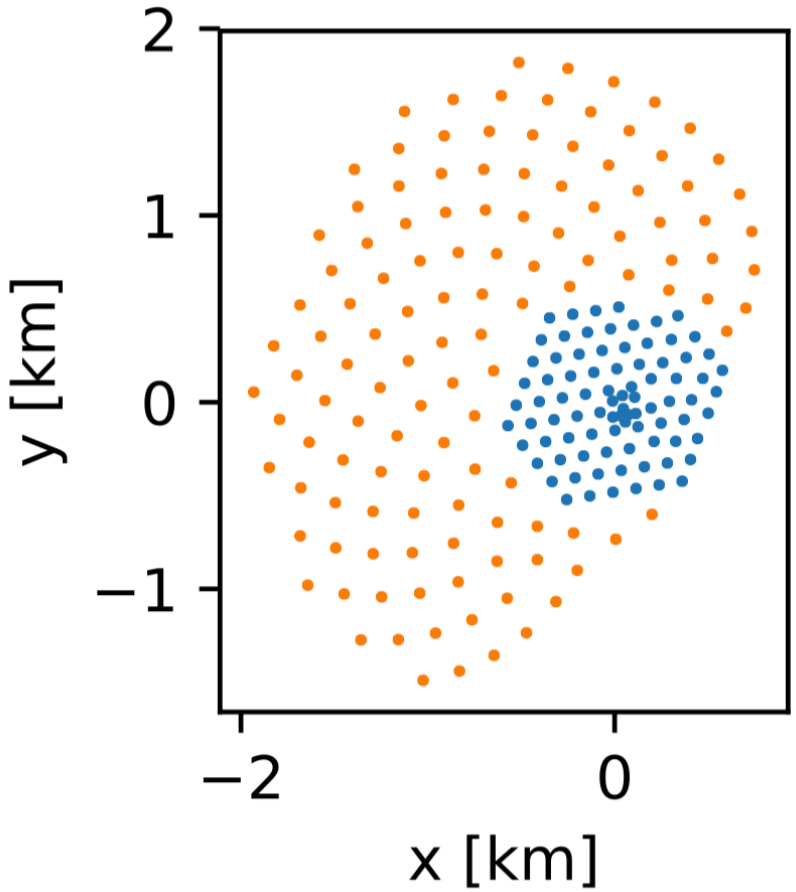
Gen2 — cables: surface

Field hub:
Deliver optical fiber and power to each string location.
Switch then to in-ice cable

R&D from scintillator array applies directly to Gen2 string architecture.

Considering taking connections and electronics above ground.

The housing approach is still at very early stage.



Surface detector Gen2

- Following the IceTop model, one unit per string.

- Cross calibration
- Cosmic rays at high energies
- Veto x 40