The IceCube Neutrino Observatory and Future Gen2: a Science Overview

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University of Wisconsin-Madison, USA

Astronomy and Astrophysics from Antarctica


THE ICECUBE COLLABORATION
AUSTRALIA
University of Adelaide
BELGIUM
Université libre de Bruxelles
Universiteit Gent
Vrije Universiteit Brussel
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SNOLAB
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Deutsches Elektronen-Synchrotron
ECAP, Universität Erlangen-Nürnberg
Humboldt–Universität zu Berlin
Karlsruhe Institute of Technology
Ruhr-Universität Bochum
RWTH Aachen University
Technische Universität Dortmund
Technische Universität München
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Westfälische Wilhelms-Universität Münster
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Lawrence Berkeley National Lab
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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
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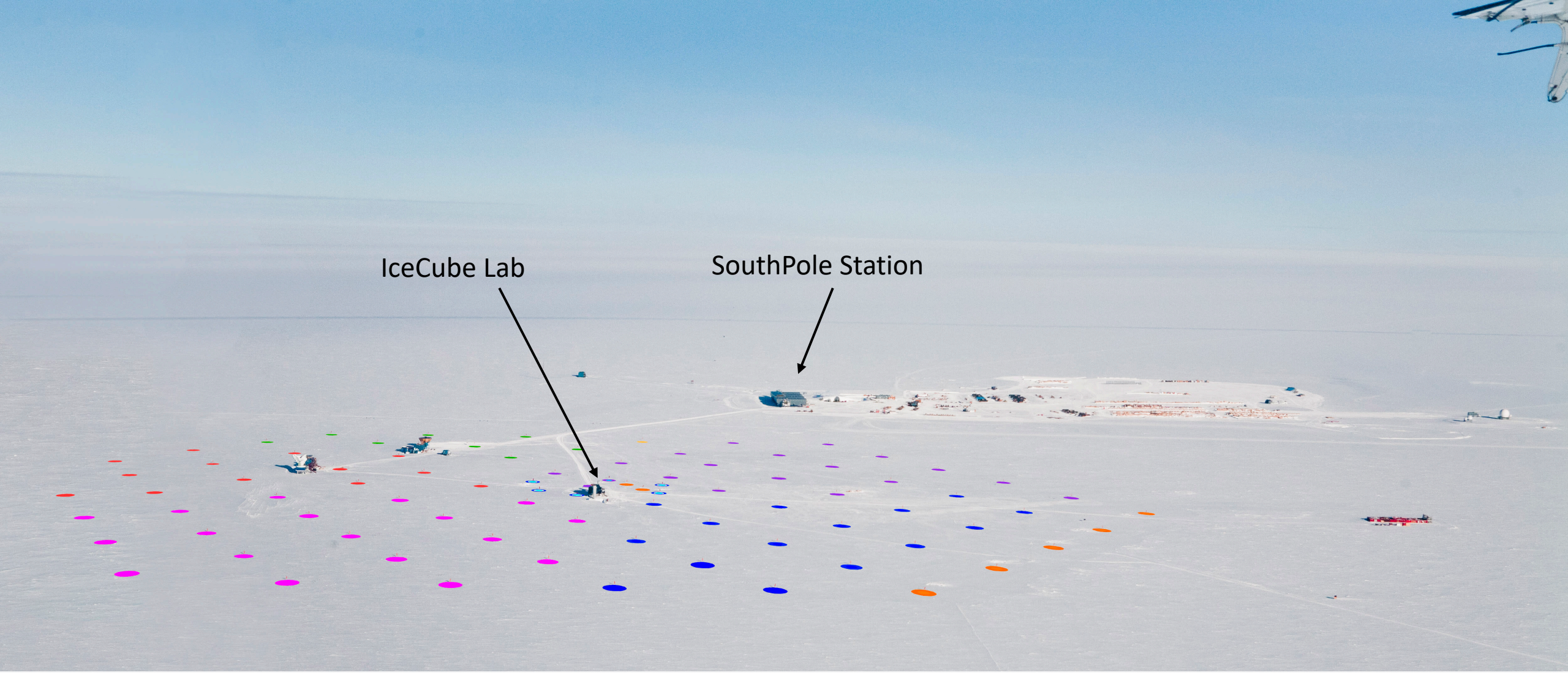
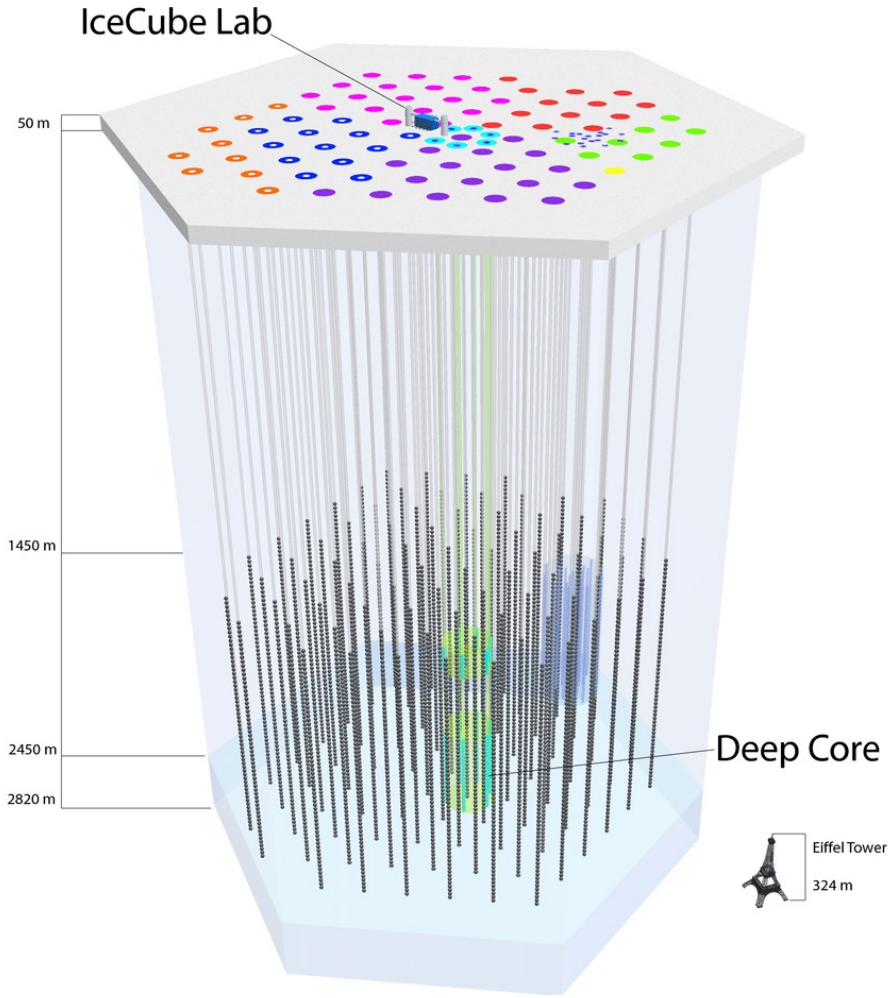
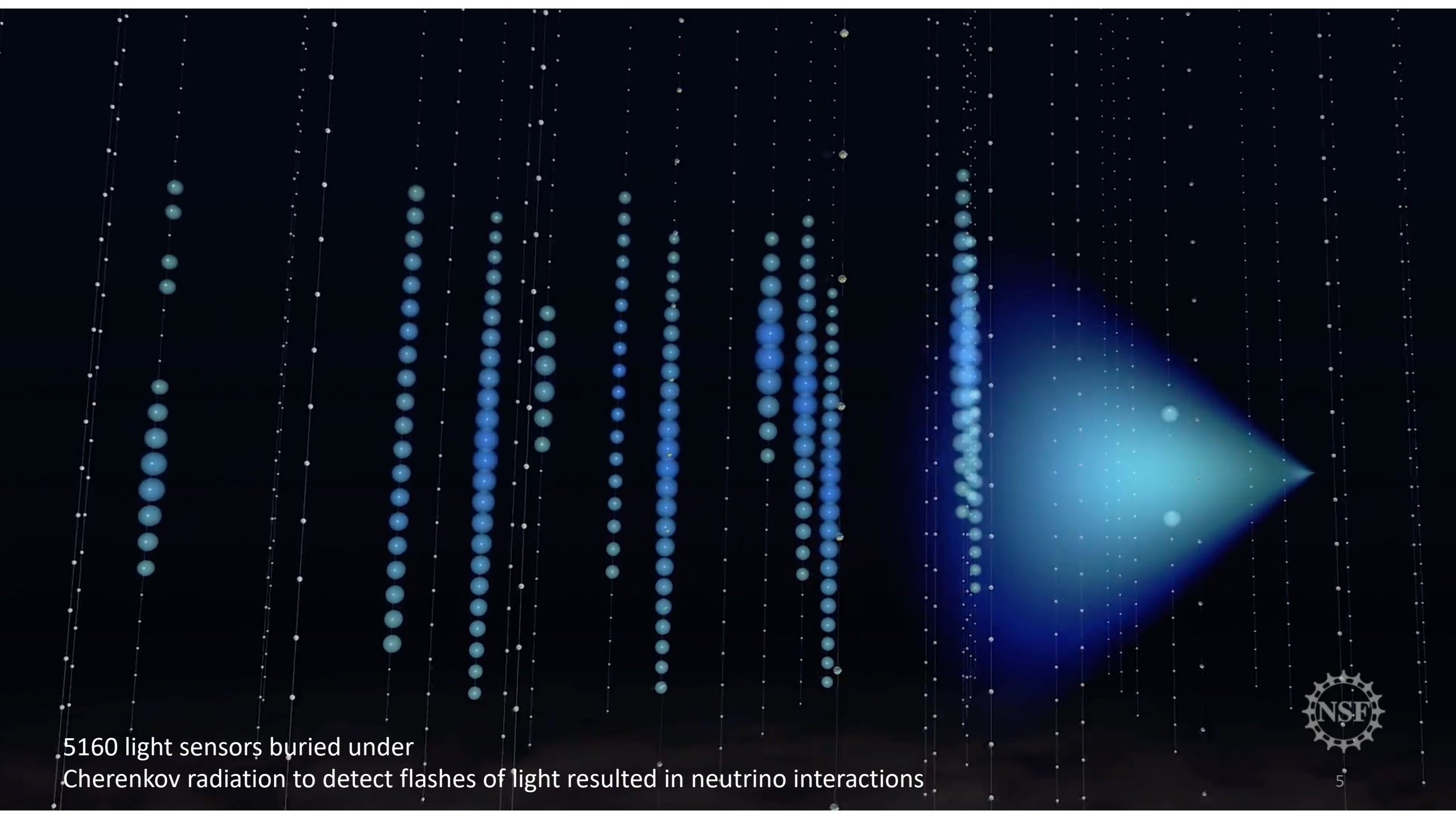
Fonds de la Recherche Scientifique (FRS-FNRS)
Fonds Wetenschappelijk Onderzoek-Vlaanderen (FWO-Vlaanderen)
Federal Ministry of Education and Research (BMBF)
German Research Foundation (DFG)
Deutsches Elektronen-Synchrotron (DESY)
Japan Society for the Promotion of Science (JSPS)
Knut and Alice Wallenberg Foundation
Swedish Polar Research Secretariat
The Swedish Research Council (VR)
University of Wisconsin Alumni Research Foundation (WARF)
US National Science Foundation (NSF)
IceCube
South Pole Neutrino Observatory
icecube.wisc.edu



IceCube Neutrino Observatory – Birdseye view

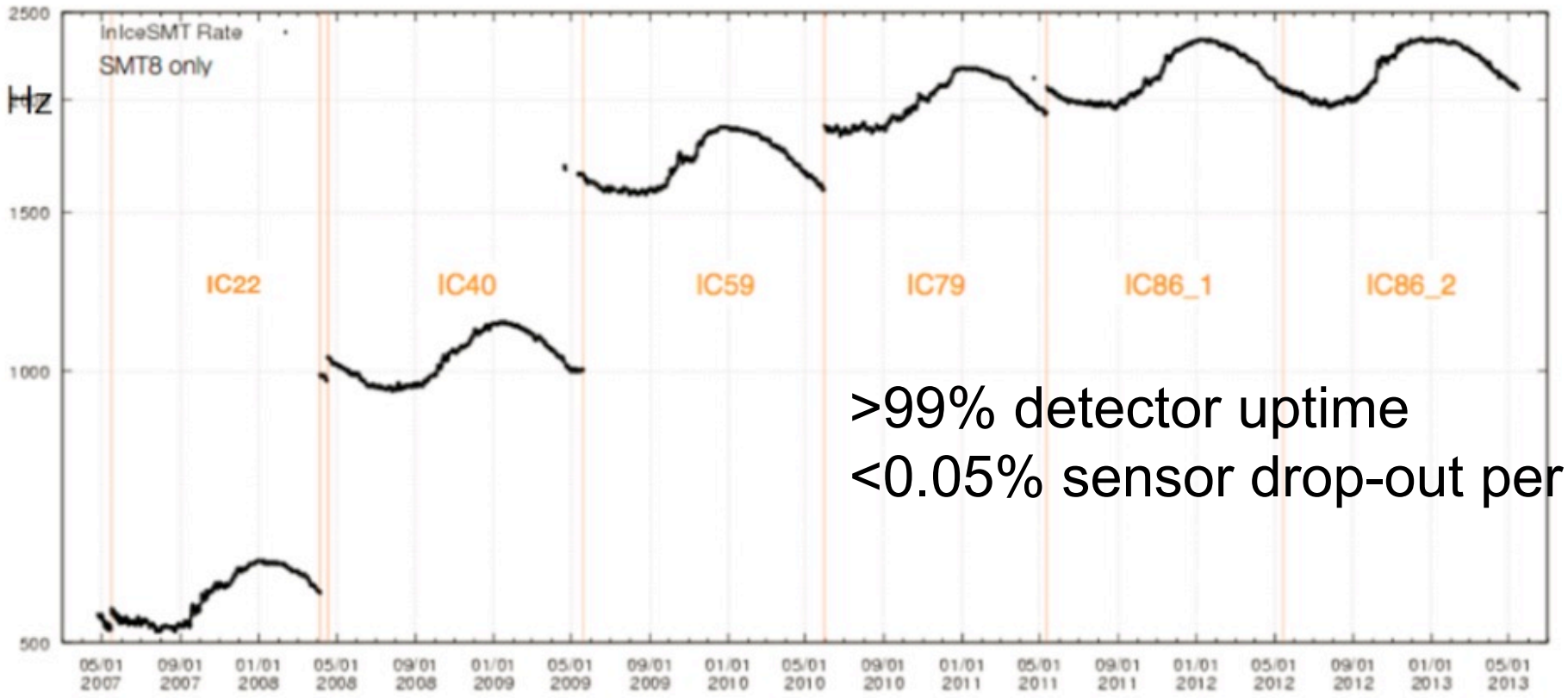
The IceCube Neutrino Observatory



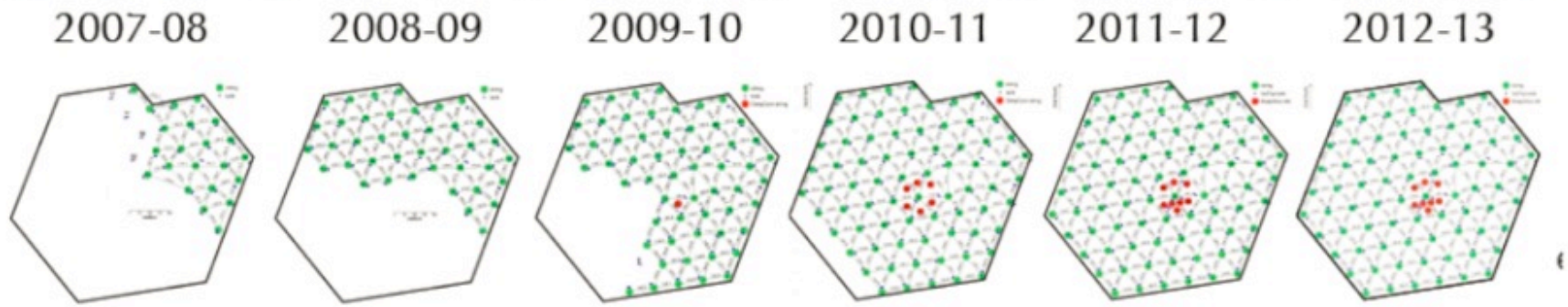


5160 light sensors buried under
Cherenkov radiation to detect flashes of light resulted in neutrino interactions

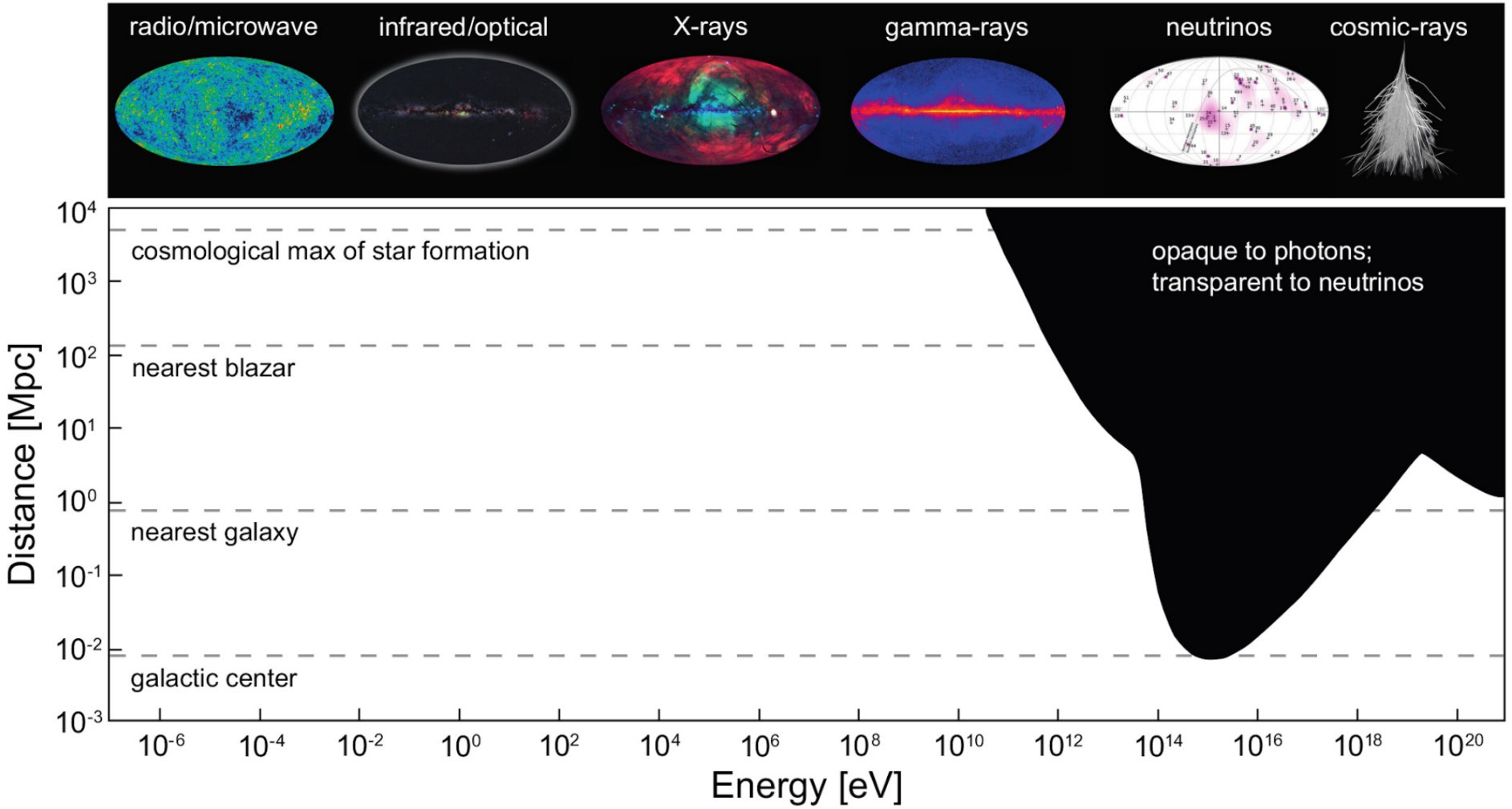
REAL-TIME TRIGGER ~2.5KHZ SINCE 2011



>99% detector uptime
<0.05% sensor drop-out per year

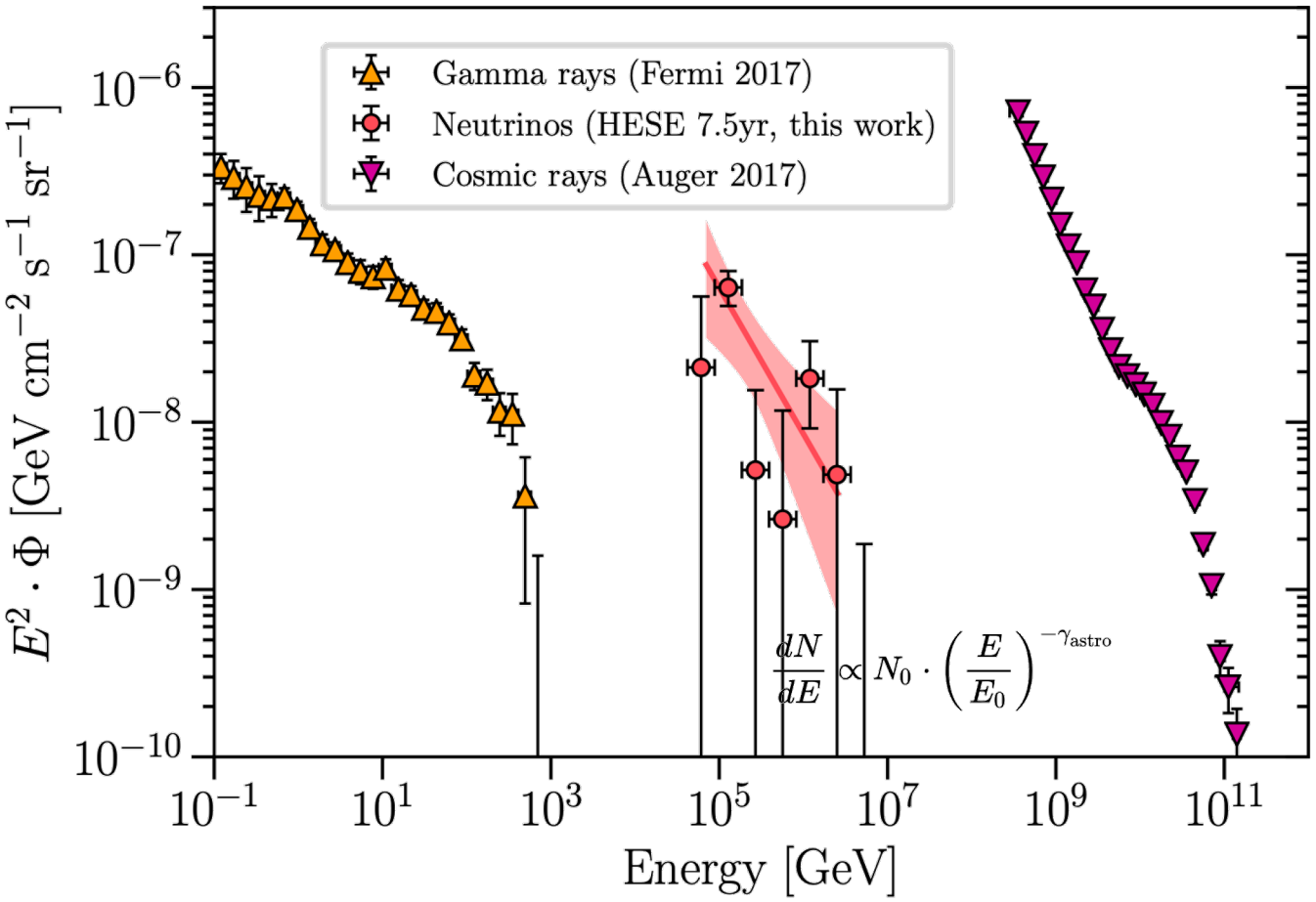


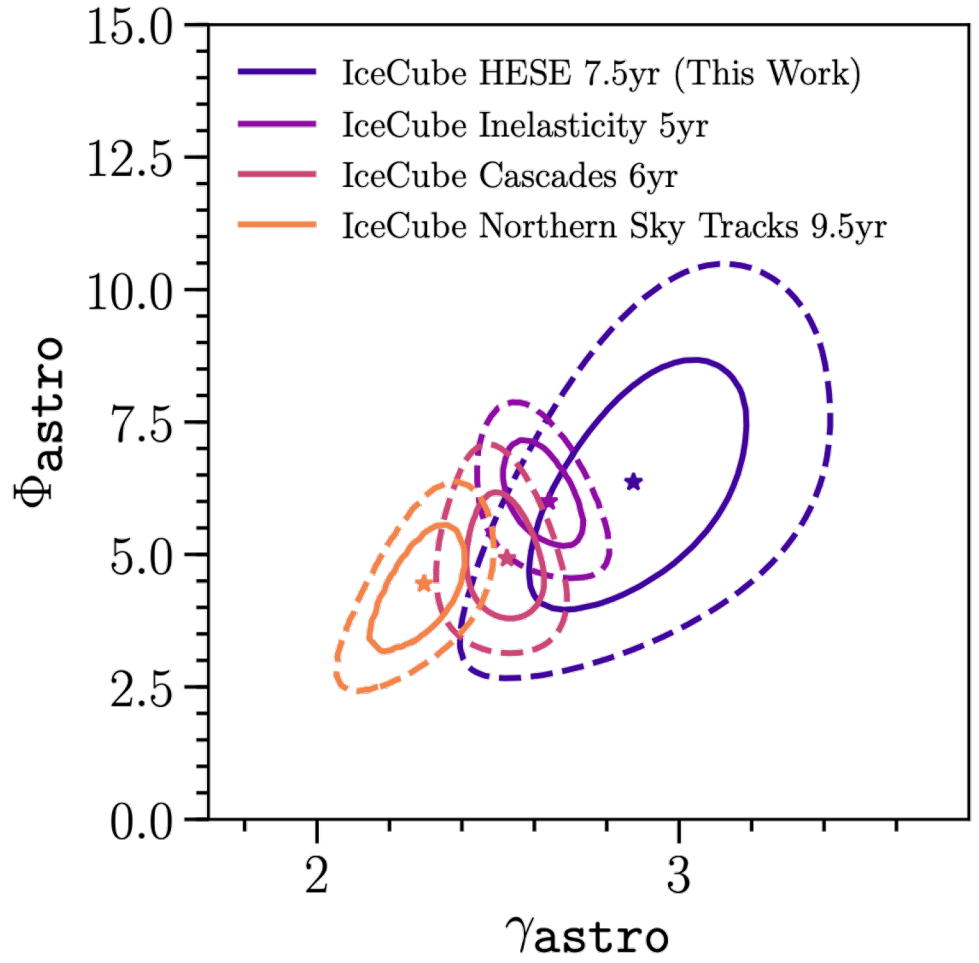
High energy neutrinos: the window to the extreme Universe



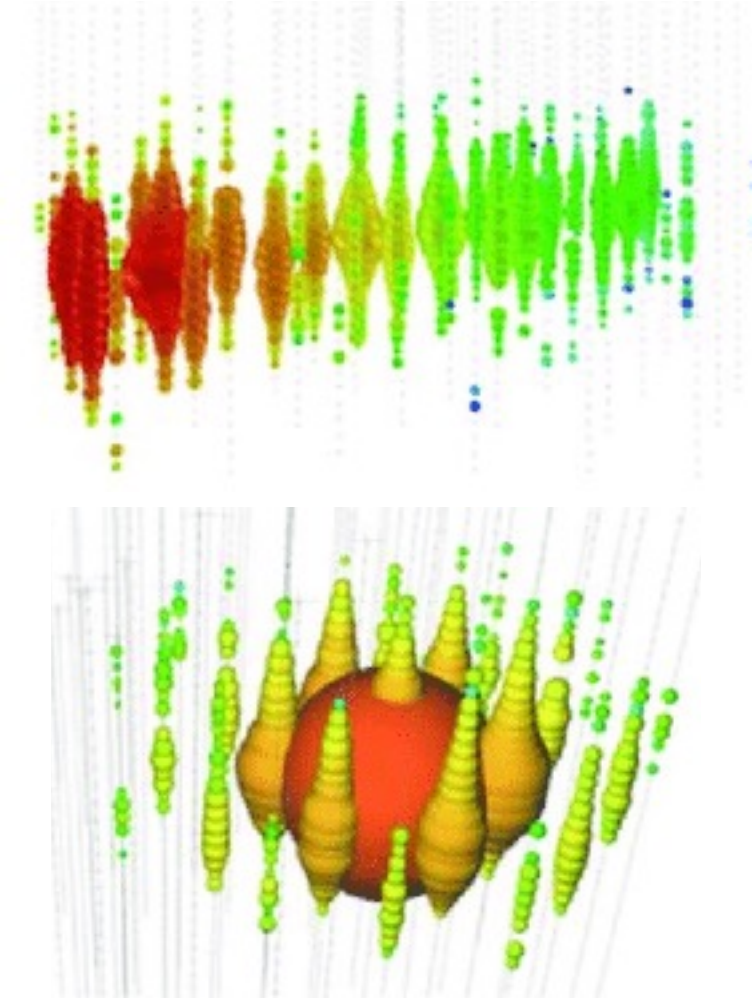
Astrophysical diffuse spectrum

Phys. Rev. D 104, 022002 (2021)

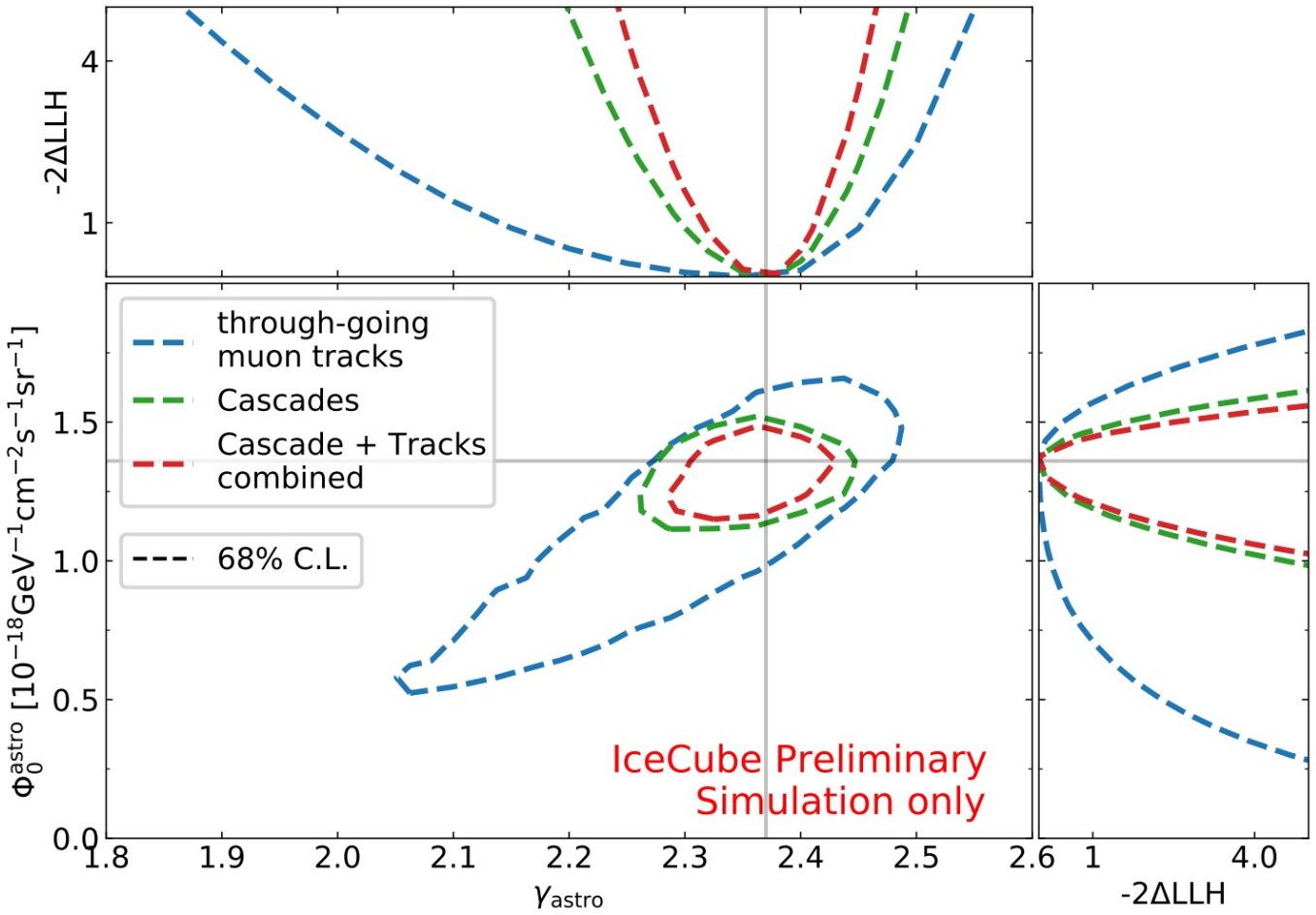




It’s coming together – the GlobalFit



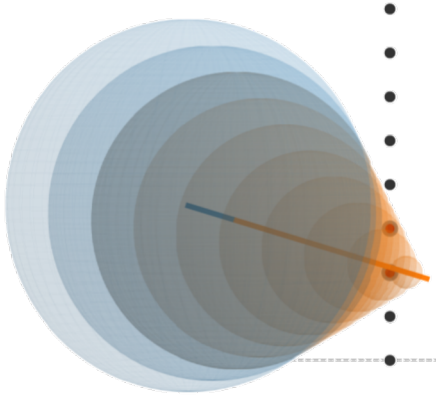
arXiv:2107.10003



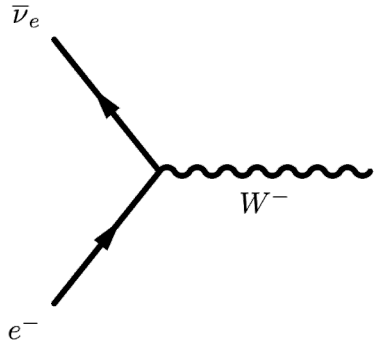
Stay tuned

First hint of W boson resonance in data (Glashow resonance)

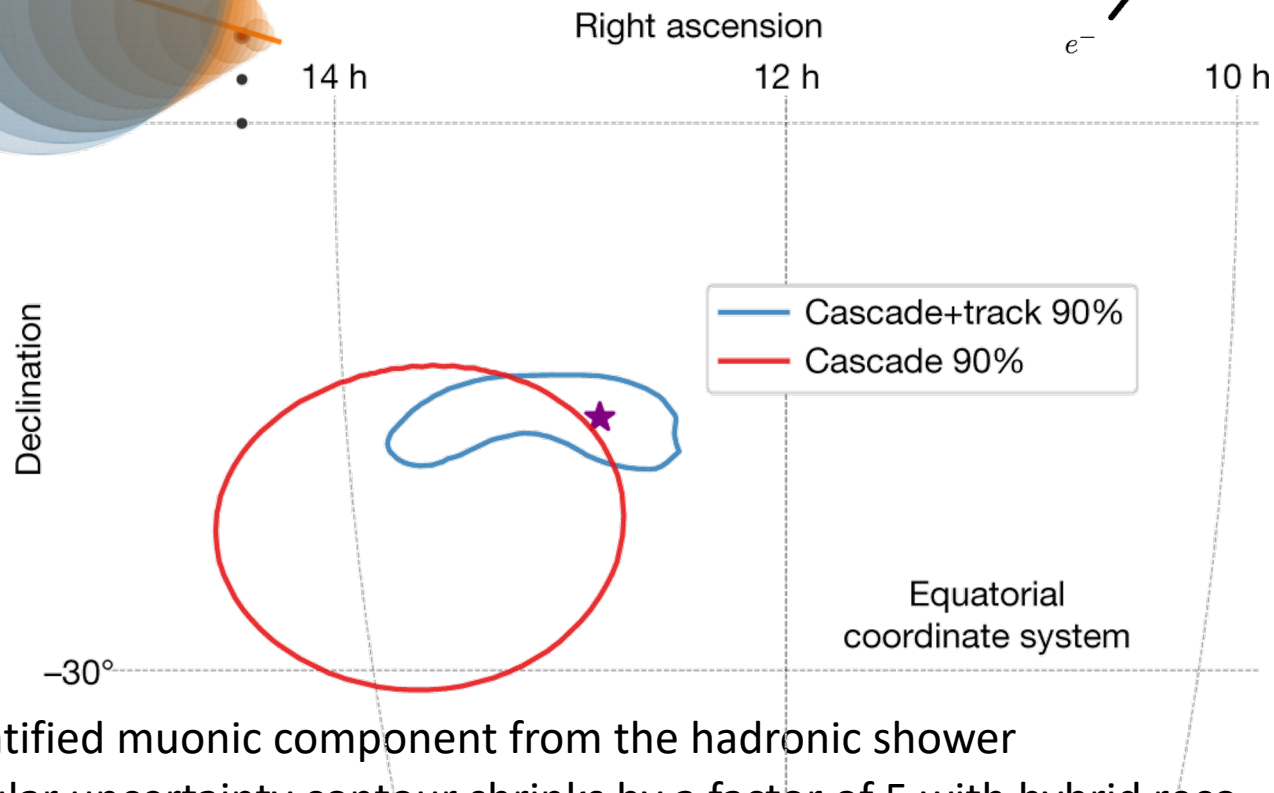
Nature **591,** 220–224 (2021)

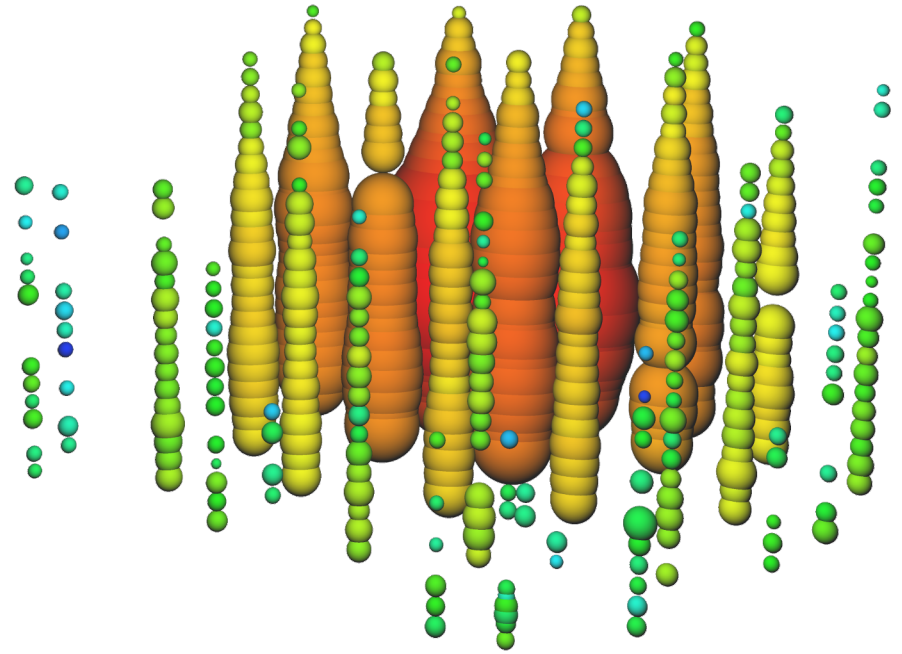


$$E_{\mathrm{R}} = M_W^2/(2m_e) = 6.32\mathrm{PeV}$$



By measuring nu/nubar -> probe source environment directly (magnetic field, pp/pgamma)



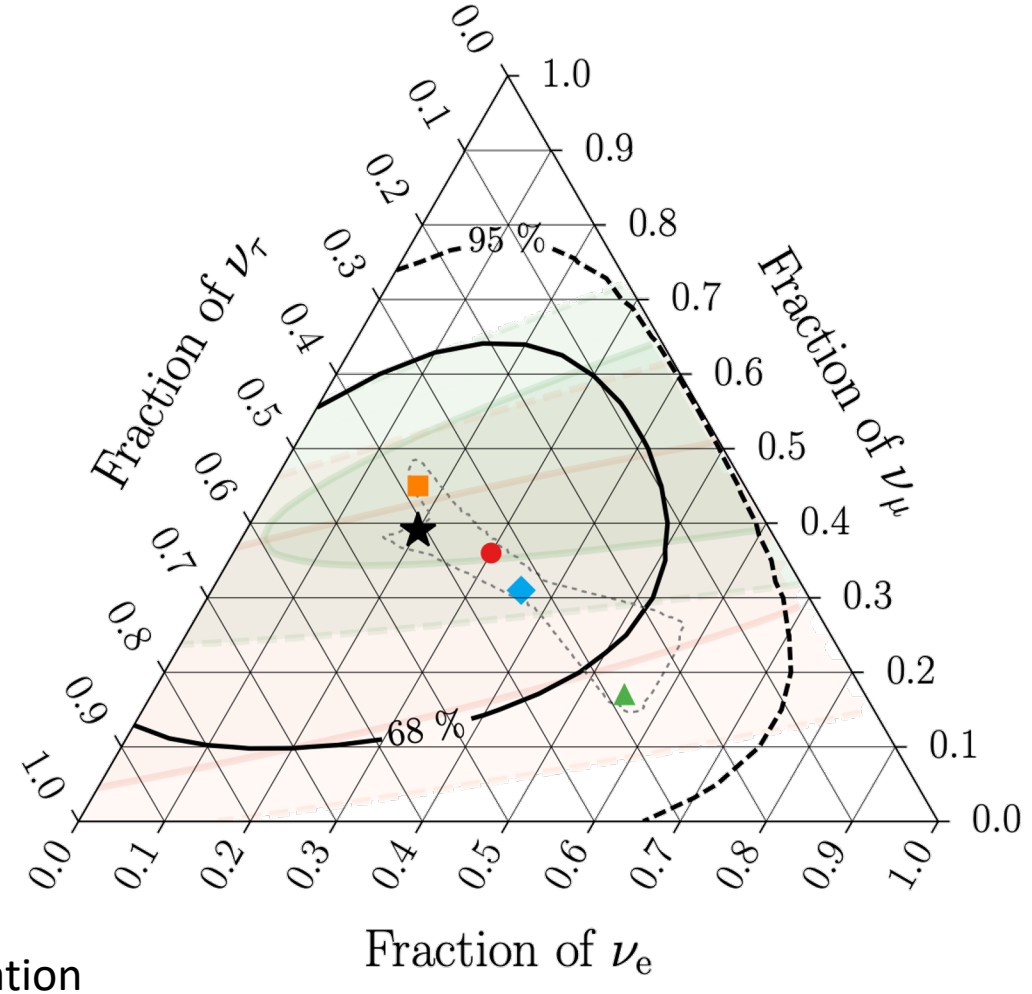


Identified muonic component from the hadronic shower

angular uncertainty contour shrinks by a factor of 5 with hybrid reco

Possibly spotted astrophysical nutau events

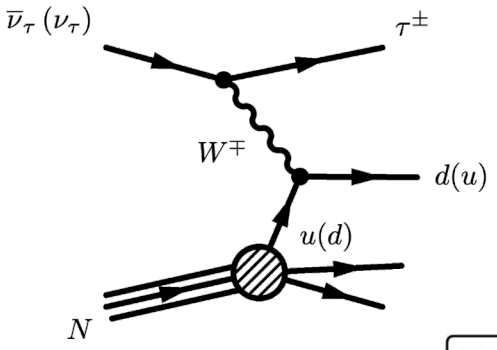
- For the first time tau candidates in data
- Observed high-energy tau neutrinos mainly due to neutrino oscillations through astronomical distances.
- Sensitive probe for physics beyond the Standard Model

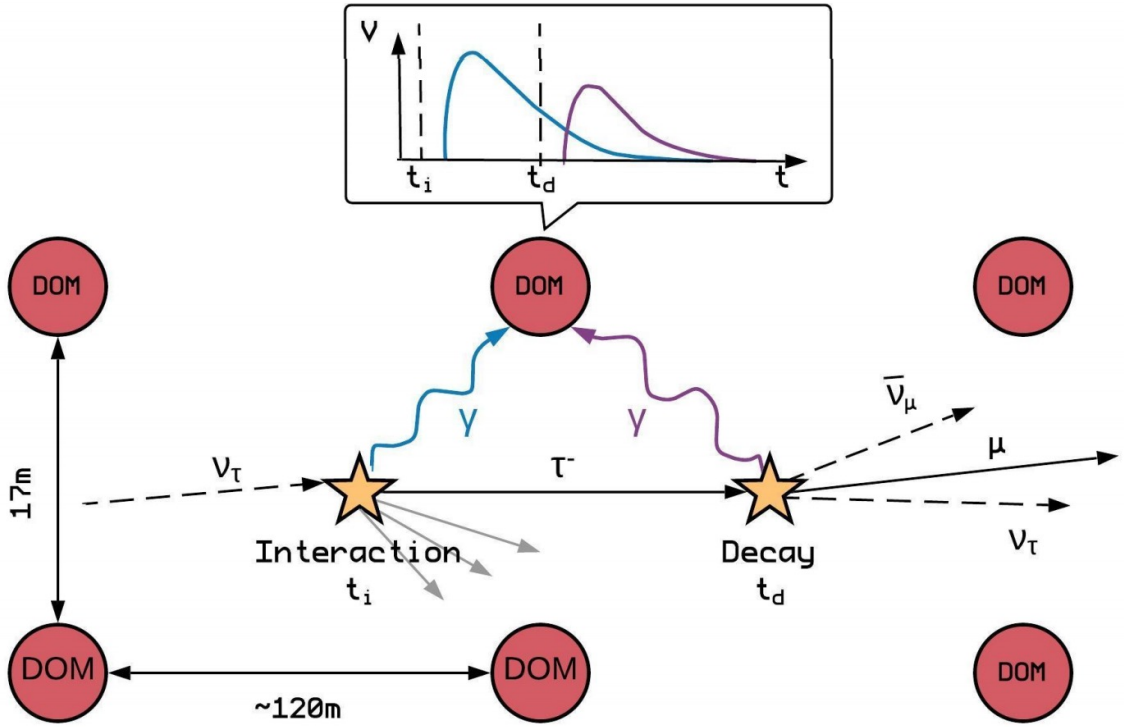


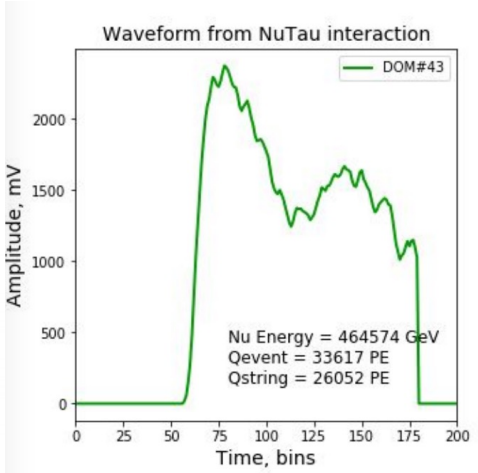
https://arxiv.org/abs/2011.03561, publication in preparation

Future - Deep learning nutau with CNN

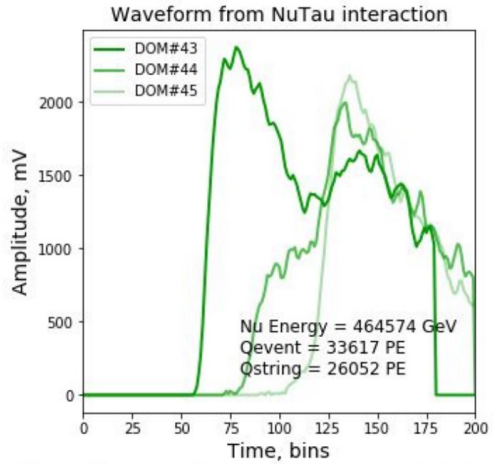
PhD thesis, D. Pankova 2021



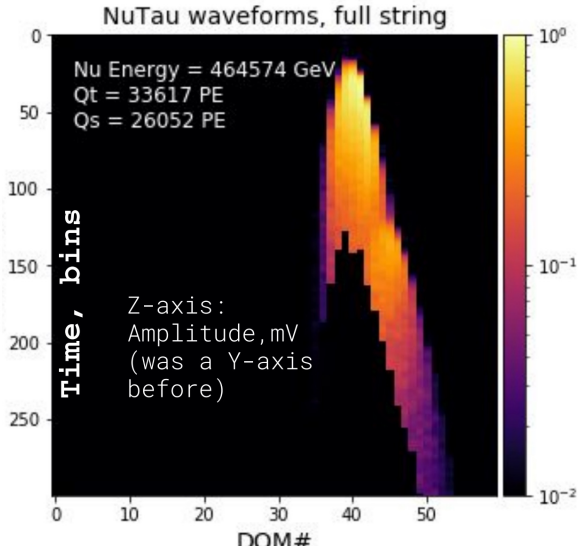




Single waveform
Bin: ~ 3 ns



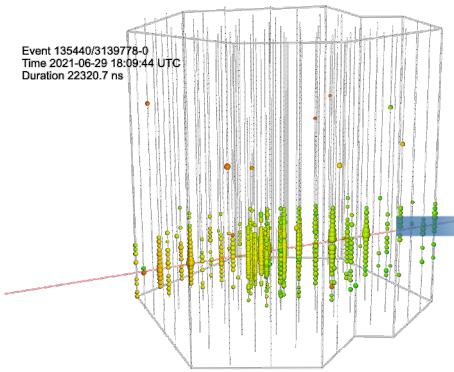
Waveforms from three neighbouring DOMs on the same string



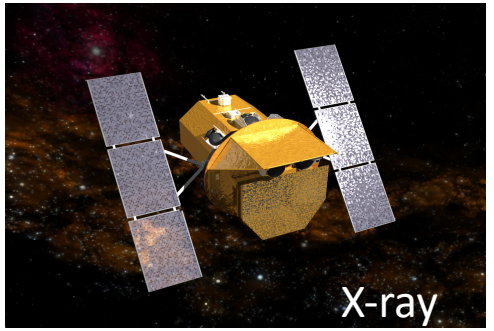
Stay tuned

Neutrino Astronomy with multimessenger partners

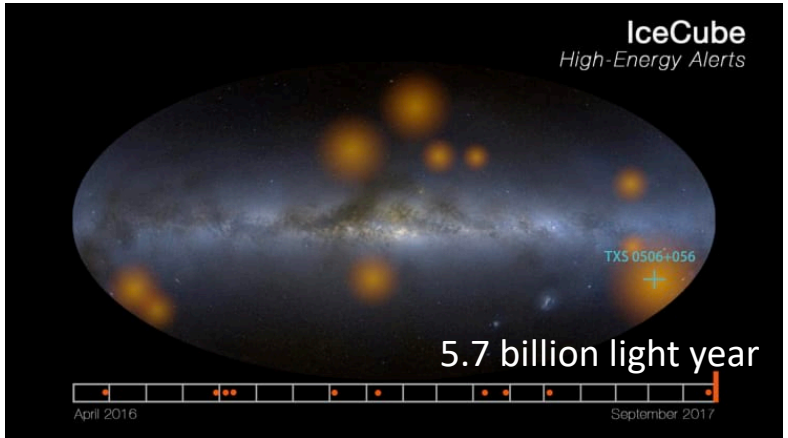
IceCube is both a triggering and following-up detector.
Welcome new collaborations (roc@icecube.wisc.edu)



Median delay ~33s



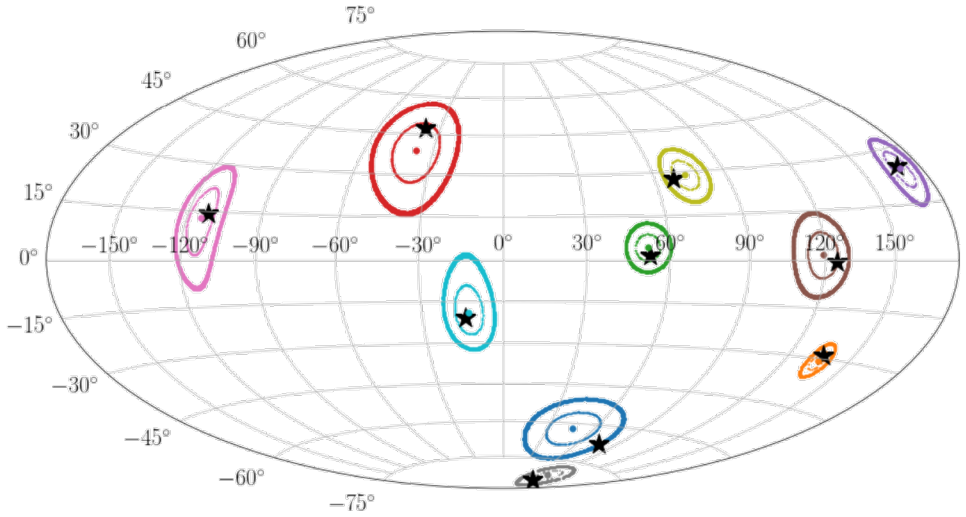
IC170922A
Spatial and timing coincidence with Fermi flare from TXS0506+056

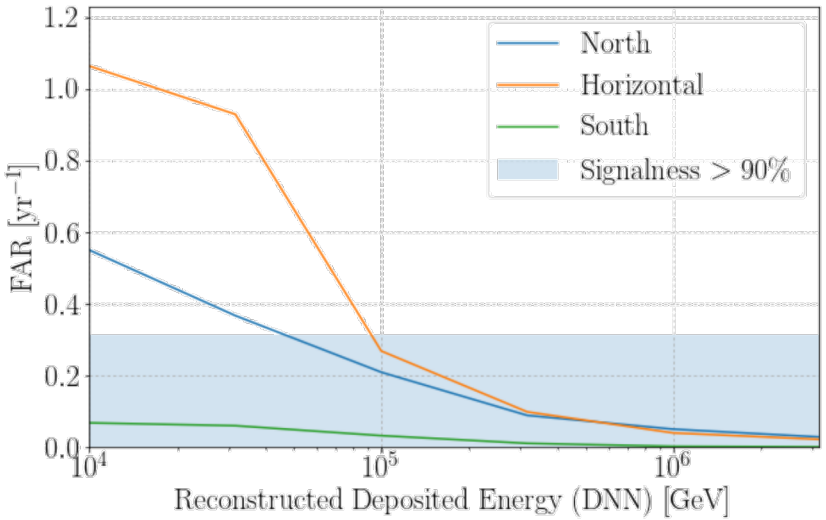


Science Vol. 361, Issue 6398, pp. 147-151
Science Vol. 361, Issue 6398, eaat1378

Opening southern sky

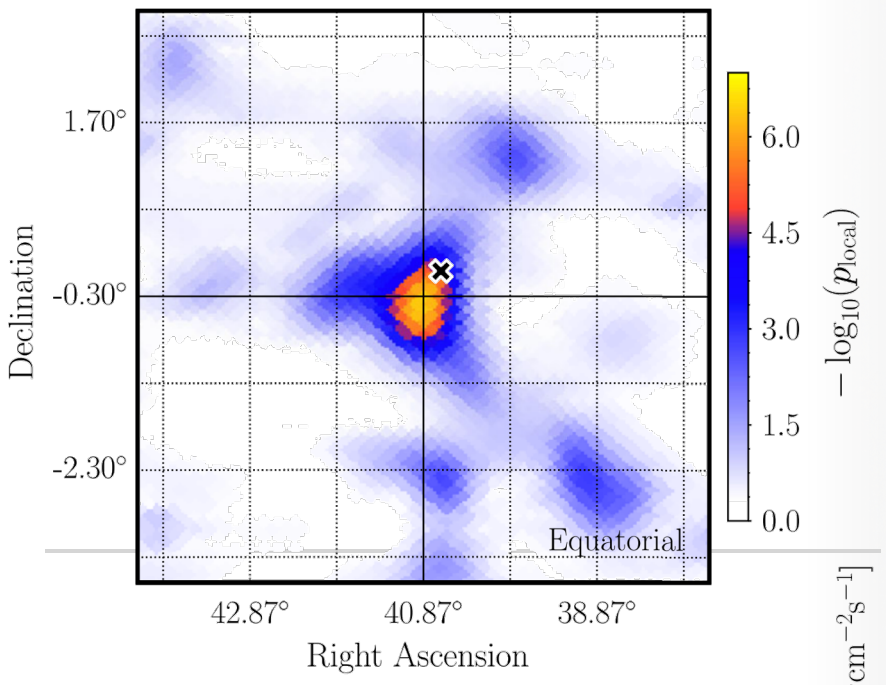
- Traditionally alerts are from the north going through/skimming Earth
- New cascade alert though with larger angular uncertainty, provides high purity events from the southern sky.
- Upcoming ESTES, PeV down-going tracks further improves sky coverage.



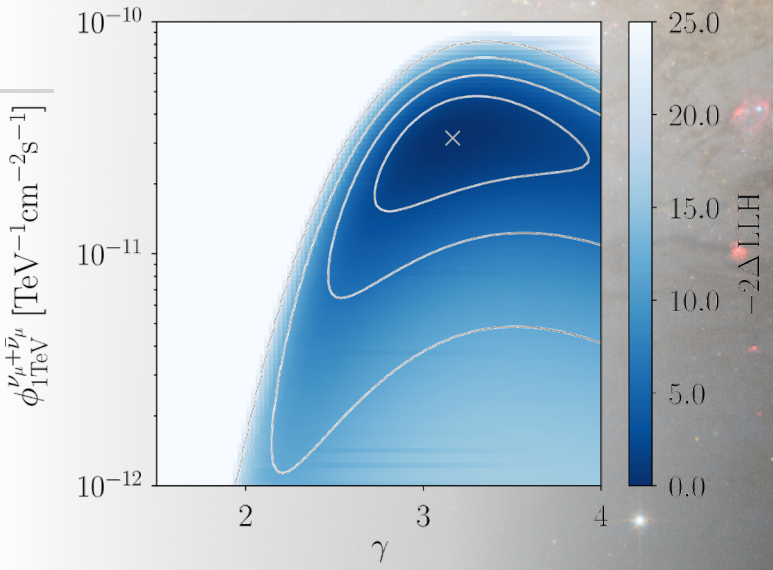


https://gcn.gsfc.nasa.gov/doc/High_Energy_Neutrino_Cascade_Alerts.pdf

First hint of a steady neutrino point source



10 year all-sky point source:
NGC 1068, 2.9σ rejection to background-only hypothesis.
0.35° from the most significant excess in the northern hemisphere.
PRL 124, 051103 (2020)



Results from improved data coming soon

10 years of IceCube data now publicly available at NASA's HEASARC archive

Browse this table...

ICECUBEPSC - IceCube All-Sky Point-Source Events Catalog (2008-2018)

HEASARC Archive

Overview

IceCube has performed several searches for point-like sources of neutrinos. The events contained in this release make up the sample used in IceCube's 10-year time-integrated neutrino point source search [1]. Events in the sample are track-like neutrino candidates detected by IceCube between April 2008 and July 2008.

The data contained in this release of IceCube's point source sample shows 3.3 sigma evidence of a cumulative excess of events from a catalog of 110 potential sources, primarily driven by four sources (NGC 1068, TXS 0506+056, PKS 1424+240, and GB6 J1542+6129). NGC 1068 gives the largest excess and appears in spatial coincidence with the hottest spot in the full Northern sky search [1].

IceCube's 10-year neutrino point source event sample includes updated processing for events between April 2012 and May 2015, leading to differences in significances of some sources, including TXS 0506+056. For more information, please refer to [2].

This release contains data beginning in 2008 (IC40) until the spring of 2018 (IC86-VII). In order to standardize the release format of IceCube's point source candidate events, this release duplicates and supplants previously released data from 2012 and earlier. Events from this release cannot be combined with other IceCube public data releases.

Please note that this dataset is dominated by background events from atmospheric muons and neutrinos detected by IceCube, with a subdominant astrophysical event contribution. Any spatial or temporal correlations should therefore be carefully evaluated on a statistical basis. See [1] and references therein for details regarding the statistical techniques used by IceCube.

[1] Time-integrated Neutrino Source Searches with 10 years of IceCube Data, Phys. Rev. Lett. 124, 051103 (2020)

[2] IceCube Data for Neutrino Point-Source Searches: Years 2008-2018, https://arxiv.org/abs/2101.09836

For additional questions about this table, please contact the authors: data [AT] icecube.wisc.edu.

Catalog Bibcode

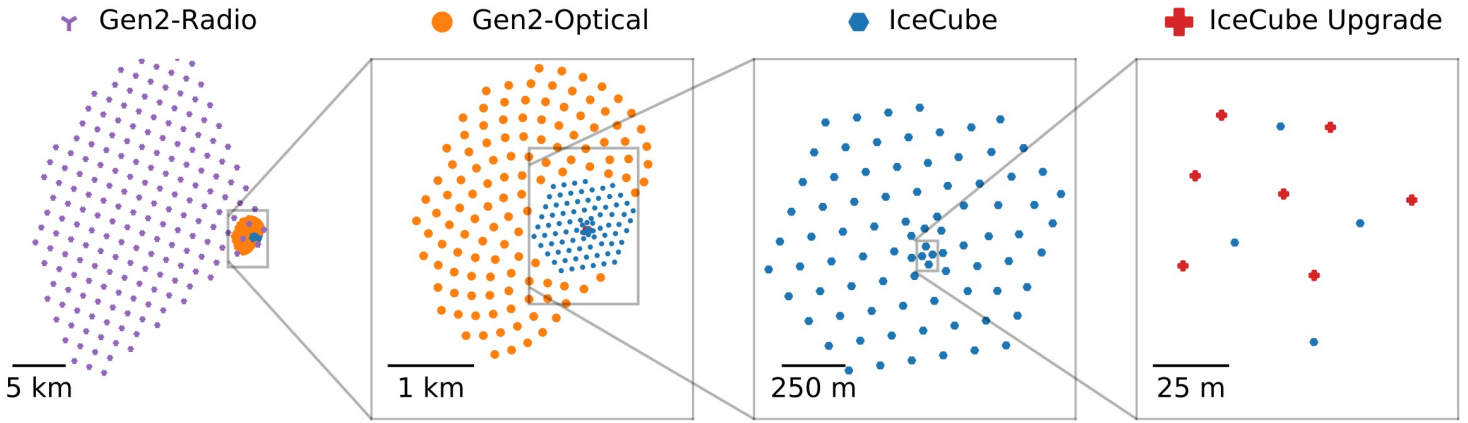
2021arXiv210109836I

https://heasarc.gsfc.nasa.gov/W3Browse/icecube/icecubepsc.html

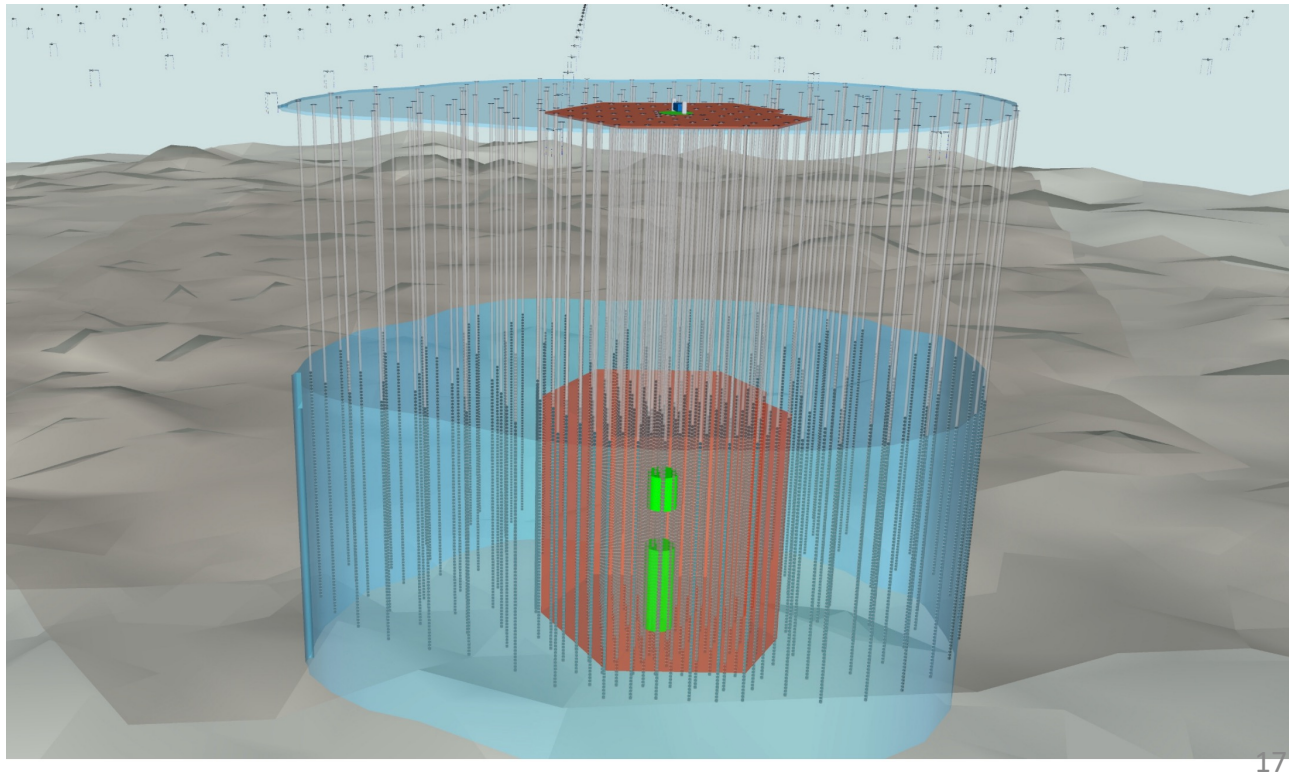
Gentoo penguin

IceCube Gen2

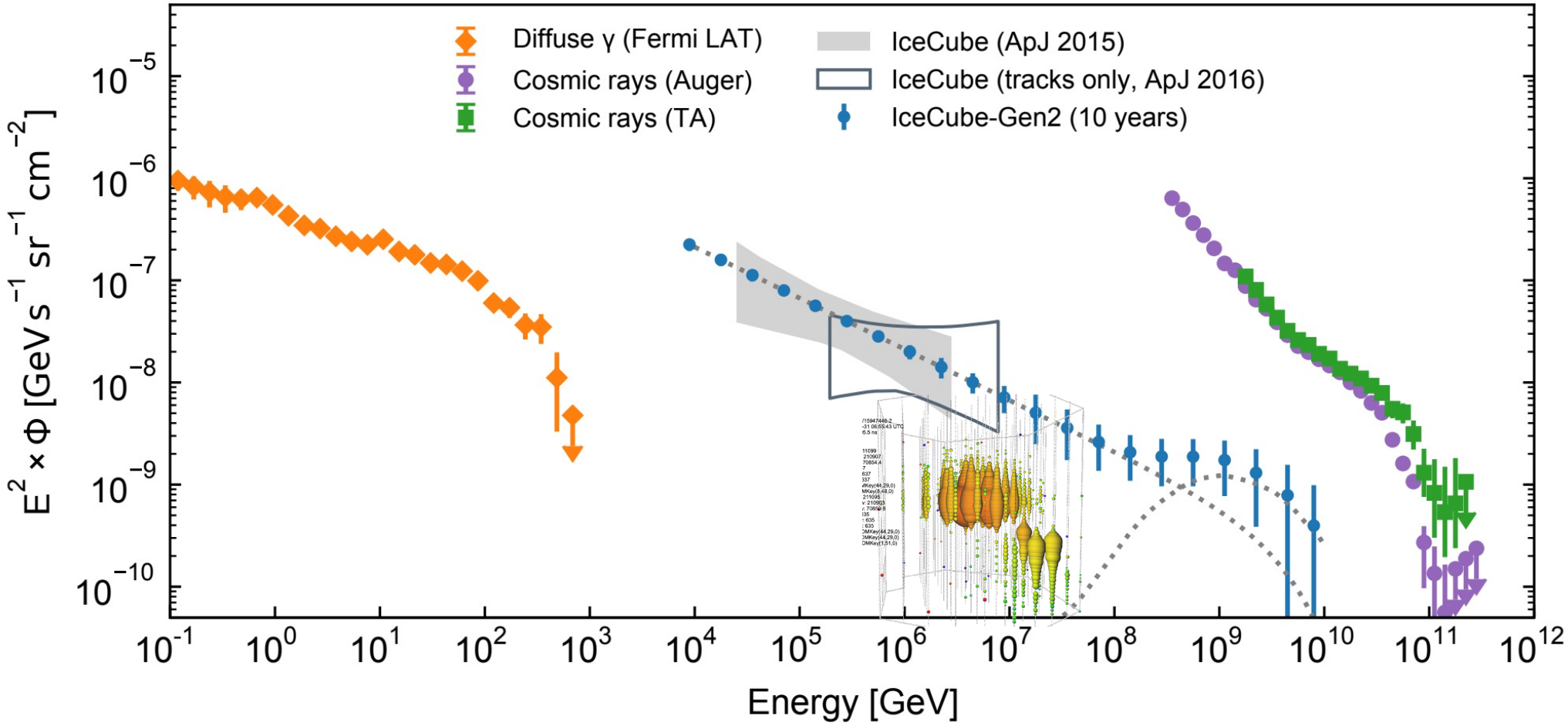
See talks from Kael, Carsten and Roxanne



Lots hints of interesting physics from IceCube – need a bigger detector to do precise measurements

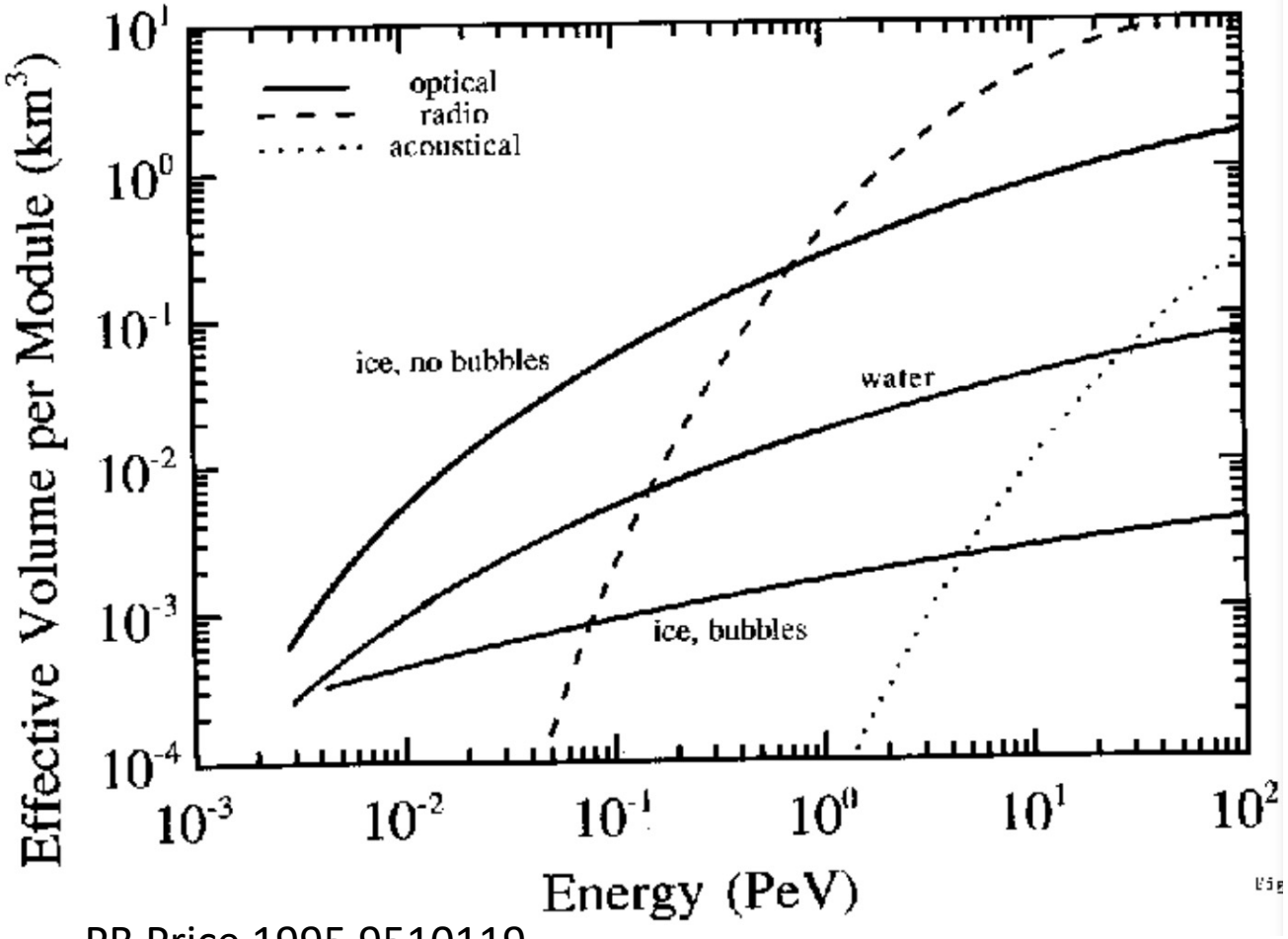


Diffuse – Does the spectrum continue? Single power law? If not, any hints on pgamma/GZK?...

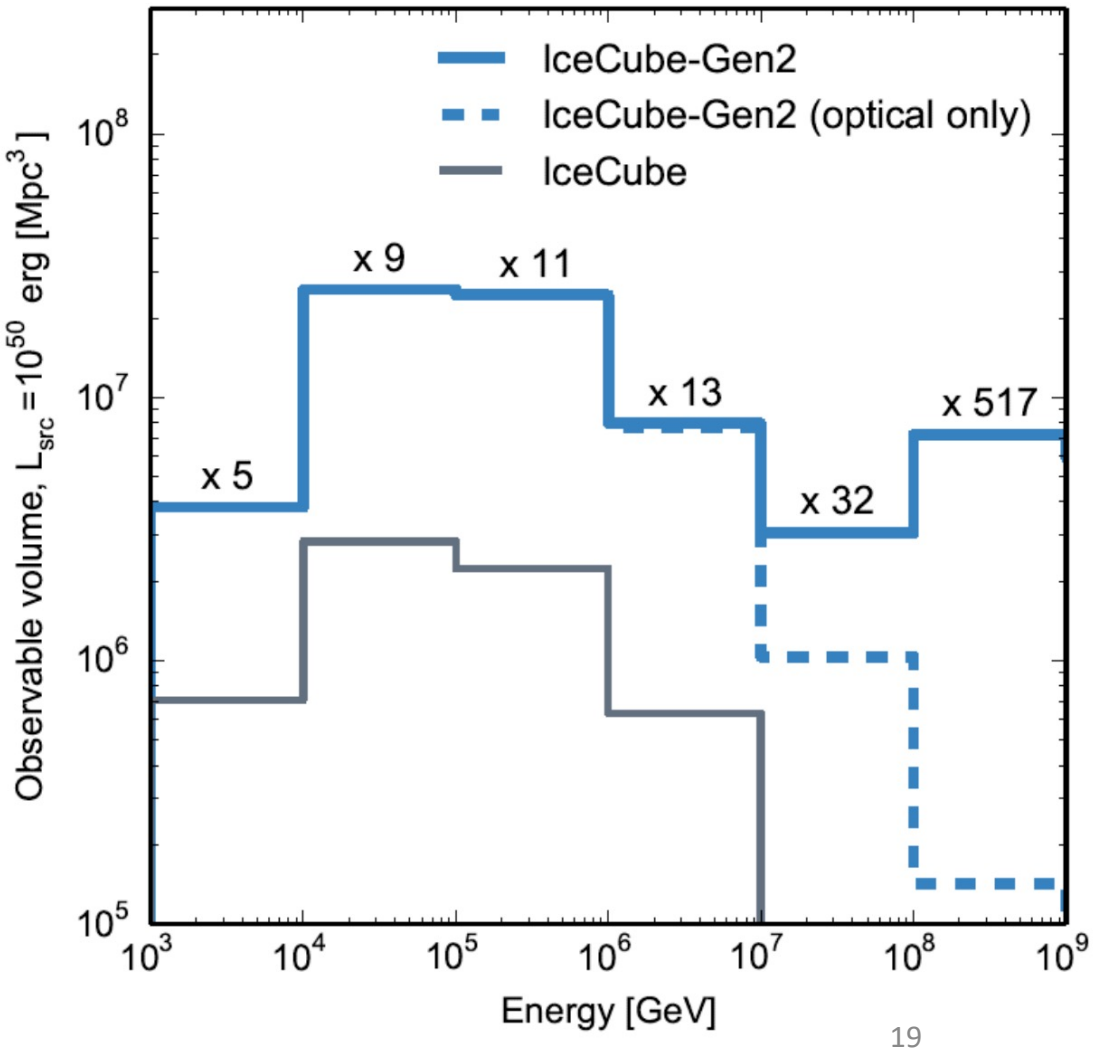


Including radio component aiming at the highest energies

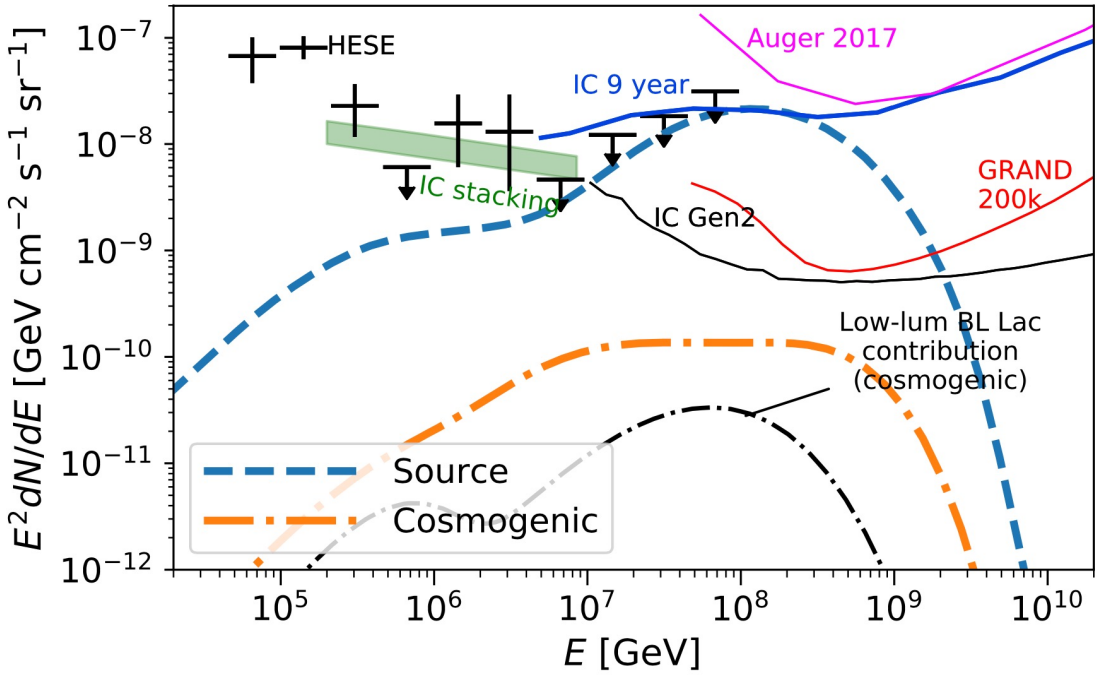
Expect to see
~10 x number of sources



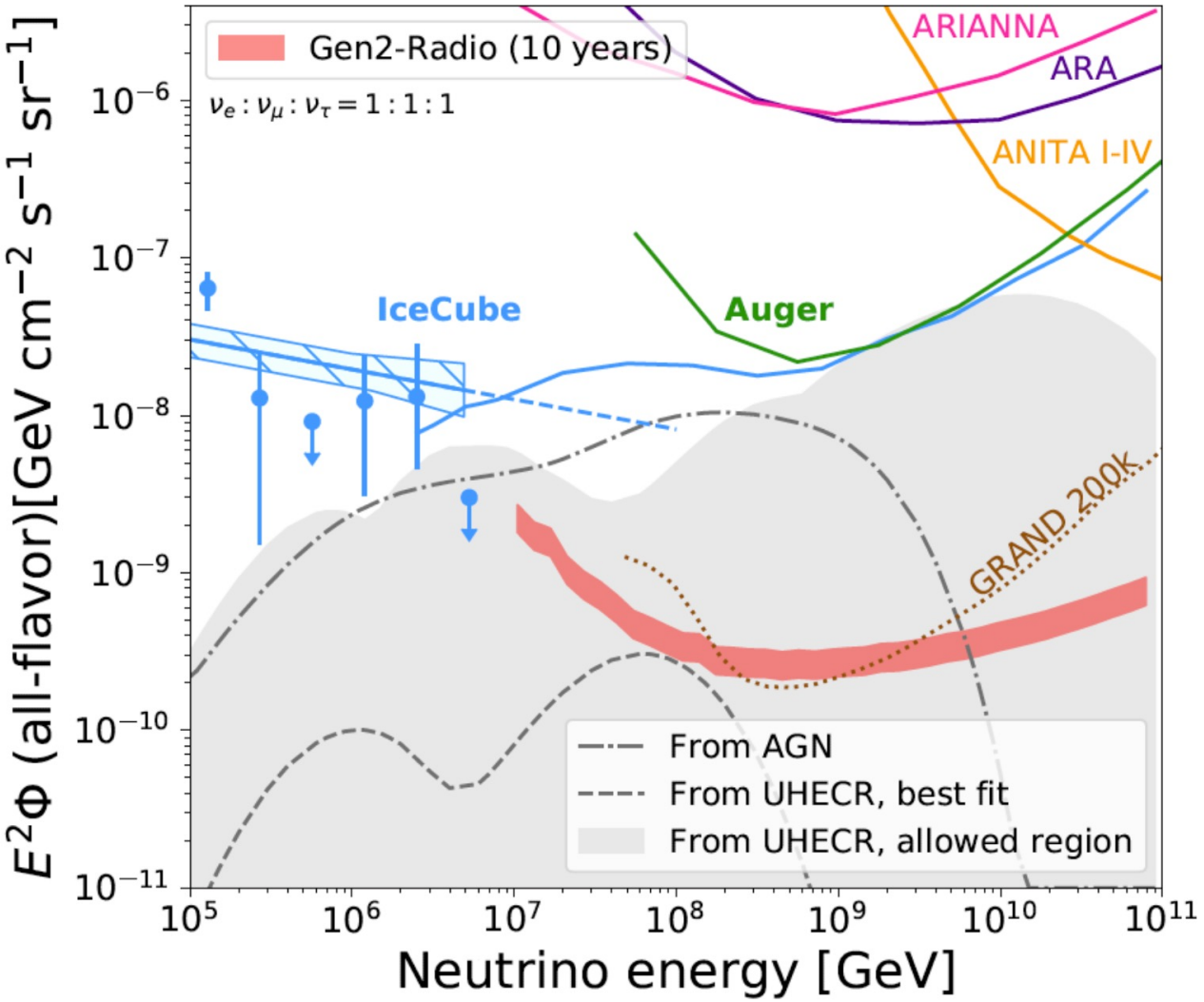
PB Price 1995 9510119



Ultra-high-energy neutrino and sources?



10.1103/PhysRevLett.126.191101



J.Phys.G 48 (2021) 6, 060501

Conclusions

IceCube has been in operation over a decade with >99% uptime.

Discovered diffuse neutrino flux, started Neutrino Astronomy, first hint of tau neutrinos, W boson resonance, transient source (TXS0506+056) and steady point source (NGC1068).

IceCube Gen2 is in R&D – aiming at explore our Universe from GeV to EeVs.

Results not included in the talk:

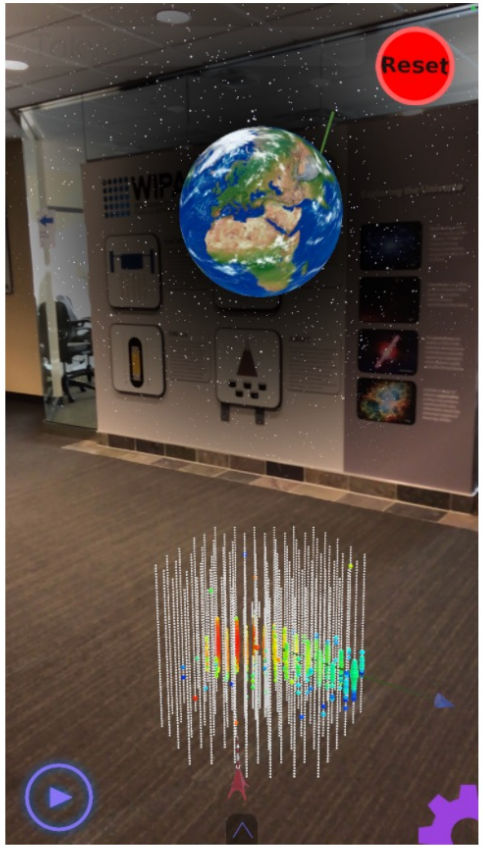
Searches for dark matter, magentic monopole and sterlie neutrinos. Measurements of cross section and inelasticity. And many more.

- Augmented reality app on mobile phones to visulise IceCube neutrino alerts
- Get notifications when alerts hit – with a few minutes delay from the GCN notice

https://icecube.wisc.edu/news/outreach/2020/10/from-outer-space-to-south-pole-to-your-phone-new-ar-app-for-icecube/

From outer space, to the South Pole, to your phone: A new AR app for IceCube

Posted on October 8, 2020 by Madeleine O'Keefe



A screenshot from the IceCubeAR

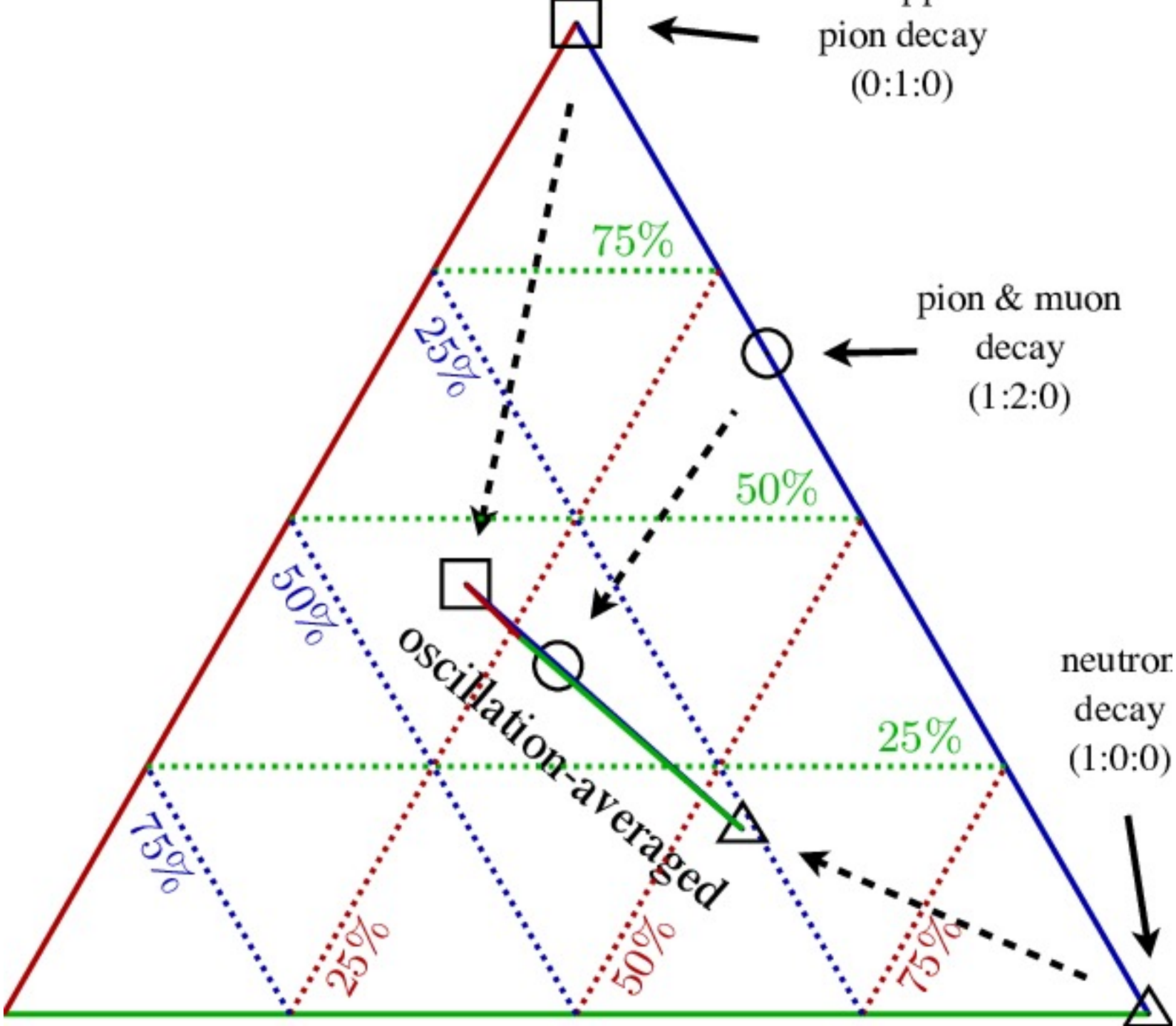
Located in the frigid desert that is the South Pole, the IceCube Neutrino Observatory isn't your typical telescope. It doesn't have an observatory dome or satellite dish. In fact, if you were standing at the South Pole looking at IceCube, you would see nothing but a small building in a vast, barren, snowy landscape.

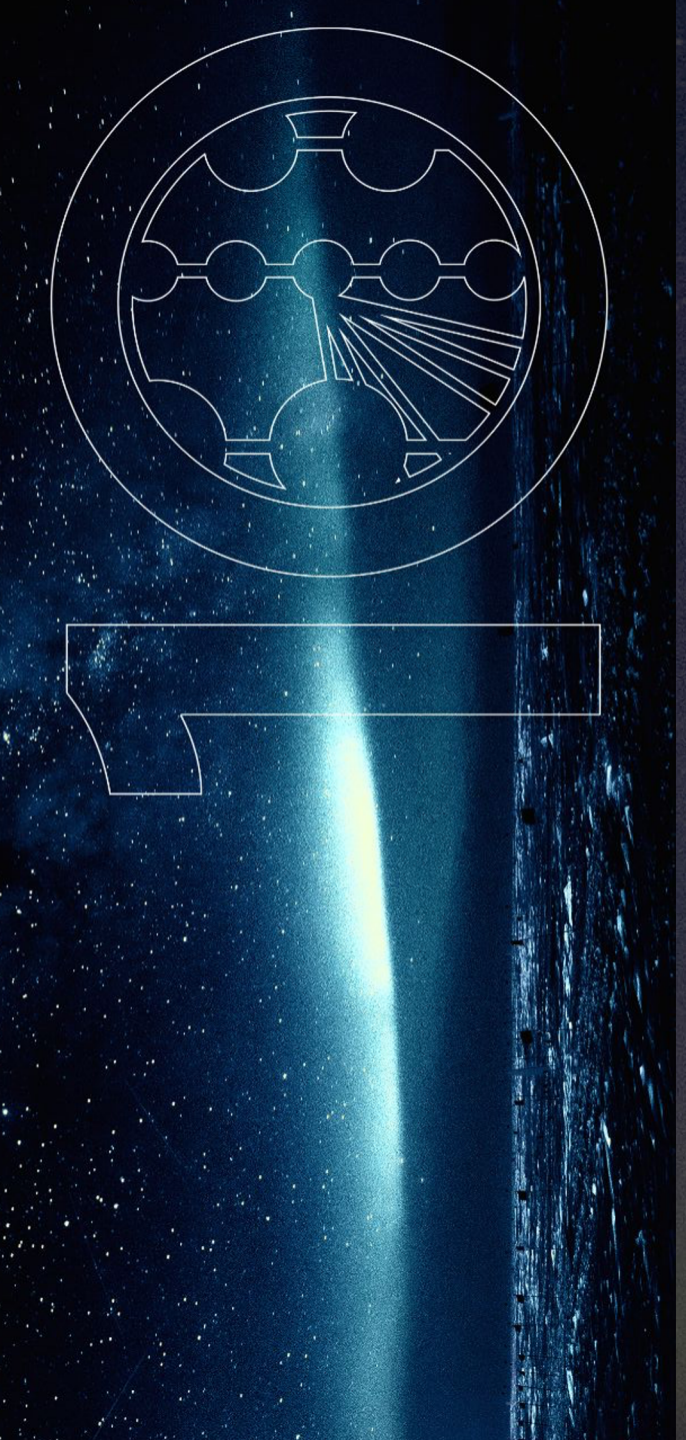
That's because the IceCube detector is *underground*. It comprises an array of 5,160 optical sensors that are frozen beneath a cubic kilometer of ice a mile beneath the surface. These sensors pick up signals left behind by mysterious particles called neutrinos.

Now, thanks to a new augmented reality (AR) app, anyone in the world can see what's happening under the ice at the South Pole. And when a neutrino candidate sails through the detector, users will find out in real time!

Introducing IceCubeAR, aka IceBear.

Neutrinos are fundamental particles that travel through


pion decay
(0:1:0)
75%
25%
pion & muon
decay
(1:2:0)
50%
50%
oscillation-averaged
neutron
decay
(1:0:0)
25%
75%
25%
50%
75%



1998
Super-Kamiokande collaboration announces evidence of nonzero neutrino mass

NT200 neutrino detector in Lake Baikal completed

1999
IceCube submits proposal for cubic-kilometer South Pole neutrino detector

2000
AMANDA (Antarctic Muon And Neutrino Detector Array) at the South Pole completed

2001
AMANDA publishes first neutrino sky map with 600 events in *Nature*

2008
ANTARES (Astronomy with a Neutrino Telescope and Abyss environmental RESearch) neutrino detector in the Mediterranean Sea completed

2010

IceCube construction completed

2013
IceCube discovers astrophysical neutrinos with energies greater than 10^{14} eV

2014
IceCube discovers highest energy neutrino to date, nicknamed Big Bird (2×10^{15} eV)

2015
IceCube confirms cosmic neutrino flux with muon neutrinos traversing Earth, including a 7×10^{15} eV neutrino

2018
Science papers describe first detected source of neutrinos—active galaxy TXS 0506+056, identified in 2017 by first successful multimessenger campaign

New discoveries