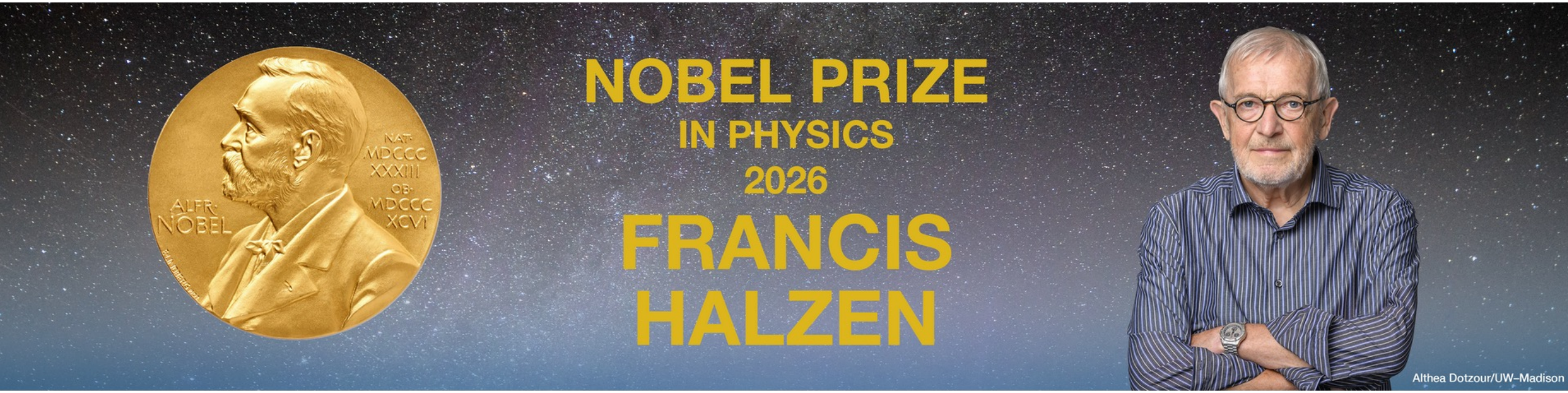
A NEW WINDOW TO THE UNIVERSE.

IceCube and the discovery of high-energy astrophysical neutrinos

Jakob van Santen
2026-10-19

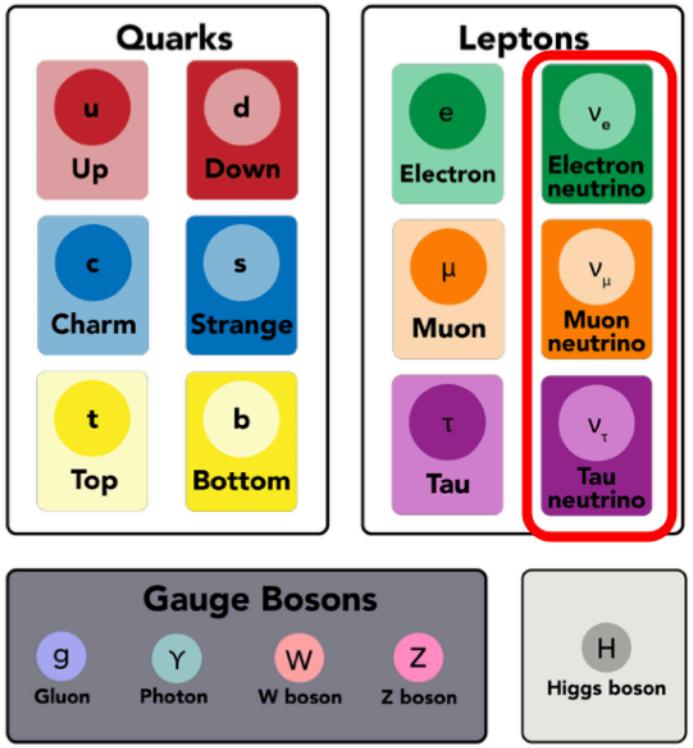
credit: M. Wolf, IceCube/NSF



"for decisive contributions to the IceCube Neutrino Observatory and the discovery of high-energy neutrinos of astrophysical origin"

How did we get here?

High-energy neutrinos as cosmic messengers

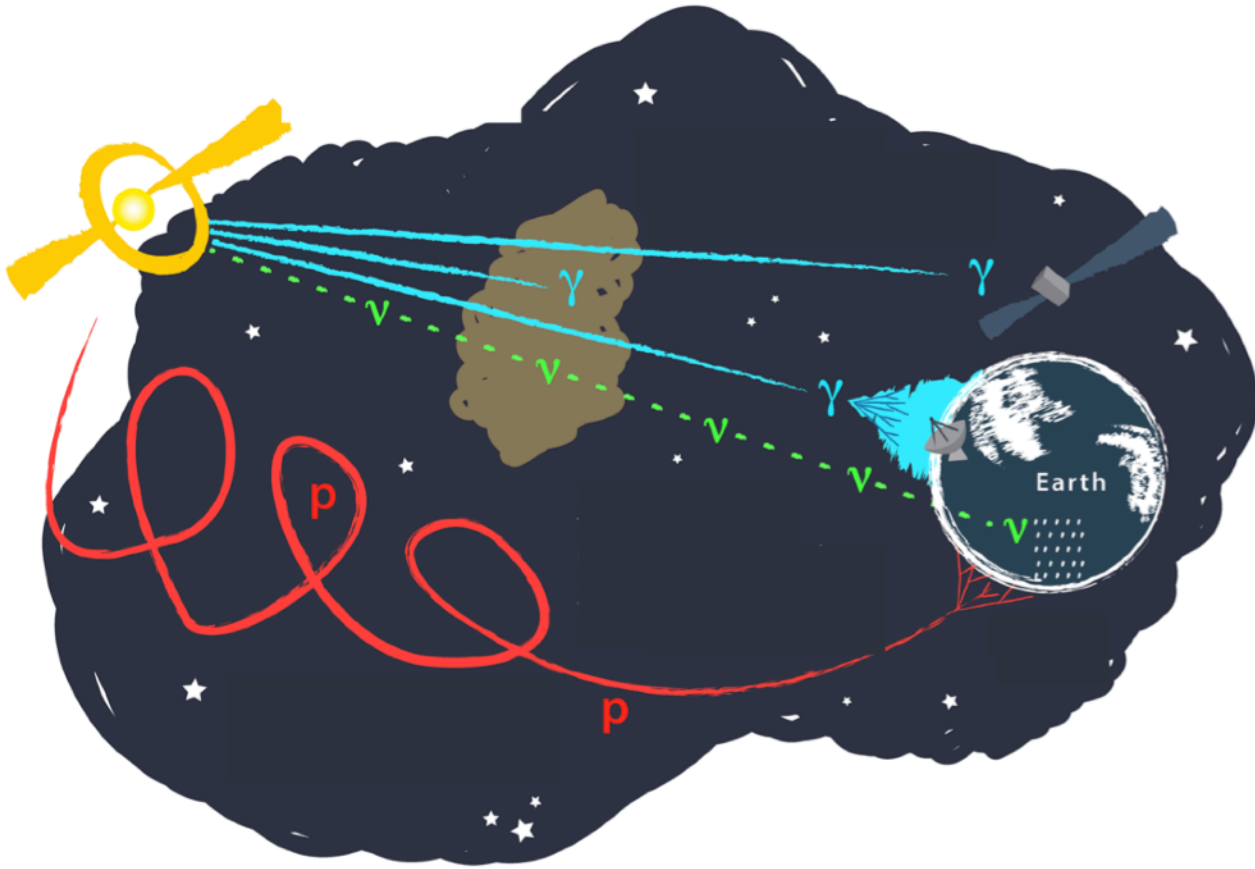


Neutrinos

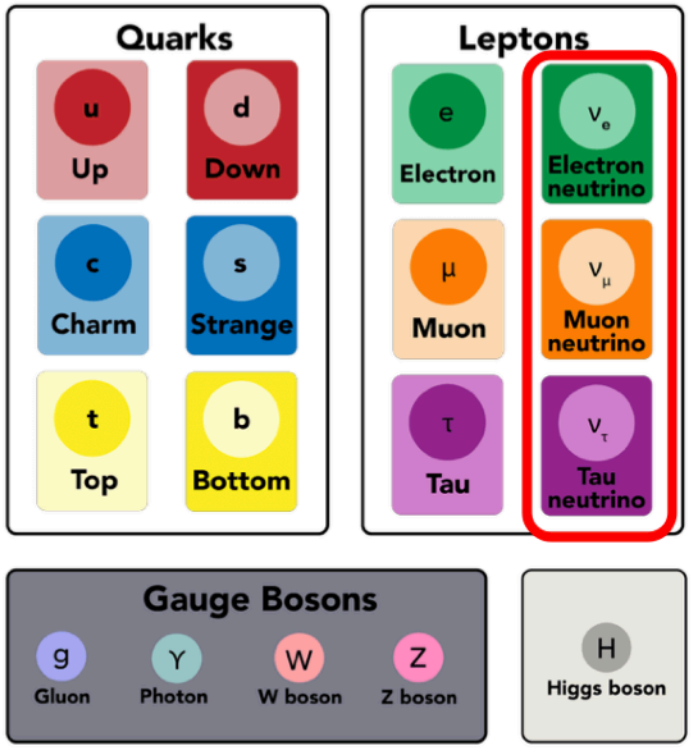
No charge

Nearly massless

Three "flavours"



High-energy neutrinos as cosmic messengers



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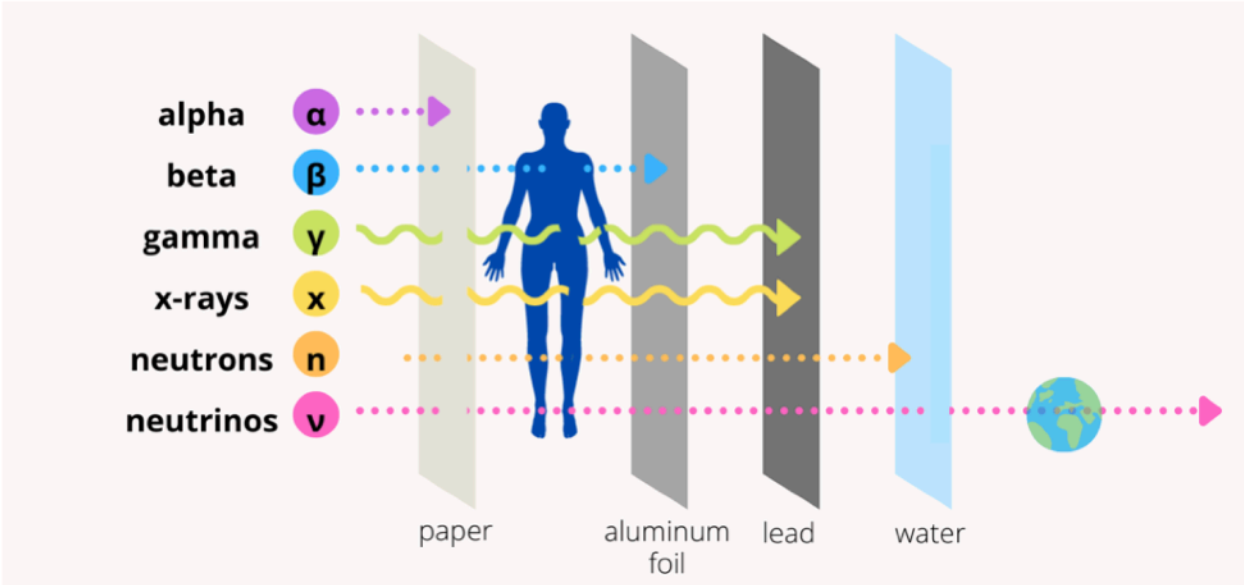
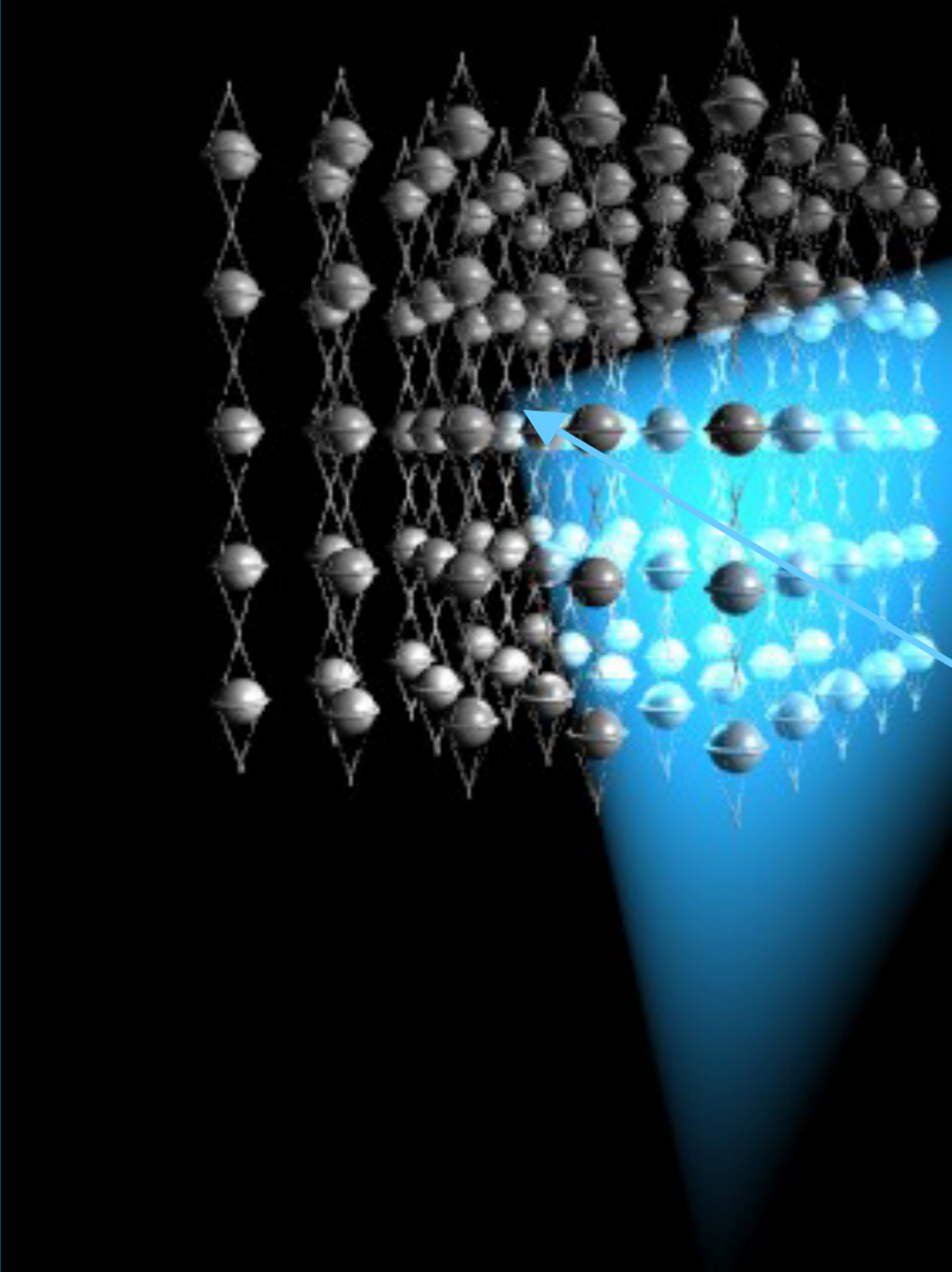


The Earth is becoming optically thick to neutrinos only above 100 TeV energies!

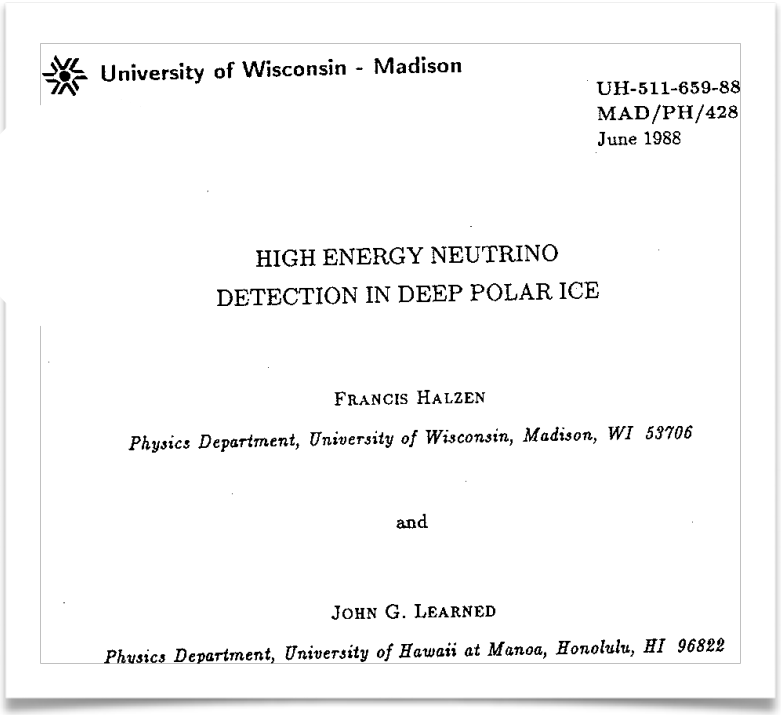


Neutrino Detection

"...to install detectors deep in a lake or a sea and to determine the direction of charged particles with the help of Cherenkov radiation. ....We consider μ-mesons produced in the ground layers under the detector"

— M. Markov, 1960

From water to ice



University of Wisconsin - Madison

UH-511-659-88
MAD/PH/428
June 1988

HIGH ENERGY NEUTRINO
DETECTION IN DEEP POLAR ICE

FRANCIS HALZEN

Physics Department, University of Wisconsin, Madison, WI 53706

and

JOHN G. LEARNED

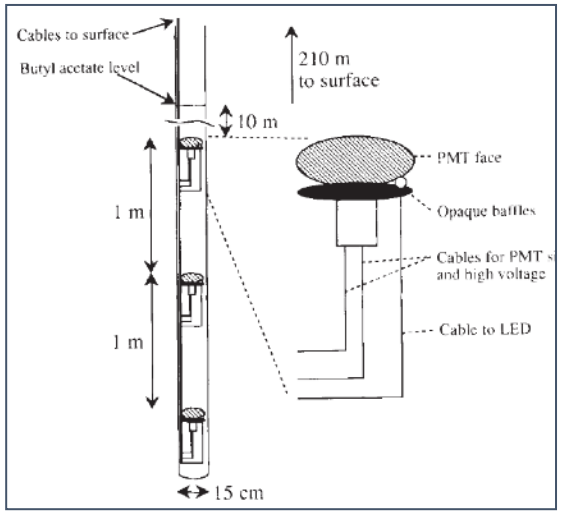
Physics Department, University of Hawaii at Manoa, Honolulu, HI 96822

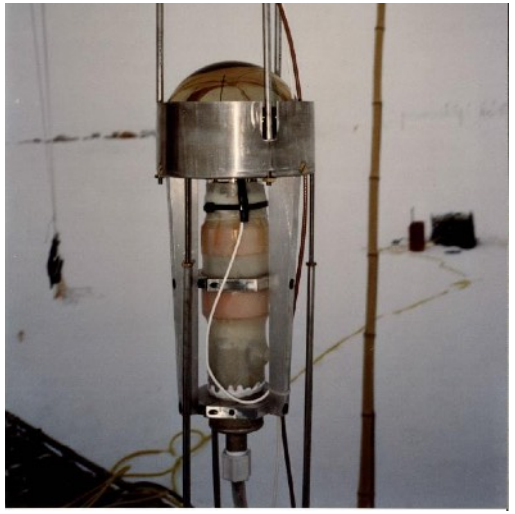
"...we suggest that field investigations begin as soon as possible to **examine the relevant optical properties of deep Antarctic ice**. It is amusing to envisage the Antarctic ice sheet as a giant neutrino telescope, with the whole earth as its rotating neutrino bandpass filter."

Nature 353, 331-333 (26 September 1991)

Observation of muons using the polar ice cap as a Cerenkov detector

D. M. Lowder*, T. Miller*, P. B. Price*, A. Westphal*, S. W. Barwick†, F. Halzen‡ & R. Morse‡





"Cerenkov radiation from muons was detected, and a comparison of count rate with the expected muon flux indicates that the ice is very transparent, with an absorption length greater than 18 m. **Our results suggest that a full-scale Antarctic ice detector is technically quite feasible.**"

First tests in ice at the South Pole: AMANDA-A

- 1991-92, 1993-94
- First demonstration of **hot water drilling**
- 80 photomultipliers deployed at **800-1000 m depth**
- Scattering still too strong for reconstruction → go even deeper for AMANDA-B!

1995: DESY and Stockholm build
~100 modules for AMANDA-B, 86 deployed in the season 95/96 at 1450-1950 m depth

DESY team 1995

NATURE 2001

AMANDA-B10: ~ 0.006 km^3

Observation of high-energy neutrinos using Čerenkov detectors embedded deep in Antarctic ice

E. Andrés*, P. Askebjer†, X. Bai‡, G. Barouch*, S. W. Barwick§, R. C. Bay‖, K.-H. Becker¶, L. Bergström†, D. Bertrand#, D. Bierenbaum§, A. Biron☆, J. Booth§, O. Botner**, A. Bouchta☆, M. M. Boyce*, S. Carius††, A. Chen*, D. Chirkin‖¶, J. Conrad**, J. Cooley*, C. G. S. Costa#, D. F. Cowen‡‡, J. Dailing§, E. Dalberg†, T. DeYoung*, P. Desiati☆, J.-P. Dewulf#, P. Doksus*, J. Edsjö†, P. Ekström†, B. Erlandsson†, T. Feser§§, M. Gaug☆, A. Goldschmidt‖, A. Goobar†, L. Gray*, H. Haase☆, A. Hallgren**, F. Halzen*, K. Hanson‡‡, R. Hardtke*, Y. D. He‖, M. Hellwig§§, H. Heukenkamp☆, G. C. Hill*, P. O. Hulth†, S. Hundertmark§, J. Jacobsen‖, V. Kandhadai*, A. Karle*, J. Kim§, B. Koci*, L. Köpke§§, M. Kowalski☆, H. Leich☆, M. Leuthold☆, P. Lindahl††, I. Liubarsky*, P. Loaiza**, D. M. Lowder‖, J. Ludvig‖, J. Madsen*, P. Marciniewski**, H. S. Matis‖, A. Mihalyi‡‡, T. Mikolajski☆, T. C. Miller‡, Y. Minaeva†, P. Miočinović‖, P. C. Mock§, R. Morse*, T. Neunhöffer§§, F. M. Newcomer‡‡, P. Niessen☆, D. R. Nygren‖, H. Ögelman*, C. Pérez de los Heros**, R. Porrata§, P. B. Price‖, K. Rawlins*, C. Reed§, W. Rhode¶, A. Richards‖, S. Richter☆, J. Rodríguez Martino†, P. Romenesko*, D. Ross§, H. Rubinstein†, H.-G. Sander§§, T. Scheider§§, T. Schmidt☆, D. Schneider*, E. Schneider§, R. Schwarz*, A. Silvestri¶☆, M. Solarz‖, G. M. Spiczak‡, C. Spiering☆, N. Starinsky*, D. Steele*, P. Steffen☆, R. G. Stokstad‖, O. Streicher☆, Q. Sun†, I. Taboada‡‡, L. Thollander†, T. Thon☆, S. Tilav*, N. Usechak§, M. Vander Donckt#, C. Walck†, C. Weinheimer§§, C. H. Wiebusch☆, R. Wischnewski☆, H. Wissing☆, K. Woschnagg‖, W. Wu§, G. Yodh§ & S. Young§

In the meantime, AMANDA-II WAS DEPLOYED

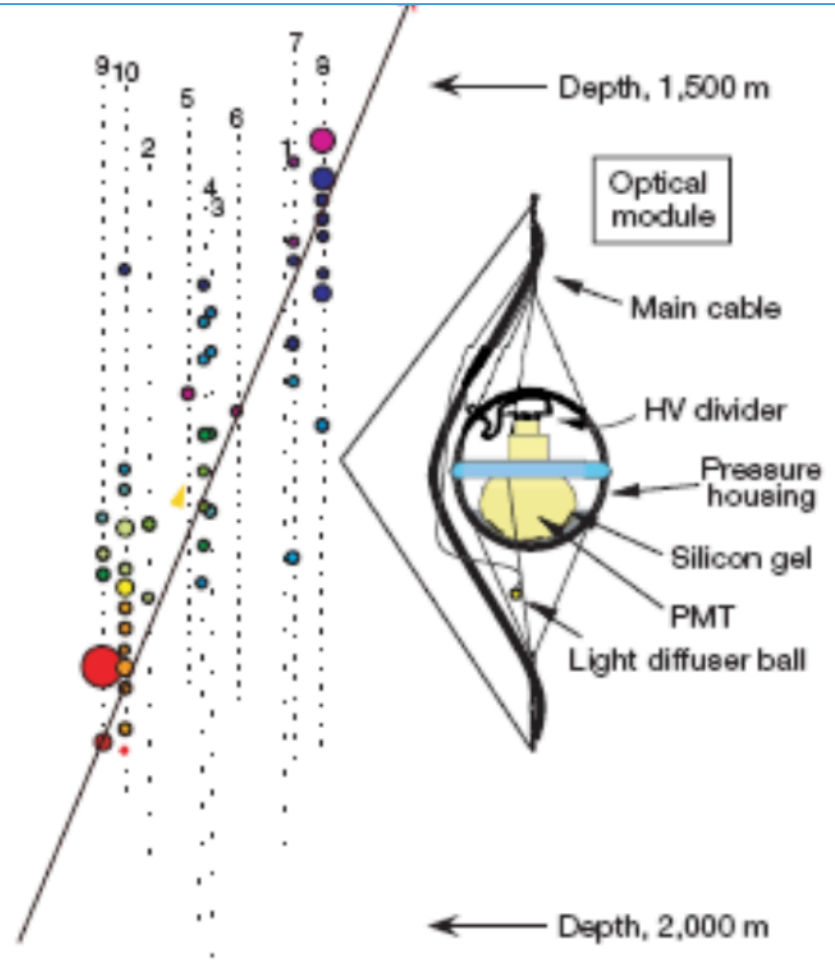
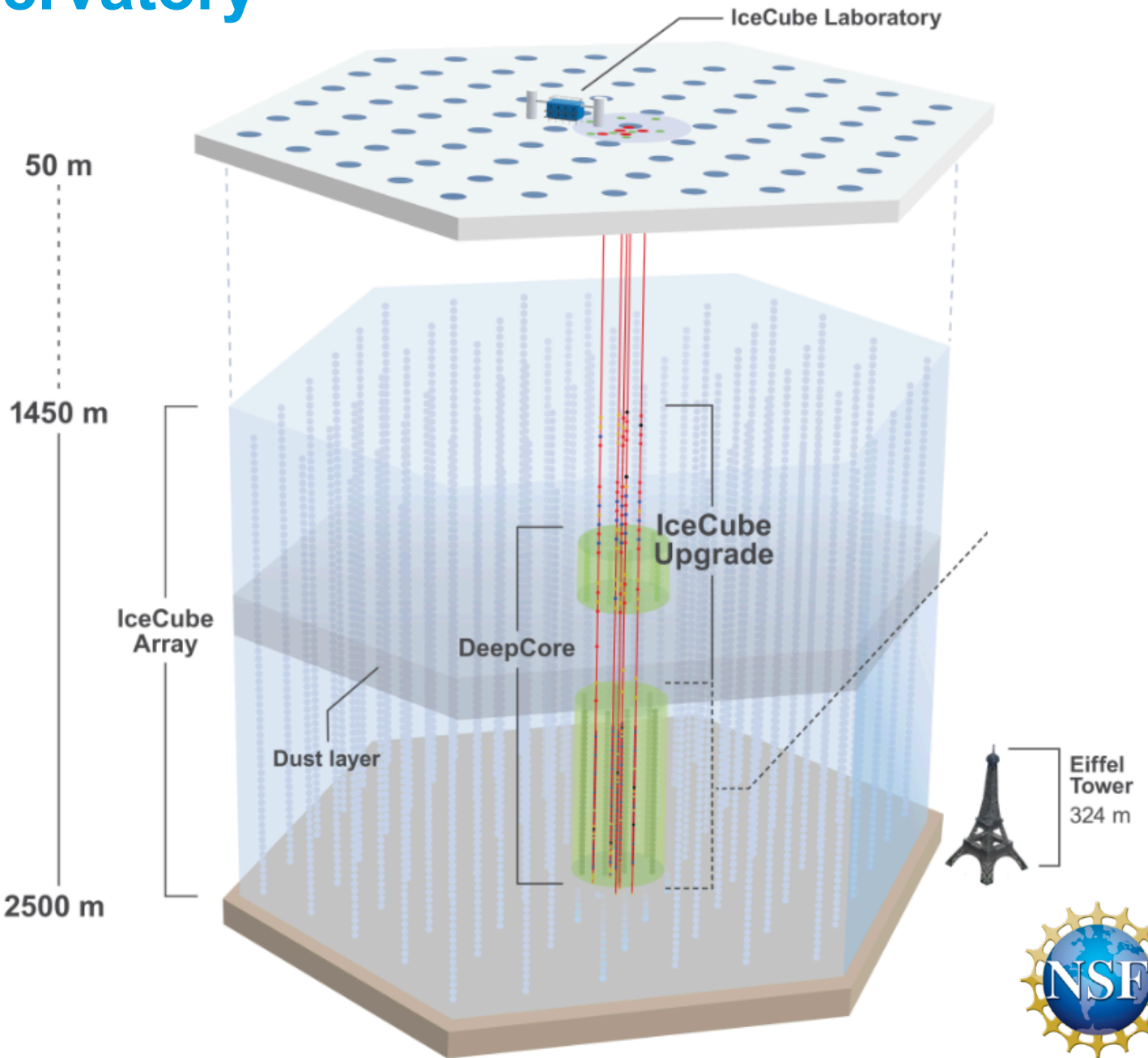


Figure 1 The AMANDA-B10 detector and a schematic diagram of an optical module. Each dot represents an optical module. The modules are separated by 20 m on the inner strings (1 to 4), and by 10 m on the outer strings (5 to 10). The coloured circles show pulses from the photomultipliers for a particular event; the sizes of the circles indicate the amplitudes of the pulses and the colours correspond to the time of a photon's arrival. Earlier times are in red and later ones in blue. The arrow indicates the reconstructed track of the upwardly propagating muon.

IceCube Neutrino Observatory

The IceCube Neutrino Observatory

- 1 km^3 volume.
- 5160 optical sensors on 86 strings.
- Construction: 2005-2011
- Costs: $ 270M
- PI: Francis Halzen

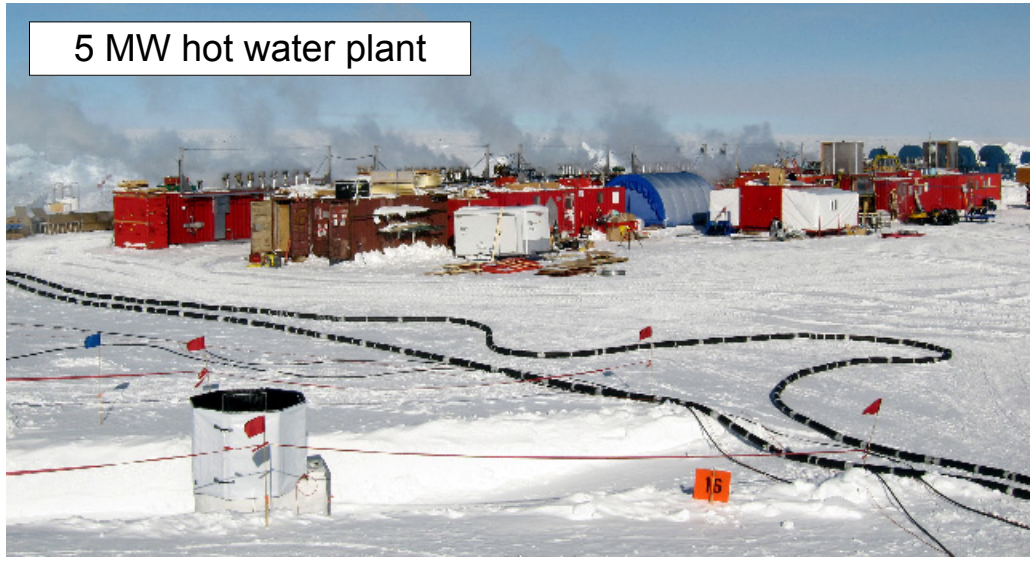


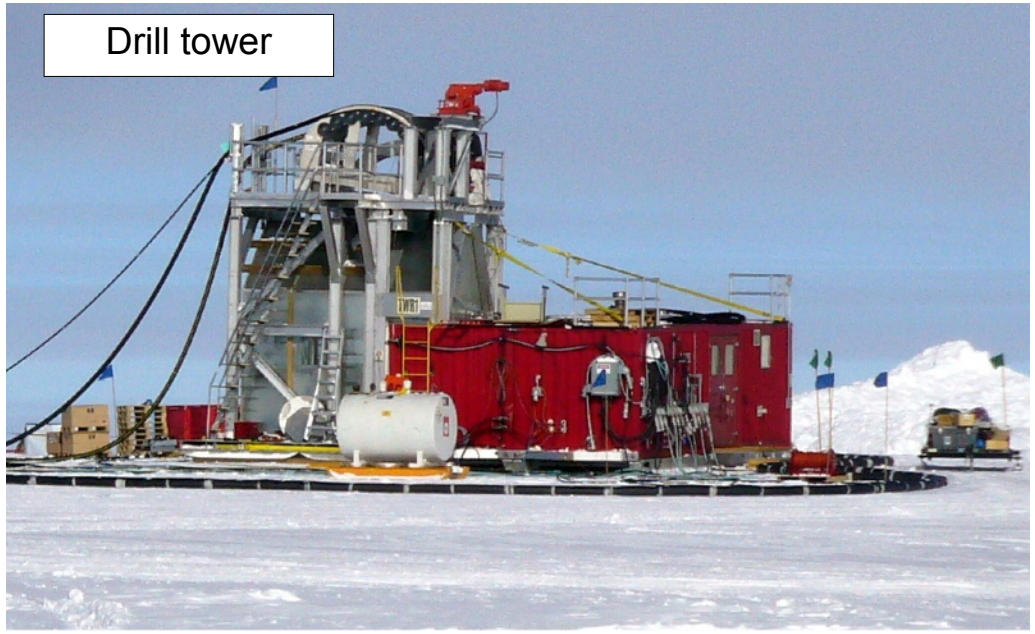
IceCube Neutrino Observatory

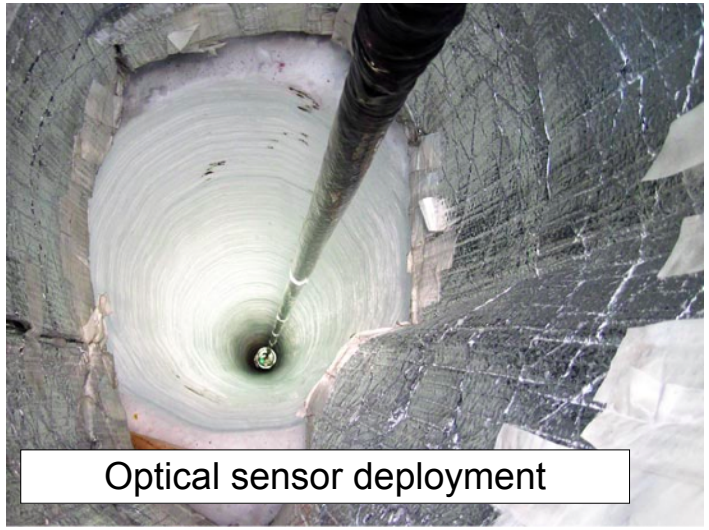
NSF

IceCube construction (2005-2011)

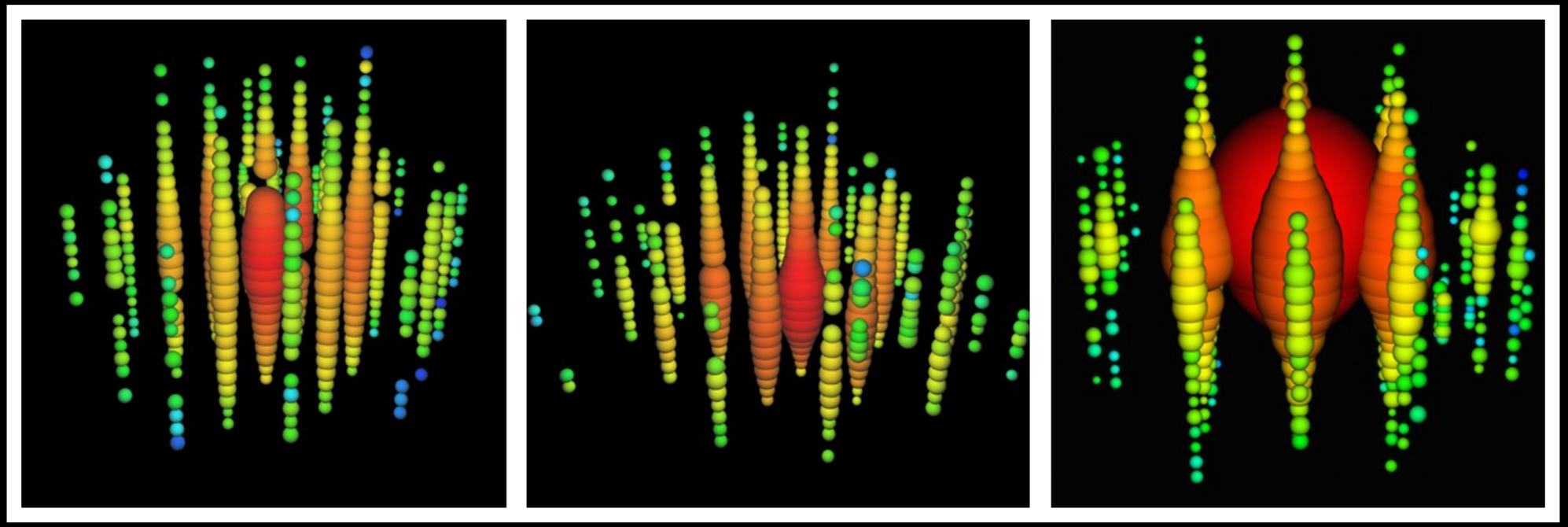
1250 of 5160 IceCube modules produced @ DESY





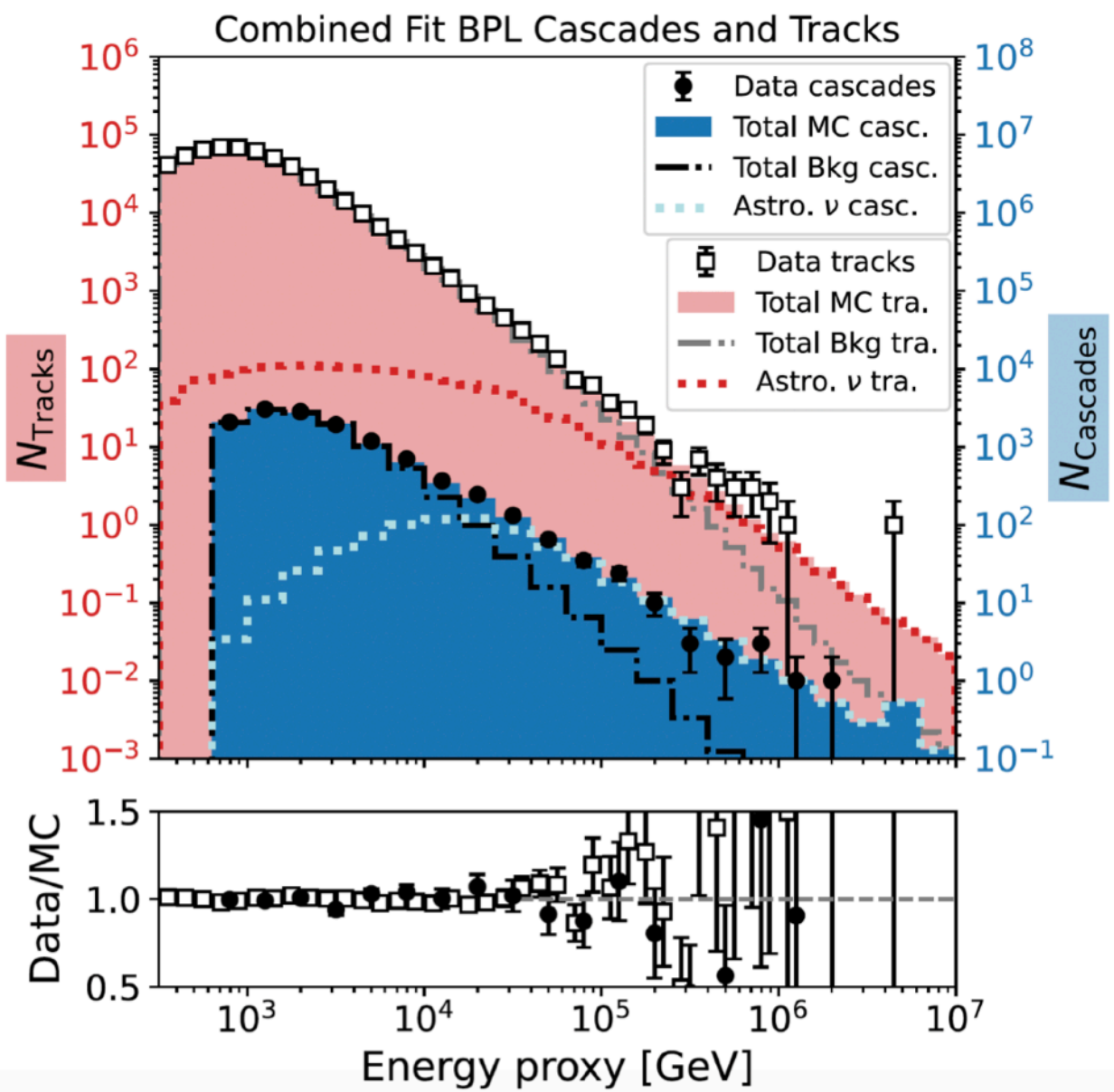


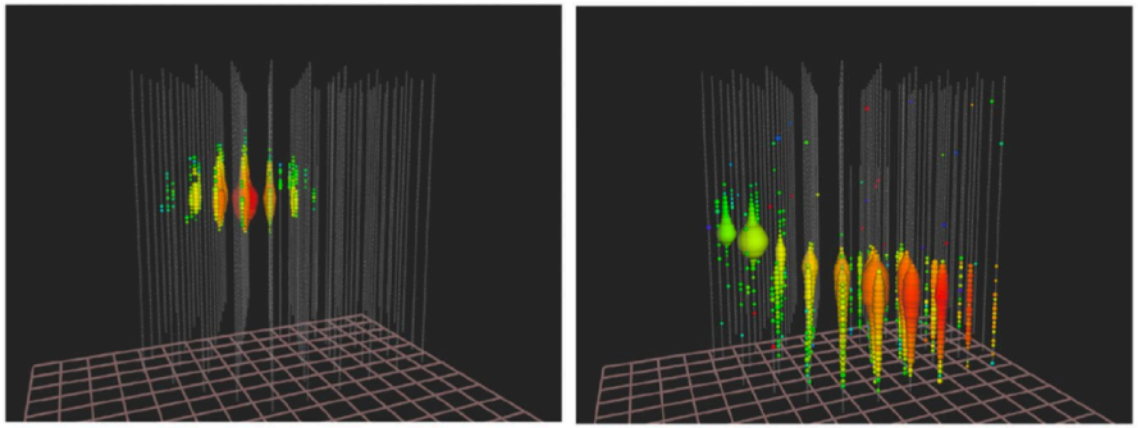
Cosmic Neutrinos!



Science, 2013

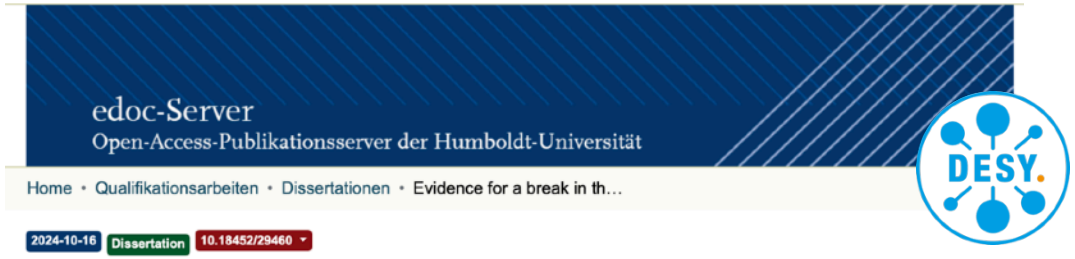
The Flux of High-Energy Cosmic Neutrinos





Nobel Prize 2026: scientific background

PRL 2026, Richard Naab, 2024, HU Dissertation



The Flux of High-Energy Cosmic Neutrinos

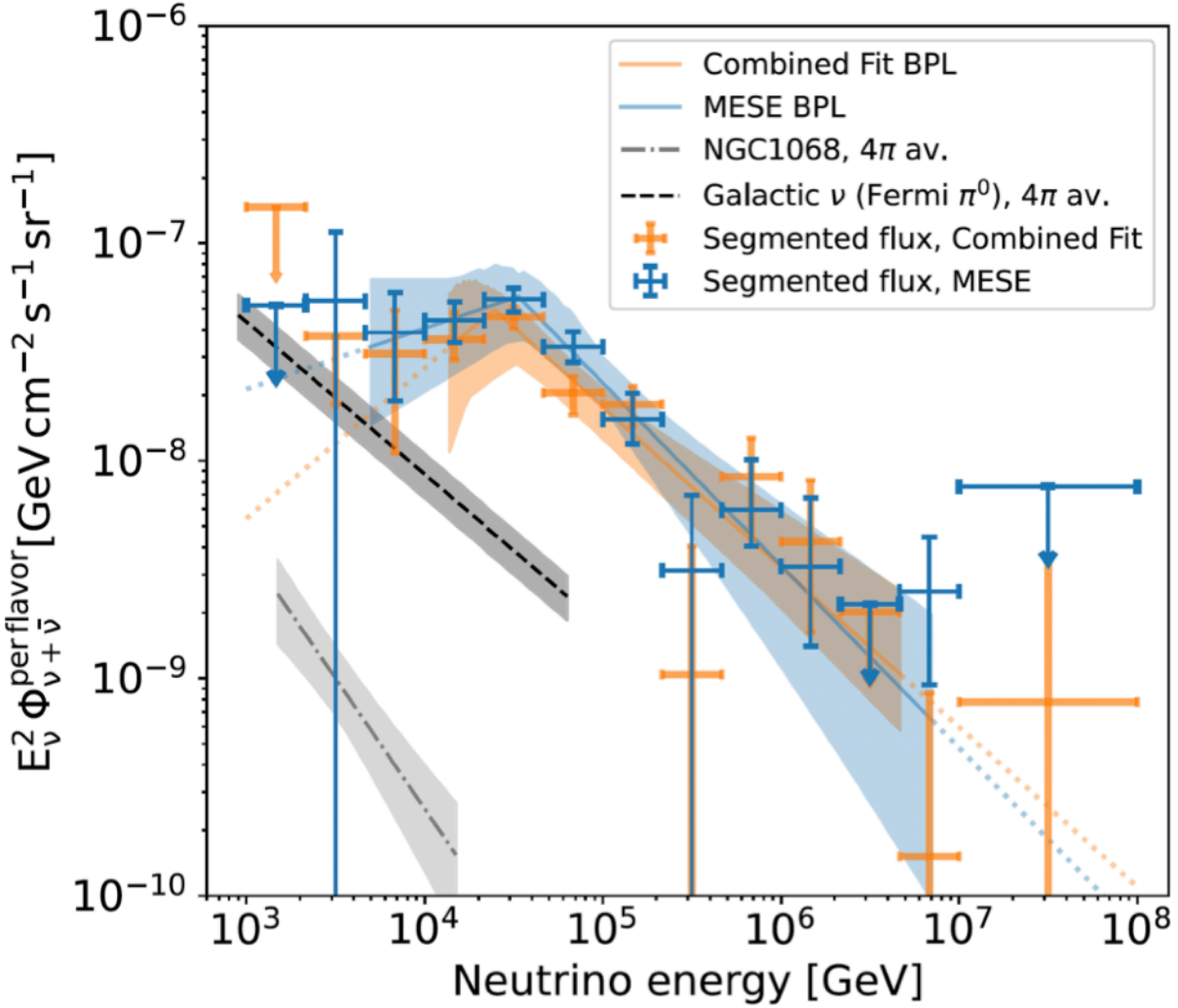


Figure 6. *The fit to the astrophysical neutrino flux, Φ(E), multiplied by E², where E is the neutrino energy. Orange markers and shaded regions are for the combined fit of cascade and track events. A broken power-law (BPL) neutrino spectrum is assumed. The blue markers and shaded region are for a complementary analysis of so-called Medium Energy Starting Events (MESE), which is not described in this report. The combined fit analysis allows stronger constraints on the higher-energy spectral index, while MESE gives stronger constrains on the lower-energy spectral index, due to their respective sensitive energy ranges. The shaded regions show 68% confidence level uncertainties. The flux from the candidate neutrino source, active galaxy NGC 1068, and Milky Way (Galactic ν) are small compared to the astrophysical neutrino flux. Figure credit: IceCube Collaboration, Physical Review Letters 136 (2026) 121002.*

Nobel Prize 2026: scientific background

PRL 2026, Richard Naab, 2024, HU Dissertation

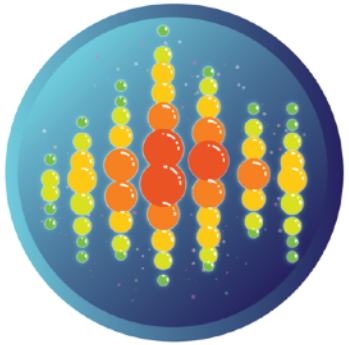
A Decade of Neutrino Astrophysics with IceCube

2013

ASTROPHYSICAL NEUTRINOS
DISCOVERED

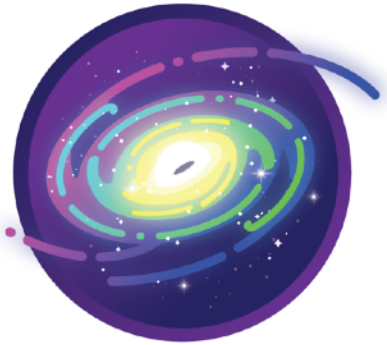
2018

BLAZAR TXS 0506+056
NEUTRINO EMISSION IDENTIFIED



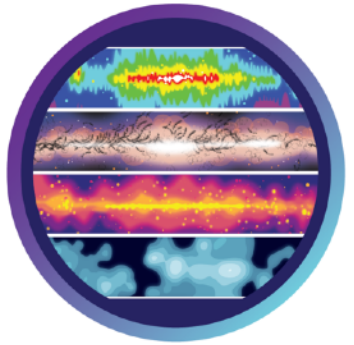
2021

GLASHOW RESONANCE
NEUTRINO IDENTIFIED



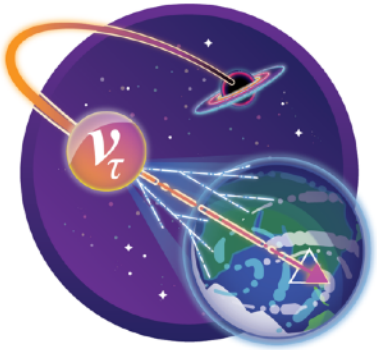
2022

ACTIVE GALAXY NGC 1068
NEUTRINO EMISSION IDENTIFIED



2023

MILKY WAY
NEUTRINO EMISSION IDENTIFIED



2024

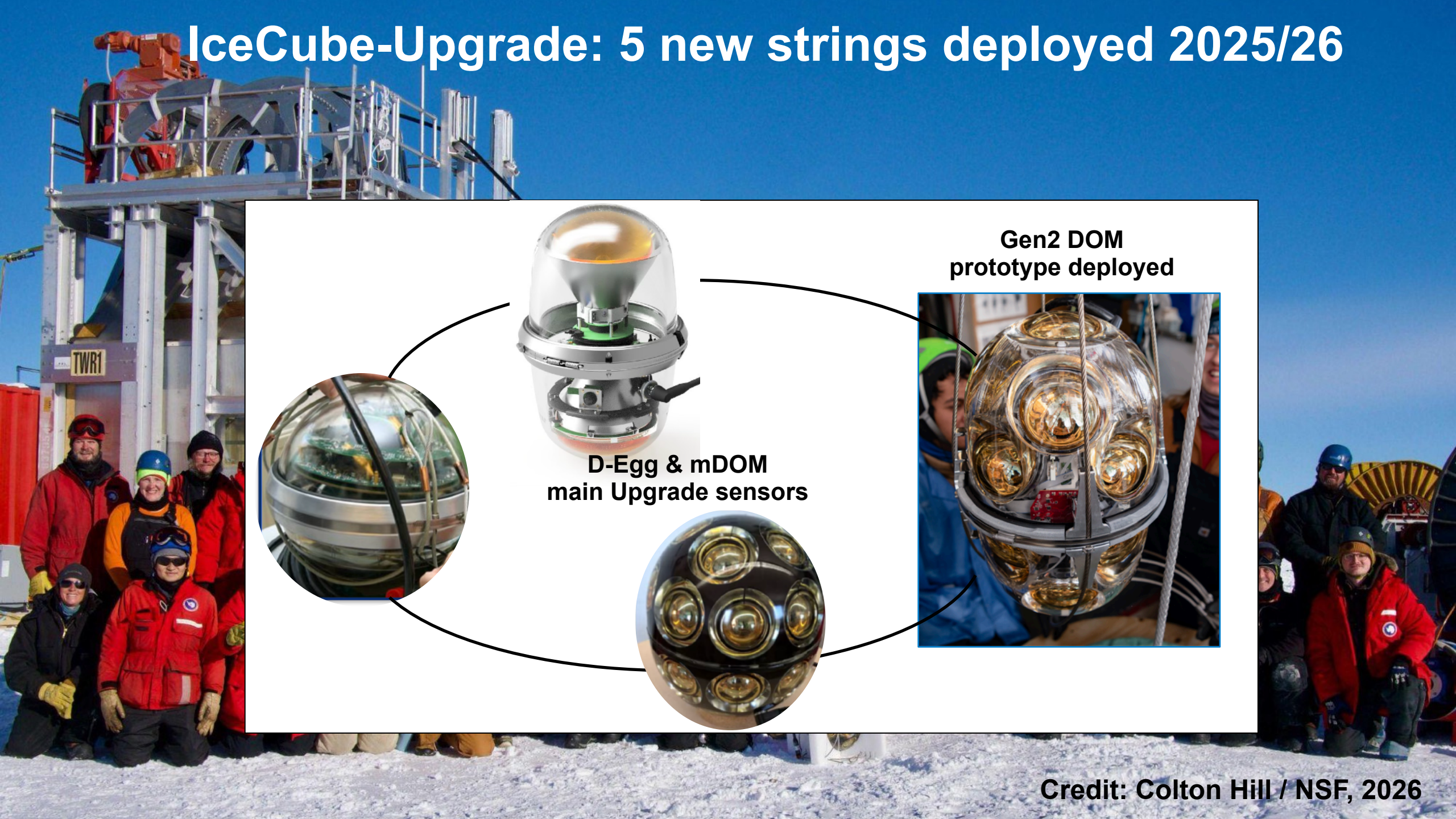
ASTROPHYSICAL TAU NEUTRINOS
IDENTIFIED

The story continues: IceCube Upgrade IceCube-Gen2

IceCube-Upgrade: 5 new strings deployed 2025/26

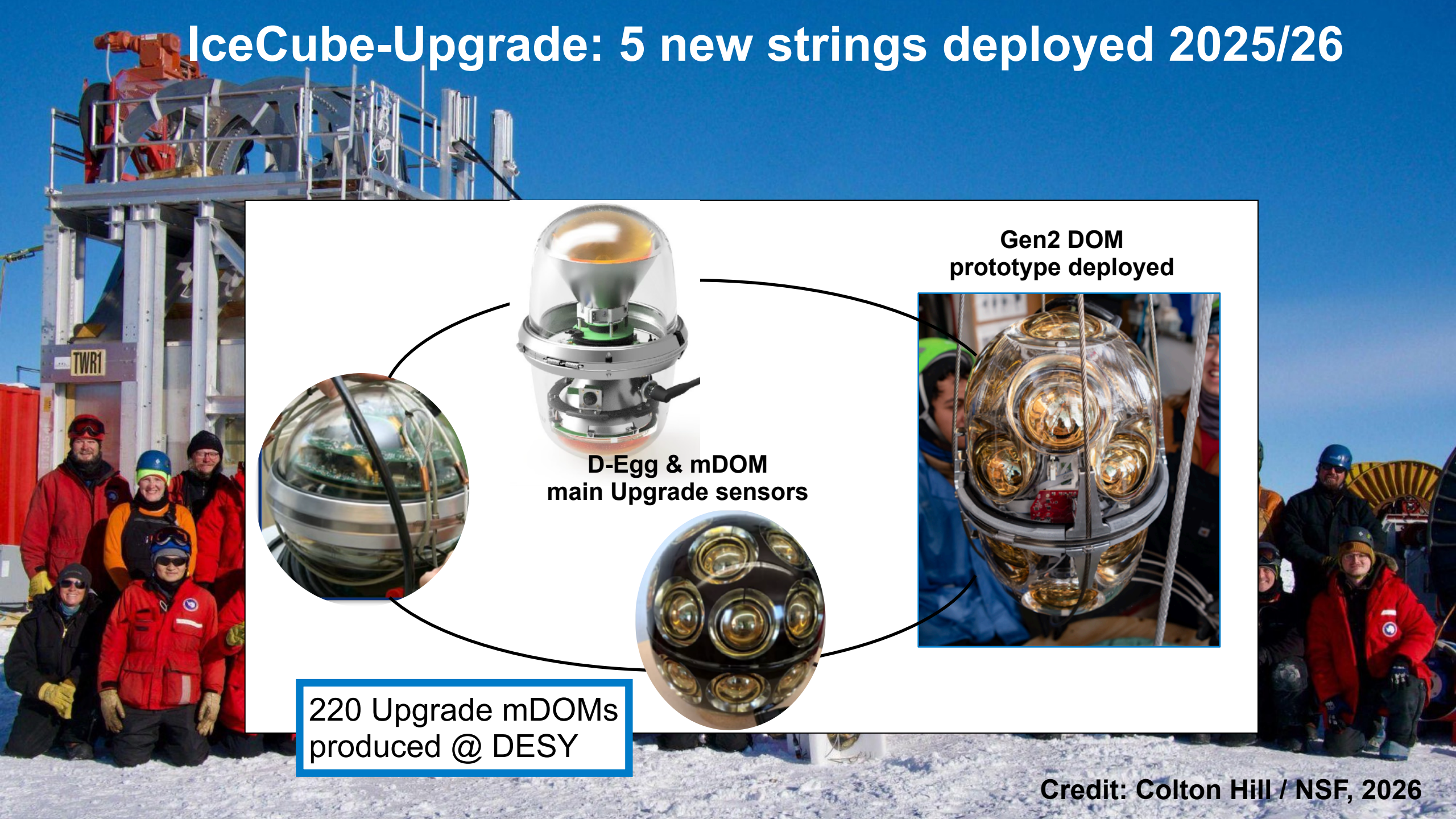
Credit: Colton Hill / NSF, 2026

IceCube-Upgrade: 5 new strings deployed 2025/26



Credit: Colton Hill / NSF, 2026

IceCube-Upgrade: 5 new strings deployed 2025/26



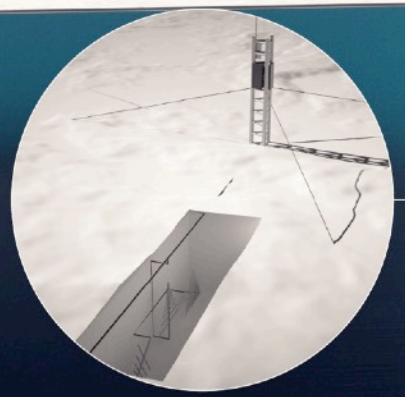
D-Egg & mDOM
main Upgrade sensors

Gen2 DOM
prototype deployed

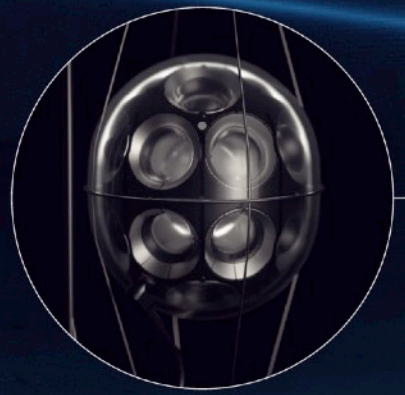
220 Upgrade mDOMs
produced @ DESY

Credit: Colton Hill / NSF, 2026

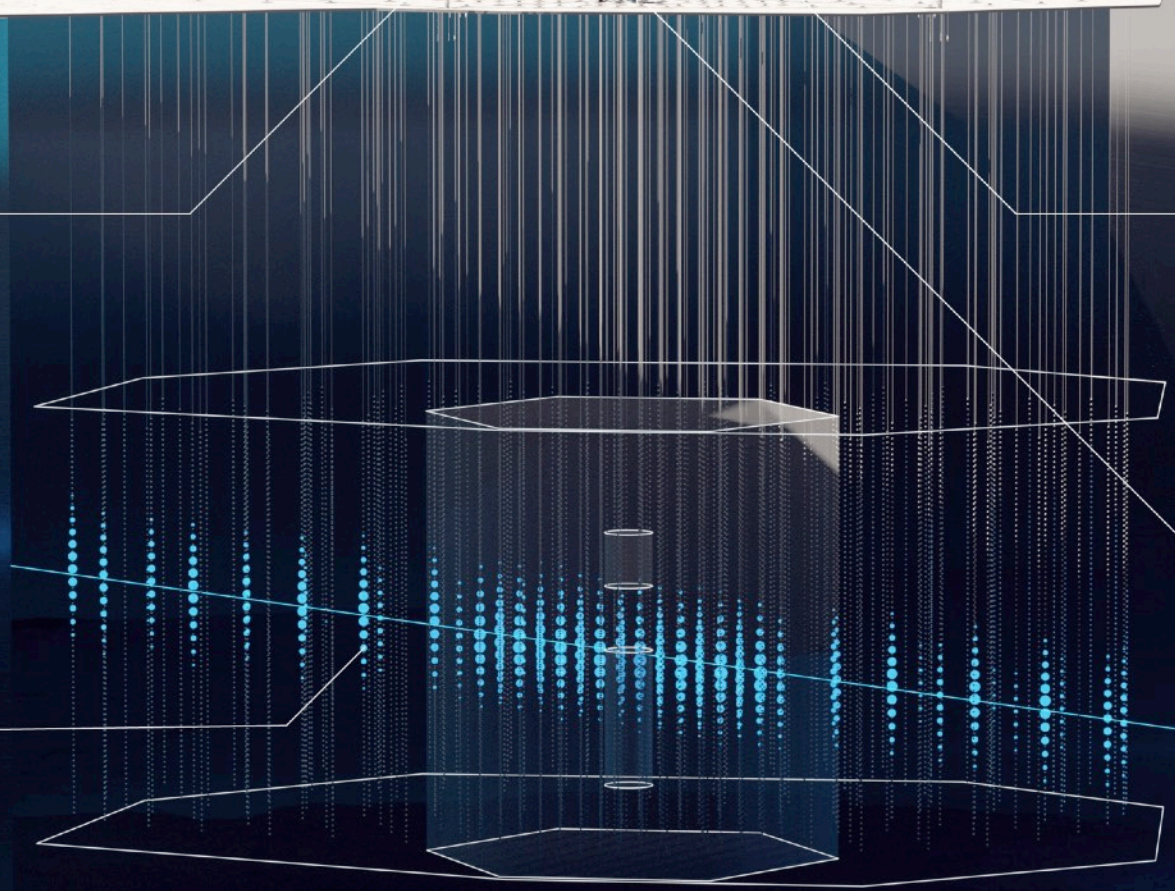
IceCube Gen2

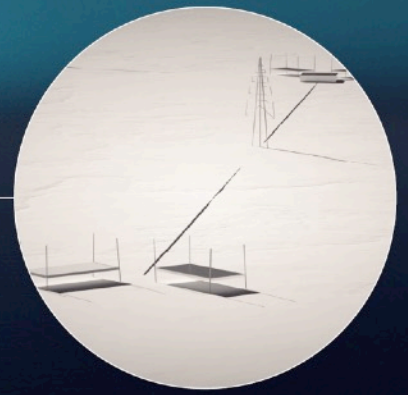


Radio Array | Station

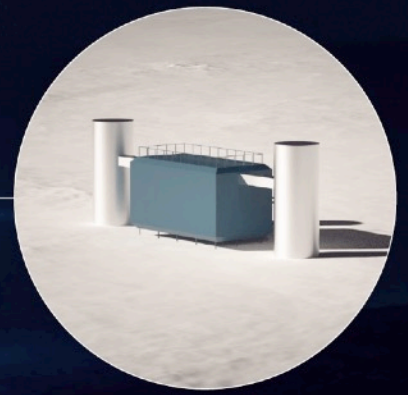


Optical Array | Sensor





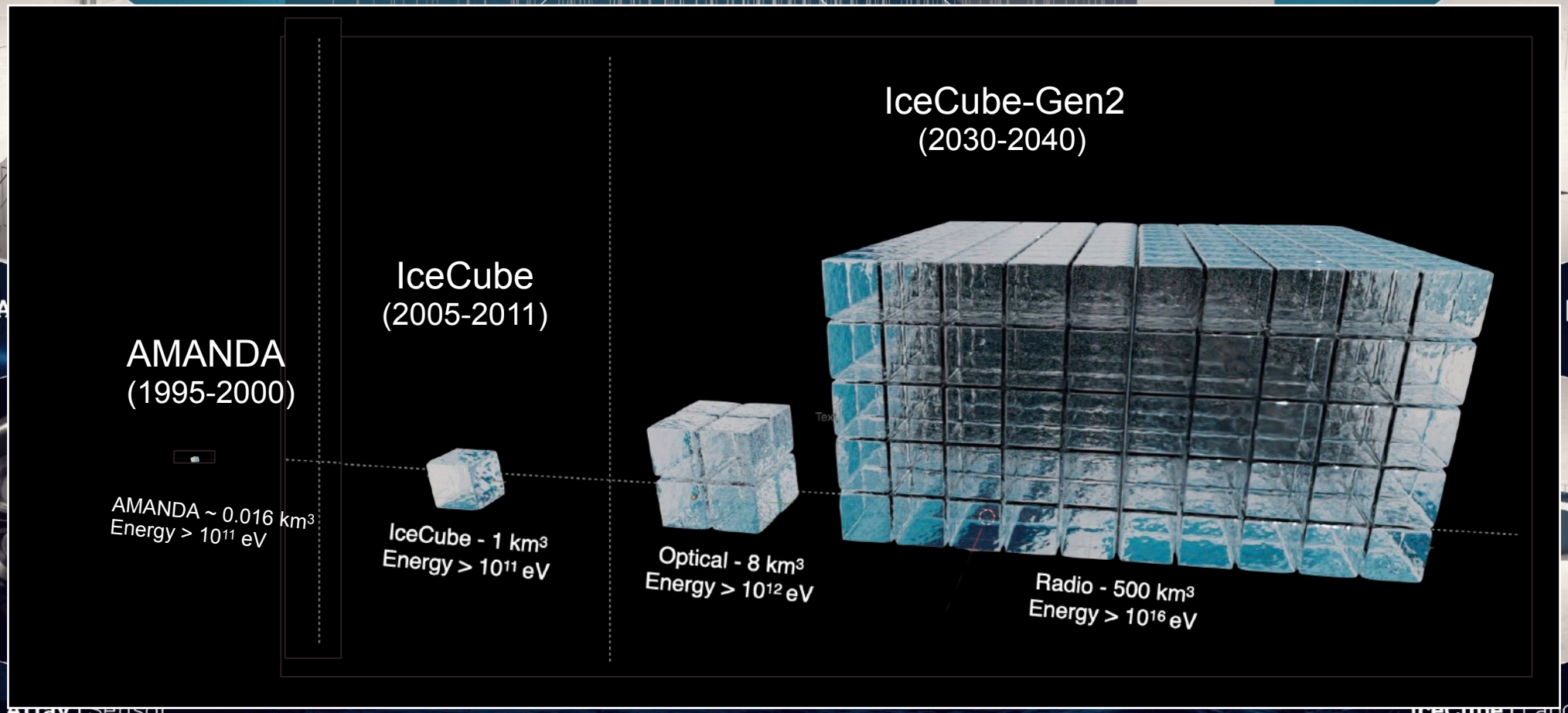
Surface Array | Station



IceCube | Laboratory

Credit: DESY & SciComLab

IceCube GEN2



Radio A

| Station

Optical Array | Sensor

IceCube | Laboratory

Credit: DESY & SciComLab

IceCube-Gen2 on the German shortlist for large research infrastructure

German proposal: 59 Mio. Euro for construction (~90 % capital costs)
Additional 15,5 Mio. Euro as in-kind

- Deliverables:
  3500 optical sensors
- A large fraction of the Radio- and surface array

Review Sep 7.-8.: update on project status, funding needs and establish decision points

IceCube GEN2

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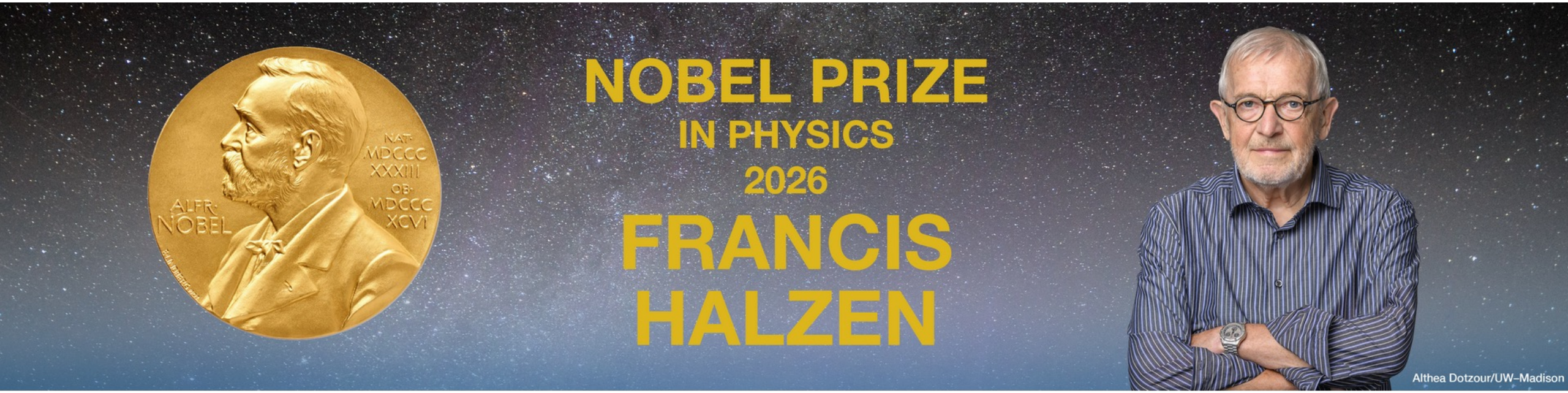
IceCube GEN2



"for decisive contributions to the IceCube Neutrino Observatory and the discovery of high-energy neutrinos of astrophysical origin"

Thank you

credit: M. Wolf, IceCube/NSF