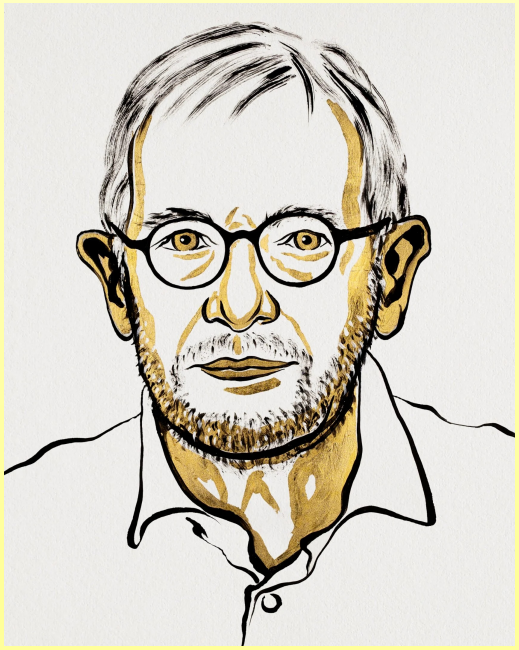
Нобелівська премія з фізики 2026

KUNGL. VETENSKAPSAKADEMIEN
THE ROYAL SWEDISH ACADEMY OF SCIENCES





Френсіс Гальзен

(University of Wisconsin-Madison, USA)

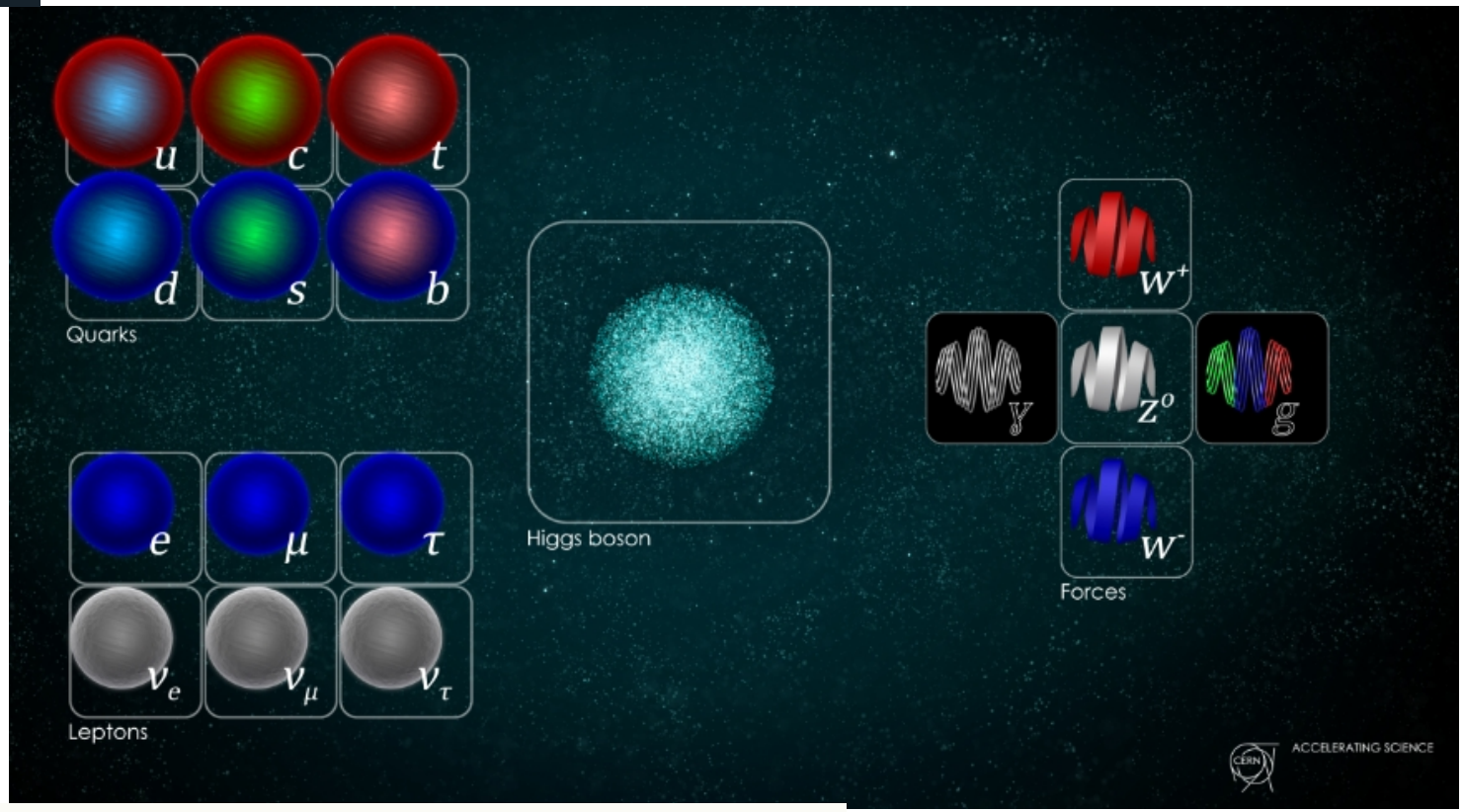
Prize amount: 12 million Swedish kronor.

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

"за вирішальний внесок у роботу нейтринної обсерваторії IceCube та відкриття нейтрино високих енергій астрофізичного походження”

The Standard Model

The Standard Model explains how the basic building blocks of matter interact, governed by four fundamental forces.



The relationship between them is parameterized by the Pontecorvo-Maki-Nakagawa-Sakata (PMNS) matrix U:

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

ν_e, ν_μ, ν_τ — are *flavor eigenstates*.

ν_1, ν_2, ν_3 — are *mass eigenstates*.

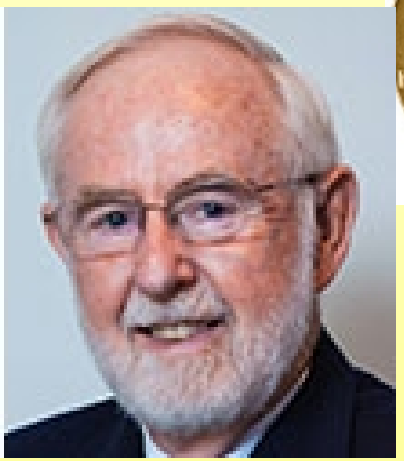
https://home.cern/science/physics/standard-model/
https://www.neutrino-physics.com/blog/neutrino-flavors/

Нобелівська премія з фізики 2015

KUNGL. VETENSKAPSAKADEMIEN
THE ROYAL SWEDISH ACADEMY OF SCIENCES







Такаакі Кадзіта
(Takaaki Kajita, University of Tokyo, Kashiwa, Japan)
Артуру Макдоналду
(Arthur B. McDonald, Queen's University, Kingston, Canada)

"for the discovery of neutrino oscillations, which shows that neutrinos have mass"



"за відкриття взаємних перетворень нейтрино, яке доводить, що нейтрино мають масу"

Детектування нейтрино

Бета-захоплення (Кан-Чанг Ванг, 1942)

$$\bar{\nu}_e + p^+ \rightarrow n^0 + e^+ \rightarrow e^- + e^+ \rightarrow \gamma + \gamma$$

$$n + {}^{108}Cd \rightarrow {}^{109m}Cd \rightarrow {}^{109}Cd + \gamma$$





Wang Ganchang
(1907-1998)



Клайд Ковен



Фредерік Райнс

1956 (Los Alamos, Hanford, Savannah)

Нобелівська премія 1995
"for the detection of the neutrino and pioneering experimental contributions to lepton physics"



1962



Leon M. Lederman
Fermi National Accelerator Laboratory, Batavia, Illinois, USA

Melvin Schwartz
Digital Pathways Inc., Mountain View, California, USA

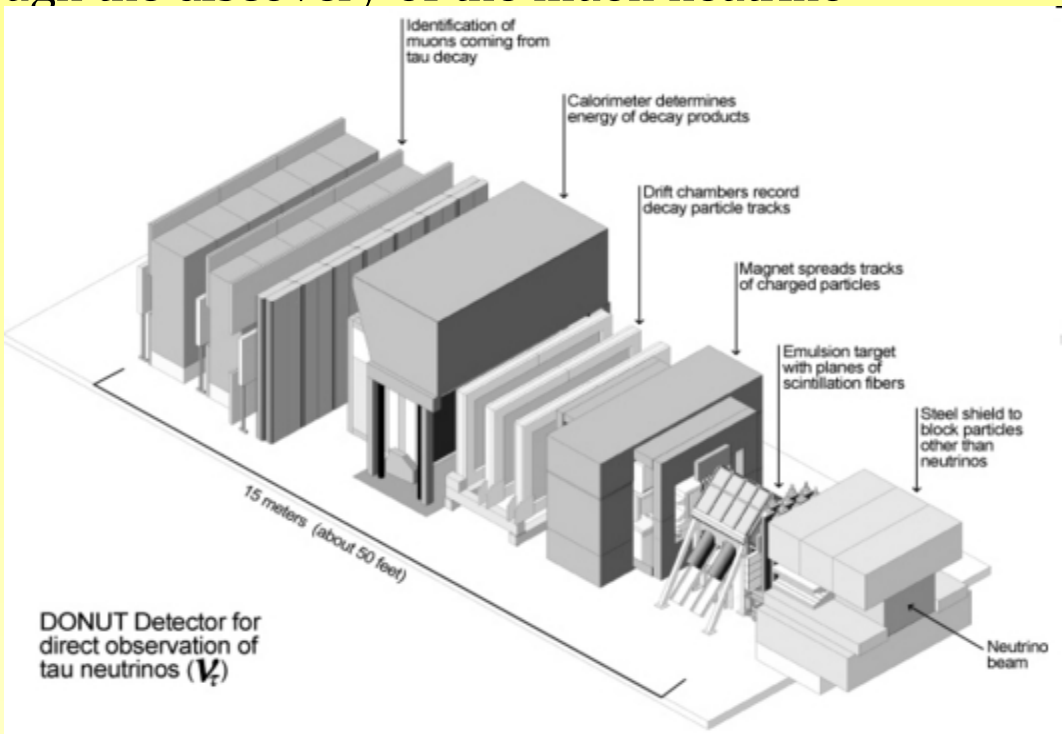
Jack Steinberger
CERN, Geneva, Switzerland

1988 Nobel Prize in Physics "for the neutrino beam method and the demonstration of the doublet structure of the leptons through the discovery of the muon neutrino"



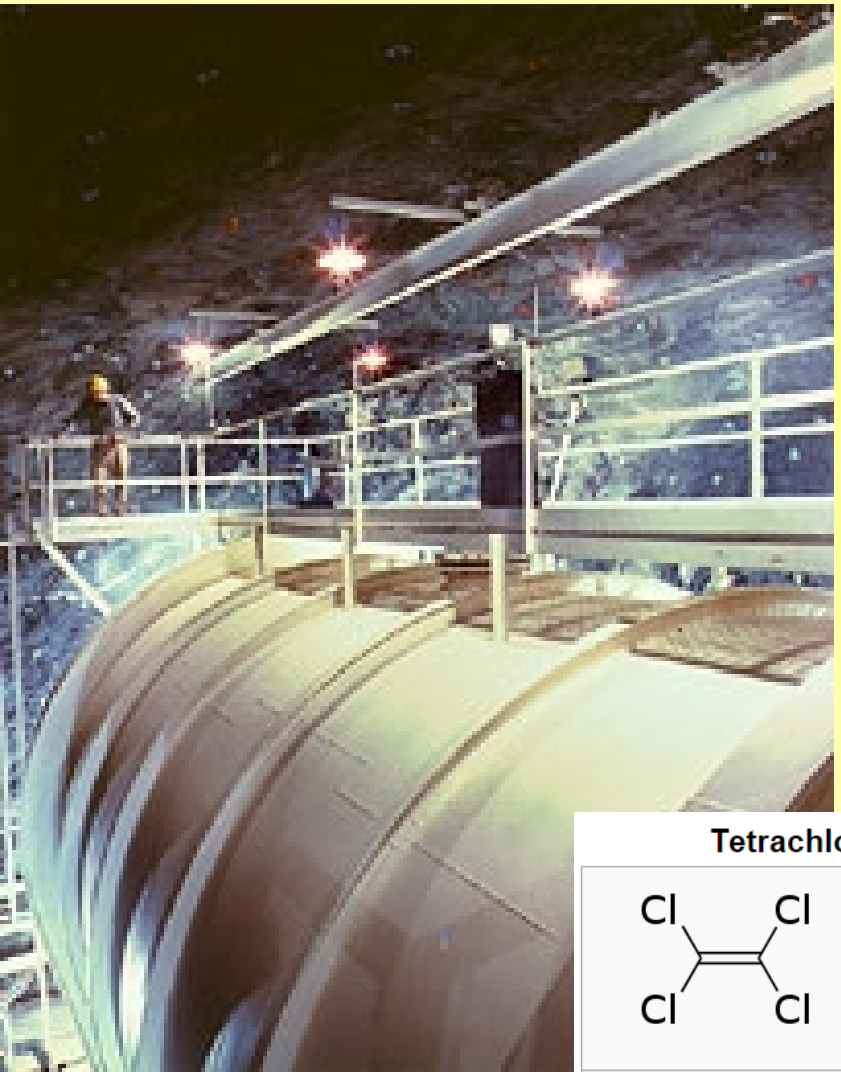
1997-2000

Direct **O**bservation of the **NU** **Tau** (DONUT) collaboration



Homestake experiment та *Solar neutrino problem*

$$\nu_e + {}^{37}\mathrm{Cl} \longrightarrow {}^{37}\mathrm{Ar} + e^-$$





Raymond Davis, Jr.

(1914-2006)

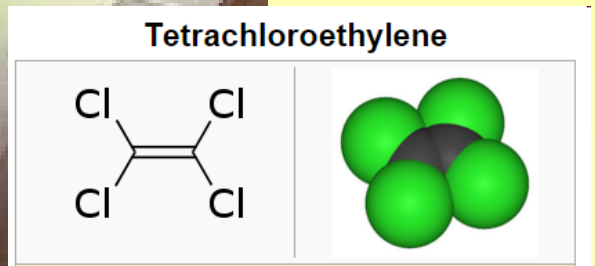


John N. Bahcall

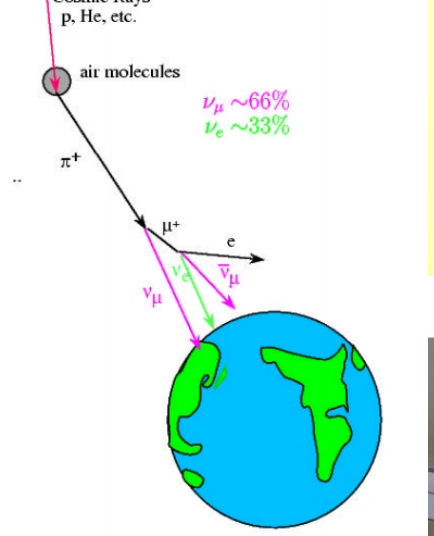
(1934-2005)

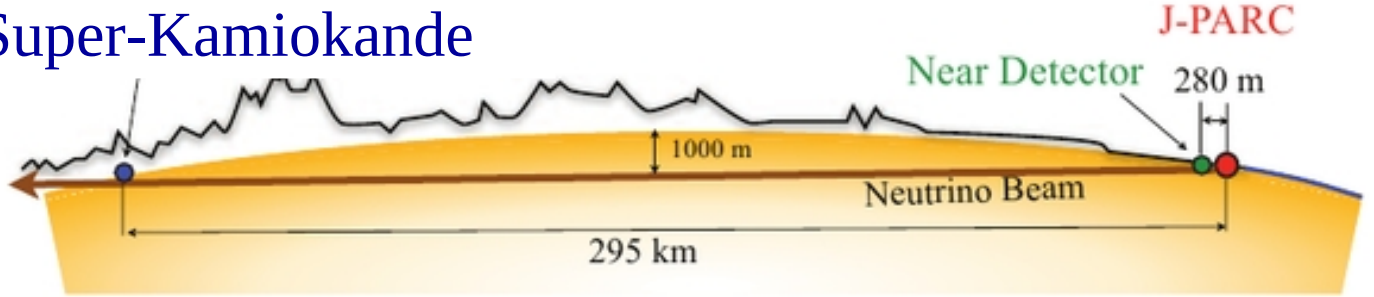
Нобелівська премія 2002
"for pioneering contributions
to astrophysics, in particular for the
detection of cosmic neutrinos“

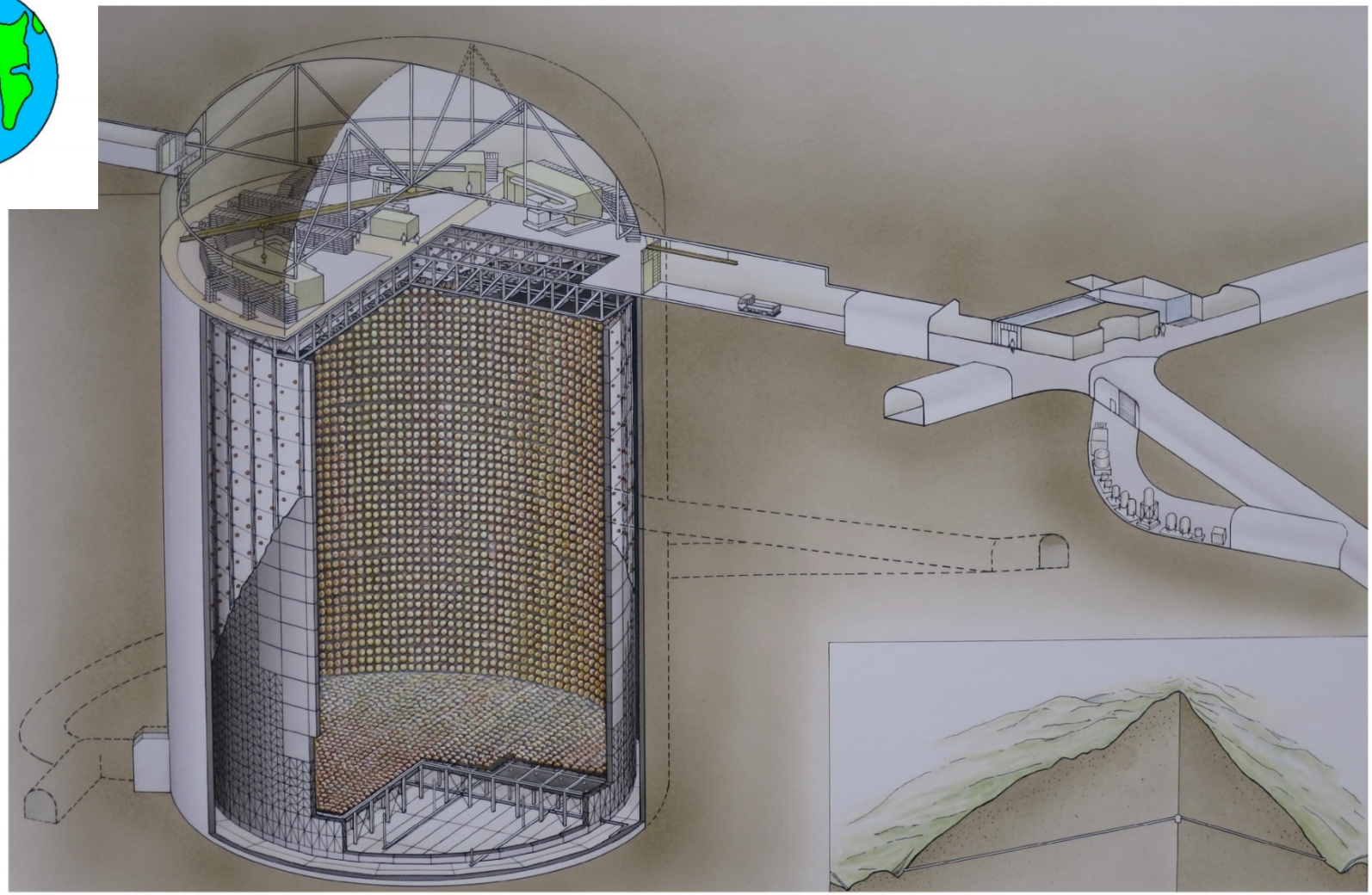
Разом з Masatoshi Koshiba (Kamiokande II)



Super-Kamiokande





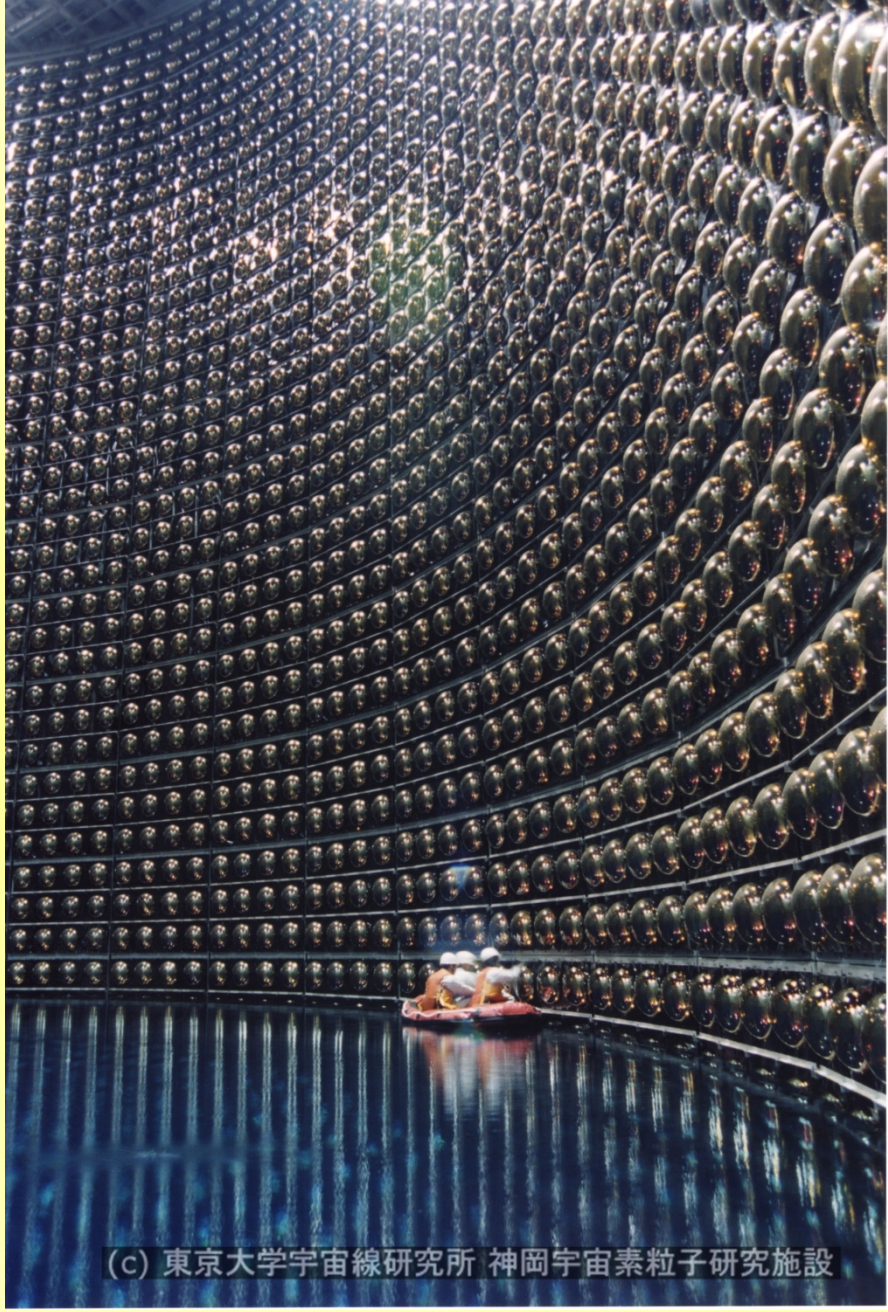


SUPERKAMIOKANDE INSTITUTE FOR COSMIC RAY RESEARCH UNIVERSITY OF TOKYO

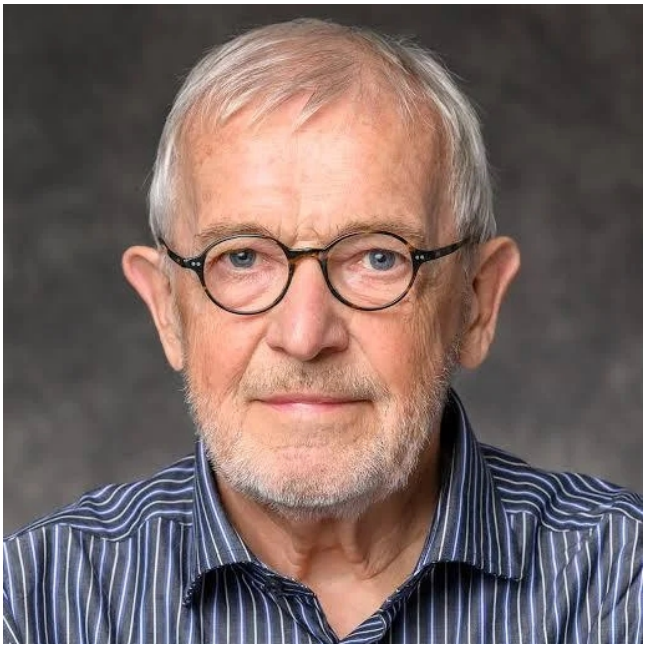
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NIKKEN SEKKEI





©Kamioka Observatory, ICRR (Institute for Cosmic Ray Research), The University of Tokyo



Francis Halzen

Born: 1944 in Tienen, Belgium.

Affiliation at the time of the award: University of Wisconsin–Madison, USA.

Professor Emeritus, Department of Computer Science

- Master's degree 1966 KU-Leuven, Belgium
- PhD 1969 from KU Leuven, Belgium
- Agrégé de l'Enseignement Supérieur, KU-Leuven, Belgium

Francis Halzen

Gregory Breit Professor and Vilas Research Professor

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Chamberlin Hall 5293

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Cell Number:	*Suite 500*
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Fax Number:	*UNITED STATES*
608-262-8628	

https://user-web.icecube.wisc.edu/~halzen/
https://www.physics.wisc.edu/directory/halzen-francis/
https://icecube.wisc.edu/



Fellowships

1994: Fellow of the American Physical Society
2013: Breakthrough of the Year Award by the journal Physics World for the first-time discovery of cosmic neutrinos beyond the Milky Way
2015: Balzan Prize
2015: Giuseppe and Vanna Cocconi Prize of the European Physical Society
2018: Bruno Pontecorvo Prize for significant contribution to the IceCube detector construction and experimental discovery of high-energy astrophysical neutrinos.
2019: Yodh Prize of IUPAP
2021: Homi Bhabha Medal and Prize of IUPAP and TIFR
2024: Elected to National Academy of Sciences
2026: APS Medal for Exceptional Achievement in Research

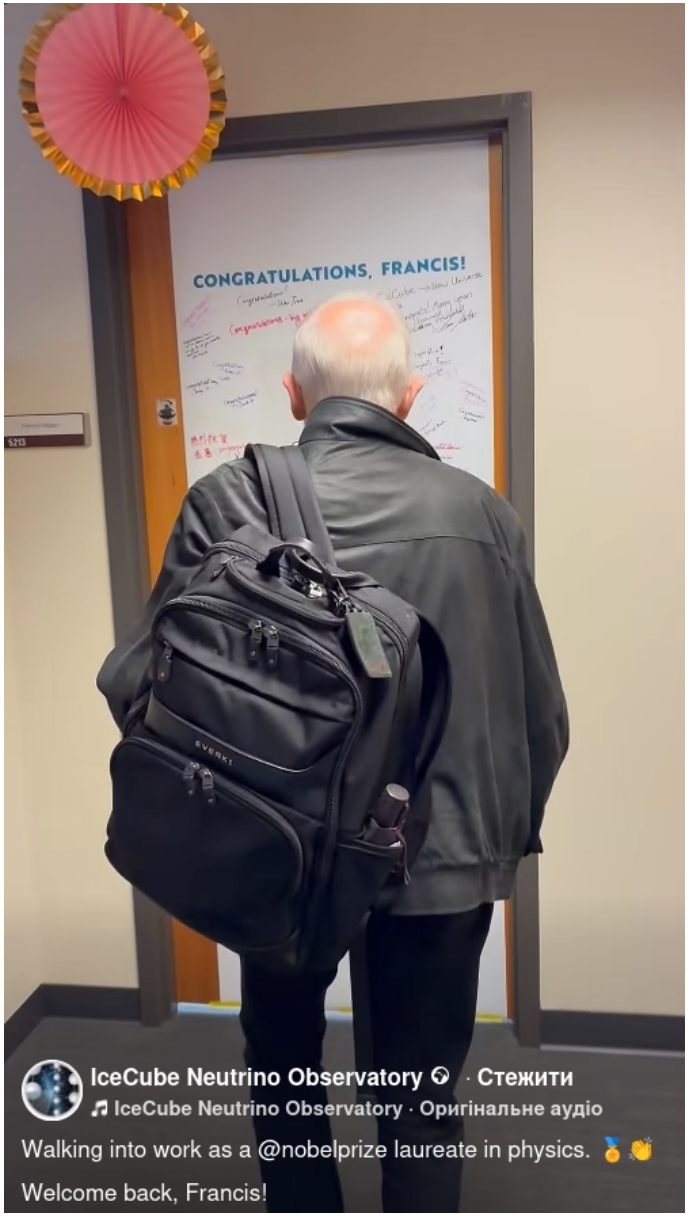
The Balzan Fellowship in His Honor: Established in 2015 at the Wisconsin IceCube Particle Astrophysics Center (WIPAC):

Marjon Moulai

Daan van Eijk (2017-2019)

https://www2.wipac.wisc.edu/people/fellows

https://www.physics.wisc.edu/wp-content/uploads/2026/02/FH_shortCV_02192026.pdf





> The Nobel Prize awarded to Francis Halzen is an exceptional recognition of a scientist who, through ambition, determination, and international collaboration, has broadened our understanding of the universe. The fact that his scientific career began in Leuven is a source of great pride for us. On behalf of the entire University community, we congratulate him on this historic award.
>
> *Rector Severine Vermeire*

Photo: Rector Vermeire with Emeritus Professor Frans Cerulus, Francis Halzen's PhD supervisor. In the back row, from left to right: Emeritus Professor Walter Troost, Emeritus Professor Raymond Gastmans, and Emeritus Professor Toine Van Proeyen, who all obtained their PhD together with Francis Halzen.

Halzen was born in Tienen and studied physics in Leuven. He obtained both his master's degree (1966) and his PhD (1969) at our University. After his studies Leuven, he moved to the United States. He has been affiliated with the University of Wisconsin–Madison since 1972.

https://nieuws.kuleuven.be/en/content/2026/ku-leuven-alumnus-francis-halzen-nobel-prize-physics

Нобелівська премія з фізики 2026



Experience

1996	Science Associate at CERN, Geneva, Switzerland
1987	NSF – Japan U.S. exchange, Univ. Tokyo, Japan
1985	Scientific Associate at CERN, Geneva, Switzerland
1983	Fellow of the Japan Society for the Promotion of Science, U of Tokyo
1982	Visiting Professor at the University of Durham, UK
1982	Nordita Professor at the University of Helsinki
1977–1983	Lector at the University of Louvain, Belgium
1980	Visiting Professor at the University of Hawaii-Honolulu
1977	Consultant at the Rutherford High Energy Laboratory, Oxford, UK
1977	Visiting Scientist at CERN, Geneva, Switzerland
1971–1983	Chercheur Agrégé of the National Science Foundation, Belgium
1969–1971	Scientific Associate at CERN, Geneva, Switzerland
1968–1969	Research Associate of the National Science Foundation, Belgium

https://user-web.icecube.wisc.edu/~halzen/CV/FH_longCV_03112025.pdf



Summer and Short-Term Positions

2012–13	Aspen Institute for Physics
2007	Summer program, CERN, Geneva, Switzerland
2007	Scientific Associate at CERN, Geneva, Switzerland
1988	Visiting Professor at the University of Durham, UK
1987	Visiting Professor at the University of Durham, UK
	Visitor in Joint Particle Physics & Astrophysics Program at Johns Hopkins University, Baltimore, MD
	NSF Japan – US Exchange, University of Tokyo, Japan
1984	Visiting Professor at the University of Durham, UK
1981	Visiting Senior Scientist of the Science Research Council at the University of Durham, UK
1980	Visiting Scientist at LRL, University of California-Berkeley
1975	Associate Scientist at the Brookhaven National Laboratory, Upton, NY
1974–1975	Consultant at the Argonne National Laboratory, Chicago, IL
1974	Consultant at Fermilab, Batavia, IL

https://user-web.icecube.wisc.edu/~halzen/CV/FH_longCV_03112025.pdf



University of Wisconsin–Madison Positions

2021–present	Vilas Research Professor
2001–present	Principal Investigator and co-Spokesperson for the IceCube project
1987–present	Gregory Breit Distinguished Professor
1984–present	Director of the Institute for Elementary Particle Physics Research
1991–2021	Hilldale Professor
2013–2014	Acting Director of the Wisconsin IceCube Particle As
1977	Romnes Faculty Fellow
1977	Professor
1974	Associate Professor
1972	Assistant Professor
1971	Research Associate

Courses Taught by Year

Academic Year	Course # (Fall)	Course # (Spring)
1972 – 73	--	731
1973 – 74	732	107
1974 – 75	107	103
1975 – 76	104	103
1976 – 77	104	--
1977 – 78	107	202
1978 – 79	208	--
1979 – 80	202	170 (U of Hawaii)
1980 – 81	801	--
1981 – 82	109	735
1983 – 84	109	735
1984 – 85	107	109
1985 – 86	109	103
1986 – 87	--	735
1987 – 88	109	505
1988 – 89	109	109
1989 – 90	109	801
1990 – 91	735	109
1991 – 92	--	735
1992 – 93	835	109
1993 – 94	835	109
1994 – 95	835	835
1995 – 96	801	109
1996 – 97	109	109
1997 – 98	109	109
1998 – 99	801	--
1999 – 2000	109	--
2003 – 04	--	107
2004 – 05	805	109
2006 – 07	109	--
2007 – 08	109	--
2008 – 09	805	--
2009 – 10	107	--
2010 – 11	107	--
2011 – 12	--	107
2014 – 15	--	535
2015 – 16	--	535
2016 – 17	--	107
2019 – 20	109	--

https://user-web.icecube.wisc.edu/~halzen/CV/FH_longCV_03112025.pdf

Halzen, Francis

College of Letters & Science, Madison, United States • Scopus ID: 16482562900 • 0009-0006-4013-4611

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Multi-messenger observations of a binary neutron star merger — 3,896 Citations

Abbott, Benjamin P.,Abbott, Richard,Abbott, Thomas D.,... Fender, Robert P.,Woudt, P. A.

Astrophysical Journal Letters, 2017, 848(2), L12

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Article

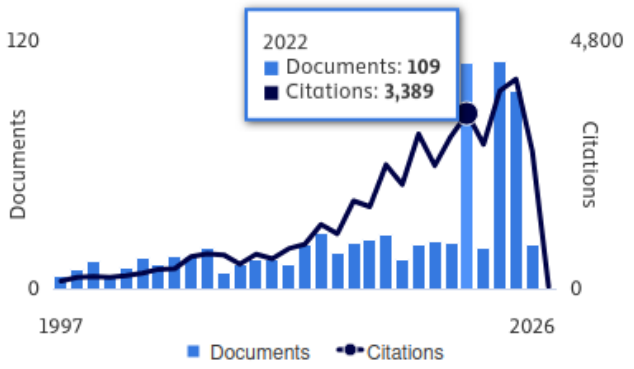
Evidence for high-energy extraterrestrial neutrinos at the icecube detector — 1,614 Citations

Aartsen, M. G.,Abbasi, Rasha U.,Abdou, Yasser,... Zierke, Simon,Zoll, Marcel

Science, 2013, 342(6161), 1242856

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Document & citation trends



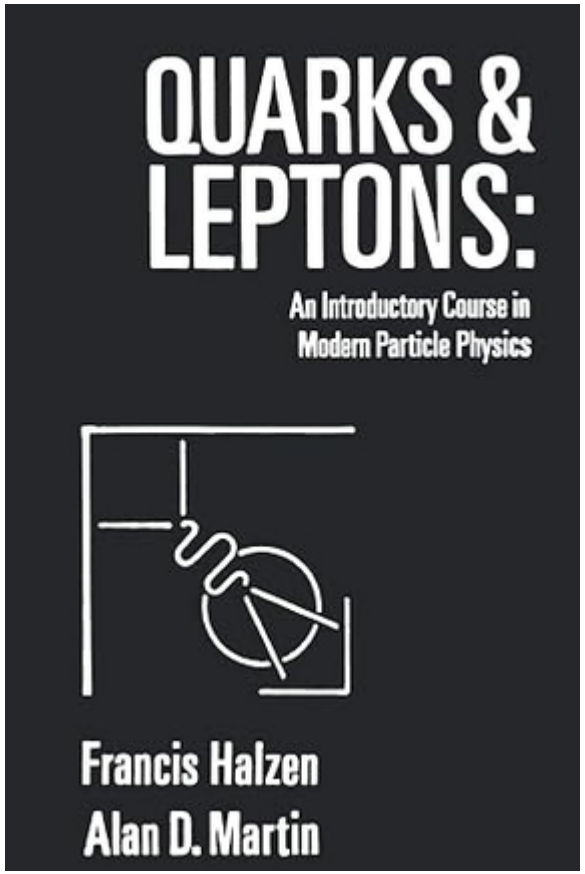
Citation overview | Analyze author output

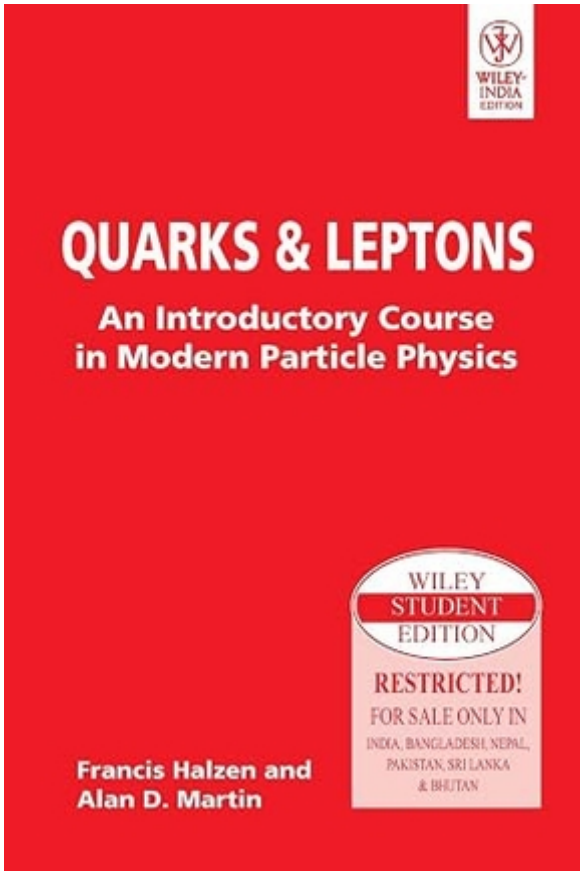
https://www.scopus.com/authid/detail.uri?authorId=16482562900

QUARKS AND LEPTONS:
An Introductory Course in Modern Particle Physics

Francis Halzen
University of Wisconsin
Madison, Wisconsin

Alan D. Martin
University of Durham
Durham, England





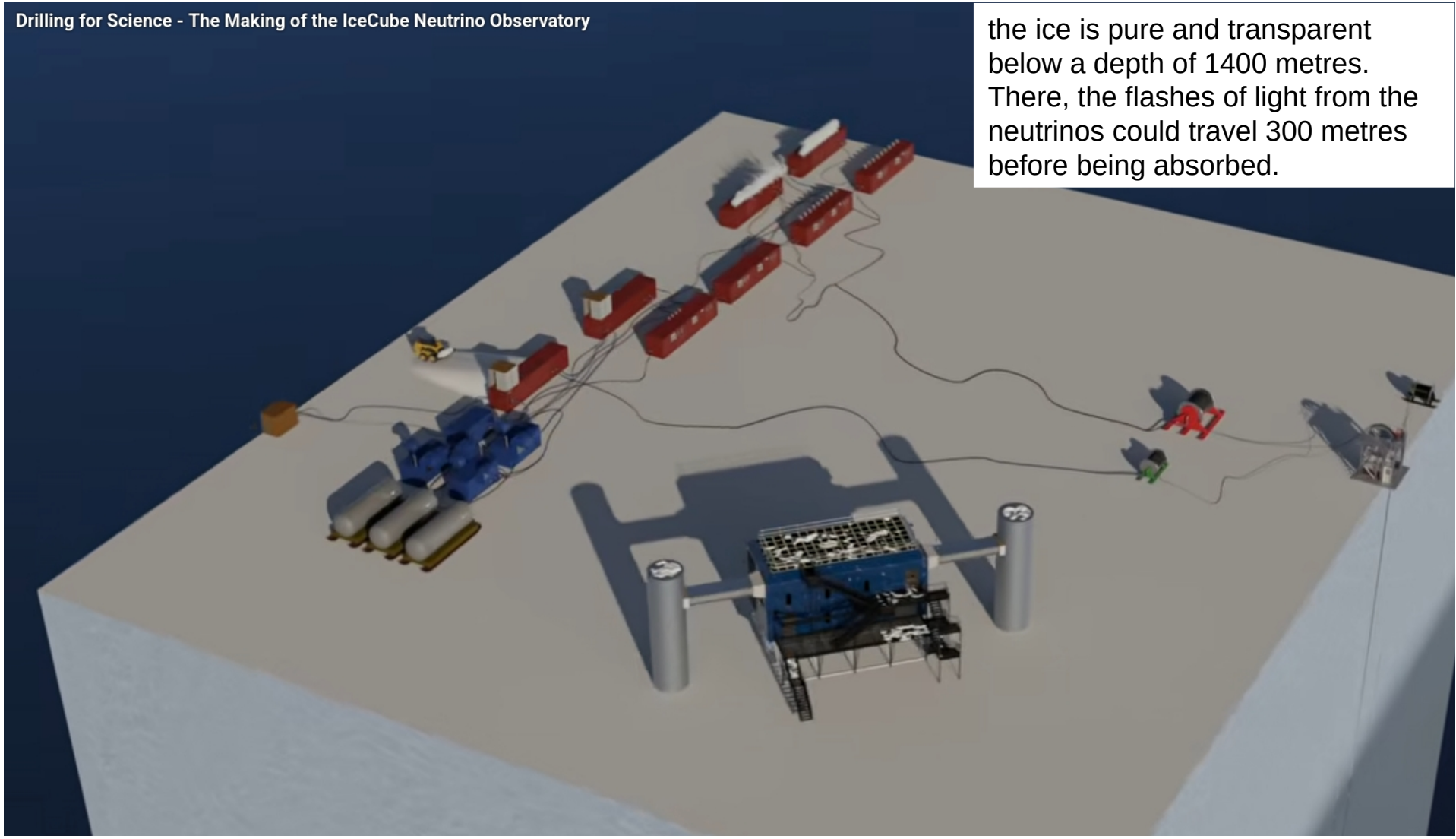
Quarks and Leptones: An Introductory Course in Modern Particle Physics by Francis Halzen, Alan D. Martin, 1984

The IceCube Neutrino Observatory in 2023 Christopher Michel via Wikimedia Commons under CC-BY-SA-4.0



https://www.smithsonianmag.com/smart-news/physicist-wins-nobel-prize-for-developing-a-massive-ice-embedded-observatory-that-detects-ghostly-cosmic-particles-180989627/

1992 - the first attempts to lower light sensors into the glacier at the South Pole,
... IceCube was finished in 2011

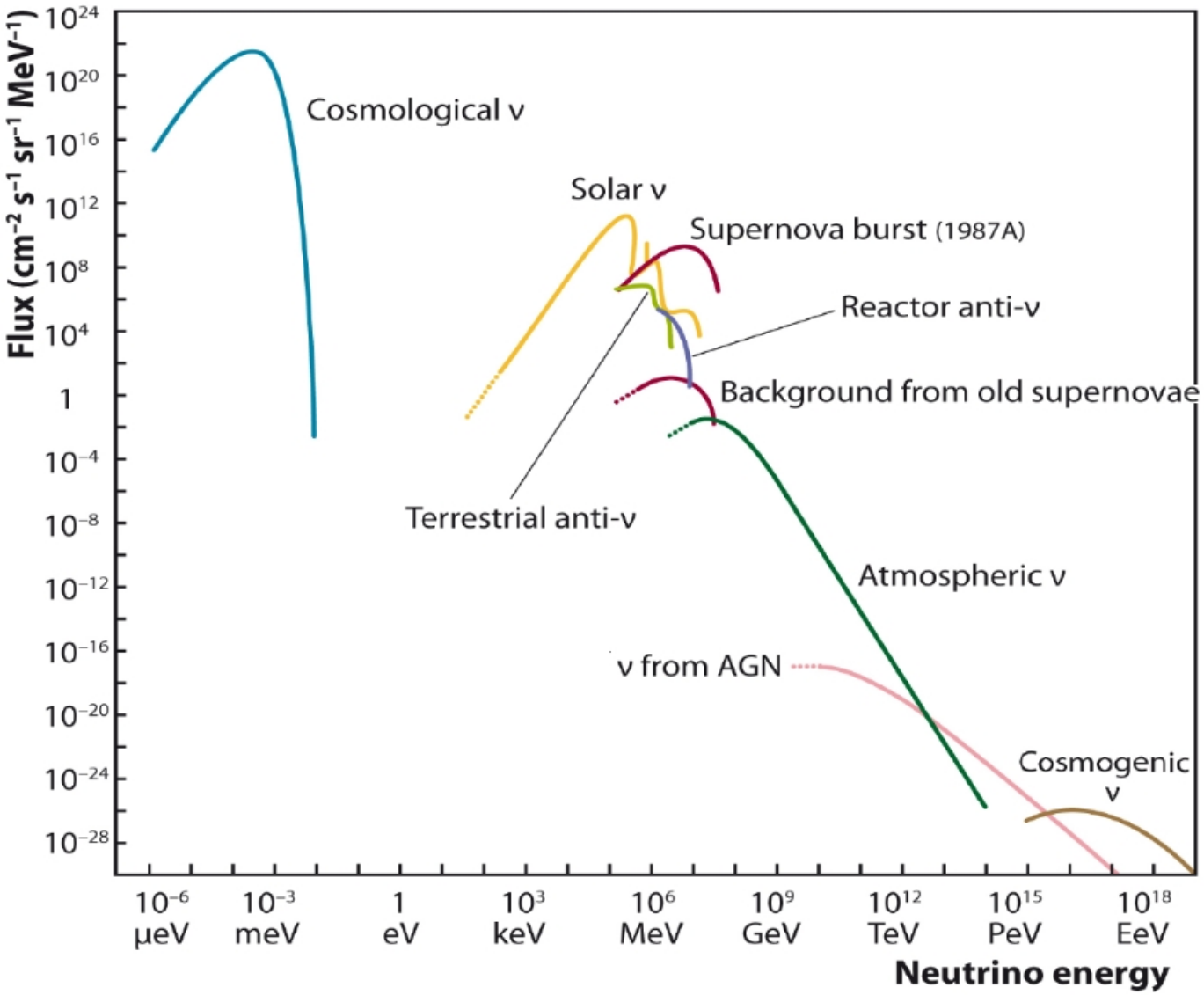


the ice is pure and transparent below a depth of 1400 metres. There, the flashes of light from the neutrinos could travel 300 metres before being absorbed.

https://www.youtube.com/watch?v=ENNIgli_k8o



https://www.youtube.com/watch?v=7PhX9NFSKBc



https://arxiv.org/pdf/1207.4952v1

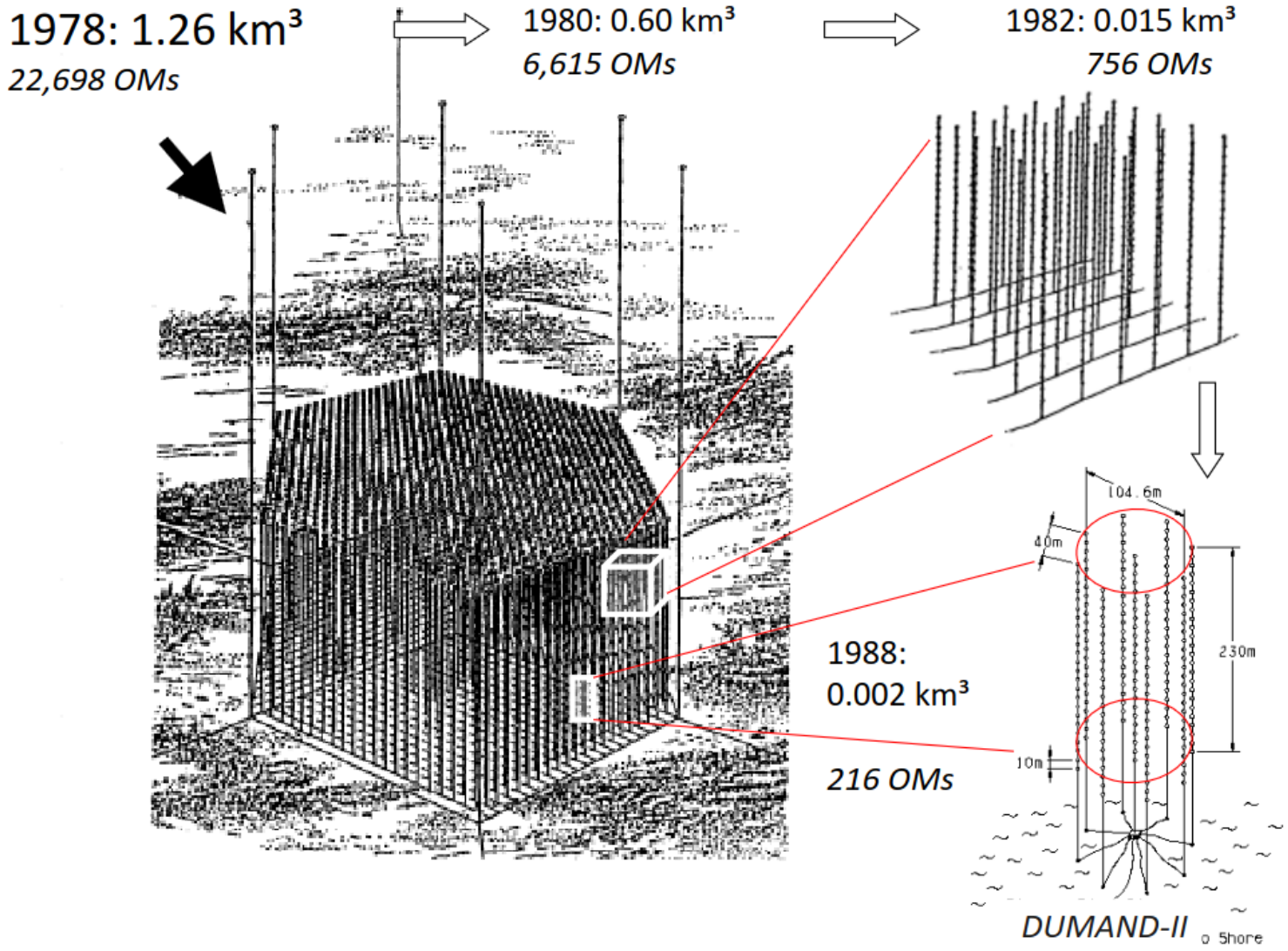
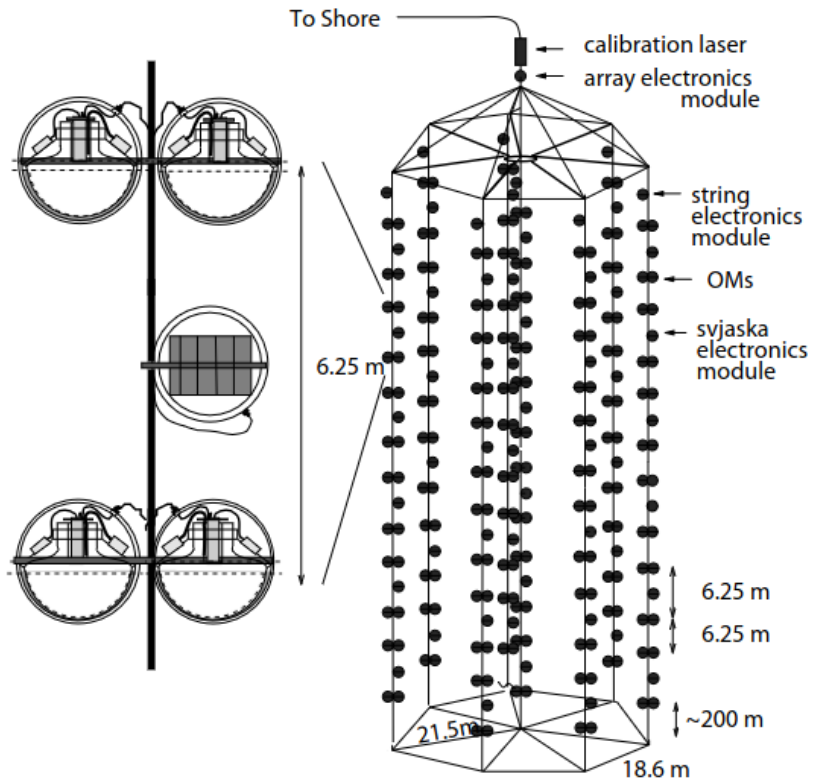
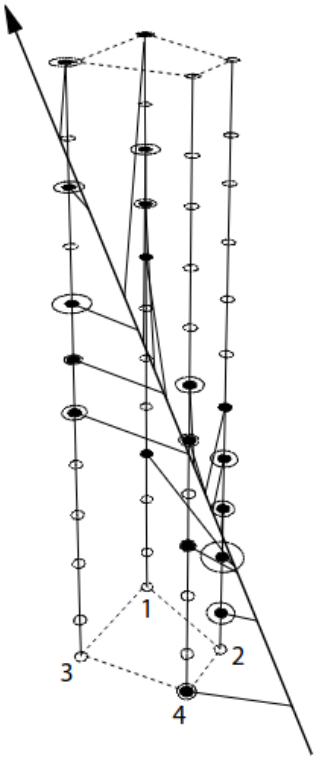


Fig. 4. The originally conceived DUMAND cubic kilometer detector and the phased downgrading to the 1988 plan for a first-generation underwater neutrino telescope DUMAND-II.

https://arxiv.org/pdf/1207.4952v1

Baikal Neutrino Telescope NT200.





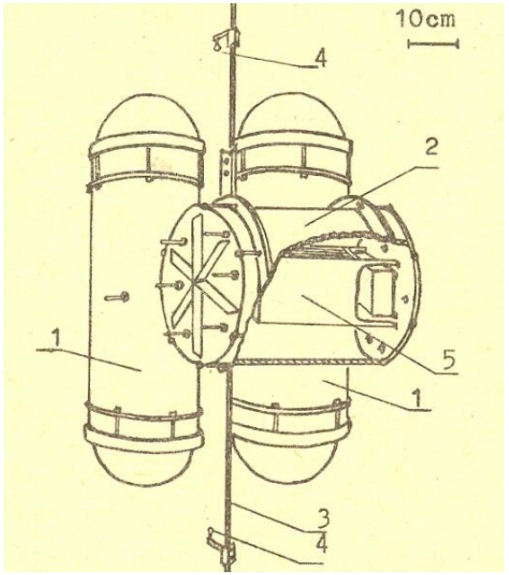


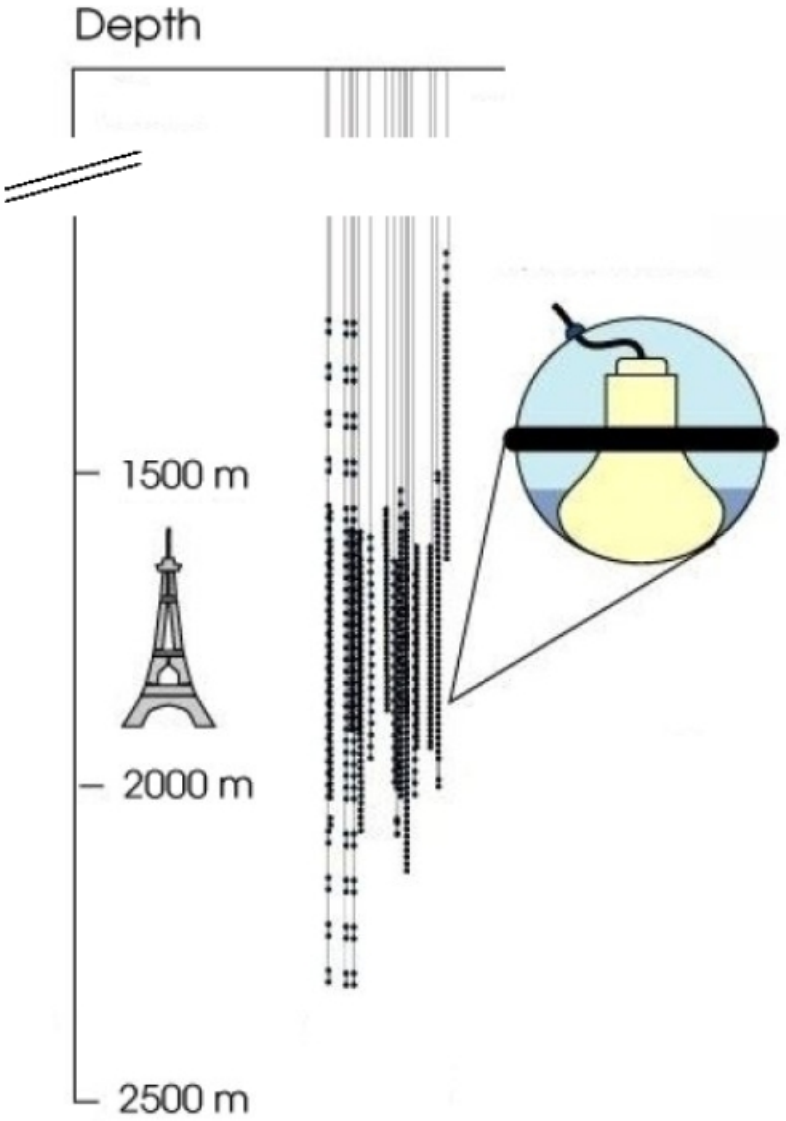
Fig. 7. A *"svjaska"* (Russian for "bundle") as used in GIRLANDA-86 for the monopole search, with 4 PMTs in 2 cylinders (1) covered by hemispheric plexiglass caps. The "backpack" module (2) contains electronics (5). Calibration LEDs (4) are fixed at the geophysical cable (3).

Fig. 9. Left: The Baikal Neutrino Telescope NT200. Right: One of the first upward moving muons from a neutrino interaction recorded with the 4-string stage of the detector in 1996 [Balkanov 1999]. The Cherenkov light from the muon is recorded by 19 channels.

The non-Russian contributions all came from DESY: the laser time calibration system, transputer farm in the shore station for fast data processing, an online monitoring system and a special underwater trigger tailored to register slowly moving very bright particles, not to mention the supply of Western electronics and glass spheres.

https://arxiv.org/pdf/1207.4952v1

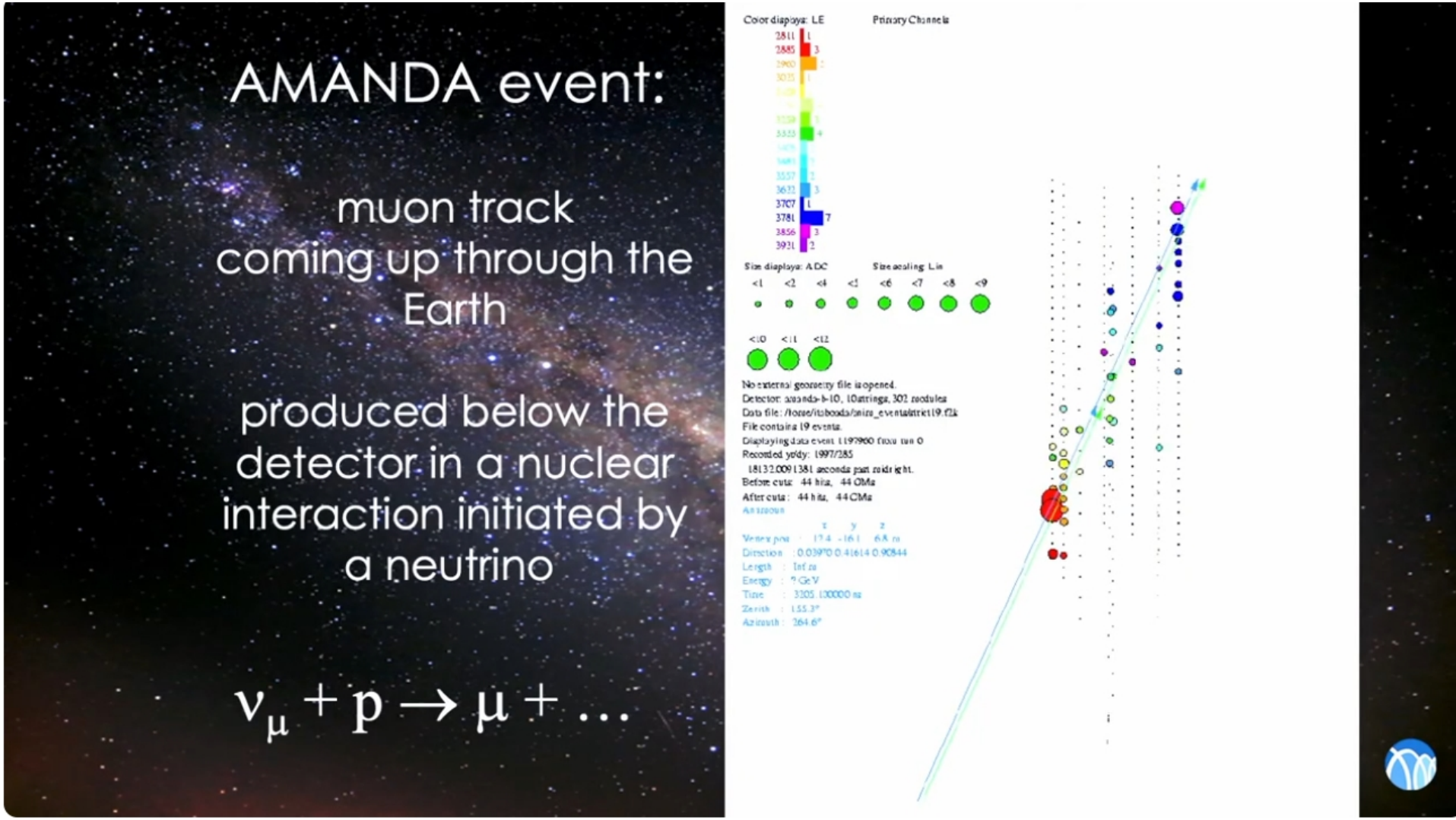
AMANDA (80 optical modules on four strings at depths between 800 and 1000 m)



switched off in April 2009, after more than 9 years of data taking

Fig. 11. The AMANDA configuration. The detector consisted of 677 optical modules at 19 strings. Three of the strings have been sparsely equipped towards larger and smaller depth in order to explore ice properties, one string got stuck during deployment at too shallow depth and was not used in analyses. The Eiffel tower is shown to scale for size comparison.

https://arxiv.org/pdf/1207.4952v1



PSW 2466 ICE CUBE The Under the Ice Neutrino Observatory in Antarctica | Francis Halzen

https://youtu.be/7PhX9NFSKBc?t=647

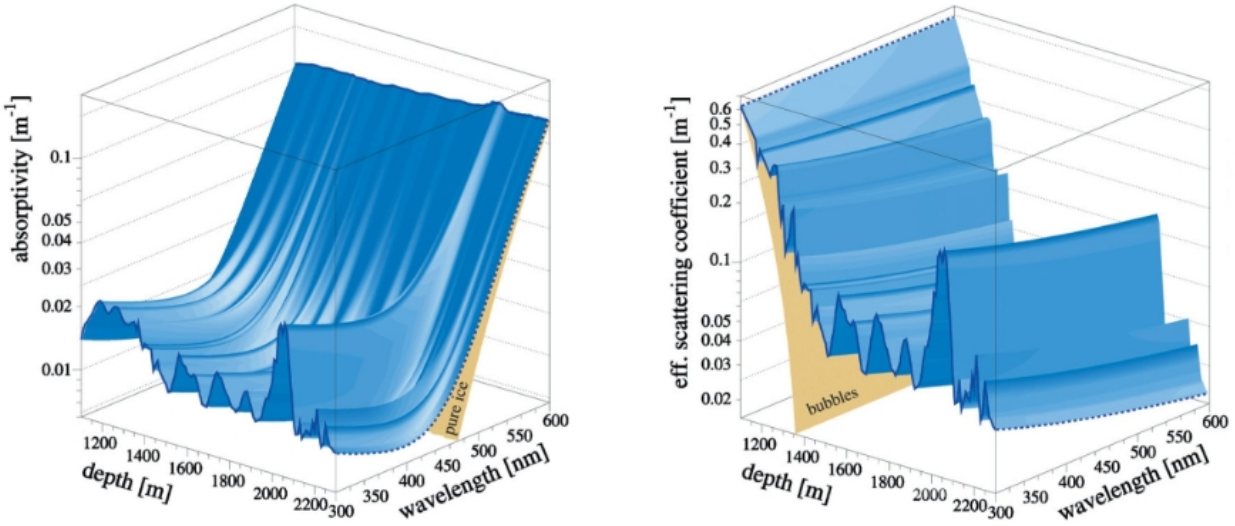


Fig. 12. Absorption coefficient (left) and scattering coefficient (right) in the South Polar ice as functions of depth and wavelength [Ackermann 2006].

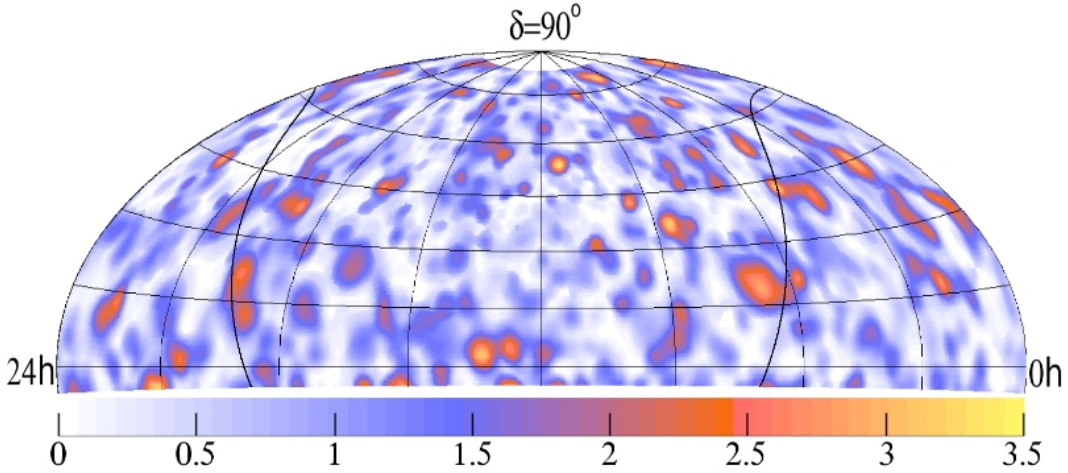


Fig. 13. 7-year significance map of the Northern hemisphere derived with AMANDA [Abbasi 2009].

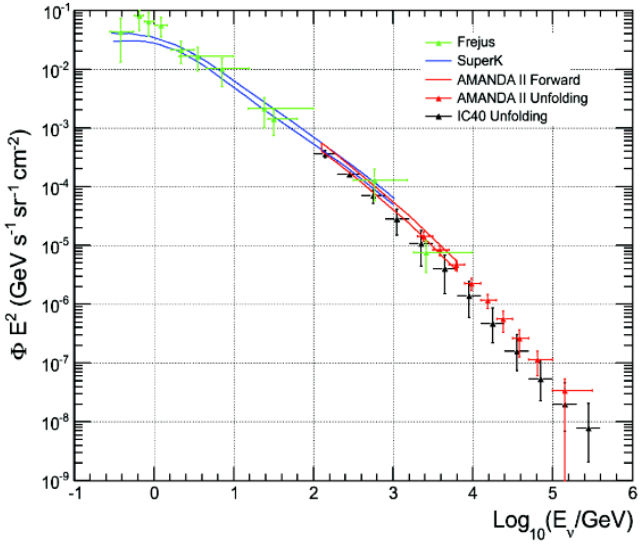
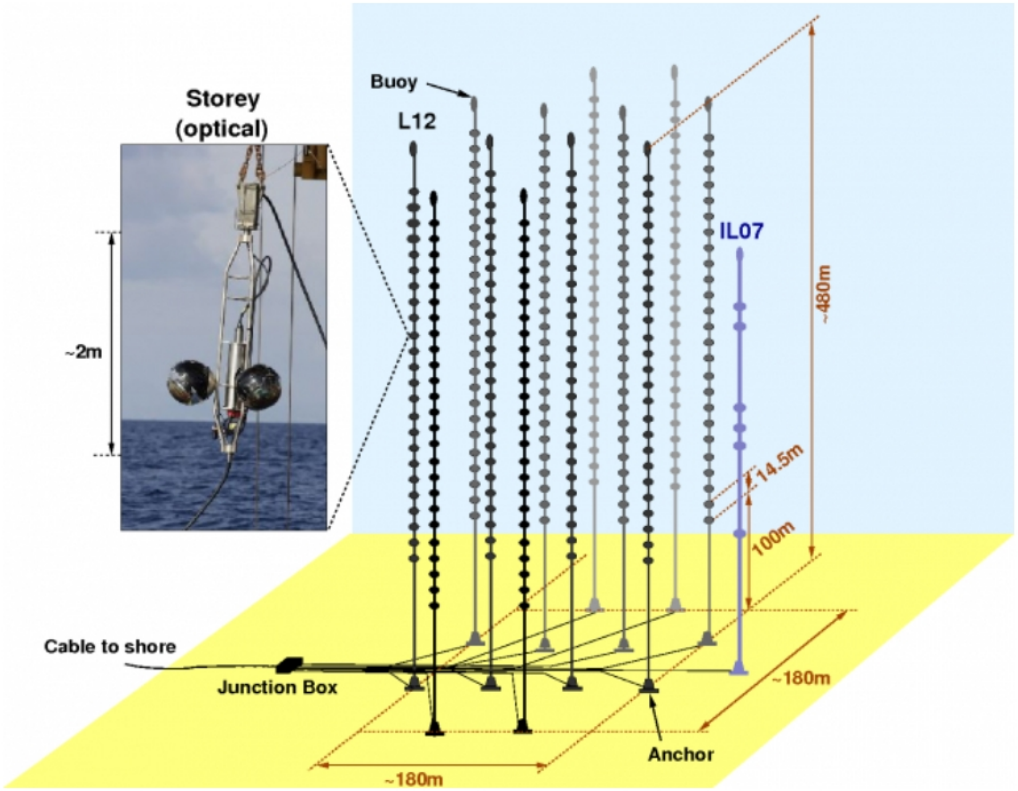


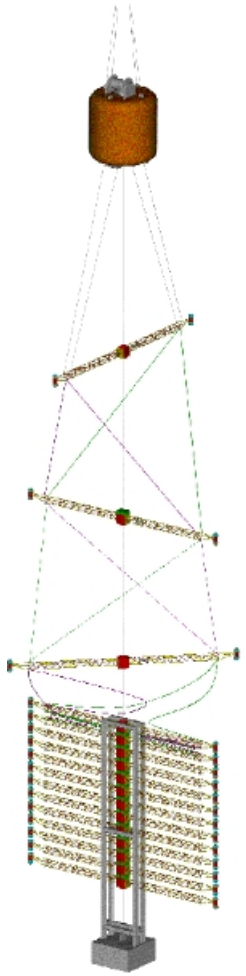
Fig. 14. Energy spectrum of atmospheric neutrinos [Abbasi 2011].

https://arxiv.org/pdf/1207.4952v1

Mediterranean Sea: NESTOR, ANTARES, NEMO



Schematic of the ANTARES detector - 12 strings
(Astronomy with a Neutrino Telescope and Abyss environmental RESearch)



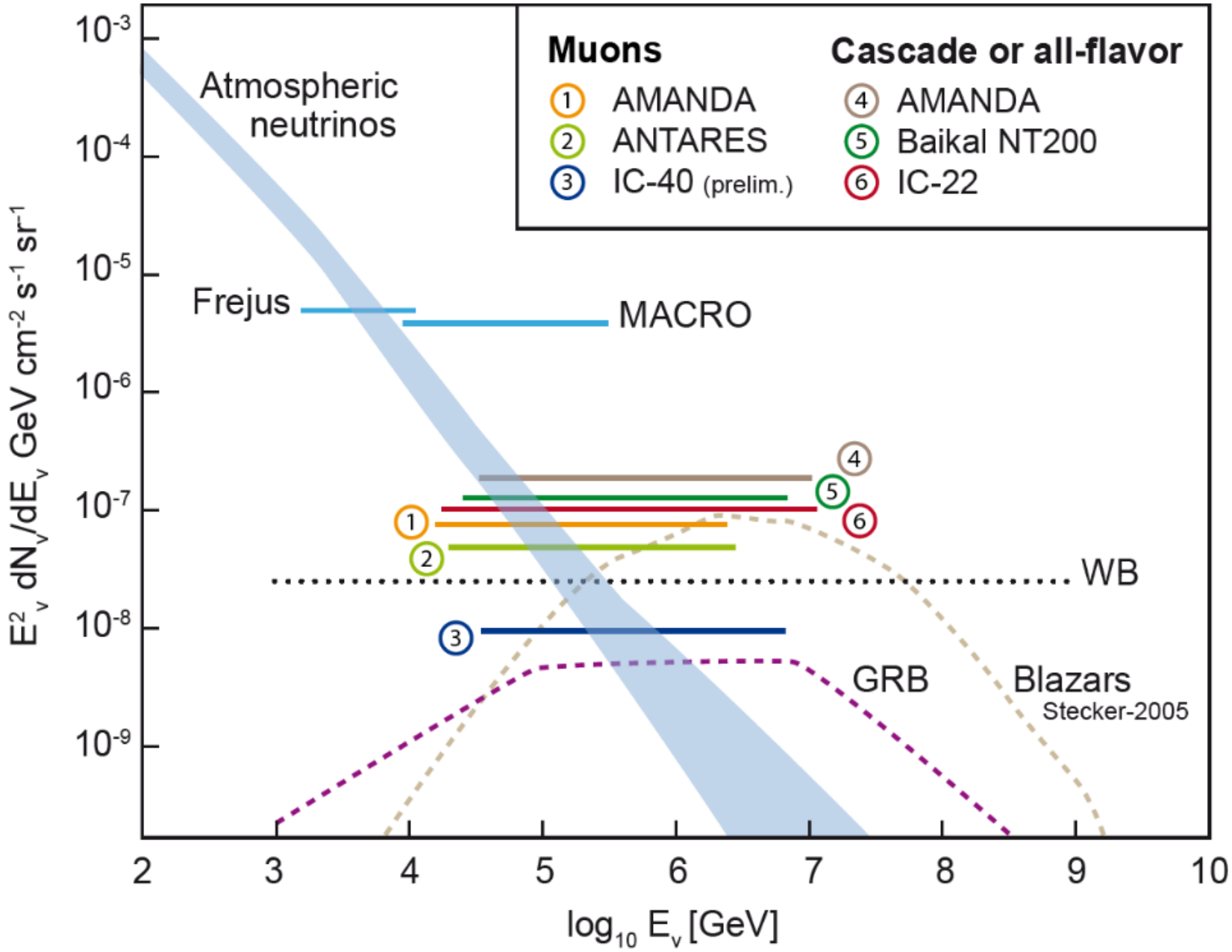
flexible NEMO tower

https://arxiv.org/pdf/1207.4952v1

Experiment	Location	Technique	Status
DUMAND	Hawaii	Water Cherenkov	turned down 1996
NT200+	Lake Baikal	Water Cherenkov	operating
GVD	Lake Baikal	Water Cherenkov	design phase
AMANDA	South Pole	Water Cherenkov	terminated 2009
IceCube	South Pole	Water Cherenkov	operating
ANTARES	Mediterranean	Water Cherenkov	operating
NESTOR	Mediterranean	Water Cherenkov	R&D for KM3NeT
NEMO	Mediterranean	Water Cherenkov	R&D for KM3NeT
KM3NeT	Mediterranean	Water Cherenkov	design phase
HIRES	USA	Air shower	terminated 2009
Auger	Argentina	Air shower	operating
TA	USA	Air shower	operating
JEM-EUSO	Satellite	Air shower	construction
ASHRA	Hawaii	air shower	partial operation
CRTNT	China	air shower	planned
ANITA	Antarctica (balloon)	Radio (ice)	flights continuing
RICE	South Pole	Radio (ice)	terminated
ARA	South Pole	Radio (ice)	construction stage 1
ARIANNA	Antarctic shelf	Radio (ice)	construction stage 1
SALSA	open	Radio (salt mine)	conceptual phase
SAUND	Caribbean Sea	Acoustic	terminated
SPATS	South Pole	Acoustic	test array operating
AMADEUS	Mediterranean Sea	Acoustic	test array operating
ONνDE	Mediterranean Sea	Acoustic	test array finished
Baikal	Lake Baikal	Acoustic	R&D
GLUE	USA	Radio (moon)	terminated
NUMOON	Netherlands	Radio (moon)	operating
Kalyzhin	Russia	Radio (moon)	operating
LORD	Satellite	Radio (moon)	planned
FORTE	Satellite	Radio (Earth)	terminated

Table 4. Instruments and R&D projects for high energy astrophysical neutrino detection

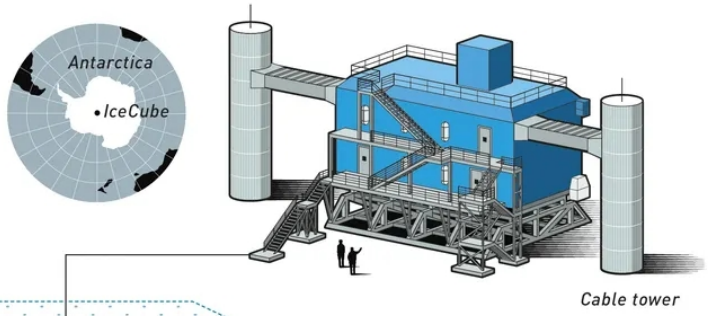
https://arxiv.org/pdf/1207.4952v1



https://arxiv.org/pdf/1207.4952v1

An observatory in the ice

IceCube is a cubic kilometre of ice equipped with light sensors on long cables, as well as a building on the surface where the signals from the ice are collected. Data are then forwarded via satellite for analysis.



PARTICLES AND LIGHT

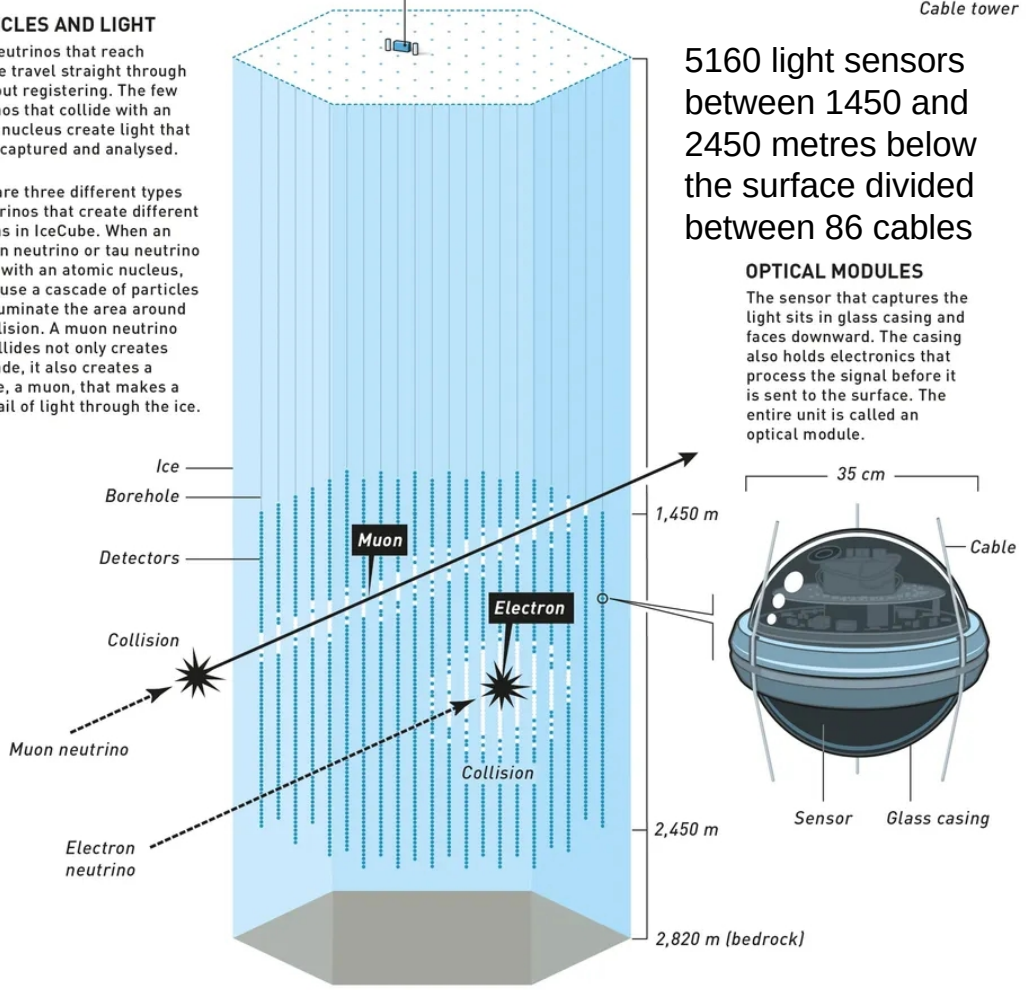
Most neutrinos that reach IceCube travel straight through it without registering. The few neutrinos that collide with an atomic nucleus create light that can be captured and analysed.

There are three different types of neutrinos that create different patterns in IceCube. When an electron neutrino or tau neutrino collide with an atomic nucleus, they cause a cascade of particles that illuminate the area around the collision. A muon neutrino that collides not only creates a cascade, it also creates a particle, a muon, that makes a long trail of light through the ice.

5160 light sensors between 1450 and 2450 metres below the surface divided between 86 cables

OPTICAL MODULES

The sensor that captures the light sits in glass casing and faces downward. The casing also holds electronics that process the signal before it is sent to the surface. The entire unit is called an optical module.



©Johan Jarnestad/The Royal Swedish Academy of Sciences



https://www.youtube.com/watch?v=xUBCvttShfA



The IceCube collaboration included about 450 international scientists at roughly 60 institutions as of January 2025.



A digital optical module of the K3MNeT collaboration telescope, which identified the high-energy neutrino. N. Busser / CNRS

https://www.smithsonianmag.com/smart-news/a-record-breaking-ghost-particle-from-outer-space-made-a-splash-of-light-in-the-mediterranean-180986062/?itm_source=related-content&itm_medium=parsely-api

digital optical module

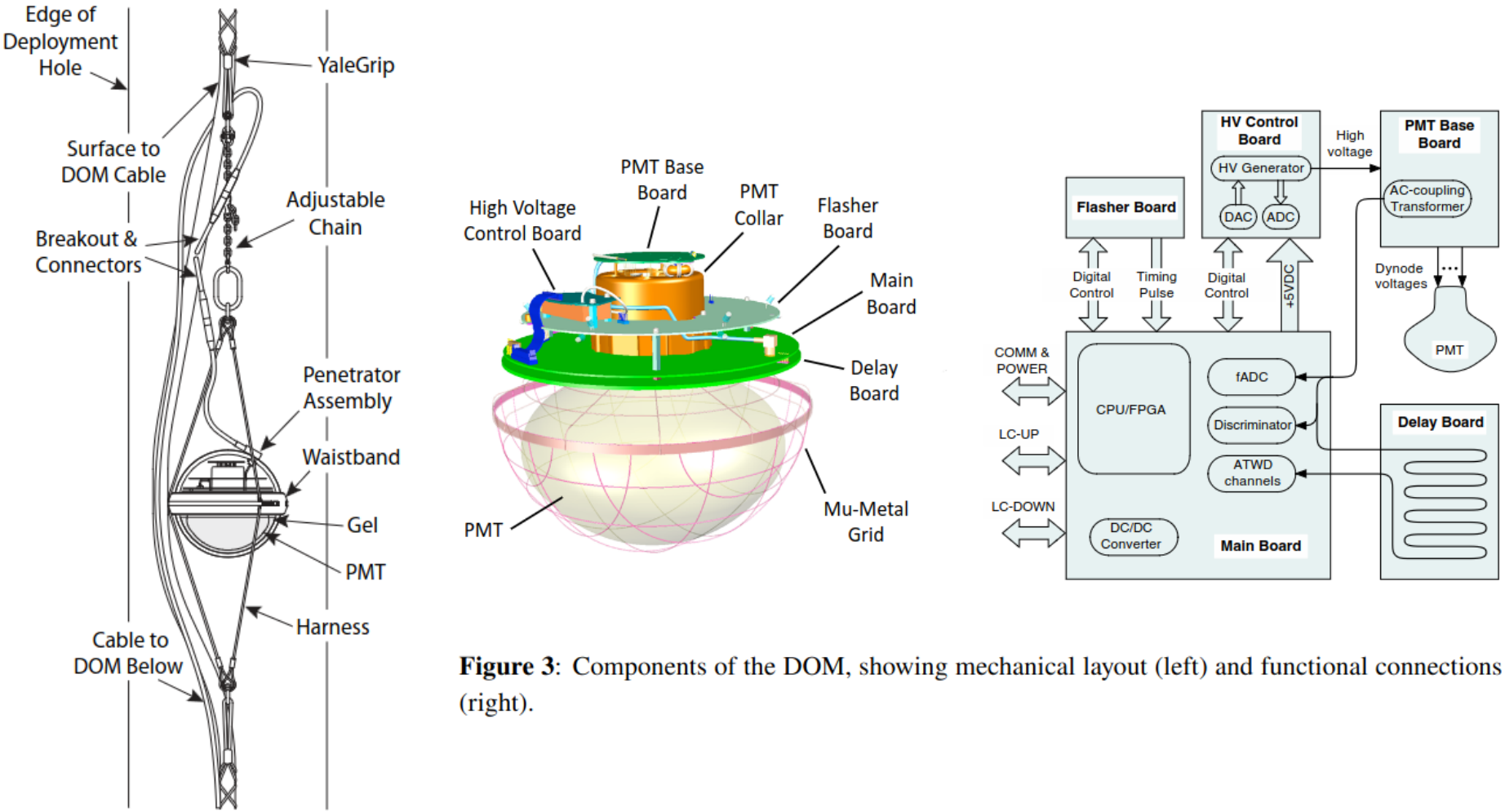


Figure 3: Components of the DOM, showing mechanical layout (left) and functional connections (right).

https://arxiv.org/pdf/1612.05093

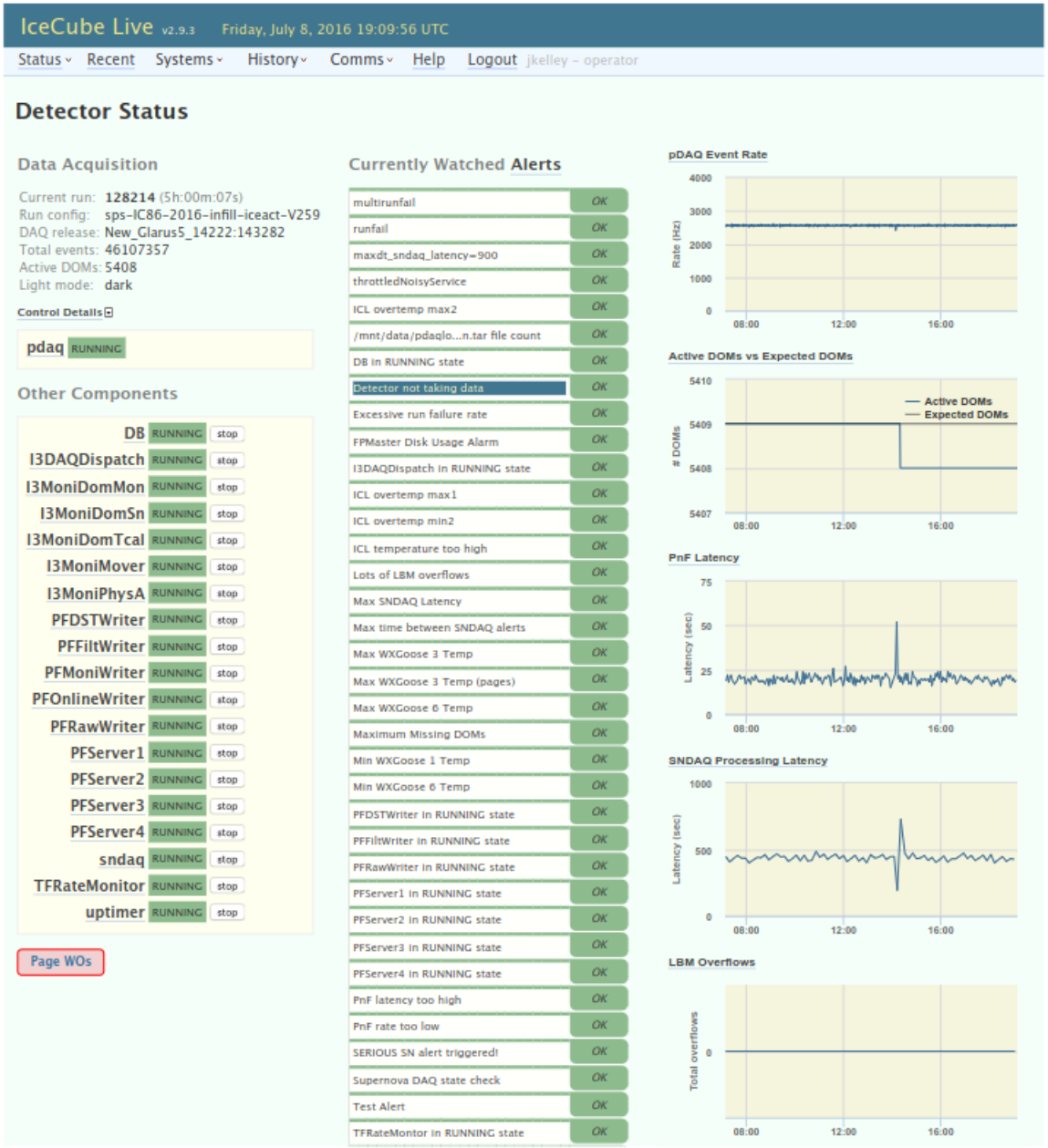
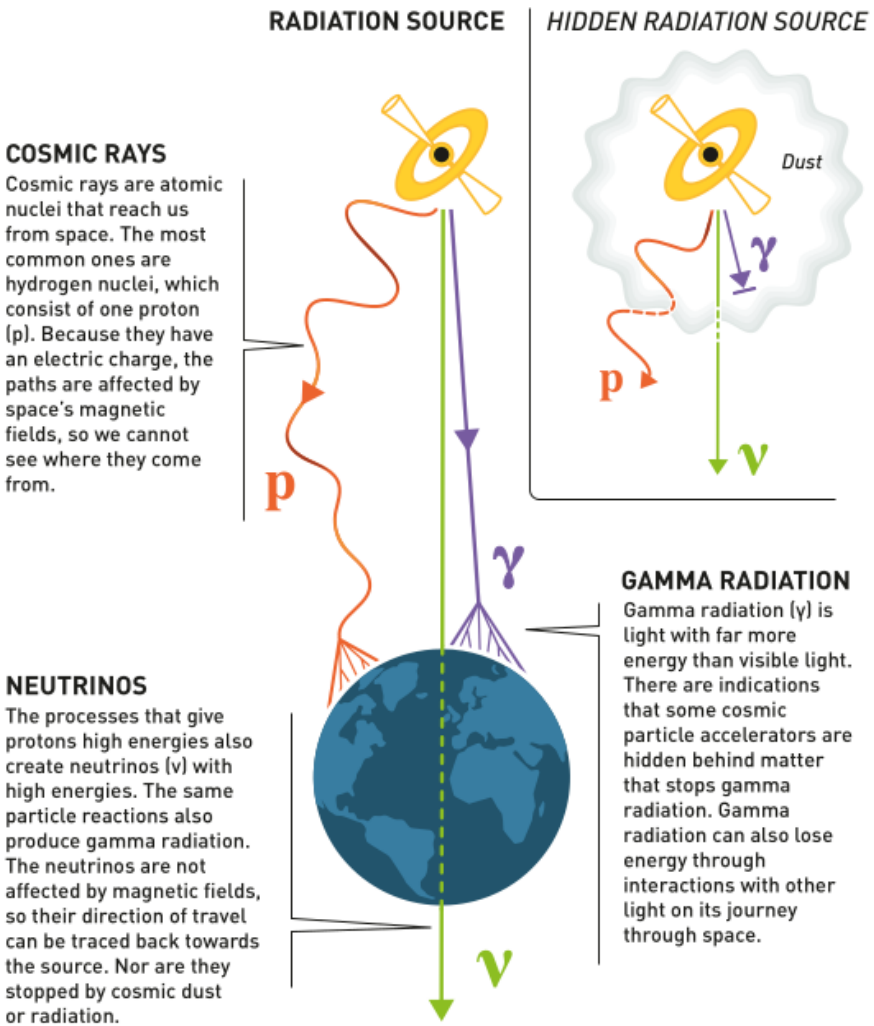


Figure 48: The IceCube Live website front page, showing near-realtime detector status. One DOM has dropped out of data-taking in the run shown. This "operator" view includes controls to start/stop components and to page the winterovers.

https://arxiv.org/pdf/1612.05093



Over a hundred million neutrinos from the atmosphere above Antarctica are registered every day.
Cosmic rays also create neutrinos in the atmosphere and, of these, a few hundred a day reach IceCube after travelling right through the Earth from the northern hemisphere.

In 2013, the research team reported the first evidence to support that they really had found cosmic neutrinos and, a couple of years later, they had gathered so much data they could be certain of their discovery.

IceCube astrophysical neutrinos are produced in hadronic interactions — pion photoproduction and proton-proton collisions in cosmic accelerators. Charged pion decay ($\pi^+ \to \mu^+ + \nu_\mu$, followed by $\mu^+ \to e^+ + \nu_e + \bar{\nu}_\mu$) produces a flavor ratio of approximately $\nu_e : \nu_\mu : \nu_\tau = 1 : 2 : 0$ at the source. After propagation over cosmological distances, oscillation averaging produces an approximately equal ratio $1 : 1 : 1$ at Earth. Deviations from this ratio could signal new physics — for example, neutrino decay or non-standard interactions.

https://www.neutrino-physics.com/blog/why-neutrinos-have-mass/



arXiv Sea

Astrophysics > High Energy Astrophysical Phenomena

[Submitted on 6 Nov 2019]

Neutrino astronomy with the next generation IceCube Neutrino Observatory

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https://doi.org/10.48550/arXiv.1911.02561

arXiv Search

Astrophysics > High Energy Astrophysical Phenomena

[Submitted on 6 Nov 2019]

Neutrino astronomy with the next generation IceCube Neutrino Observatory

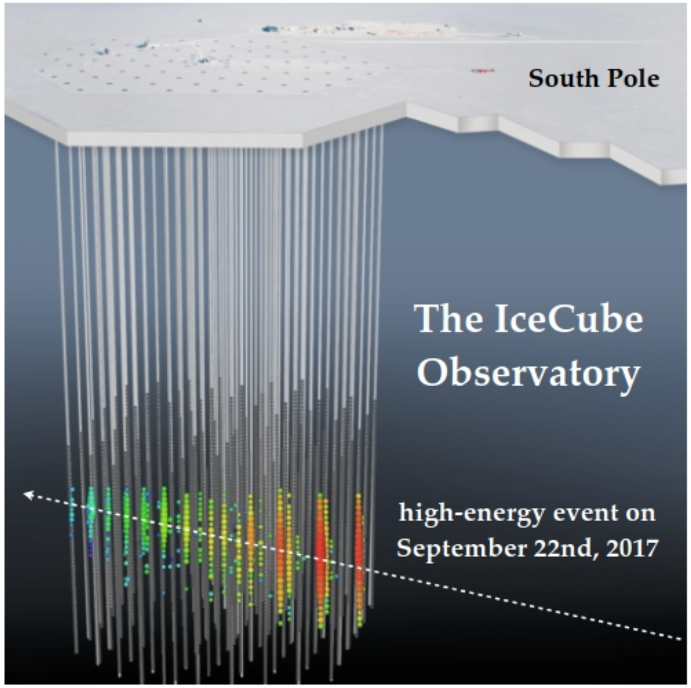
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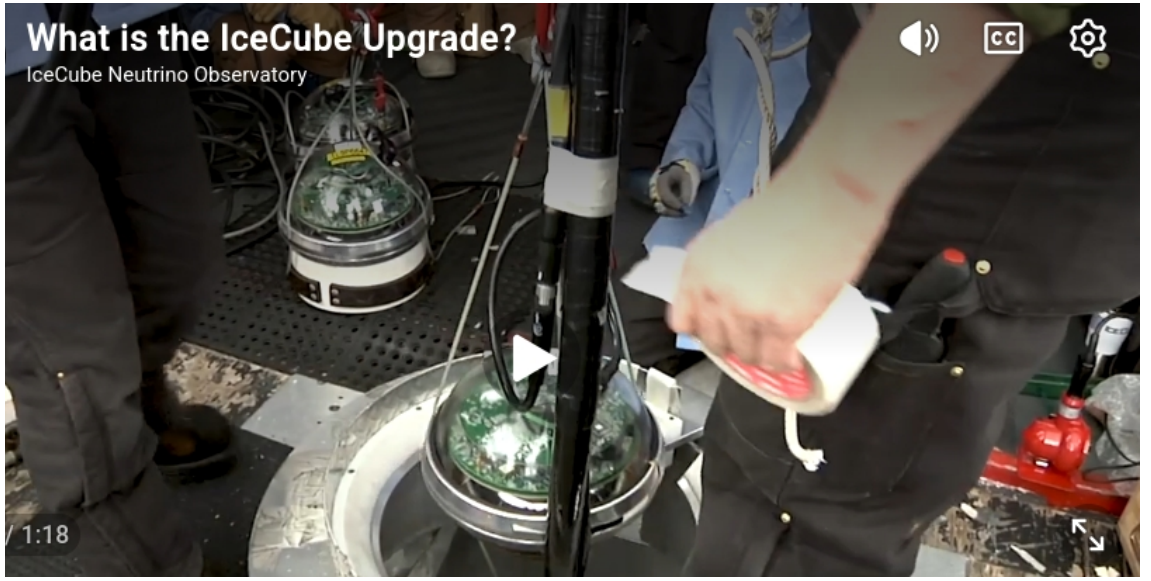
arXiv:1911.02561v1 [astro-ph.HE] 6 Nov 2019

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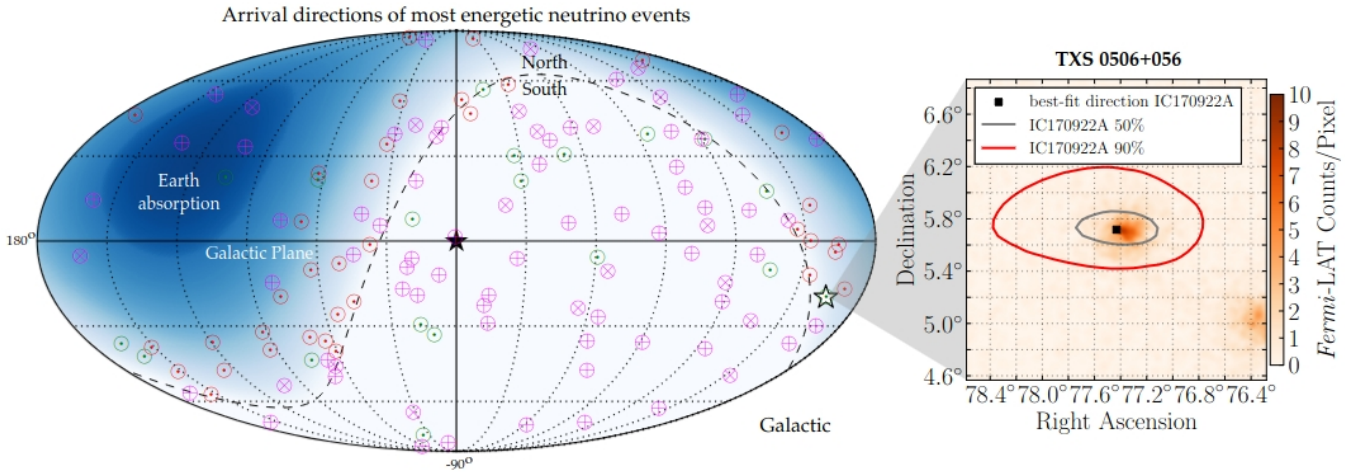
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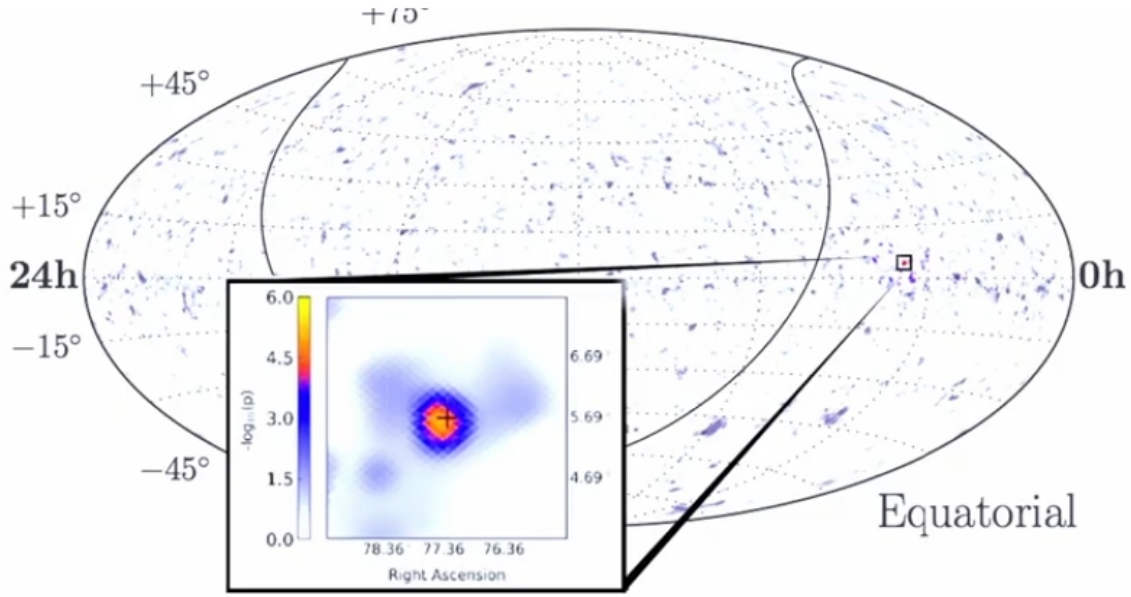


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Figure 1: Schematic illustration of the current IceCube array, located near the ge
Pole at depths of up to 2.5 km.
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https://arxiv.org/pdf/1911.02561

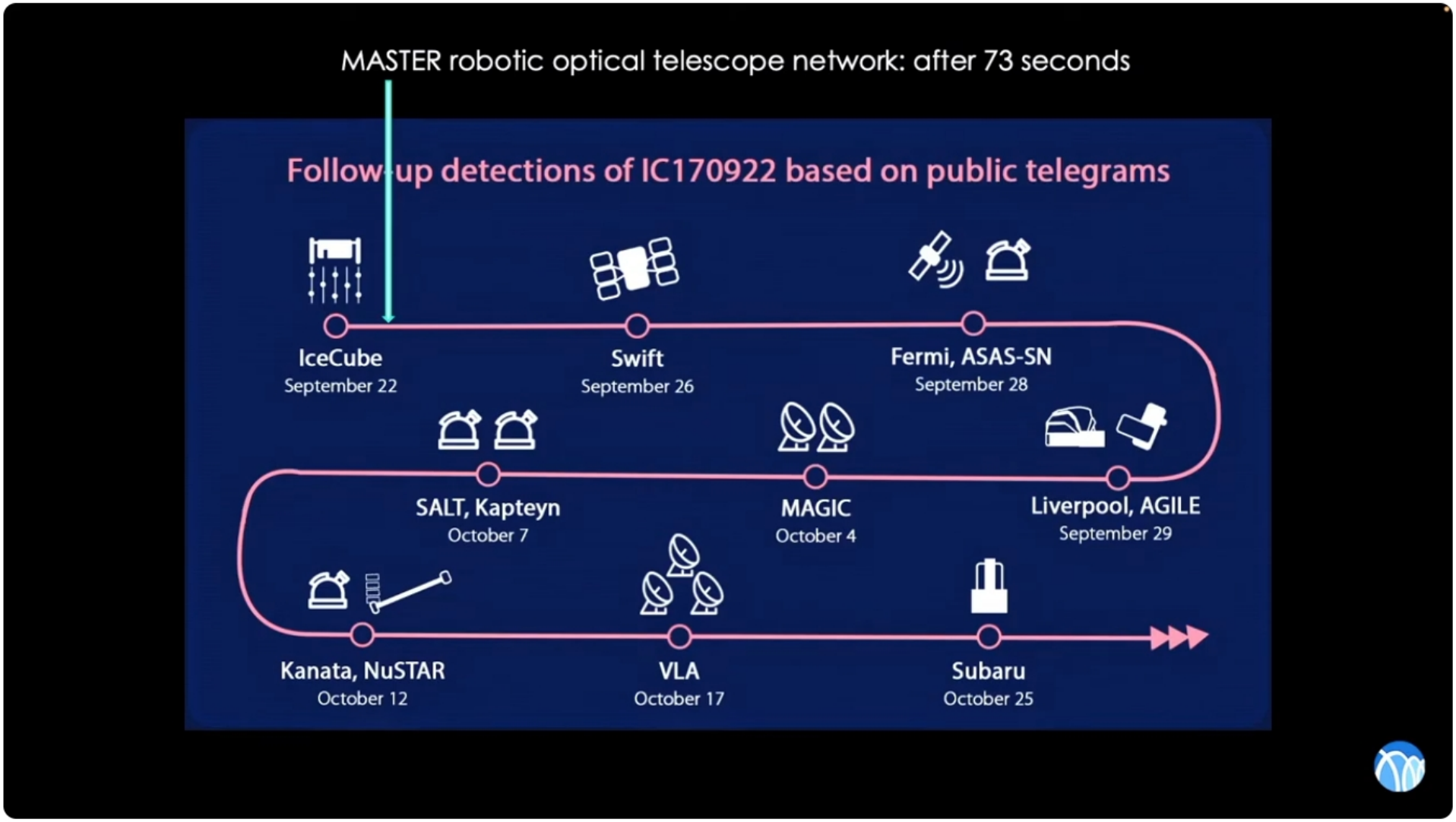


hottest spot coincident with
NGC 1068 (M77) at 2.9σ

evidence for non-uniform sky map in 10 years of IceCube data :
mostly resulting from 4 active galaxies (including TXS 0506+056) !

PSW 2466 ICE CUBE The Under the Ice Neutrino Observatory in Antarctica | Francis Halzen

https://youtu.be/7PhX9NFSKBc?t=647



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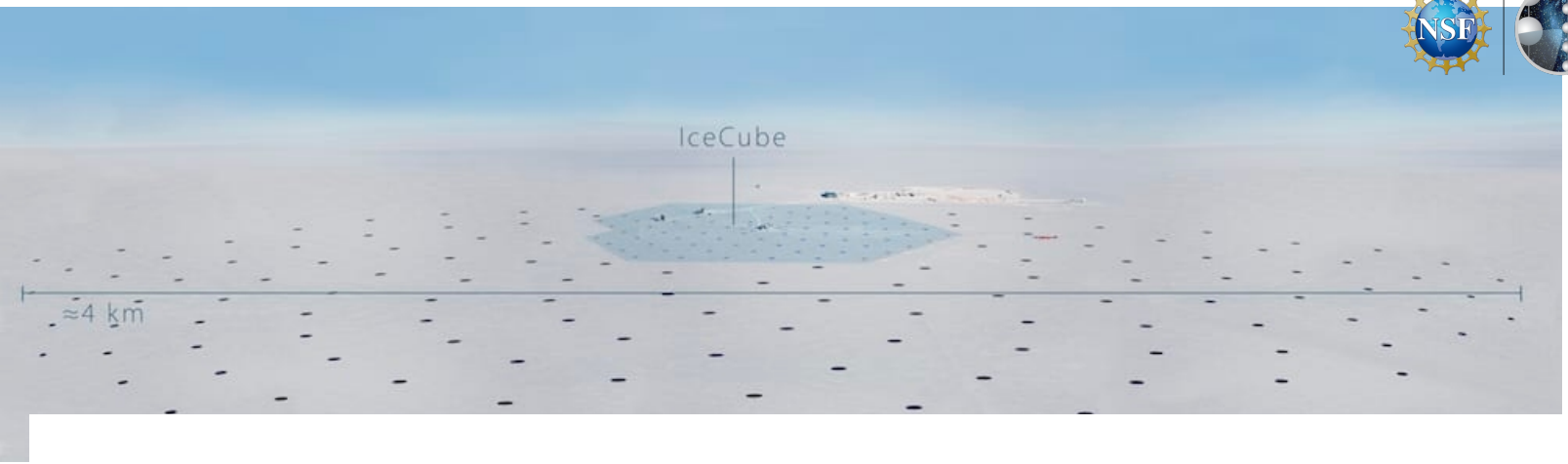


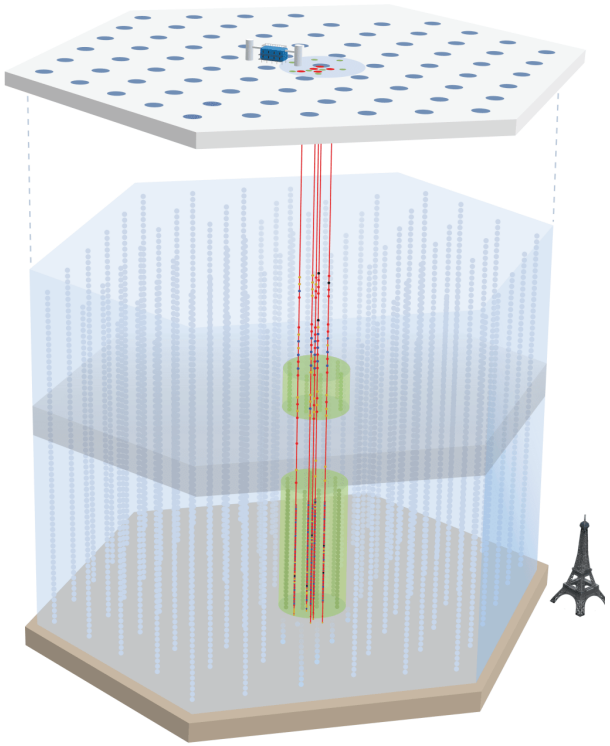


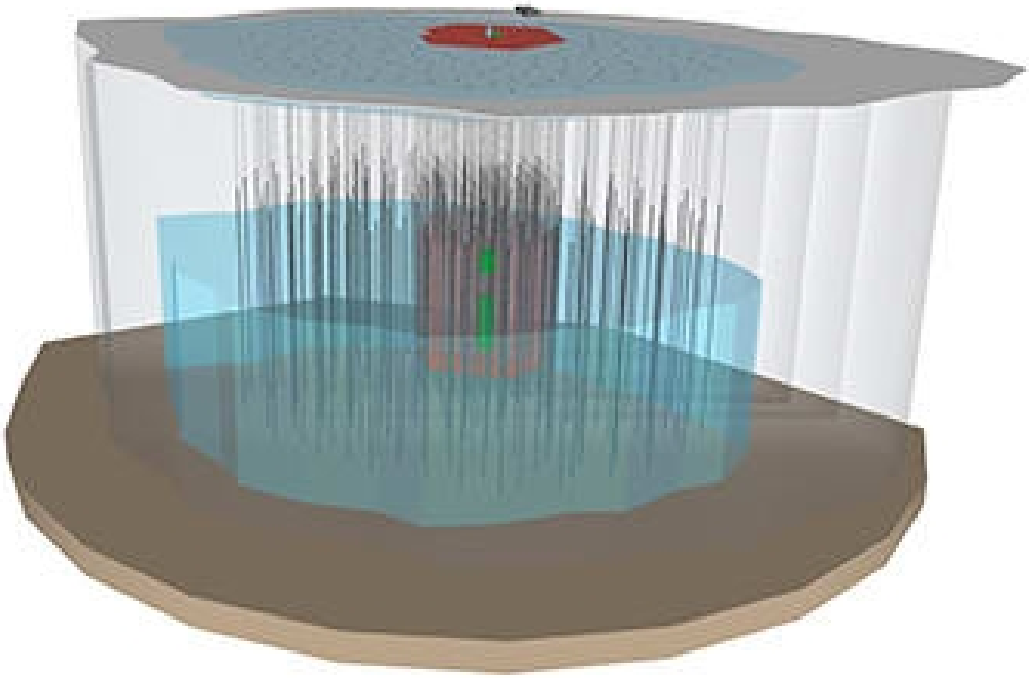
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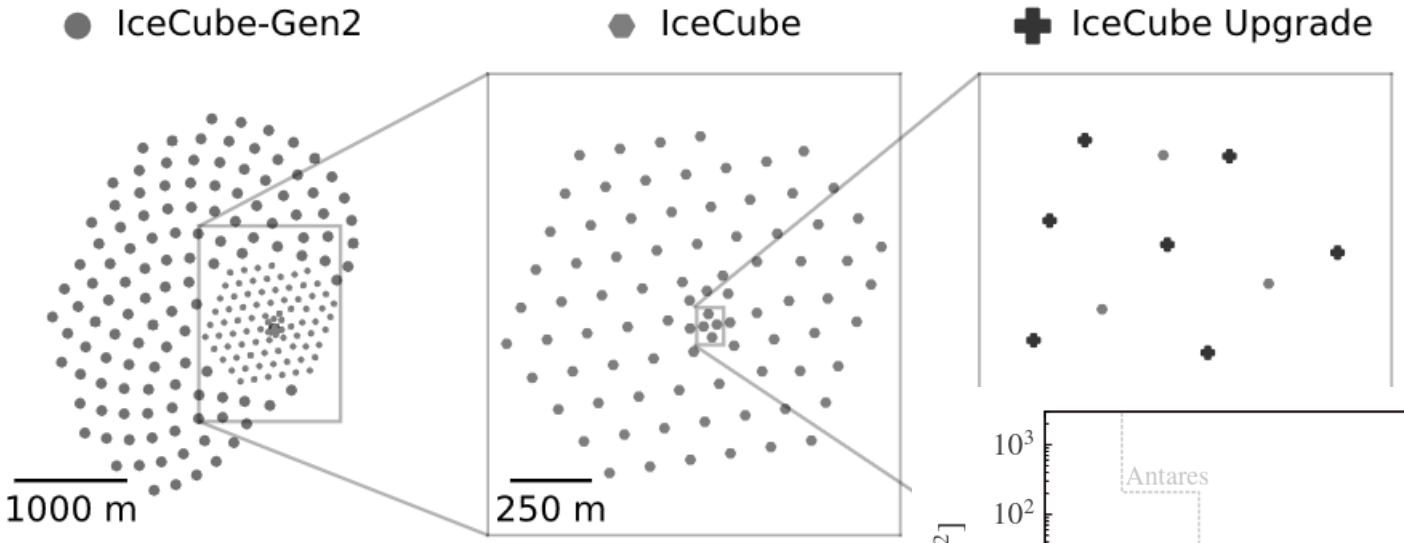


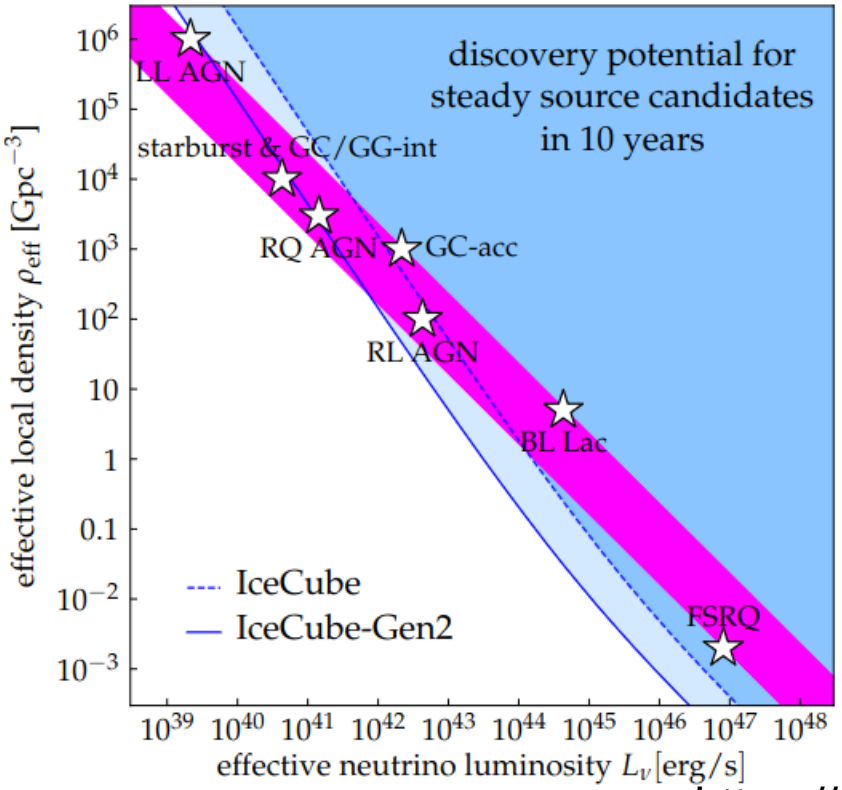


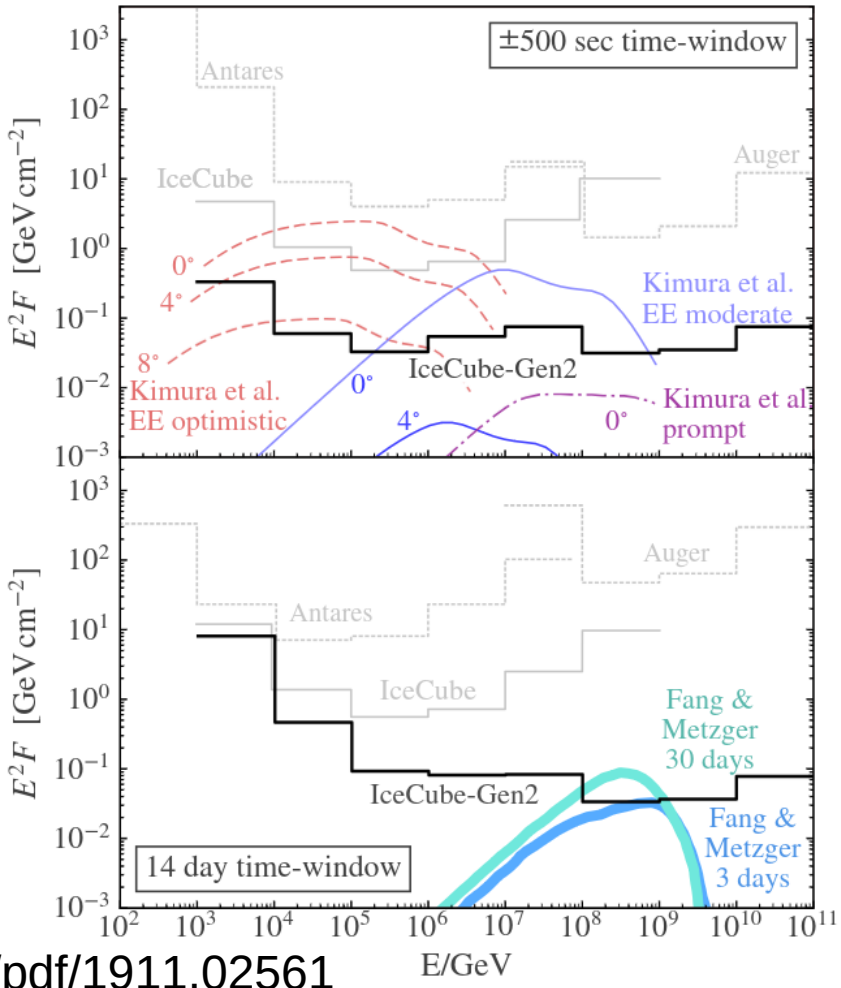




https://icecube.wisc.edu/science/beyond/



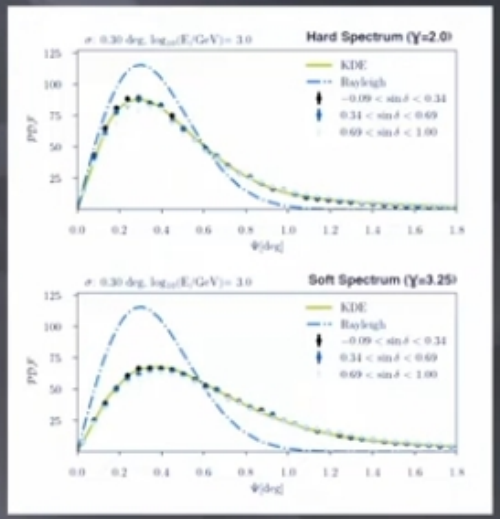




https://arxiv.org/pdf/1911.02561

ongoing program to upgrade the performance of IceCube

- improved detector geometry
- each photomultiplier individually calibrated
- improved characterization of the optics of the ice
- improved muon angular resolution and energy reconstruction using machine learning
- *point spread function consistent with simulation*



applied to 10 years of archival data (pass 2), data unblinded, answer soon…

https://youtu.be/7PhX9NFSKBc?t=647



Використані джерела

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The Official Web Site of the Nobel Prize

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NSF

IceCube Neutrino Observatory

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6,57 тис. підписників

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Physics

KU LEUVEN

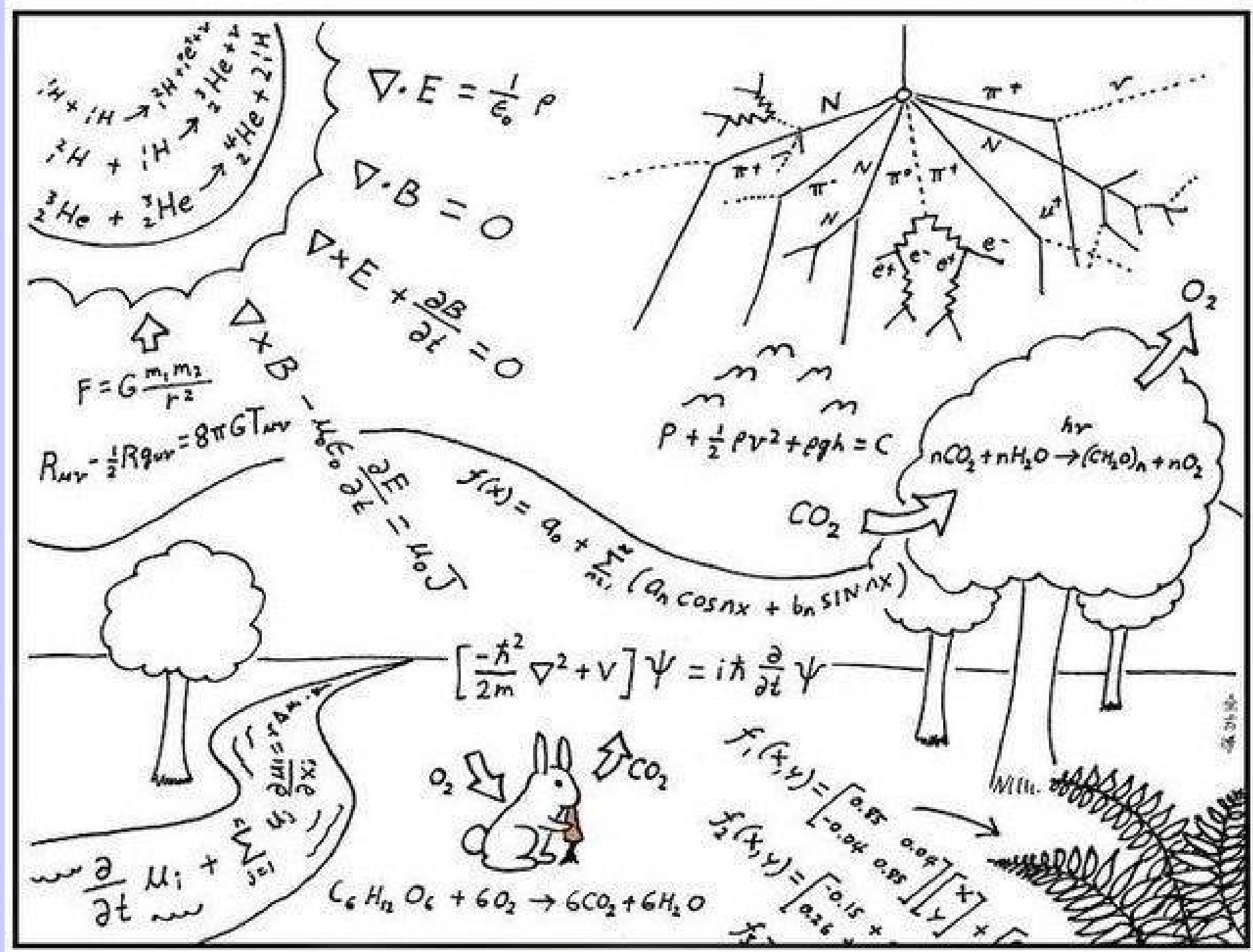
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Research, teaching and public engagement in Physics at UW–Madison




$^1H + {}^1H \rightarrow {}^2H + e^+ + \nu$
$^2H + {}^1H \rightarrow {}^3He + \gamma$
$^3He + {}^3He \rightarrow {}^4He + 2\,{}^1H$
$\nabla \cdot E = \frac{1}{\epsilon_0}\rho$
$\nabla \cdot B = 0$
$\nabla \times E + \frac{\partial B}{\partial t} = 0$
$\nabla \times B - \mu_0\epsilon_0\frac{\partial E}{\partial t} = \mu_0 J$
$F = G\frac{m_1 m_2}{r^2}$
$R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} = 8\pi G T_{\mu\nu}$
$P + \frac{1}{2}\rho v^2 + \rho g h = C$
$f(x) = a_0 + \sum_{n=1}^{\infty}(a_n \cos nx + b_n \sin nx)$
$\left[\frac{-\hbar^2}{2m}\nabla^2 + V\right]\psi = i\hbar\frac{\partial}{\partial t}\psi$
$\frac{\partial}{\partial t}\mu_i + \sum_{j=1}^{n}\mu_j \frac{\partial \mu_i}{\partial x_j}$
$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$
$nCO_2 + nH_2O \xrightarrow{h\nu} (CH_2O)_n + nO_2$
CO_2
O_2
O_2
CO_2
N
π^+
π^-
π^0
e^+
e^-