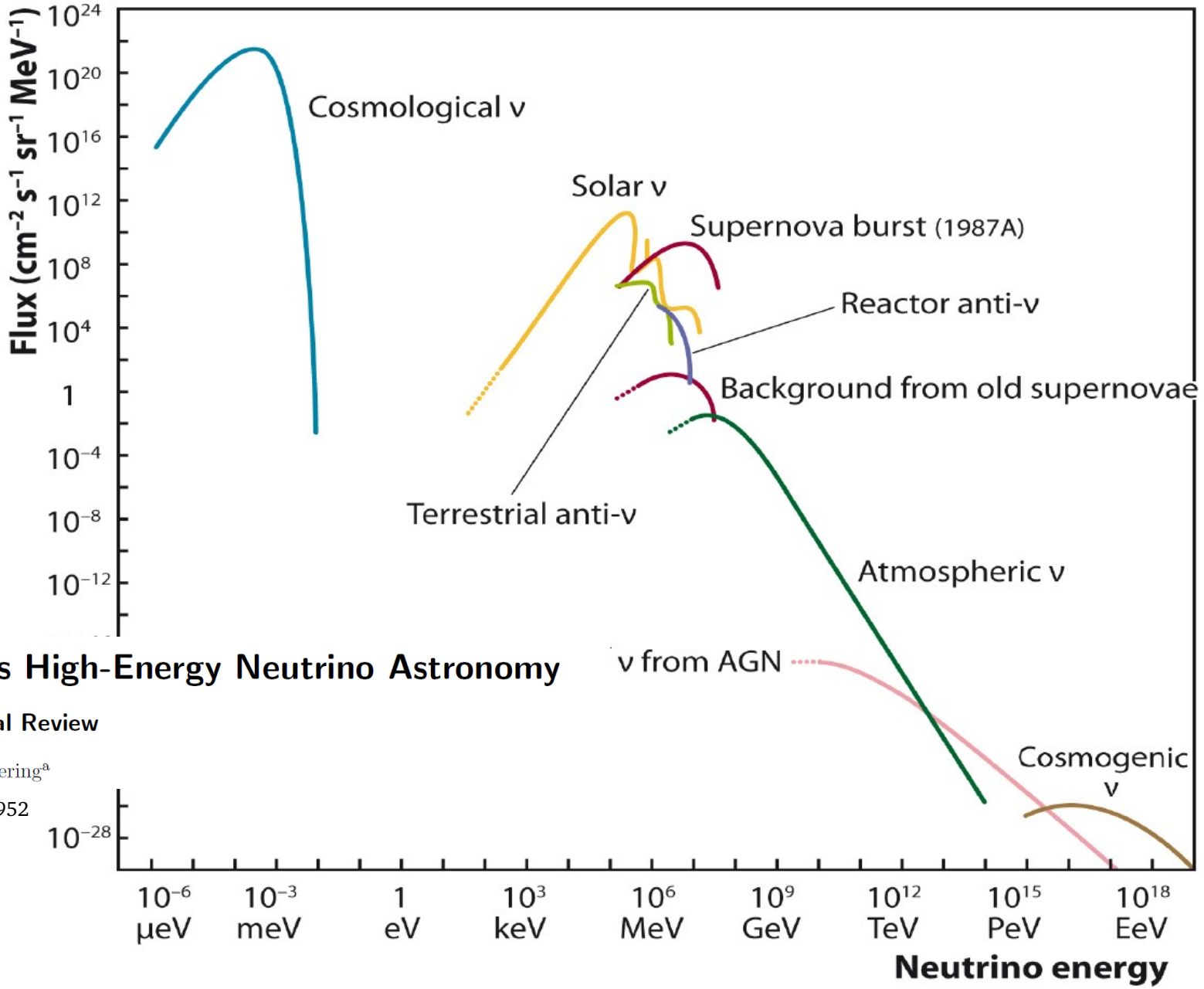
Neutrino Astronomy

Seminar
October 1st, 2015

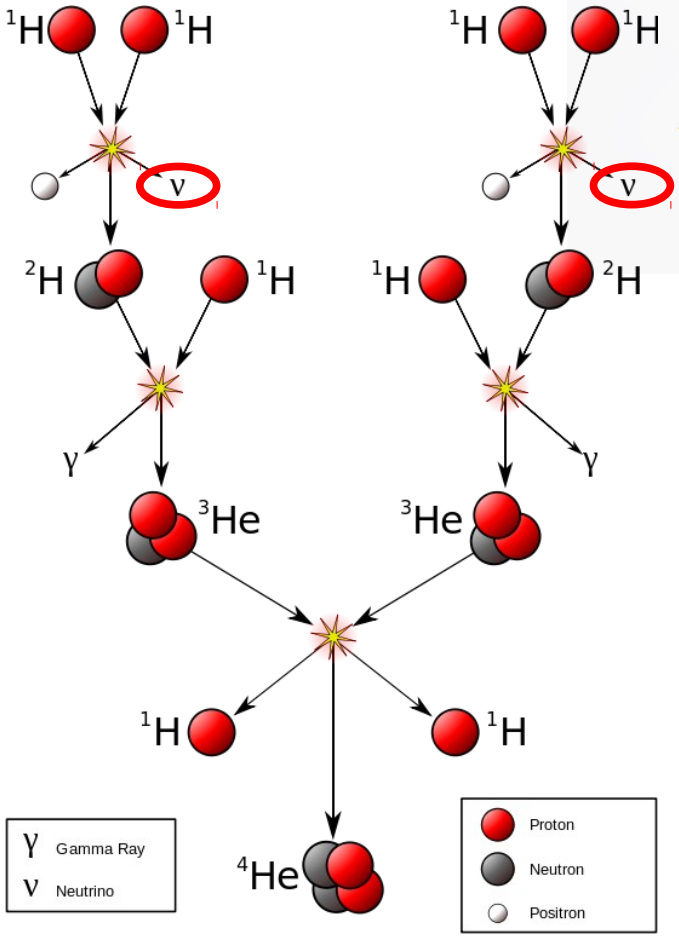


Towards High-Energy Neutrino Astronomy

A Historical Review

Christian Spiering[a]

arxiv:1207.4952



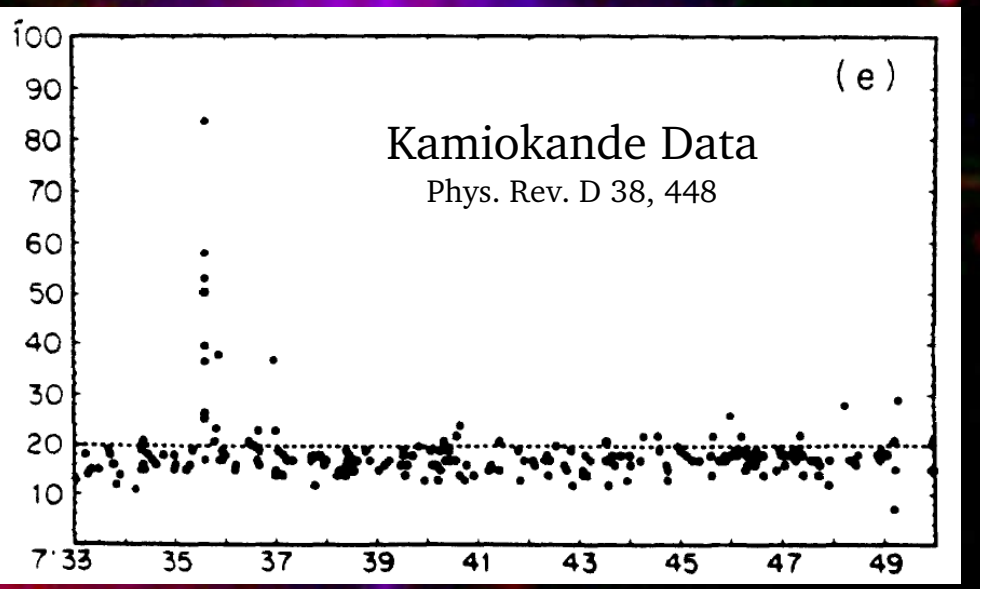
VOLUME 20, NUMBER 21 PHYSICAL REVIEW LETTERS 20 MAY 1968

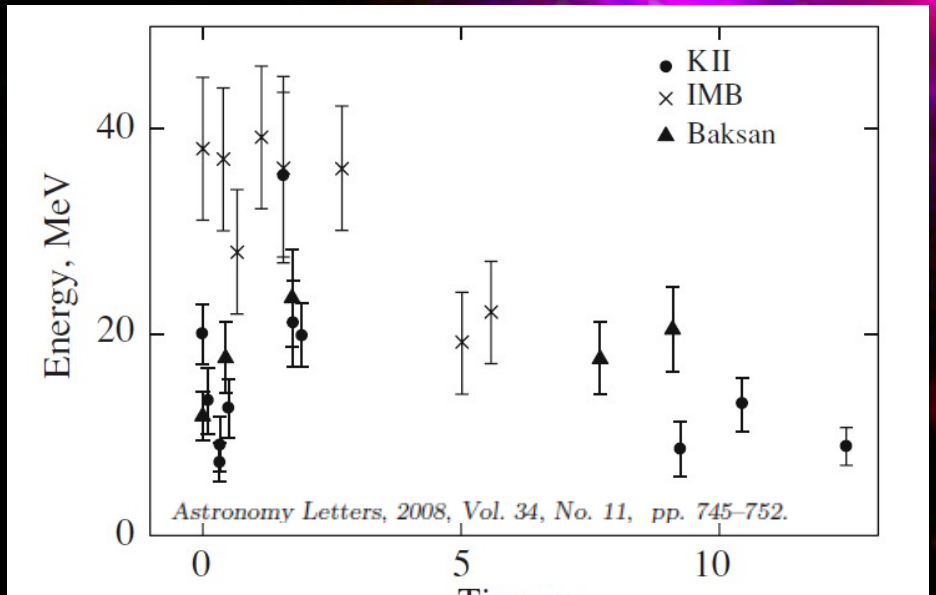
SEARCH FOR NEUTRINOS FROM THE SUN*

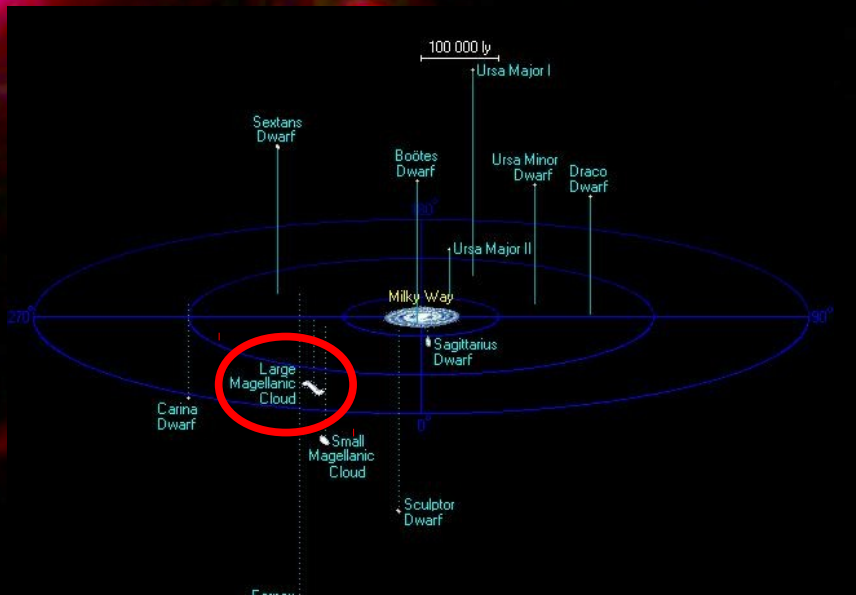
Raymond Davis, Jr., Don S. Harmer,† and Kenneth C. Hoffman
Brookhaven National Laboratory, Upton, New York 11973
(Received 16 April 1968)

A search was made for solar neutrinos with a detector based upon the reaction $Cl^{37}(\nu, e^-)Ar^{37}$. The upper limit of the product of the neutrino flux and the cross sections for all sources of neutrinos was 3×10^{-36} sec^{-1} per Cl^{37} atom. It was concluded specifically that the flux of neutrinos from B^8 decay in the sun was equal to or less than 2×10^6 cm^{-2} sec^{-1} at the earth, and that less than 9% of the sun's energy is produced by the carbon-nitrogen cycle.

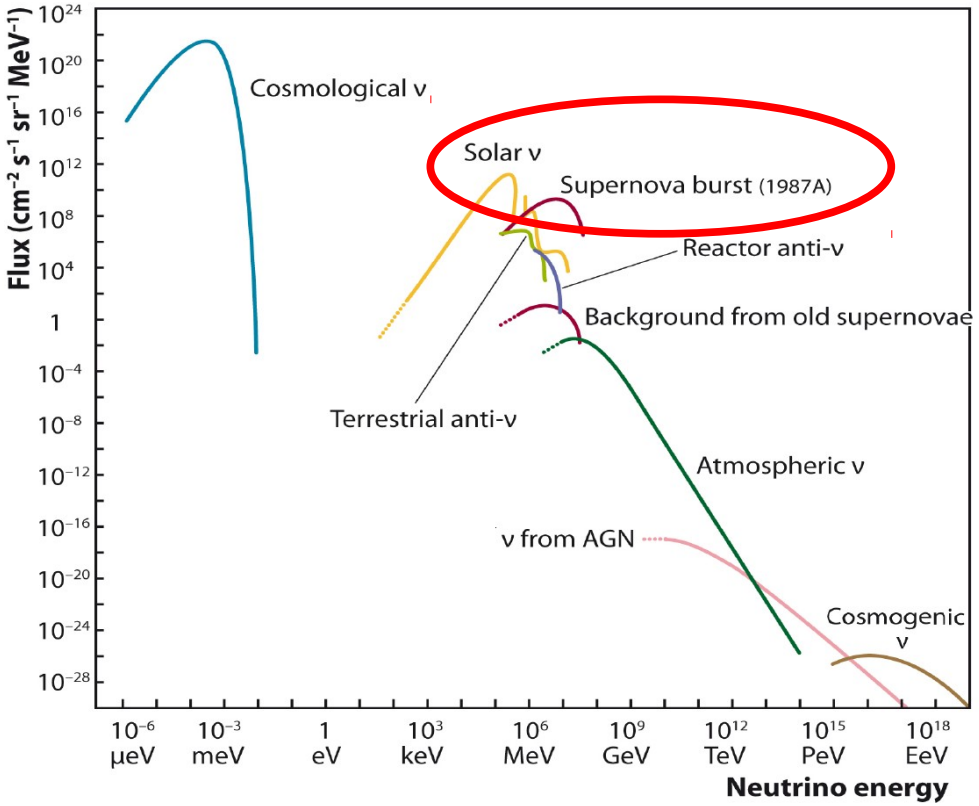
Supernova 1987a

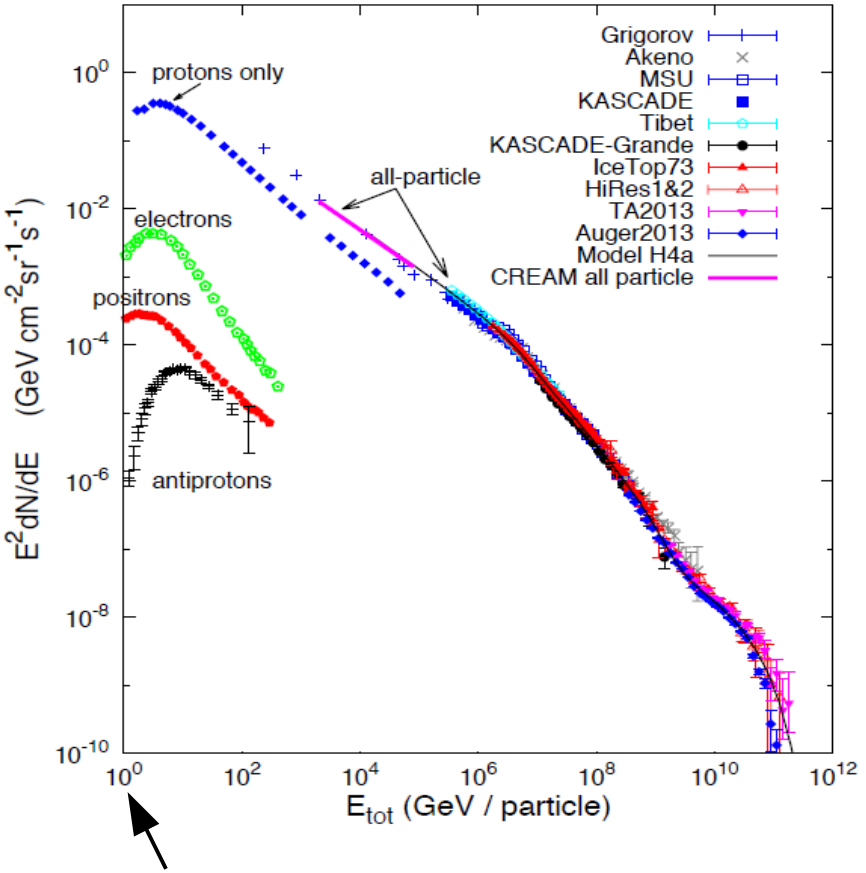




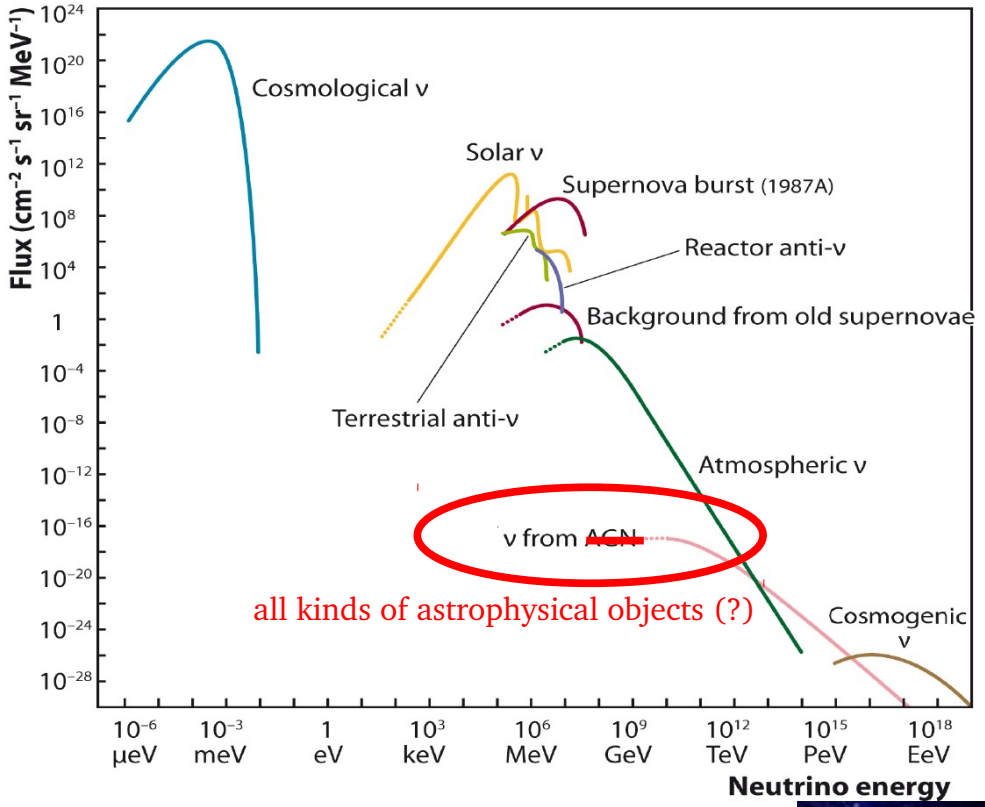


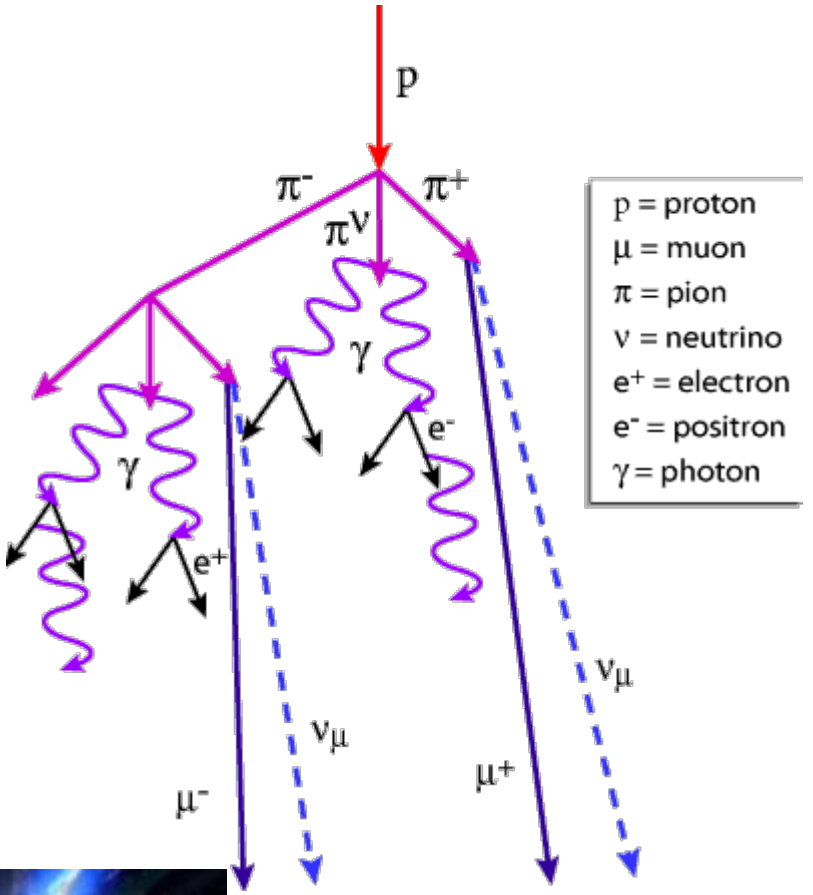
Seen: MeV Neutrinos





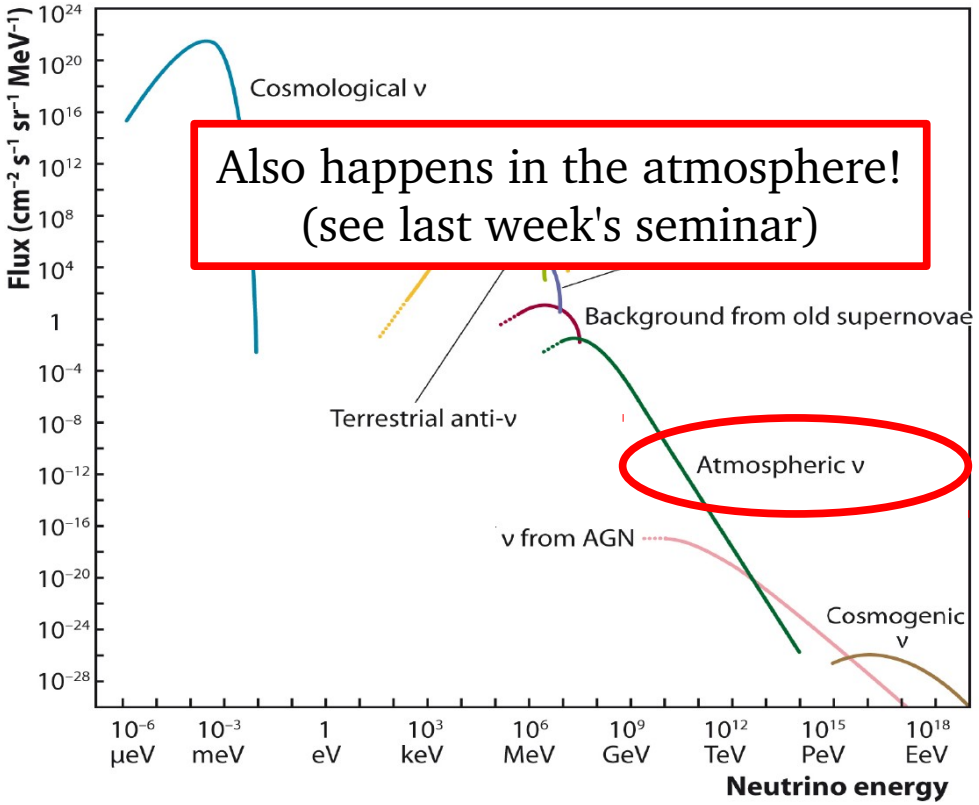
(Extrasolar) Cosmic Rays: Starting at GeV Energies



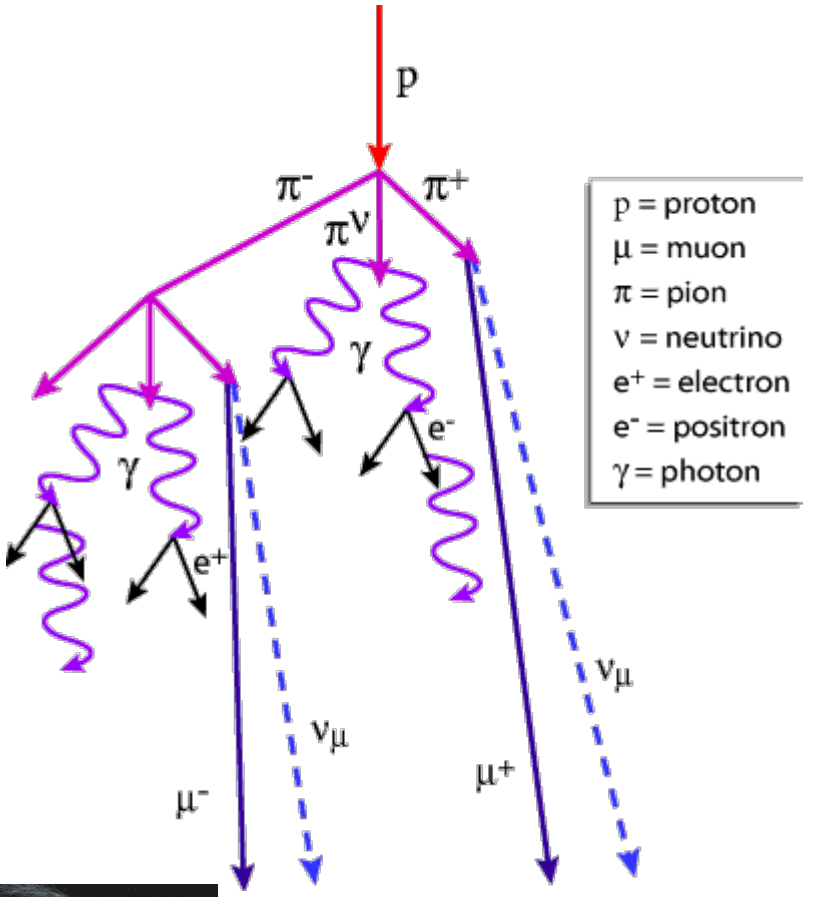


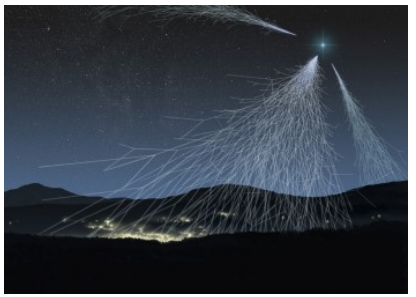
p + anything → a bunch of hadrons, some of which will be charged mesons

charged mesons → leptons, some of which will be neutrinos



Also happens in the atmosphere!
(see last week's seminar)





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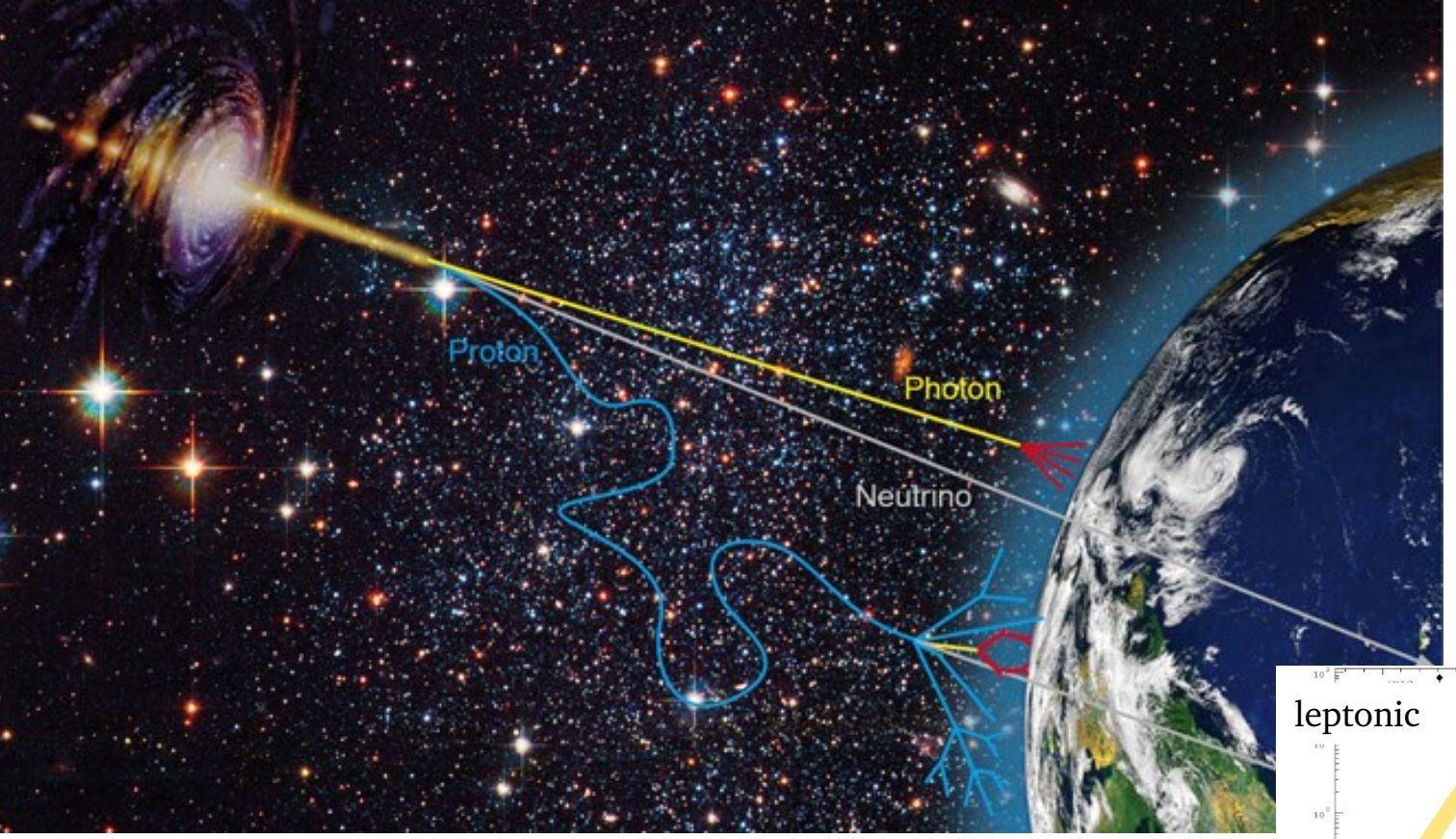
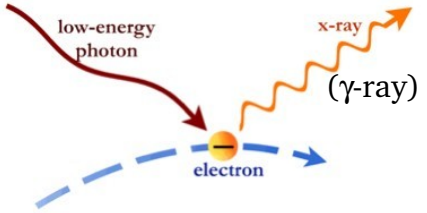
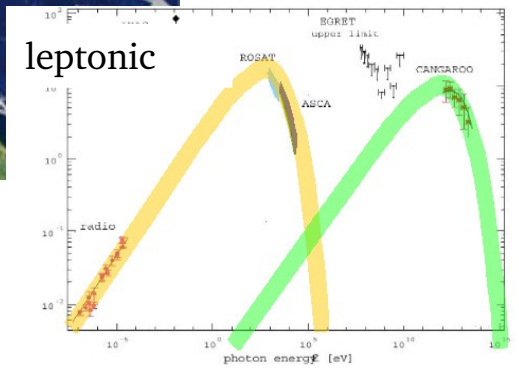


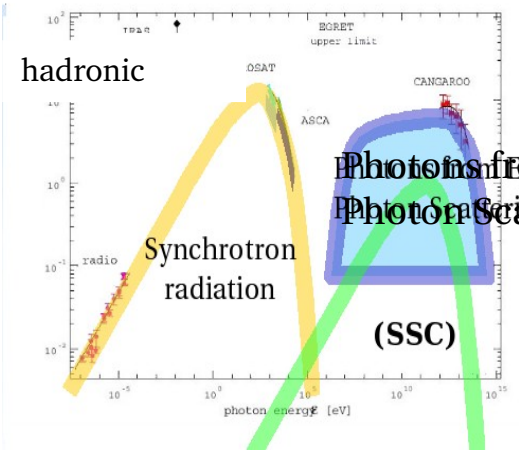
Inverse Compton Scattering



Protons/Nuclei:
Direction will be scrambled by magnetic fields

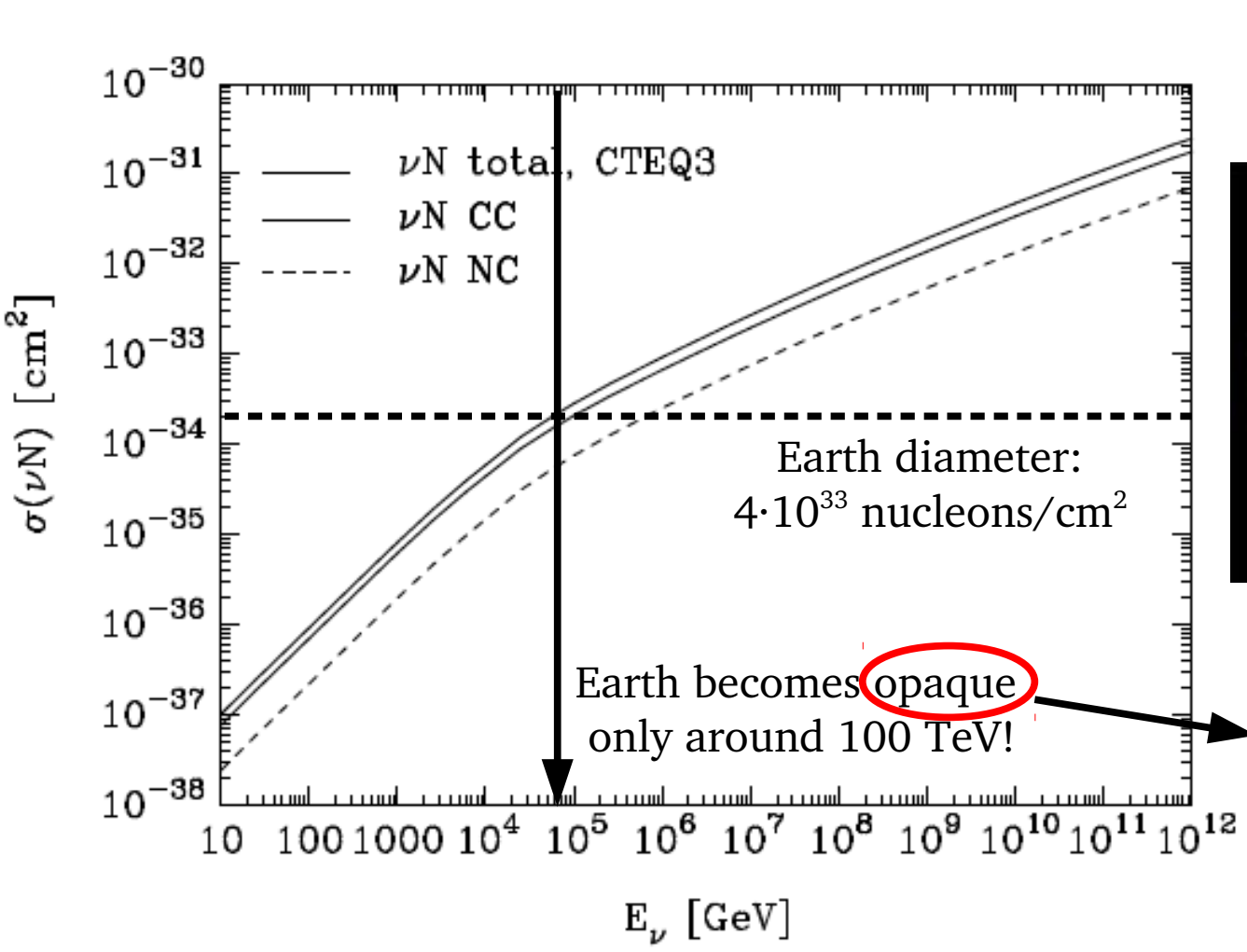
Photons:
Can be absorbed
Not an unambiguous sign of hadron acceleration





Photons from Electron/Photon Scattering

Neutrinos:
Will always come through!



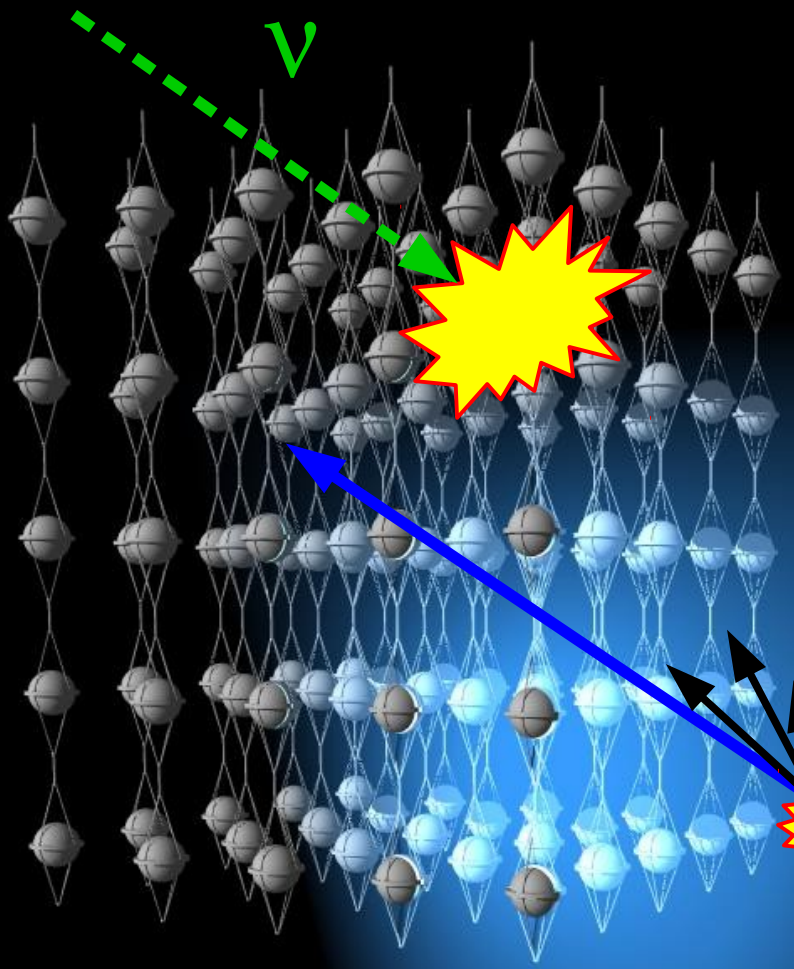
Reason: Tiny cross section!

Problem: How to detect neutrinos?

M. A. Markov
1908-1994

Godfather of Neutrino Astronomy

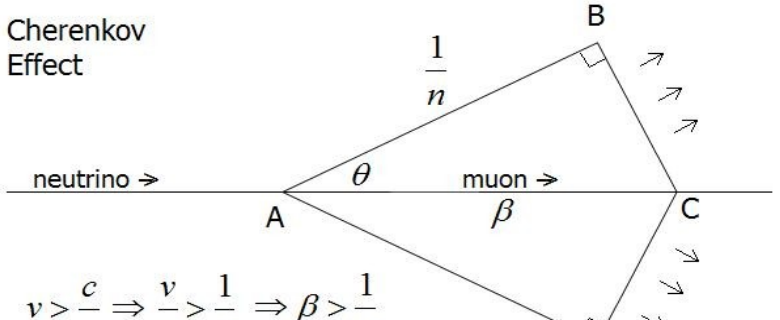
1960 Concept



Detector in transparent medium (deep water)

Particle Shower

Cherenkov Effect



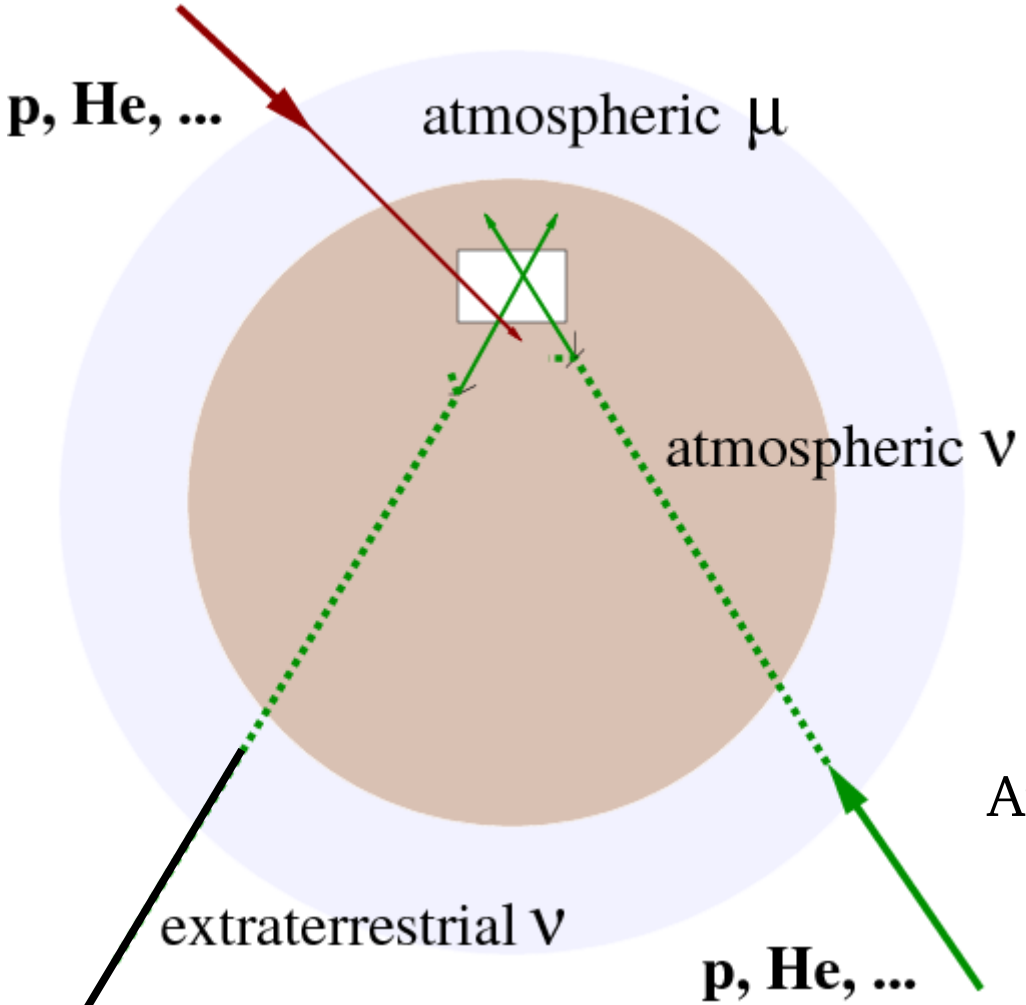
$$v > \frac{c}{n} \Rightarrow \frac{v}{c} > \frac{1}{n} \Rightarrow \beta > \frac{1}{n}$$

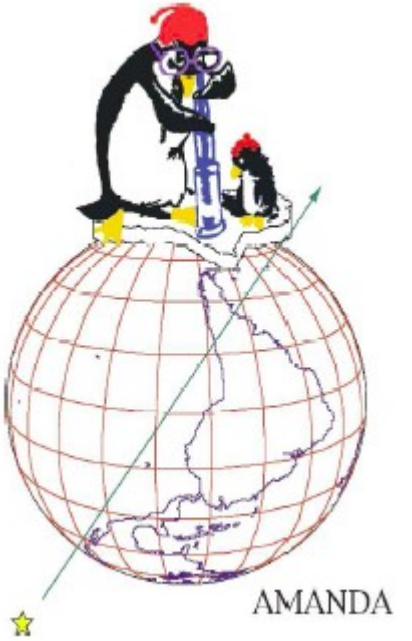
$$\cos\theta = \frac{AB}{AC} = \frac{1/n}{\beta} = \frac{1}{n\beta} = \frac{1}{n}$$

Main Principle:

Detection of neutrino interactions through Cherenkov light emission of secondary charged particles

Cosmic Rays from above
(BAD)



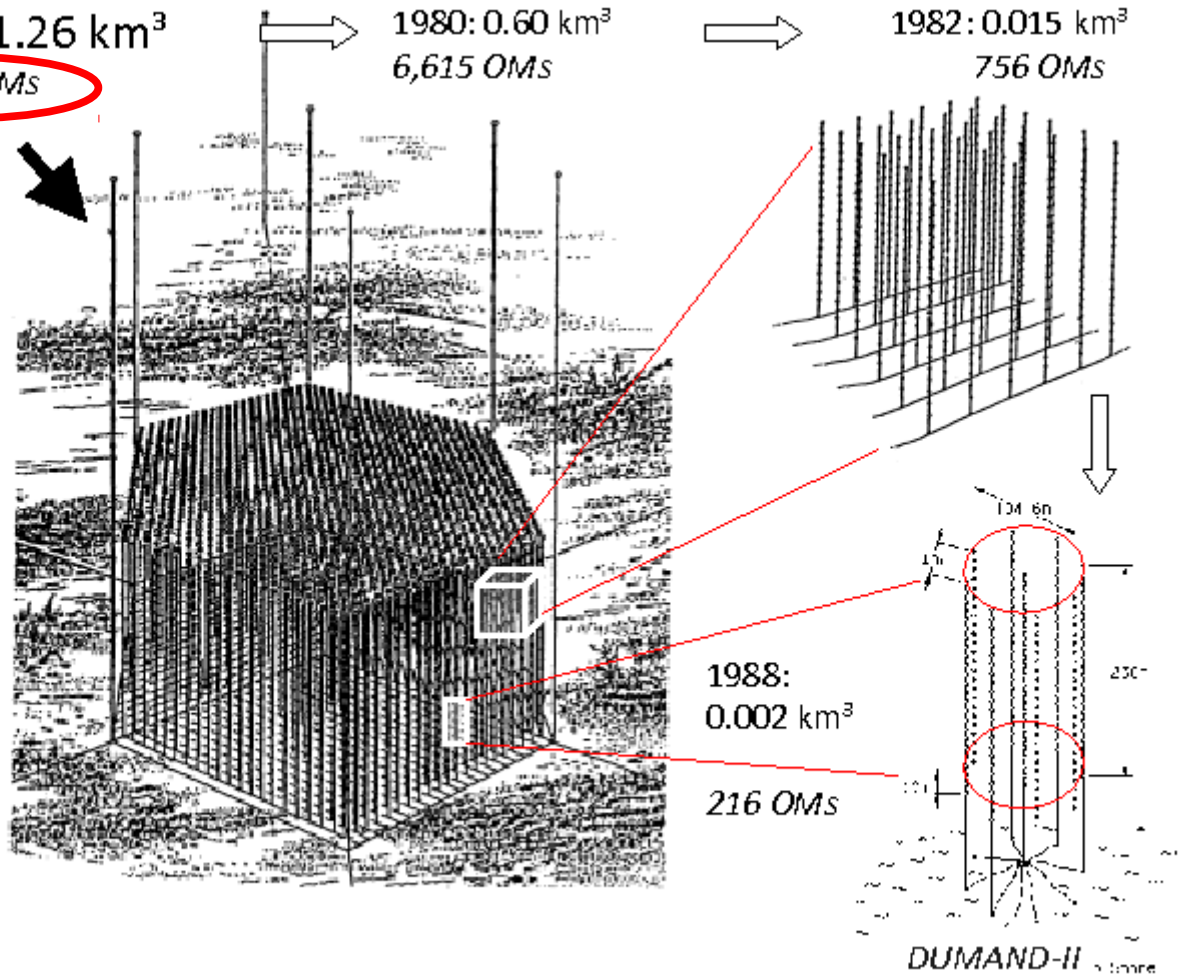


Atmospheric Neutrinos
from below
(BAD)

Astrophysical Neutrinos
from below
(GOOD)

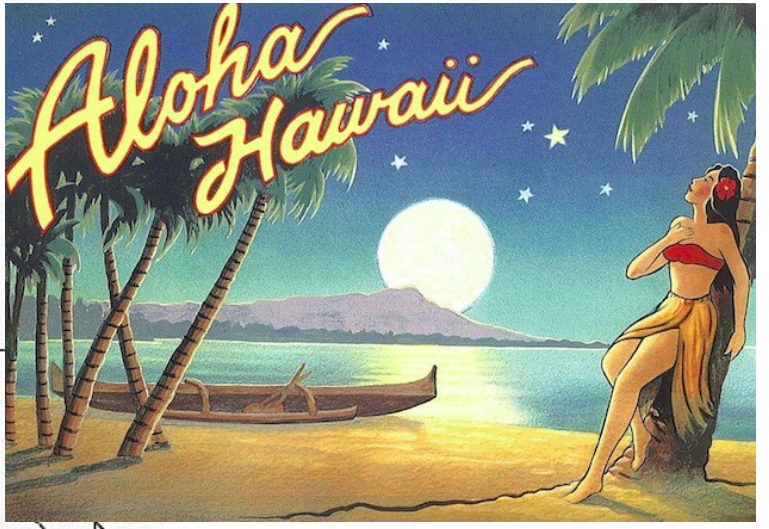
pointing to source

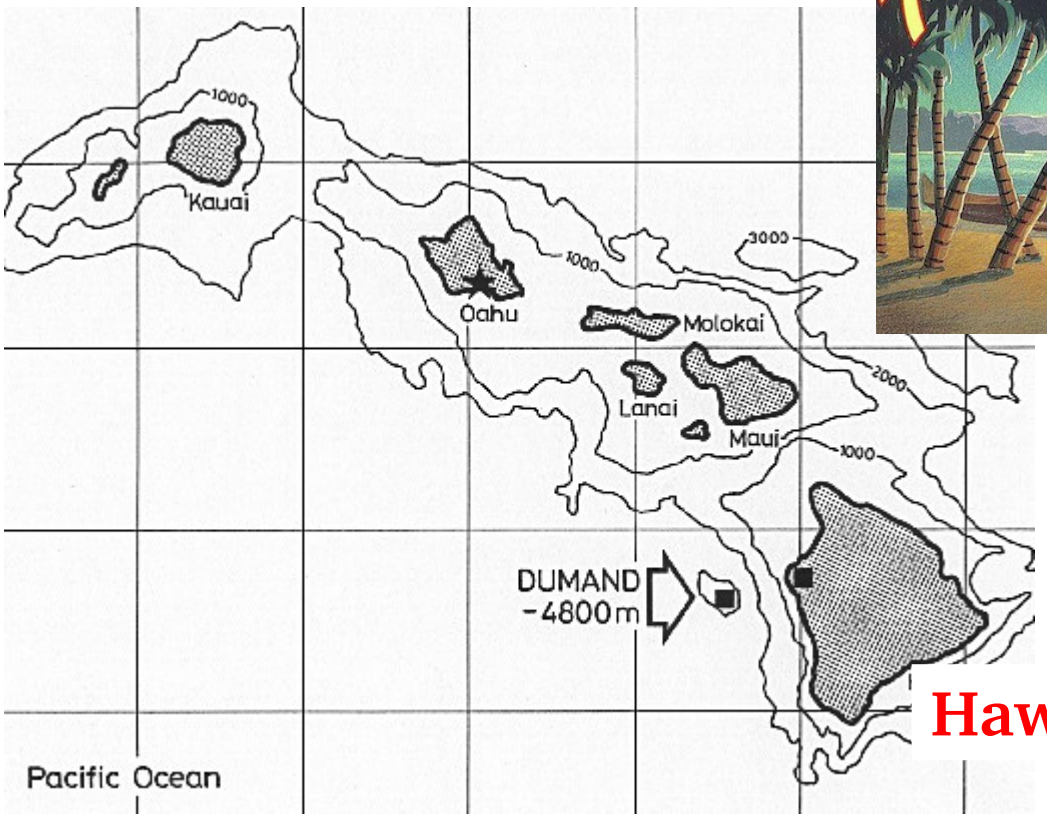
IceCube (2010):
86 x 60 = 5160



DUMAND

Deep **U**nderwater **M**uon **A**nd **N**eutrino **D**etector





Hawaii

DUMAND

Deep **U**nderwater **M**uon **A**nd **N**eutrino **D**etector

The Future of Neutrino Astronomy?


No.

The 1976 Conference in Hawaii, hosted by the University of Hawaii, was the first international DUMAND meeting. It included scientists from Japan, Switzerland, Germany, and Russia; the Russian contingent consisted of A. E. Chudakov, V. S. Berezinsky, B. A. Dolgoshein, and A. A. Petrukhin. Russian participation in DUMAND was strong at this time, and continued strong until it was abruptly cut off by the Reagan administration.[2]

A. Roberts, Rev.Mod.Phys. 64 (1992) 259-312

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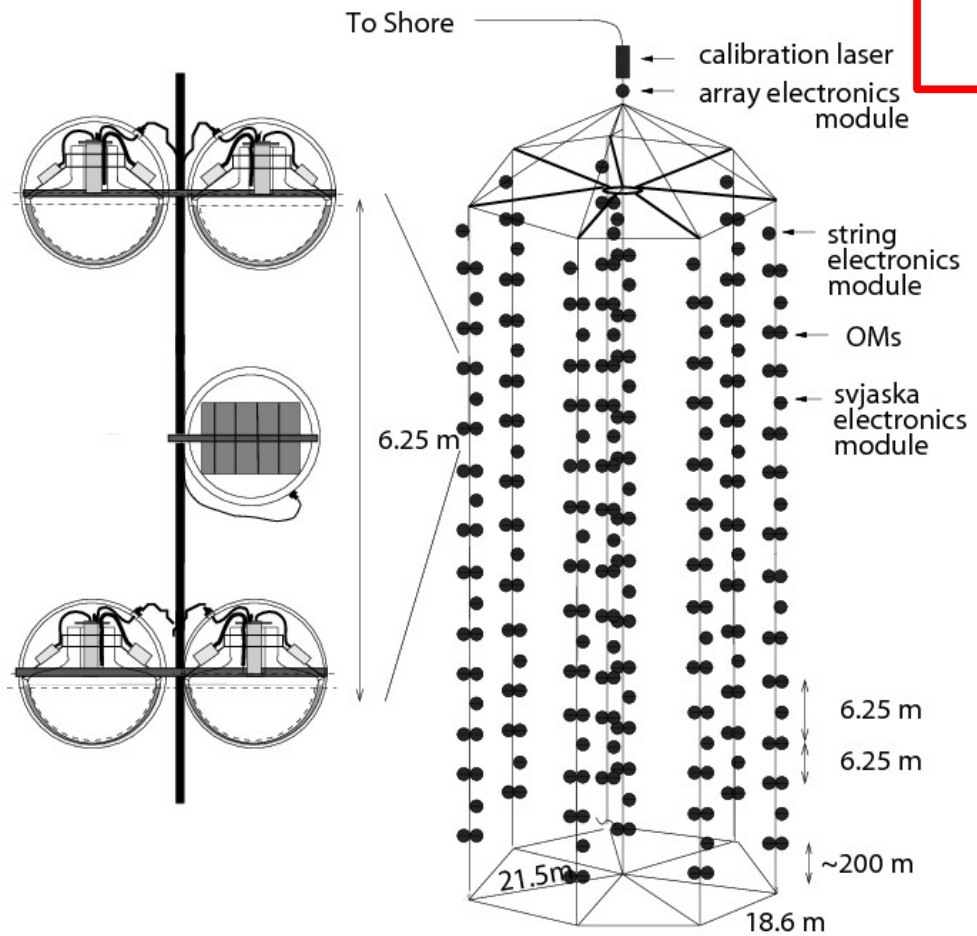
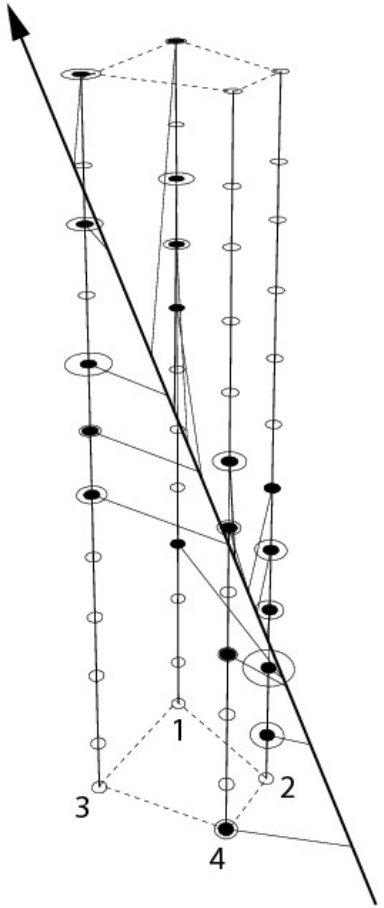
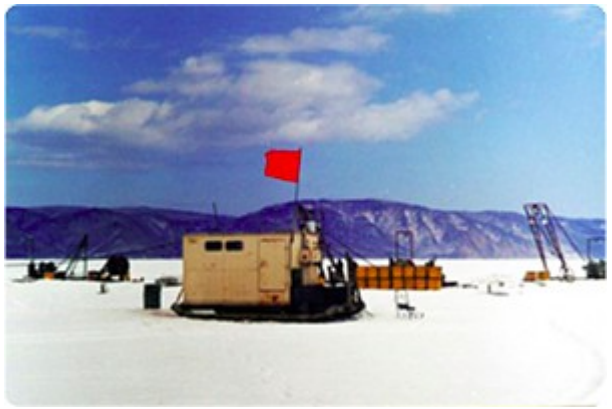
A. Roberts, Rev.Mod.Phys. 64 (1992) 259-312

In 1988, the Baikal experiment was approved as a long-term direction of research by the Soviet Academy of Sciences and the USSR government which included considerable funding.



3-dimensional reconstruction:
direction!



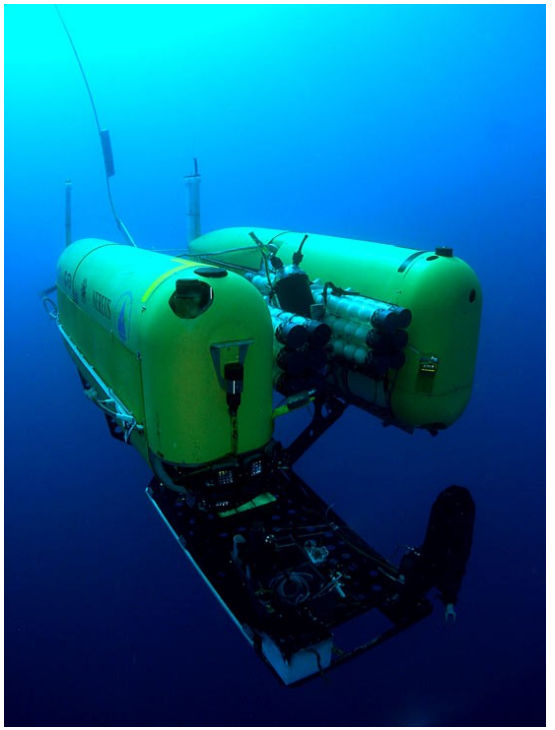


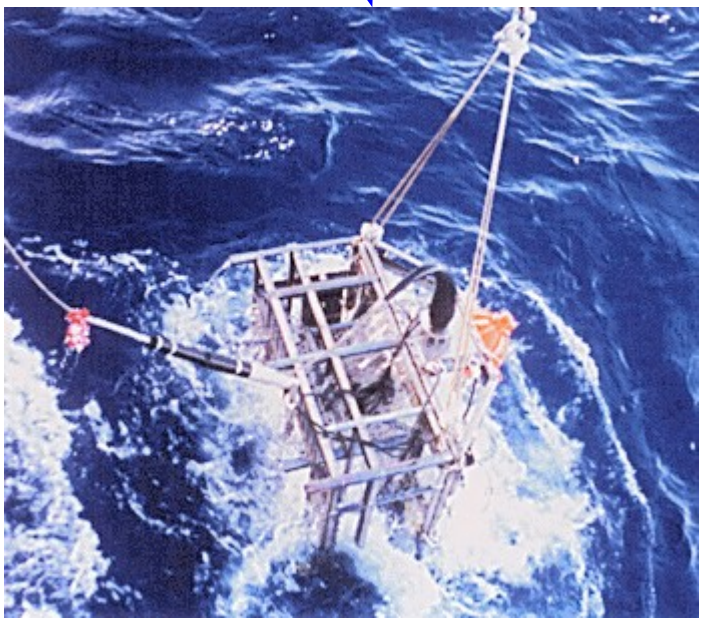
First 3-string neutrino, 1994

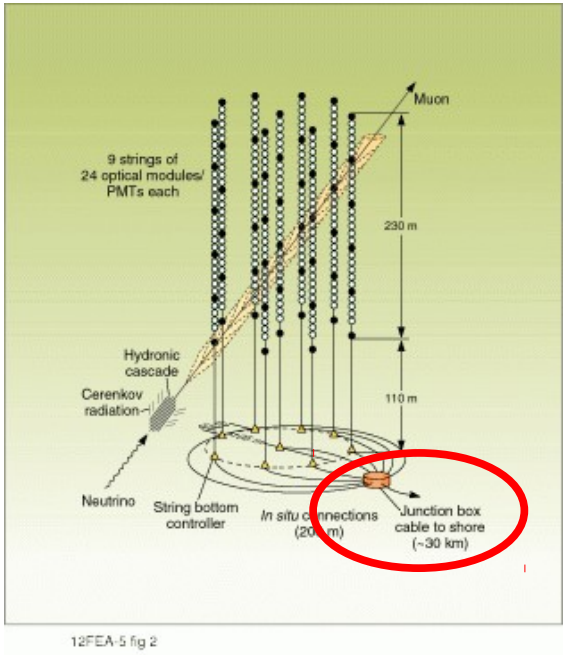
(Shown: 4-String Event, 1996)

In June, 1995, the US Navy's Advanced Tethered Vehicle (ATV) ... successfully performed connecting operations… This eliminated a short circuit observed on the shore cable power conductor, but the short reappeared after a few hours... due to the extremely limited time window available for ATV operations, **it was not possible to complete diagnosis and repair of the junction box**.

http://www.phys.hawaii.edu/~dumand/dumacomp.html







12FEA-5 fig 2

OBSERVATION OF TeV GAMMA RAYS FROM THE CRAB NEBULA USING THE ATMOSPHERIC CERENKOV IMAGING TECHNIQUE

T. C. WEEKES,[1] M. F. CAWLEY,[2] D. J. FEGAN,[3] K. G. GIBBS,[1] A. M. HILLAS,[4] P. W. KWOK,[1] R. C. LAMB,[5] D. A. LEWIS,[5] D. MACOMB,[5] N. A. PORTER,[3] P. T. REYNOLDS,[1,3] AND G. VACANTI[5]

Received 1988 August 1; accepted 1988 December 9

TeV GAMMA RAYS FROM CRAB NEBULA

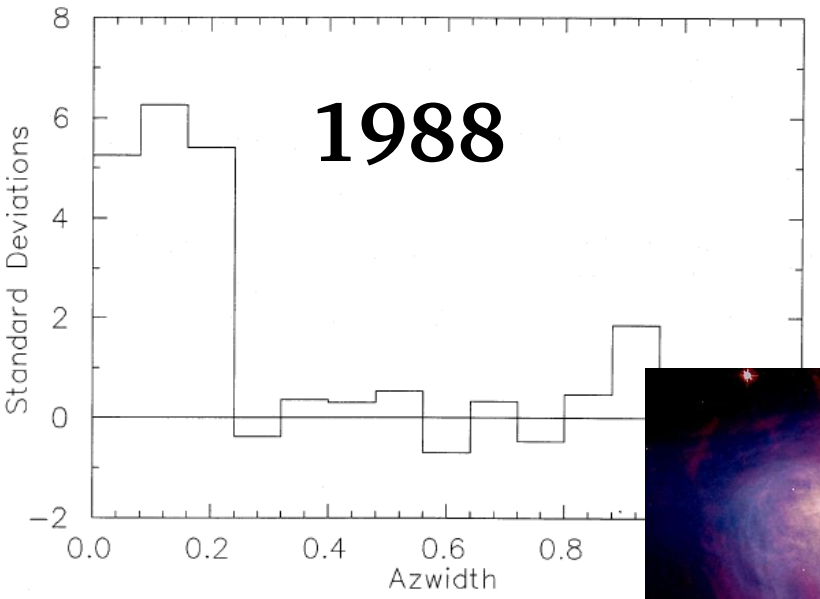
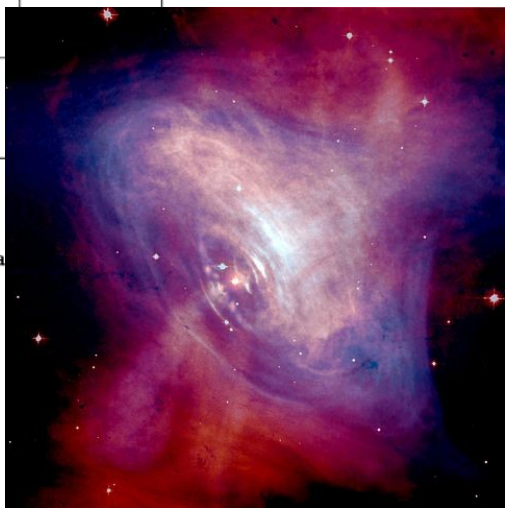
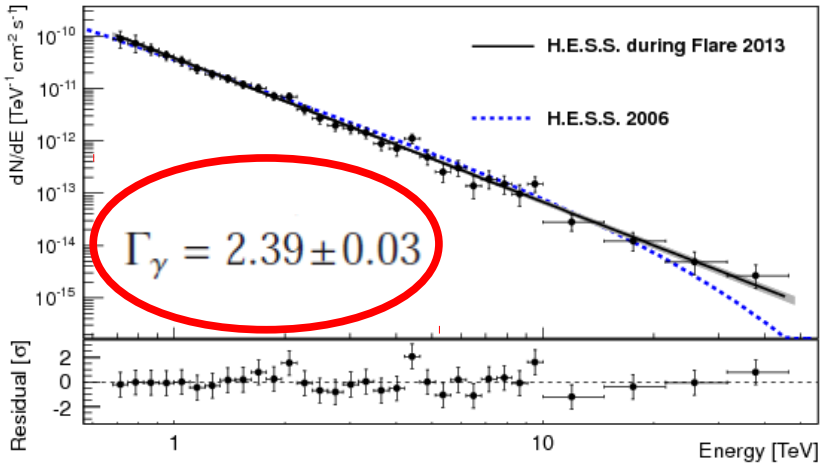


FIG. 7.—Distribution of *azwidth* (ON − OFF) in terms of standard deviations a

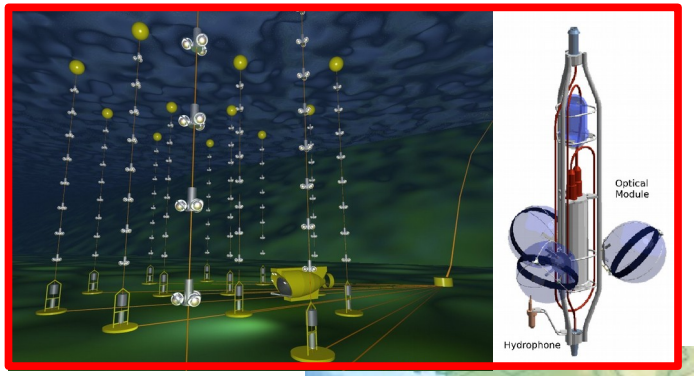


Constraint of Spectral Index: Better Neutrino Flux Predictions!

Source Name	Assumed Spectr. Index γ	μ/yr in DUM-II $\varepsilon_{\nu/\gamma}=1$ Min.γ	$\varepsilon_{\nu/\gamma}=30$ Max.γ
Vela PSR	2.0-3.5	.1	1506
Vela X-1	2.0-4.0	.2	126
Crab SNR	2.0-4.0	.2	438
Crab PSR	2.0-4.0	.06	38
Geminga	2.0-3.2	.49	1506
4U 0115	2.0-4.0	.47	273
Her X-1	2.0-4.0	.24	141
SS433	2.0-4.0	$< .88$	< 510
Cen X-3	2.0-4.0	$< .08$	< 48
Cyg X-3	2.1-4.0	.4	234
LMC X-4	2.0-4.0	0.0001	0.048
M 31	2.0-4.0	1.8	1050
Cen A	2.0-4.0	.14	6
3C 273	2.0-3.3	$< .4$	< 1506



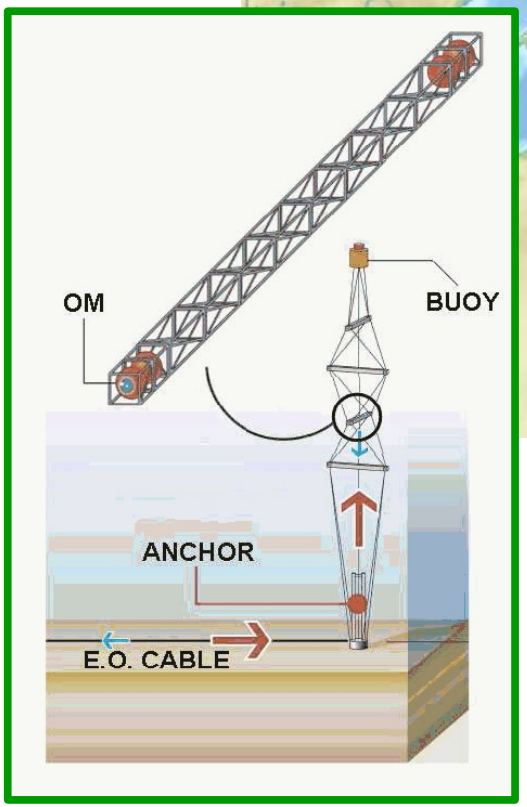
Bosetti, P. et al. (DUMAND Coll.) 1988, DUMAND II: Proposal to construct a deep-ocean laboratory for the study of high energy neutrino astrophysics and particle physics, Tech. Rep. HDC-2-88, Hawaii DUMAND Center, University of Hawaii.

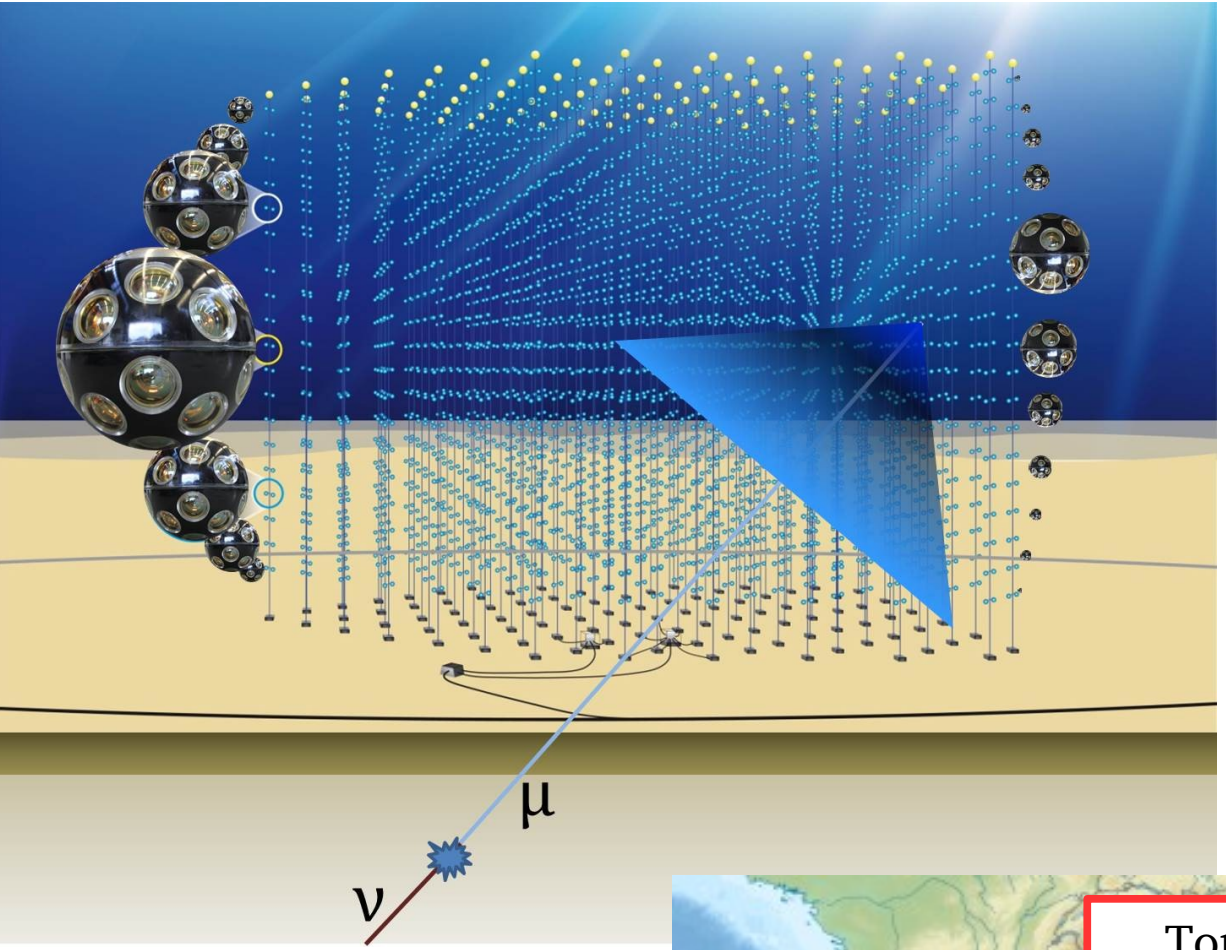


Toulon, France:
ANTARES
12 Strings (2007)

Catania, Italy:
NEMO
Prototype Only

Pylos, Greece:
NESTOR
Prototype Only



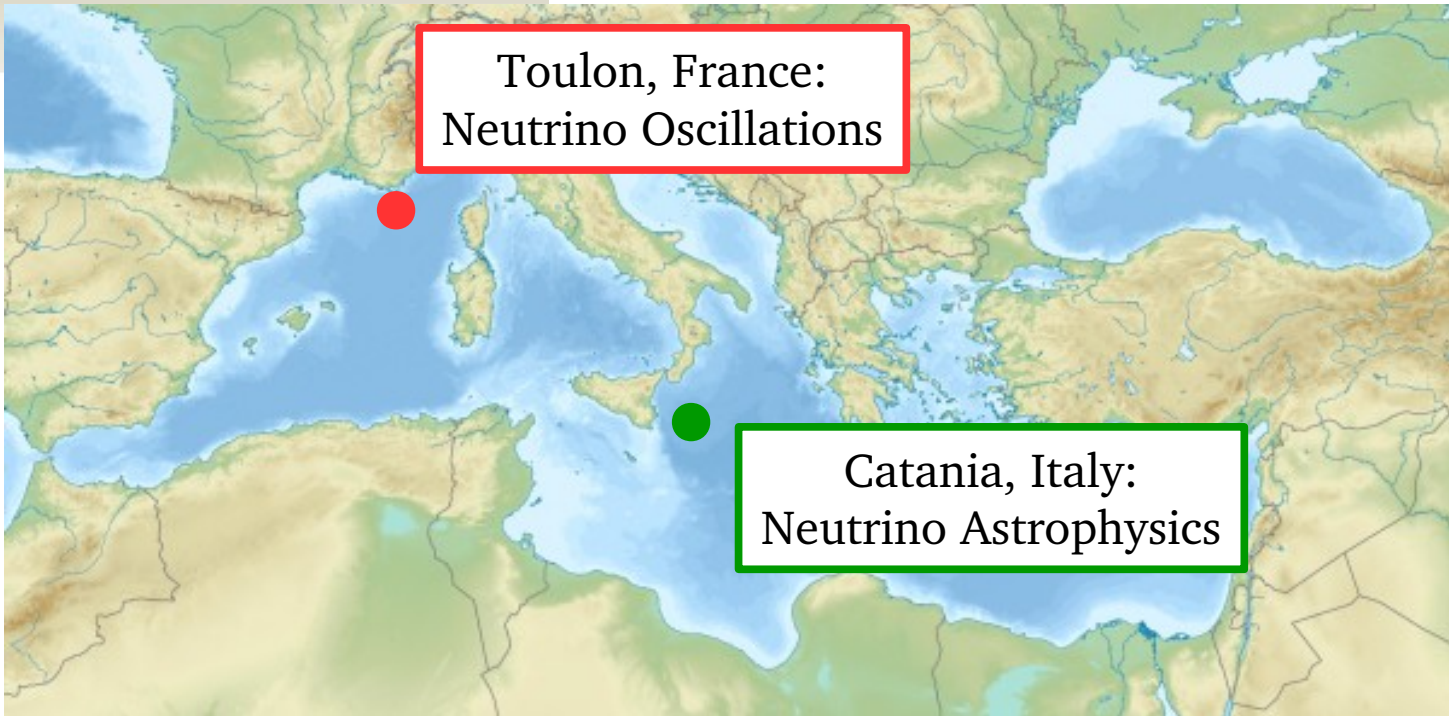


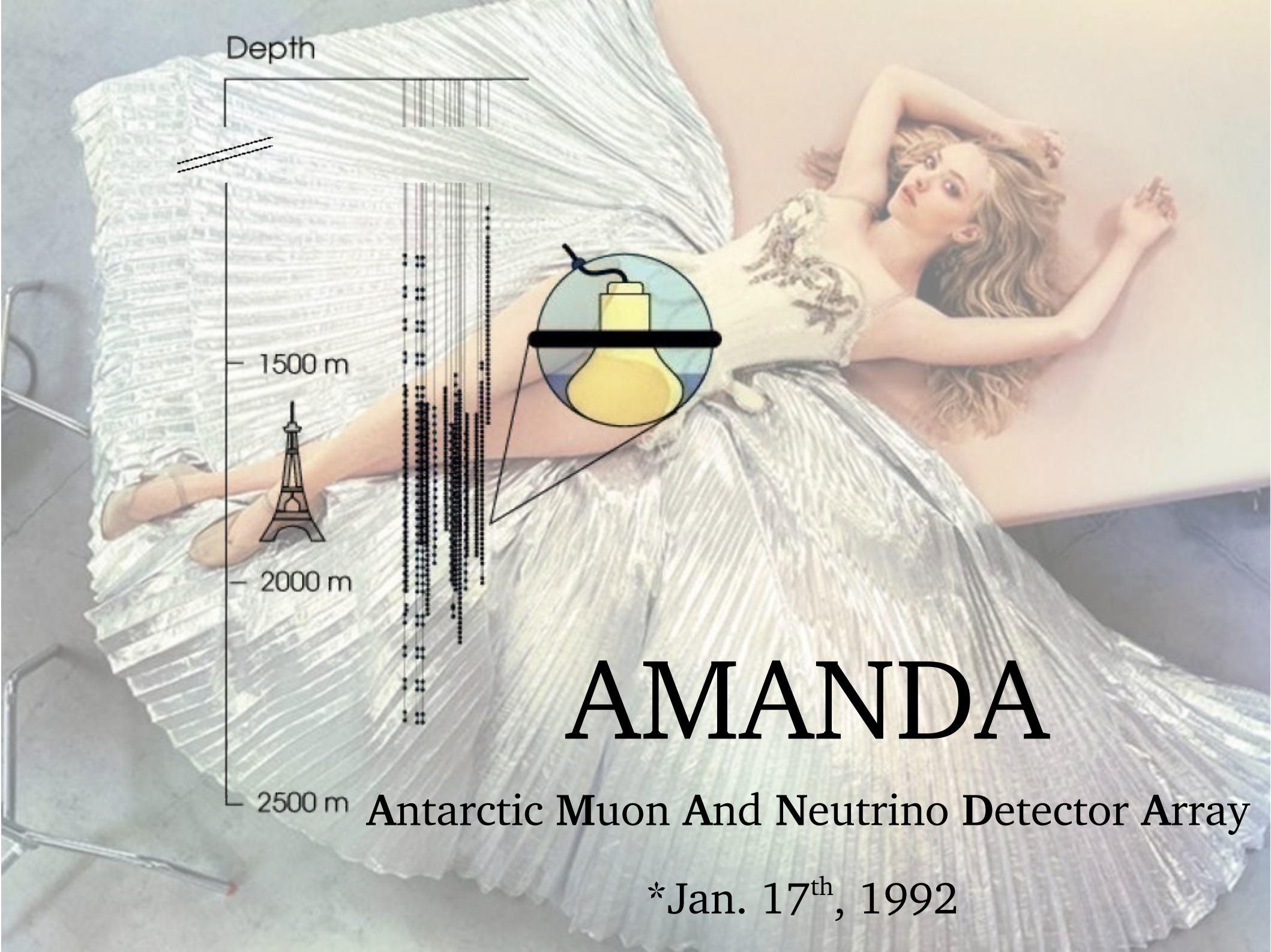
KM3Net

(Under Construction)

Water-based: Less Light Scattering, homogeneous medium

"Multi-PMTs": 4π acceptance





AMANDA

Antarctic **M**uon **A**nd **N**eutrino **D**etector **A**rray

*Jan. 17th, 1992

Water

Ice

AMANDA SOUTH POLE NEUTRINO DETECTOR

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F. Halzen, J. Jacobsen, V. Kandhadai, I. Liubarsky, R. Morse, S. Tilav
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Madison, WI 53706 USA

16 Authors
3 Institutions

1992

(IceCube)

312 Authors
50 Institutions

2015

M. G. Aartsen[b], K. Abraham[af], M. Ackermann[av], J. Adams[o], J. A. Aguilar[l], M. Ahlers[ac], M. Ahrens[am], D. Altmann[w], T. Anderson[as], M. Archinger[ad], C. Argüelles[ac], T. C. Arlen[as], J. Auffenberg[a], X. Bai[ak], S. W. Barwick[z], V. Baum[ad], R. Bay[g], J. J. Beatty[q,r], J. Becker Tjus[j], K.-H. Becker[au], E. Beiser[ac], S. BenZvi[ac], P. Berghaus[av,*], D. Berley[p], E. Bernardini[av], A. Bernhard[af], D. Z. Besson[aa], G. Binder[h,g], D. Bindig[au], M. Bissok[a], E. Blaufuss[p], J. Blumenthal[a], D. J. Boersma[ai], C. Bohm[am], M. Börner[t], F. Bos[j], D. Bose[ao], S. Böser[ad], O. Botner[at], J. Braun[ac], L. Brayeur[m], H.-P. Bretz[av], A. M. Brown[o], N. Buzinsky[y], J. Casey[e], M. Casier[m], E. Cheung[p], D. Chirkin[ac], A. Christov[x], B. Christy[p], K. Clark[ap], L. Classen[w], S. Coenders[af], D. F. Cowen[as,ar], A. H. Cruz Silva[av], J. Daughhetee[e], J. C. Davis[q], M. Day[ac], J. P. A. M. de André[u], C. De Clercq[m], H. Dembinski[ag], S. De Ridder[y], P. Desiati[ac], K. D. de Vries[m], G. de Wasseige[m], M. de With[i], T. DeYoung[u], J. C. Díaz-Vélez[ac], J. P. Dumm[am], M. Dunkman[as], R. Eagan[as], B. Eberhardt[ad], T. Ehrhardt[ad], B. Eichmann[j], S. Euler[at], P. A. Evenson[ag], O. Fadiran[ac], S. Fahey[ac], A. R. Fazely[f], A. Fedynitch[j], J. Feintzeig[ac], J. Felde[p], K. Filimonov[g], C. Finley[am], T. Fischer-Wasels[au], S. Flis[am], T. Fuchs[t], M. Glagla[a], T. K. Gaisser[ag], R. Gaior[n], J. Gallagher[ab], L. Gerhardt[h,g], K. Ghorbani[ac], D. Gier[a], L. Gladstone[ac], T. Glüsenkamp[av], A. Goldschmidt[h], G. Golup[m], J. G. Gonzalez[ag], D. Góra[av], D. Grant[y], P. Gretskov[a], J. C. Groh[as], A. Groß[af], C. Ha[h,g], C. Haack[a], A. Haj Ismail[y], A. Hallgren[at], F. Halzen[ac], B. Hansmann[a], K. Hanson[ac], D. Hebecker[i], D. Heereman[l], K. Helbing[au], R. Hellauer[p], D. Hellwig[a], S. Hickford[au], J. Hignight[u], G. C. Hill[b], K. D. Hoffman[p], R. Hoffmann[au], K. Holzapfel[af], A. 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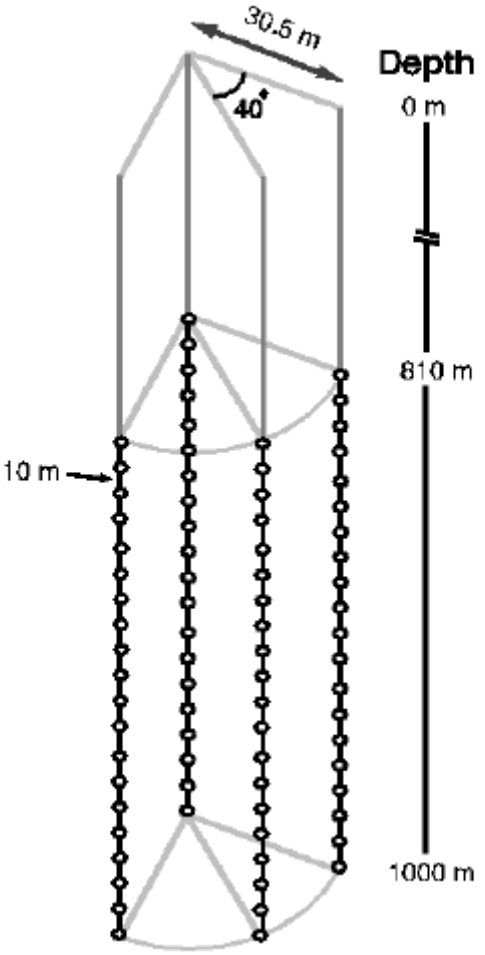
Yoshida[n], P. Zarzhitsky[aq], M. Zoll[am]

AMANDA SOUTH POLE NEUTRINO DETECTOR

S. Barwick, J. Lynch, R. Porrata, G. Yodh
The University of California,
Irvine, CA 92717 USA

D. Lowder, T. Miller, B. Price, A. Richards, D. Snowden-Ifft, A. Westphal
The University of California,
Berkeley, CA 94720 USA

F. Halzen, J. Jacobsen, V. Kandhadai, I. Liubarsky, R. Morse, S. Tilav
University of Wisconsin
Madison, WI 53706 USA



We conclude that 800 m deep ice is free of bubbles

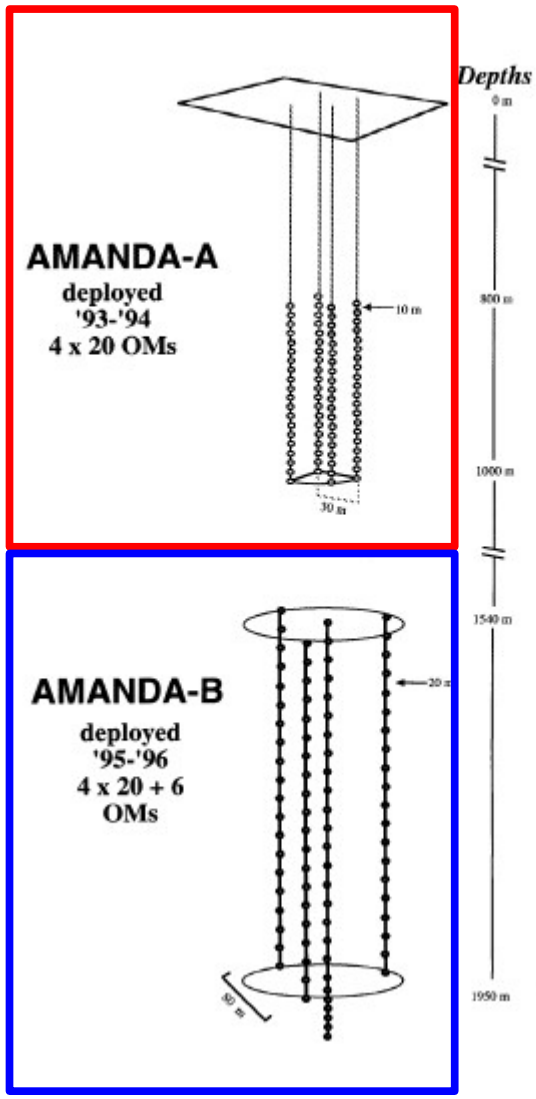
We computed that the Mie scattering length exceeds the absorption length and should not affect our experiment.

AMANDA-A

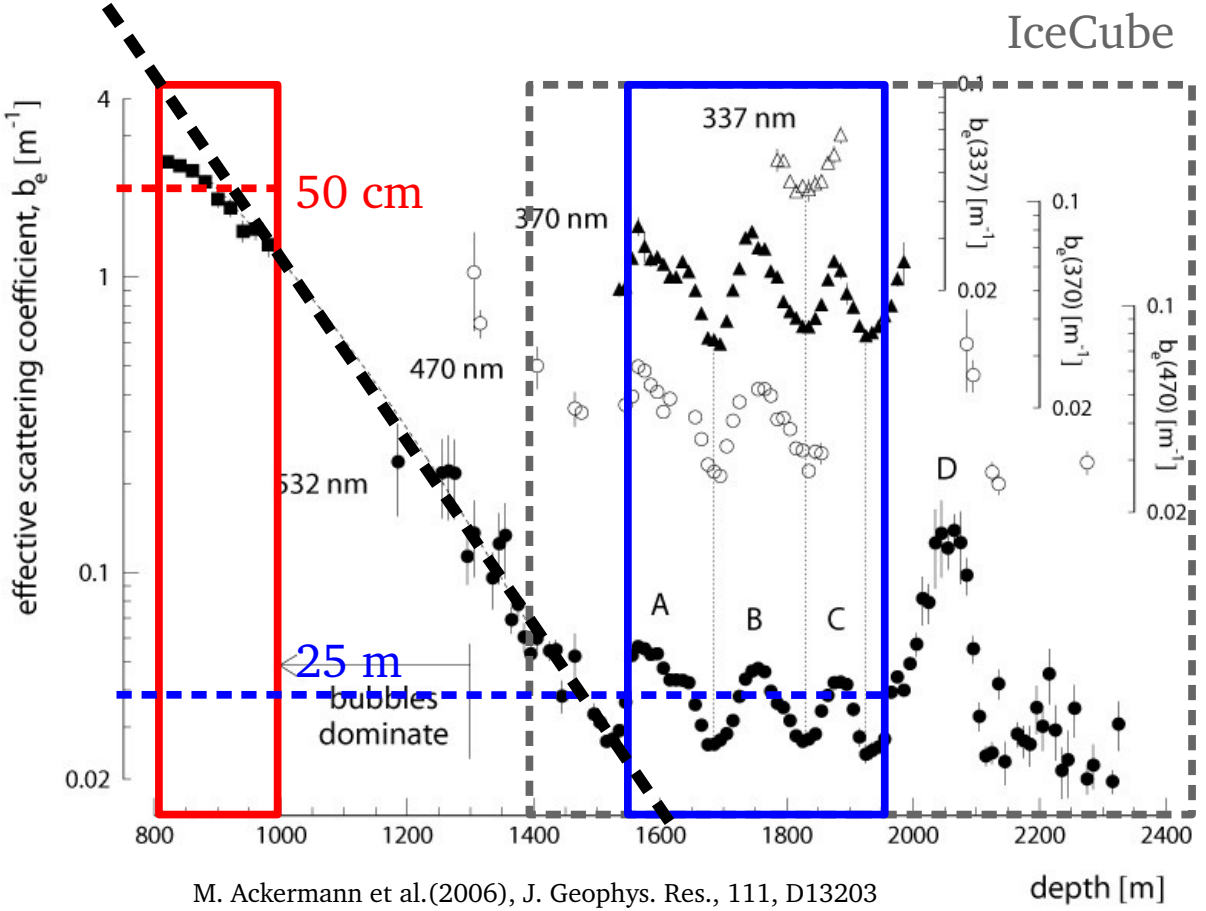
4 Strings
800-1000 meters

Domogatsky informed Francis Halzen about results from an ice core extracted at the geomagnetic South Pole where the Russian Vostok station is located.

scattering length was found to be between 40 cm at 830 m depth and 80 cm at 970 m. The scattering by air bubbles trapped in the ice made track reconstruction impossible.



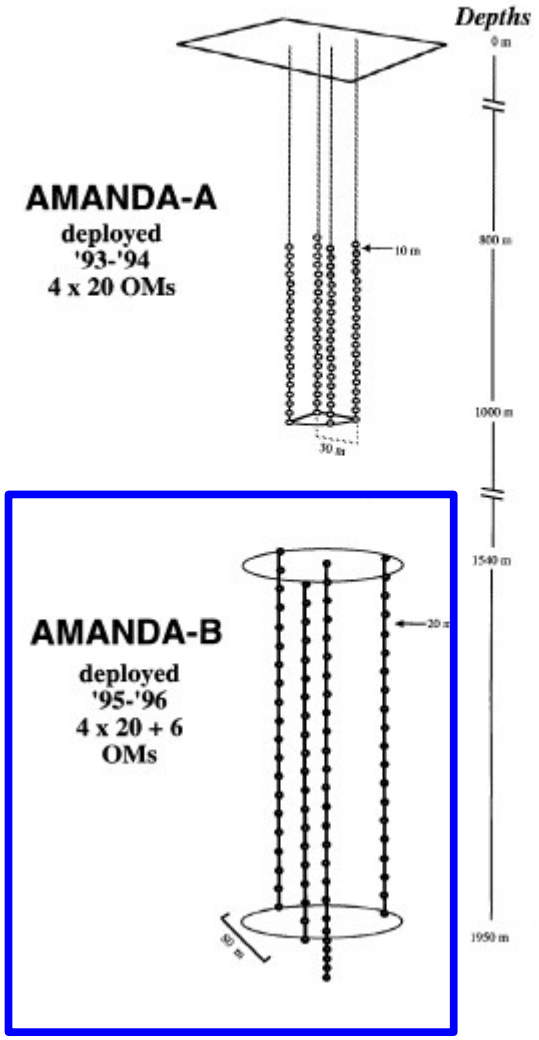
Bubbles: Exponential decrease

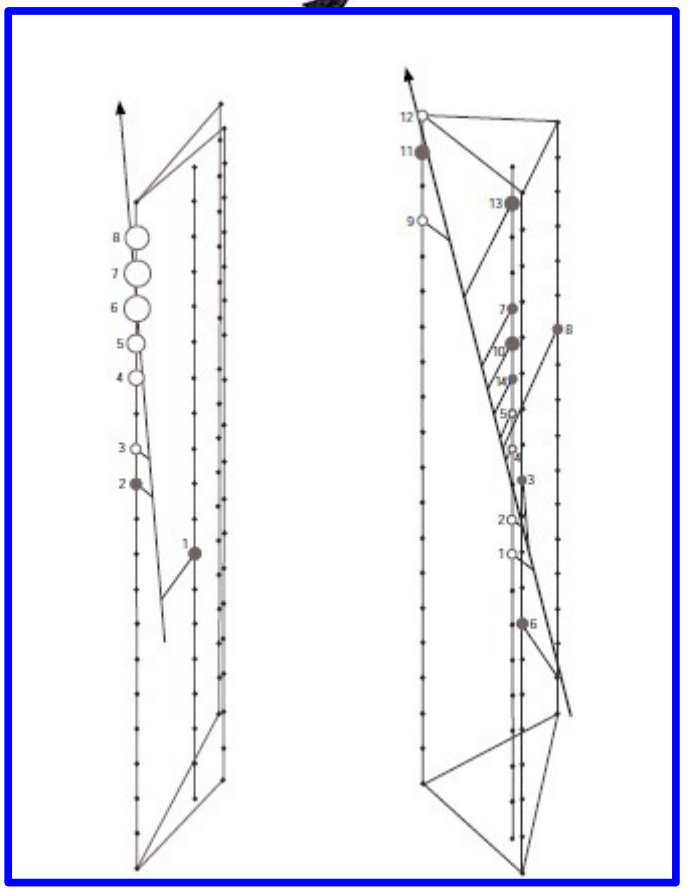


M. Ackermann et al.(2006), J. Geophys. Res., 111, D13203

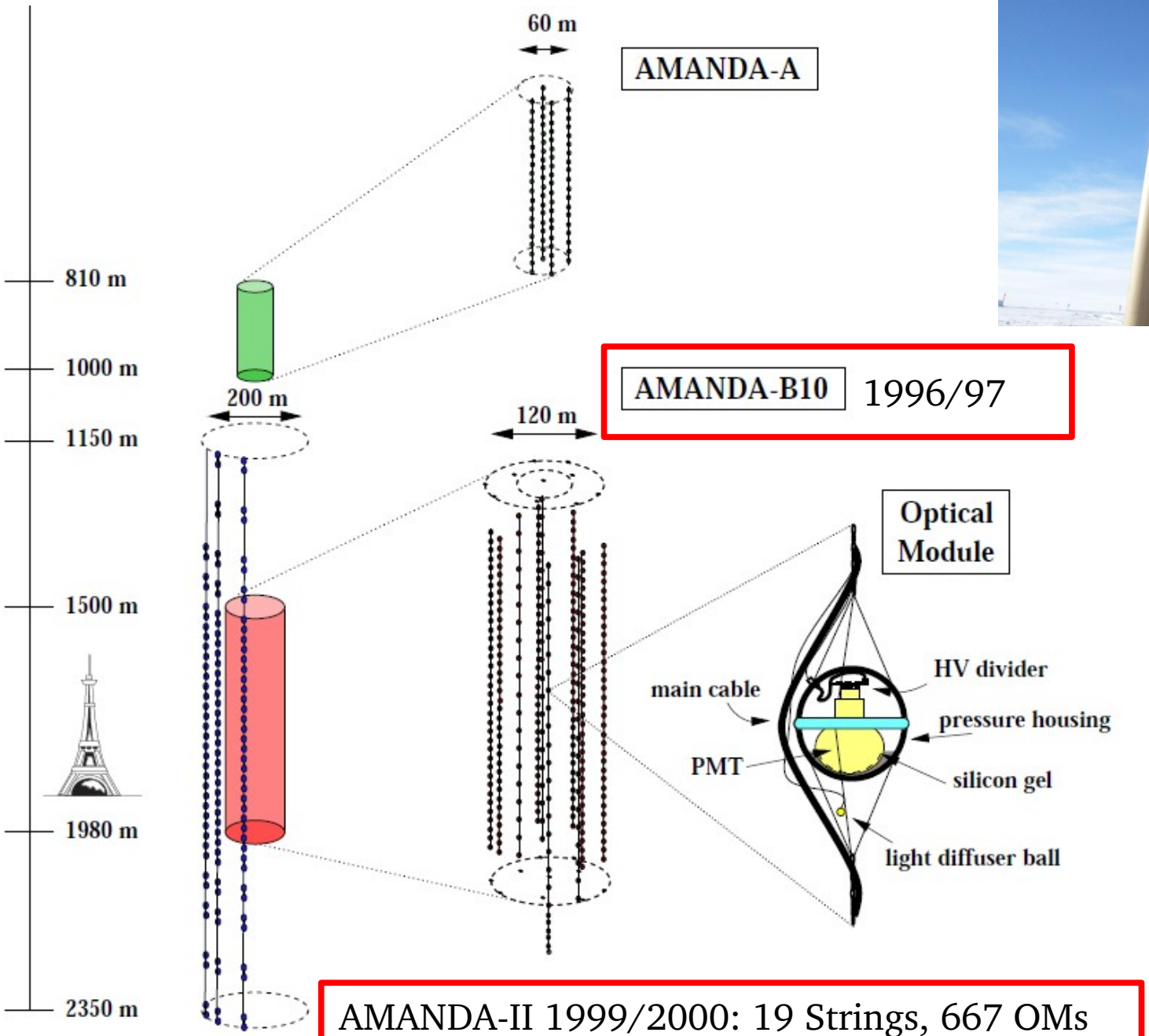
Go Deeper!

1996

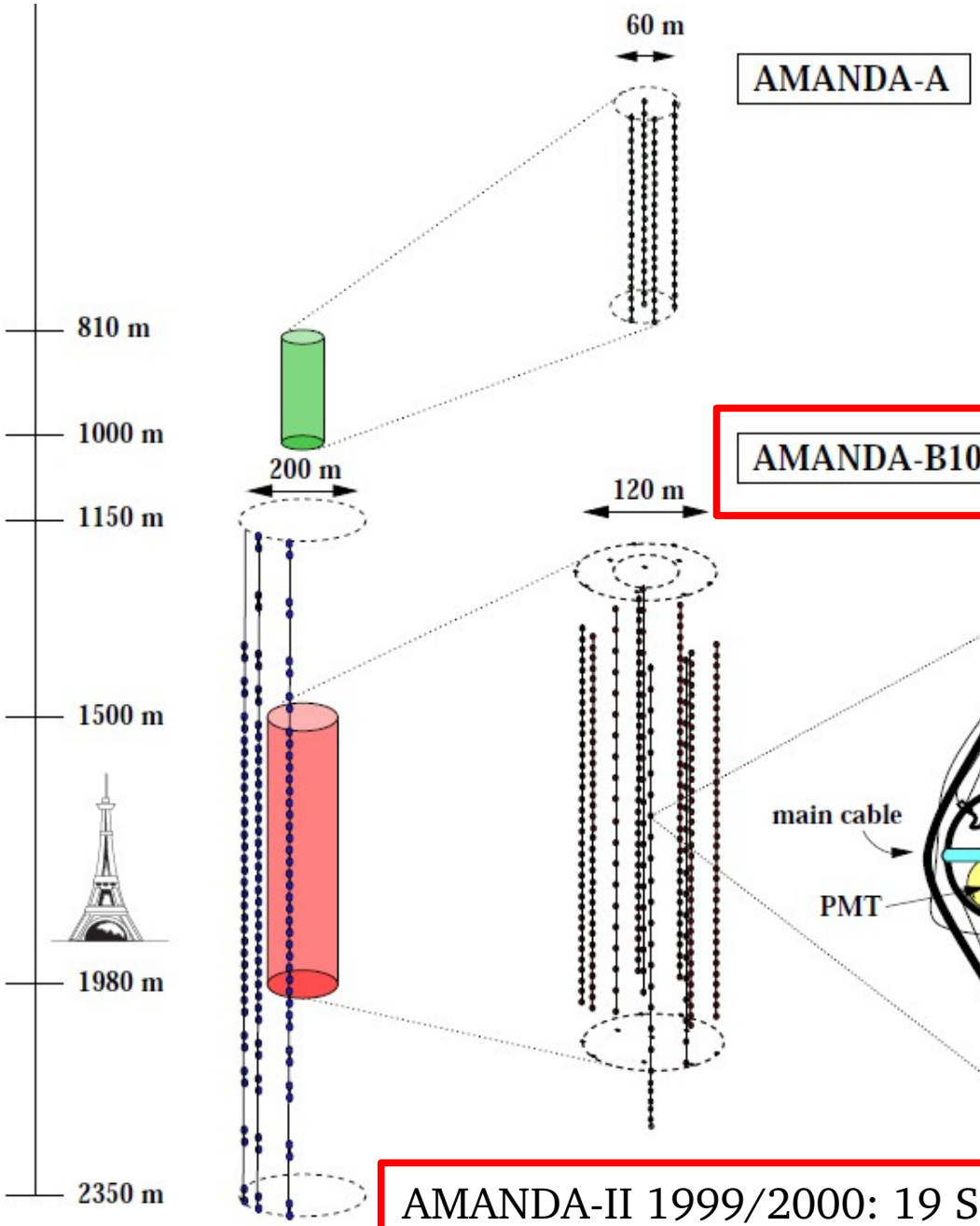


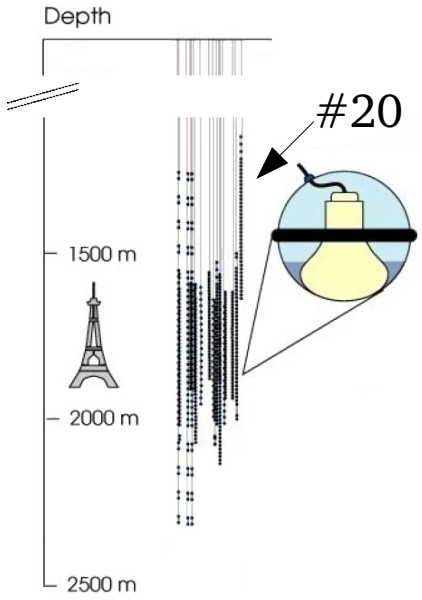


NEUTRINOS!!!



AMANDA-II 1999/2000: 19 Strings, 667 OMs

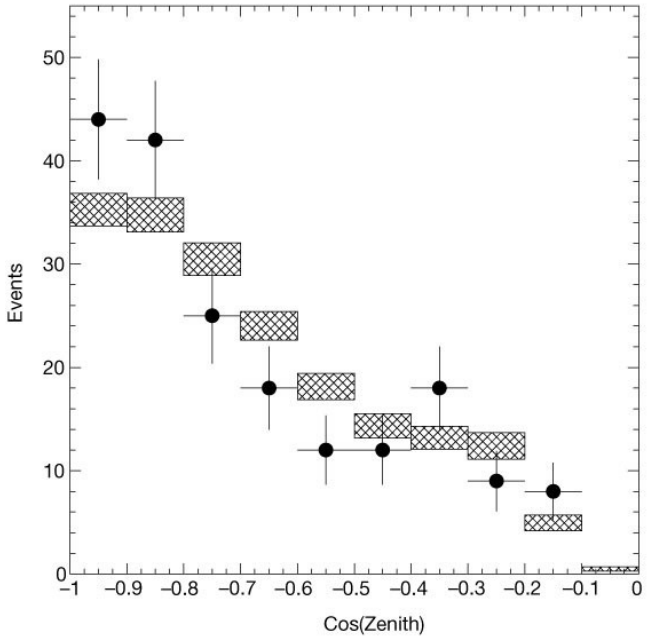


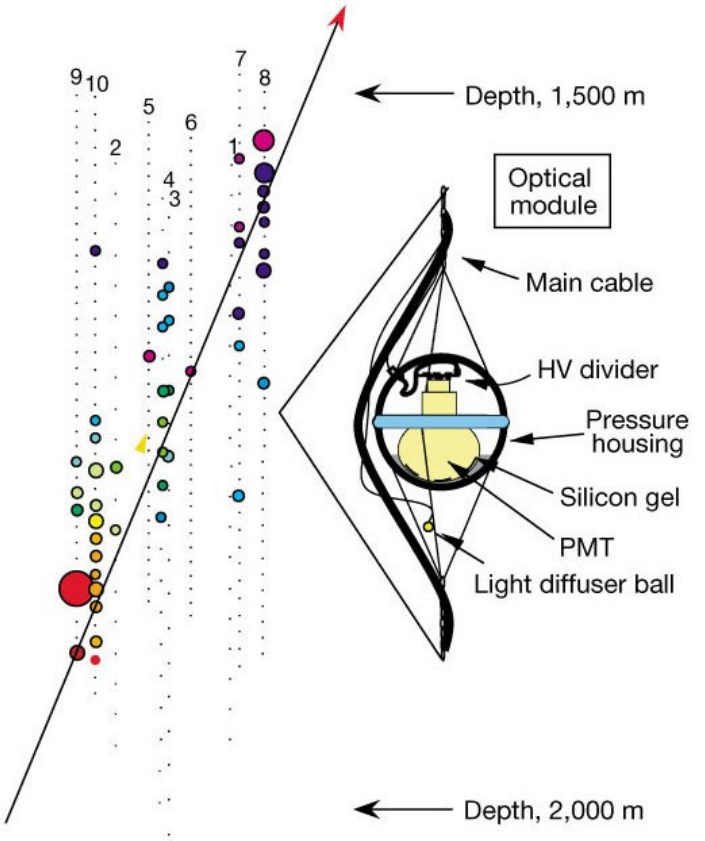


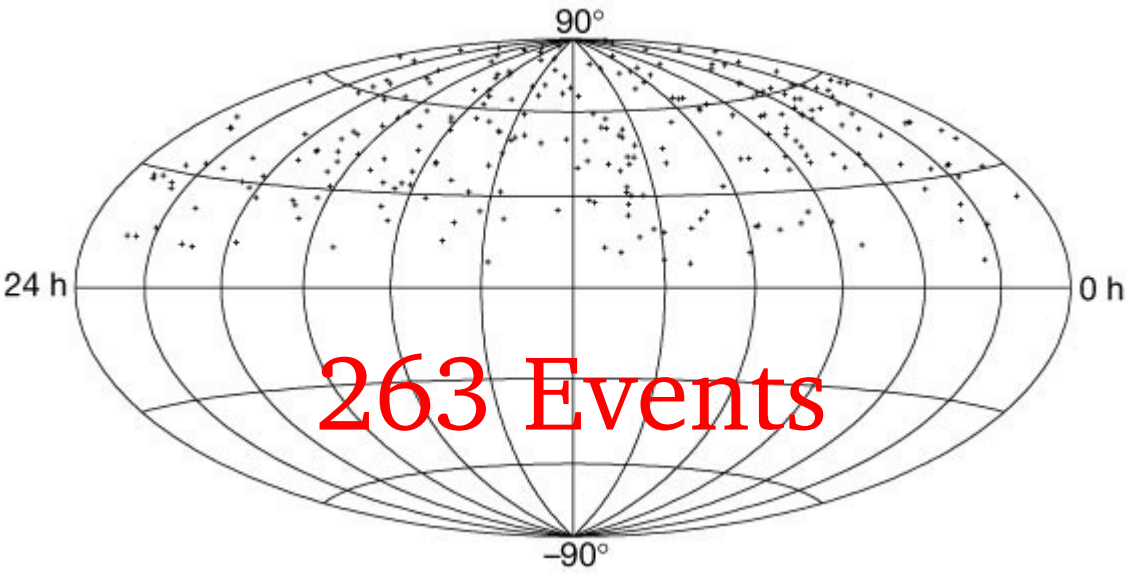
AMANDA-II 1999/2000: 19 Strings, 667 OMs

nature
International weekly journal of science

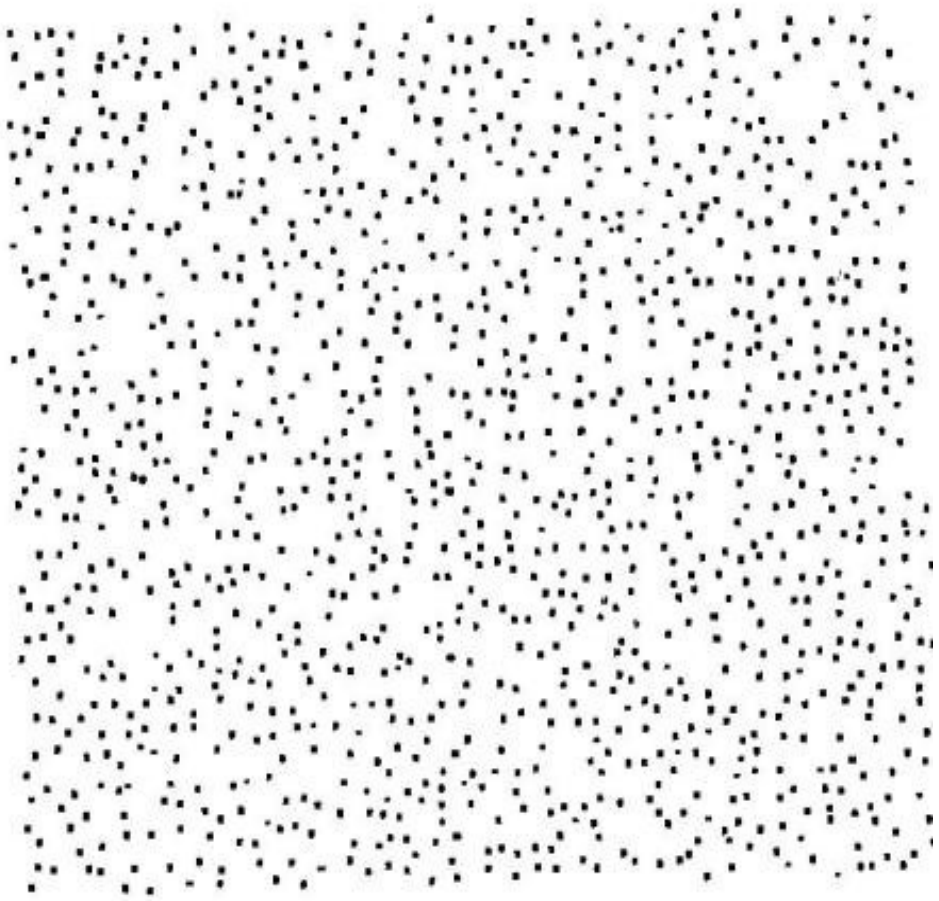
Observation of high-energy neutrinos using Cherenkov detectors embedded deep in Antarctic ice
Nature 410, 441-443 (22 March 2001)

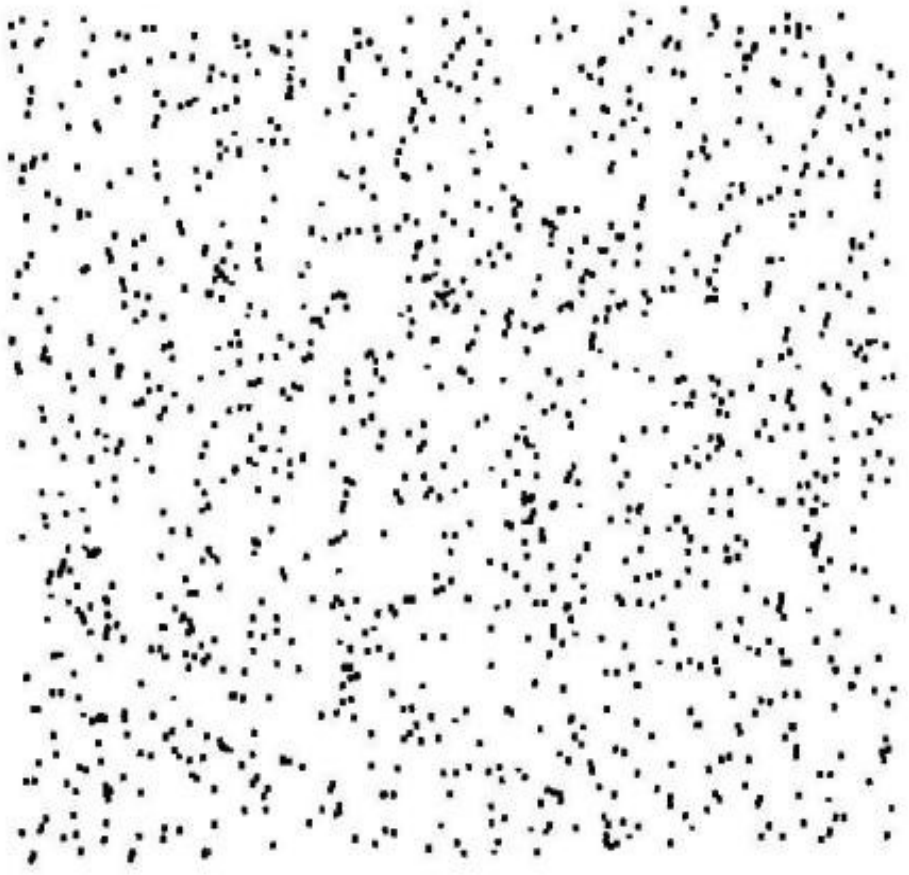






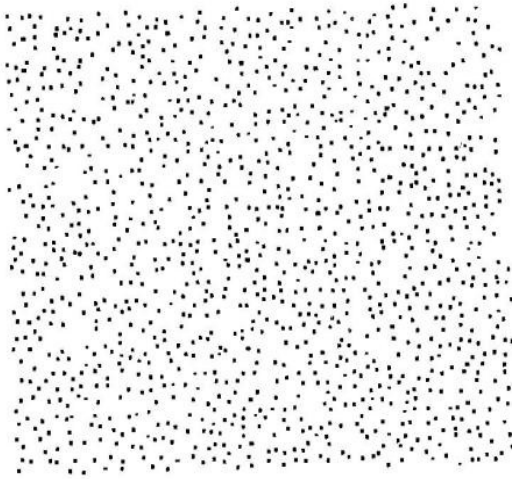
Random Dots

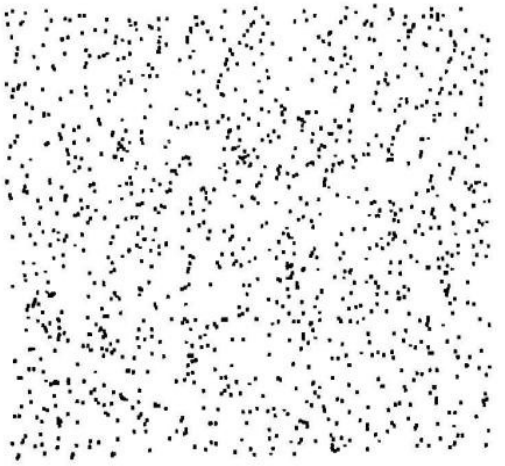


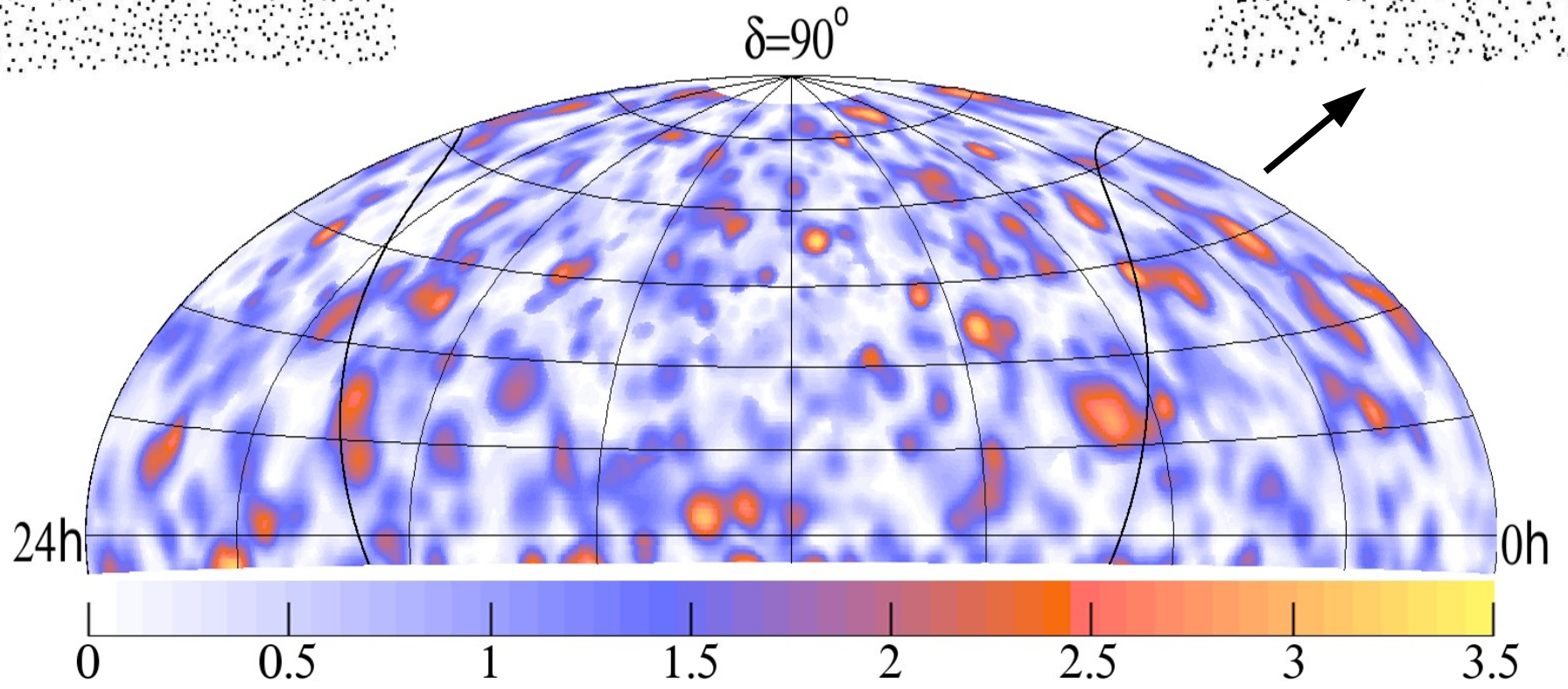


A

B

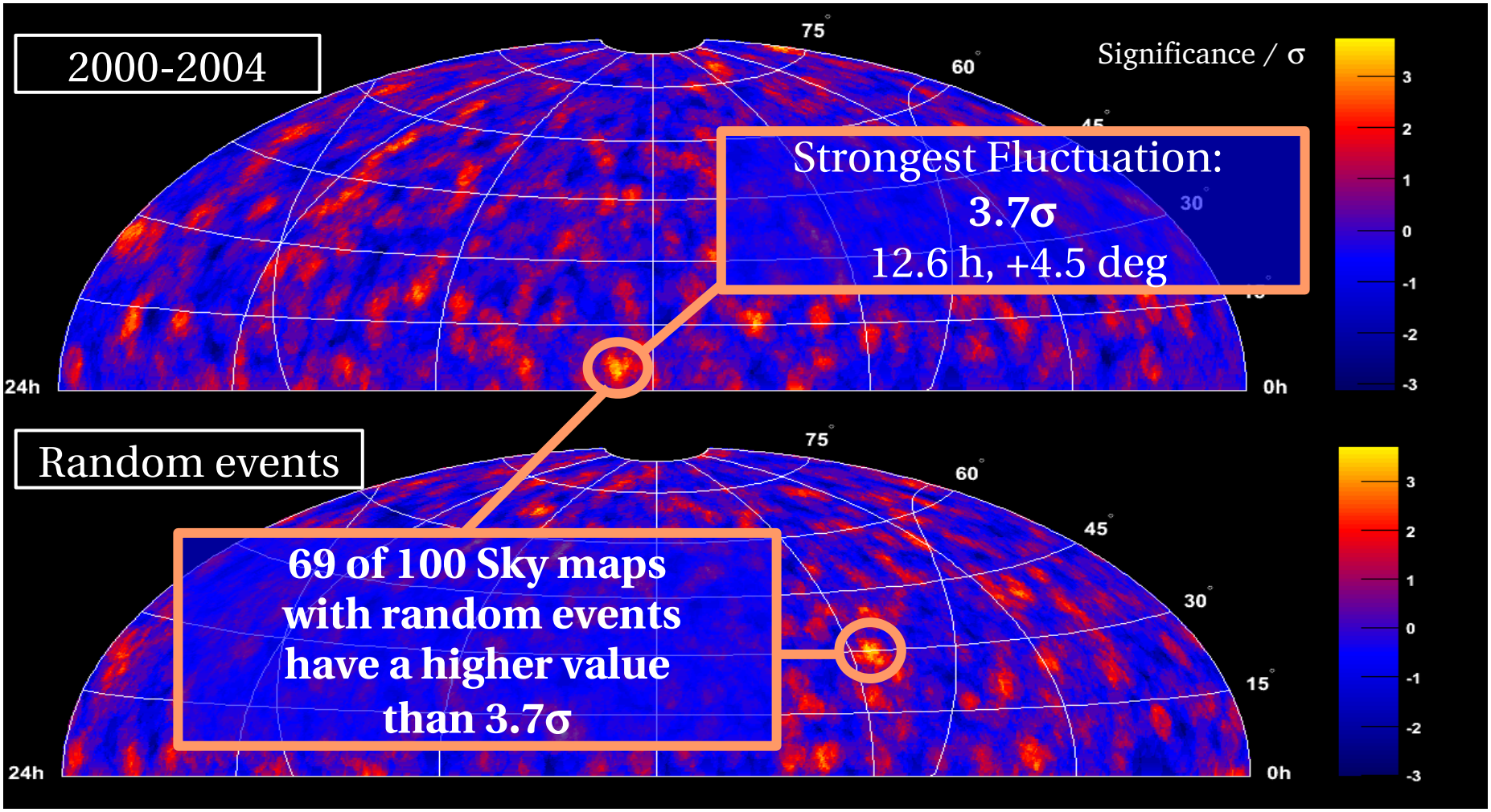


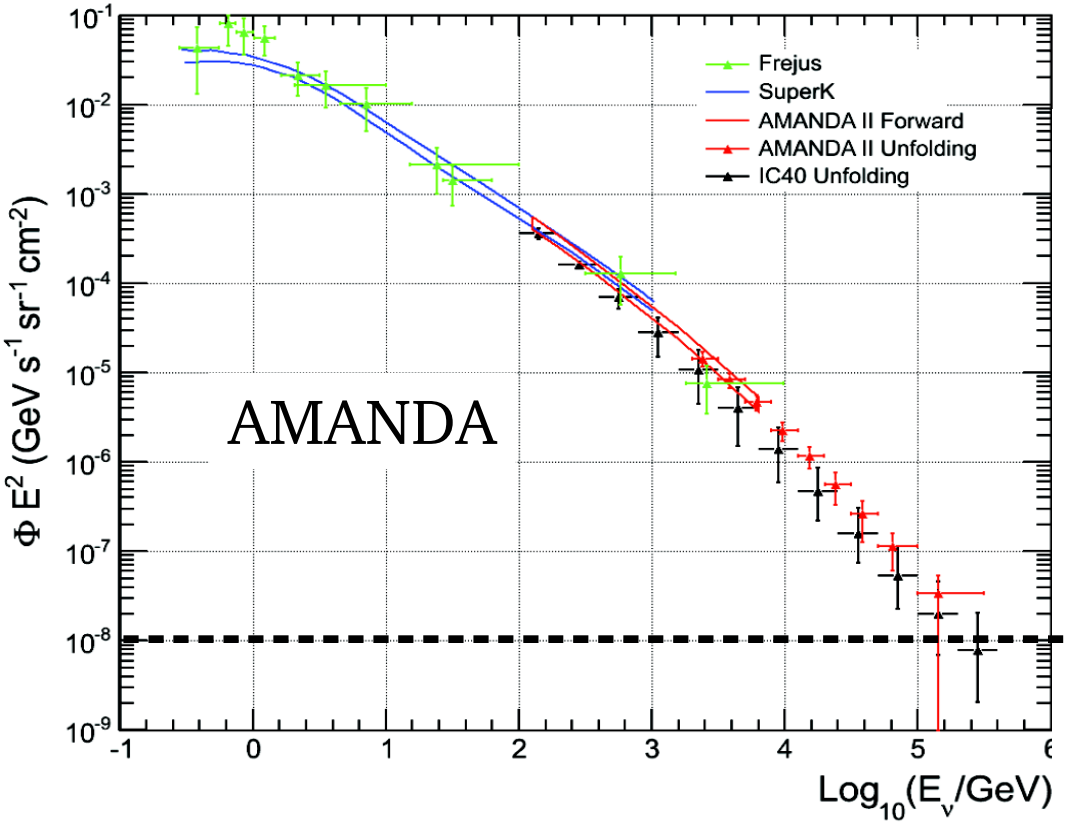


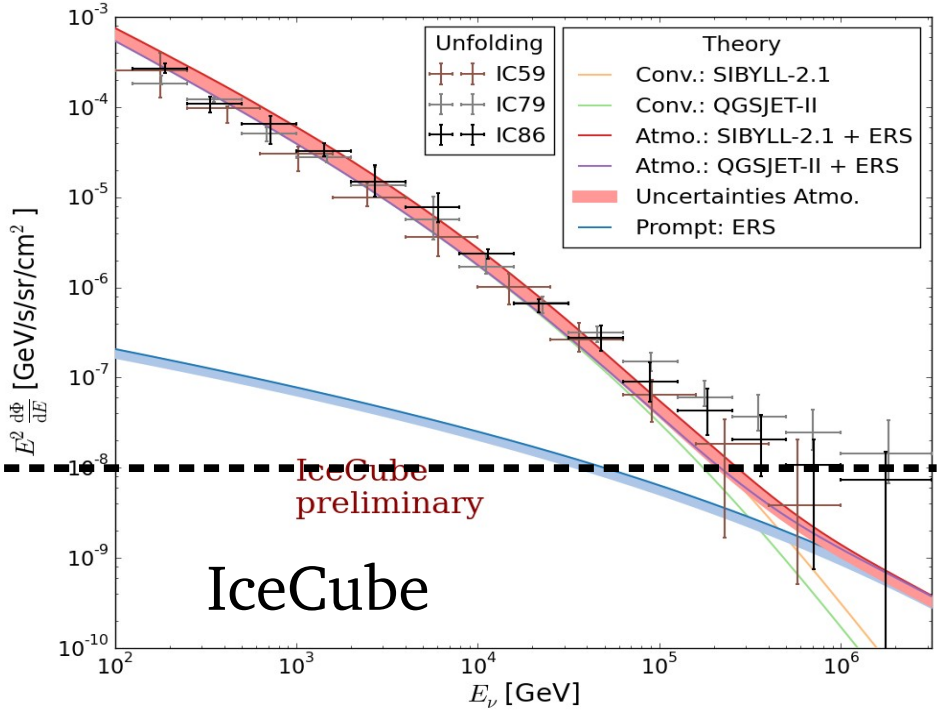


6959 Events

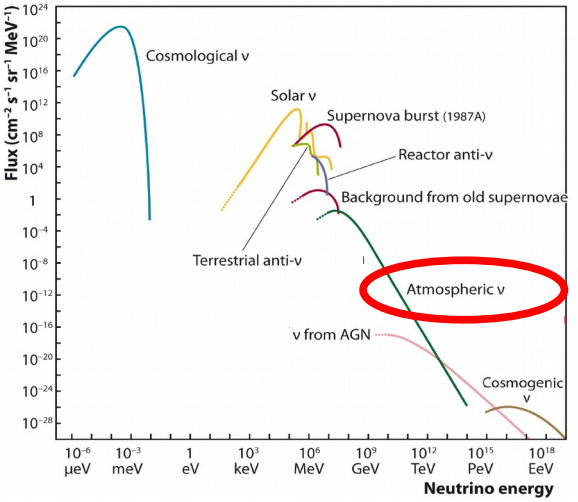
IF this point in the sky had been selected IN ADVANCE, it would have had a significance corresponding to 3.7 standard deviations (probability 10^{-4}).



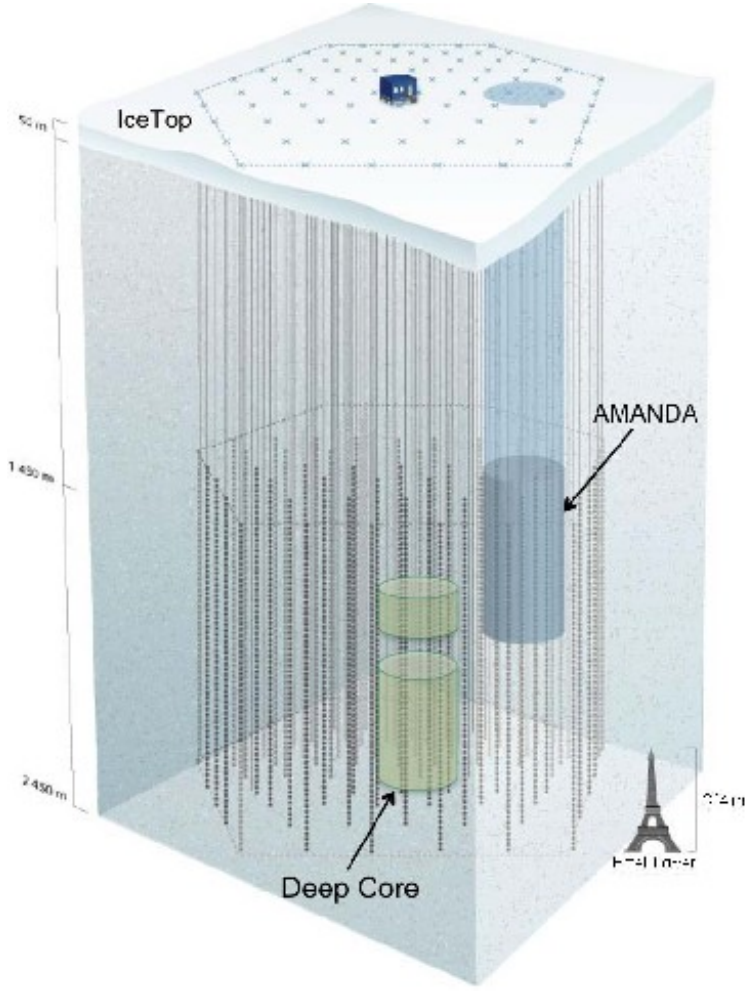




Neutrino Energy Spectrum



IceCube

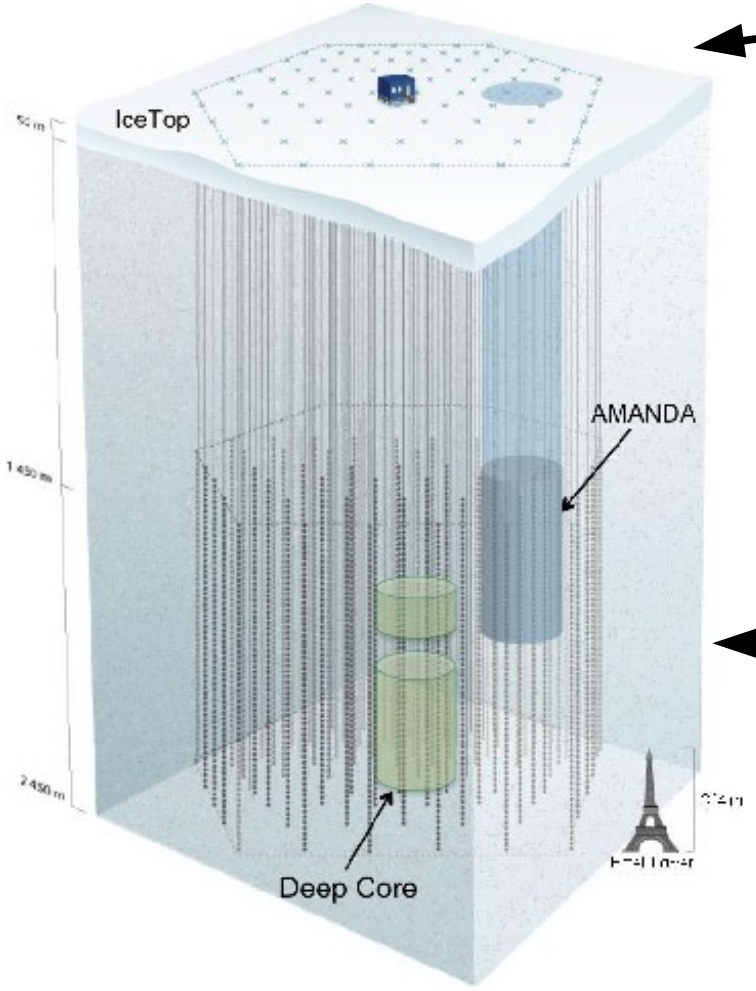


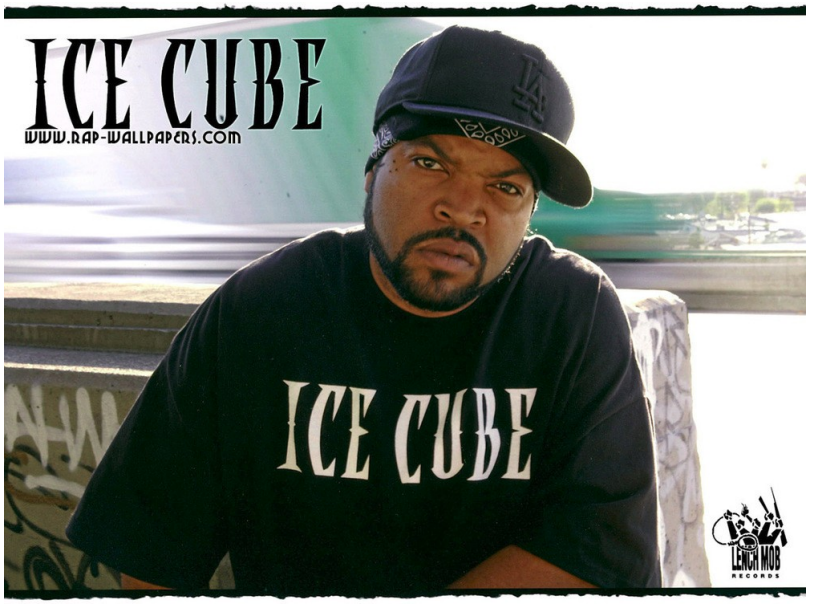
$1\ km^3$

86x60 DOMs

built between 2004 and 2010

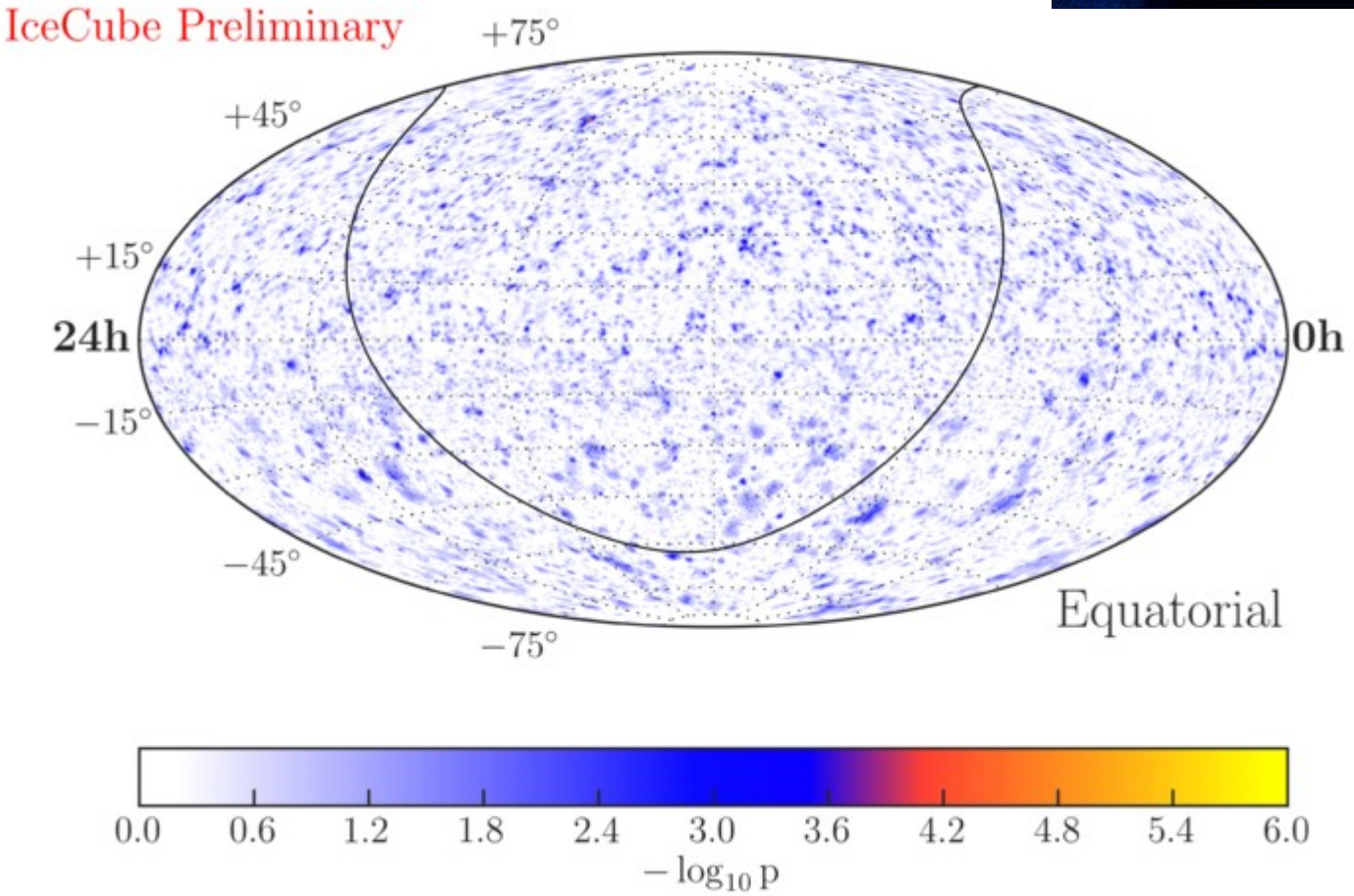
A Badass Detector...

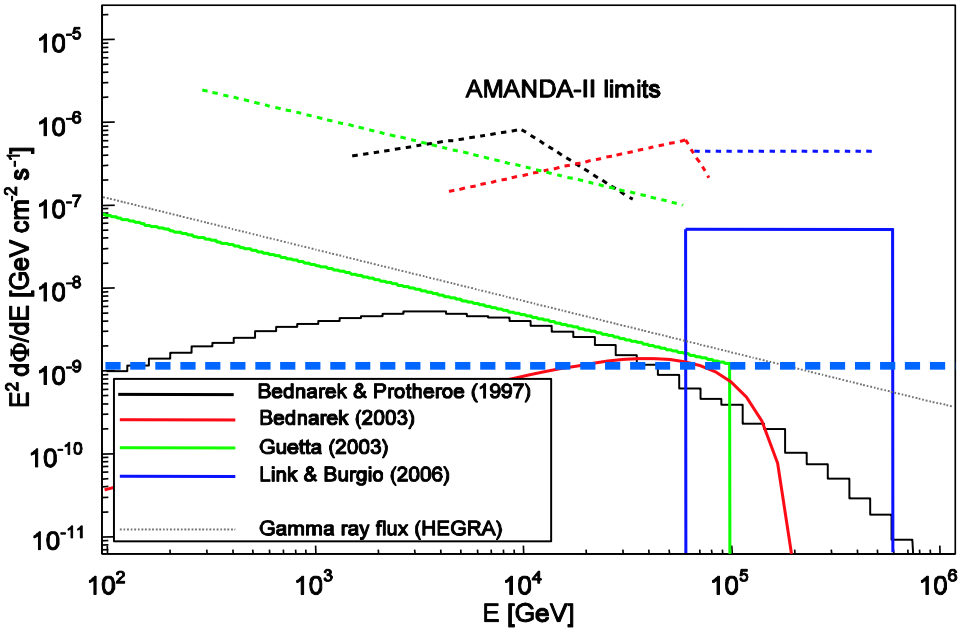


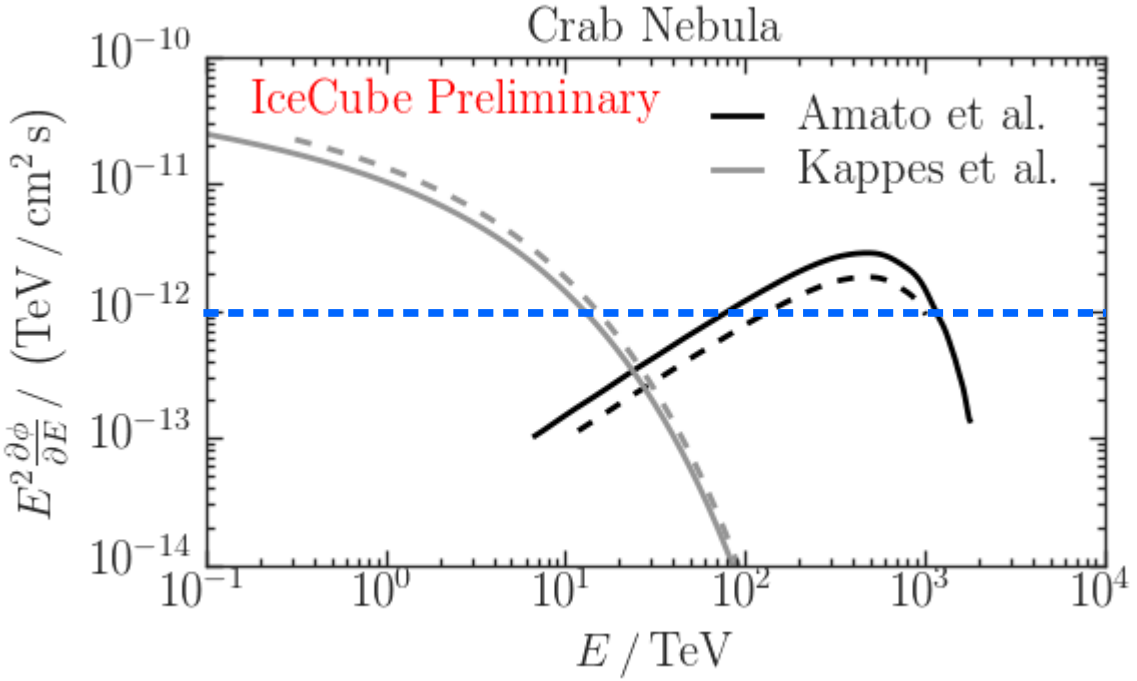



...built by dorks.

No Point Sources!





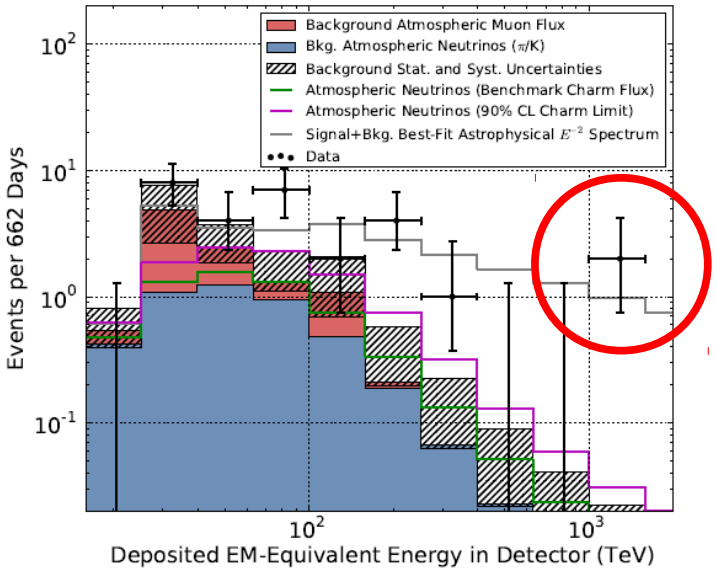


But better limits!

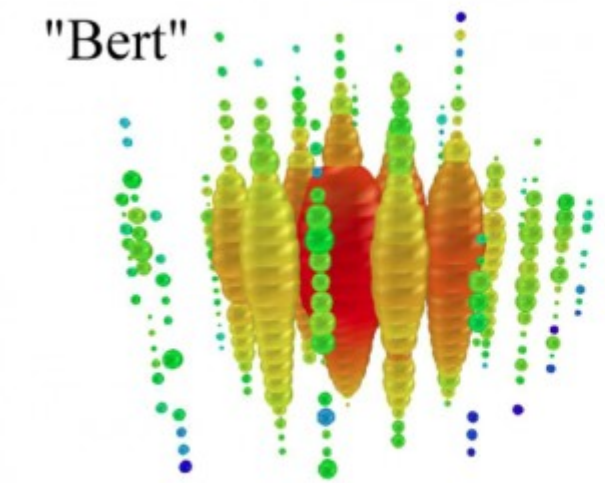
First observation of PeV-energy neutrinos with IceCube

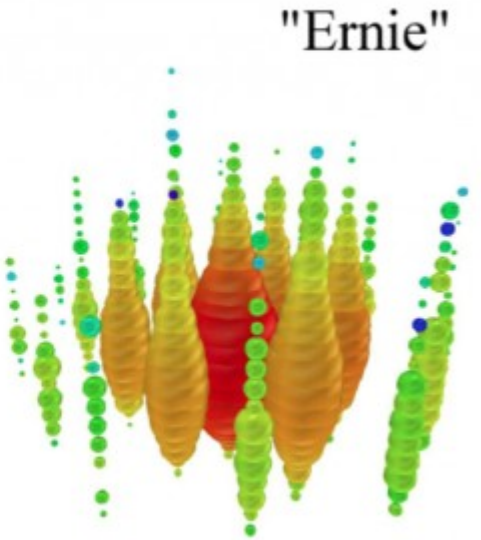
Phys. Rev. Lett. 111, 021103 (2013)

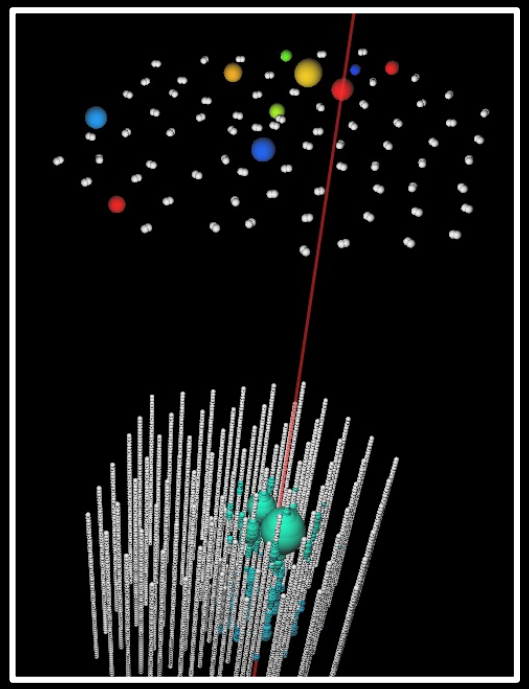
2012



arxiv:1311.5238







Track passed through surface array, no evidence for air shower

Primary Interaction (200 TeV) Inside Detector Volume

2014

"Platinum Event"

Muon Energy: > 100 TeV

Now this is not the end. It is not even the beginning of the end. But it is, perhaps, the end of the beginning.

-Winston Churchill