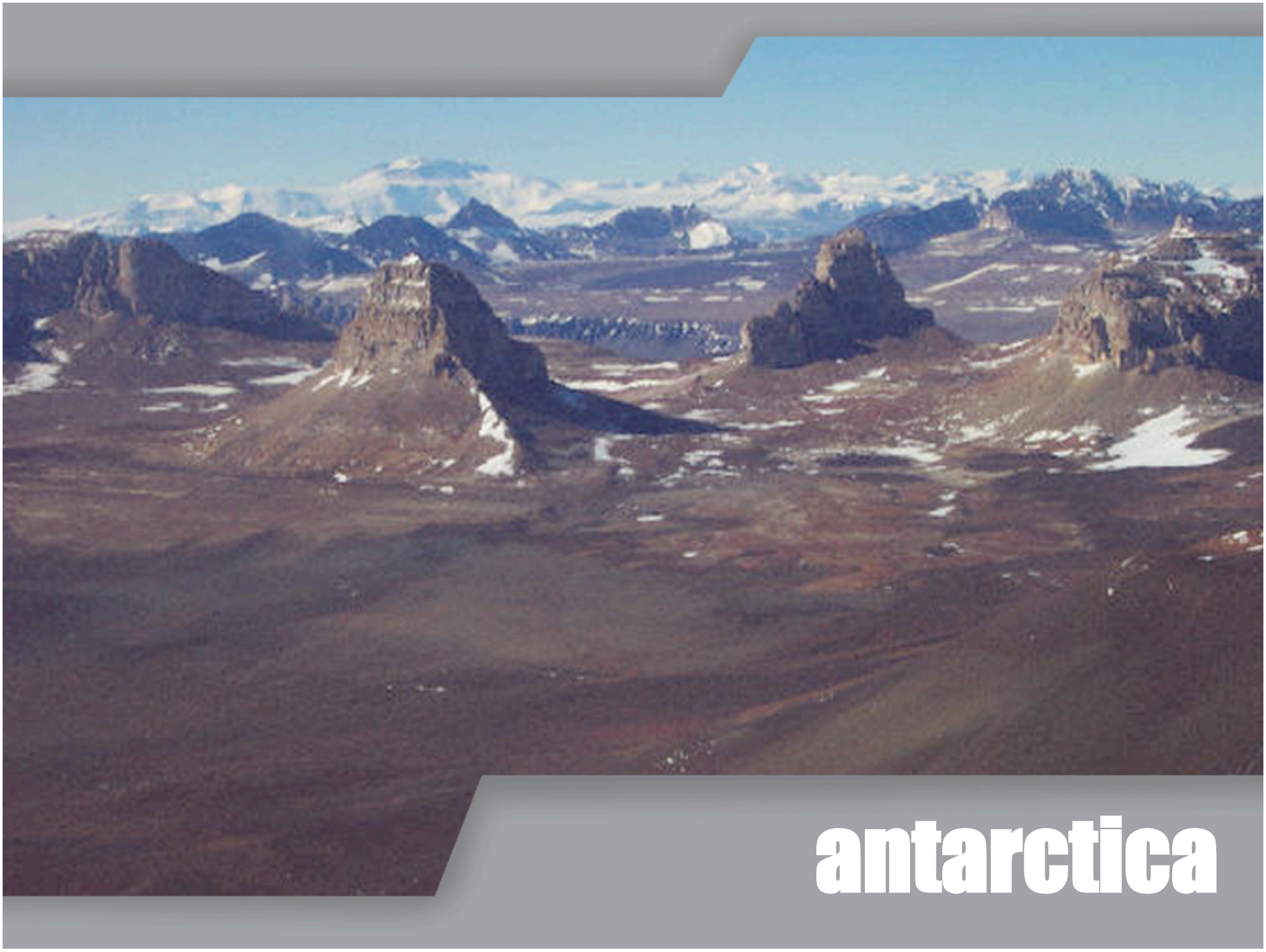
The real voyage is not to travel to new landscapes,
but to see with new eyes. . .

Marcel Proust

icebound neutrinos

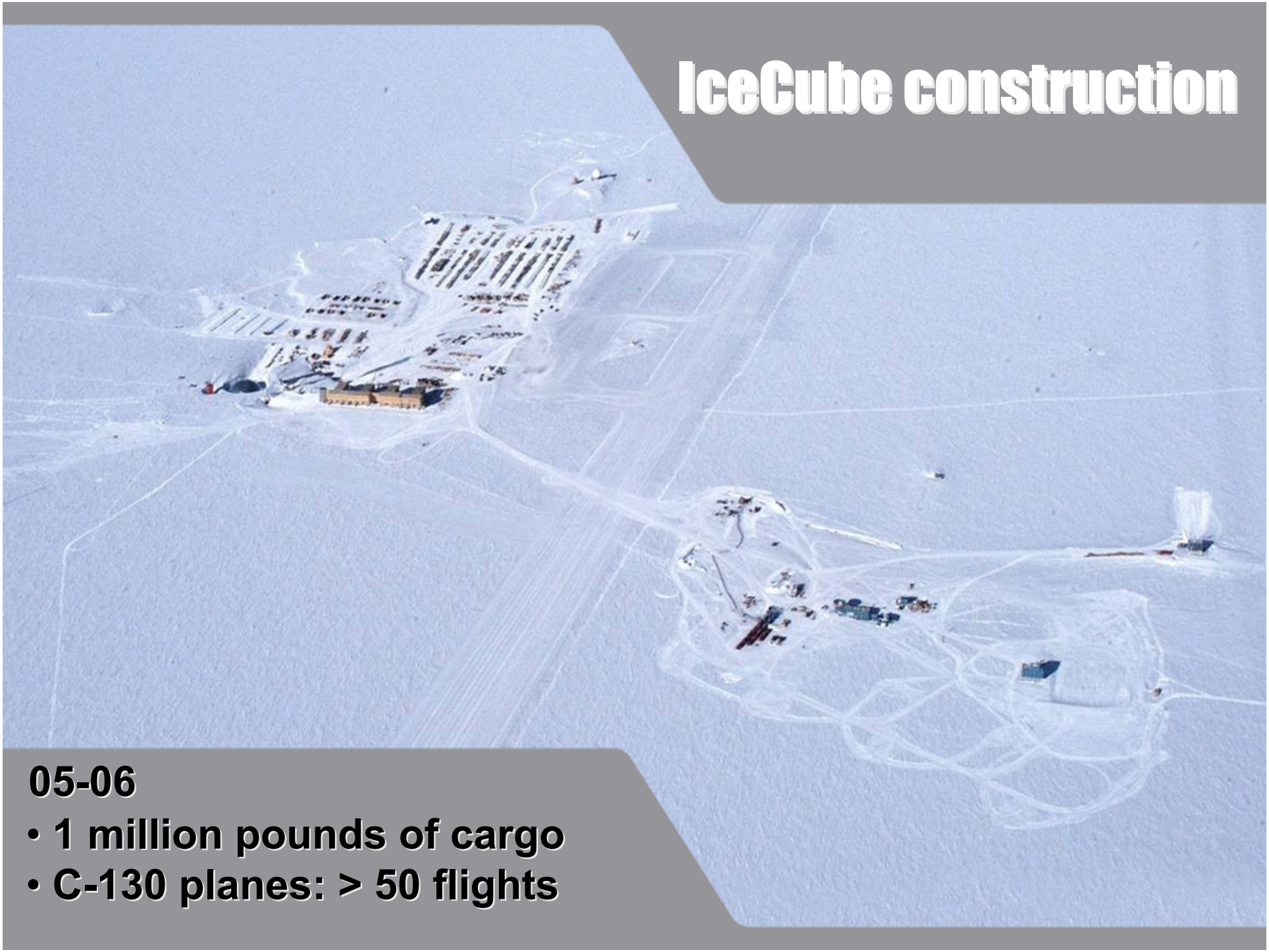
Francis Halzen

University of Wisconsin
http://icecube.wisc.edu


antarctica

new South Pole station

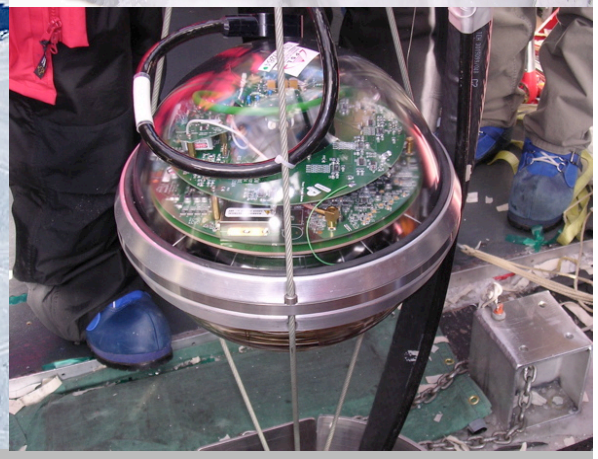
IceCube construction



05-06

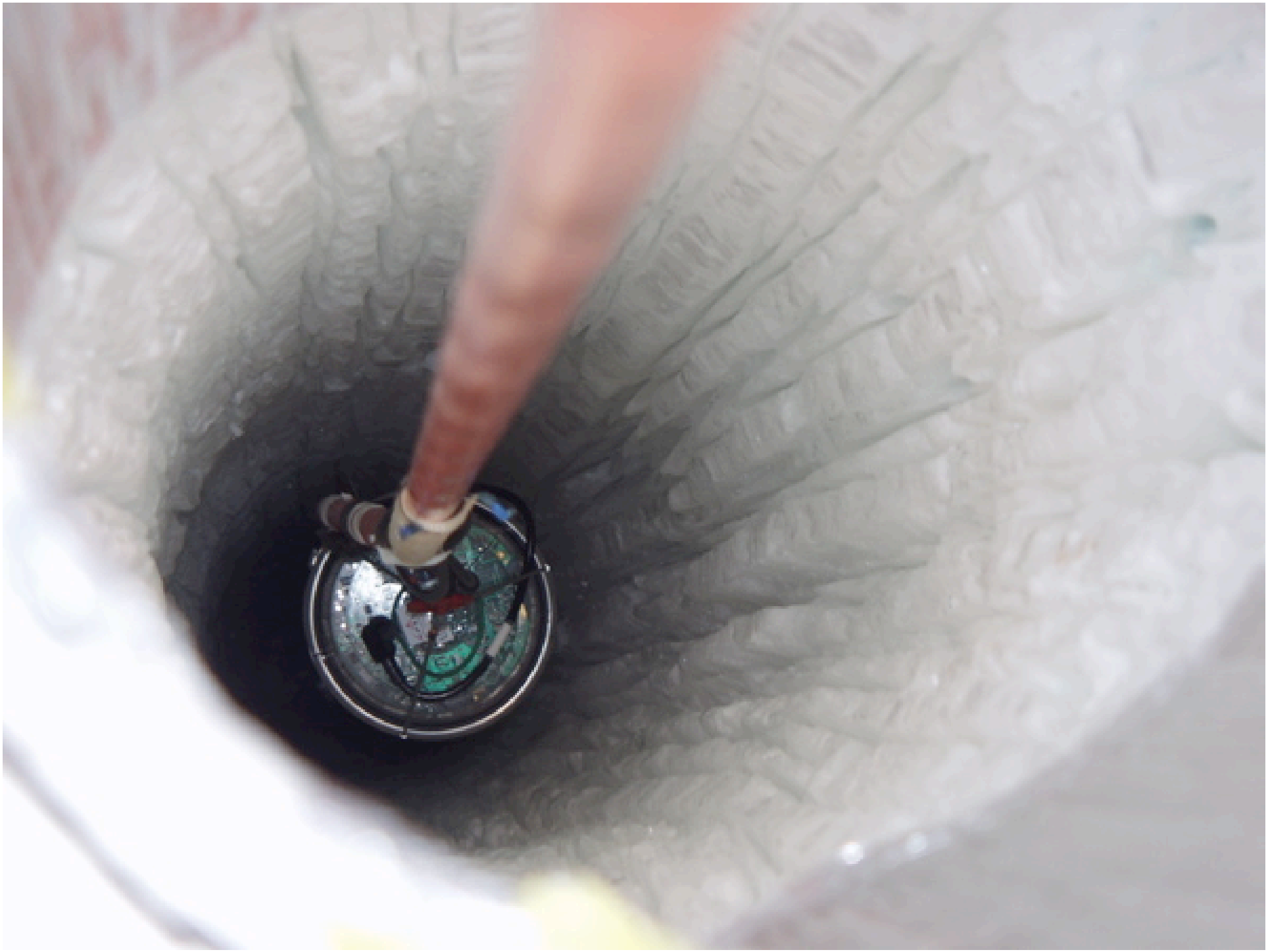
- **1 million pounds of cargo**
- **C-130 planes: > 50 flights**

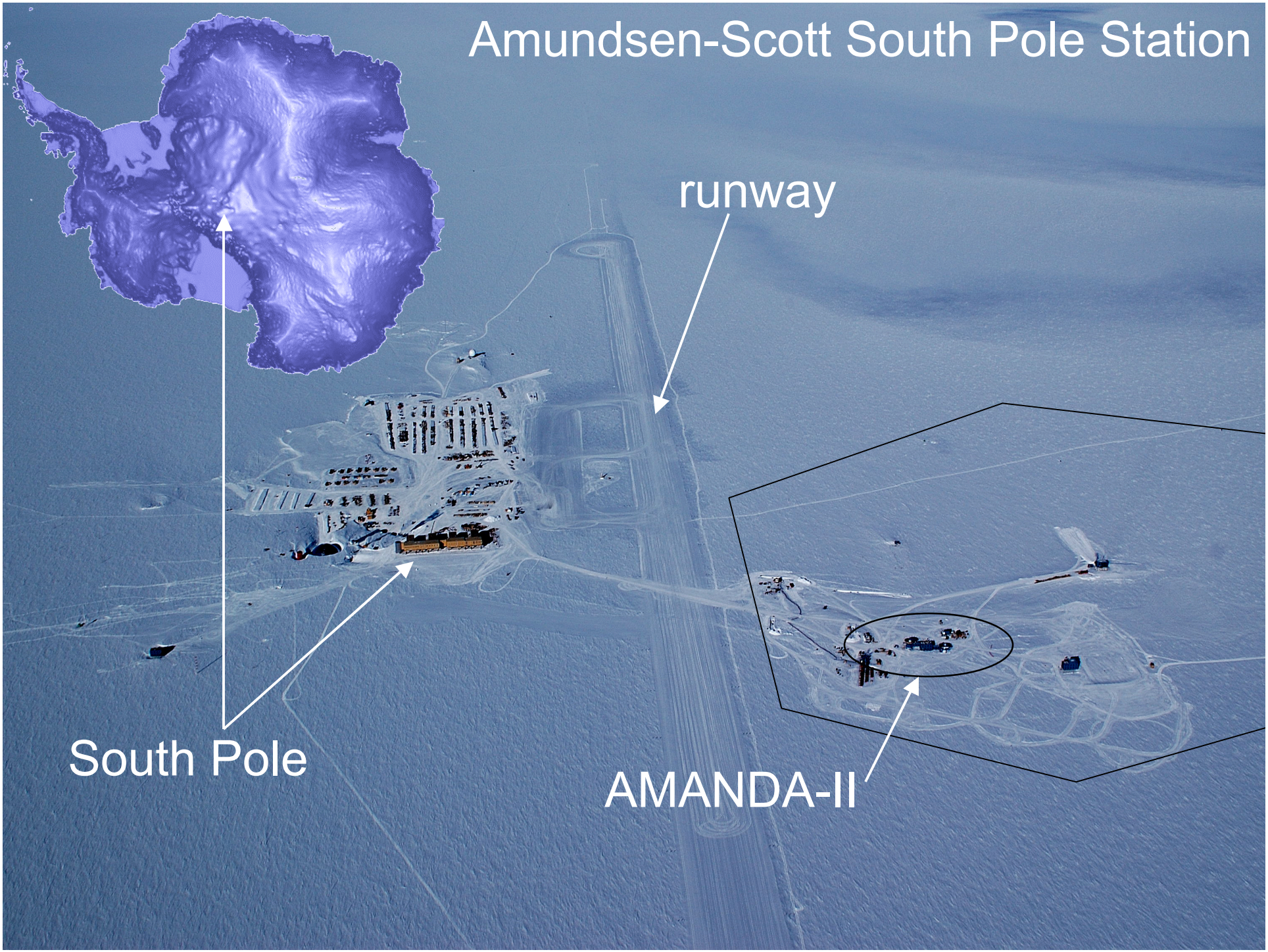
IceCube construction



one of 21 drill modules arrive in antarctica

5 megawatt hot water drilling system




Amundsen-Scott South Pole Station
runway
South Pole
AMANDA-II

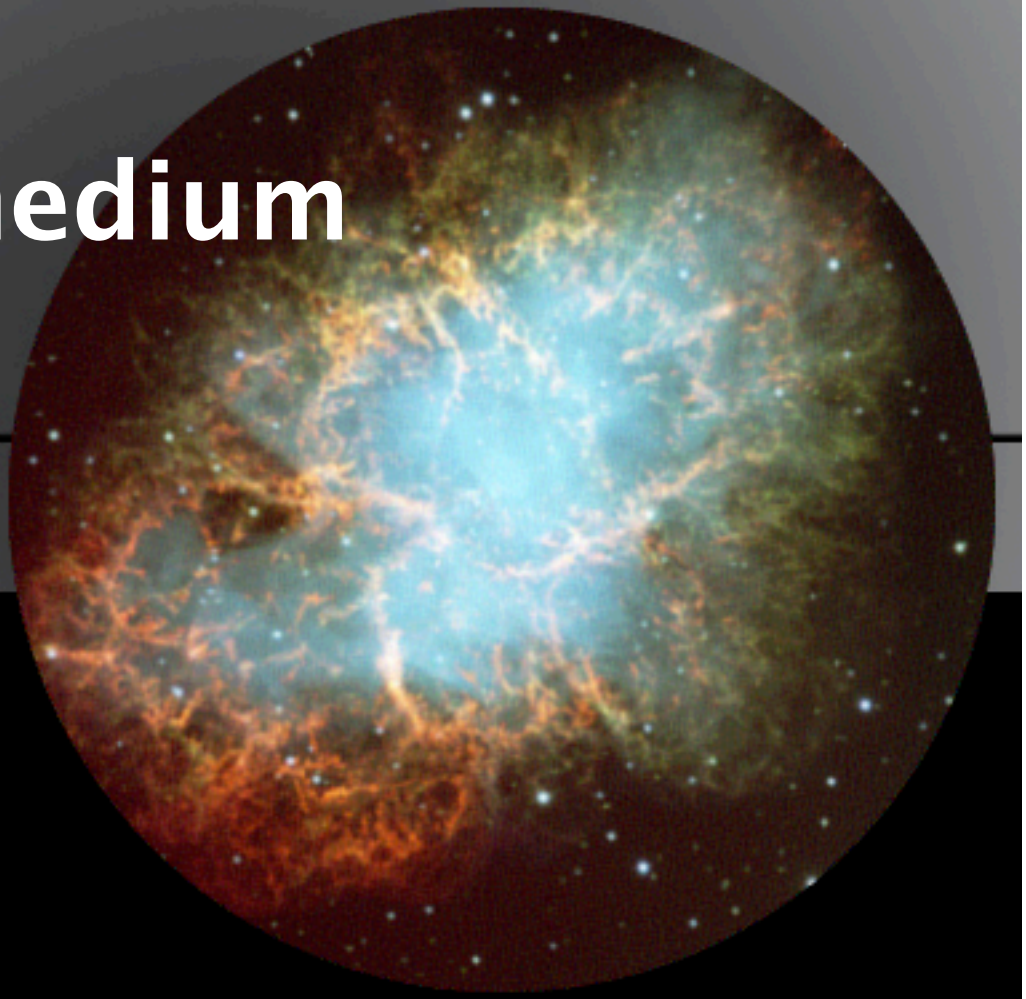
astronomy without light

Seeing: Cosmic Messengers

- visible light (Alhassan 1000)
- light of other wavelengths: blue, red, infrared, X-rays, radiowaves,....

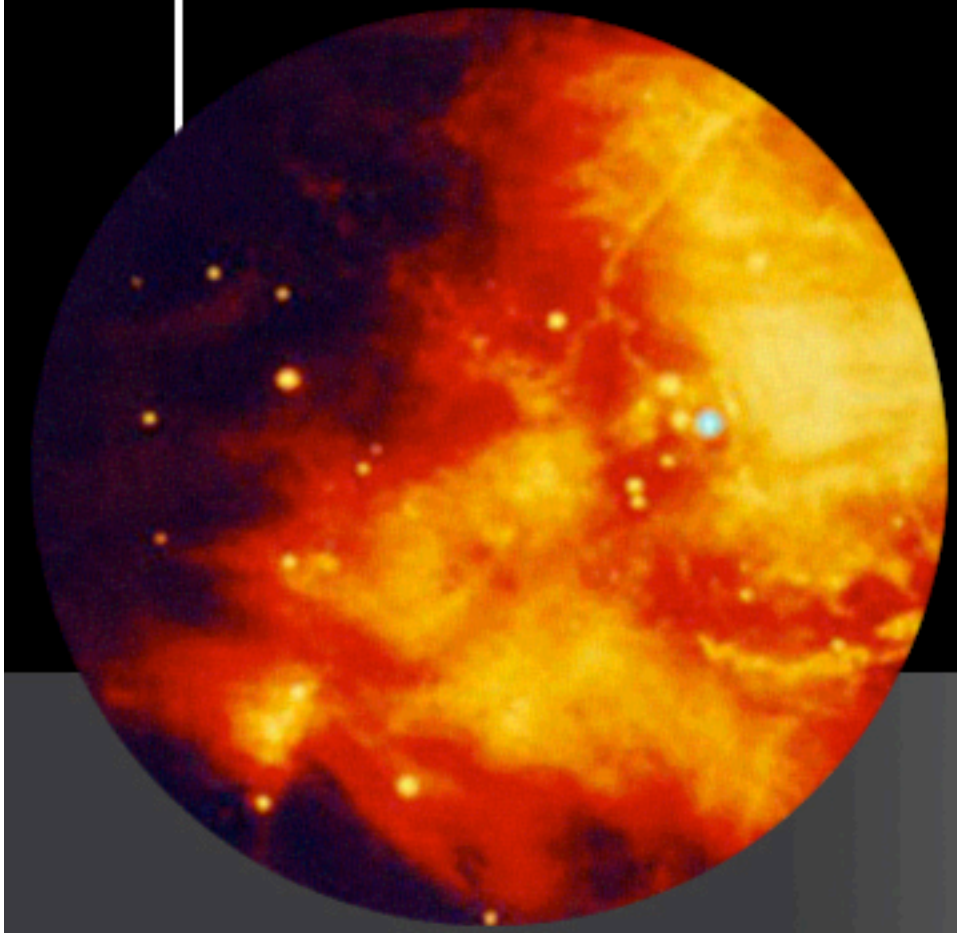
Ibn al-Haytham
El Basri
Alhazen

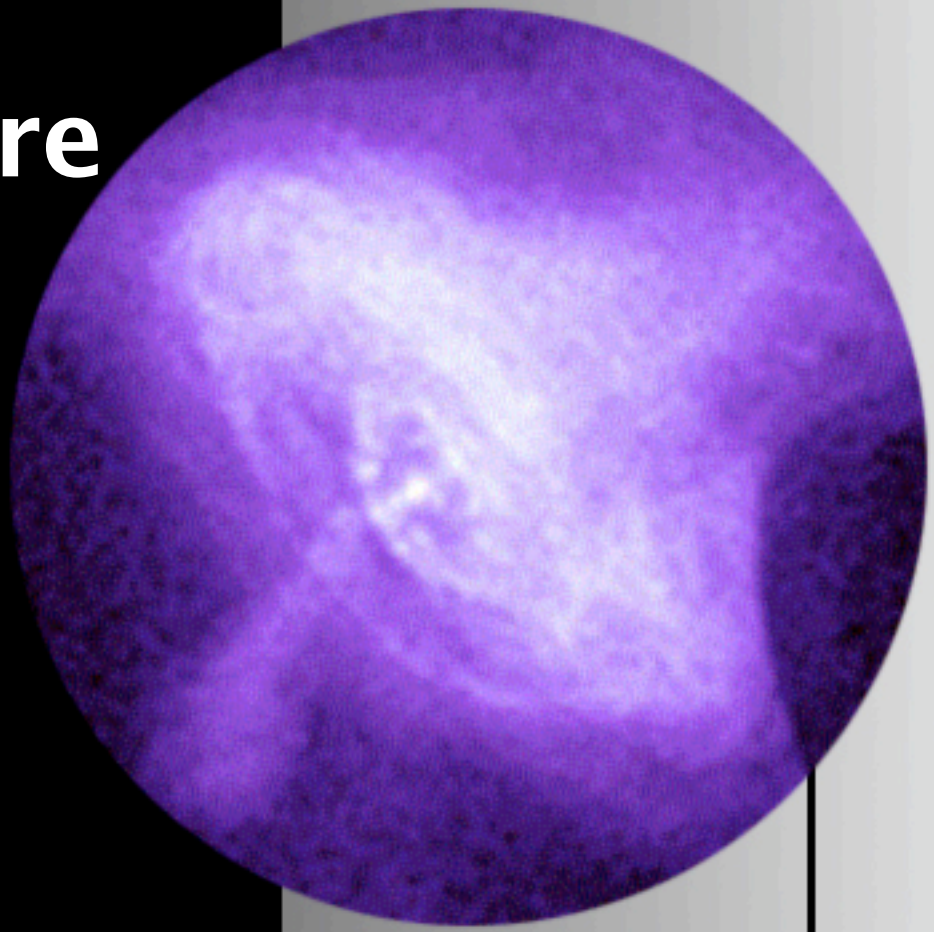
Supernova shocks expanding in interstellar medium



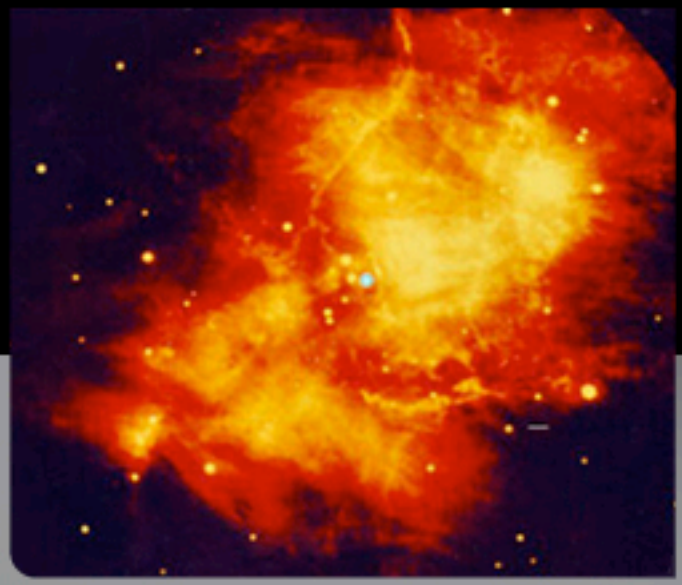
Crab Nebula

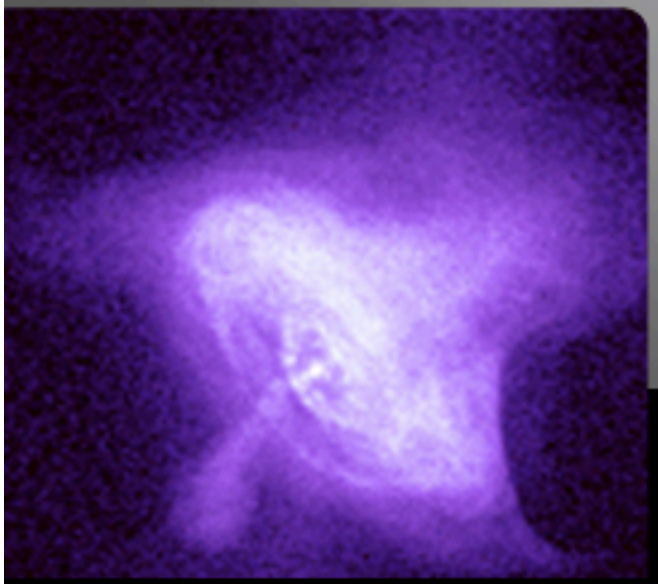
Infrared Picture





X-ray Picture





neutrinos ?

New Window on Universe? Expect Surprises

Telescope	User	date	Intended Use	Actual use
Optical	Galileo	1608	Navigation	Moons of Jupiter
Optical	Hubble	1929	Nebulae	Expanding Universe
Radio	Jansky	1932	Noise	Radio galaxies
Micro-wave	Penzias, Wilson	1965	Radio-galaxies, noise	3K cosmic background
X-ray	Giacconi …	1965	Sun, moon	neutron stars accreting binaries
Radio	Hewish, Bell	1967	Ionosphere	Pulsars
γ-rays	military	1960?	Thermonuclear explosions	Gamma ray bursts

the “professional” reason

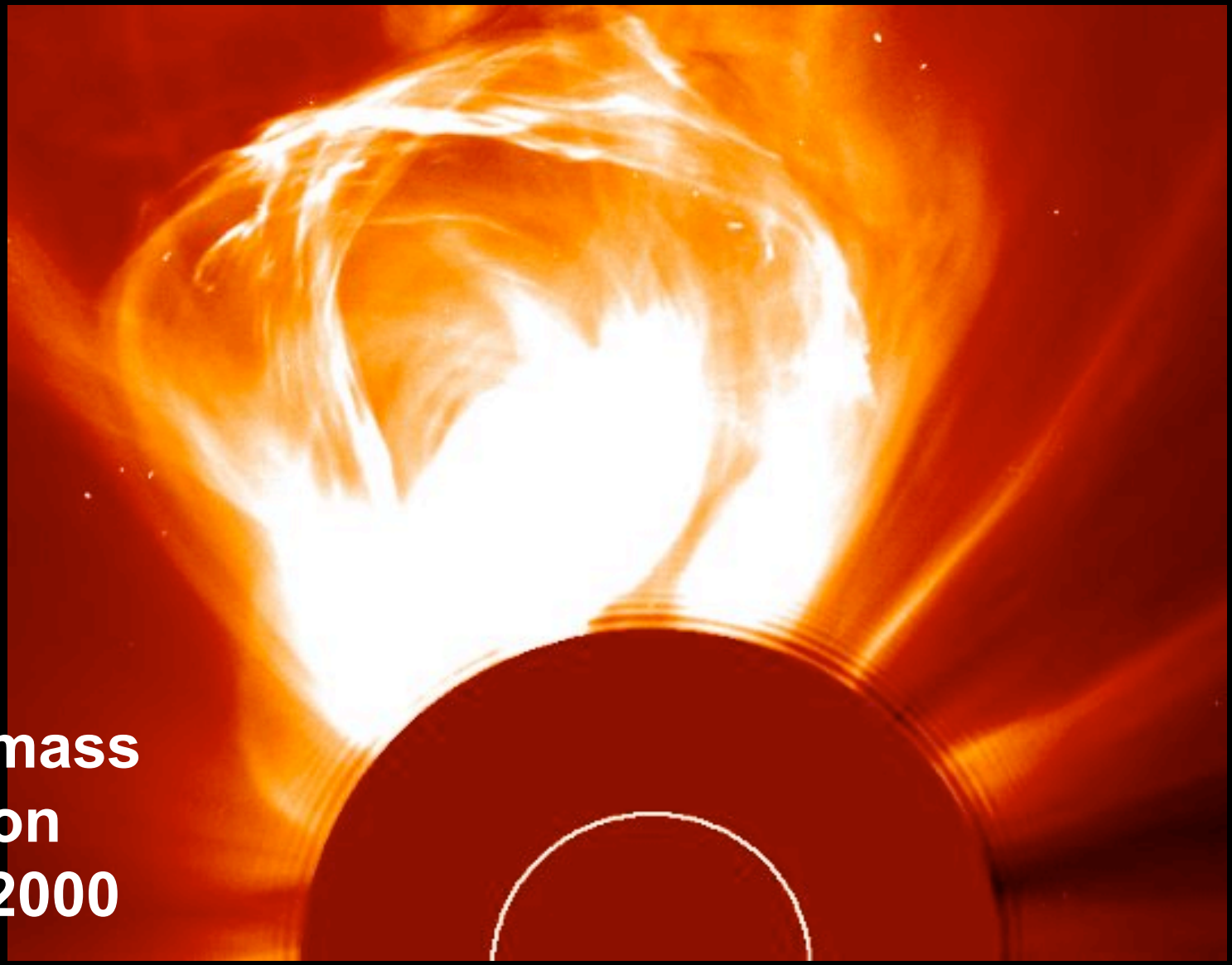
Nature's Accelerator ?

- protons > 10^8 Te
- photons > 10 TeV
- neutrinos > 10^2 T

Cosmic Rays Observations

first discovered in 1912 by Austrian scientist ***Victor Hess***, measuring radiation levels aboard a balloon at up to 17,500 feet ***(without oxygen!)***

solar flare shock acceleration



Coronal mass ejection
09 Mar 2000

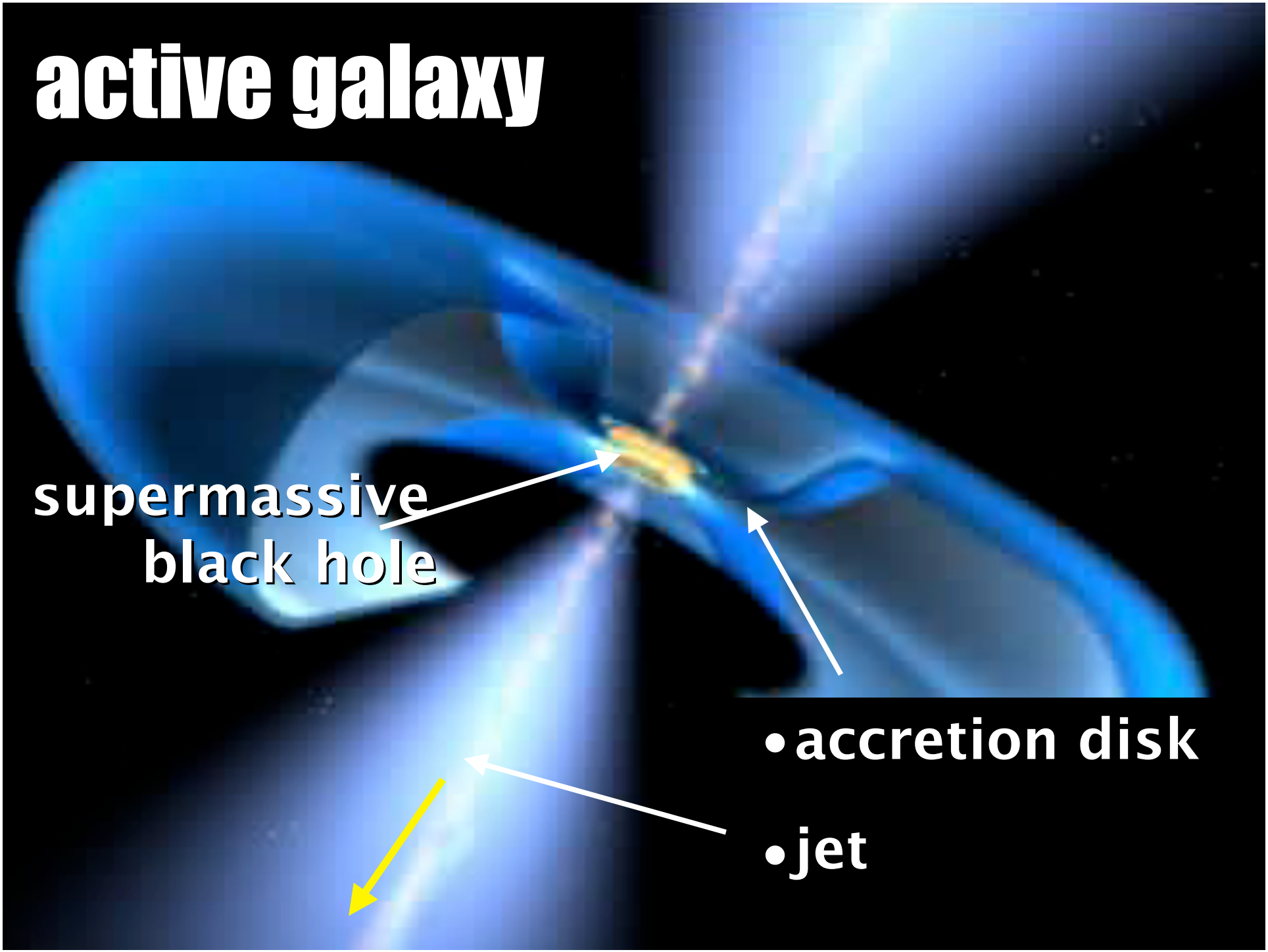
Acceleration to 10^{21} eV ?

$\sim 10^2$ *Joules*

$\sim 0.01\ M_{GUT}$

dense regions with exceptional gravitational force creating relativis flows of charged particles, e.g.

- dense cores of exploding stars
- supermassive black holes
- merging galaxies


active galaxy
supermassive
black hole
• accretion disk
• jet

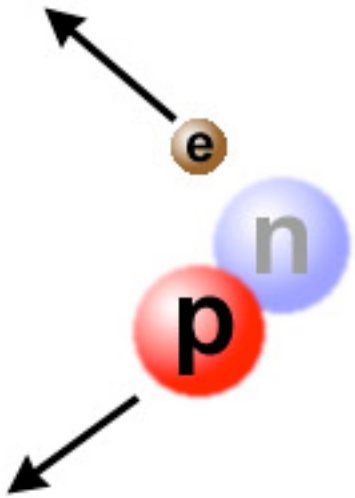
Georges Lemaitre believed that cosmic rays where primordial radiation from the Big Bang

why neutrinos ?

Neutrinos, by John Updike

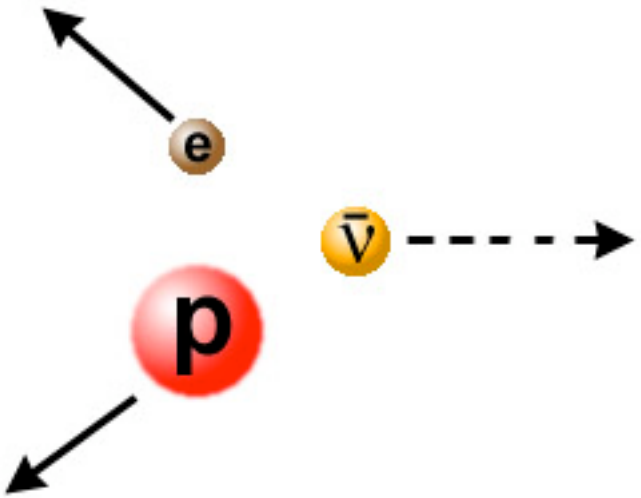
Neutrinos: they are very small
They have no charge; they have no mass;
They do not interact at all.
The Earth is just a silly ball
To them, through which they simply pass
Like dustmaids down a drafty hall
Or photons through a sheet of glass.
They snub the most exquisite gas,
Ignore the most substantial wall,
Cold shoulder steel and sounding brass,
Insult the stallion in his stall,
And, scorning barriers of class,
Infiltrate you and me. Like tall
And painless guillotines they fall
Down through our heads into the grass.
At night, they enter at Nepal
And pierce the lover and his lass
From underneath the bed. You call
It wonderful; I call it crass.

What is the world made off ?



- **neutrons**, and
- **protons** and **electrons**, that
- switch their identity back and forth in "nuclear reactions"

Whoops, a correction....



- There is also a **neutrino**
- Just high school physics
- We cannot see it anyway

cosmic sources →

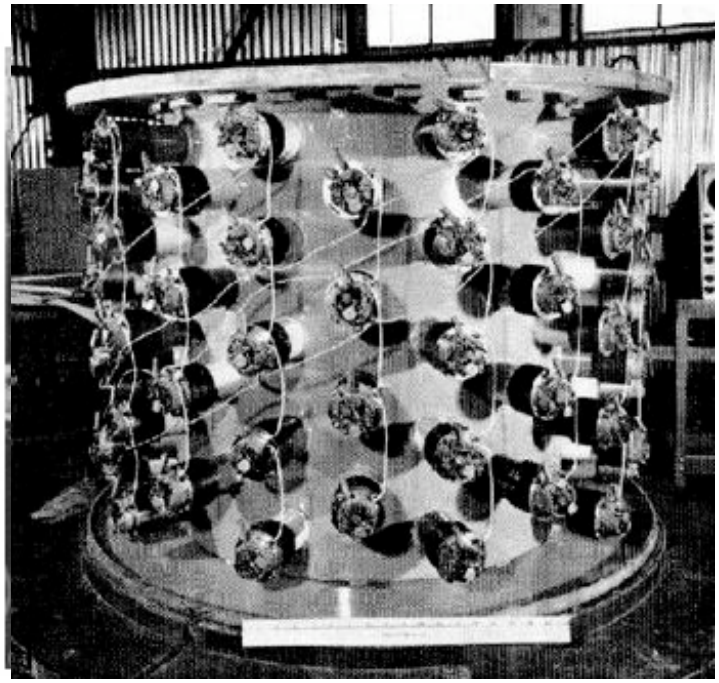
cosmic rays ~ photons ~ neutrinos

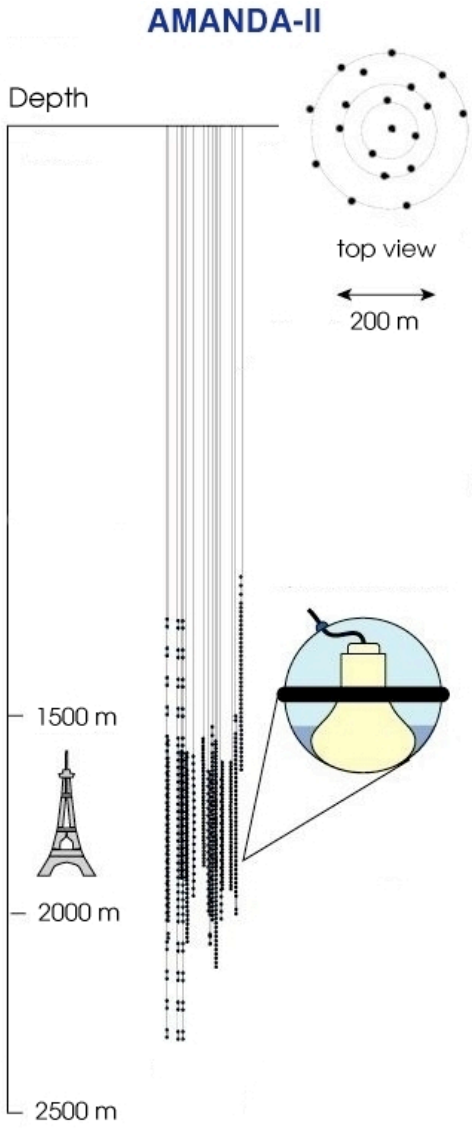
John Bahcall

I have done a terrible thing, I have invented a particle that cannot be detected.

Wolfgang Pauli

Requires Kilometer-Scale Neutrino Detectors

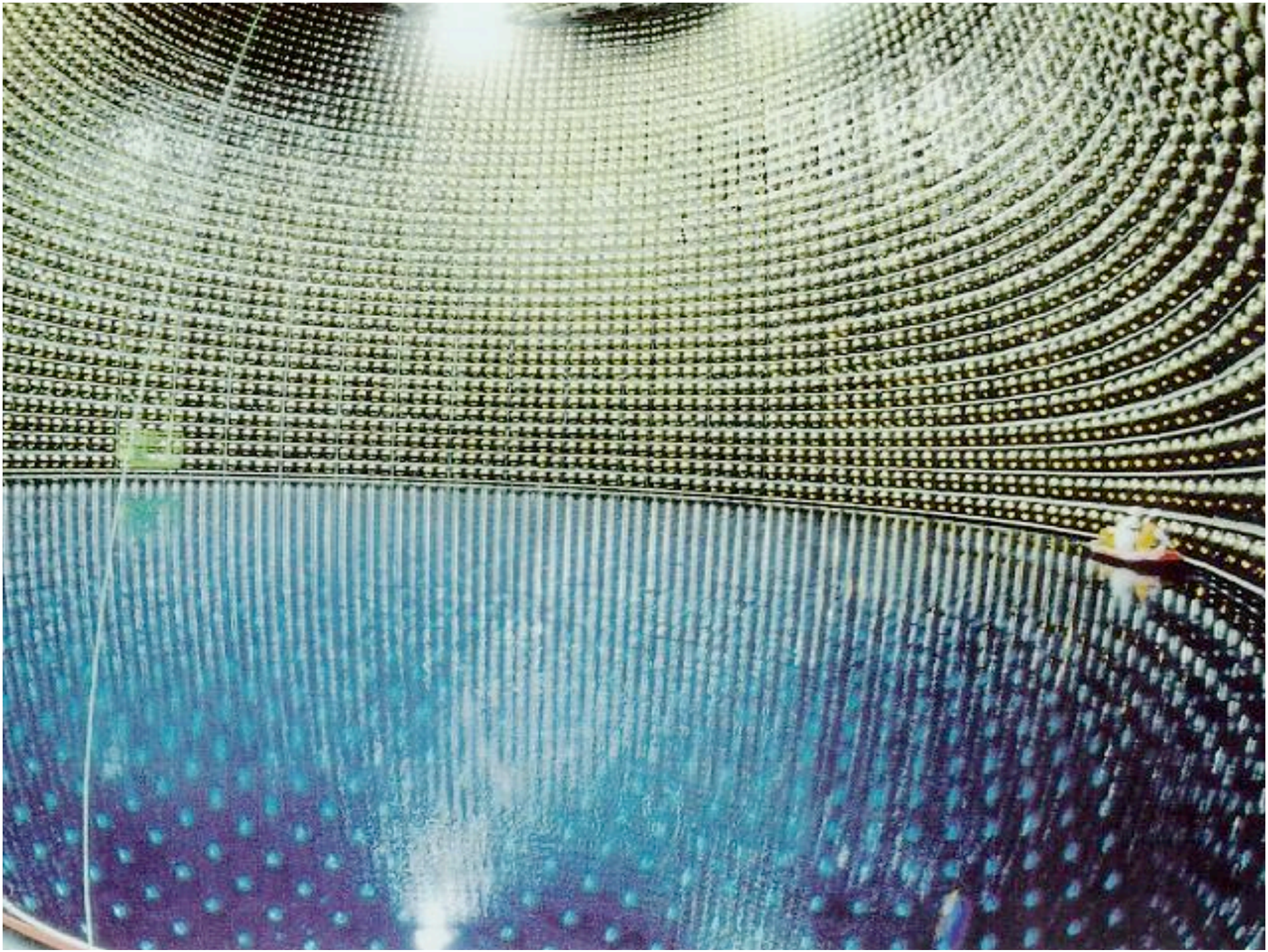




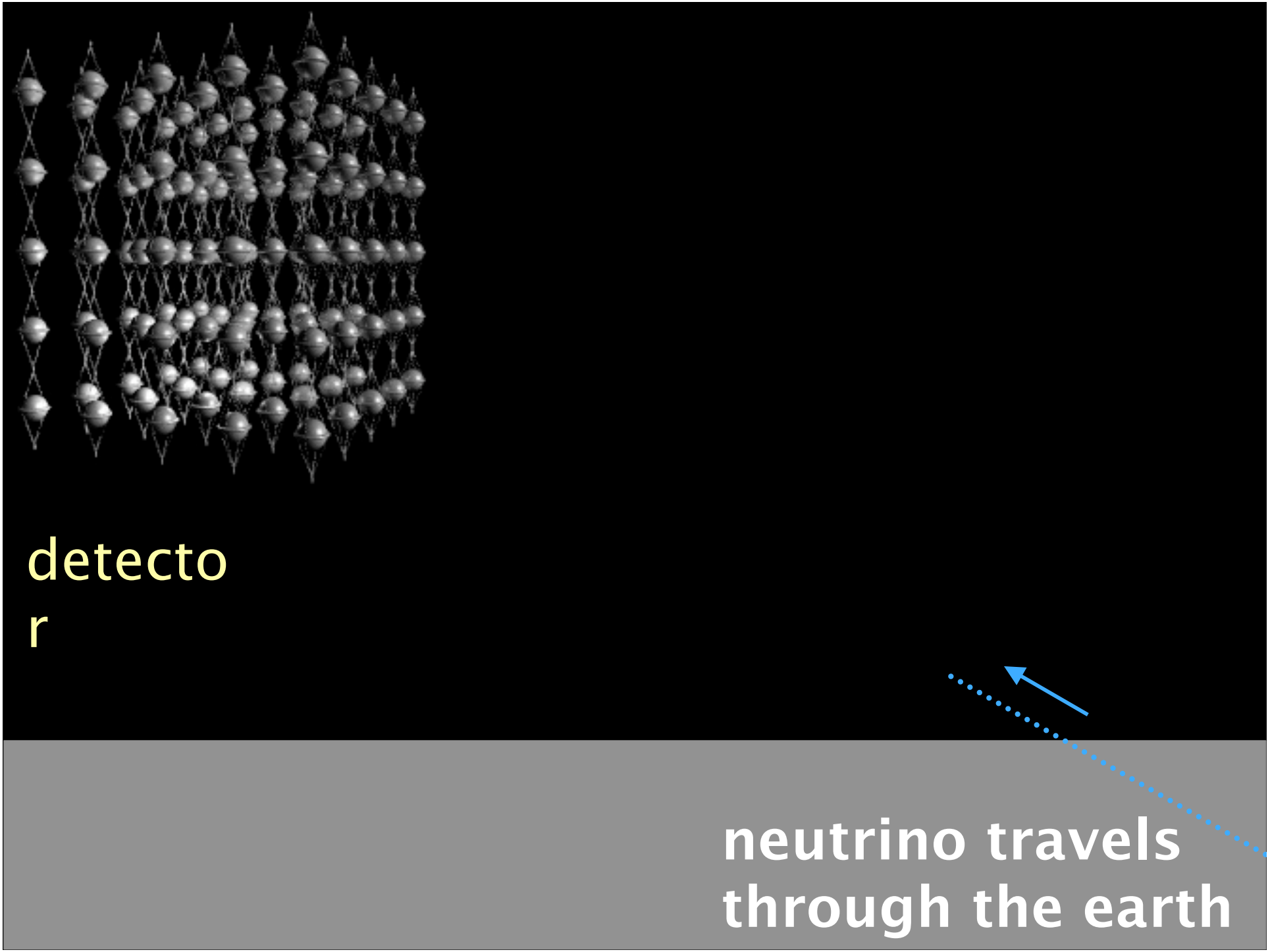
Fred Reines

proposed neutrinos
as
cosmic messengers

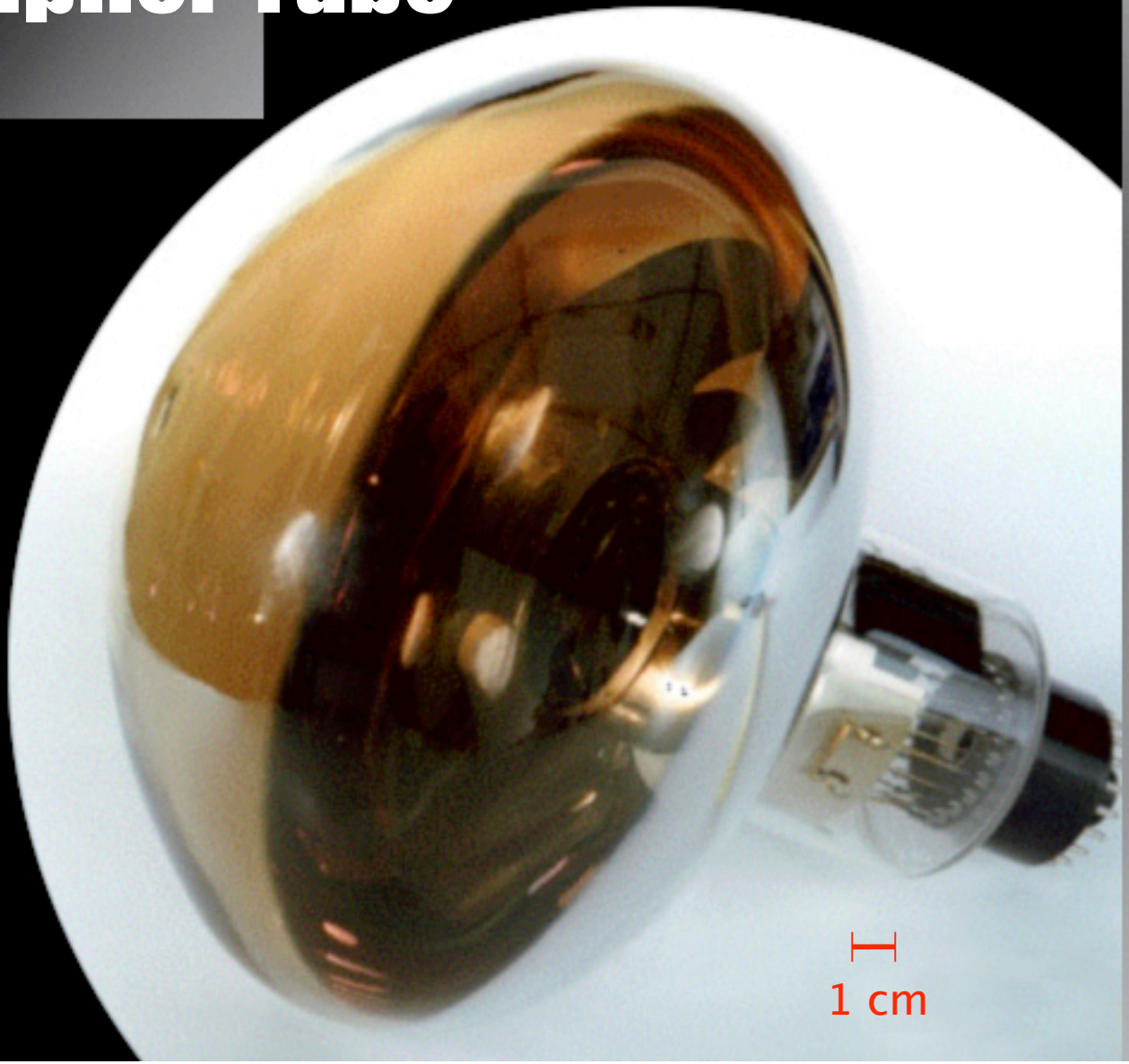
SuperKamiokande in the Japanese alps



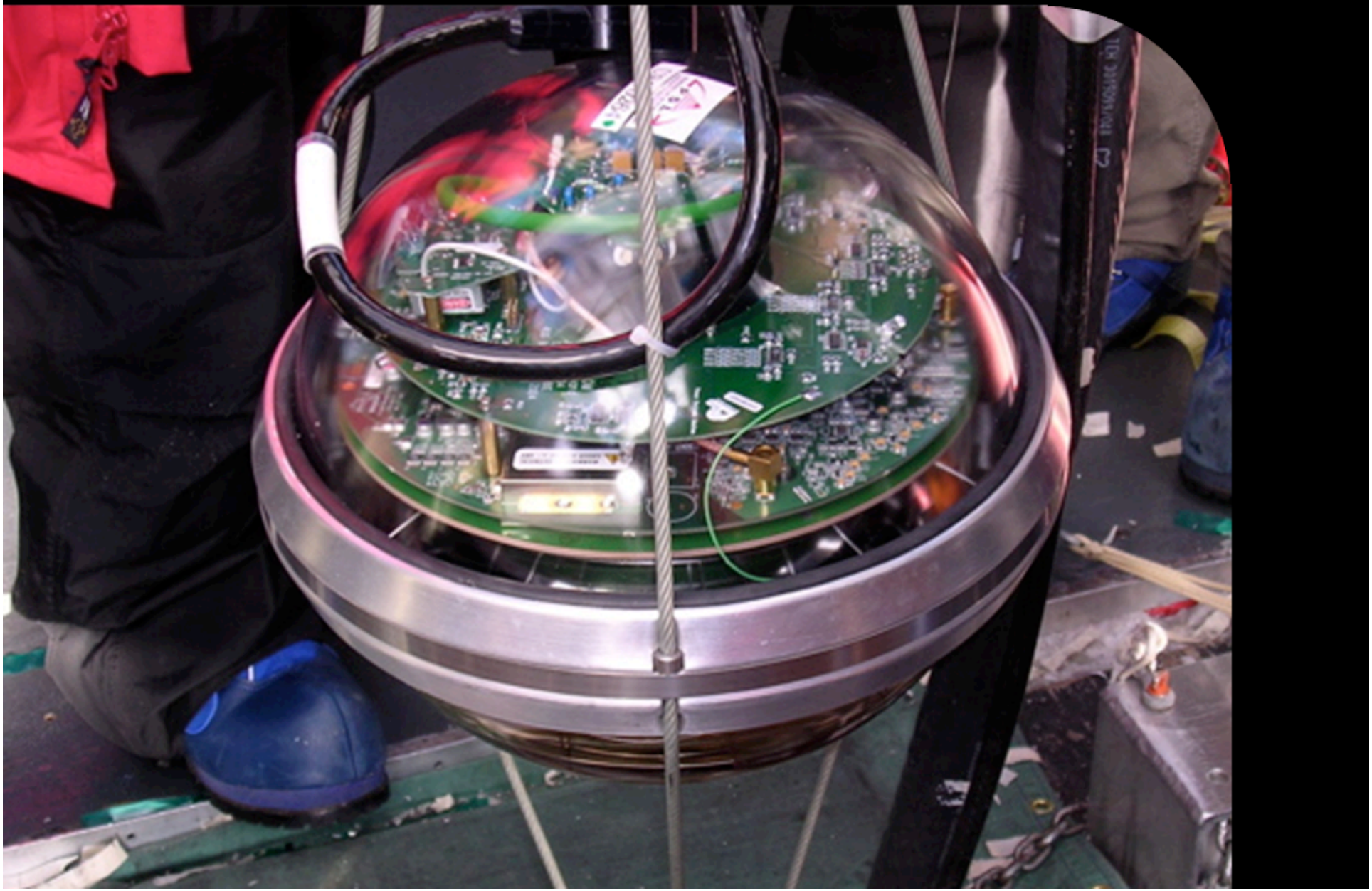
a one billion ton neutrino detector ?

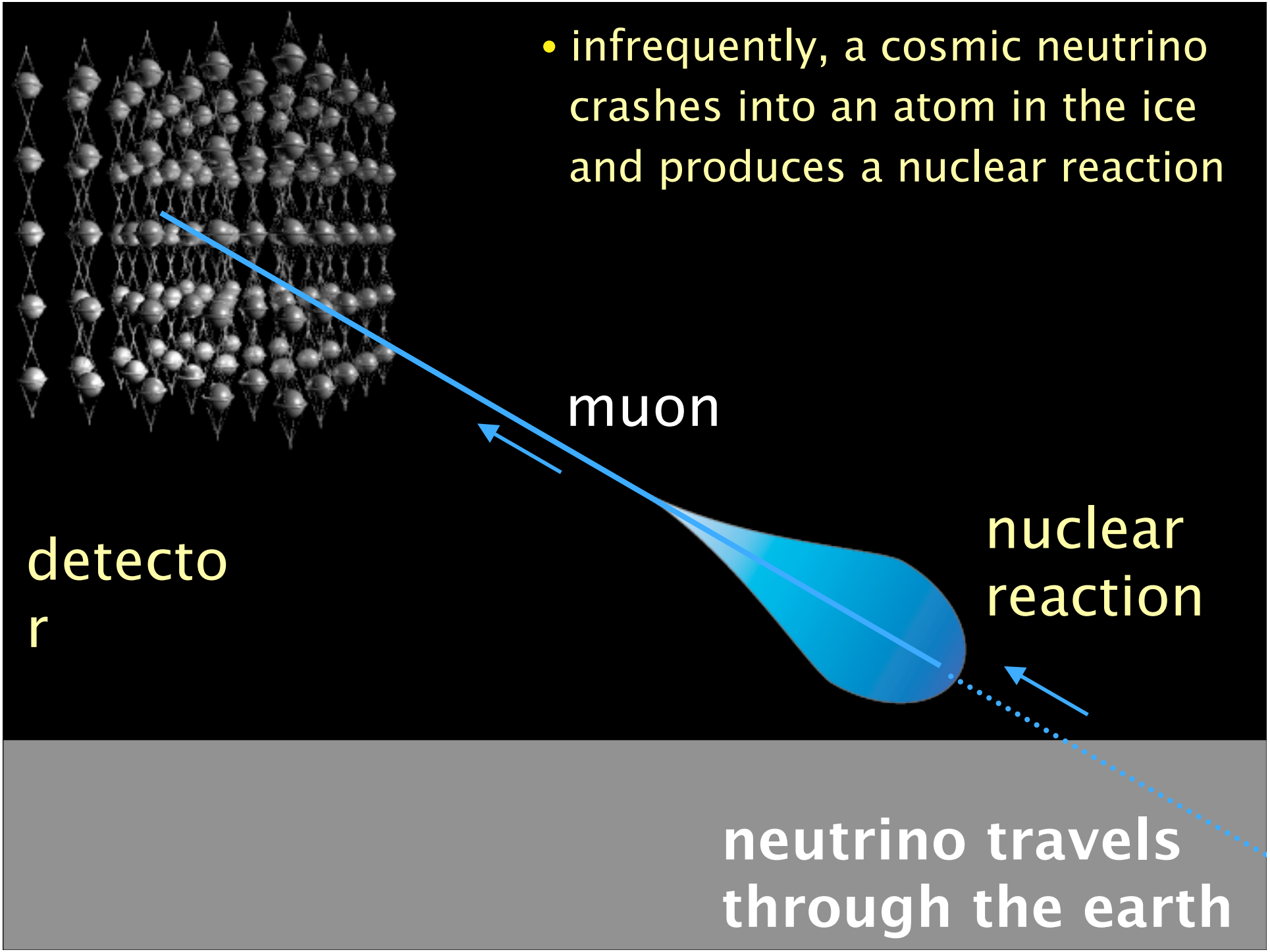

detecto
r
neutrino travels
through the earth

Photomultiplier Tube

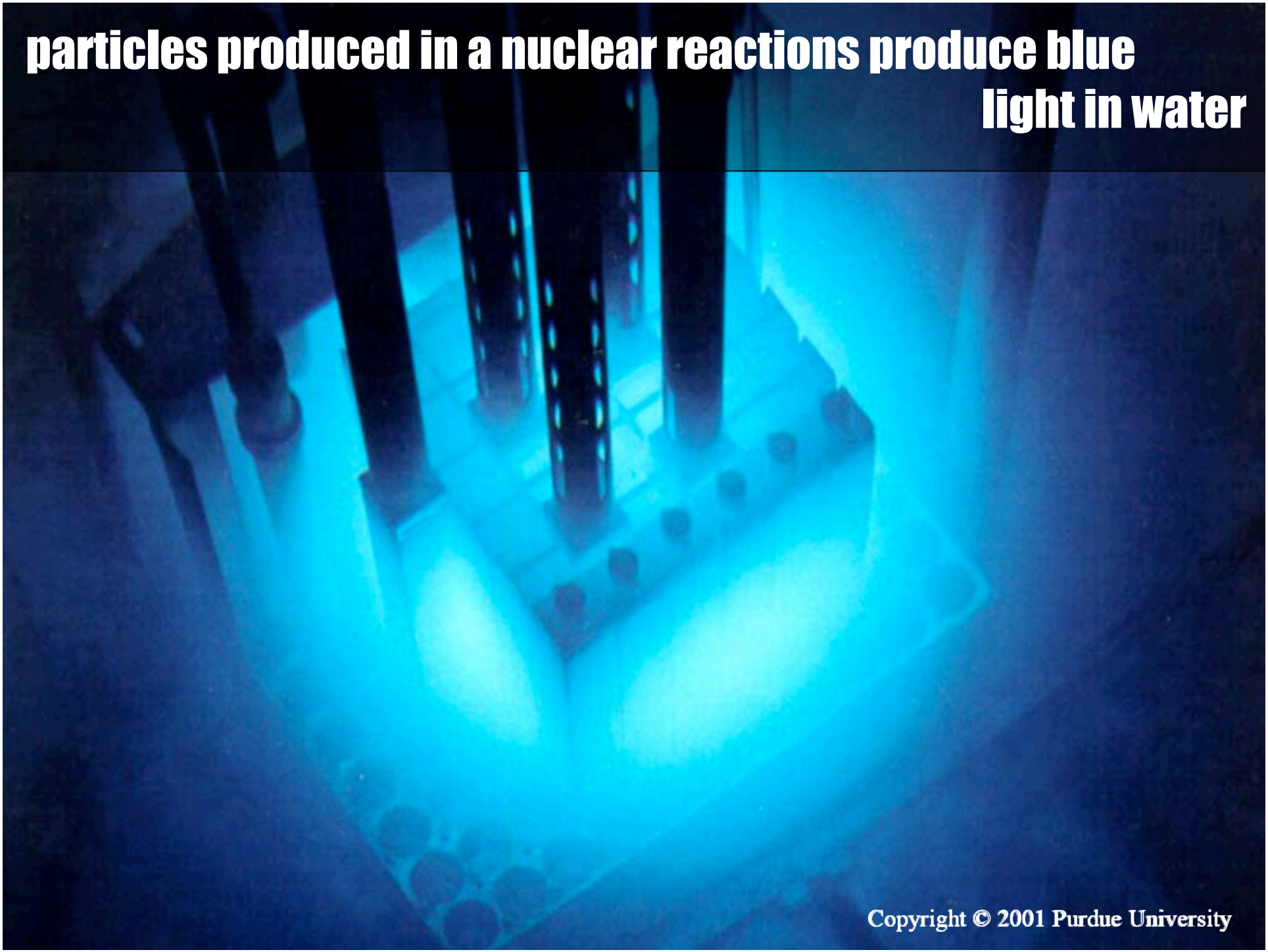


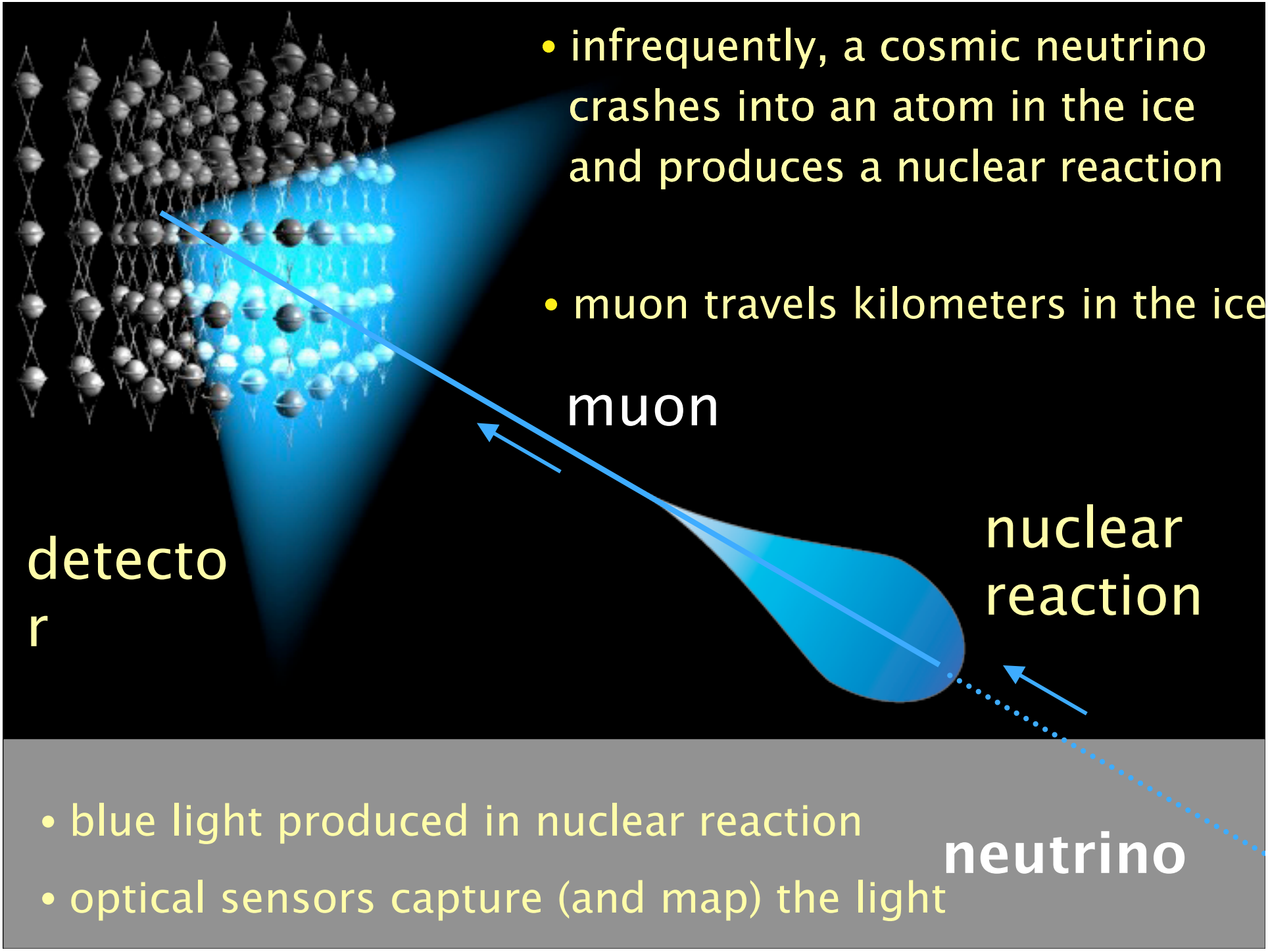
optical sensor




• infrequently, a cosmic neutrino crashes into an atom in the ice and produces a nuclear reaction
muon
detecto r
nuclear reaction
neutrino travels through the earth

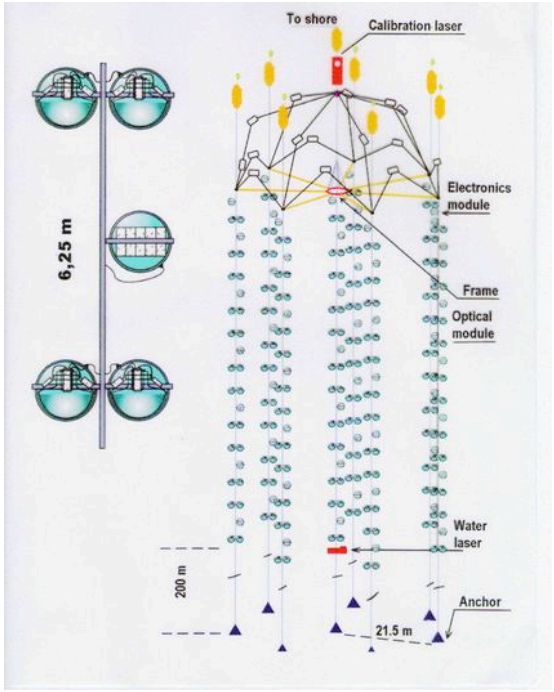
particles produced in a nuclear reactions produce blue light in water




• infrequently, a cosmic neutrino crashes into an atom in the ice and produces a nuclear reaction
• muon travels kilometers in the ice
muon
detecto r
nuclear reaction
• blue light produced in nuclear reaction
• optical sensors capture (and map) the light
neutrino

Northern hemisphere detectors

Baikal NT200



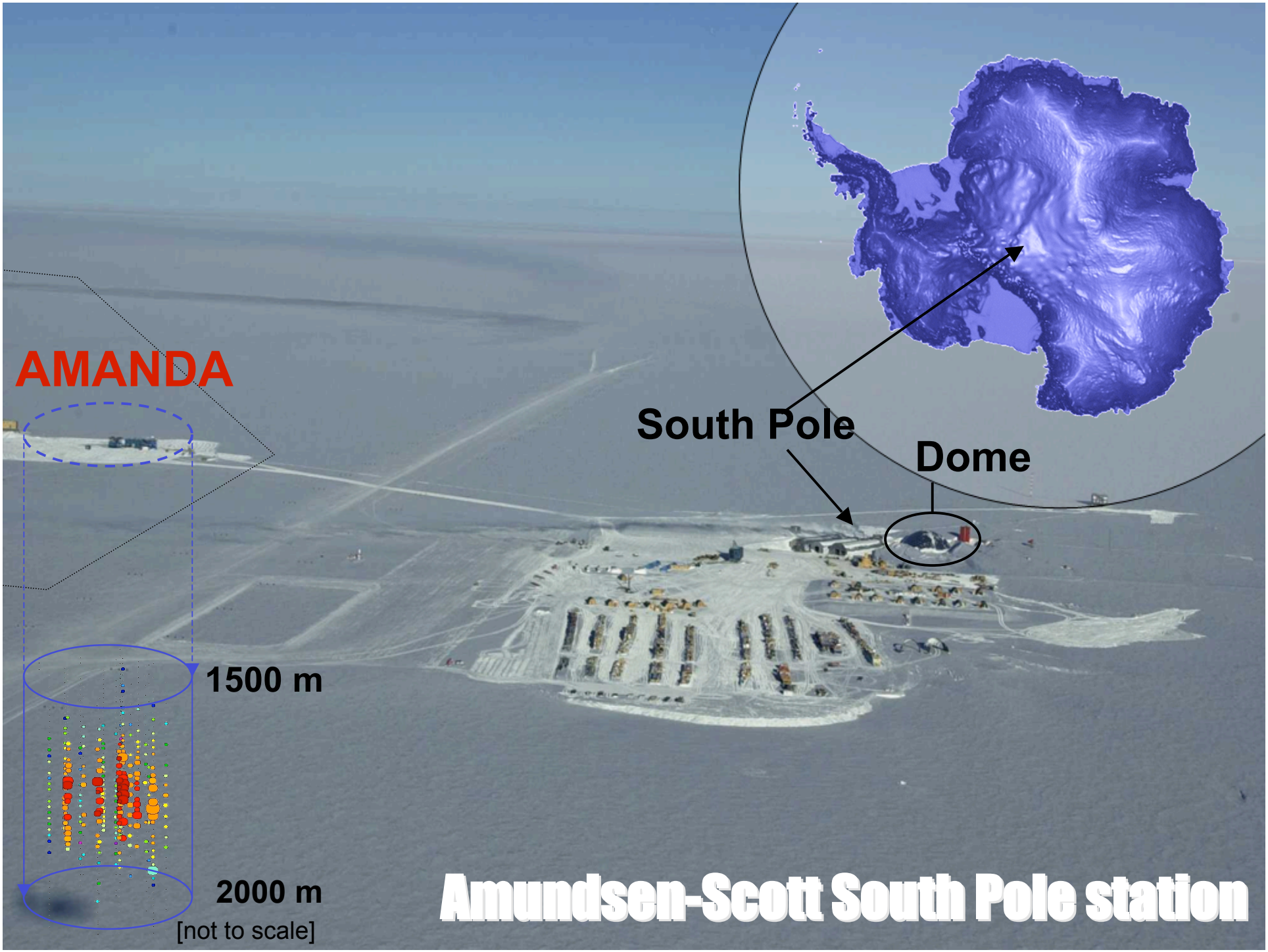
1100 m deep
data taking since 1998
new: 3 distant strings

Antares

March 17, 2003
2 strings connected
2400 m deep
completion: start 2006

Nestor

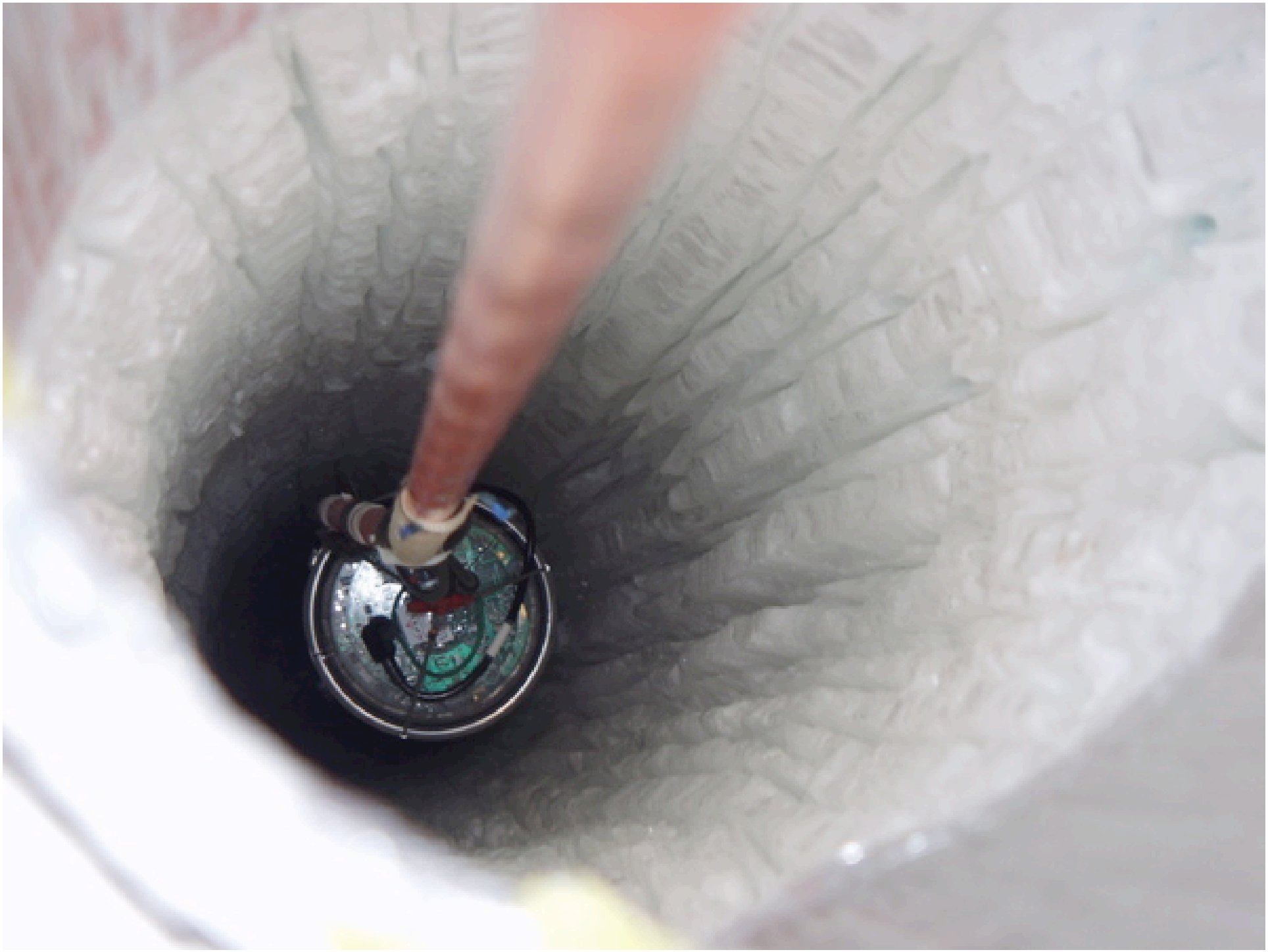
March 29, 2003
1 of 12 floors deployed
4000 m deep
completion: 2006

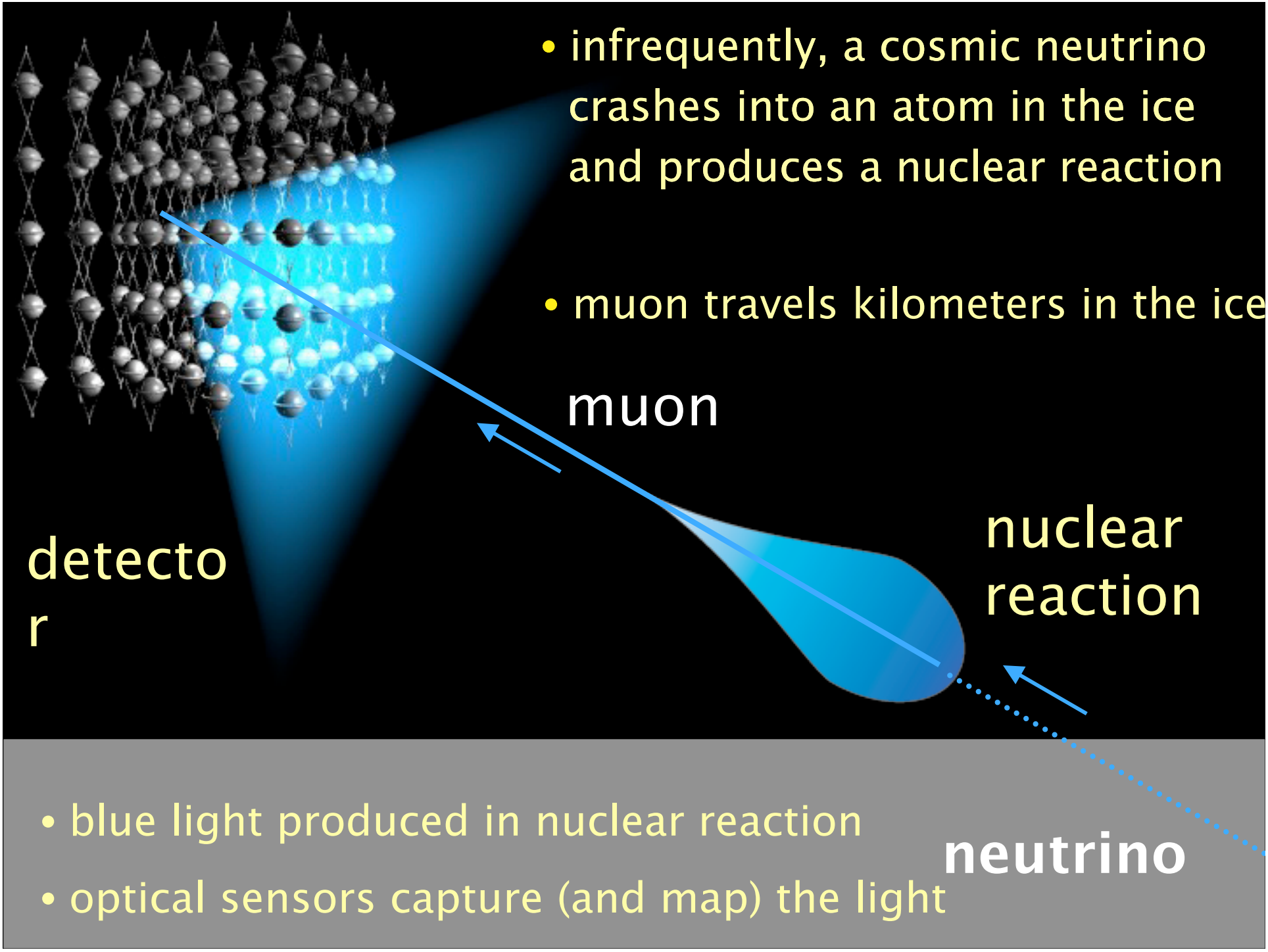

AMANDA
South Pole
Dome
1500 m
2000 m
[not to scale]
Amundsen-Scott South Pole station

Building AMANDA

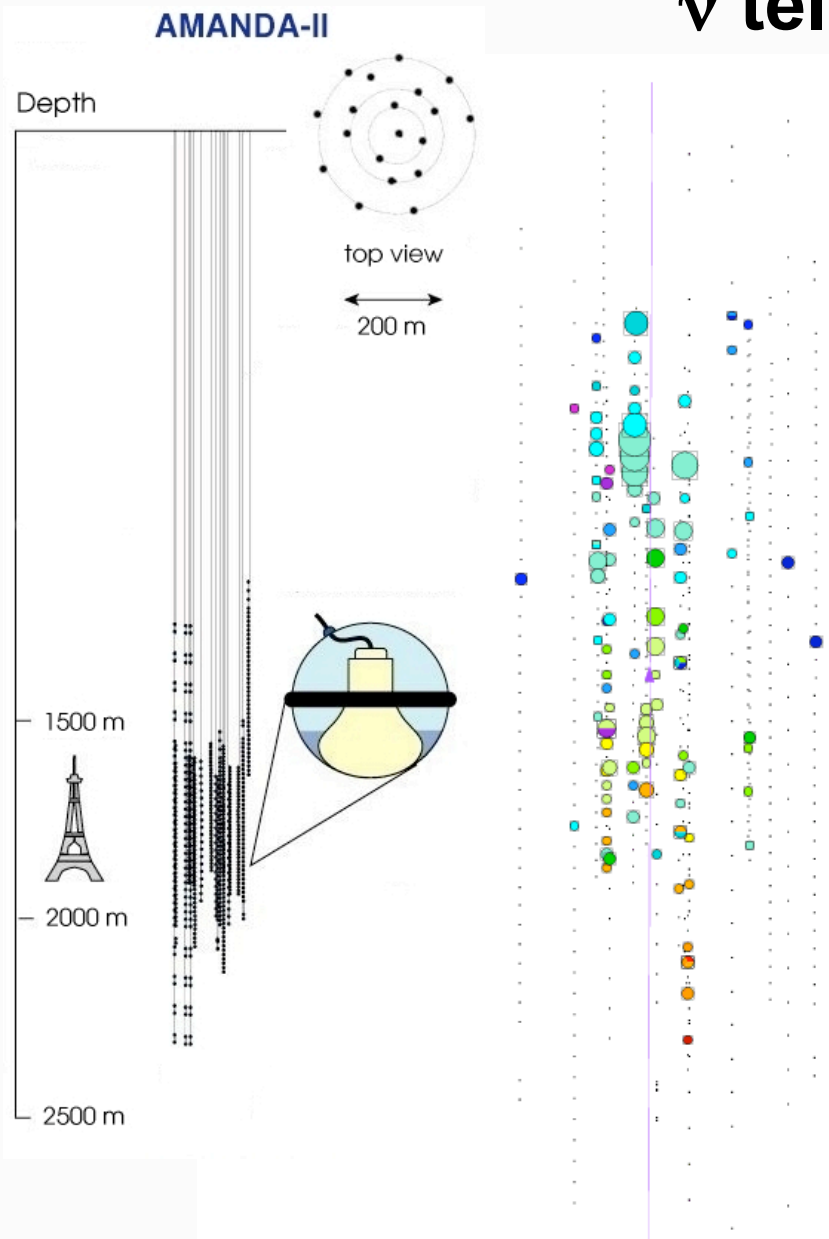
Drilling Holes with Hot Water

The Optical Module

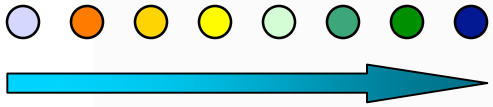



• infrequently, a cosmic neutrino crashes into an atom in the ice and produces a nuclear reaction
• muon travels kilometers in the ice
muon
detecto r
nuclear reaction
• blue light produced in nuclear reaction
• optical sensors capture (and map) the light
neutrino

ν telescope : AMANDA event



energy deposited in OM



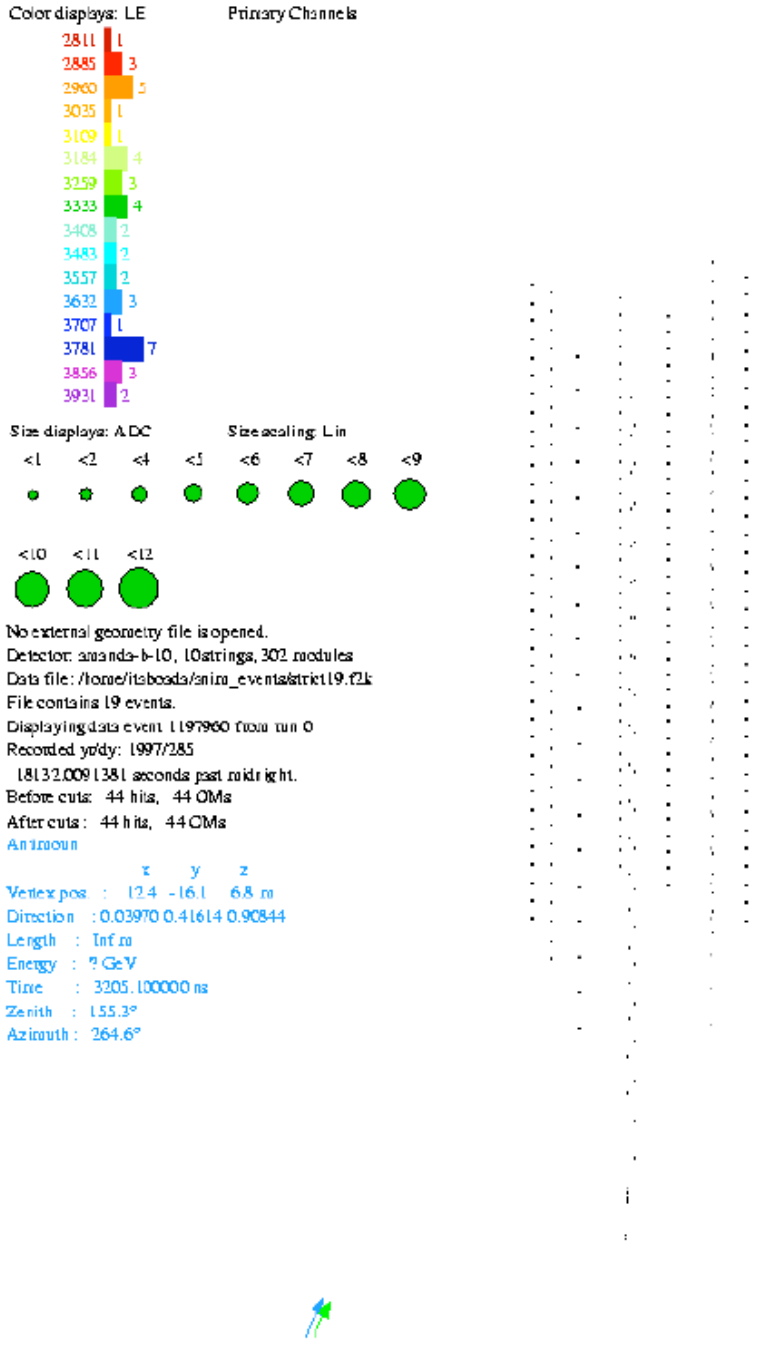
time recorded on OM

AMANDA Event Signatures: Muons

CC muon neutrino Interaction

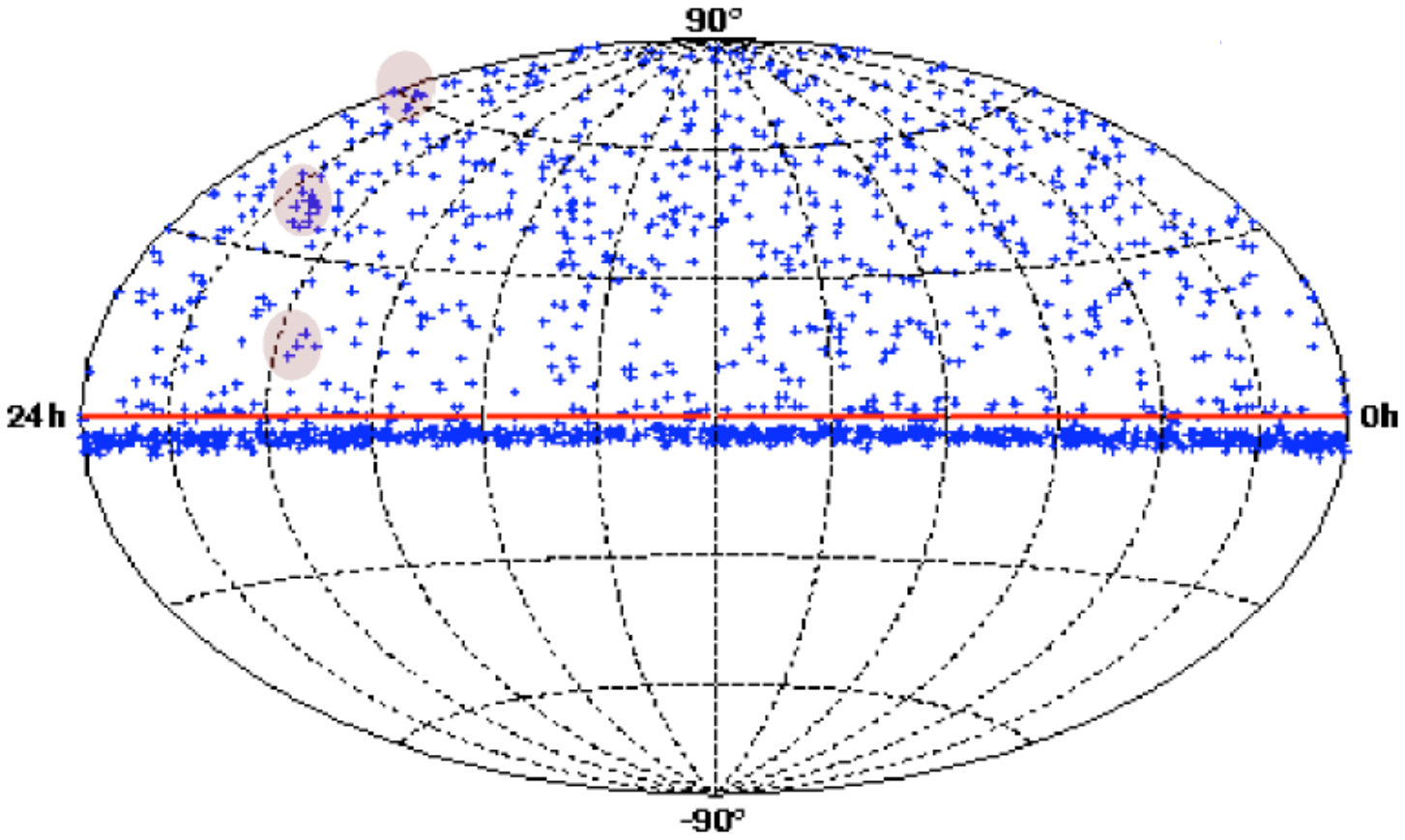
→ track

$$\nu_\mu + N \rightarrow \mu + X$$



AMANDA II 2000

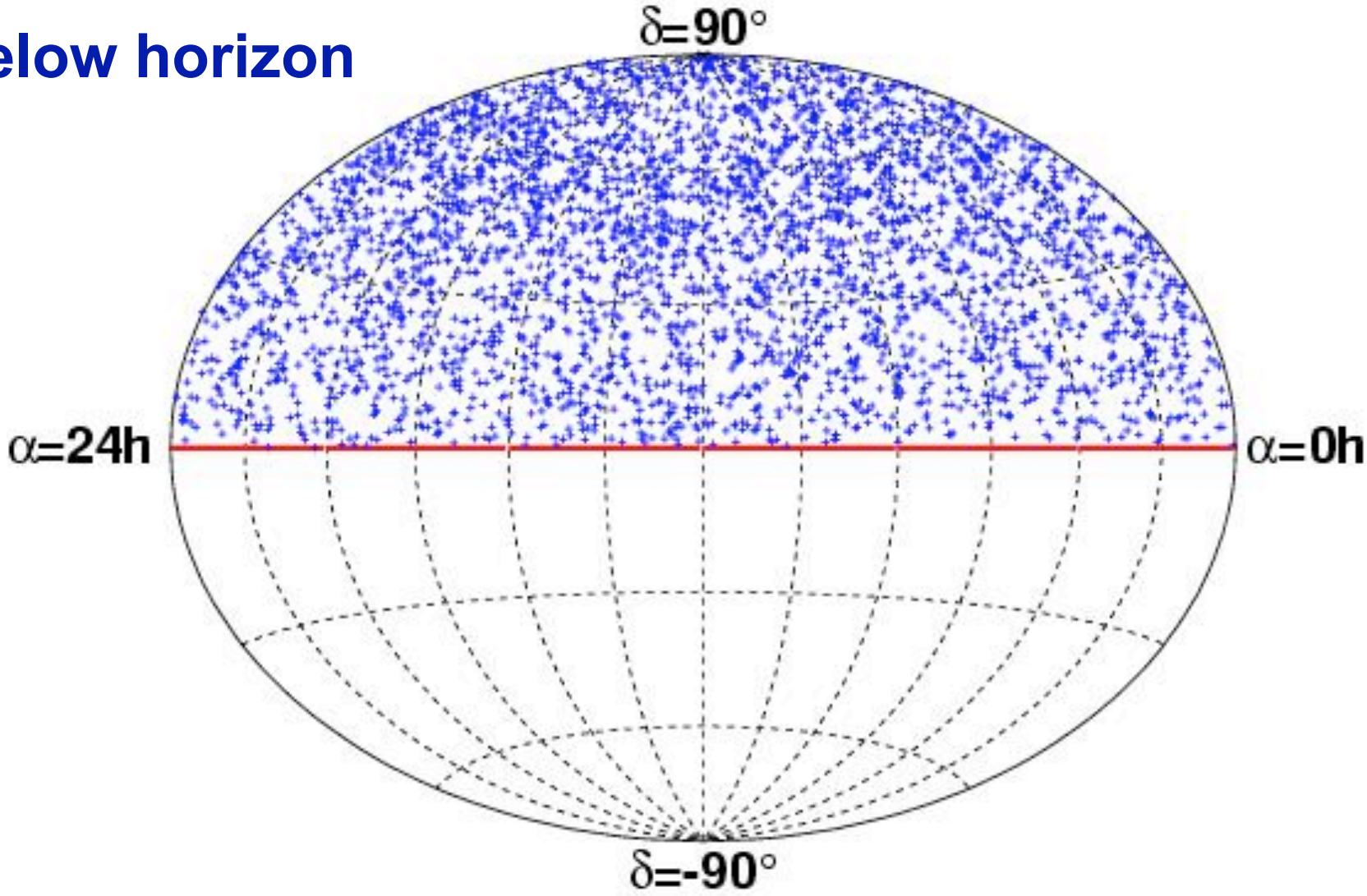
1555 Events



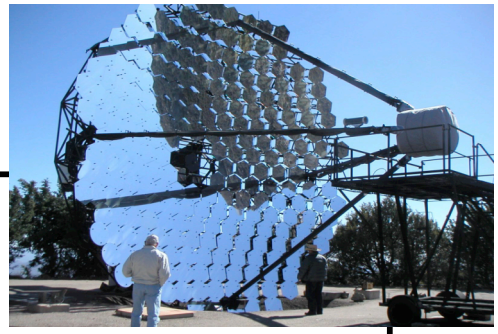
AMANDA skyplot 2000-2003

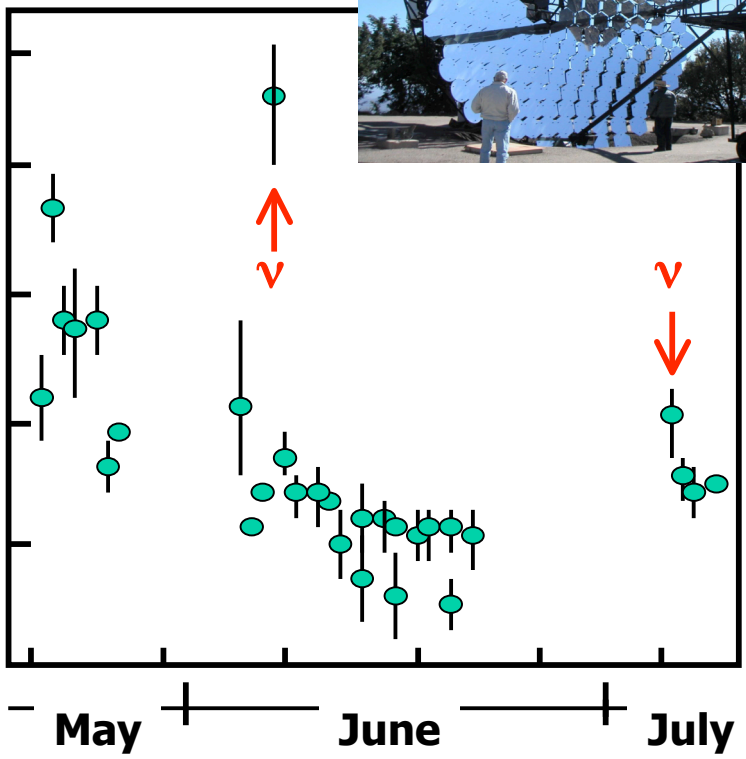
3369 events

below horizon



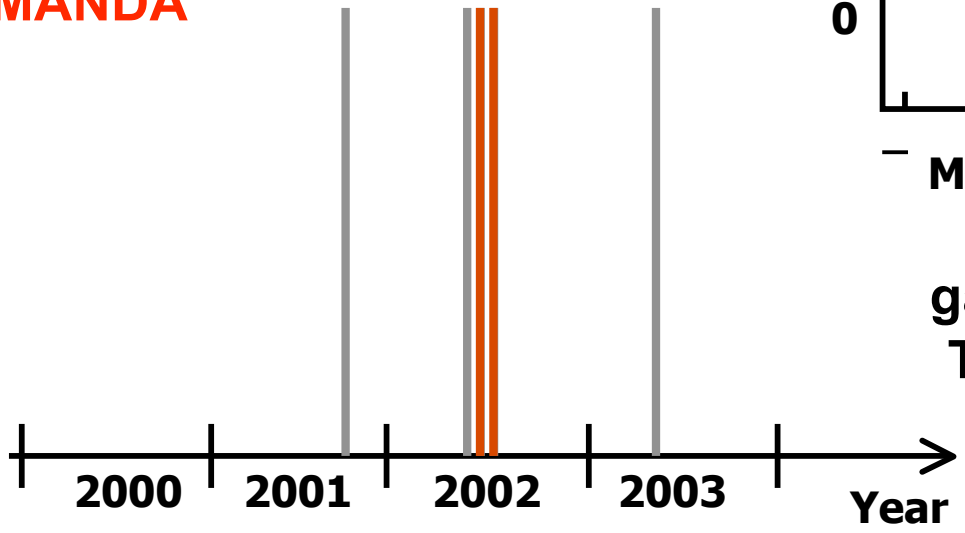
need a larger detector





gamma-rays detected by
TeV gamma telescopes

Arrival time of the neutrinos from the direction of ES1959+650 detected by AMANDA

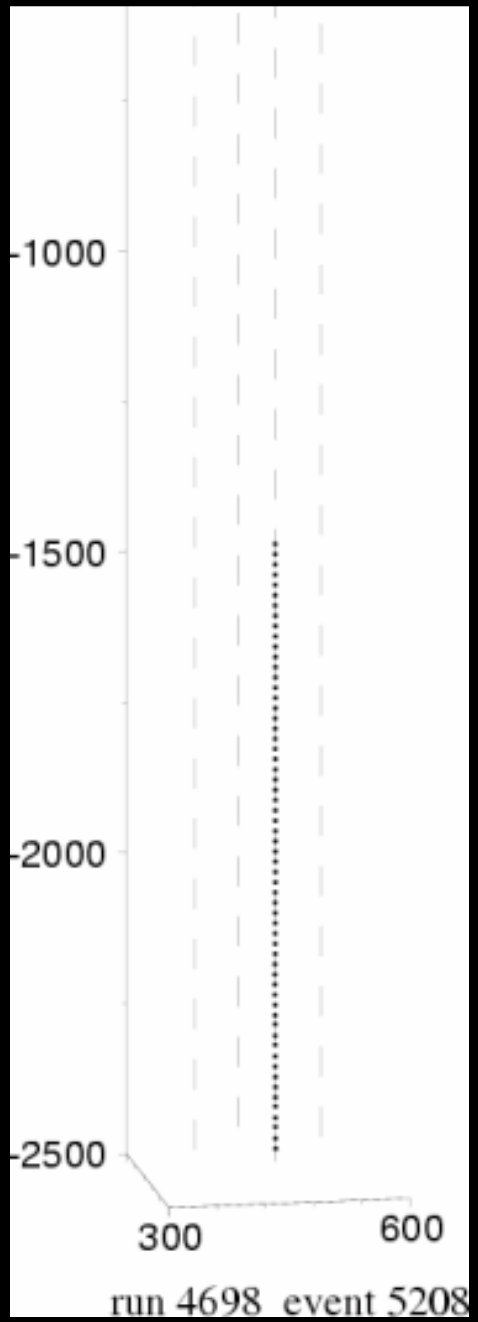


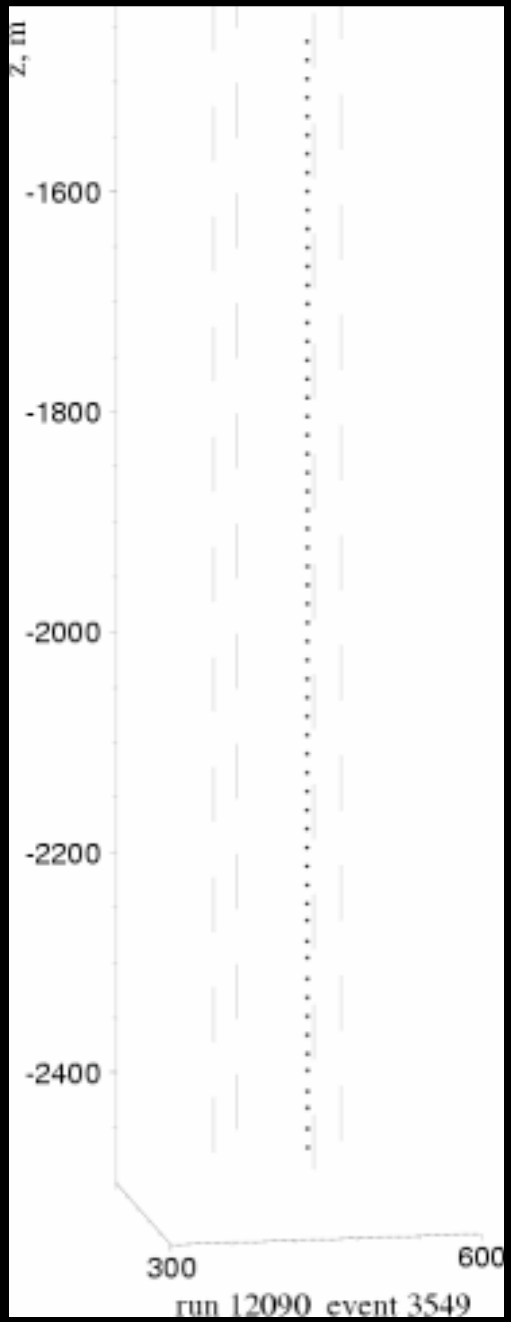
AMANDA: proof of concept

down

background
cosmic ray
muon produced
in the atmosphere

100 per second





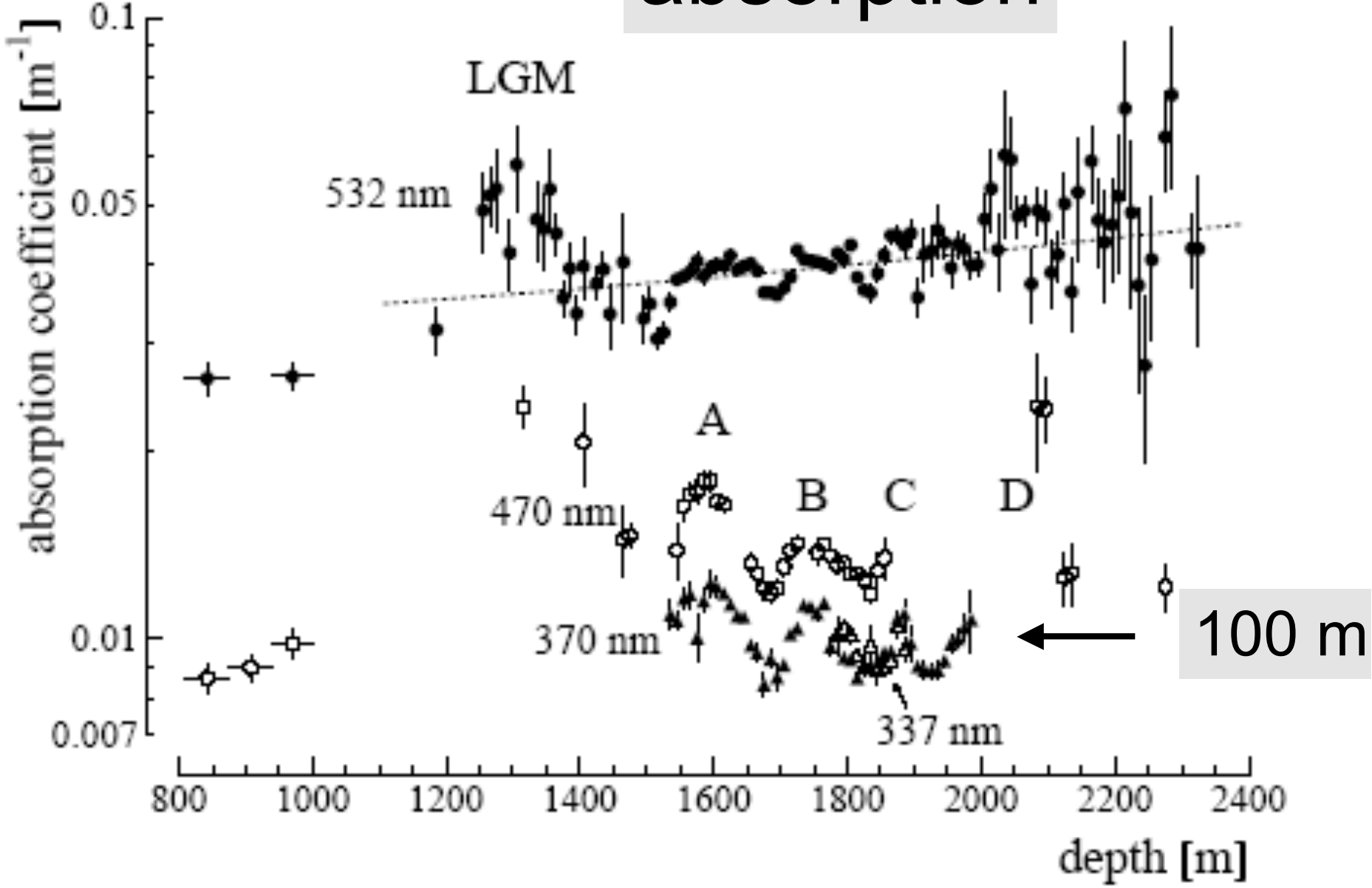
up

neutrino
traveled
through the
earth

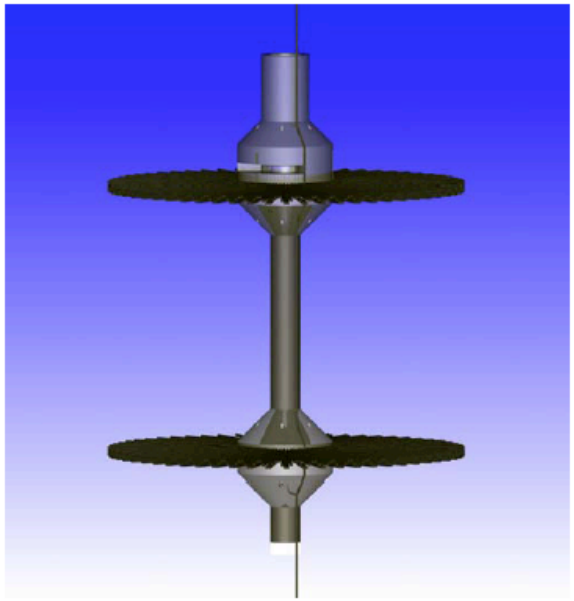
10 per day

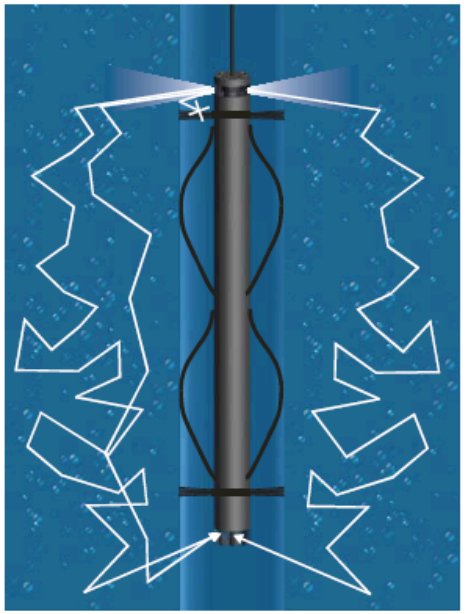
the challenge !

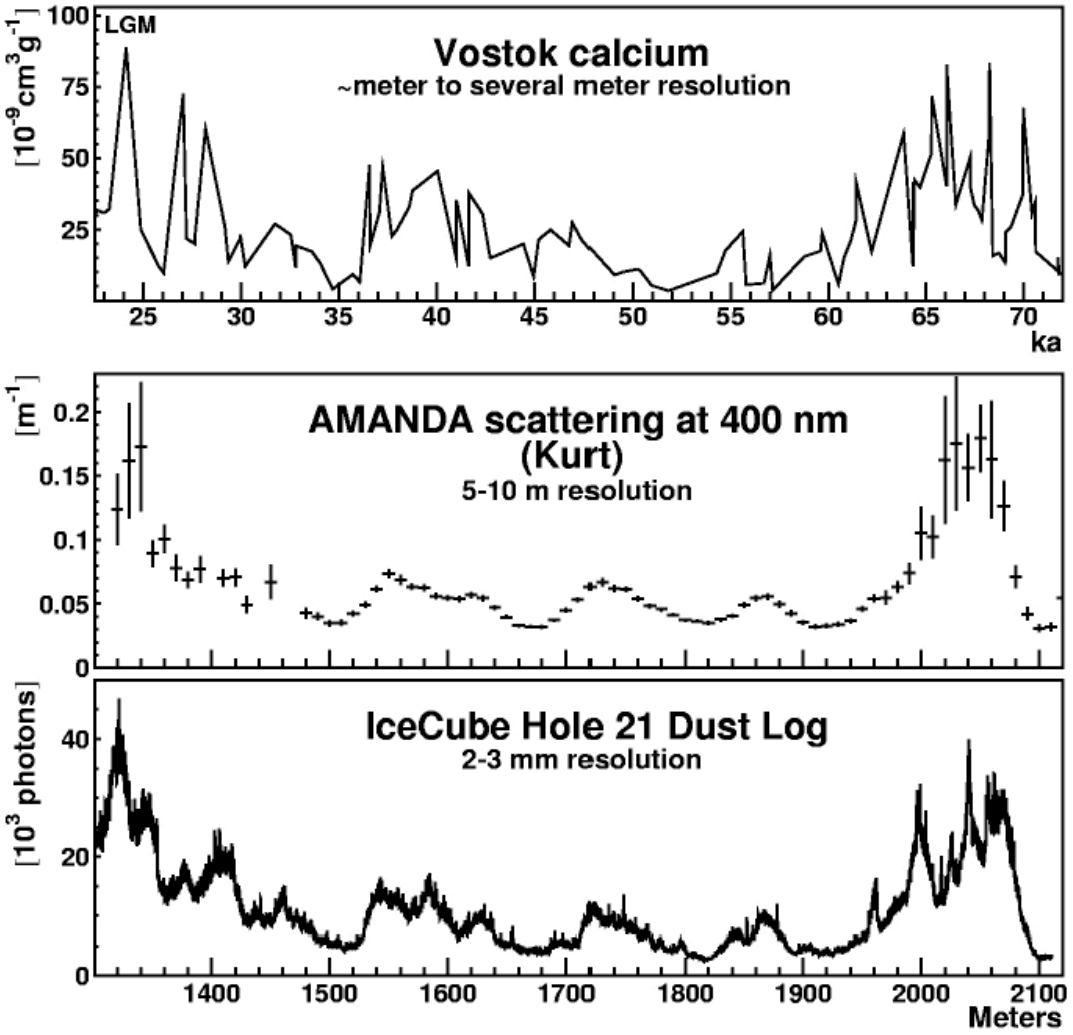
absorption

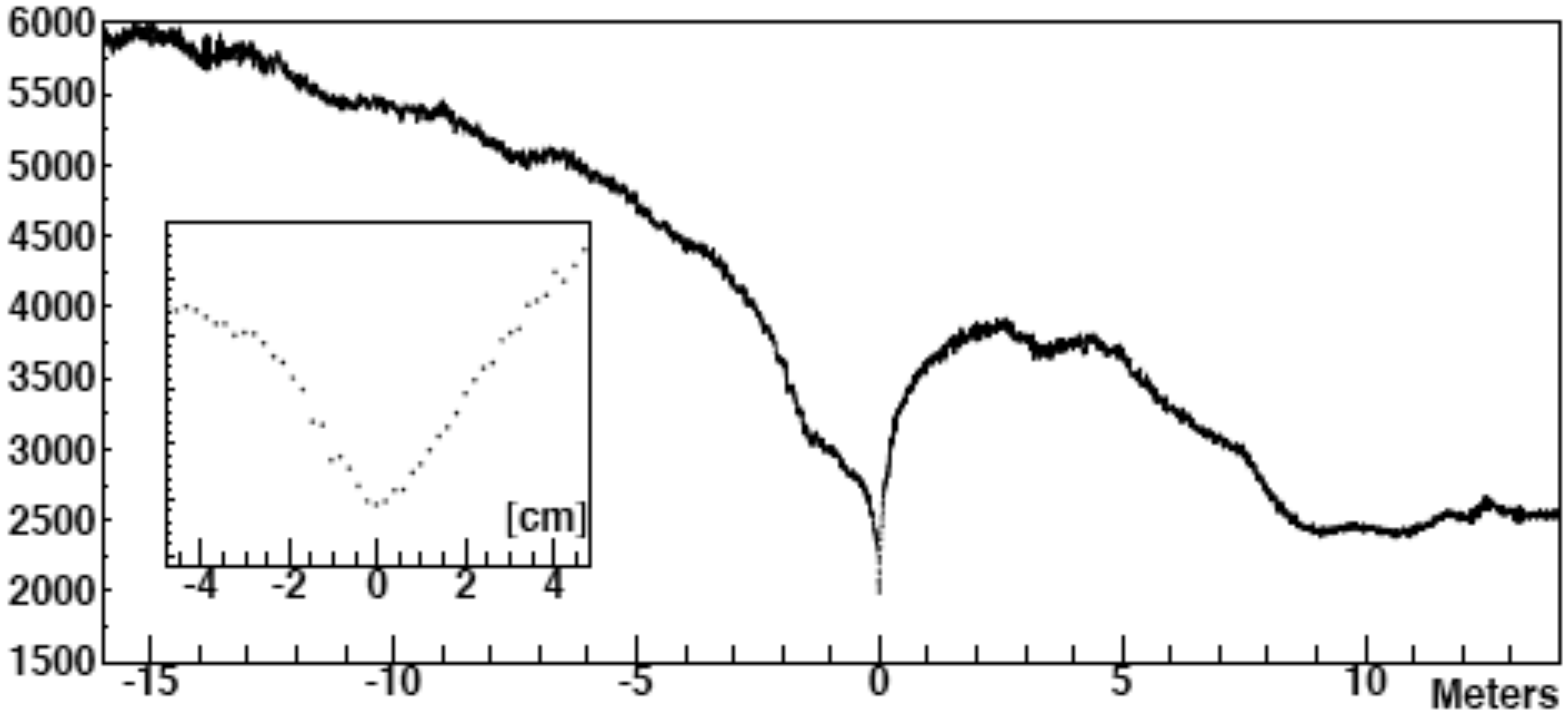

absorption coefficient [m^{-1}]
0.1
0.05
0.01
0.007
LGM
532 nm
470 nm
370 nm
337 nm
A
B
C
D
100 m
800
1000
1200
1400
1600
1800
2000
2200
2400
depth [m]

Glaciology with Light





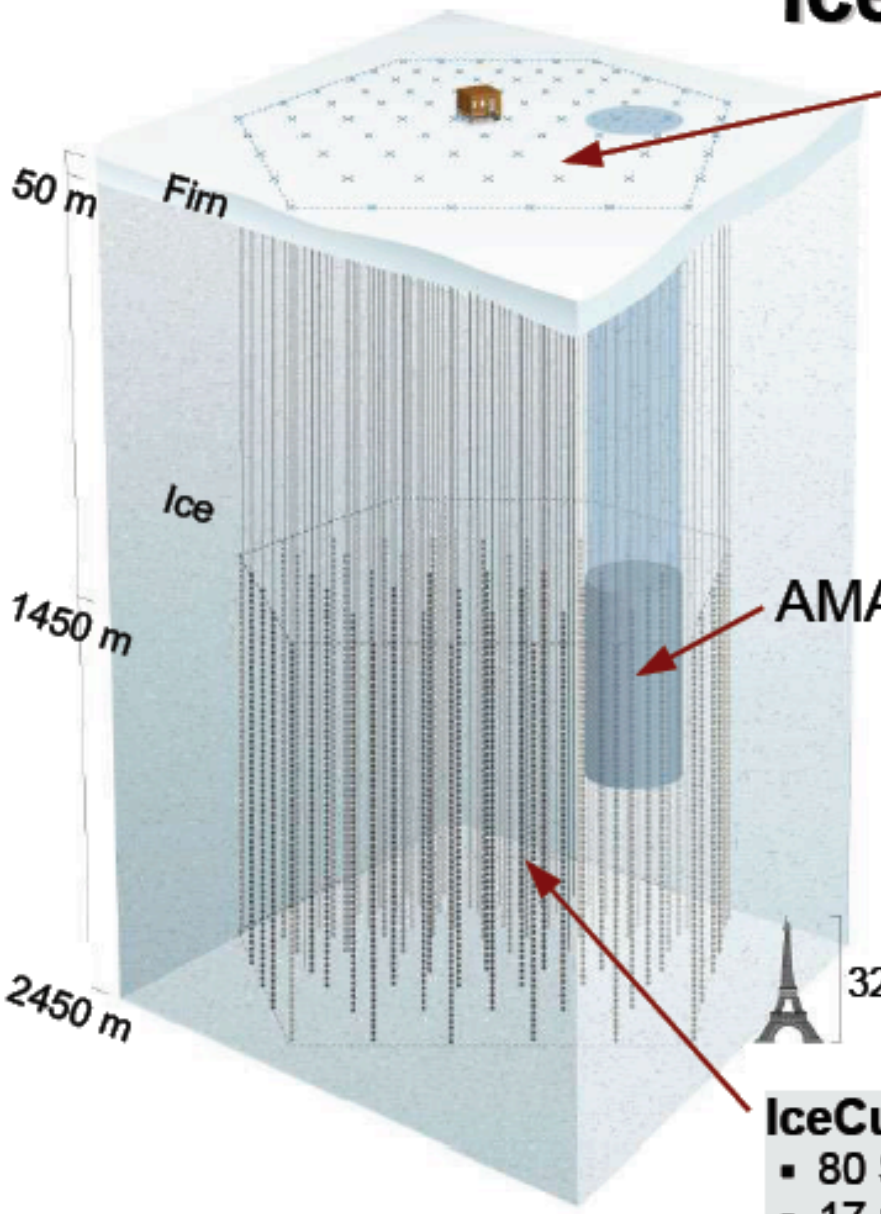




volcanic ash layer

icecube

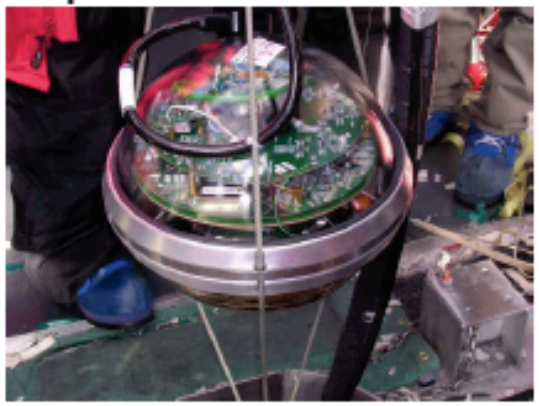
IceCube



IceTop: air shower array

- 80 Stations / 2 Tanks each
- 2 DOMs each per tank
- 125 m grid, 1 km^2 at 690 g/cm^2
- E_{thres} ~ 300 TeV for ≥ 4 stations
- Useful rate up to ~EeV

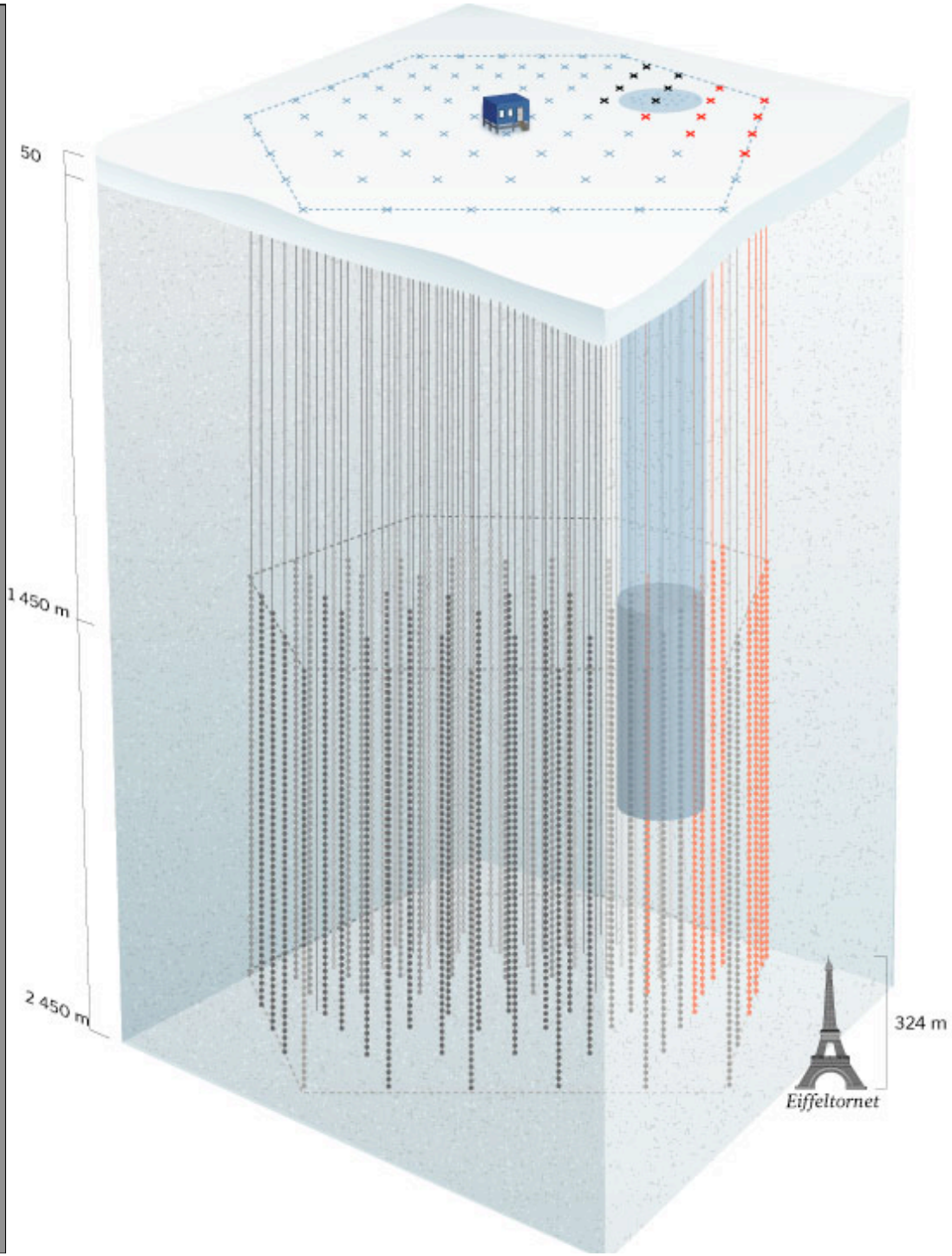
Digital **O**ptical **M**odule



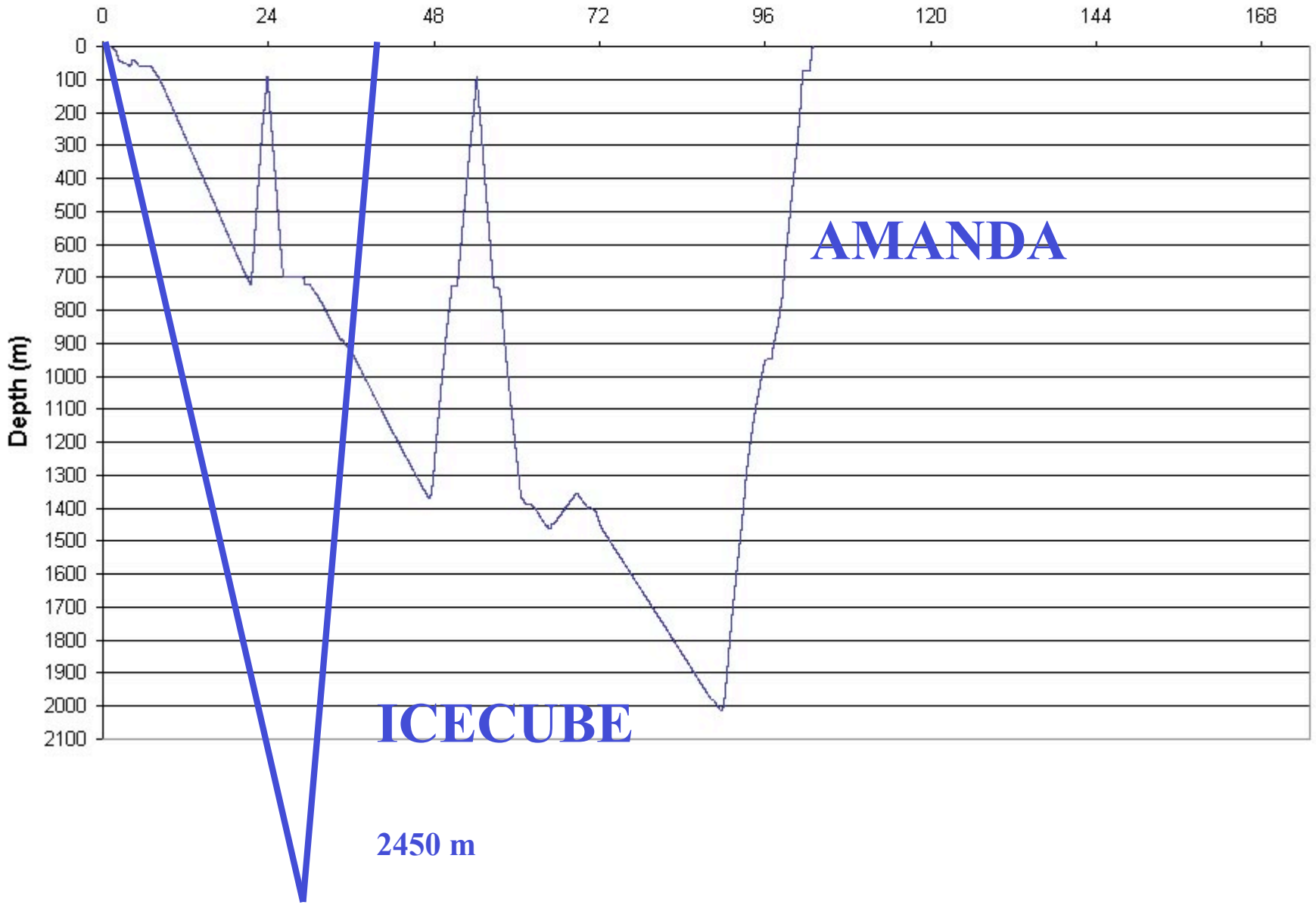
IceCube: deep ice array

- 80 Strings / 60 DOMs each
- 17 m DOM spacing
- 125 m between strings
- 1 km^3 instrumented

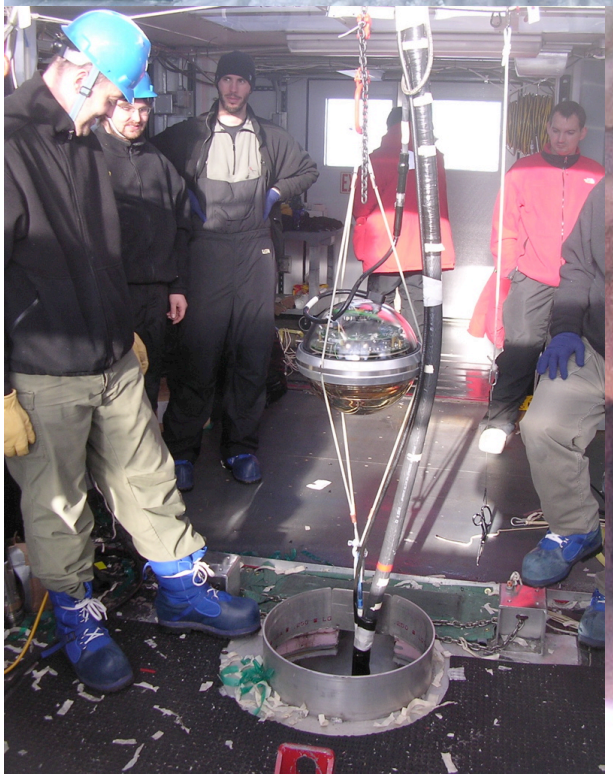
IceCube February 2006

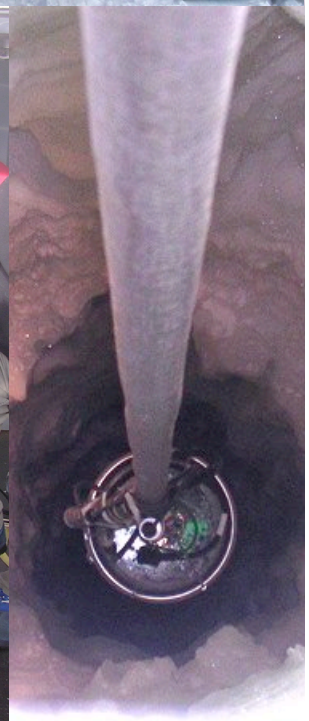


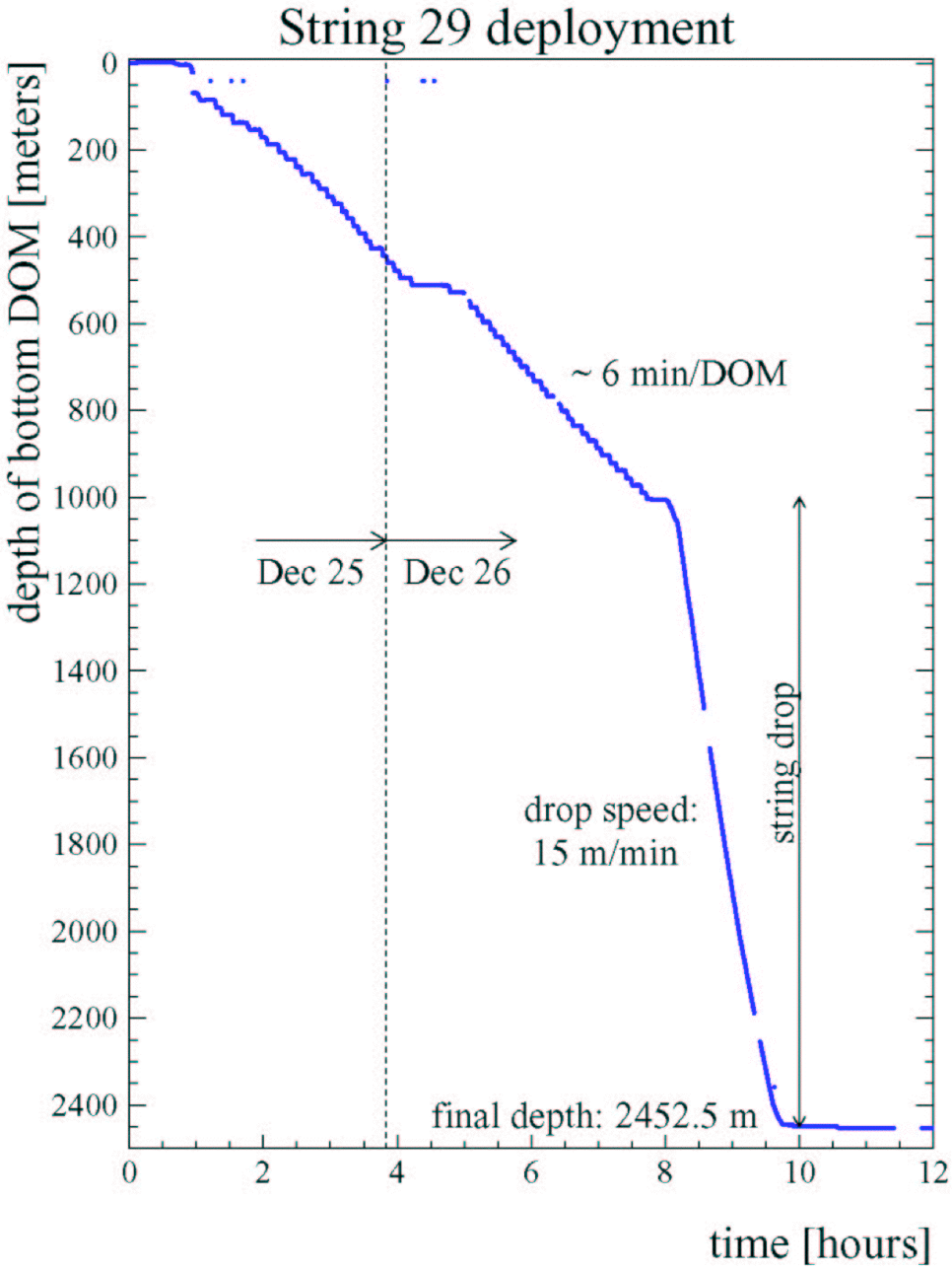
AMANDA String 19 drilling time (h)



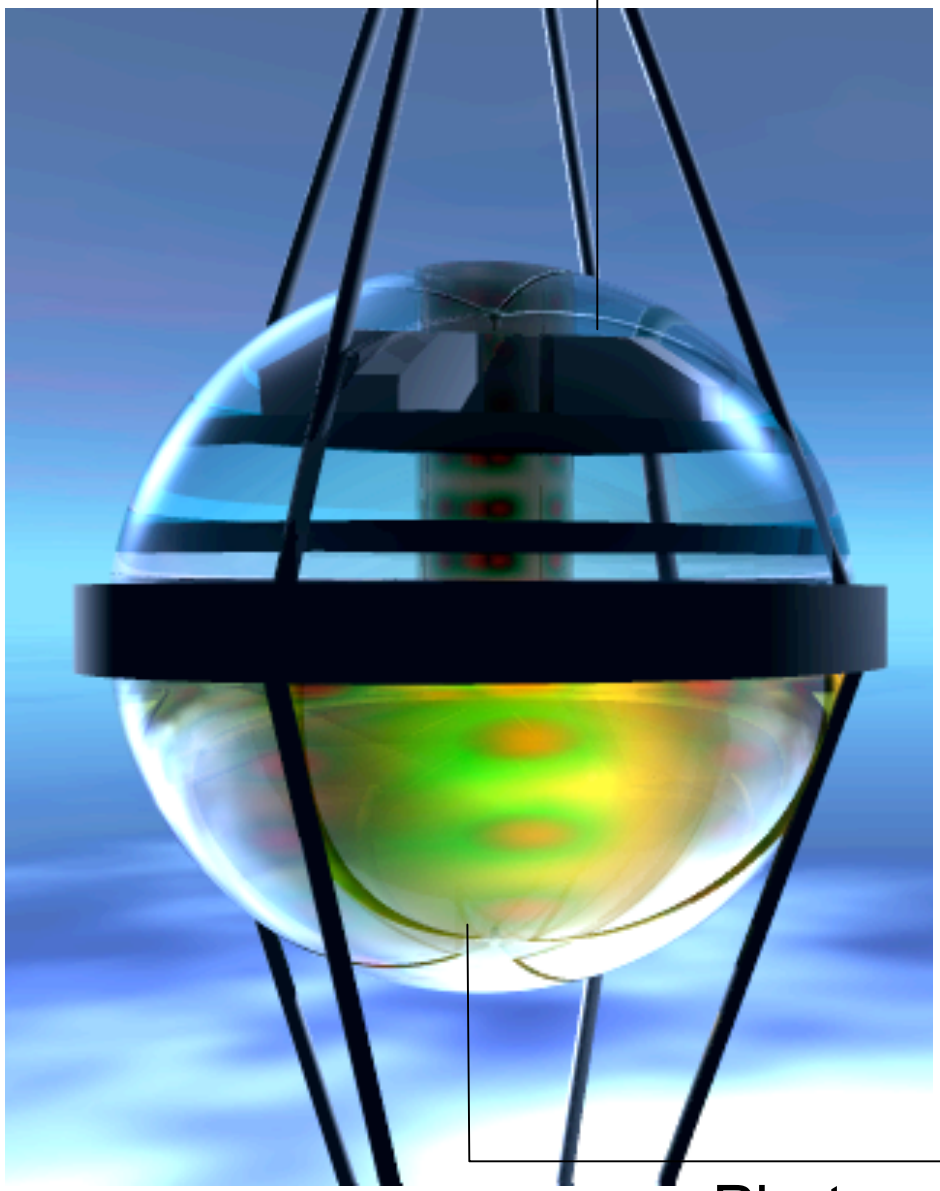
string cable: 2500 m, weight ~ 6 tons

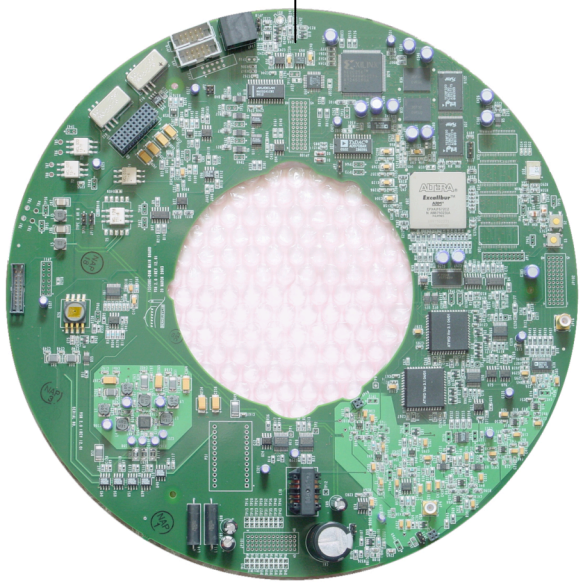






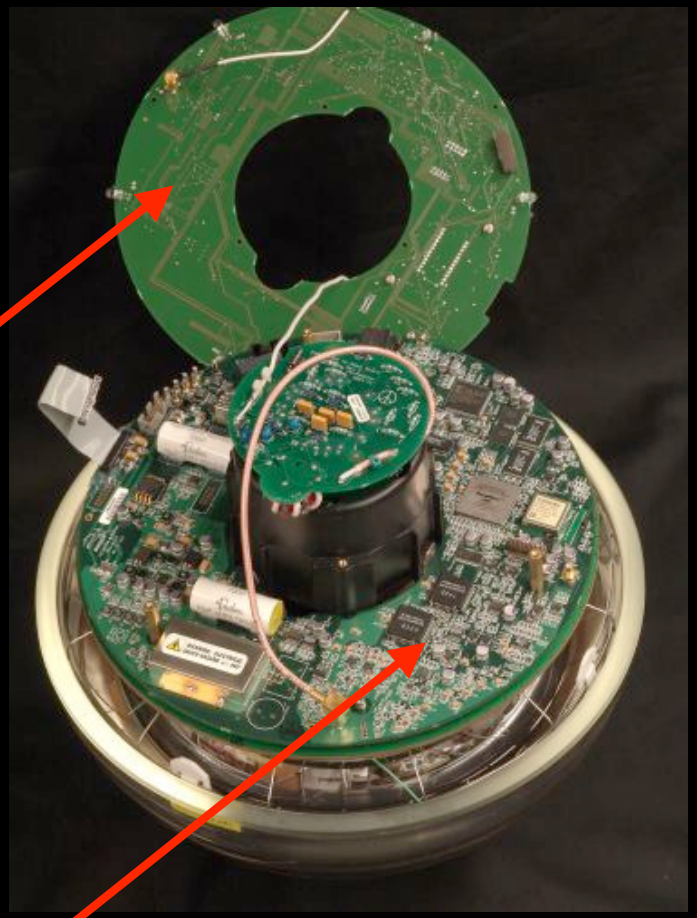
Digital Optical Module





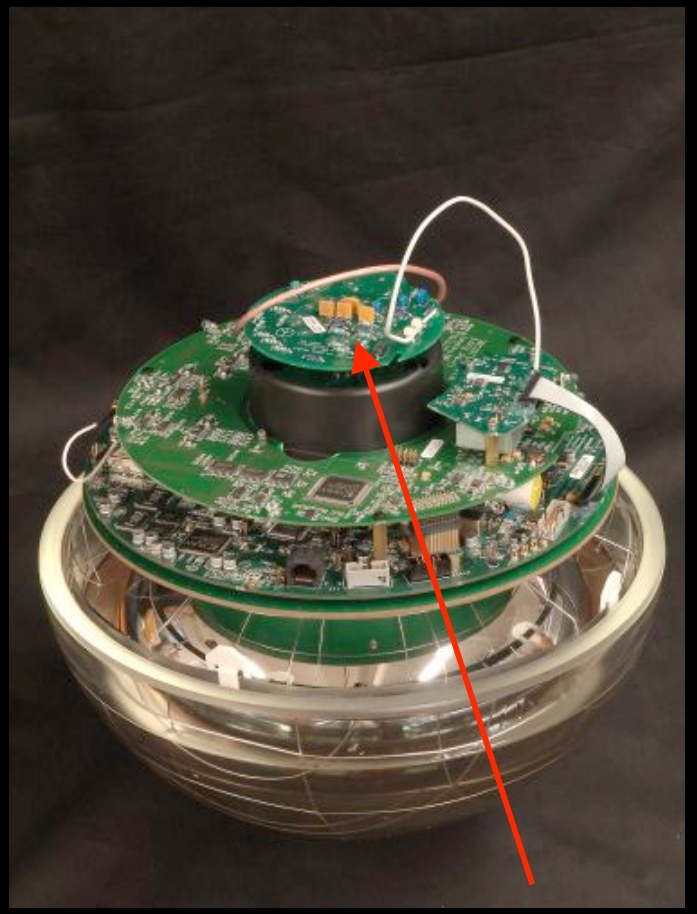
Photomultiplier Tube

Digital Optical Module



LED flasher board

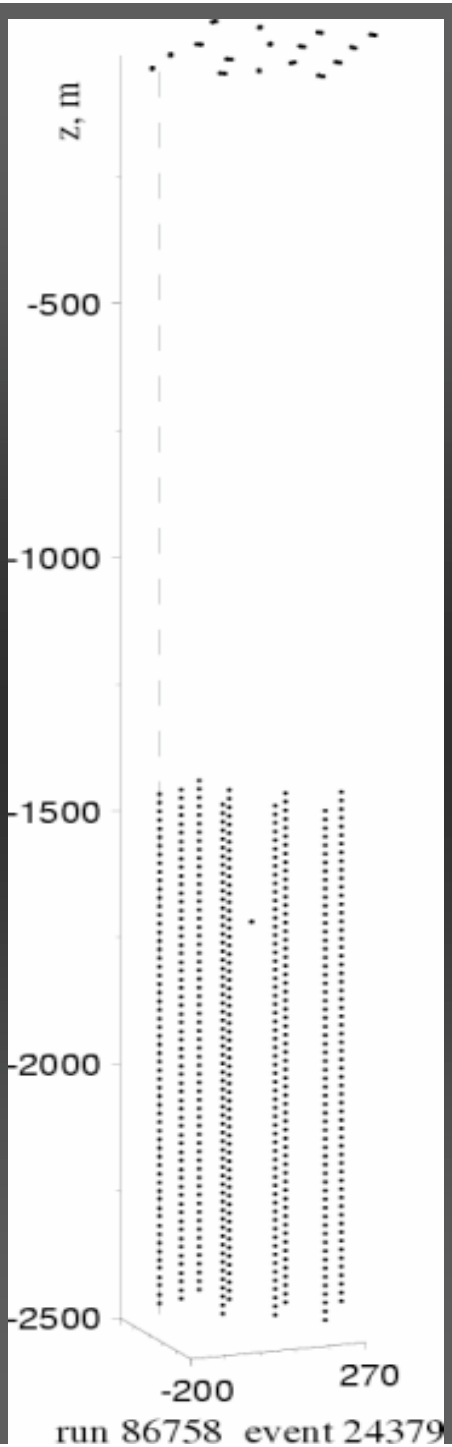
main board



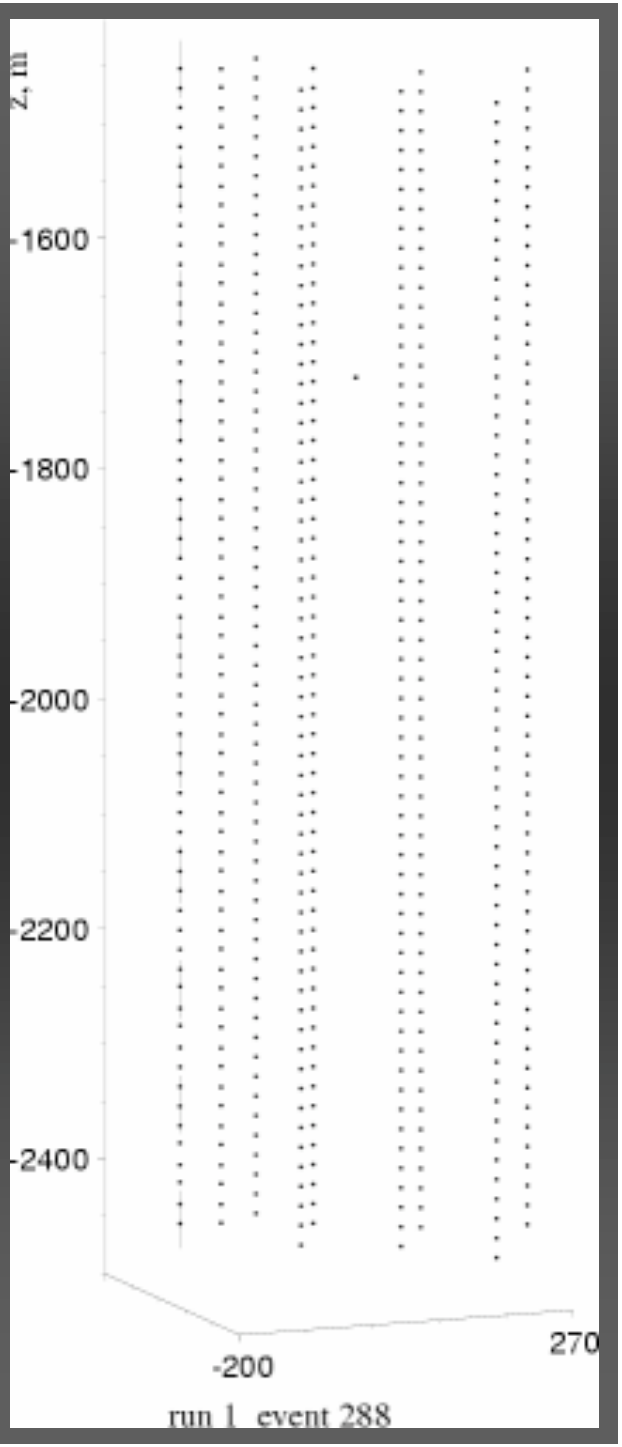
HV board

sample of events

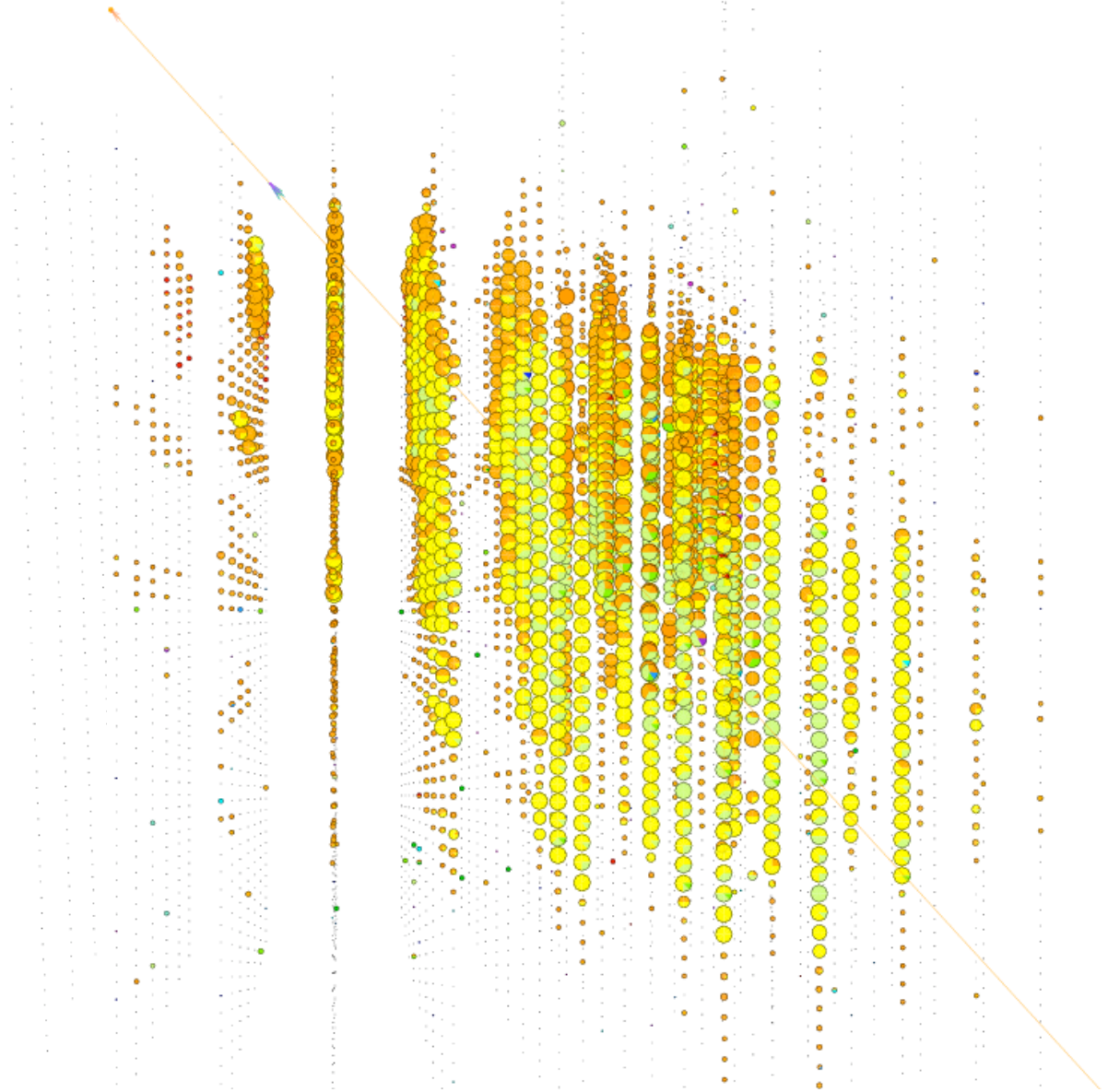
IceCube/IceTop coincident event



first IceCube neutrino



GZK event: cosmic ray + cmb photon → 10 EeV neutrino



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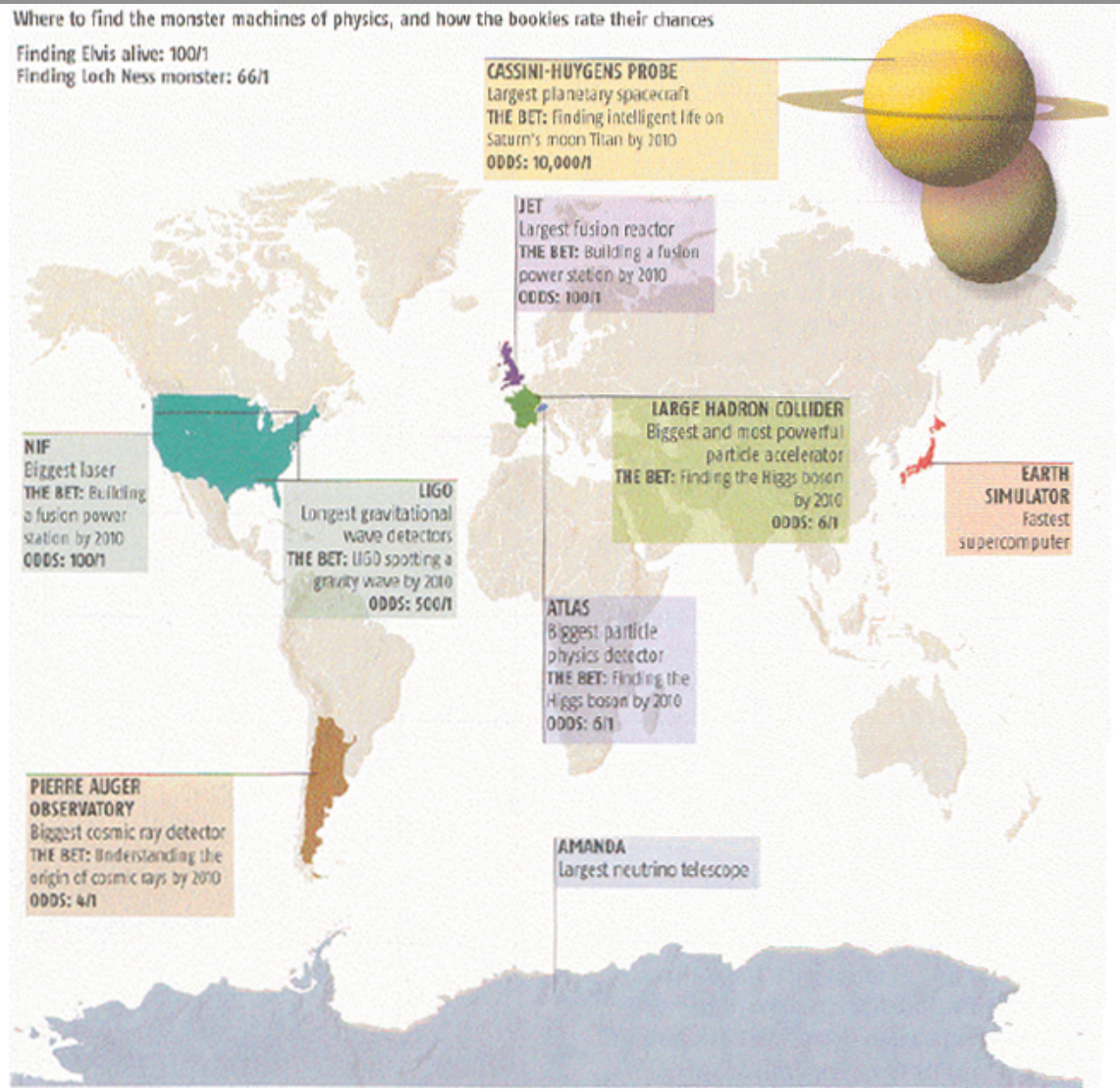

IceCube Collaboration

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Universität Wuppertal, Germany
Universität Dortmund, Germany

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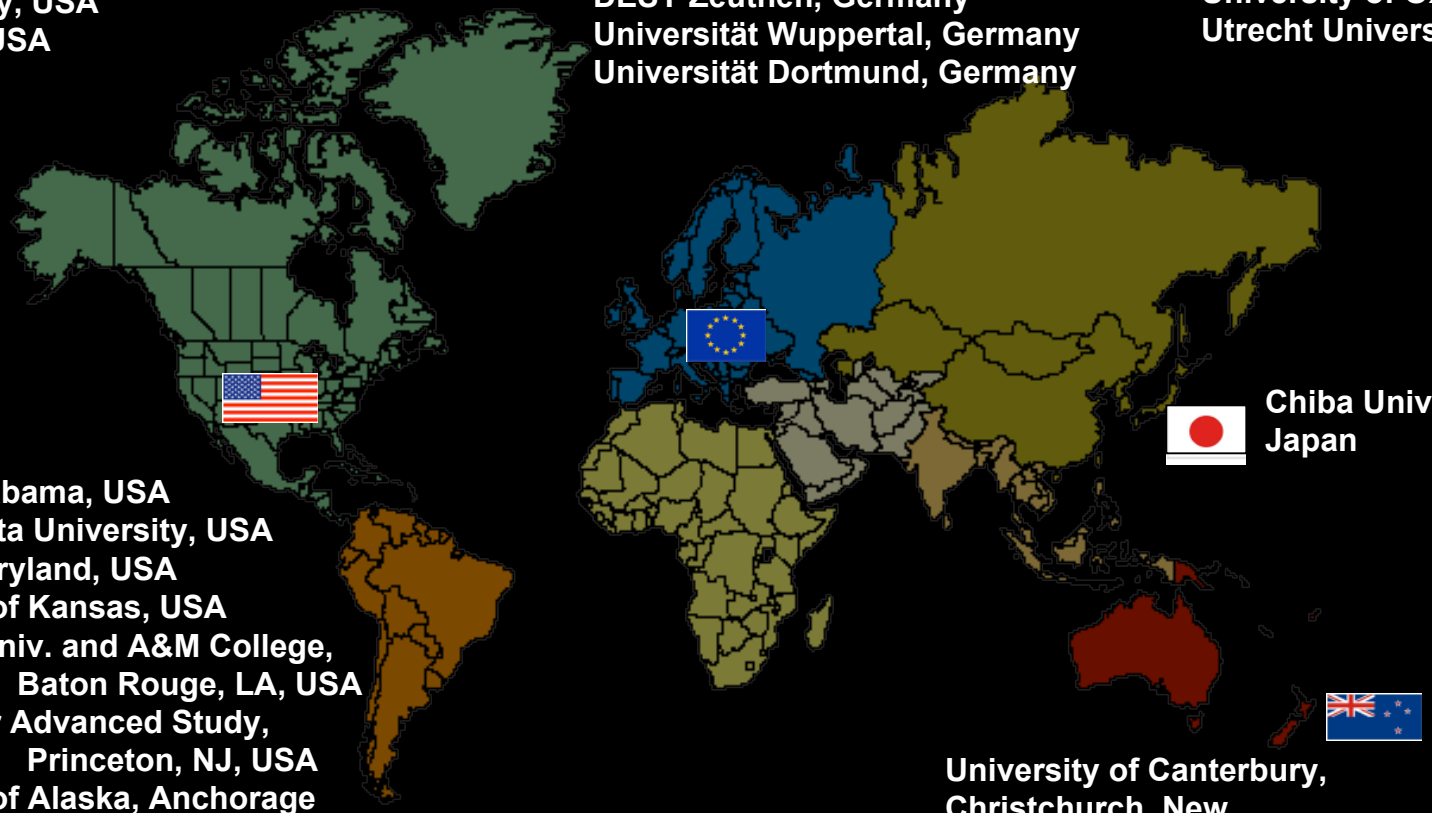
Uppsala Universitet, Sweden
Stockholm Universitet, Sweden
Kalmar Universitet, Sweden
Imperial College, London, UK
University of Oxford, UK
Utrecht University, Netherlands



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