NEUTRINO DETECTORS

UNVEILING THE INVISIBLE UNIVERSE

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BASICS OF NEUTRINOS

DISCOVERY

Wolfgang Pauli suggested a third particle was being emitted in the nuclear beta decay of a neutron, which produces a proton, electron, and an unseen particle — now known as the neutrino.

KEY PROPERTIES

- Tiny mass
- Electrically Neutral
- Small cross-section

SOURCES OF NEUTRINOS

- Solar
- Atmospheric
- Supernova
- Big Bang Neutrinos
- From other stars
- Astrophysical

NEUTRINO FLAVORS

- Electron
- Muon
- tau

(Each has a corresponding antiparticle)

NEUTRINO DETECTION

- The way we've chosen to go about detecting neutrinos is quite fascinating!
- Neutinos are neutral and there interactions are very weak making them difficult to observe directly. So we build humongous detectors that detect charged particles that are produced as a result of the neutrino interaction.
- Depending on the detector type, charged particles create either cherenkov light, scintillation light or Ionization.
- We then capture the data often using photomultiplier tubes for light, and wires or pixels for ionization.
- After we've captured the data we then reconstuct the visible particles and signals, the interaction left behind to find out the original charitaristcs of the neutrino.

NEUTRINO DETECTION

How to observe a large number of Neutrinos?

- A large number of target materials

– We choose materials that maximize the chance of interatons and allow us to observe the resulting particles clearly. That would include water, heavy water, liquid scintillator, liquid argon and Ice.

- High Intensity source of neutrinos

– We choose a high-intensity neutrino source because neutrinos interactions are extremely rare — so to detect a meaningful number of interactions, we need as many neutrinos as possible flying through the detector.

- Lots of time

– Neutrinos interactions are extremely rare so detecting them is like waiting for a ghost to bump into something.

NEUTRINO DETECTION

Number of observed interactions

Cross-section: m^2 per nucleon

Number of target nucleons

$$n_{obs} = \Phi \times \sigma \times \epsilon \times N \times t$$

Flux: neutrinos from source per s per m^2

Detection efficiency

Time in s

- Flux – intense source of neutrinos
- Cross Section – the probability of an interaction
- Detection Efficency – a measure of how well a detector can record interactions
- N – standing for the number of nucleons that the neutrinos have a chance to interacte with
- T – standing for the duration of the experiment

SNO / SNO+ DETECTOR

What is it?

- SNO (**Sudbury Neutrino Observatory**) is a heavy-water Cherenkov neutrino detector located 6800 feet underground in a nickel mine in Sudbury, Canada.
- It operated from 1999 to 2006 and was instrumental in solving the Solar Neutrino Problem.
- SNO+ is the successor to SNO. It reuses the same cavern and detector vessel but replaces the heavy water (D_2O) with a liquid scintillator for broader sensitivity.

What Was SNO's Mission?

- To detect solar neutrinos and prove neutrino flavor oscillation.

SNO / SNO+ DETECTOR

Detection Method (SNO)

- Uses 860 tons of liquid scintillator. in a 12-meter acrylic vessel.
- Detects neutrinos using Cherenkov radiation

Three types of interactions detected

- Charged-current (CC): sensitive to electron neutrinos only.
- Neutral-current (NC): sensitive to all neutrino flavors.
- Elastic scattering (ES): sensitive primarily to electron neutrinos, but also others.

Cool Facts

- The facility is underground (6000 ft) to shield against cosmic rays.
- Collaboration involves institutions across Canada, the US, and Europe.

KAMLAND DETECTOR

What is Kamland

- A large-volume liquid scintillator neutrino detector
- Designed to detect antineutrinos, especially from nuclear reactors
- Operated since 2002

Where is Kamland

- Located 1,000 meters underground in the Kamioka mine in Gifu Prefecture, Japan
- Shares the site with the Super-Kamiokande detector

Misson and Purpose

- To detect electron antineutrinos from nuclear reactors hundreds of kilometers away.
- Proved neutrino oscillation for antineutrinos — complementing solar neutrino studies.
- Helped measure the mass-squared difference for neutrino oscillation.

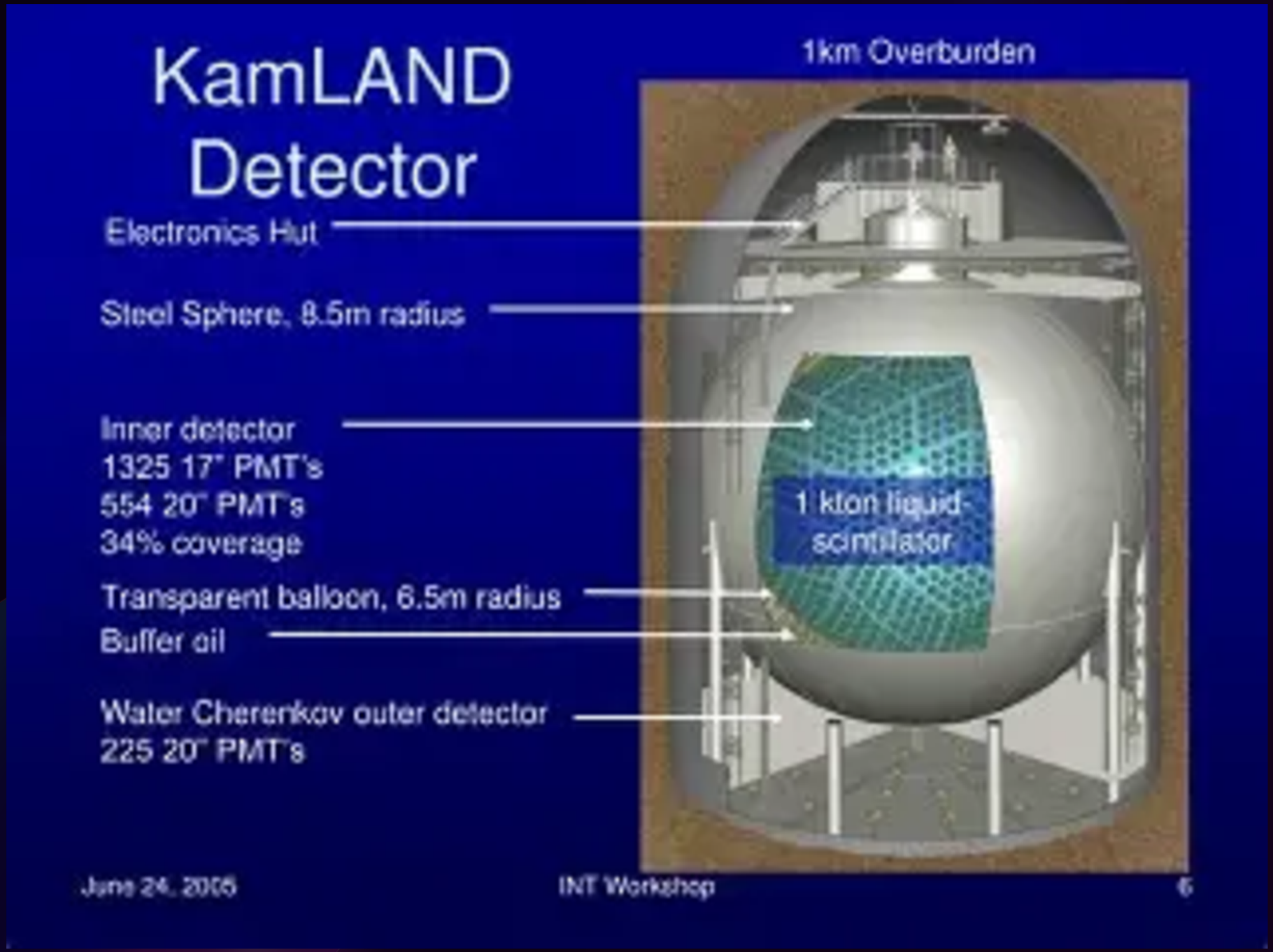
KAMLAND DETECTOR

Detection Method

- Uses 1,000 tons of ultra-pure liquid scintillator contained in a 13-meter diameter balloon
- Surrounded by photomultiplier tubes (PMTs) that detect flashes of light from neutrino interactions

Structure Highlights

- Balloon filled with scintillator fluid inside a stainless-steel sphere
- Surrounded by a buffer oil and a 1,879 PMT array for light detection
- Enclosed in a water Cherenkov outer detector for shielding and cosmic ray rejection



ICECUBE NEUTRINO DETECTOR

What is the IceCube Neutrino Detector?

- The IceCube Neutrino Observatory is a massive neutrino telescope embedded in a cubic kilometer of clear ice at the South Pole

Location and Structure

- Located at the Amundsen-Scott South Pole Station, buried 1.5 to 2.5 km deep in Antarctic ice
- Covers a volume of 1 cubic kilometer
- Uses 5,160 Digital Optical Modules (DOMs) on 86 strings, spaced 125 m apart

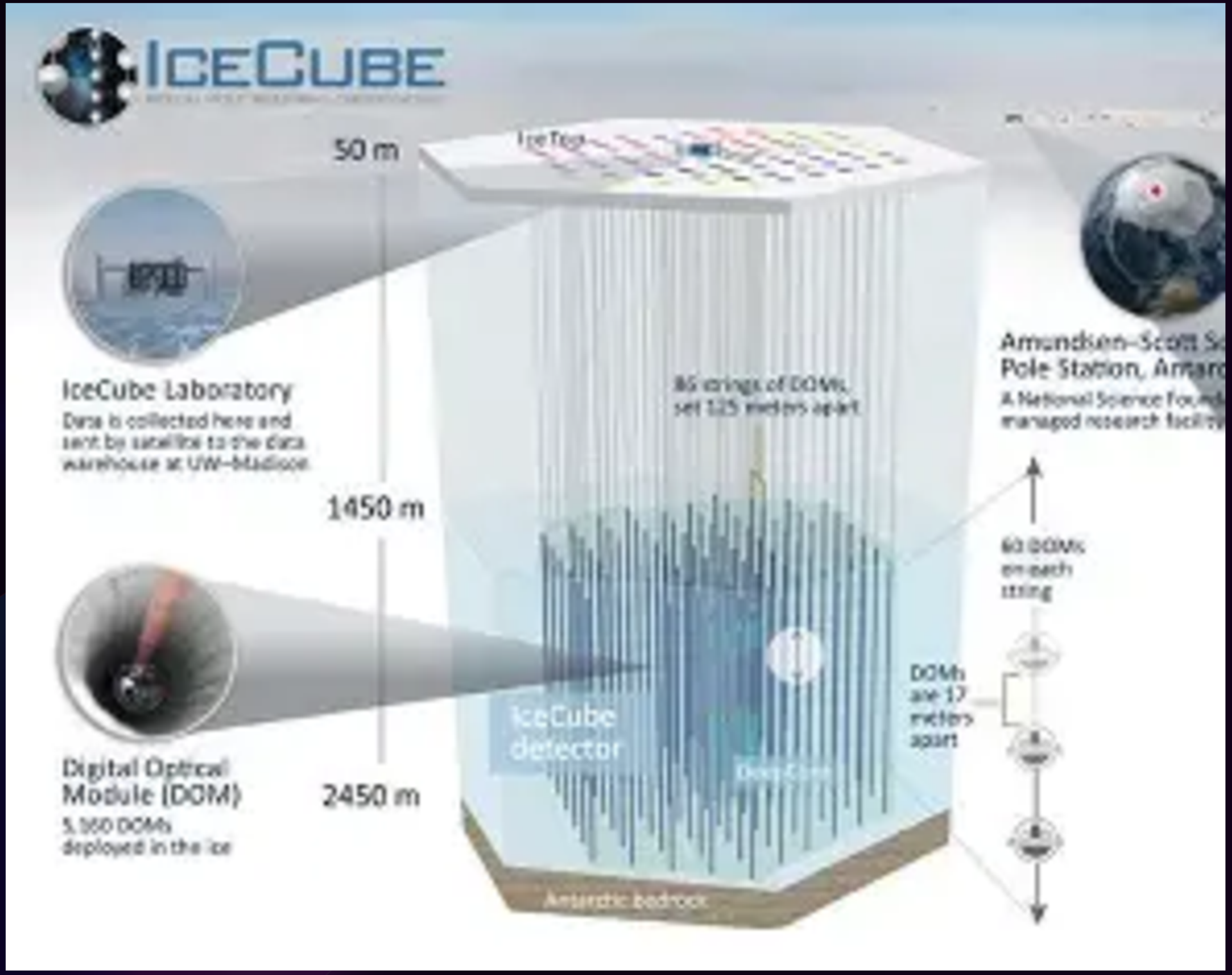
Includes:

- DeepCore: a denser sub-array for low-energy neutrinos (10 GeV)
- IceTop: a surface array to study cosmic rays and filter background

ICECUBE NEUTRINO DETECTOR

Scientific Goals & Discoveries

- First to detect high-energy cosmic neutrinos from outside the Milky Way
- Confirmed neutrino oscillations using atmospheric neutrinos
- Conducted dark matter searches, studied cosmic rays, and measured neutrino cross-sections



ICECUBE NEUTRINO DETECTOR

Detection Method

- Detects Cherenkov radiation from neutrino interactions in ultra-clear ice
- Each DOM contains a photomultiplier tube that records light pulses with nanosecond precision
- DOMs digitize and transmit data using cables to a central IceCube Lab at the surface
- Uses timing and light pattern reconstruction to identify neutrino direction and energy
- Real-time alert system sends extreme-energy neutrino events to observatories worldwide