Neutrinos

Invisible particles all around us

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Why care about invisible neutrinos?

1. (Pragmatist:) They are needed for the Sun to shine
2. (Philosopher:) They are responsible for our existence
3. (Fatalist:) They are everywhere: we can't escape them
4. (Quizmaster:) They set up interesting puzzles
5. (Adventurer:) Detecting them is a challenge !

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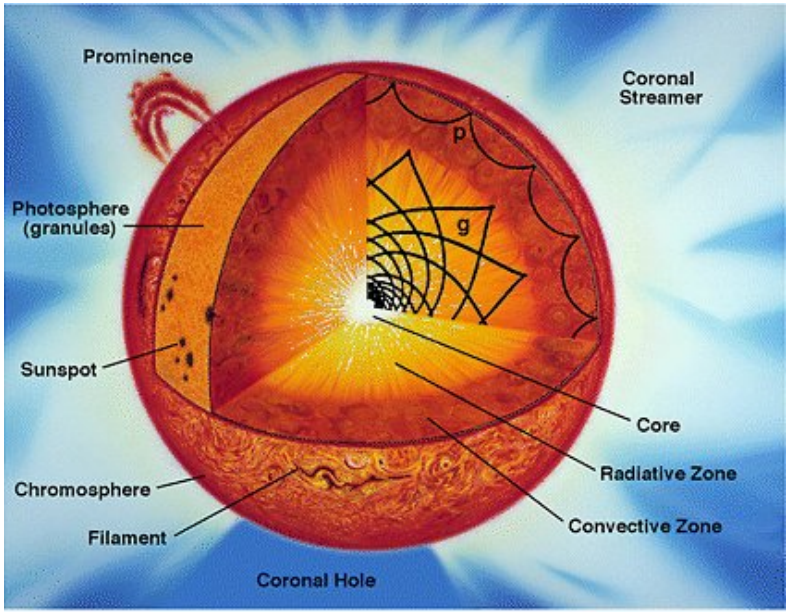

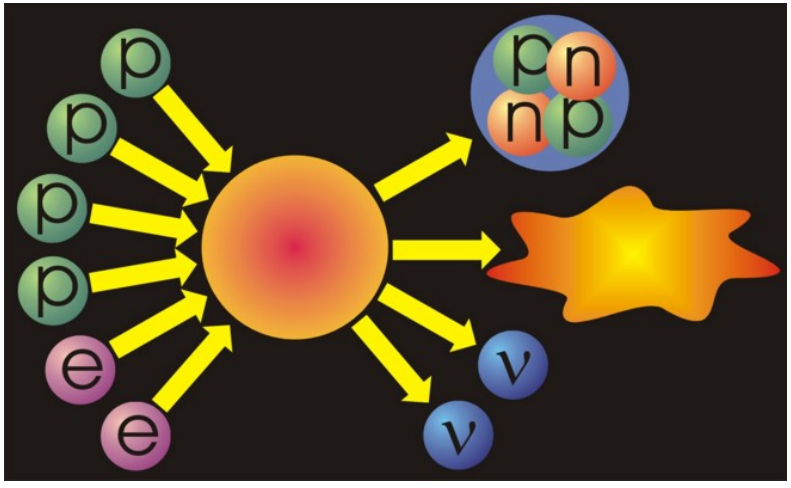

- Nuclear fusion reactions: mainly

$$4\,{}^{1}_{1}\mathrm{H} + 2e^{-} \rightarrow {}^{4}_{2}\mathrm{He} + \text{light} + 2\nu_e$$

- Neutrinos needed to conserve energy, momentum, angular momentum

Neutrinos essential for the Sun to shine !!

Davis-Koshiba Nobel prize 2002

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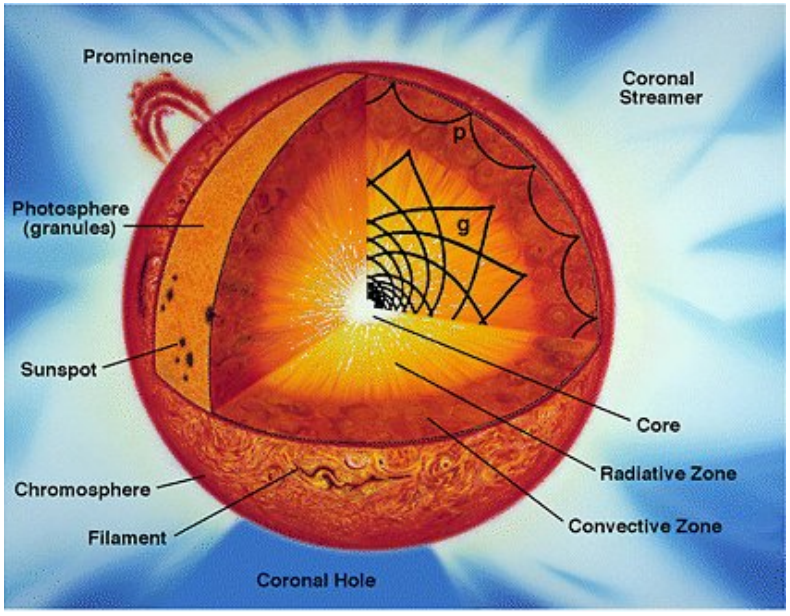

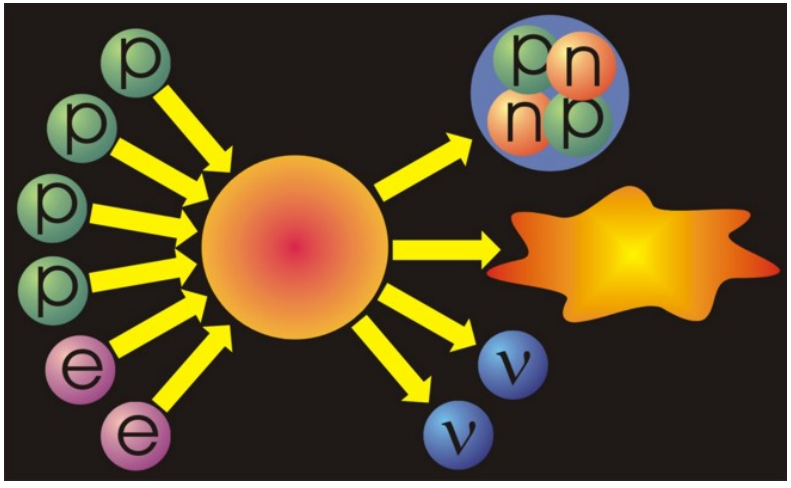

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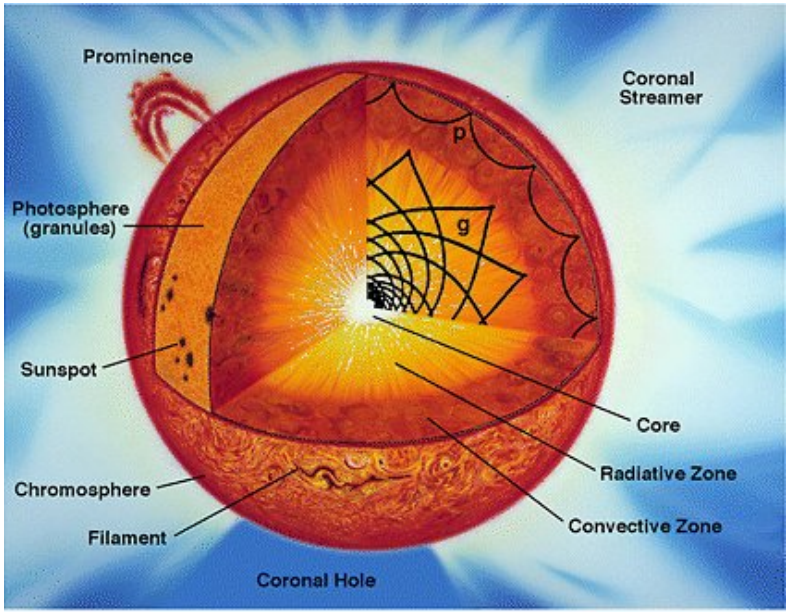

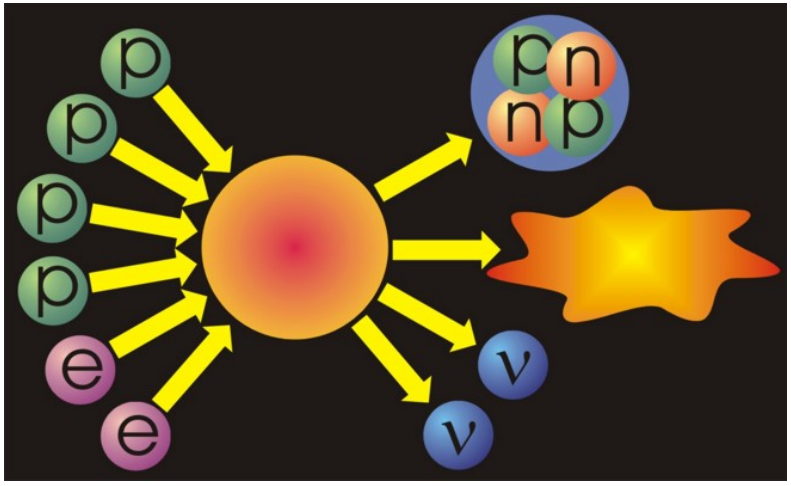

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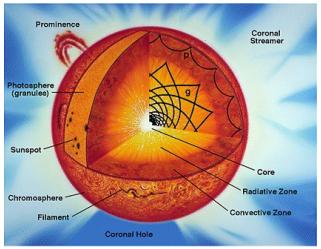
Neutrinos from the Sun



A very very large number of neutrinos

About hundred trillion through our body per second

Hundred trillion = 100 000 000 000 000

Even during night !

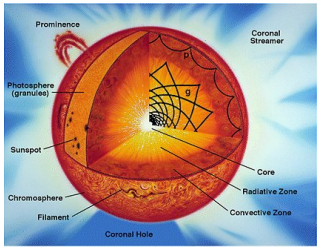
Neutrinos during night = Neutrinos during day

Reach us directly from the core of the Sun

Light from the Sun's core cannot reach us directly

Why do we not notice them ?

Neutrinos from the Sun



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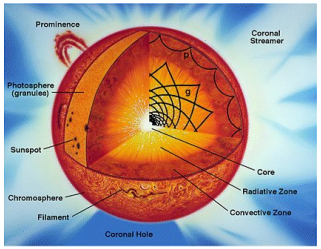

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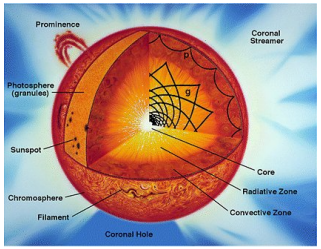

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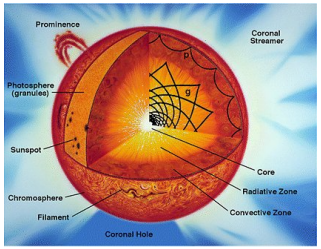

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Three questions, the same answer

- Why did the *roti* char ?
- Why did the betel leaves *(paan)* rot ?
- Why could the horse not run ?

Because they were not moved !

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Three questions about neutrinos

Pauli Dirac

- Why do we not notice neutrinos passing through us?
- Why do neutrinos from the Sun reach us during night ?
- Why can we see “inside” the sun with neutrinos ?

Because neutrinos interact extremely weakly !

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Because neutrinos interact extremely weakly !

The most weakly interacting particles

Stopping radiation with lead shielding

- Stopping α, β, γ radiation: 50 cm
- Stopping neutrinos from the Sun: light years of lead !

Answers to the three questions

- Why do we not notice neutrinos passing through us?
  Neutrinos pass through our bodies without interacting
- Why do neutrinos from the Sun reach us during night ?
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How do we see the neutrinos then ?

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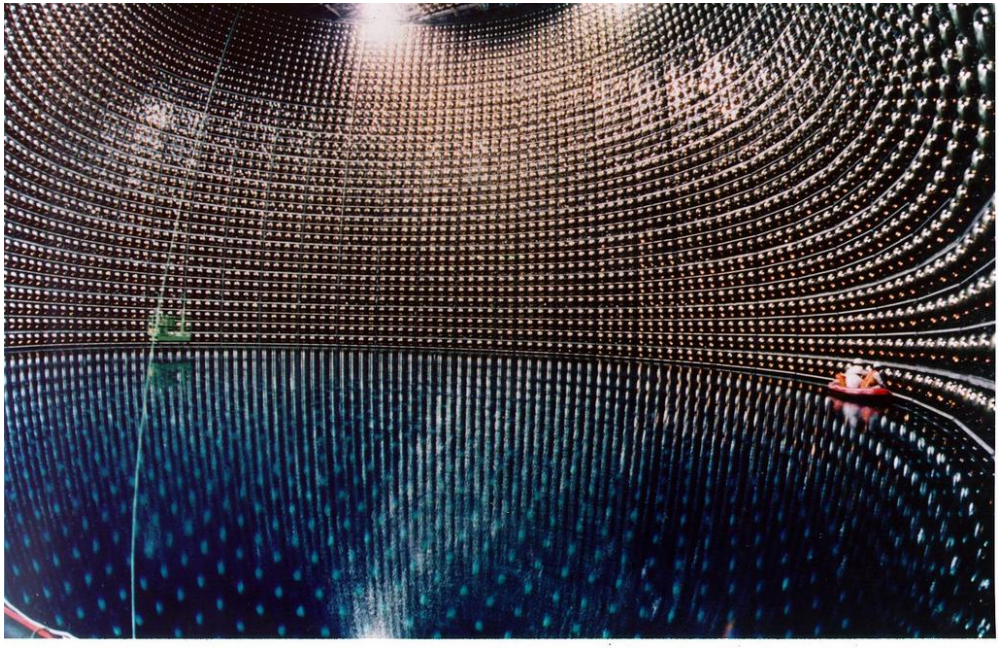
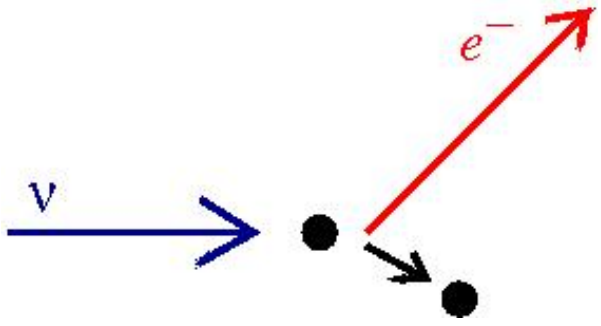
SuperKamiokande: 50 000 000 litres of water



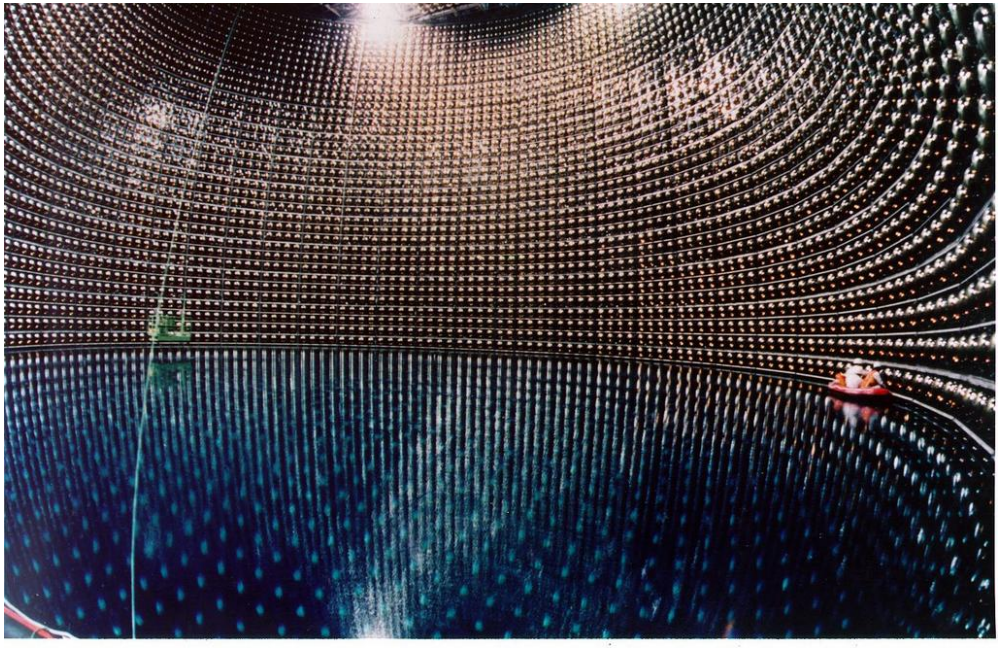


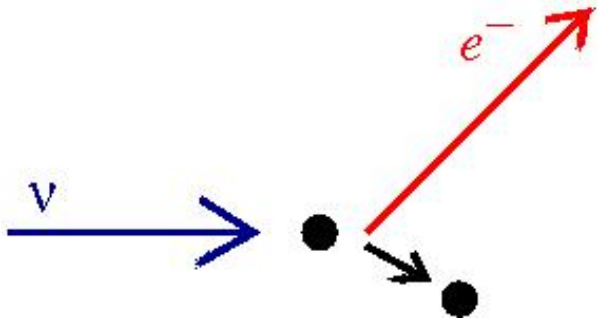
Recipe for observing neutrinos

- Build very large detectors
- Wait for a very long time

SuperKamiokande observes about 5-10 neutrinos per day

SuperKamiokande: 50 000 000 litres of water





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A view from the Hubble telescope

The world without neutrinos

The world without neutrinos

Role of neutrinos in creating atoms

Neutrinos helped create the matter-antimatter asymmetry, without which, no atoms, no stars, no planets, no galaxies

Role of neutrinos in creating the Earth

- Earth has elements heavier than iron, which can be created only inside an exploding star (supernova)
- A supernova must have exploded bilions of years ago whose fragments formed the solar system
- Supernovae explode by neutrinos pushing the shock wave

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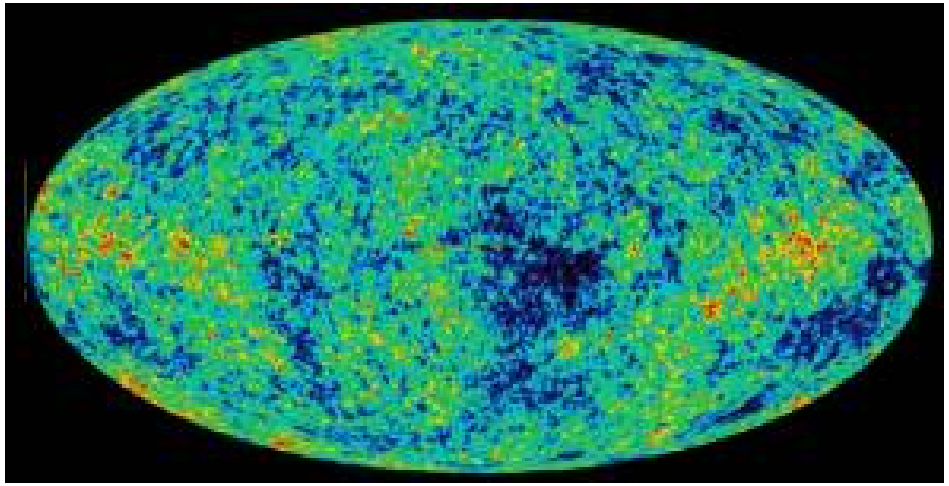
The second-most abundant particles in the universe

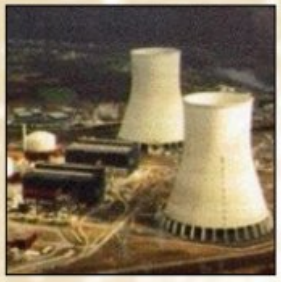


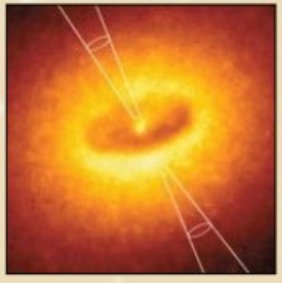
- Cosmic microwave background: 400 photons/ cm^3
  Temperature: $\sim$ 3 K
- Cosmic neutrino background: 300 neutrinos / cm^3
  Temperature: $\sim$ 2 K

Even empty space between galaxies is full of neutrinos !

Neutrinos everywhere

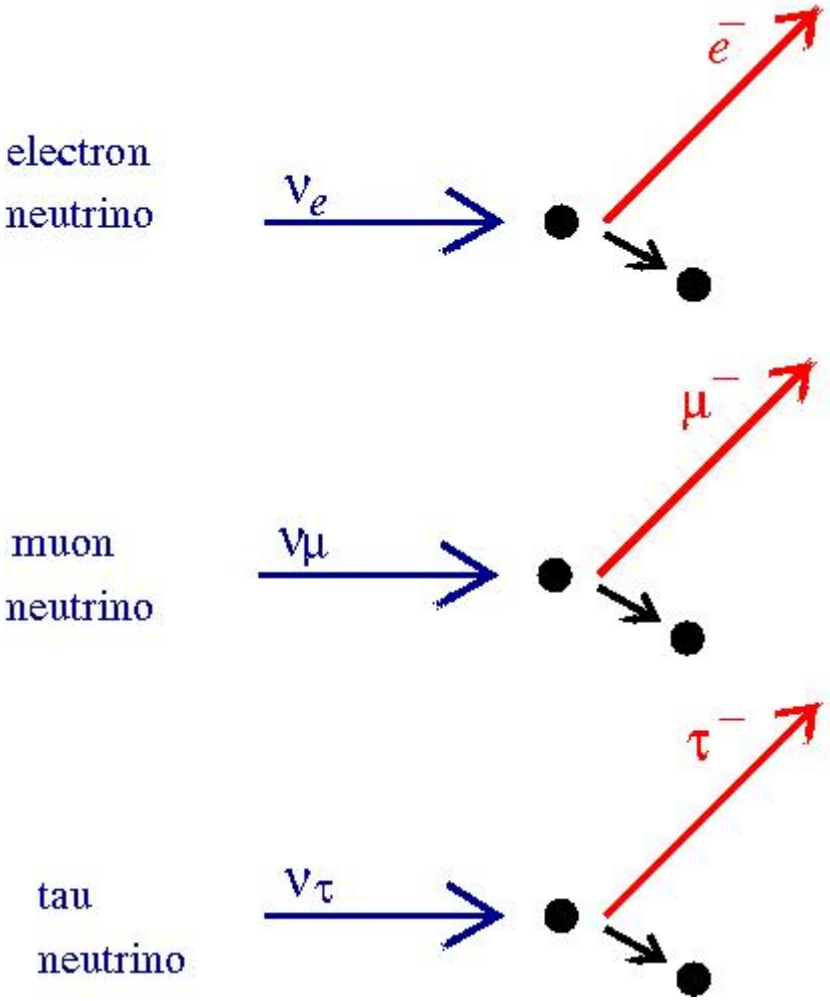
Where do Neutrinos Appear in Nature?



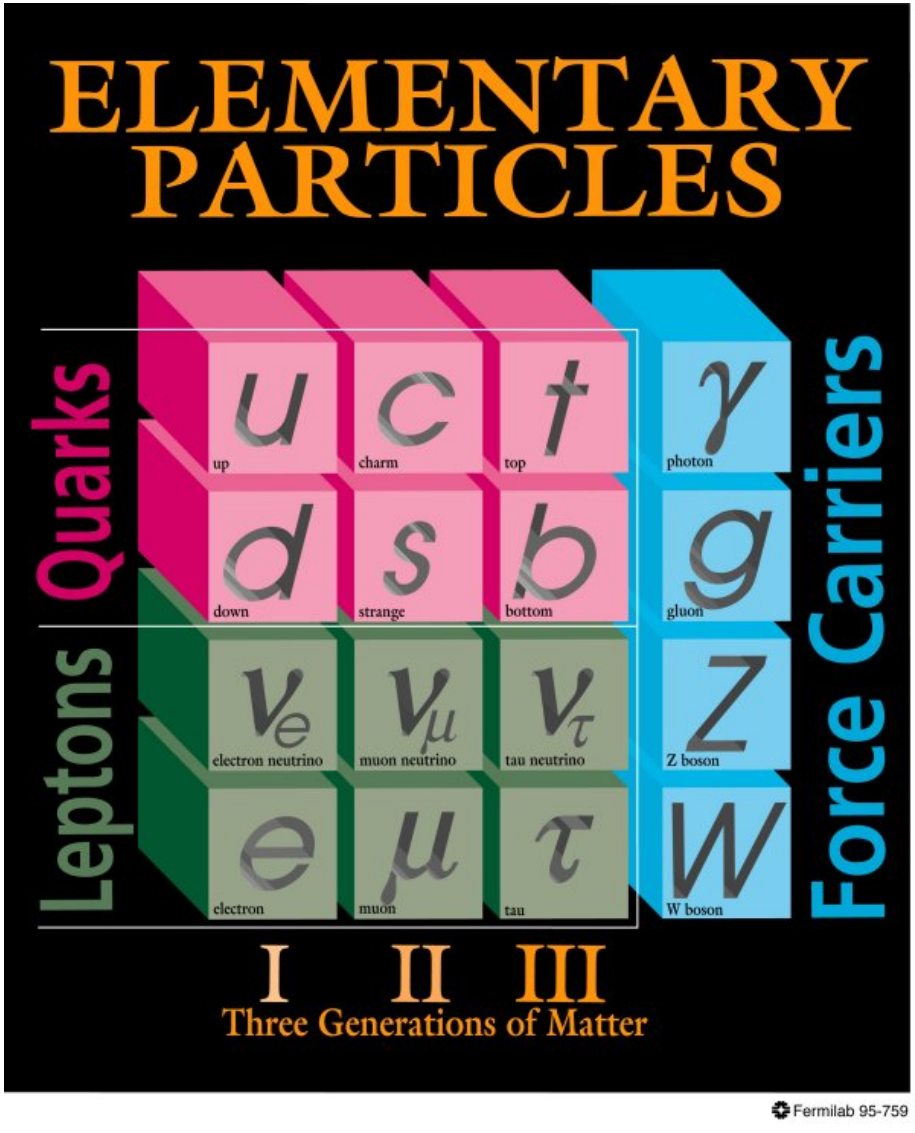


- ✓ Earth Crust (Natural Radioactivity)
- ✓ Nuclear Reactors
- ✓ Particle Accelerators
- ✓ Earth Atmosphere (Cosmic Rays)
- Sun ✓
- Supernovae (Stellar Collapse) SN 1987A ✓
- Cosmic Big Bang (Today 330 ν/cm^3) Indirect Evidence
- Astrophysical Accelerators Soon ?

Three kinds of neutrinos: ν_e ν_μ ν_τ



The Standard Model of Particle Physics



+ Higgs

- 3 neutrinos:
  ν_e, ν_μ, ν_τ
- Zero charge
- spin 1/2
- almost massless:
  at least a million
  times lighter
  than electron

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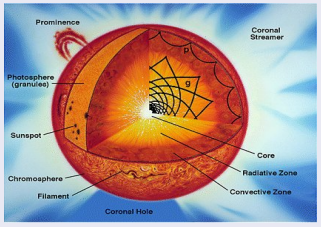
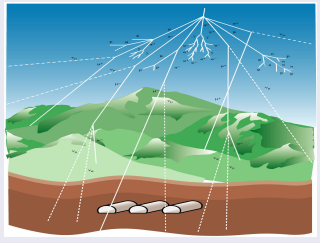
Neutrinos setting long-term puzzles

Solar neutrino puzzle: 1960s – 2002



- Only about half the expected ν_e observed!
- Possible solution: ν_e change to ν_μ/ν_τ

Atmospheric neutrino puzzle: 1980s – 1998



- Half the ν_μ lost in the Earth!
- Possible solution: ν_μ change to ν_τ

Reactor neutrino experiments

- Breaking news of 2012:
  10% of reactor $\bar{\nu}_e$ are lost !
- Possible solution: $\bar{\nu}_e$ change to $\bar{\nu}_\tau/\bar{\nu}_\tau$

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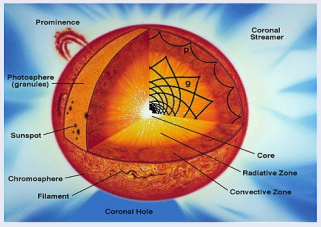

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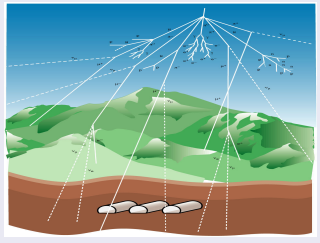

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Three questions, the same answer

ν conference participants

- Why did half the ν_e from the sun become ν_μ/ν_τ ?
- Why did half the ν_μ from the atmosphere become ν_τ ?
- Why did 10% $\bar{\nu}_e$ from the reactors become ν_μ/ν_τ ?

Because neutrinos have different masses and they mix !

$\Uparrow$

Quantum Mechanics

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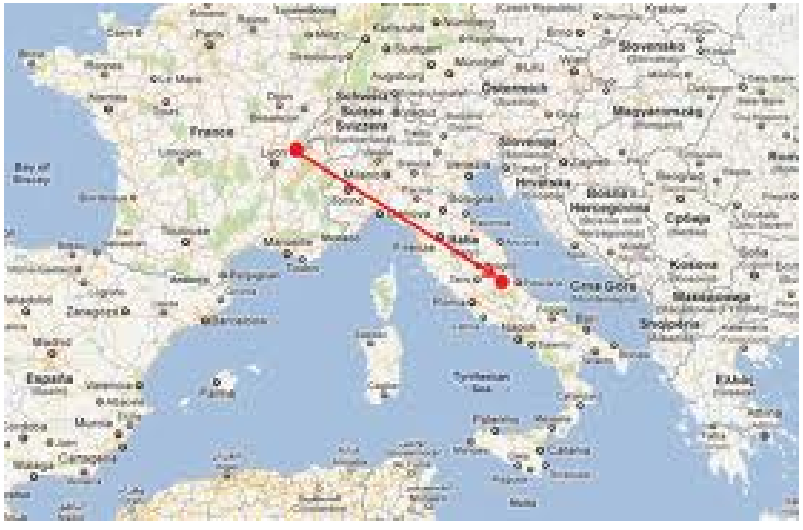
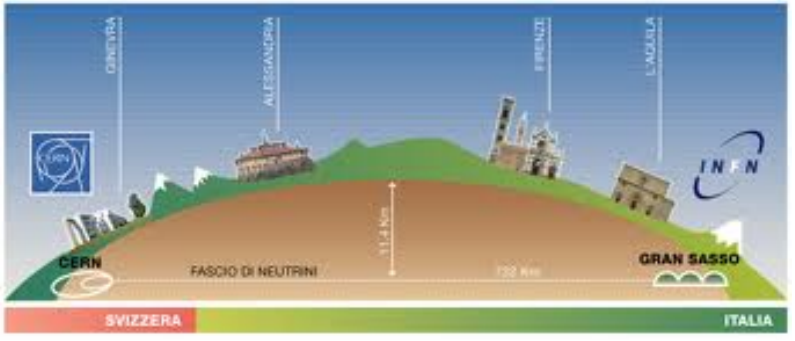
Quantum Mechanics

A short-lived puzzle (2011-12)





Superluminal neutrinos ?

The neutrinos do not travel faster than light

$\Uparrow$

Relativity

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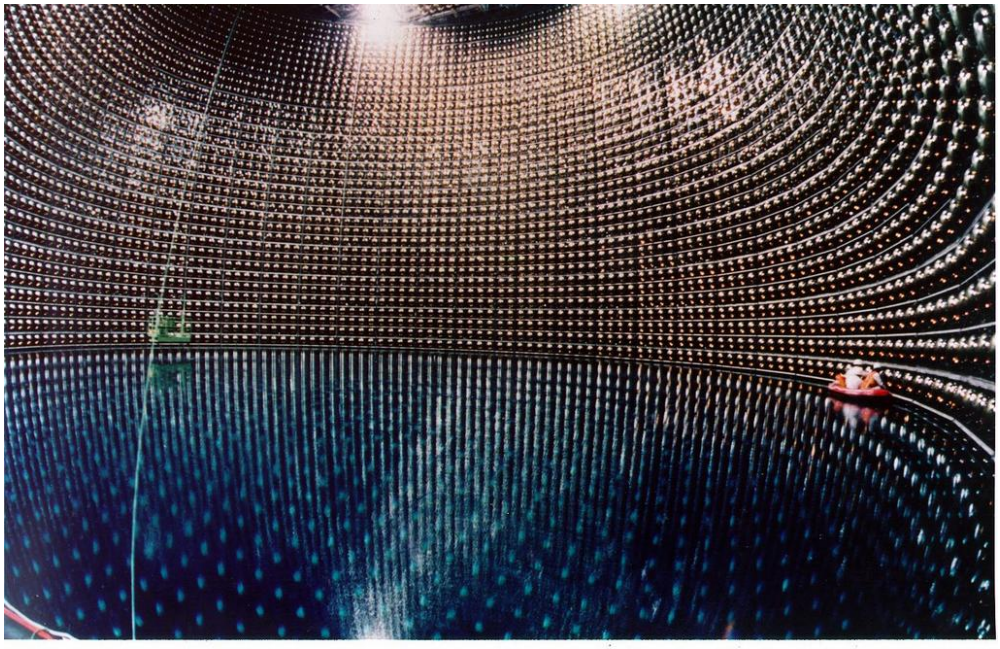
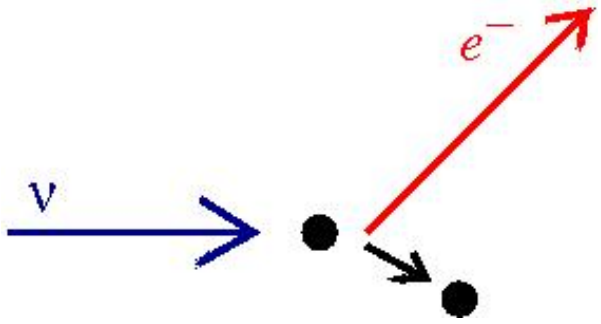
Bigger and better detectors needed

Superkamiokande: 50 kiloton

50 kiloton water = 50 000 000 litres



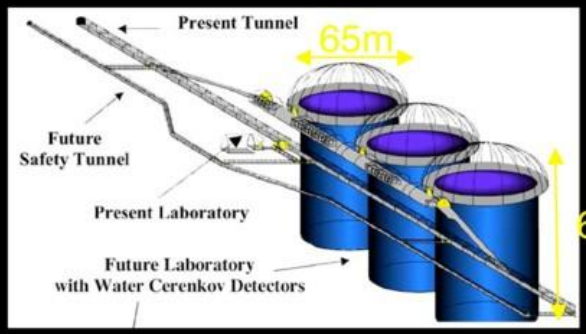


Observes about 5-10 neutrinos per day

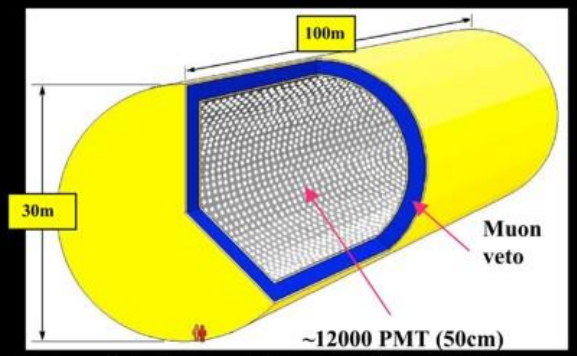
Bigger and better: Megaton detectors

1 Megaton water = 1 000 000 000 litres

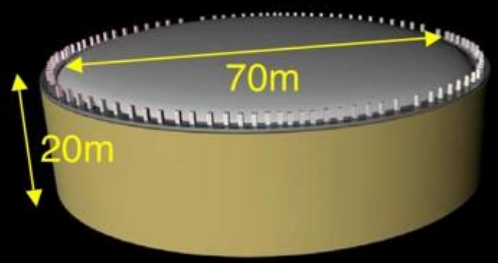
- Three types of large multi-purpose underground detectors with astrophysical program



Water Cherenkov (≈0.5 → 1 Mton)
MEMPHYS



Liquid Scintillator (→ 50 kton)
LENA

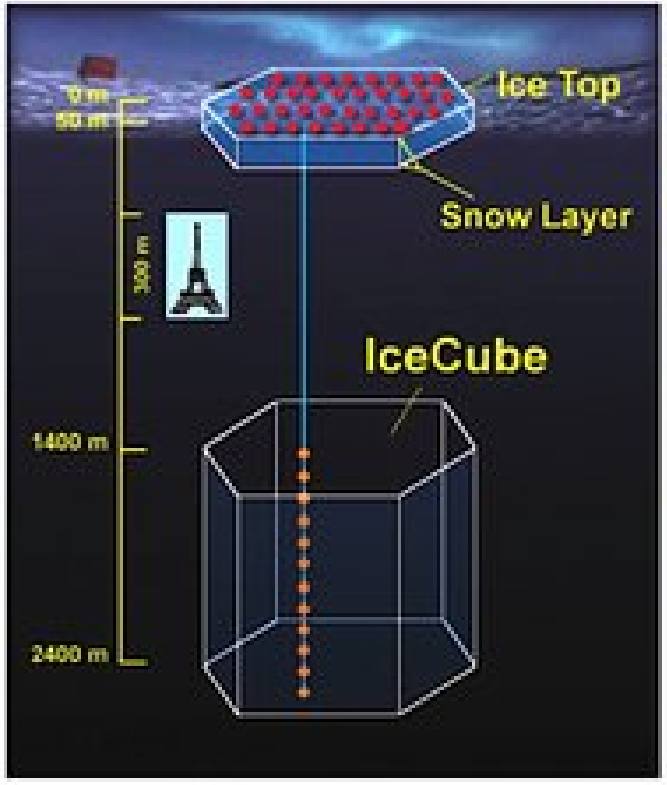


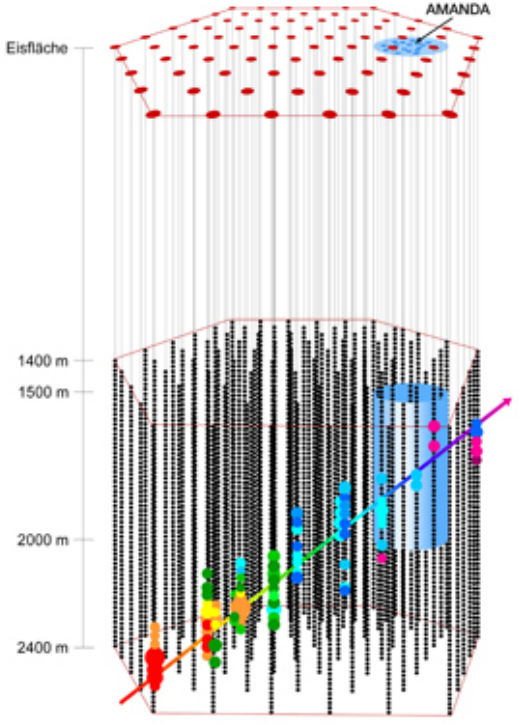
Liquid Argon (≈10→100 kton)
GLACIER

- R&D continues...
- Have to locate deep underground to remove cosmic ray background

Below the antarctic ice: Gigaton IceCube

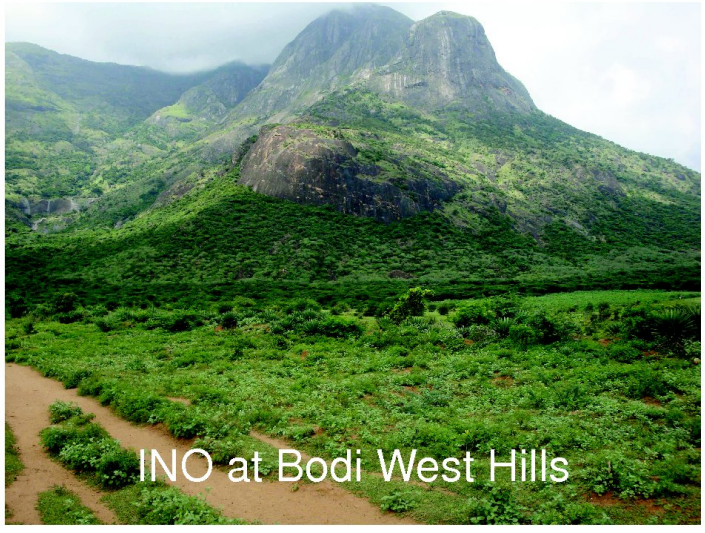
1 gigaton water = 1 000 000 000 000 litres

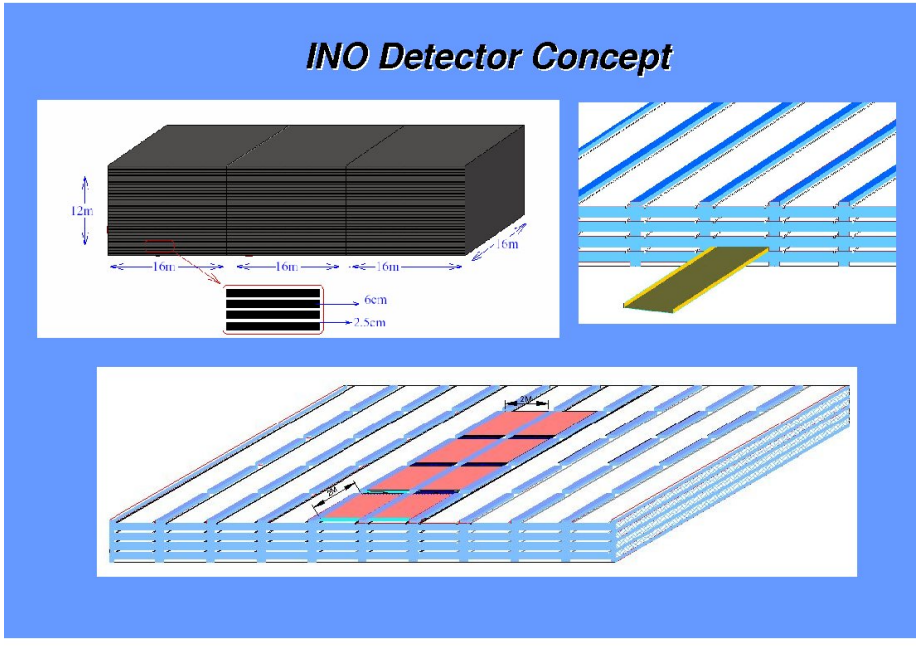




Only look at “upward-going” neutrinos
to remove cosmic ray background

Coming soon inside a mountain near you: INO





India-based Neutrino Observatory

- Under a mountain, inside a tunnel (Bodi Hills, TN)
- 1 km rock coverage from all sides
- 50 kiloton of magnetized iron (50 000 000 kg)
- $\gtrsim$ 25 years: a lifelong project

What do I take back from this talk ?

Neutrinos are everywhere, a wide energy range

They are essential for our existence

They tend to pose interesting puzzles

Their detection needs LARGE detectors and a LOT of patience

They may provide clues to many fundamental questions:
What are we made of ? Where do we come from ?

The actual nature of neutrinos is still unknown $\Rightarrow$
A very active field of research

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