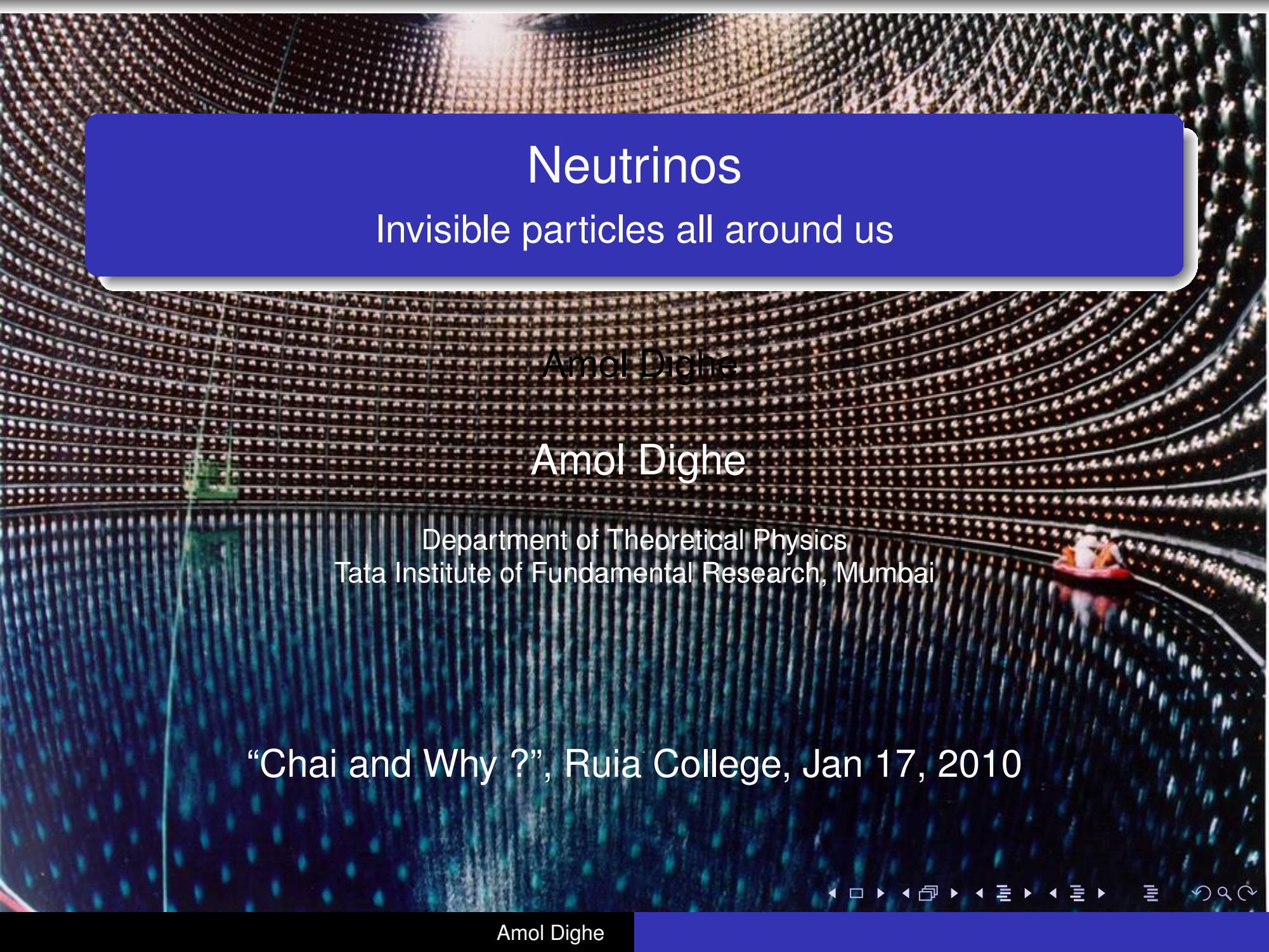


Neutrinos

Invisible particles all around us

Amol Dighe

Amol Dighe

Department of Theoretical Physics
Tata Institute of Fundamental Research, Mumbai

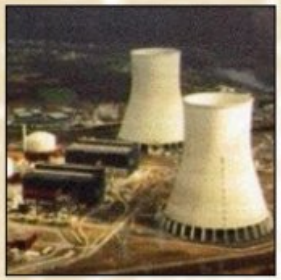
"Chai and Why ?", Ruia College, Jan 17, 2010

Neutrinos everywhere

Where do Neutrinos Appear in Nature?

✓ Earth Crust (Natural Radioactivity)

Sun ✓



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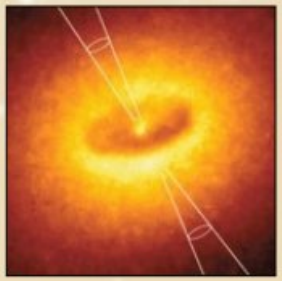
Supernovae (Stellar Collapse) SN 1987A ✓

✓ Particle Accelerators

Cosmic Big Bang (Today 330 ν/cm^3) Indirect Evidence



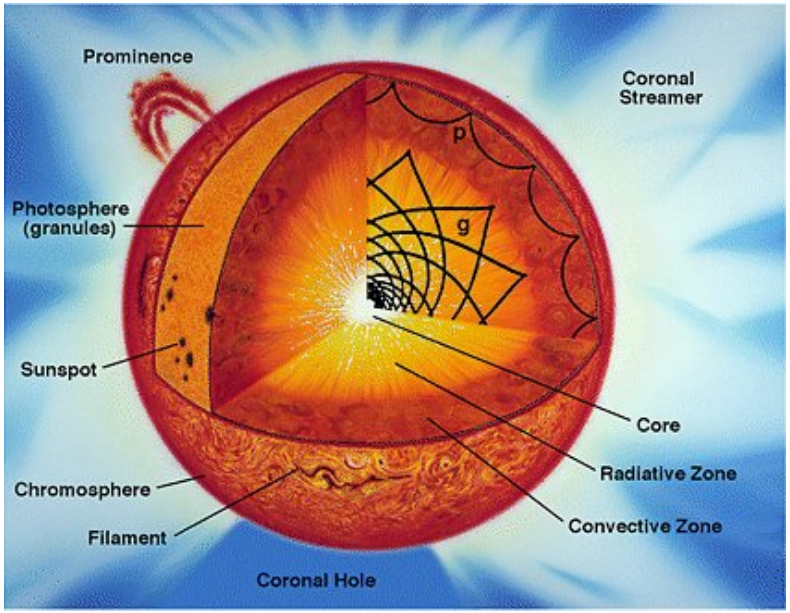
✓ Earth Atmosphere (Cosmic Rays)

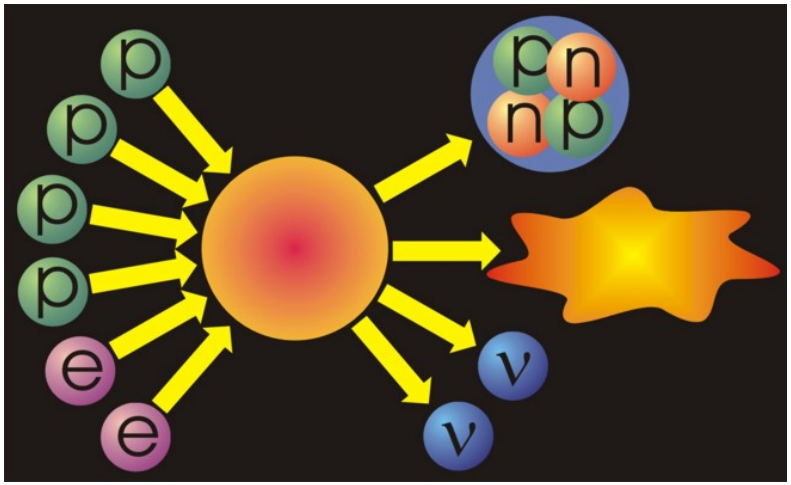
Astrophysical Accelerators Soon ?

Georg Raffelt, Max-Planck-Institut für Physik, München, Germany

Neutrino Physics & Astrophysics, 17-21 Sept 2008, Beijing, China

How does the sun shine ?





- Nuclear fusion reactions: mainly

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

- Neutrinos needed to conserve energy, momentum, angular momentum

Neutrinos essential for the Sun to shine !!

Neutrinos from the Sun

A very very large flux

About a trillion through the palm per second

One trillion = 1 000 000 000 000

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 ?

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Three questions, the same answer

- Why did the *roti* char ?
- Why did the fallen leaves rot ?
- Why could the horse not run ?

Because they were not moved !

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- Why could the horse not run ?

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Three questions about neutrinos

Pauli Dirac

- Why do we not notice neutrinos ?
- Why does the neutrino flow not change 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

Invisible particles

Do not interact with light

Stopping radiation with lead shielding

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

Answers to the three questions

- Neutrinos pass through our bodies without interacting
- Neutrinos pass through the Earth without interacting
- Neutrinos pass through the Sun without interacting

How do we see the neutrinos then ?

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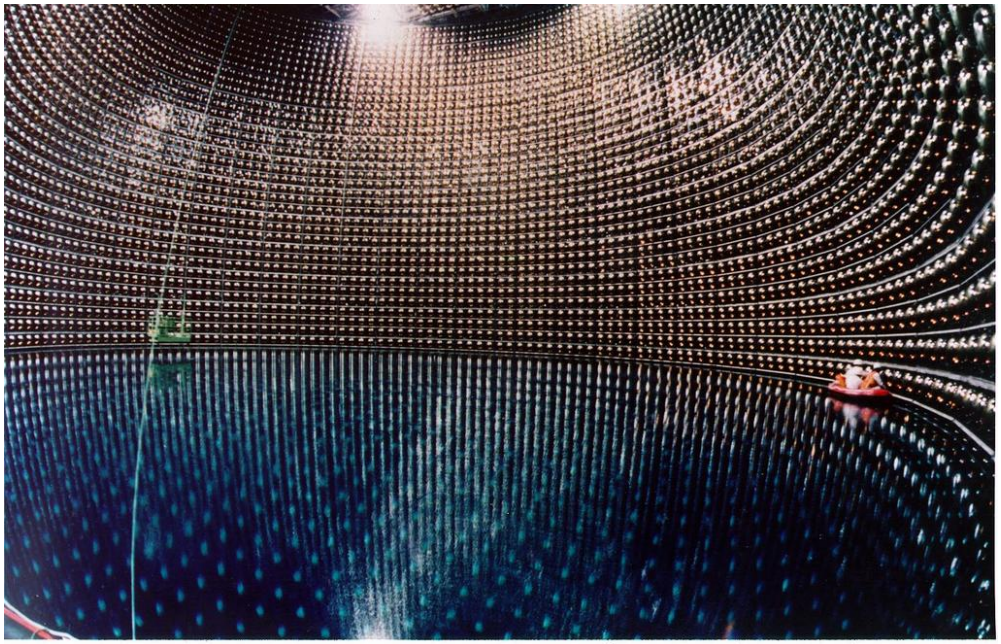
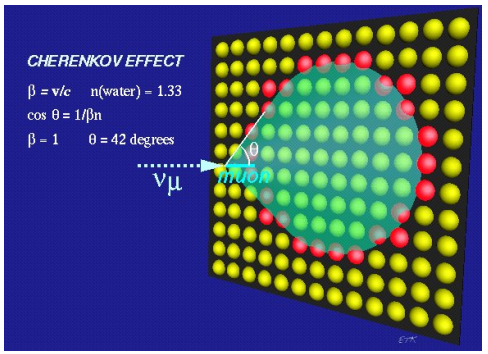
How do we see the neutrinos then ?

SuperKamiokande: 40 000 000 litres of water





Cherenkov radiation

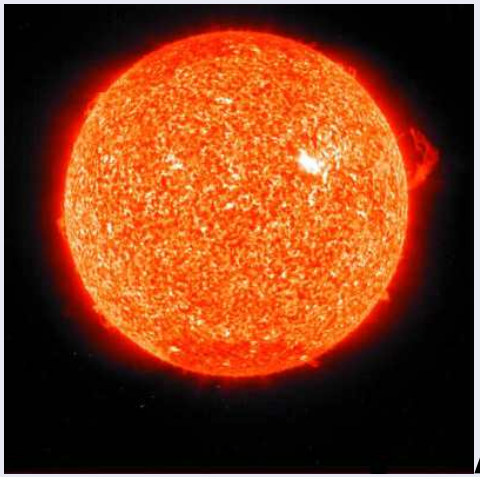
Recipe for observing neutrinos

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

SuperKamiokande observes about 5-10 neutrinos per day

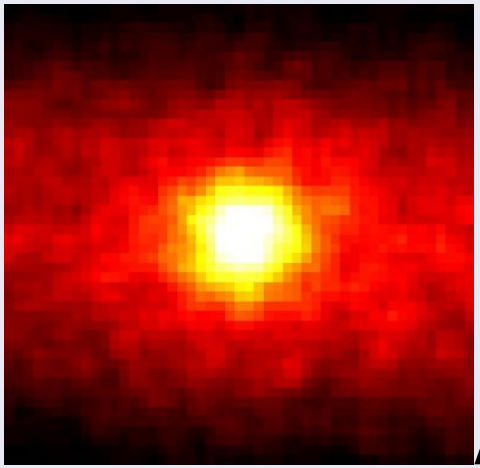
How does the Sun look in neutrinos ?

Sun in photons: a few million years ago



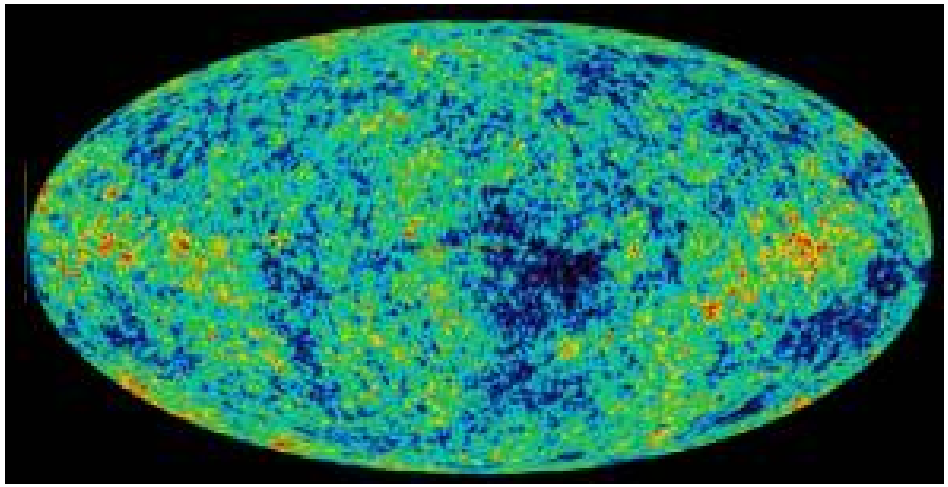
Angular size $\sim 1^\circ$

Sun in neutrinos: 8 minutes ago



Angular size $\sim 20^\circ$

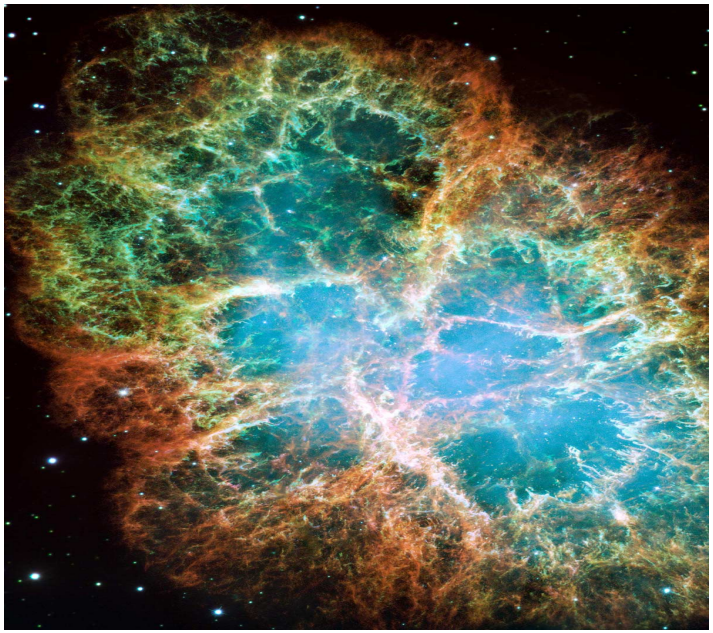
The second most abundant particles in the universe



- Cosmic microwave background: 400 photons/ cm^3
- Cosmic neutrino background: 300 neutrinos / cm^3

Even empty space between galaxies is full of neutrinos !

Supernova explosions



Crab nebula: SN in 1054

SN1987A

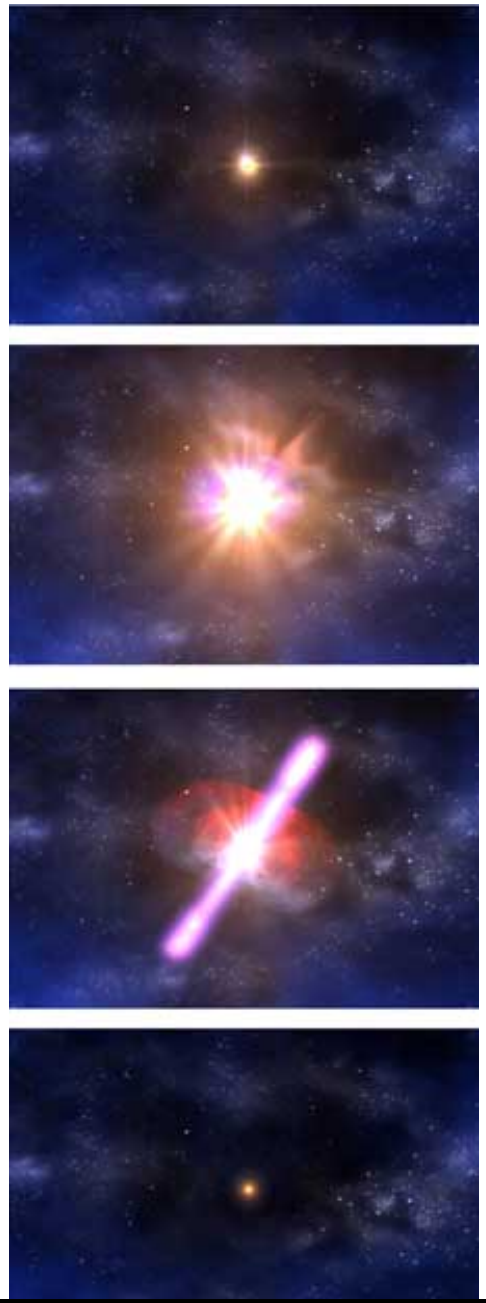
Neutrinos make supernovae explode

Neutrinos push the shock wave and blow up the star !

Early warning of supernova explosions

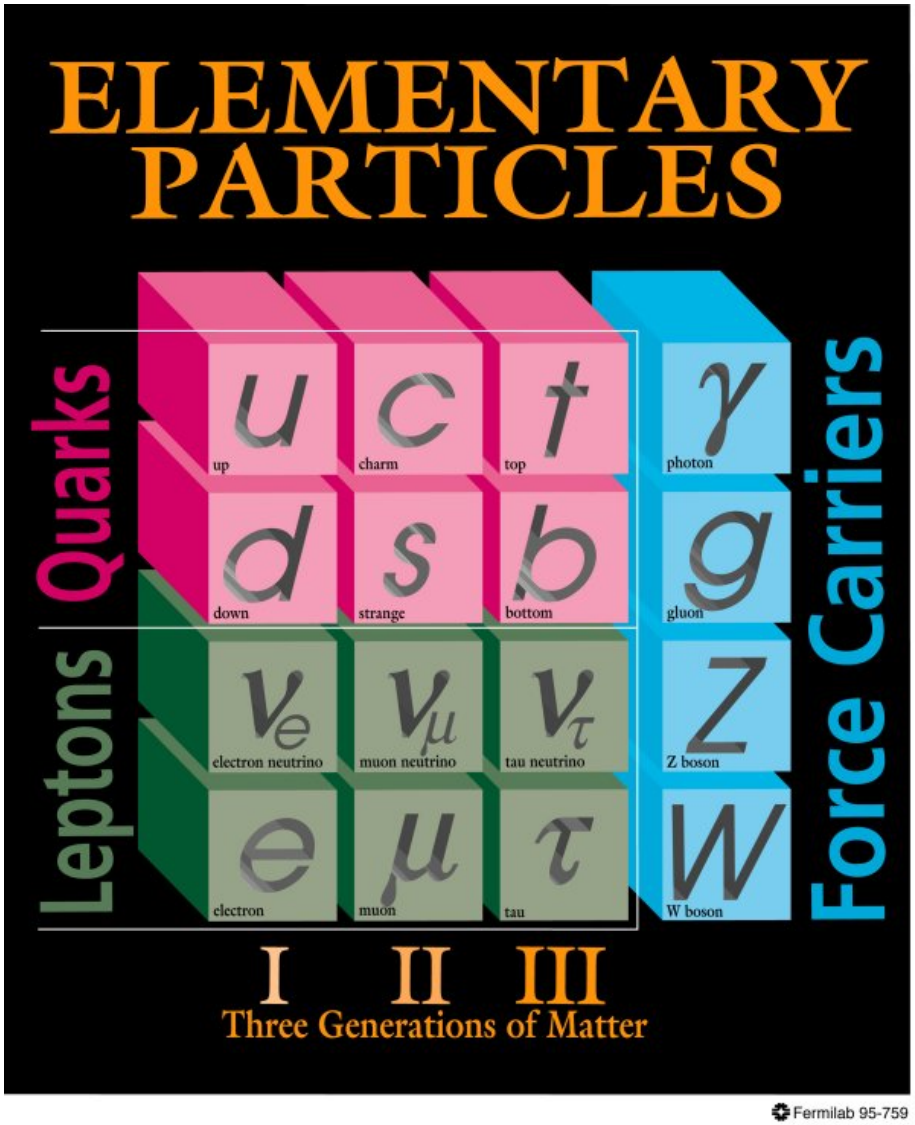
Neutrinos arrive $\sim$ 10 hours before light !

Gamma ray bursts



- Extremely energetic events
- Exact nature still unknown
- Neutrinos may provide a clue
- Neutrinos not observed yet

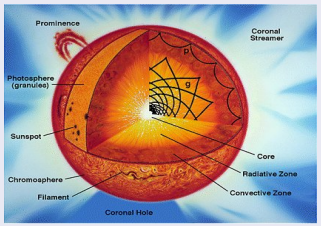
The Standard Model of Particle Physics



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

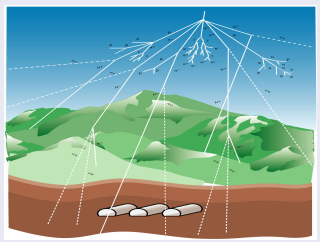
Recent excitement in neutrino physics

Solar neutrino puzzle: 1960s – 2002



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

Atmospheric neutrino puzzle: 1980s – 1998



- Half the ν_μ lost in the Earth!
- But no ν_e are affected !
- Possible solution: ν_μ convert to ν_τ

Reactor neutrino experiments

- No $\bar{\nu}_e$ are lost

Three questions, the same answer

ν conference participants

- Why did solar ν_e become ν_μ/ν_τ ?
- Why did atmospheric ν_μ become ν_τ ?
- Why did the $\bar{\nu}_e$ from the reactors not convert ?

Because neutrinos have different masses and they oscillate !

Three questions, the same answer

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Because neutrinos have different masses and they oscillate !

What more do we want to know about neutrinos ?

Are neutrinos their own antiparticles ?

Neutrino = Antineutrino ?

Where can we see with neutrinos ?

Neutrinos can reach where light cannot !

Did neutrinos create the matter-antimatter asymmetry ?

If yes, they are responsible for our existence !

Ongoing activities in neutrino physics

Solar neutrinos

Measuring the energy of the sun in neutrinos

Long baseline experiments

- "Manufacture" a lot of neutrinos
- See how many of them survive after travelling the "long baseline" ($\sim$ 1000–10000 km)

Astrophysical observations

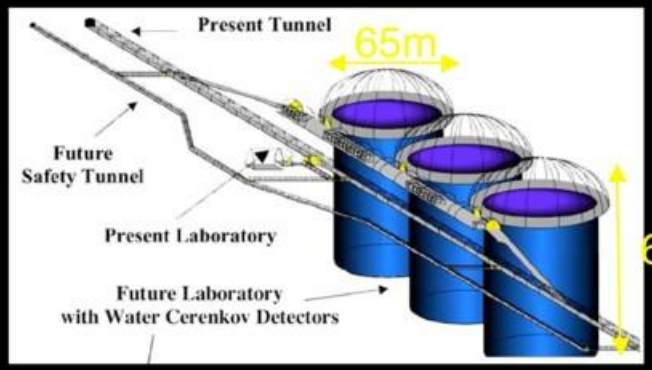
Keep an eye on supernovae, AGN etc.

Need bigger and better detectors !

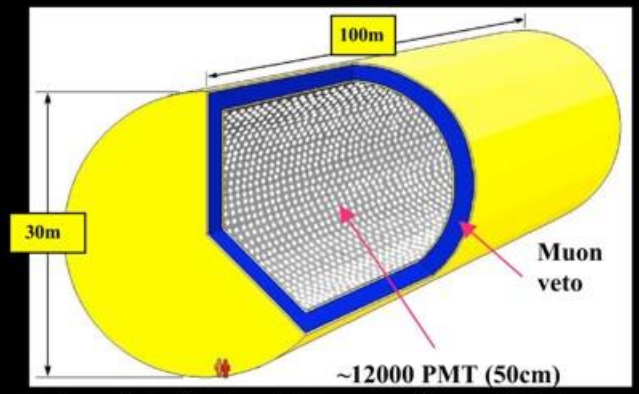
Bigger and better: Megaton detectors

1 Megaton water = 1 000 000 000 litres

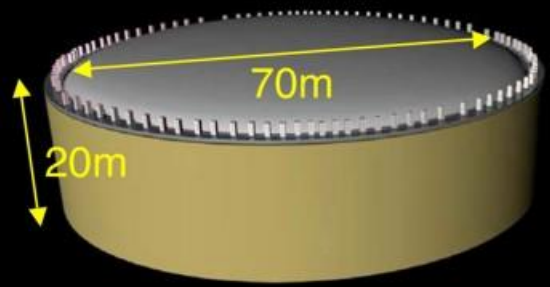
- Three types of large multi-purpose underground detectors with astrophysical program



Water Cherenkov (≈0.5 → 1 Mton)
MEMPHYS



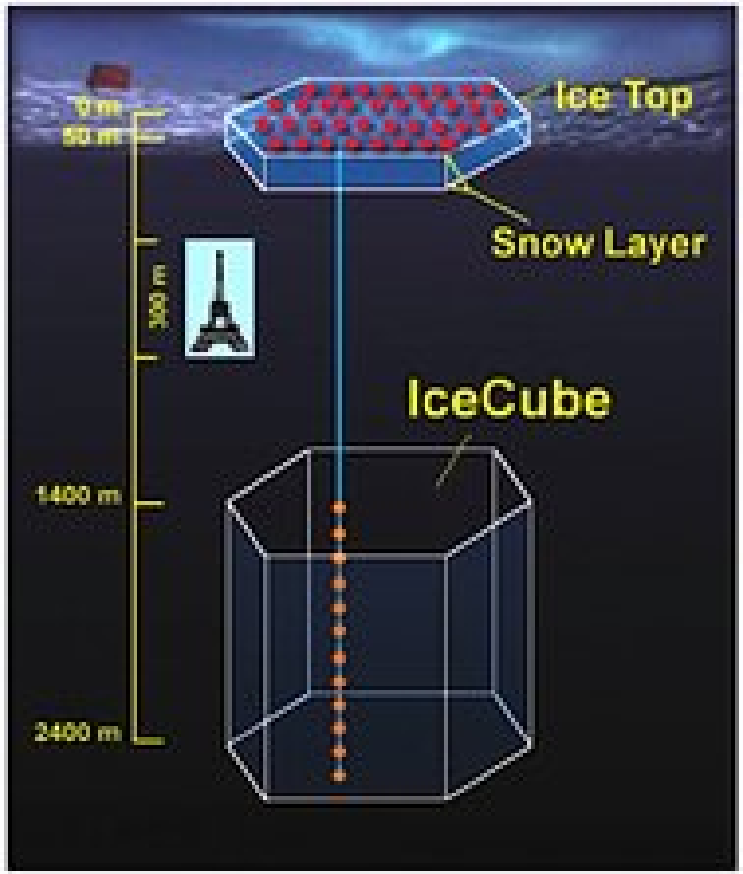
Liquid Scintillator (→ 50 kton)
LENA

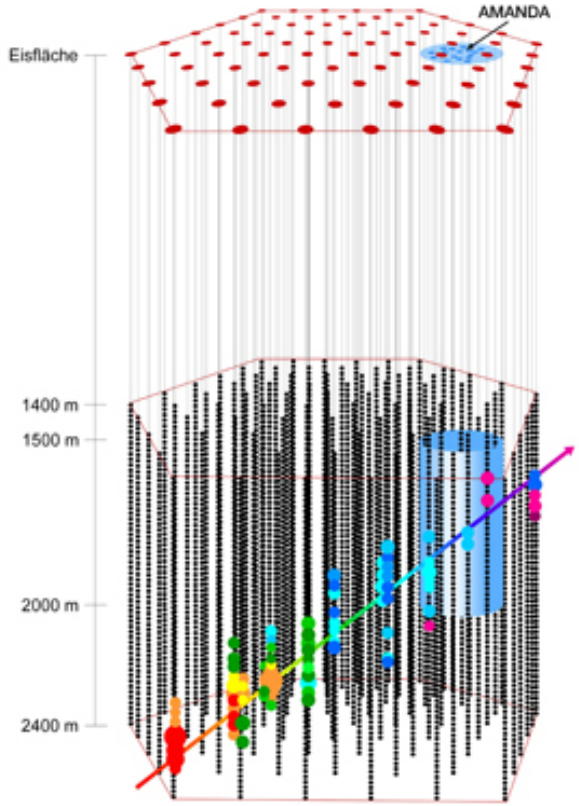


Liquid Argon (≈10→100 kton)
GLACIER

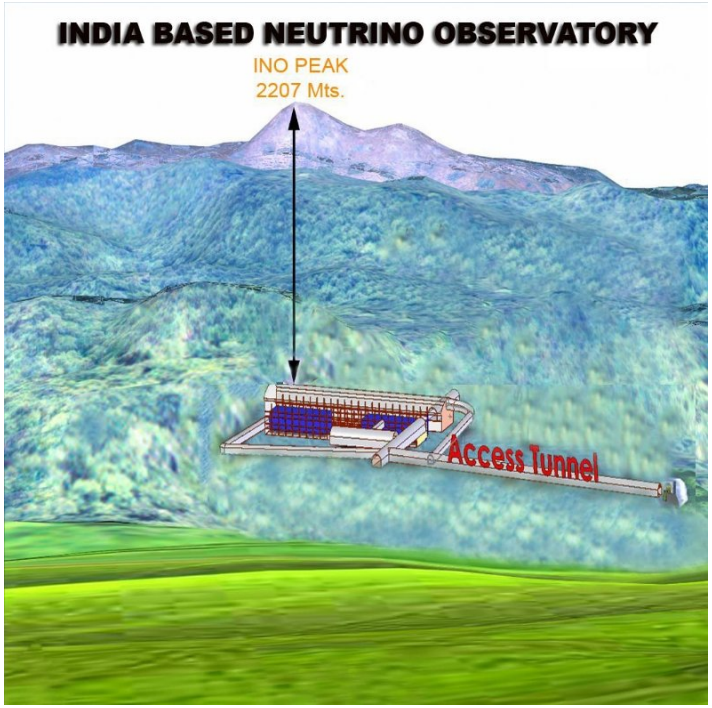
Below the antarctic ice: Gigaton IceCube

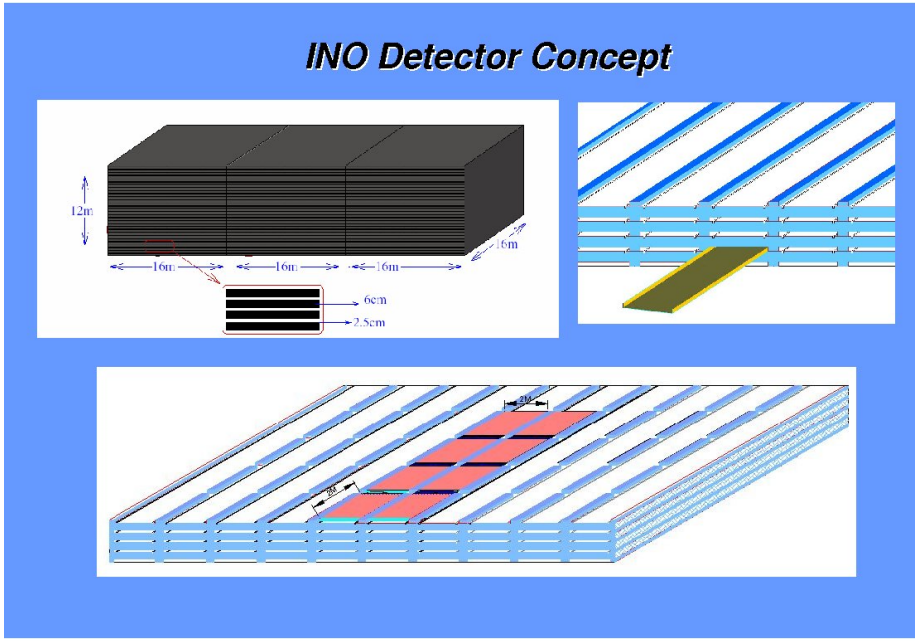
1 gigaton water = 1 000 000 000 000 litres





Coming soon inside a mountain near you: INO





India-based Neutrino Observatory

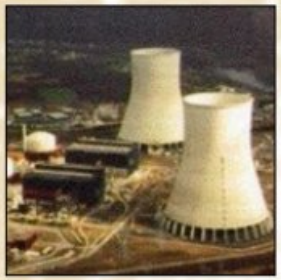
- Under a mountain, inside a tunnel
- 1 km rock coverage from all sides
- 50 kiloton of magnetized iron (50 000 000 kg)
- $\gtrsim$ 25 years: a lifelong project

Neutrinos everywhere

Where do Neutrinos Appear in Nature?

✓ Earth Crust (Natural Radioactivity)

Sun ✓



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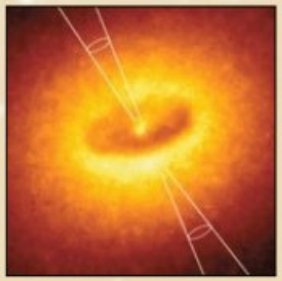

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