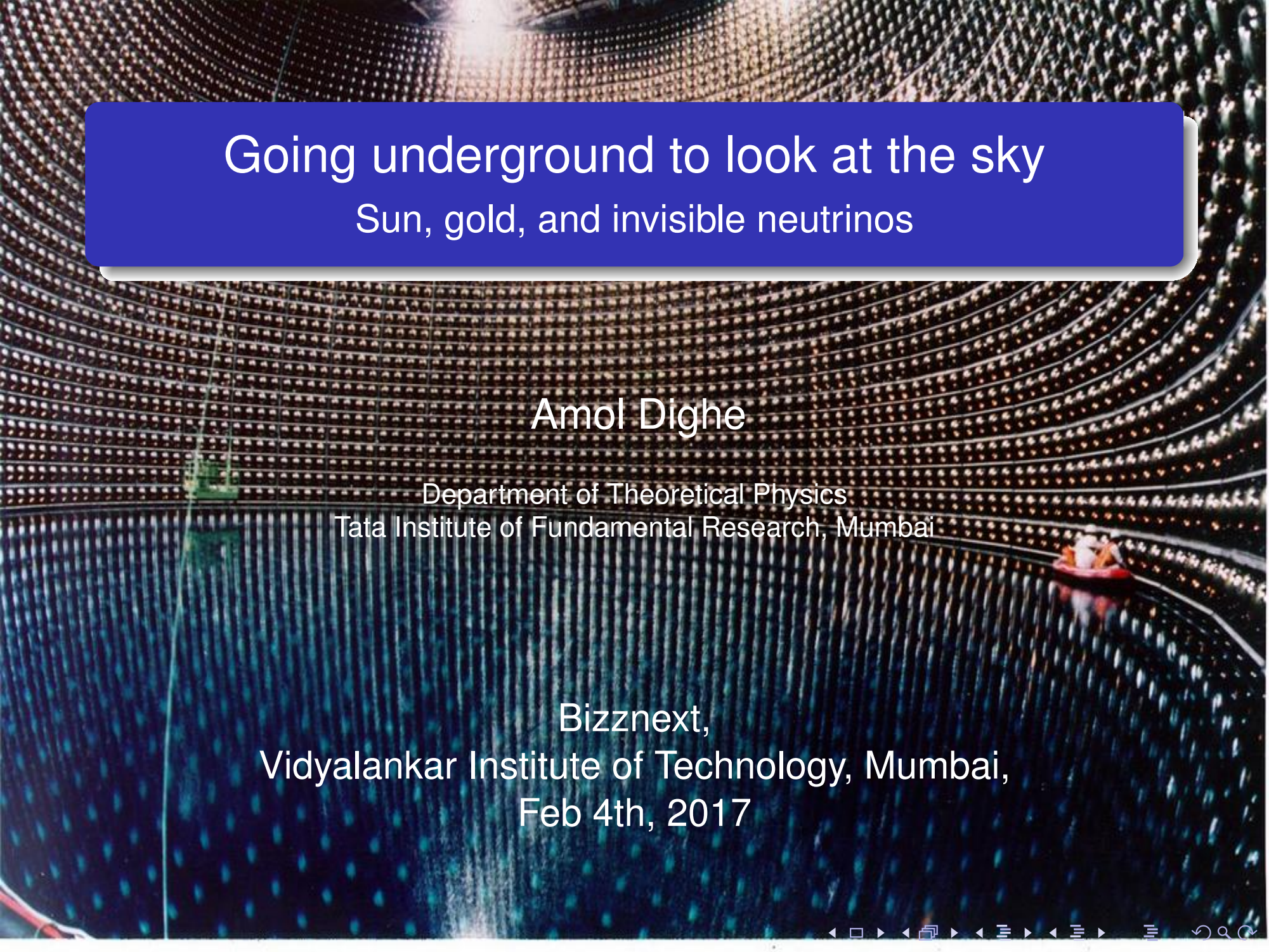

Going underground to look at the sky

Sun, gold, and invisible neutrinos

Amol Dighe

Department of Theoretical Physics
Tata Institute of Fundamental Research, Mumbai

Bizznext,
Vidyalankar Institute of Technology, Mumbai,
Feb 4th, 2017

The search for invisible neutrinos

1. Why look for neutrinos ?
   - How does the Sun shine ?
   - Where did all the gold come from ?
   - What will we learn from neutrinos ?

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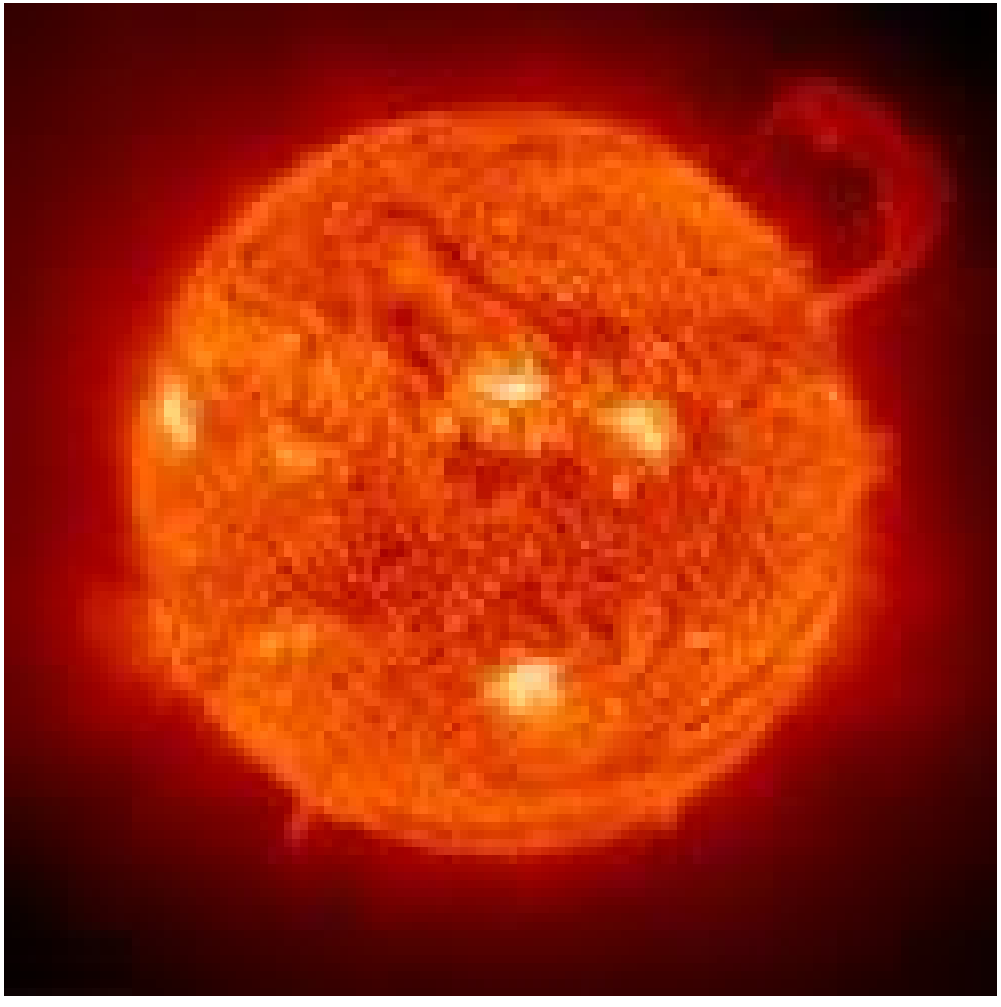
Burning ball of fire ?



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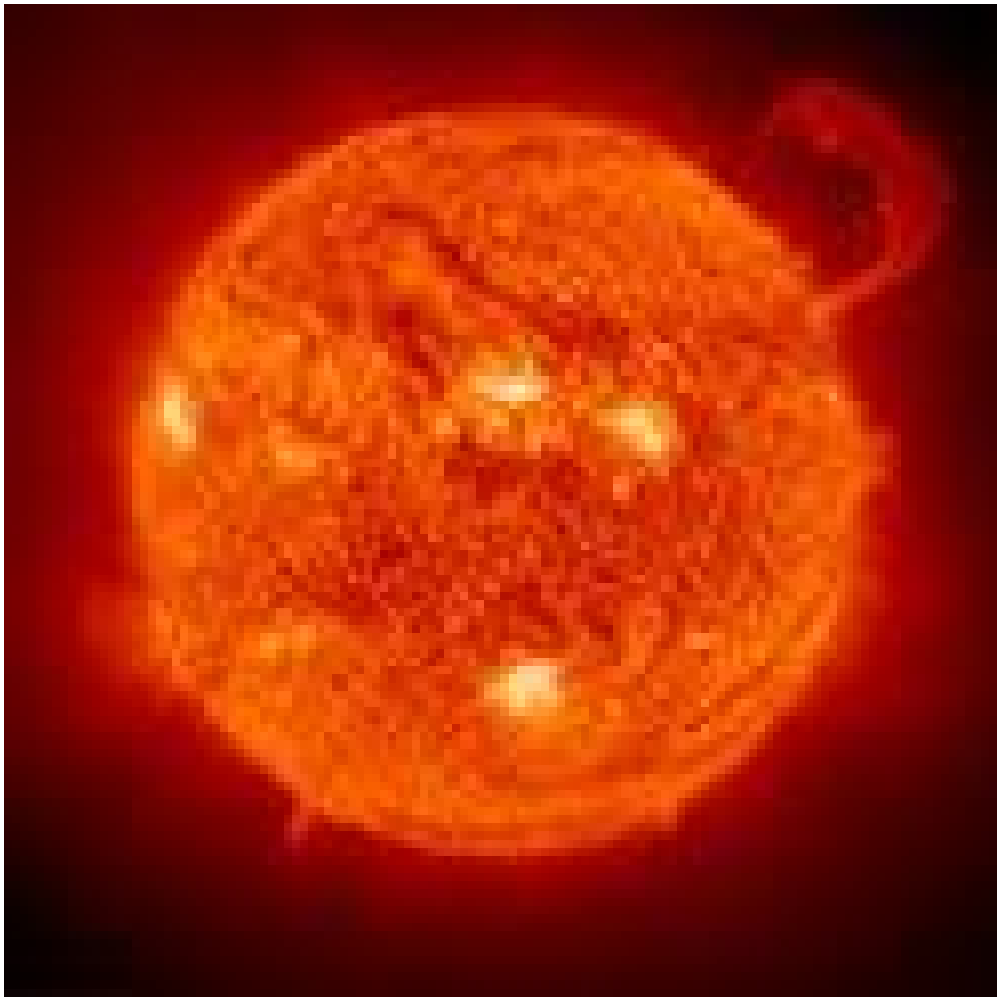
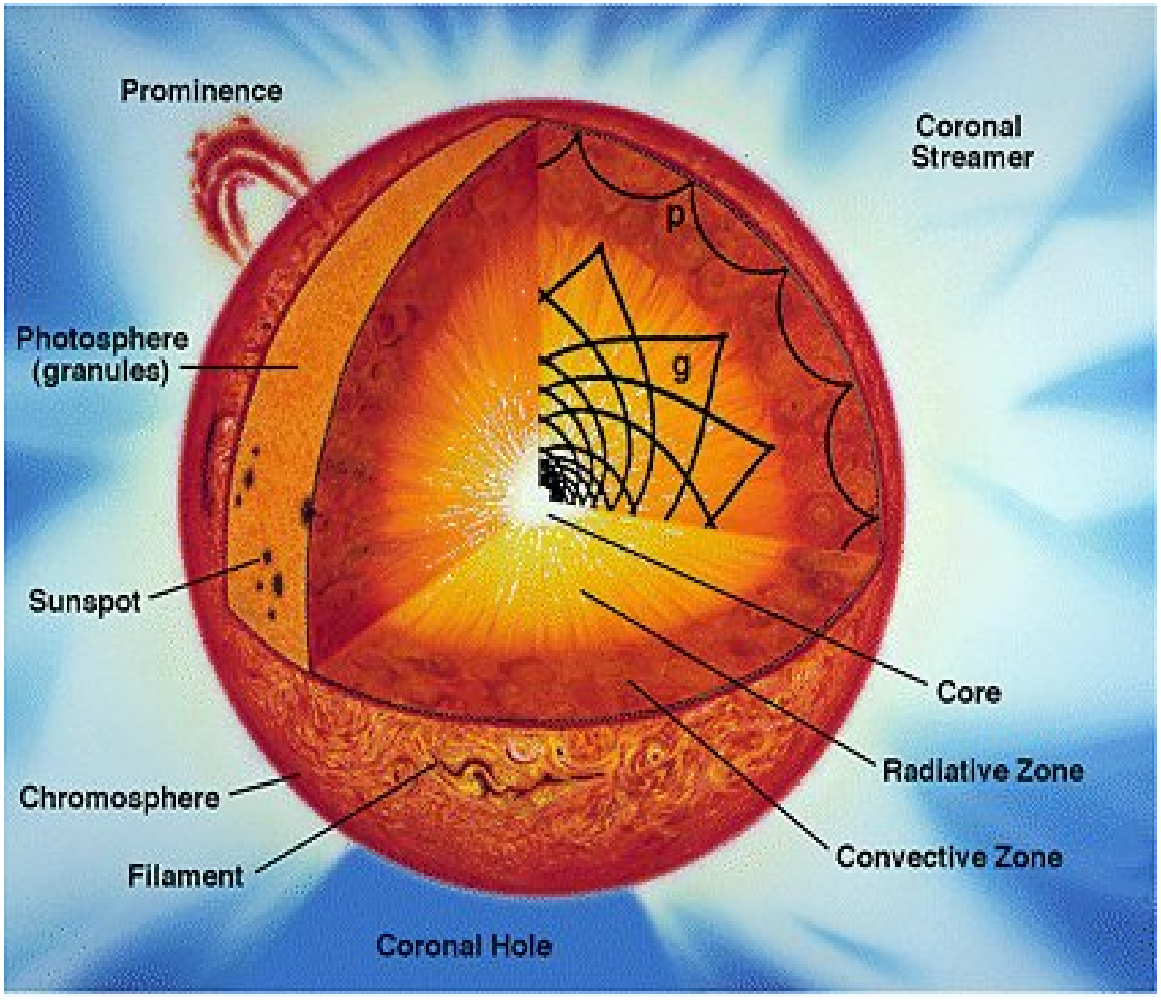


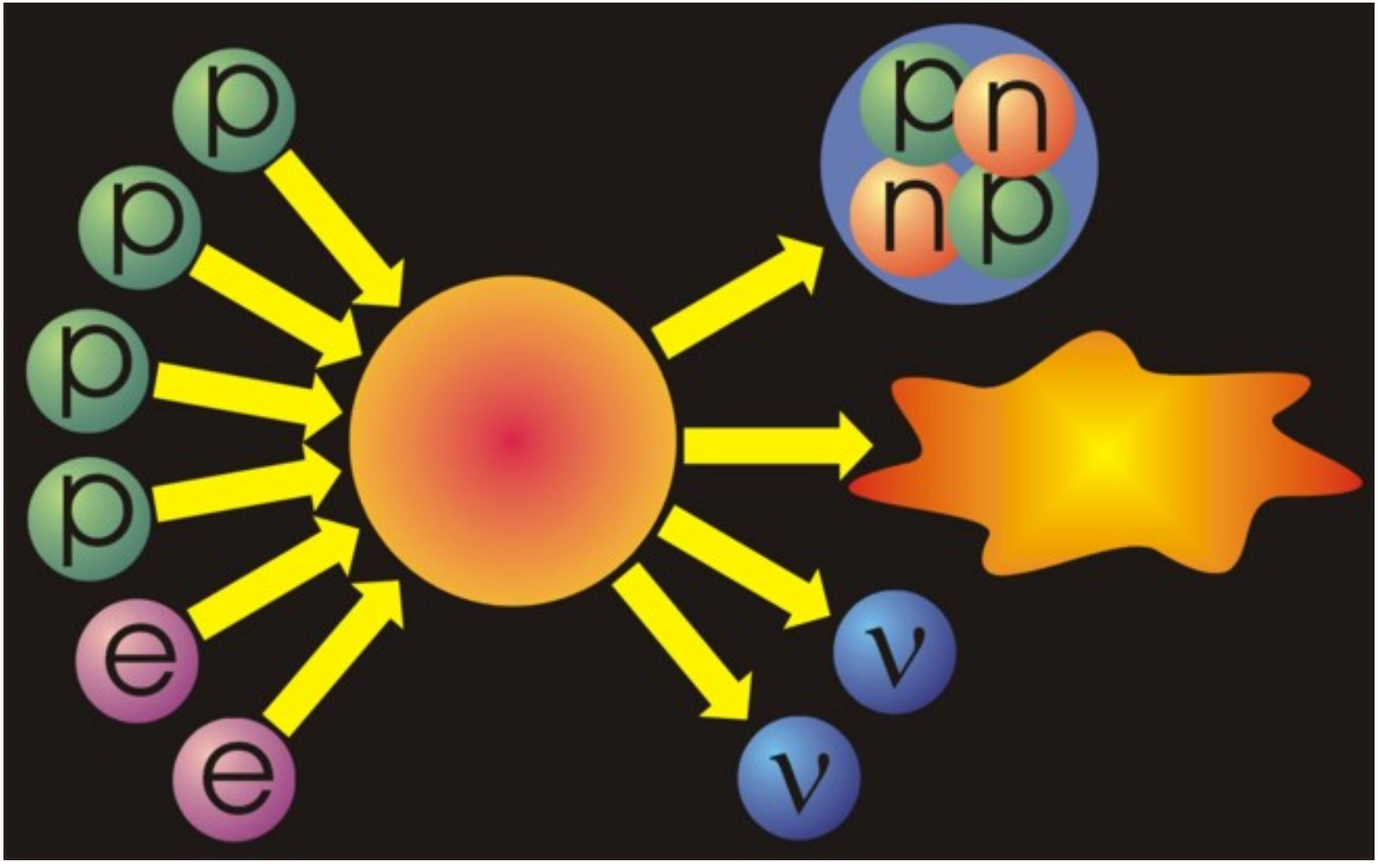
- Would have burnt out in a few thousand years
- But has been around for many more !!

The structure of the Sun



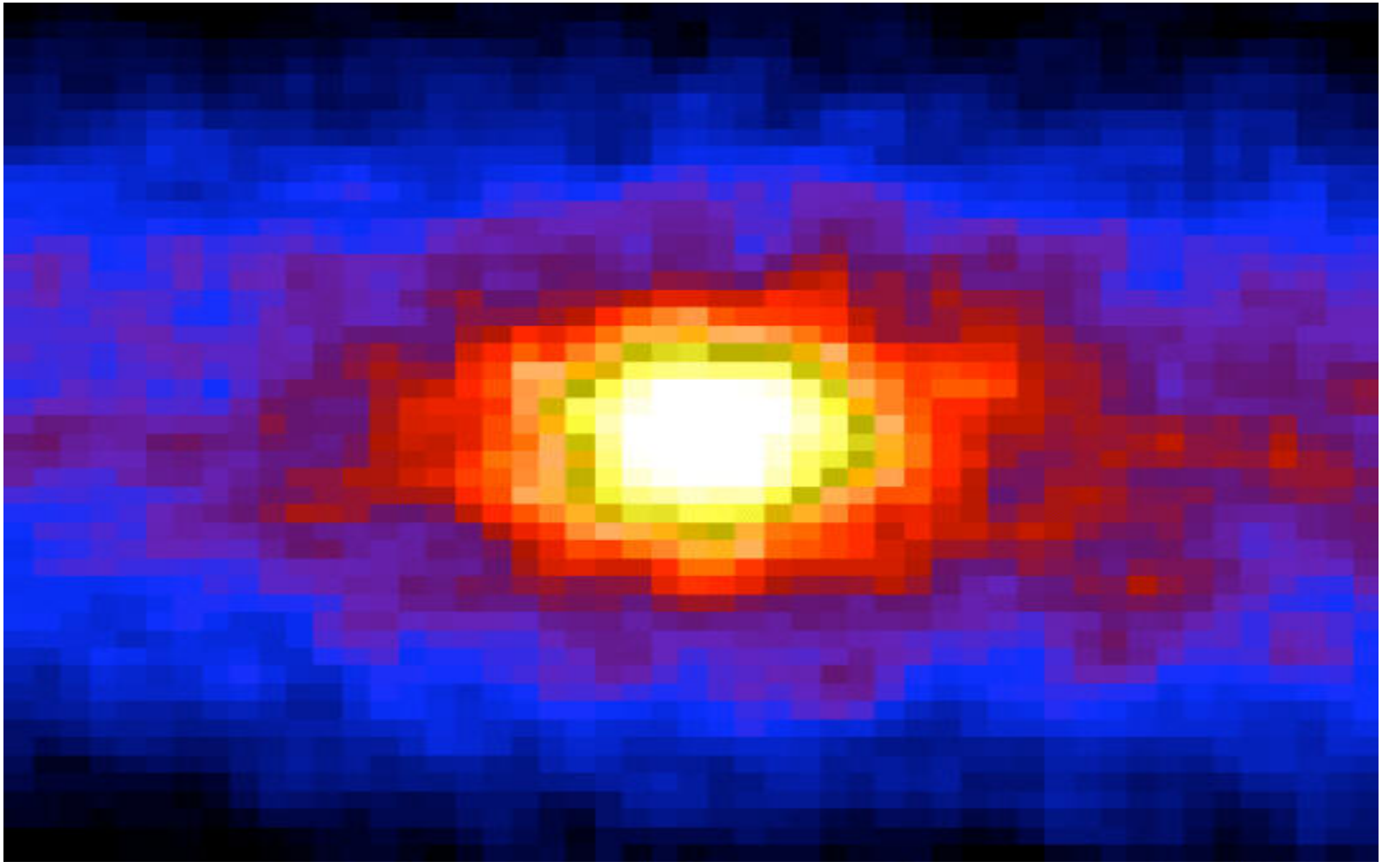
It is a nuclear reactor !

The nuclear reactions



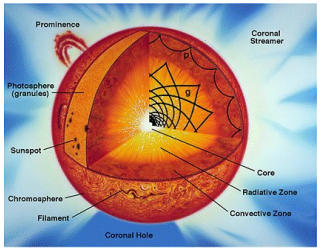
How do we know this ? Can we see some evidence ?

Neutrinos from the Sun: tiny point particles



- Can indeed see neutrinos from the Sun now !

Neutrinos from the Sun



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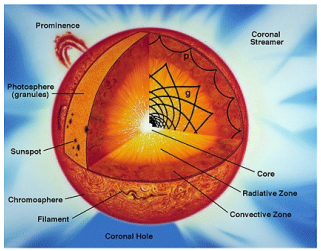

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About hundred trillion through our body per second

Hundred trillion = 100 000 000 000 000

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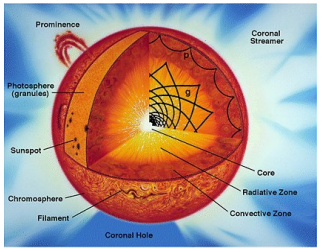

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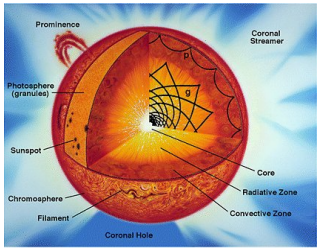

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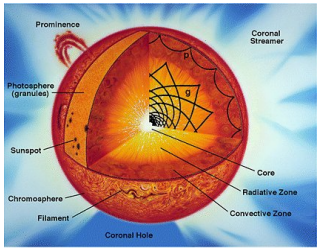

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Why do we not notice them ?

Three questions, the same answer

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

Three questions, the same answer

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

Because they were not moved !

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 ?

Three questions about neutrinos

Pauli Dirac

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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

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.... Neutrinos play a crucial role in the Sun shining !

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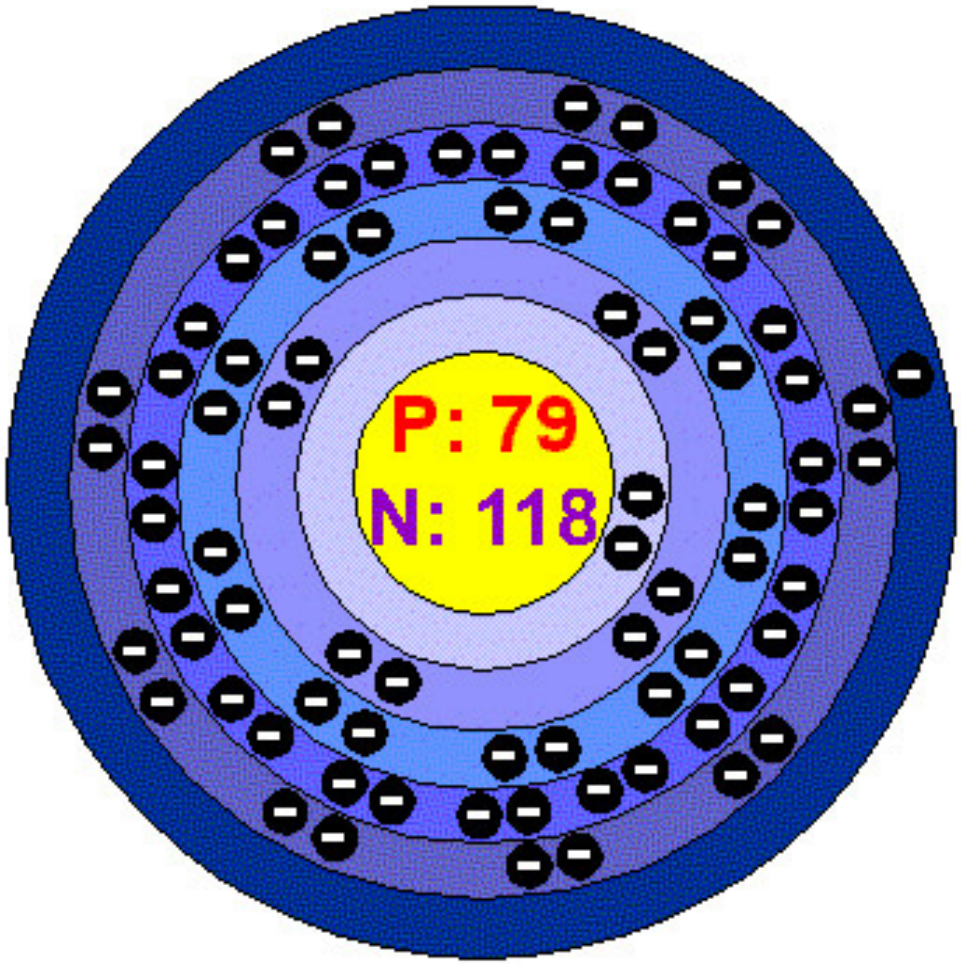
Many forms of gold: origin ?

The gold mine

But where did the gold in the mines come from ?

The essence of gold



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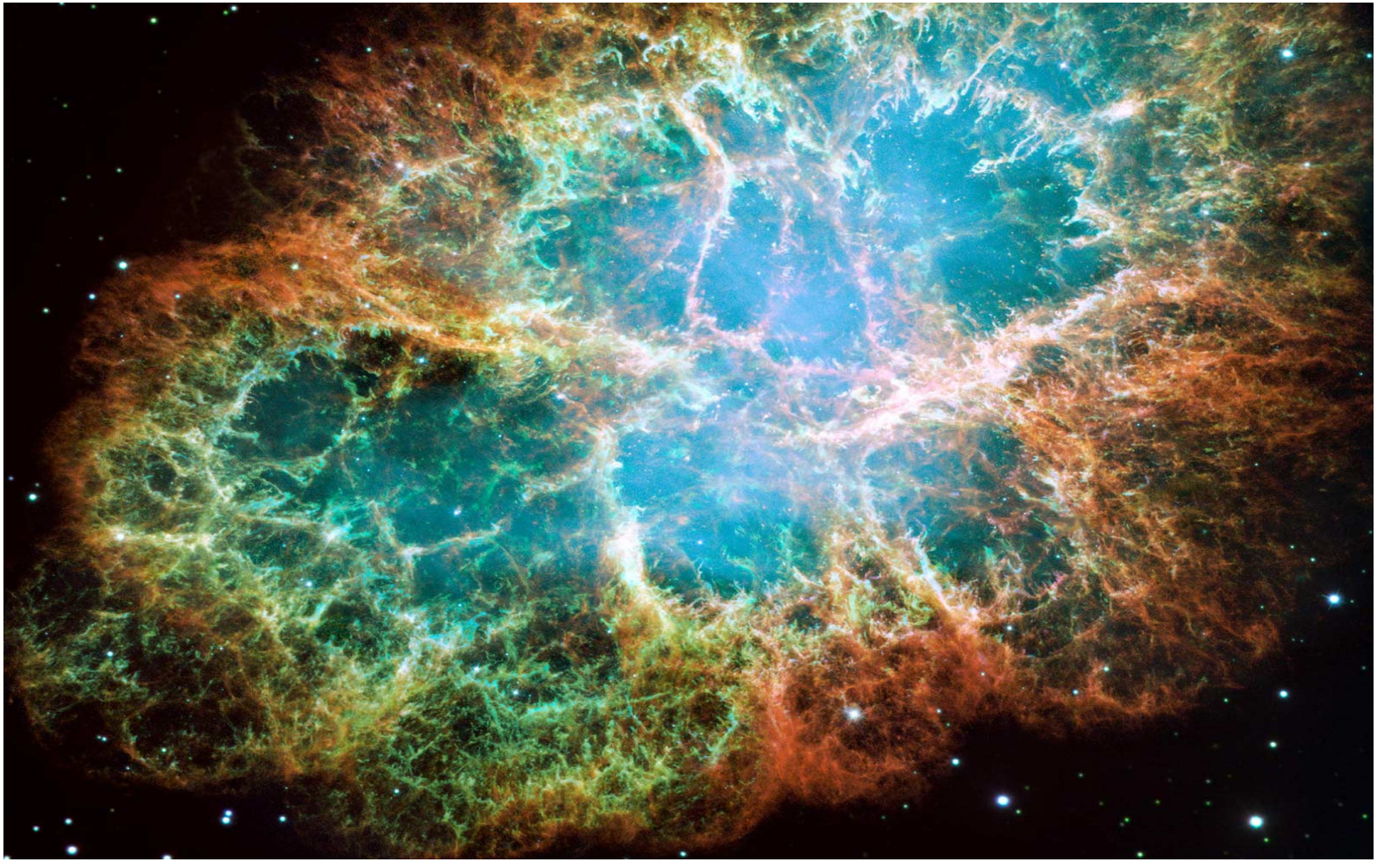
- Even the intense temperature and pressure inside stars cannot make elements heavier than iron (26 protons, 30 neutrons)
- Gold has 79 protons and 118 neutrons. How is this possible ?
- There is just one phenomenon we know in nature that can do this...

A supernova !



Crab nebula, Supernova seen exploding in 1054

So that's the story...

- Once upon a time, there was a big star, which exploded (supernova)
- The exploded material travelled far and wide in the galaxies
- It is from this material that the solar system was made.
- We are, literally, "Stardust"

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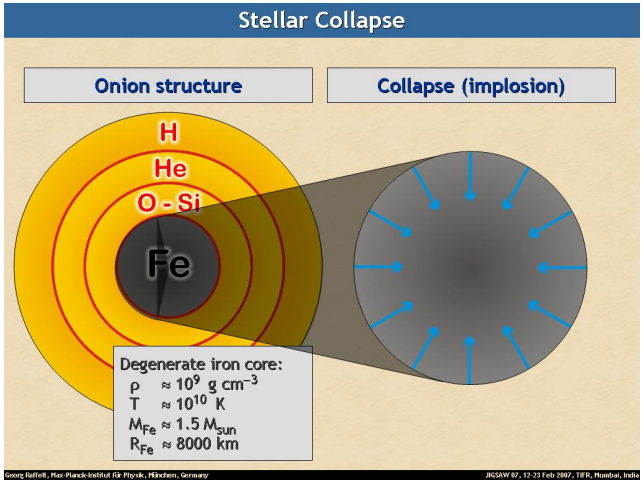
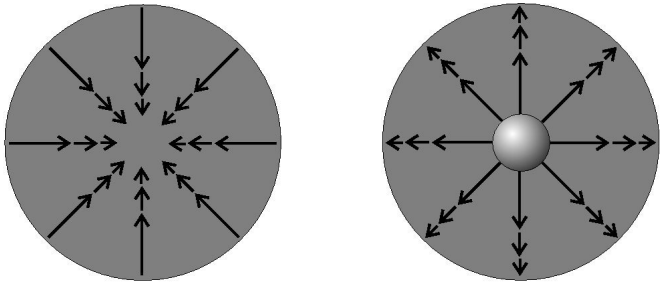
But, how does a supernova explode ?
(This is now a search to understand where we came from.)

Supernova: the death of a star

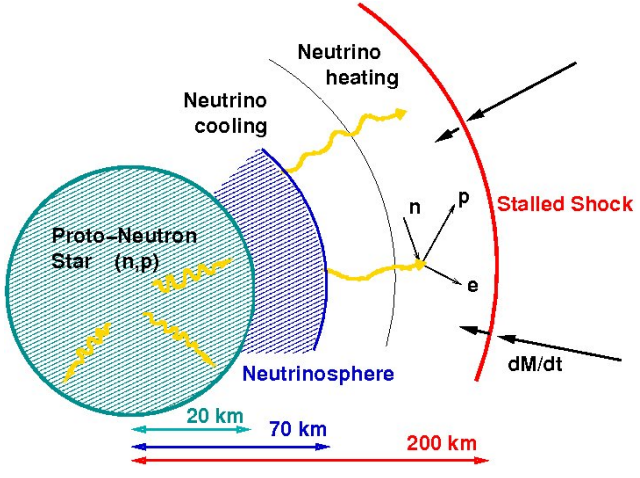
Gravity $\Rightarrow$



Strong nuclear force $\Rightarrow$



Weak nuclear force
(Neutrino push) $\Rightarrow$



Electromagnetism
(Hydrodynamics) $\Rightarrow$

(Crab nebula, SN seen in 1054)

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A view from the Hubble telescope

The world without neutrinos

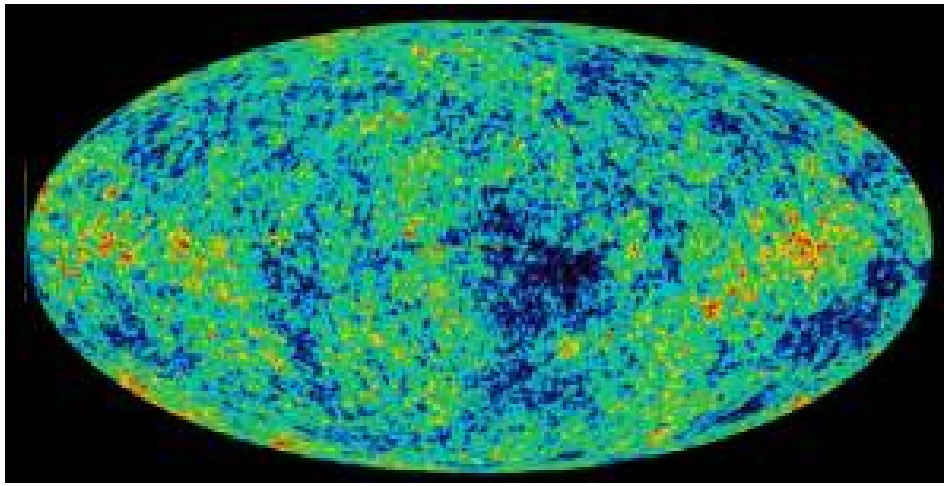
The world without neutrinos

Role of neutrinos in creating atoms

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

The second-most abundant particles in the universe

Even empty space between galaxies is full of light and neutrinos!



- Cosmic microwave background: 400 photons/ cm^3
  Temperature: $\sim$ 3 K
- Tell us about the universe when it was *only* 400,000 years old (Now it is $\sim$ 14 000 000 000 years old.)

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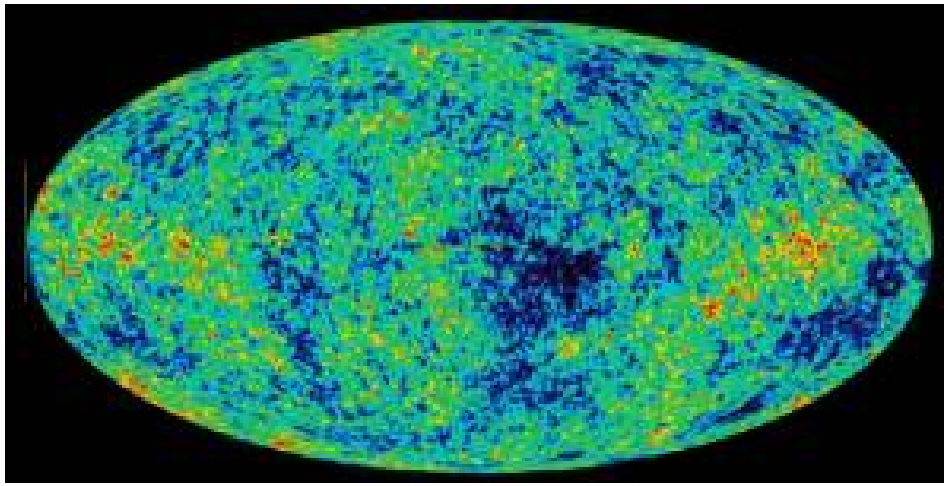


- Cosmic microwave background: 400 photons/ cm^3
  Temperature: $\sim$ 3 K
- Tell us about the universe when it was *only* 400,000 years old (Now it is $\sim$ 14 000 000 000 years old.)
- Cosmic neutrino background: 300 neutrinos / cm^3
  Temperature: $\sim$ 2 K
- Can tell us about the universe when it was 0.18 sec old !

Neutrinos as messengers

- No bending in magnetic fields $\Rightarrow$
  point back to the source
- Minimal obstruction / scattering $\Rightarrow$
  can arrive directly from regions from where light cannot come (inside the stars, behind the galaxy...)

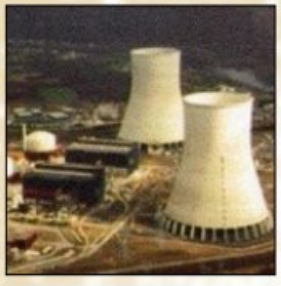
Neutrinos everywhere

Where do Neutrinos Appear in Nature?

- ✓ Earth Crust (Natural Radioactivity)

- Sun ✓

- ✓ Nuclear Reactors



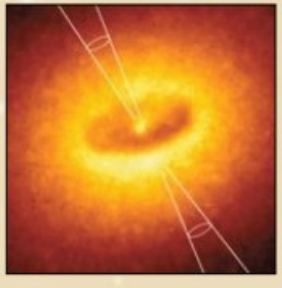
- Supernovae (Stellar Collapse) SN 1987A ✓

- ✓ Particle Accelerators

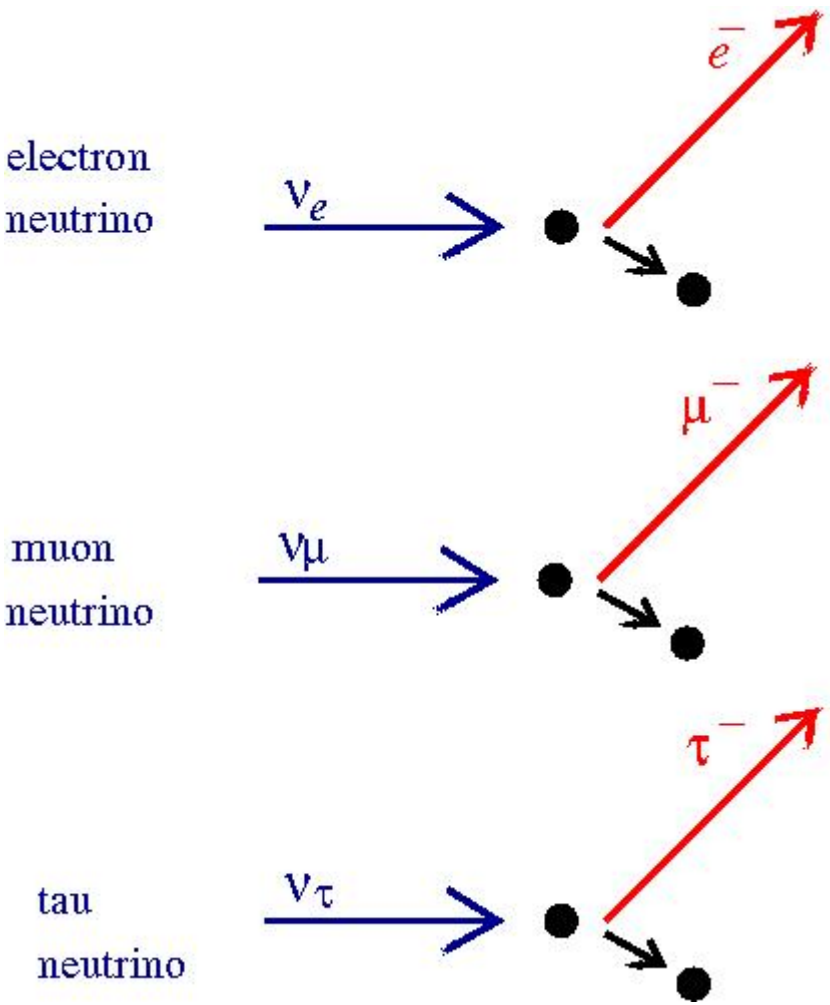
- Cosmic Big Bang (Today 330 ν/cm^3) Indirect Evidence

- ✓ Earth Atmosphere (Cosmic Rays)

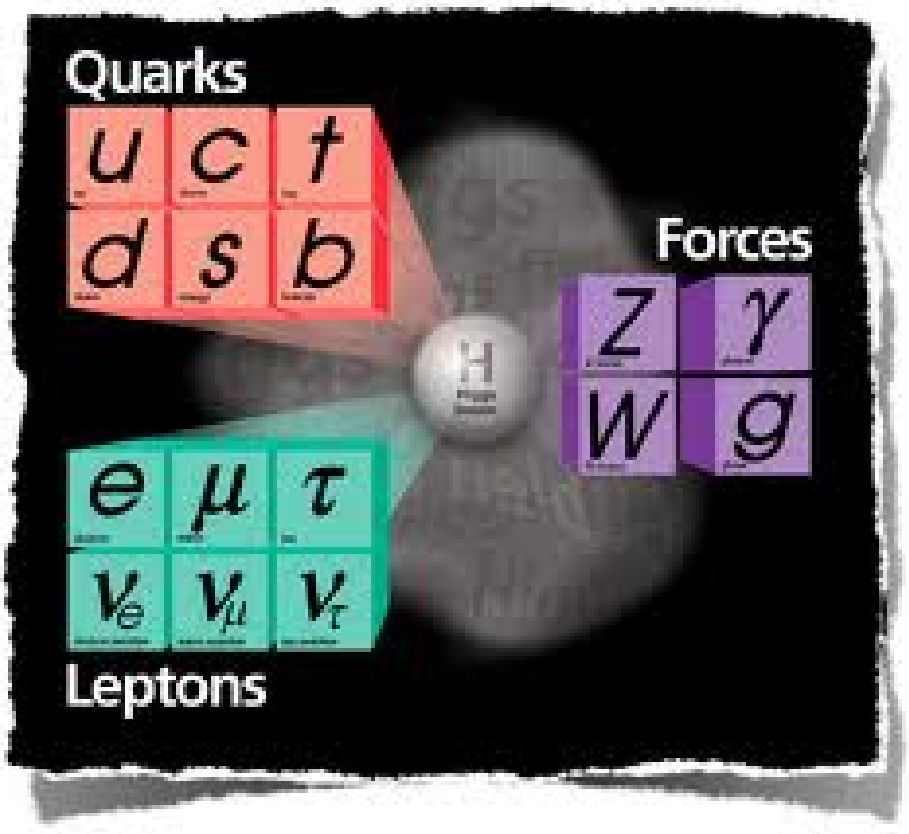
- Astrophysical Accelerators Soon ?



Three kinds of neutrinos: ν_e ν_μ ν_τ



The Standard Model of Particle Physics



- 3 neutrinos: ν_e, ν_μ, ν_τ
- chargeless
- spin 1/2
- almost massless (at least a million times lighter than electrons)
- only weak interactions

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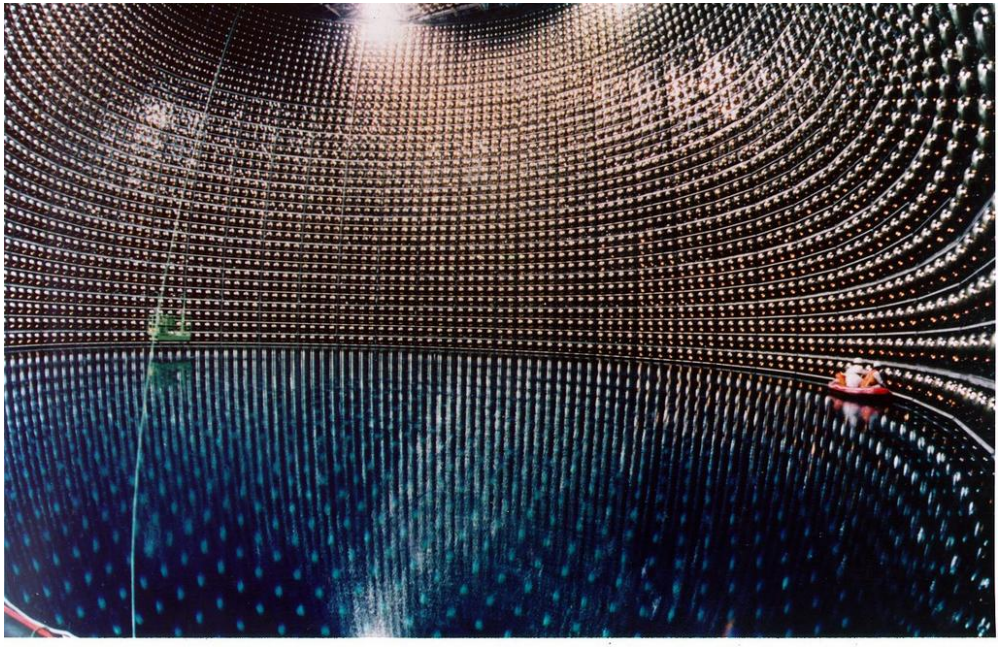
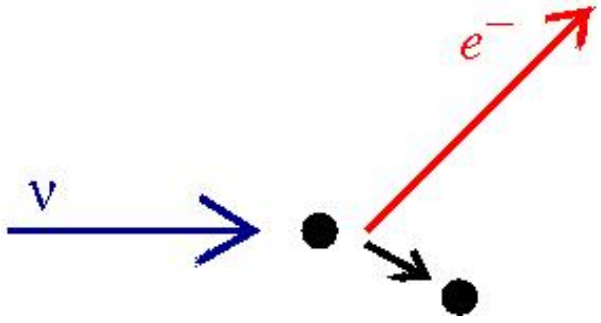
SuperKamiokande: 50 000 000 litres of water





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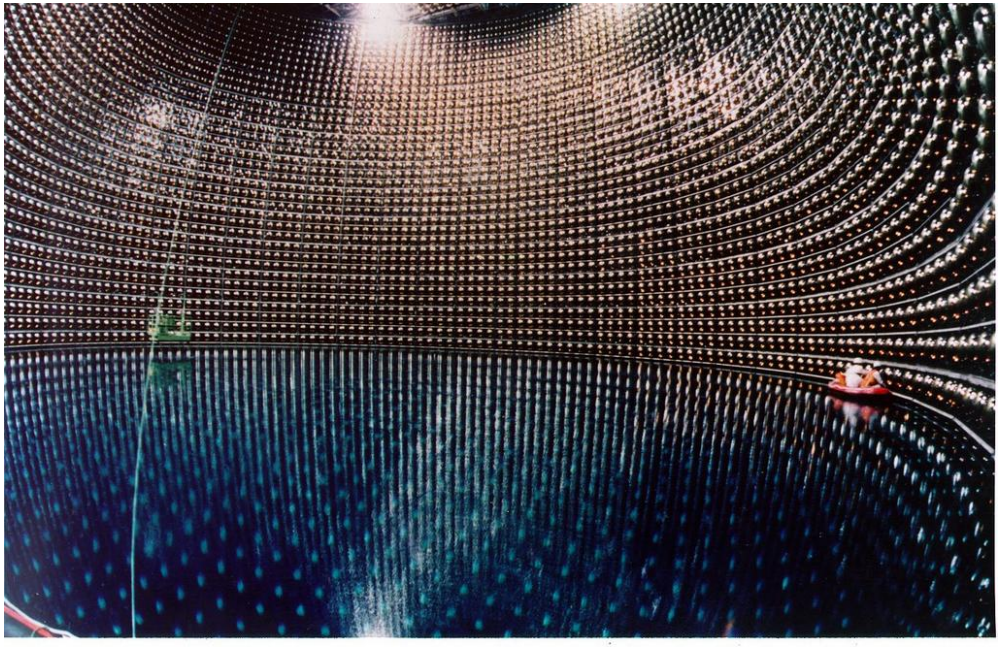

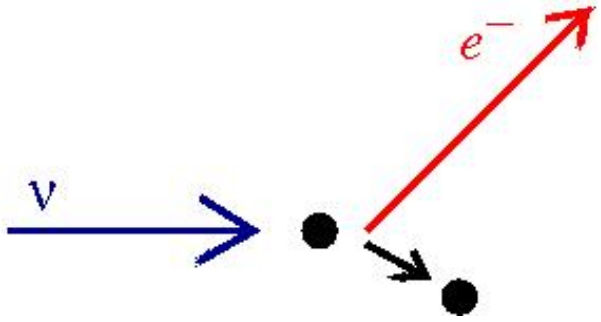

- Neutrinos passing through SK per day: 10^{25}
- Neutrino interactions in SK per day: 5-10

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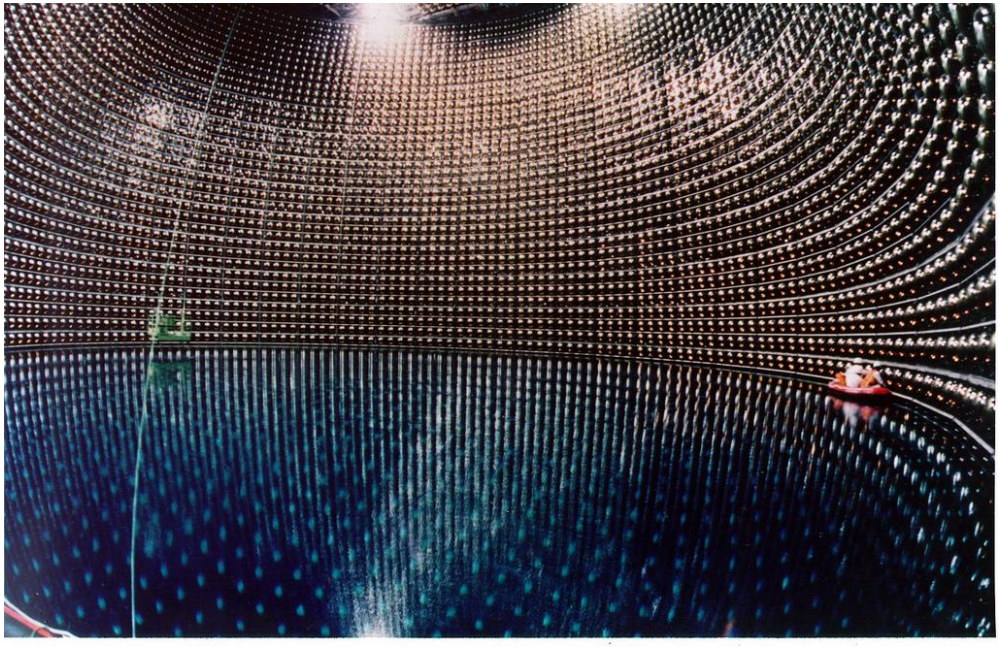

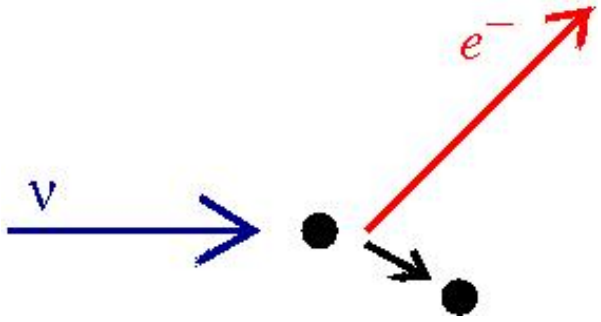

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Recipe for observing neutrinos

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

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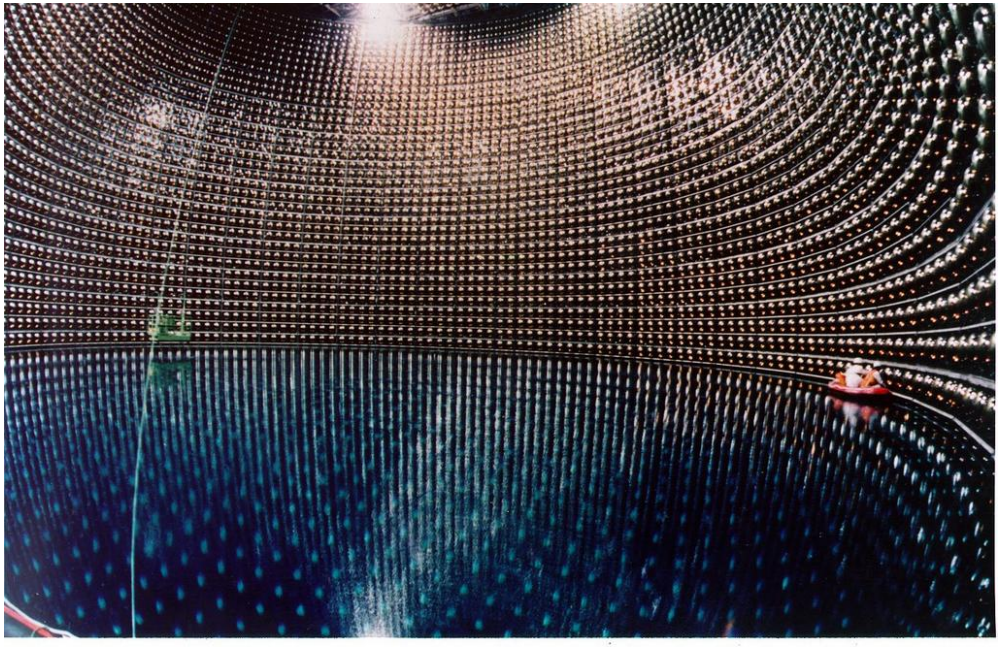

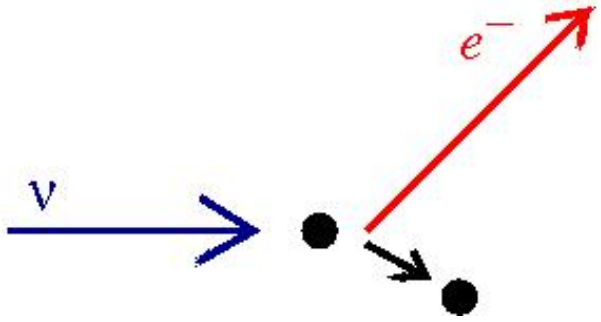

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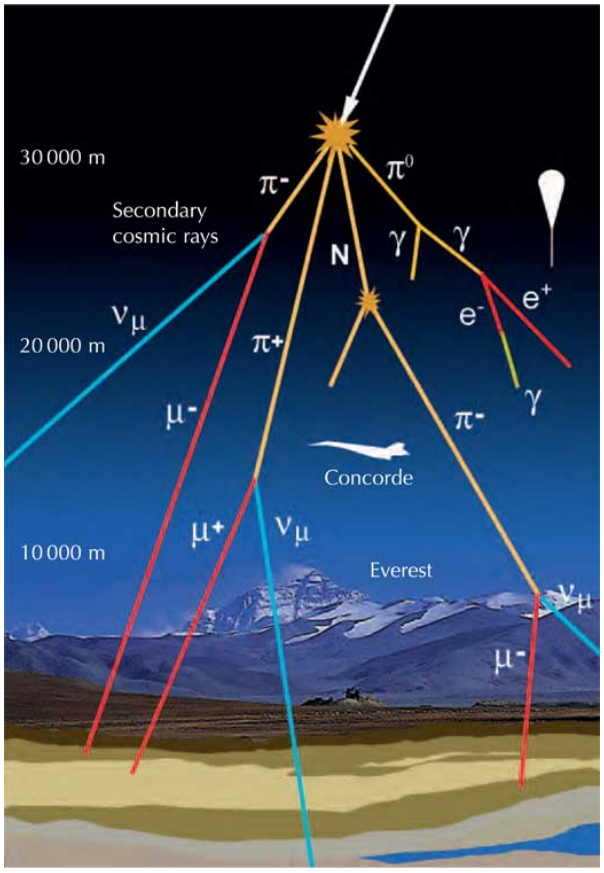
- Go deep underground: why ?

Cosmic rays: muon background and neutrinos



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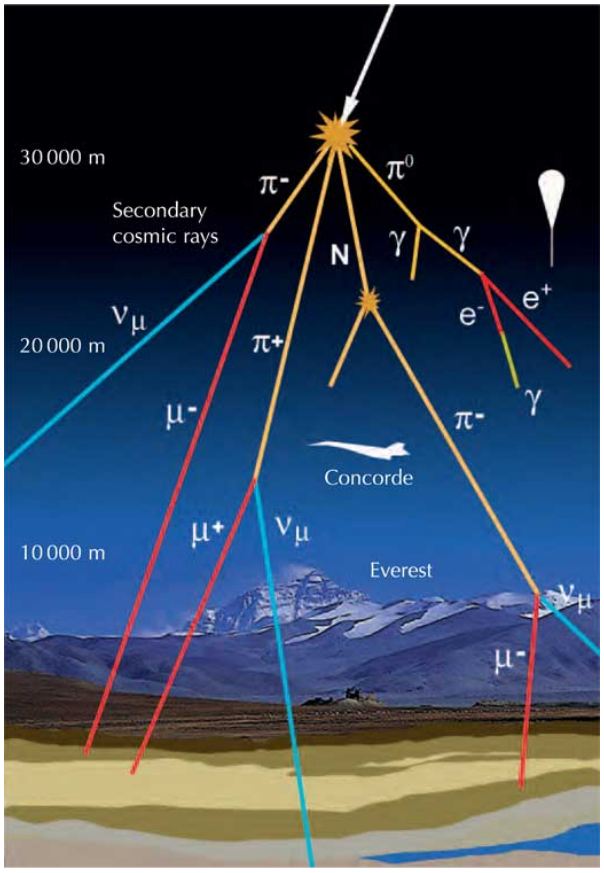

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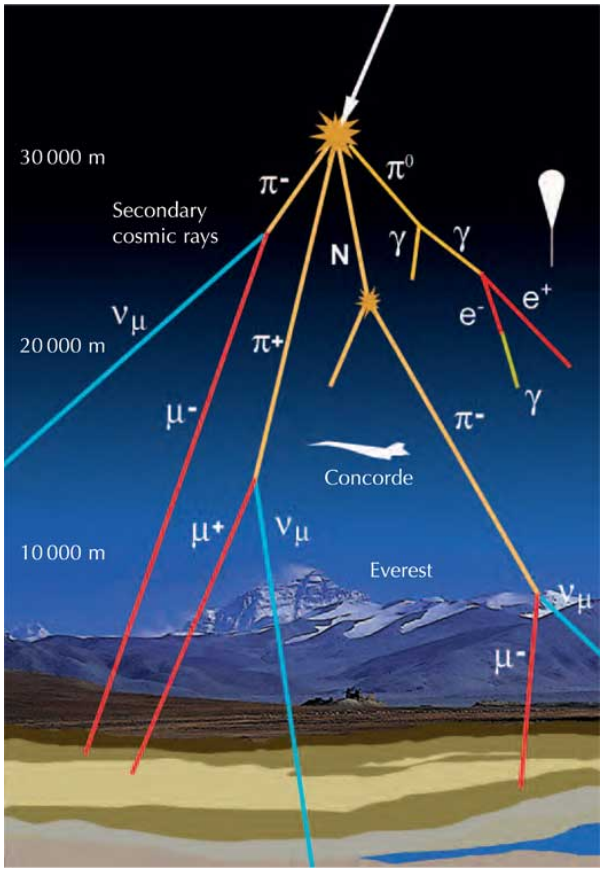

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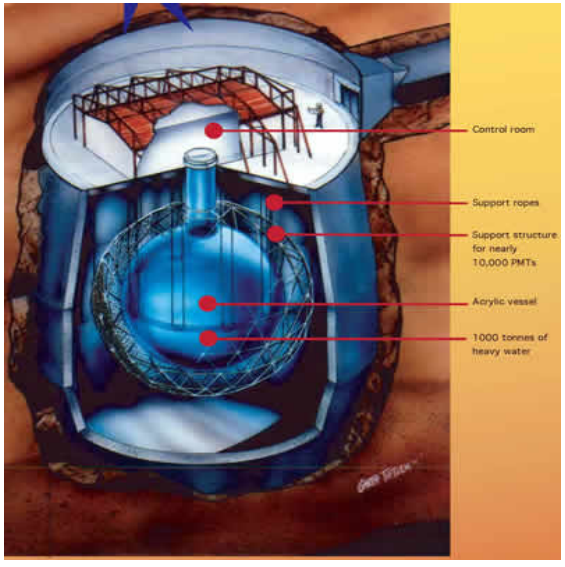
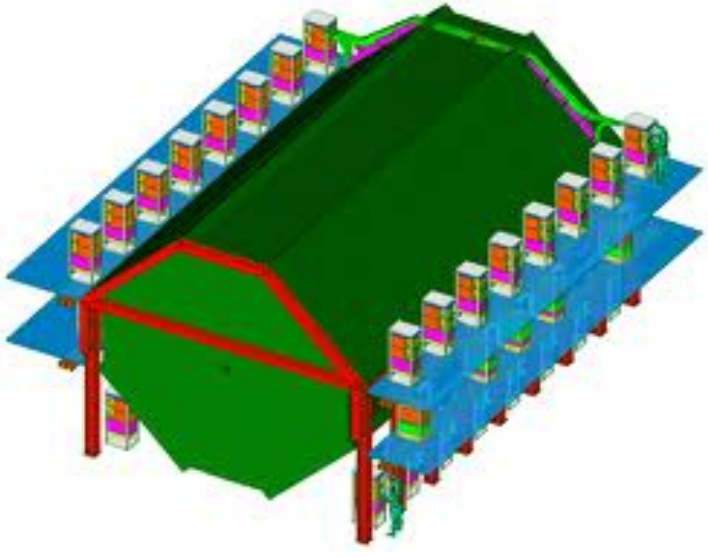
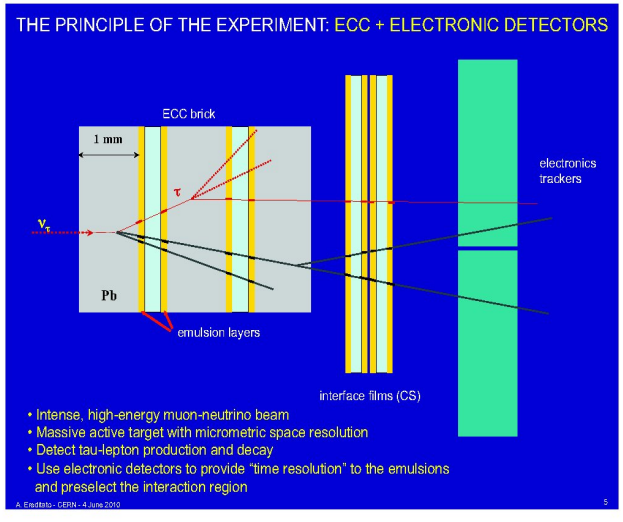
Neutrinos from atmosphere
first discovered in Kolar gold mines !

Some neutrino detectors

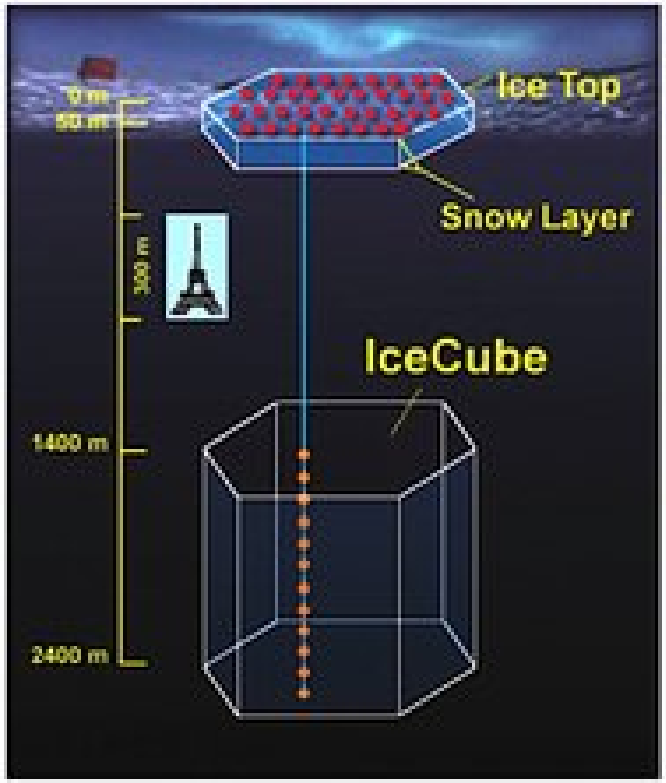


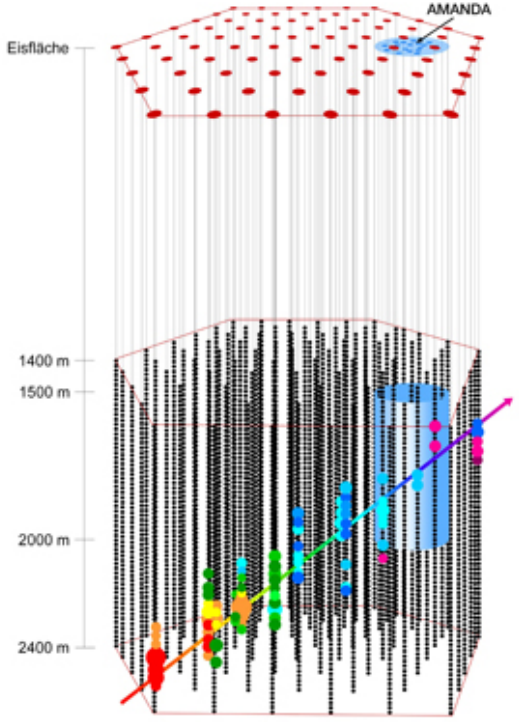




Common feature: all underground

Below the antarctic ice: Gigaton IceCube





1 000 000 000 000 litres of ice

- Looks at neutrinos coming from below
- The whole Earth acts as a shield from cosmic muons

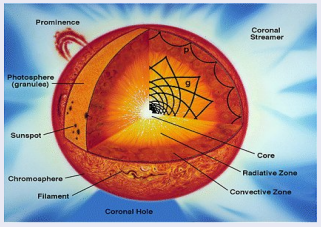
The search for invisible neutrinos

1. Why look for neutrinos ?
   - How does the Sun shine ?
   - Where did all the gold come from ?
   - What will we learn from neutrinos ?

2. How to look for neutrinos
   - Going underground...
   - Neutrino mysteries: some solved, some unsolved
   - The India-based Neutrino Observatory (INO)

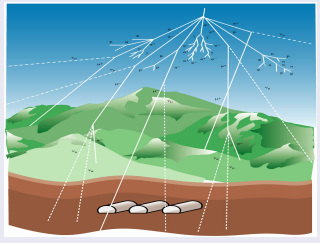
The long-term mysteries $\Rightarrow$ neutrino oscillations

Solar neutrino mystery: 1960s – 2002



- Only about half the expected ν_e observed!

Atmospheric neutrino mystery: 1980s – 1998



- Half the ν_μ lost in the Earth!

Reactor neutrino experiments

- Breaking news of 2012-13:
  10% of reactor $\bar{\nu}_e$ are lost !

The long-term mysteries $\Rightarrow$ neutrino oscillations

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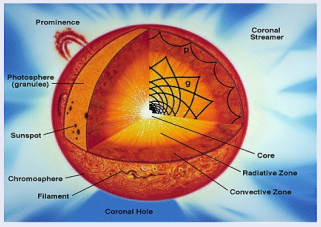

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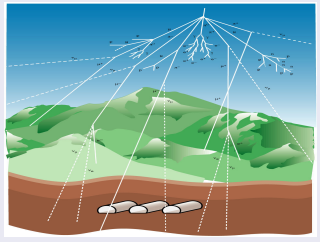

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Reactor neutrino experiments

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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 $\bar{\nu}_\mu/\bar{\nu}_\tau$?

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 $\bar{\nu}_\mu/\bar{\nu}_\tau$?

Because neutrinos have different masses and they mix !

$\Uparrow$

Quantum Mechanics

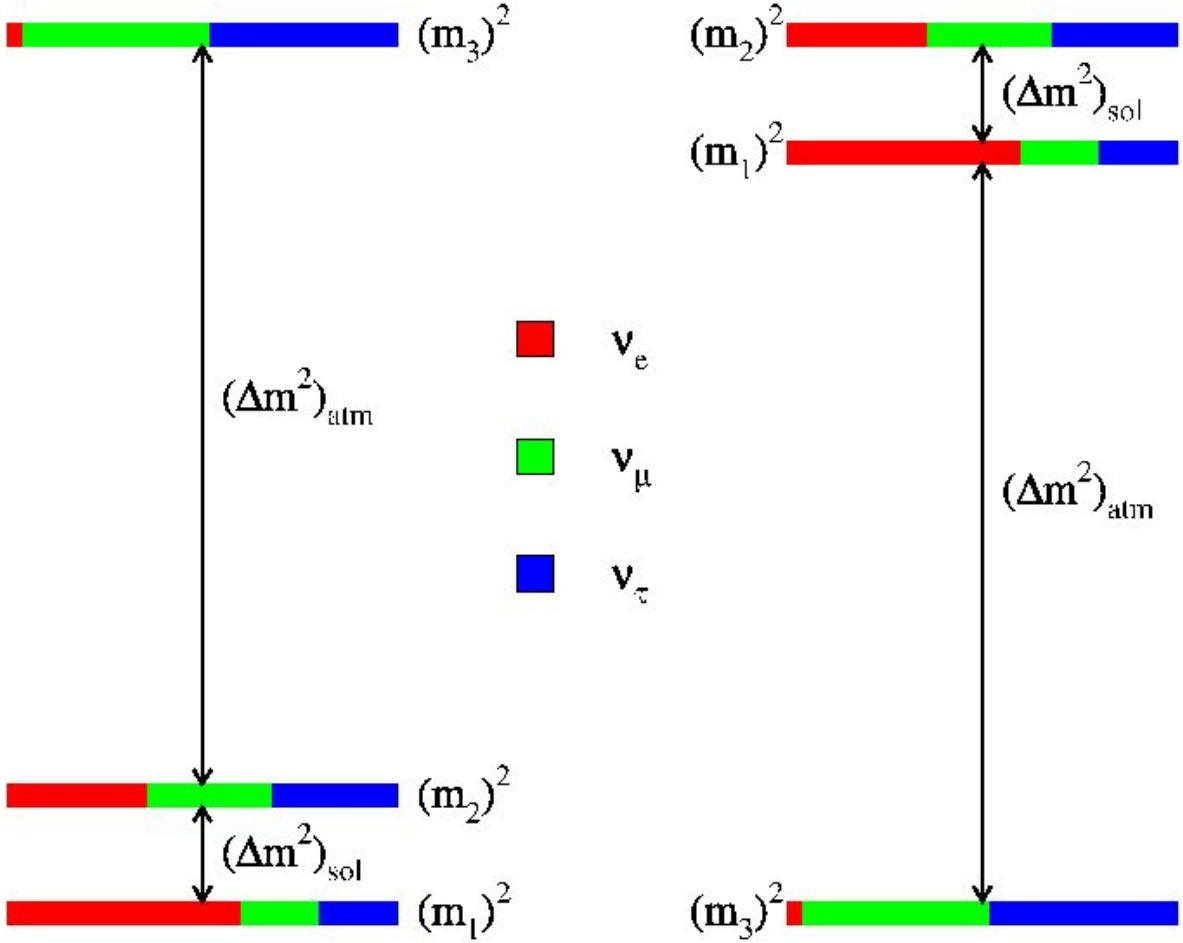
What is meant by neutrino mixing ?

ν_e, ν_μ, ν_τ do not have fixed masses !!

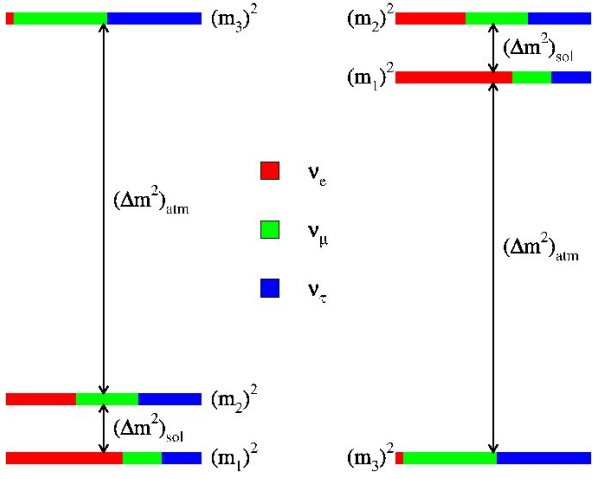
What is meant by neutrino mixing ?

ν_e, ν_μ, ν_τ do not have fixed masses !!

Mixing of ν_e, ν_μ, $\nu_\tau \Rightarrow \nu_1, \nu_2, \nu_3$ (These have fixed masses!)



Still open mysteries about neutrino masses



- Mass ordering: Normal or Inverted ?
- What are the absolute neutrino masses ?
- Are there more than 3 neutrinos ?
- Do neutrinos behave differently than antineutrinos ?
- Can neutrinos be their own antiparticles ?

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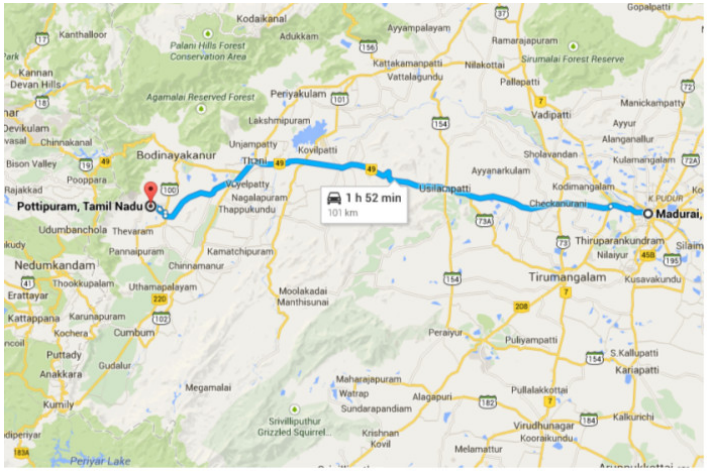
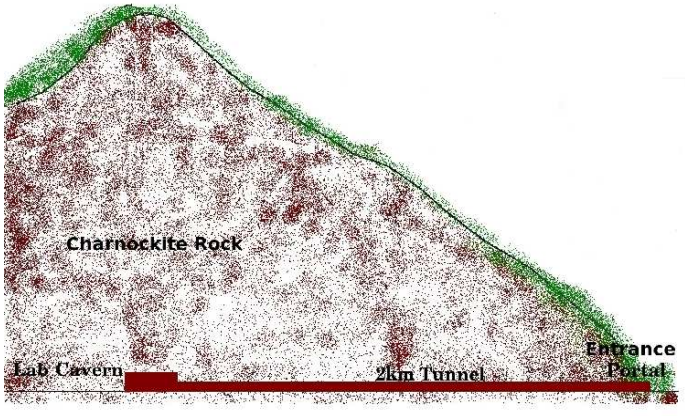
The location



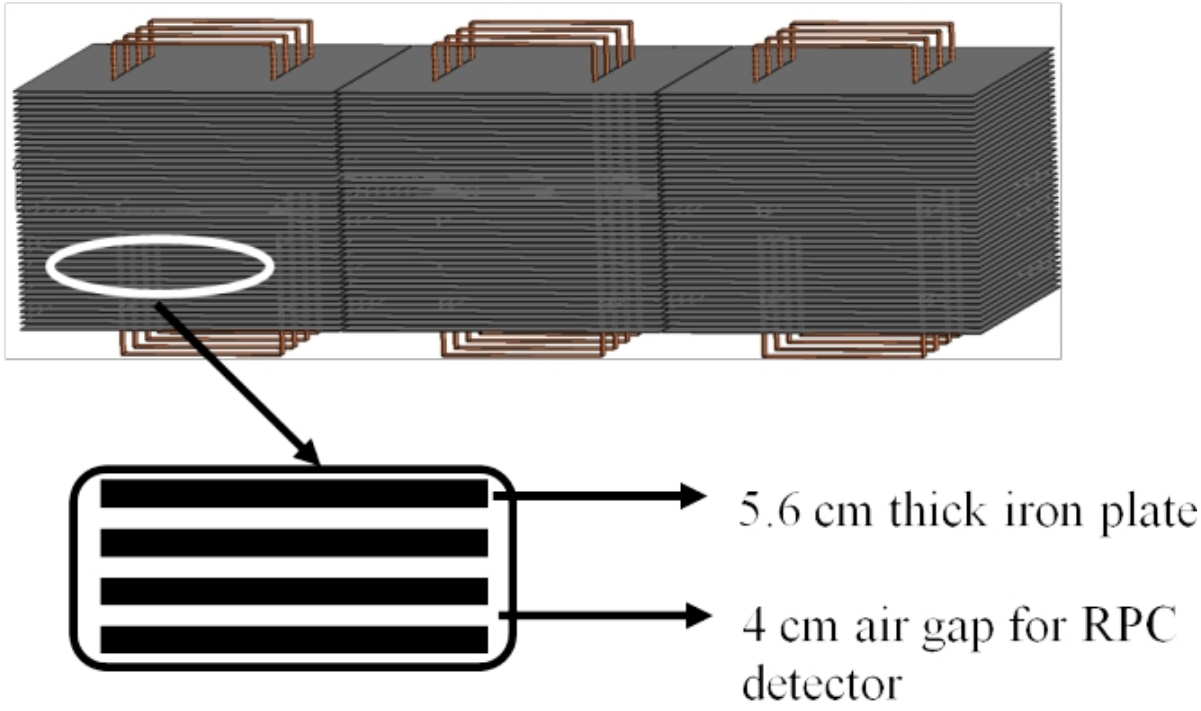


- In a tunnel below a peak (Bodi West Hills, near Madurai)
- 1 km rock coverage from all sides

The cavern plan

- Largest cavern: 132 m x 26 m x 20 m
- Other smaller sensitive experiments possible (dark matter etc.)

The iron calorimeter (ICAL) experiment



India-based Neutrino Observatory

- The world's largest electromagnet:
  50 kiloton of magnetized iron (50 000 000 kg)
- Can distinguish neutrinos from antineutrinos
- Determining mass ordering from atmospheric neutrinos

INO: an opportunity

- The largest (planned) experimental facility in India
- Combines expertise of physicists and engineers, from more than 25 universities, research institutes, and industry
- Many opportunities available for students
- Inter-Institutional Centre for High Energy Physics (IICHEP) to be established at Madurai
- Please visit `http://www.ino.tifr.res.in`

Some technological speculations....

- Nuclear reactor monitoring (for non-proliferation)
- Oil exploration
- Faster communication

A scientist's view....