What is common between Life, The Universe, and an Underground Lab?

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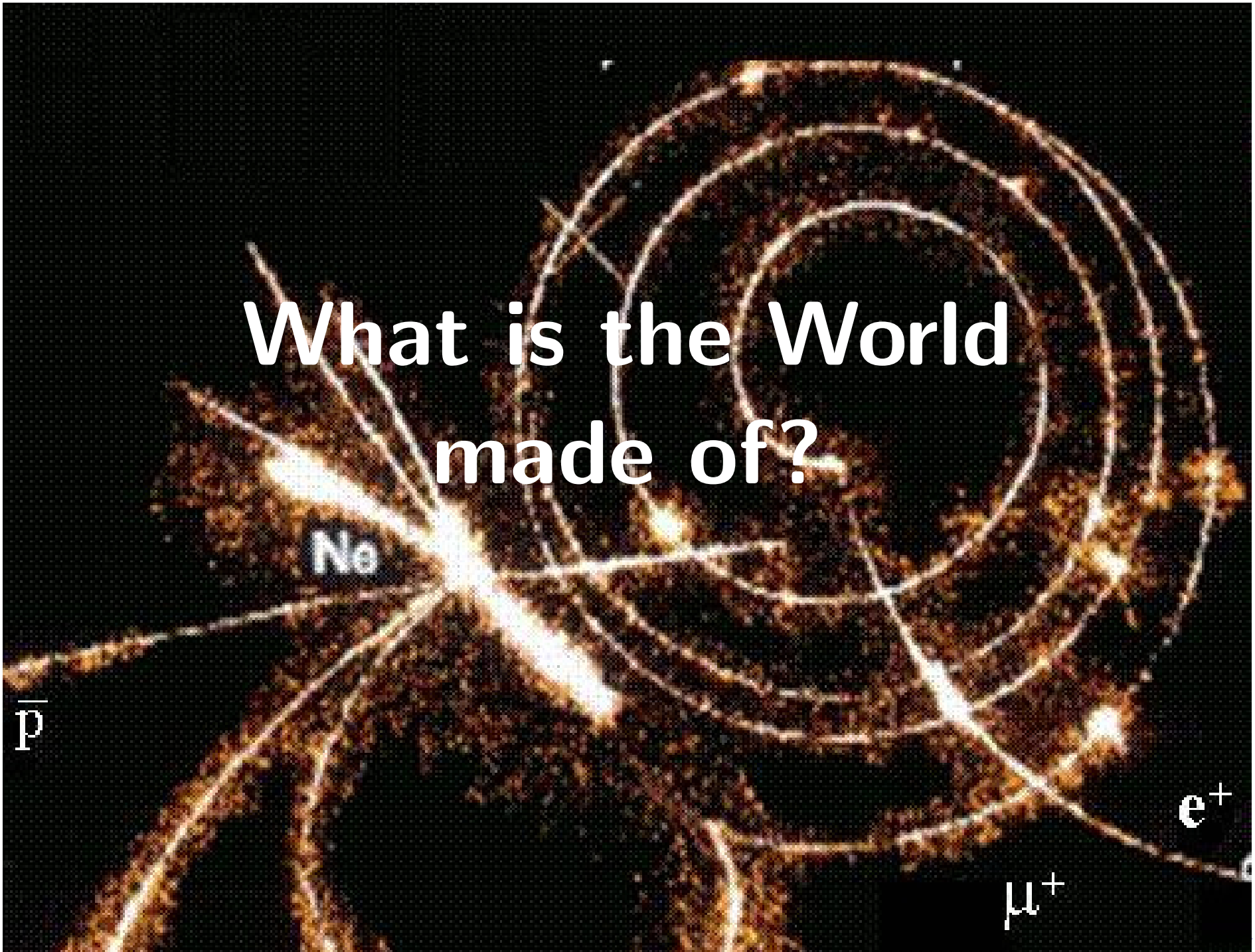
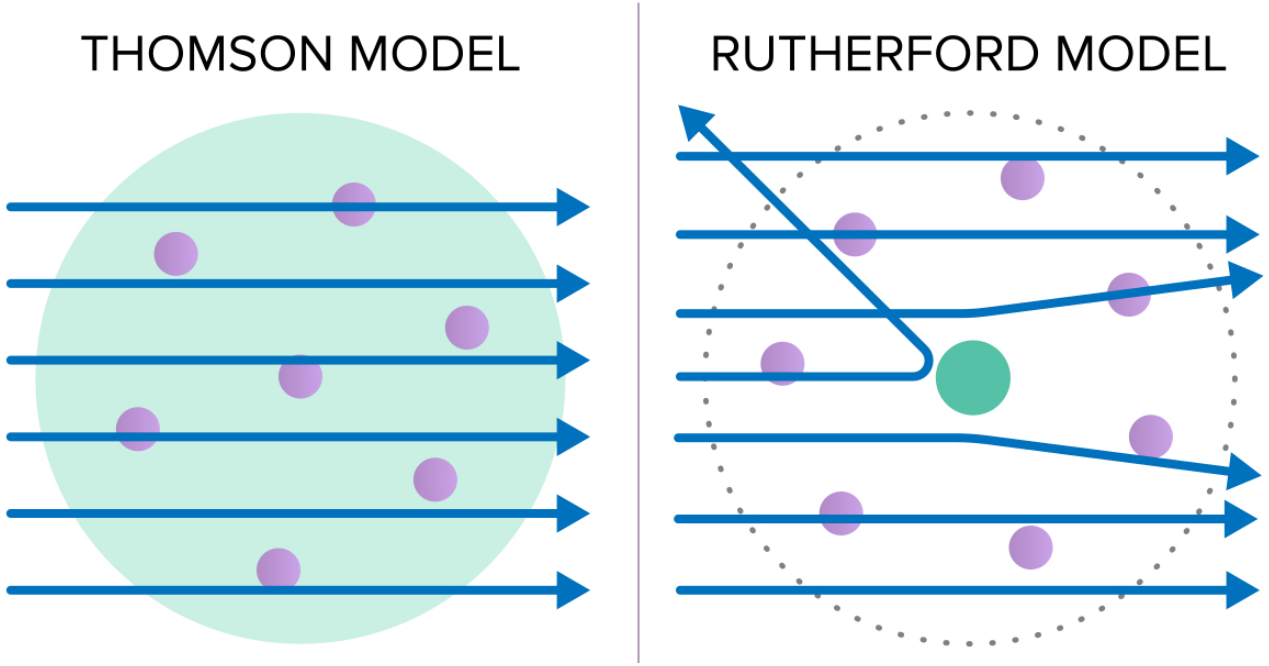

What is the World made of?
Ne
$\bar{p}$
e^+
μ^+

Matter and Radiation

- Matter is made up of particles: atoms or molecules. Einstein proved this in 1905 (Brownian Motion).
- Light is made up of waves. It has a *wave* nature. Established conclusively by end of 19th century (Maxwell's equations of electrodynamics).
- Light also behaves as a particle, called *photon*. The photon is a light quantum. Its discovery lead to the birth of quantum theory.
- Hence light is said to have a dual nature.

Flip-flop



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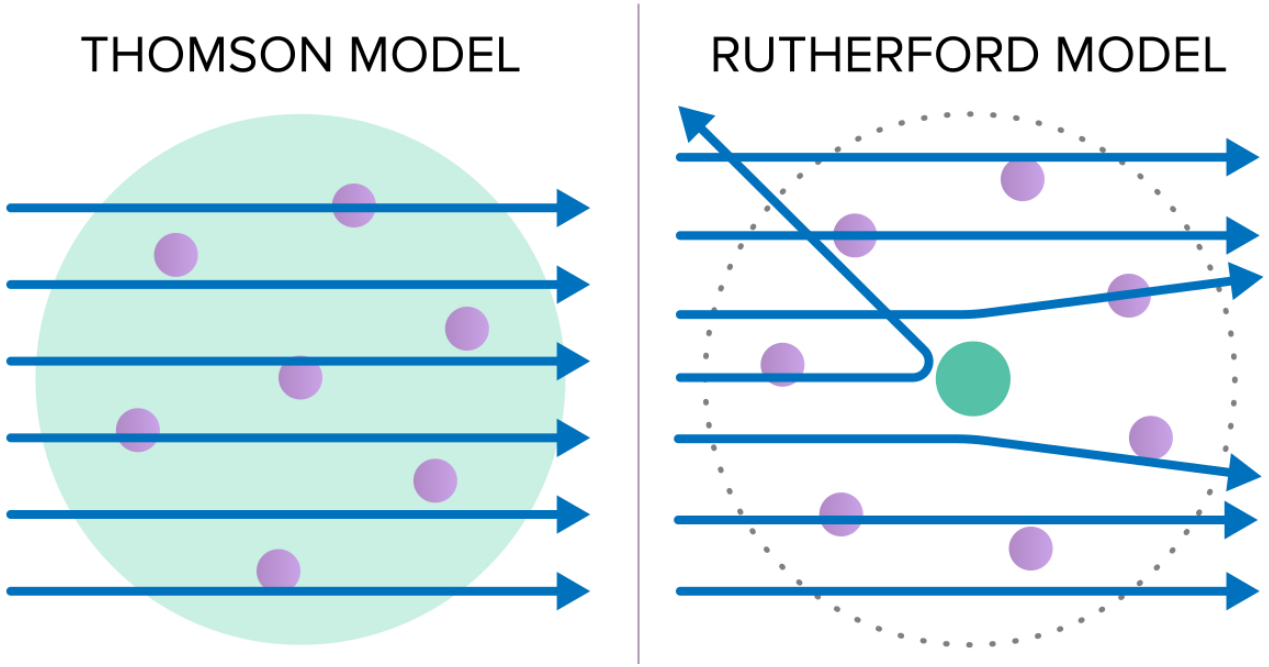

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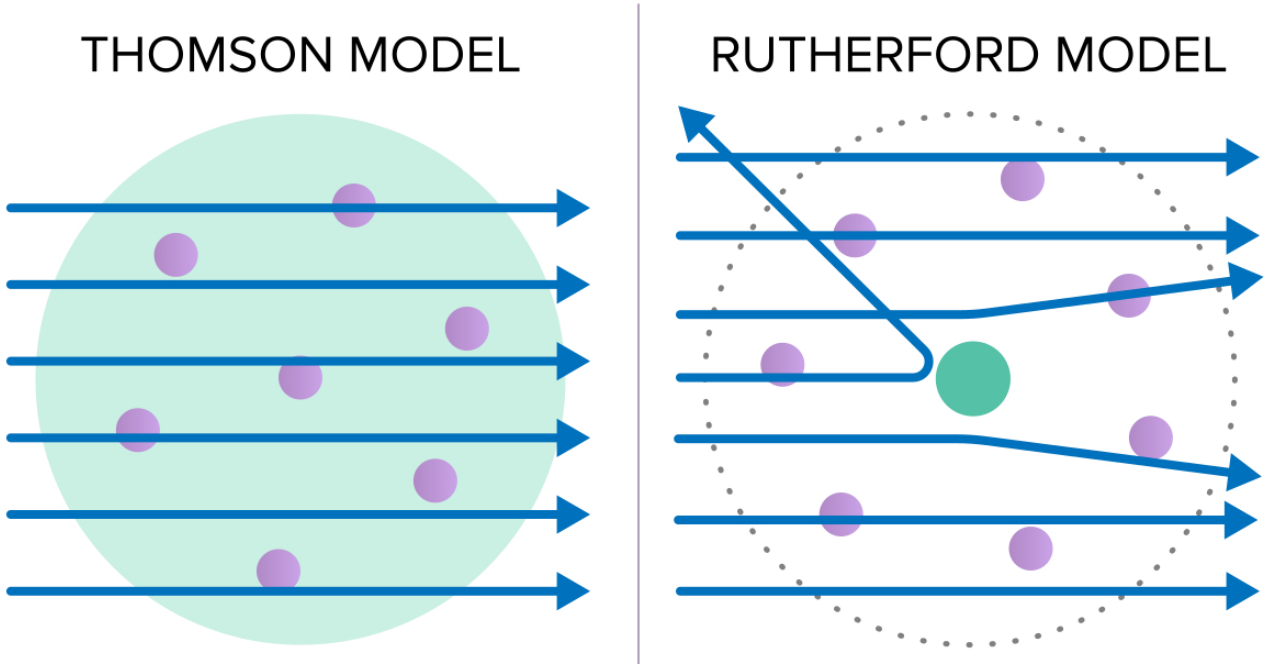

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- Dirac, 1928, gave new relativistic wave equation: two new ideas: *spin* and *antiparticle*.
- Matter and antimatter have related properties like same mass, opposite charge, etc. Eg: p^+, $\bar{p}^-$, e^-, $\bar{e}^+$.

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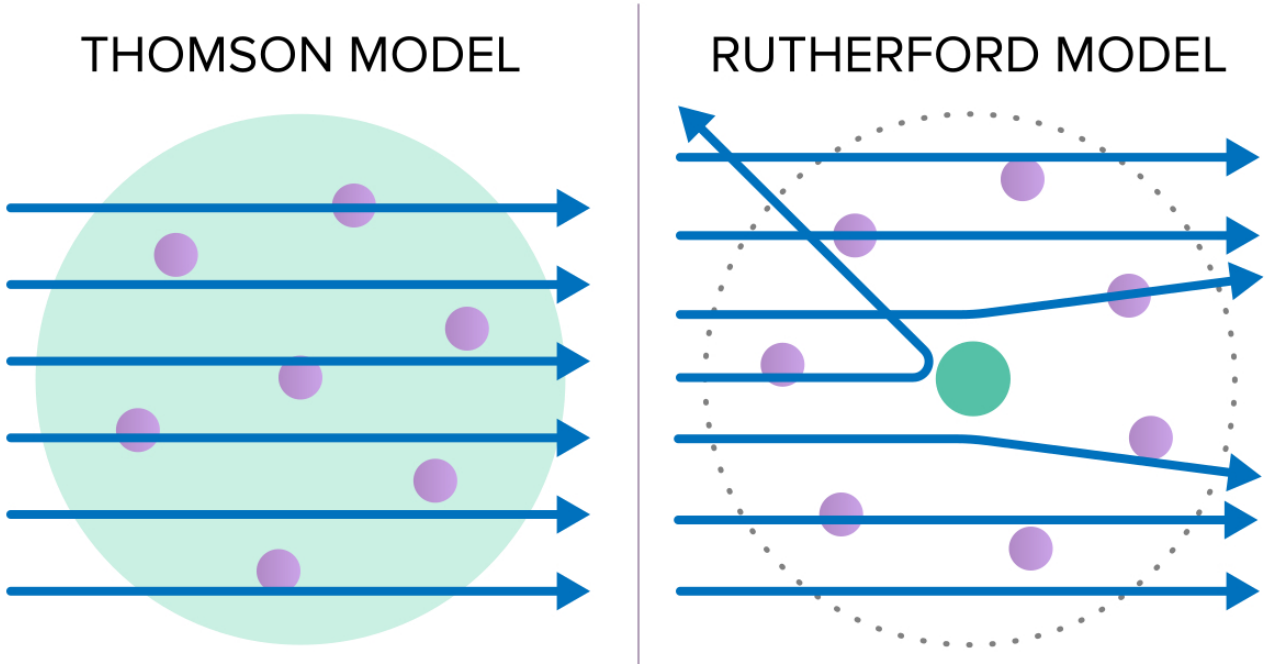

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- Electrons also have a dual nature (de Broglie, 1929 Nobel).
- In fact, *all* particles have dual nature.

From Science to Engineering and Technology

Some questions

- Why is it important that electrons are outside the nucleus of atoms and not uniformly distributed?

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- Answer: Will appear towards the end of this talk!

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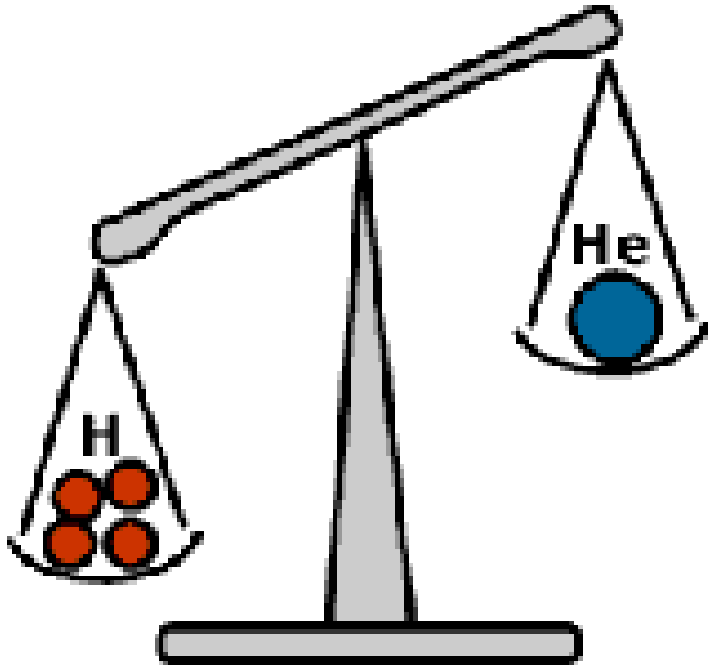
- In the case of nuclear fusion, it comes from Aston's discovery (1920) that 4 hydrogen nuclei are heavier than a helium nucleus due to nuclear binding.



Profound Consequences

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How does the Sun shine?

An old puzzle:

- Kelvin: Our Sun has enough energy to burn for about 30 million years.
- Darwin: Our Earth (the Weald in southern England) must be at least 300 million years old for natural selection to produce such diversity.

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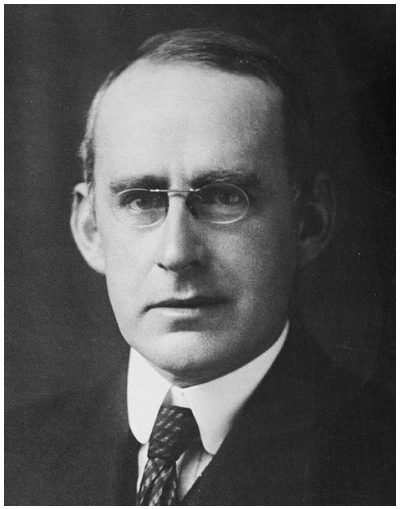
- Darwin: Our Earth (the Weald in southern England) must be at least 300 million years old for natural selection to produce such diversity.
- Resolution: Nuclear energy is (per unit mass) about 100,000 times larger than chemical or electronic energy.

The key to the old puzzle

- Arthur Eddington (1920): Nuclear fusion could keep the Sun and other stars shining for 100 billion years.
- von Weizäcker and Hans Bethe (1939):

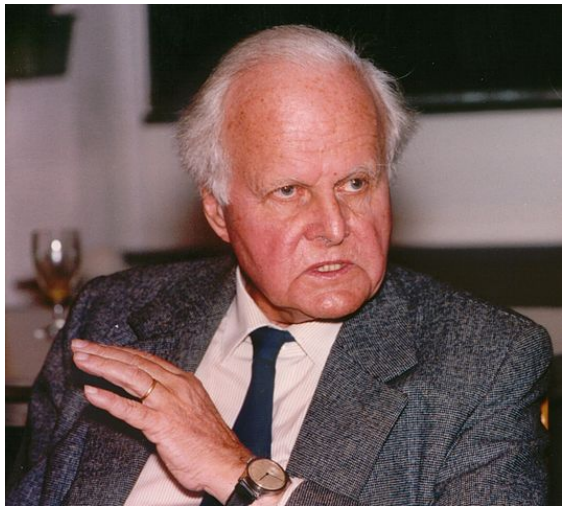
$$\mathrm{H} + \mathrm{H} + \mathrm{H} + \mathrm{H} \rightarrow \mathrm{He} + 2\nu_e + 26.7 \text{ MeV} \ .$$

- The energy of 26.7 MeV is emitted by the Sun as sunlight.
- The new particles are chargeless, nearly massless, neutrinos: about 70 billion per square cm per second fall on Earth, whether day or night.



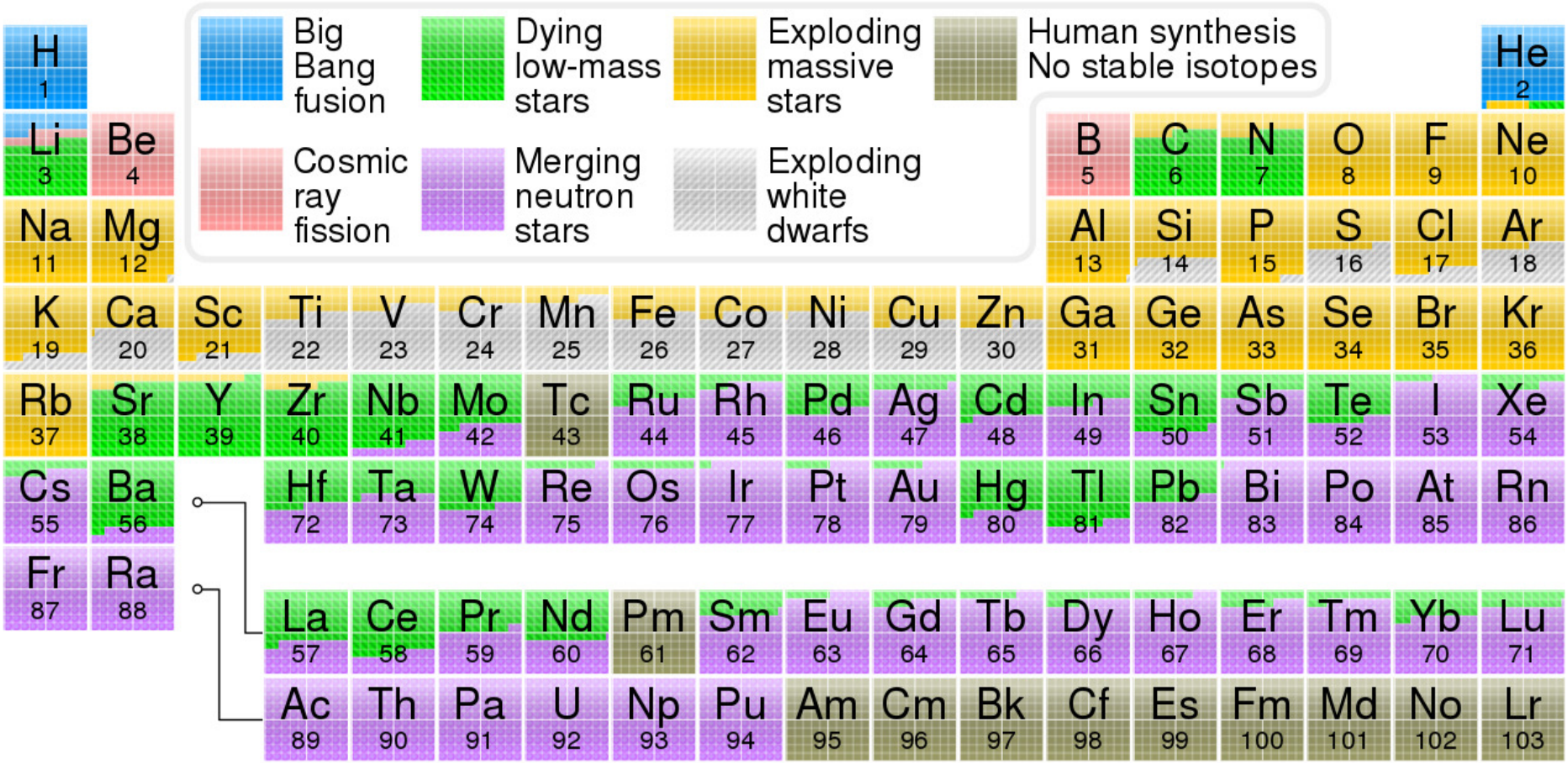
Arthur Eddington

Hans Bethe



C.F. von Weizsäcker

Stars, Supernovae and Life



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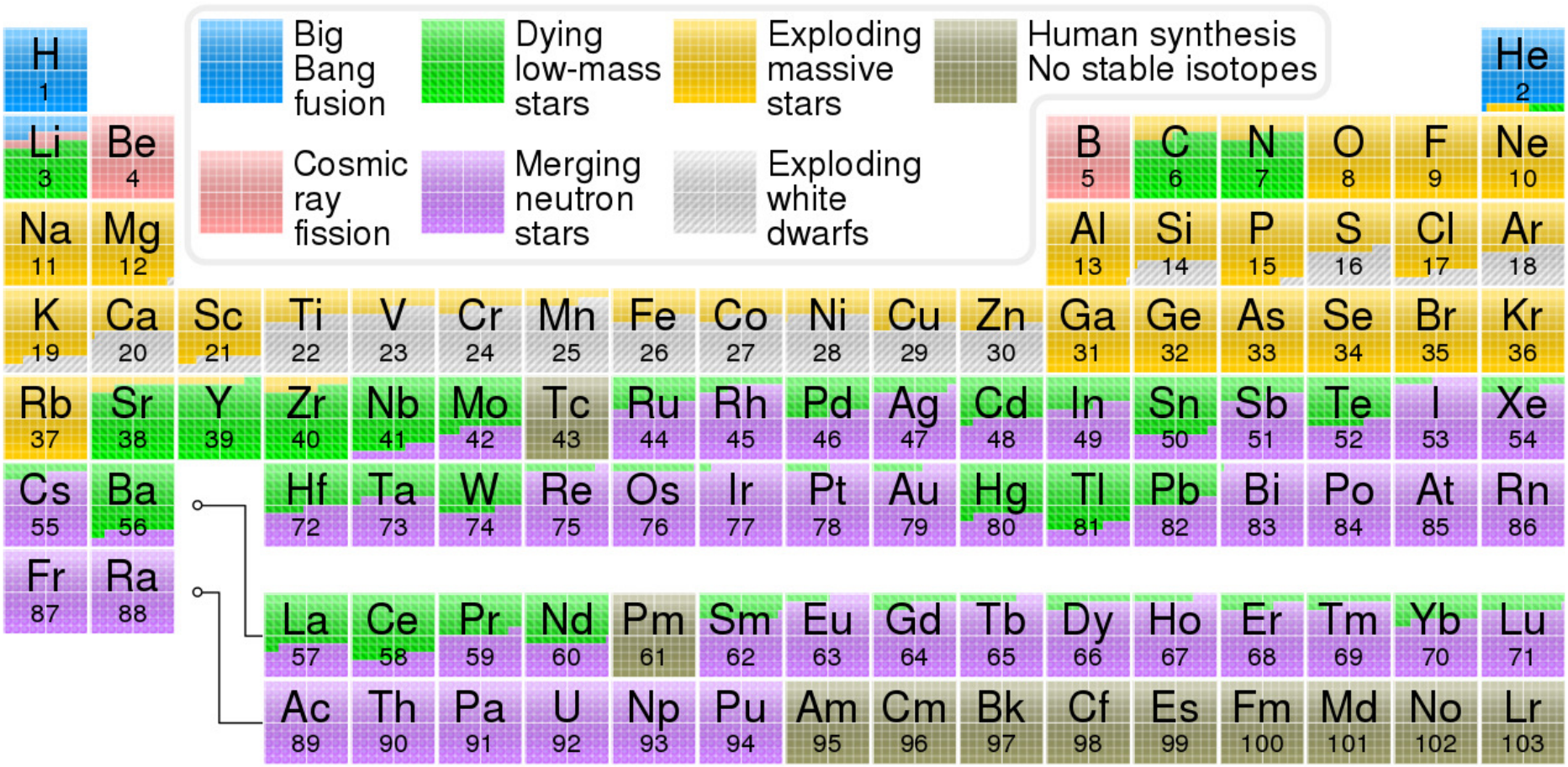


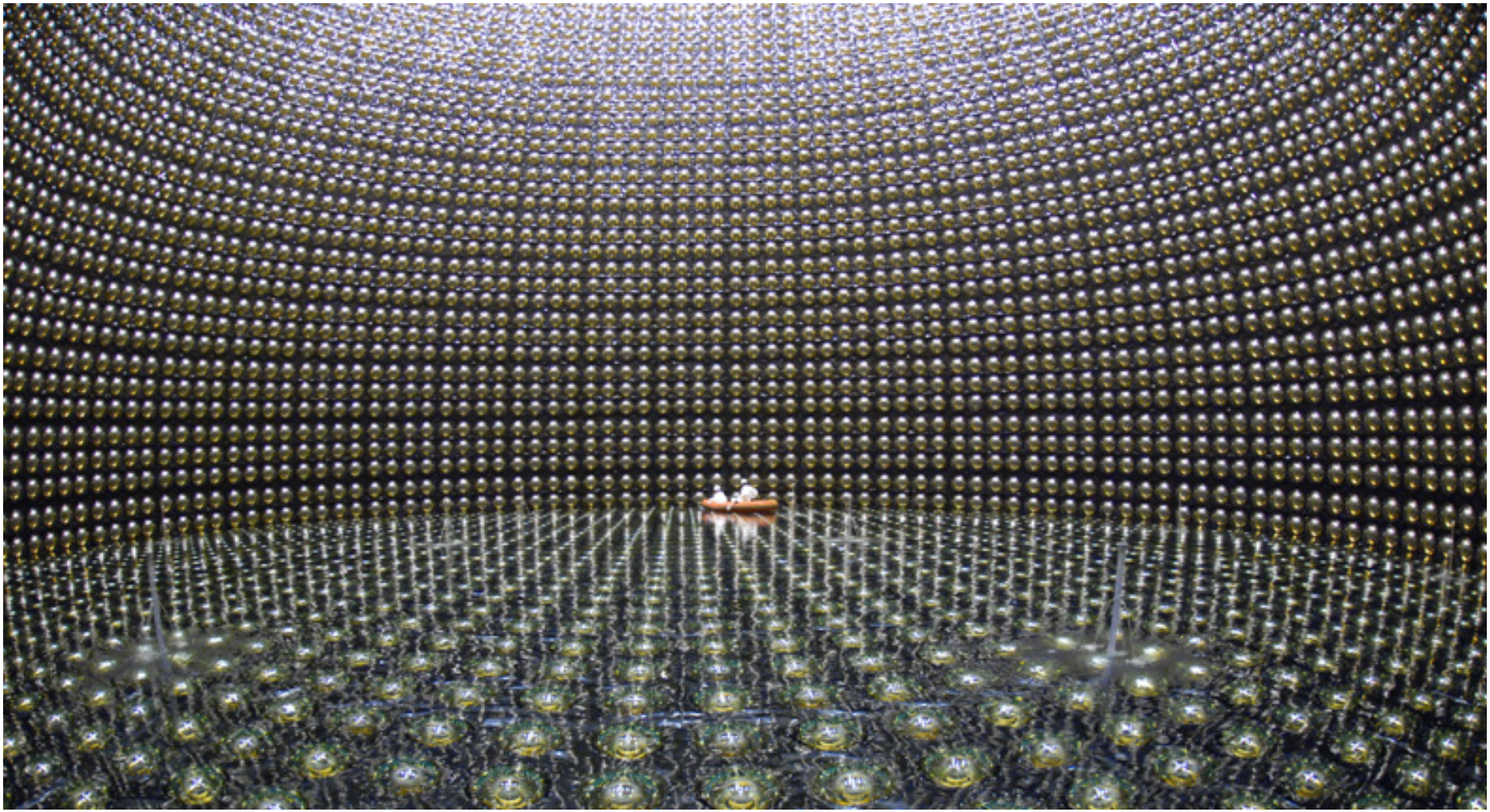
- Stars shine because neutrinos exist and enable weak nuclear fusion. Without the Sun (and neutrinos) there would be no life on Earth.
- We are all made of star-dust! No wonder that our ancestors looked to the sky to learn about ourselves!

The proof of the pudding

- . . . is to be able to detect these neutrinos and confirm this idea.
- First attempt in 1967 by Ray Davis, Homestake Mine, USA, using 600 tons of perchloroethylene.

Won Nobel in 2002.

The Super Kamiokande detector



- Added to the proof the Sun shines through nuclear fusion.
- Added some amazing technology in both construction and detection.

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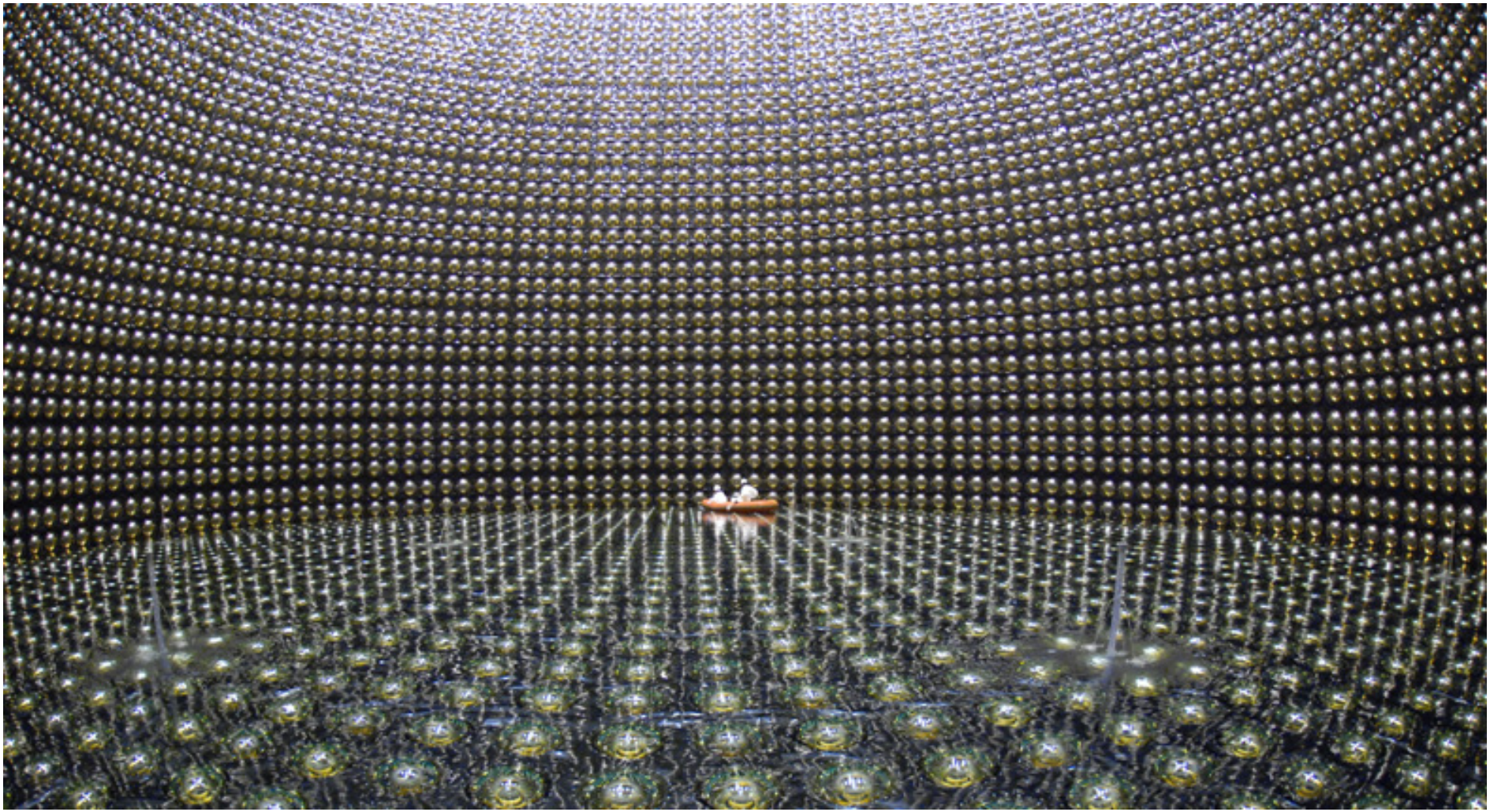

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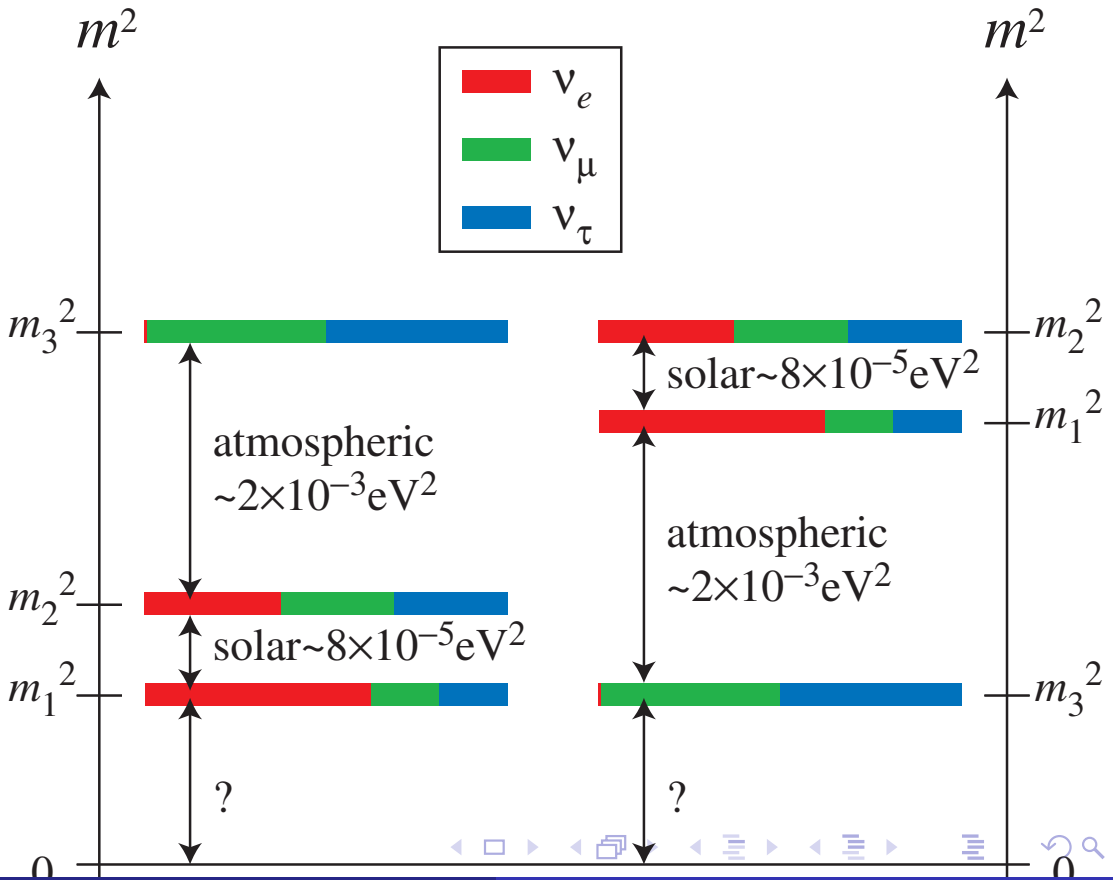
Our old question

- Why is it important that electrons (all particles) have dual nature?
- Answer: Neutrinos with wave-like nature can superpose like light, mix, and exhibit new properties: called neutrino oscillations.

$\theta_{12} \sim 34^\circ$;
$\theta_{23} \sim 45^\circ$;
$\theta_{13} \sim 8^\circ$.



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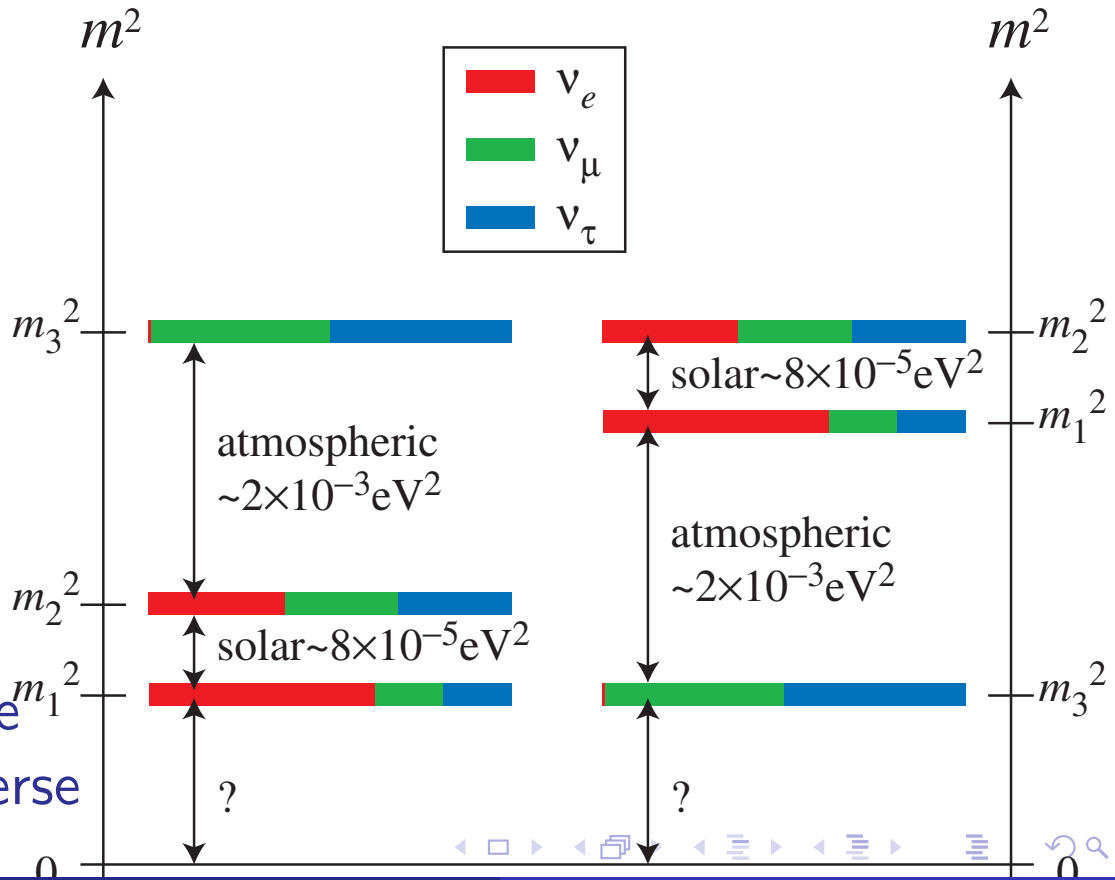
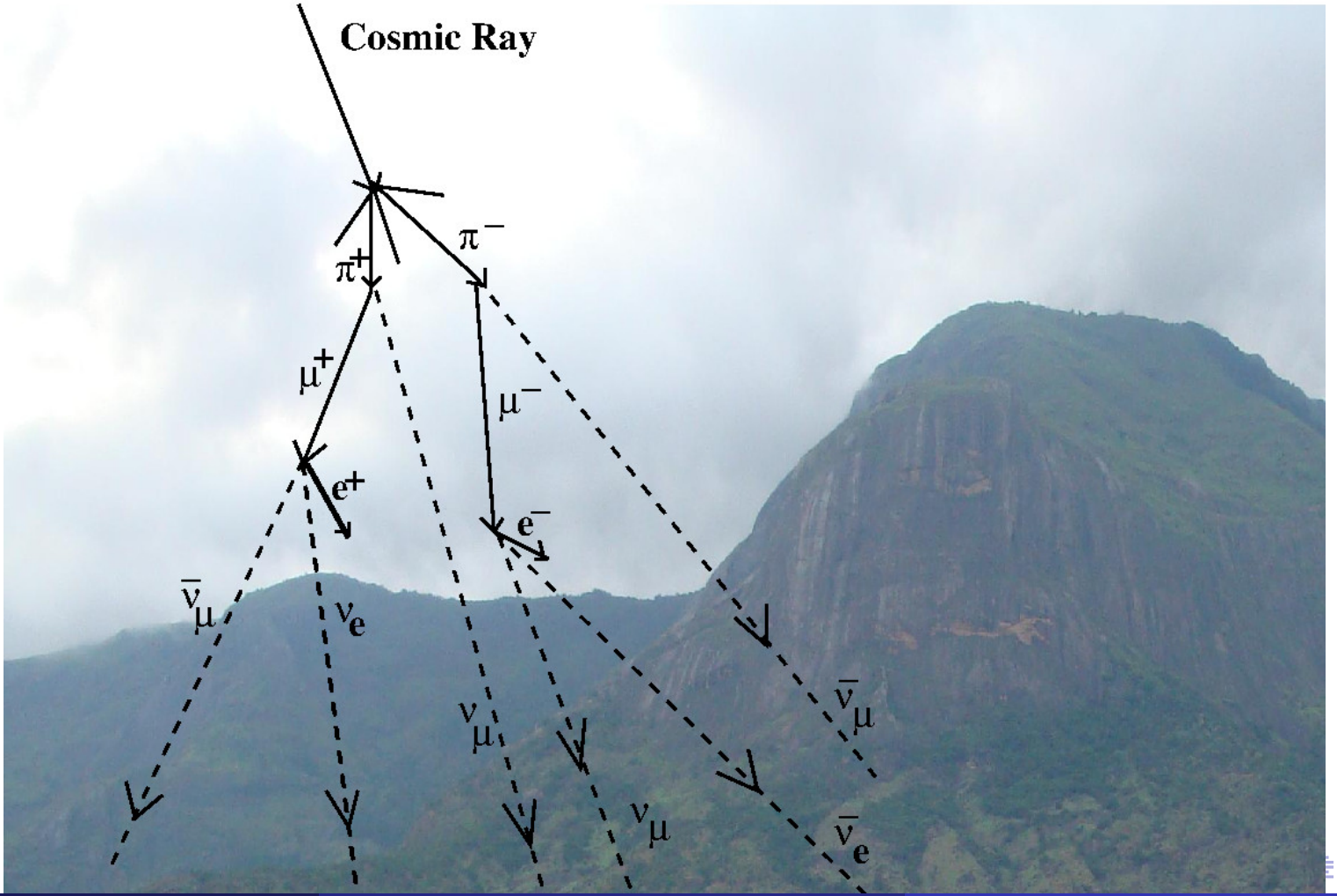
CP Phase: δ_{CP}
Neutrinos and antineutrinos mix differently
value currently unknown.
May answer the question of the baryon asymmetry in the Universe



Atmospheric Neutrinos

- Cosmic rays reach Earth's atmosphere and interact with C, O nuclei to give pions and kaons. These decay to muons and neutrinos.
- Neutrino oscillations were observed here as well, by Superkamioka.



Towards a neutrino detector located in India

- The iron calorimeter (ICAL) detector proposed at INO will be 50 ktons of iron, in layers of 5.6 cm, interspersed with active detectors called RPCs.

$$\nu_\mu N \to \mu^- X \ , \quad \overline{\nu}_\mu N \to \mu^+ X \ .$$

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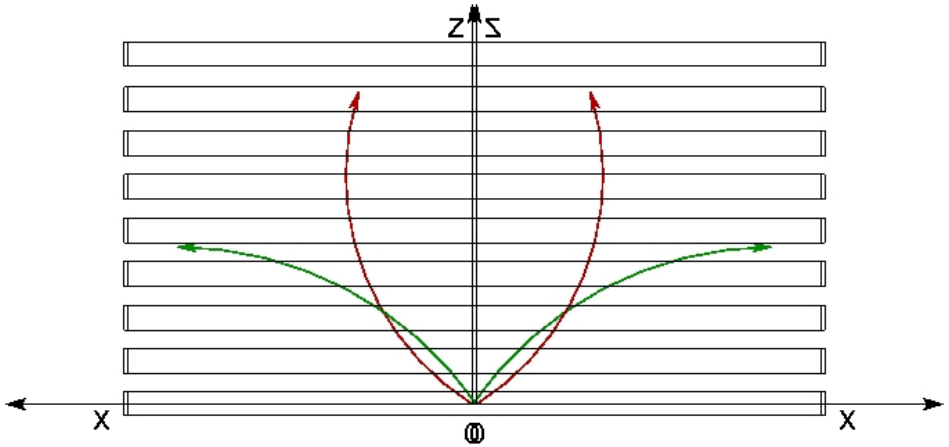
- The detector will be magnetised up to 1.4 T.
- The μ^- and μ^+ bend in *opposite* directions in the magnetic field. Hence we can detect ν and $\overline{\nu}$ events separately.



The India-based Neutrino Obervatory

INO Project Highlights

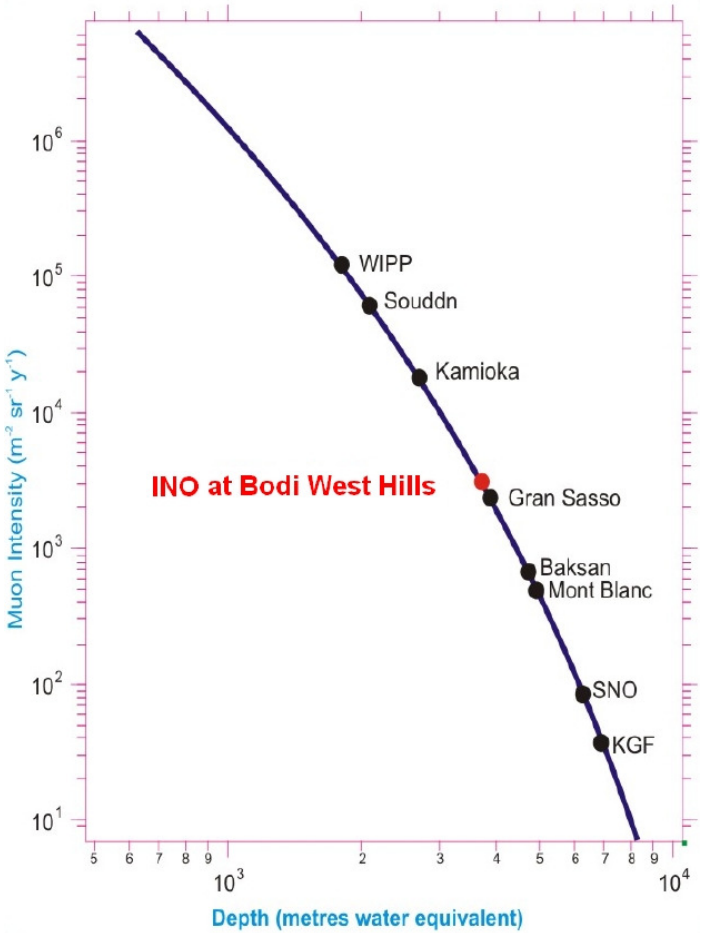
- Approved in principle by the Planning Commission as a Mega Science Project under XI 5-year plan—jointly funded by DAE-DST
- Lab comprising one large and three small underground caverns to house detectors at Bodi West Hills, Pottipuram Village, Theni District, Tamil Nadu. An access tunnel to reach the caverns.
- Construction, in situ, of *the ICAL neutrino detector*—world's most massive magnetised detector, when built.
- Completely in-house R&D with substantial industry interface and technology development. No strategic or defence applications. Its operation involves no radioactivity release or toxic emissions.
- National Centre for High Energy Physics—Nodal Centre for INO—to be located in Madurai.
- Many statutory clearances obtained; awaiting a few more.

The INO Collaborating Institutions

- American College
- AMU
- BHU
- Calicut U
- Delhi U
- IGCAR
- IITG
- IITM
- Jammu U
- Lucknow U
- Panjab U
- Sambalpur U
- TIFR
- BARC
- Calcutta U
- CMEMS
- HRI
- IITB
- IITI
- IMSc
- Kashmir U
- Mysore U
- RMVU
- SINP
- VECC

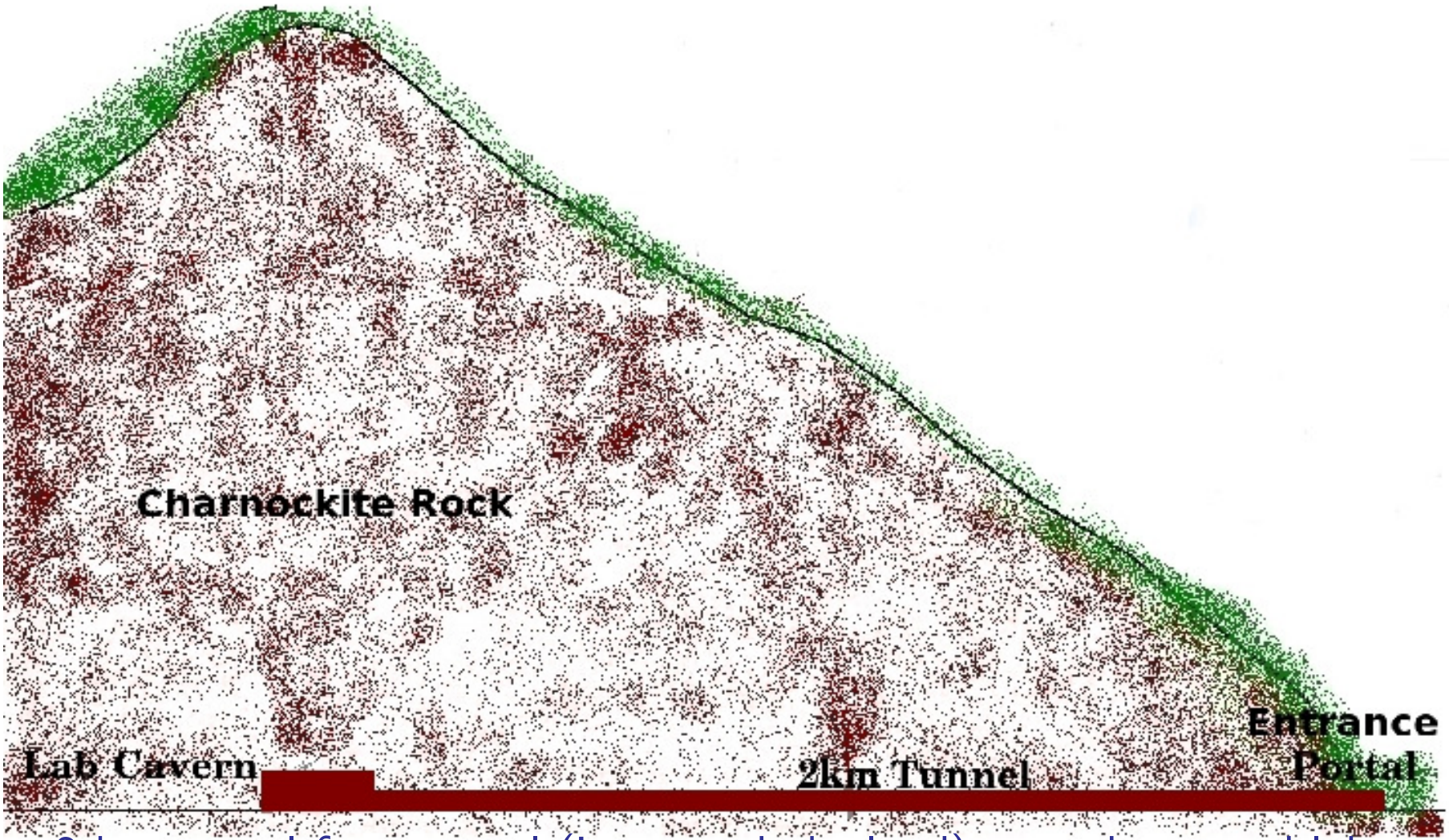
Spokesperson: Vivek Datar, Host Institute: TIFR

Why Underground?



- The earth acts as a filter and removes the cosmic background radiation.
- The primary criteria are safety (and hence good rock quality) and minimal environmental impact
- Charnockite rock in India found mostly below 13° N latitude
- Low rainfall/humidity for best working of detectors implies that the possible sites are in Tamil Nadu

Schematic of INO Underground Lab



$\approx$ 2 km tunnel from portal (in poromboke land) to underground lab.

A few last words

- INO has been conceived on a very large scale. One of the most ambitious projects in India.
- Many misconceptions about scope and environmental impact of INO. These are misplaced.
- A prototype is working well in Madurai and all are welcome to see it function. A 1/8th scale upgrade is in the pipeline.
- Being completely indigenous, large industry interface is needed, and has already begun.
- Will use cutting edge technology in construction, detection, electronics, computer simulations, etc. Details in the next talk.

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