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Geoneutrinos

A source study

Earth origin & composition

Solar nebula

accretion

~~on the 1st day~~
Sun
&
planetesimals
-4.6 byr

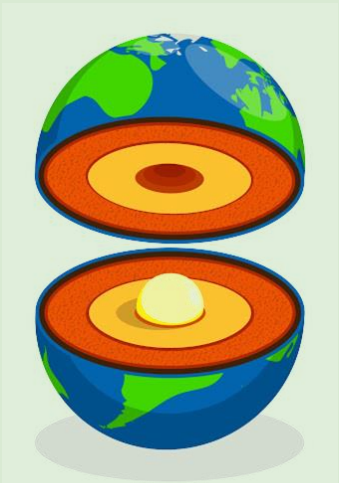
more
accretion

-4.54 byr
Earth, constantly bombarded by asteroids

convection

cooling

Crust	Si, O
Mantle	Si, Mg, O, Fe
Core (liquid)	Fe, Ni, Si, S
Core (solid)	Fe, Ni



U, Th, K concentrated in crust & mantle

Modern Earth, with heavy elements in the middle, light elements near surface

Layered through sedimentation
-4 byr

Interlude: particle physics

$$\beta^- \text{ decay} : {}^{A}_{Z}\mathrm{X} \rightarrow {}^{A}_{Z+1}\mathrm{Y} + e^- + \bar{\nu}_e$$

$$\mathrm{EC} : {}^{A}_{Z}\mathrm{Y} + e^- \rightarrow {}^{A}_{Z-1}\mathrm{X} + \nu_e$$

^{238}U decay chain:

$$^{238}\mathrm{U} \xrightarrow{\alpha} {}^{234}\mathrm{Th} \xrightarrow{\beta^-}_{\downarrow \bar{\nu}_e} {}^{234}\mathrm{Pa} \xrightarrow{\beta^-}_{\downarrow \bar{\nu}_e} {}^{234}\mathrm{U} \xrightarrow{\alpha} {}^{230}\mathrm{Th} \xrightarrow{\alpha} {}^{226}\mathrm{Ra} \xrightarrow{\alpha} {}^{222}\mathrm{Rn} \xrightarrow{\alpha} {}^{218}\mathrm{Po} \xrightarrow{\alpha} {}^{214}\mathrm{Pb} \xrightarrow{\beta^-}_{\downarrow \bar{\nu}_e} {}^{214}\mathrm{Bi} \xrightarrow{\beta^-}_{\downarrow \bar{\nu}_e} {}^{214}\mathrm{Po} \xrightarrow{\alpha} {}^{210}\mathrm{Pb} \xrightarrow{\beta^-}_{\downarrow \bar{\nu}_e} {}^{210}\mathrm{Bi} \xrightarrow{\beta^-}_{\downarrow \bar{\nu}_e} {}^{210}\mathrm{Po} \xrightarrow{\alpha} {}^{206}\mathrm{Pb}$$

$$^{238}\mathrm{U} \rightarrow {}^{206}\mathrm{Pb} + 8\alpha + 6e^- + \boxed{6\bar{\nu}_e} + \sim 52\,\mathrm{MeV}$$

^{235}U decay chain:

$$^{235}\mathrm{U} \rightarrow {}^{207}\mathrm{Pb} + 7\alpha + 4e^- + \boxed{4\bar{\nu}_e} + \sim 46\,\mathrm{MeV}$$

^{232}Th decay chain:

$$^{232}\mathrm{Th} \rightarrow {}^{208}\mathrm{Pb} + 6\alpha + 4e^- + \boxed{4\bar{\nu}_e} + \sim 43\,\mathrm{MeV}$$

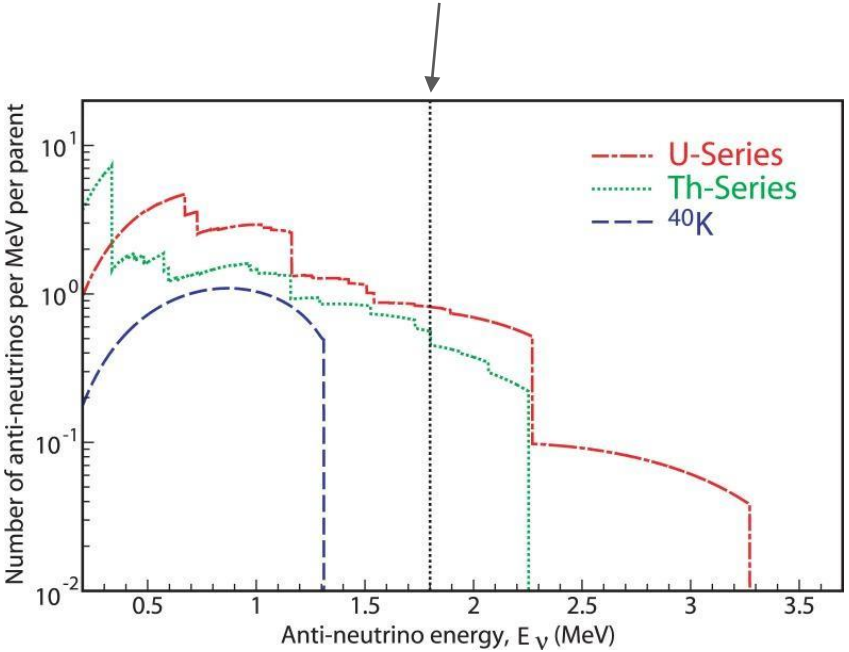
^{40}K decay chain:

$$^{40}\mathrm{K} \rightarrow {}^{40}\mathrm{Ca} + e^- + \boxed{\bar{\nu}_e} + \sim 1\,\mathrm{MeV}$$

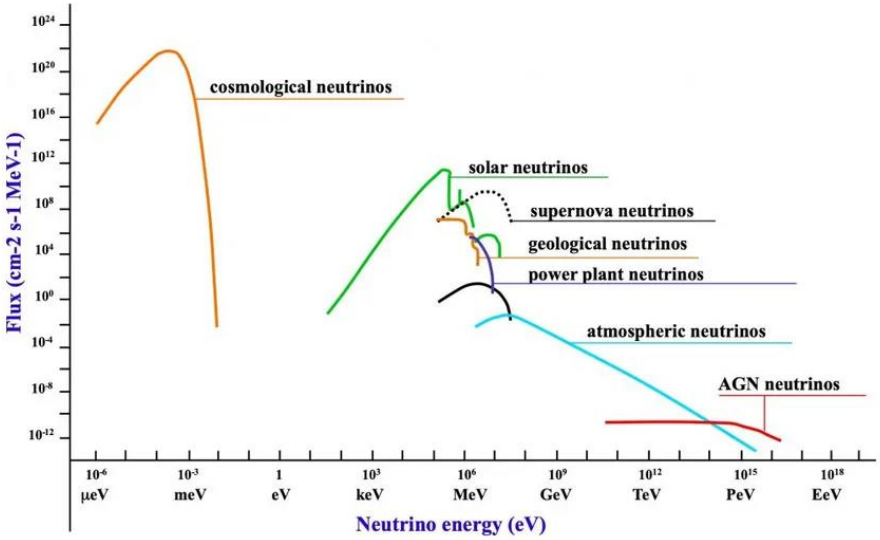
$$^{40}\mathrm{K} + e^- \rightarrow {}^{40}\mathrm{Ar} + \boxed{\nu_e} + \sim 2\,\mathrm{MeV}$$

Interlude: particle physics

Question for credit: what's this mysterious line?



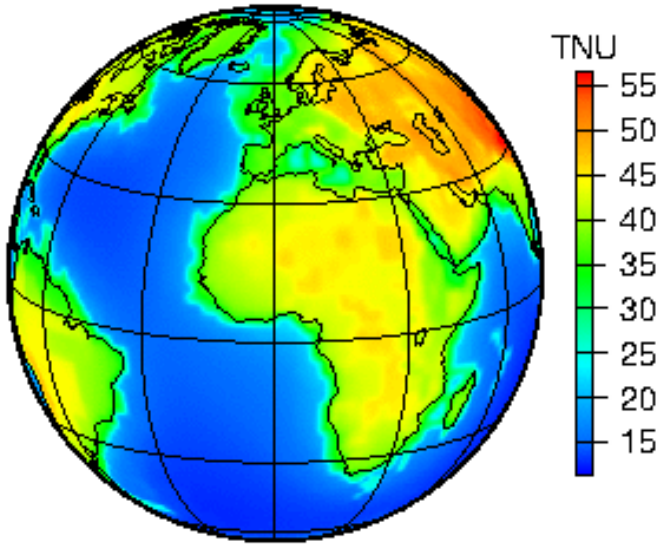
In the grand scheme of ~~things~~ neutrinos:



Heat in the Earth

The Earth generates 47TW of heat from (in unknown ratio):

- “Primordial” (residual) heat
- Radioactive decay energy



Heat in the Earth:

- Keeps the core liquid => allows convection
- Generates Earth’s magnetic field
- Drives plate tectonics
- Causes volcanic activity
- Cycles heat from the core to the surface

Open questions

What proportion of the Earth's heating power comes from radioactive decay vs primordial heat?

This affects whether the Earth is in steady state or cooling.

What is the composition of the Earth's mantle?

This would allow us to discriminate between our current geological models.

Missing elements problem: Earth's composition differs from meteors in certain elements. One of these elements is potassium.

What is the U/Th ratio in the Earth?

This sheds light on our Earth's history and how it was formed.

Bit of History

Neutrinos first predicted in 1930 by Wolfgang Pauli, and first detected in 1956 from a reactor.

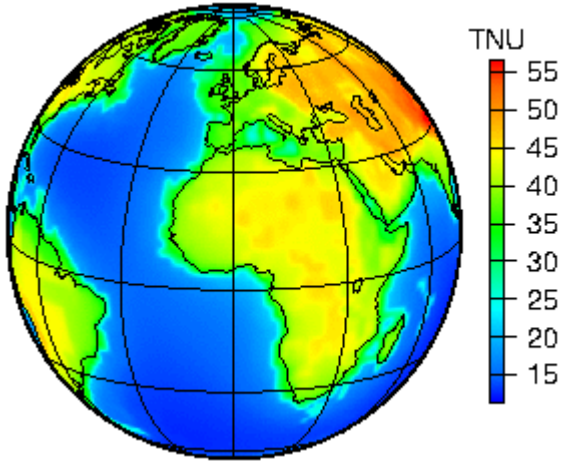
In the 1960’s, people started wondering if you could use Geologically produced neutrinos to study the Earth’s composition.

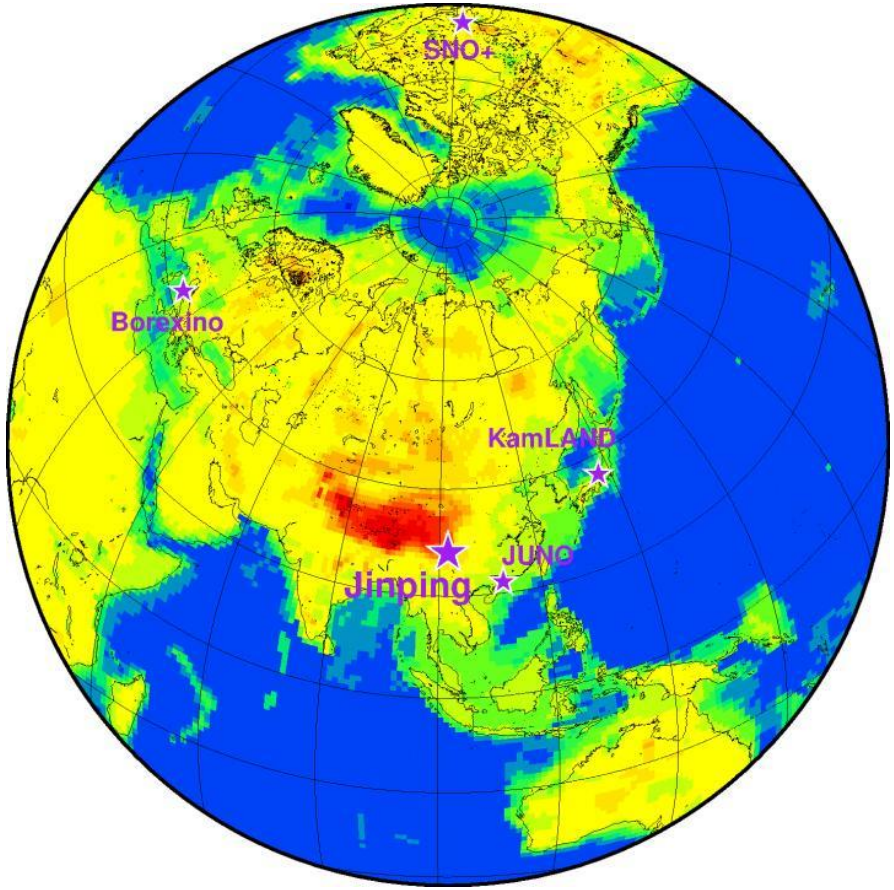
In 1984, Krauss, Glashow, and Schramm predict flux of geoneutrinos, and discuss detection.

In 2005, the first geoneutrinos were detected at KamLAND.

Detectors being used

- KamLAND
- Borexino
- SNO+
- Juno

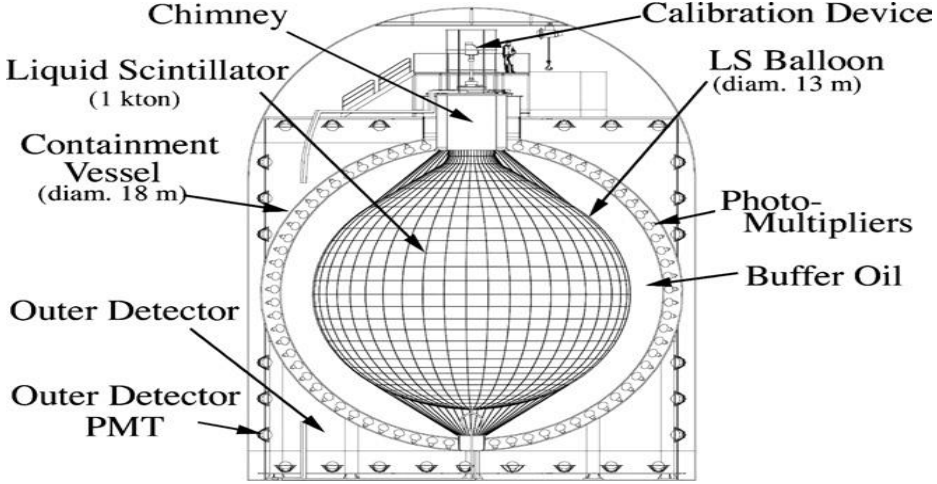




KamLAND

1.0 Kiloton Detector.

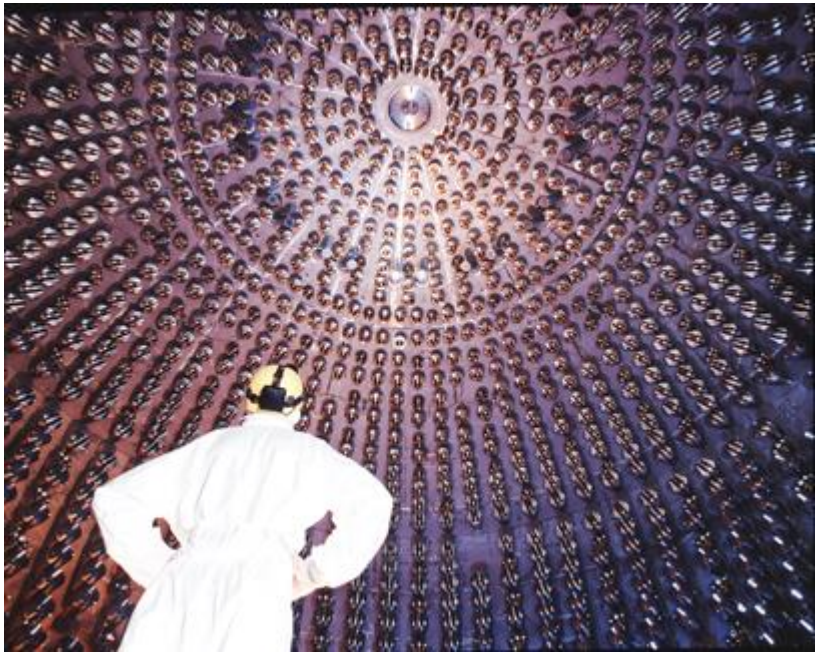
Located at the Kamioka Observatory in Japan.

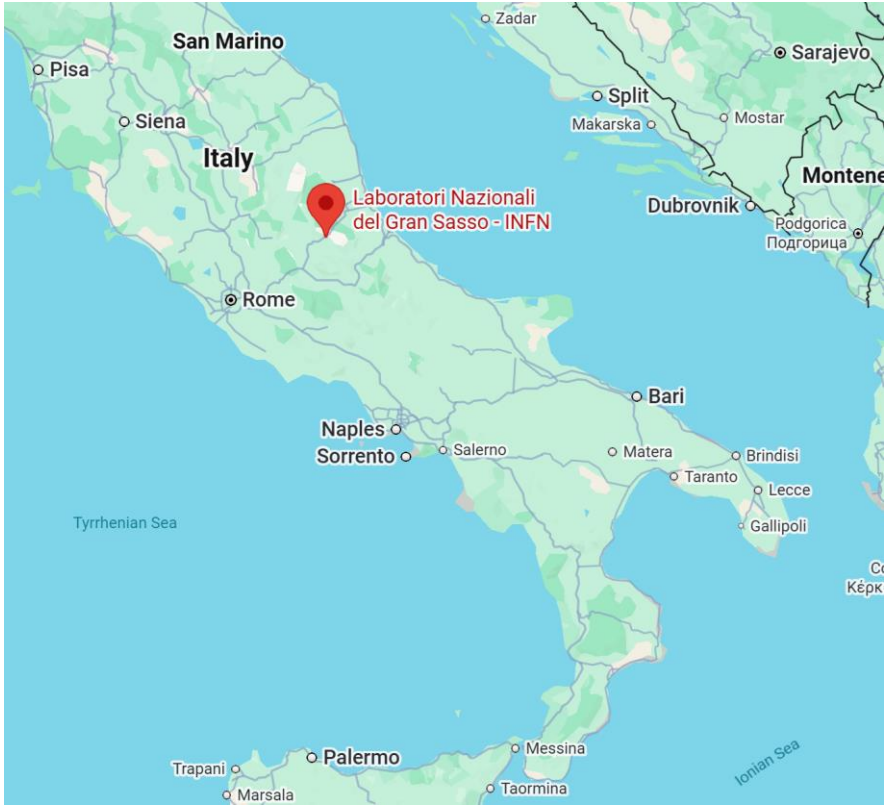


Borexino

0.3 Kiloton Detector.

Located at LNGS in Italy

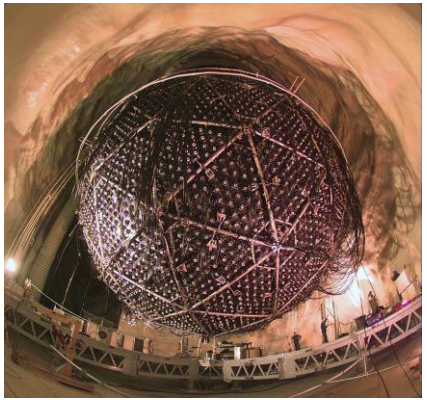


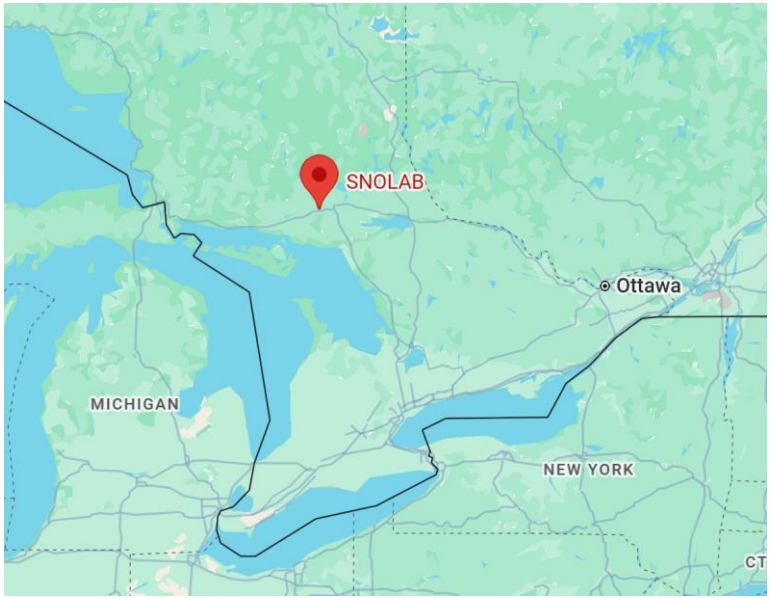


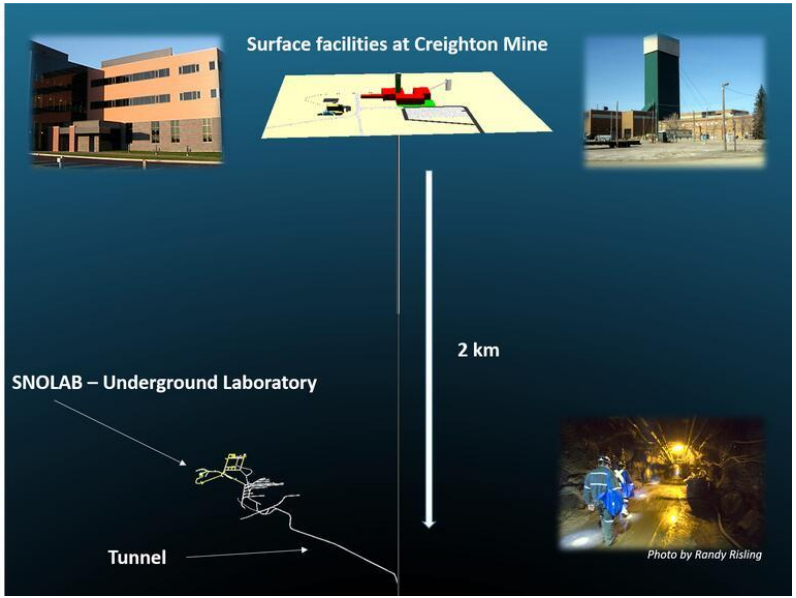
SNO+

0.8 Kiloton Detector.

Located at SNOLAB in Canada



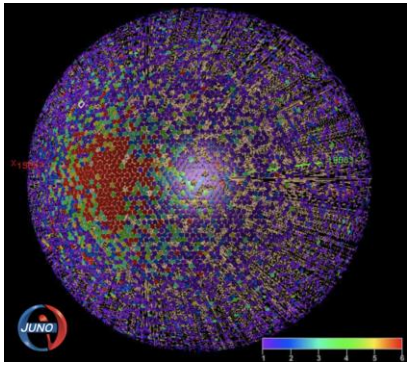


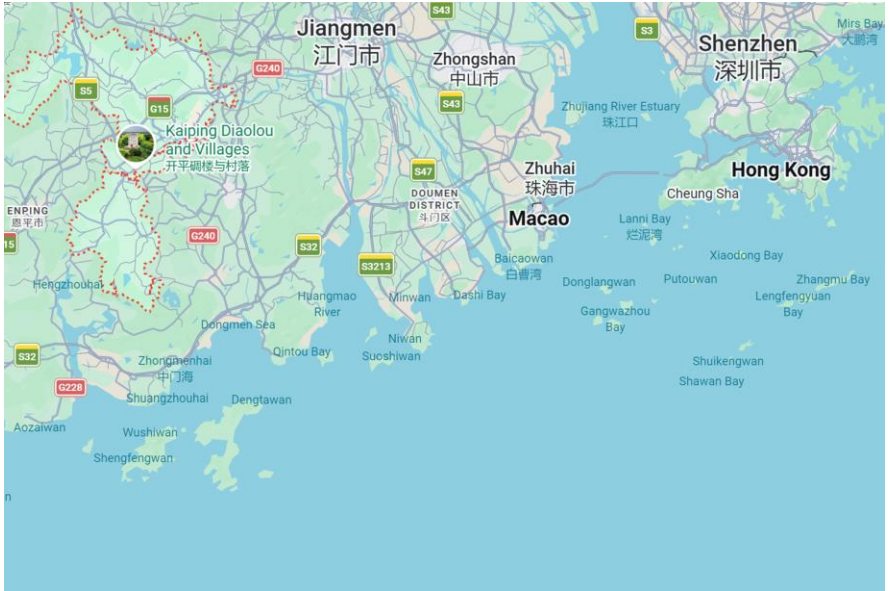


JUNO

20 Kiloton Detector.

Located at Kaiping in China

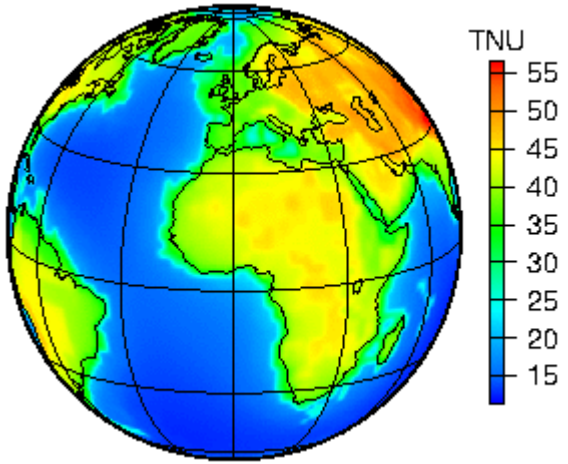




What is a TNU?

TNU is a Terrestrial Neutrino Unit.

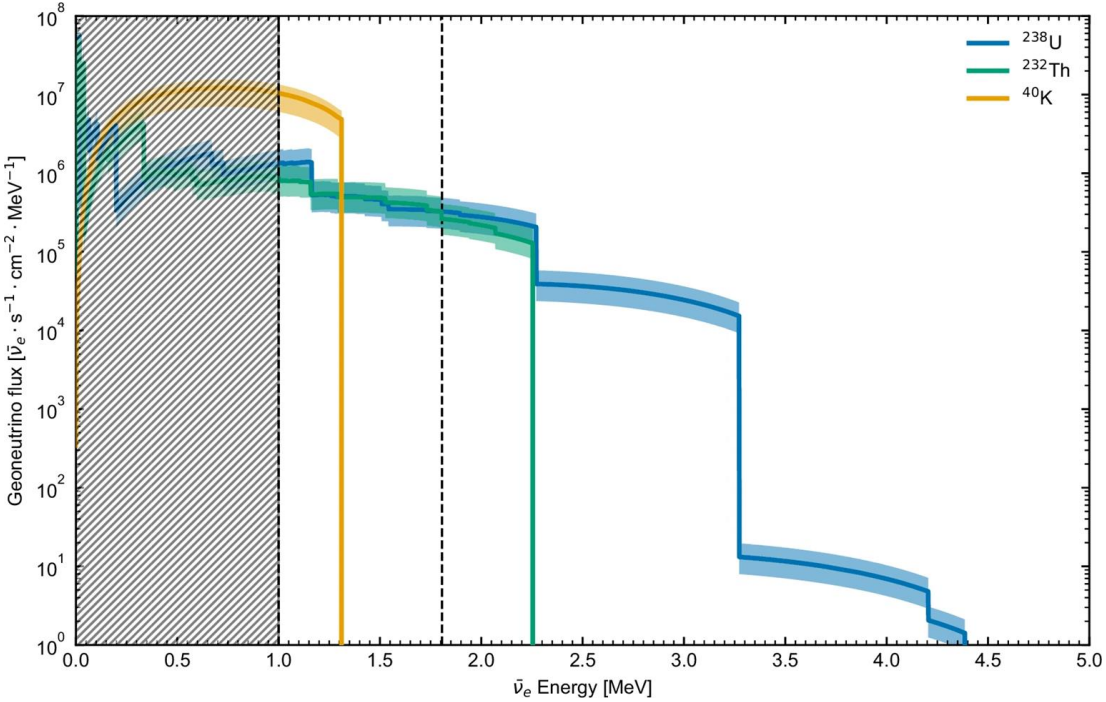
One TNU is equivalent to one geoneutrino event recorded over a year-long, fully efficient exposure of 10^{32} free protons, approximately the number of protons in 1 kiloton of liquid scintillator. The conversion between flux units and TNU units dependent on the Thorium to Uranium (Th/U) abundance ratio.



Challenges: Energy threshold

The inverse beta decay reaction has a threshold of 1.806 MeV.

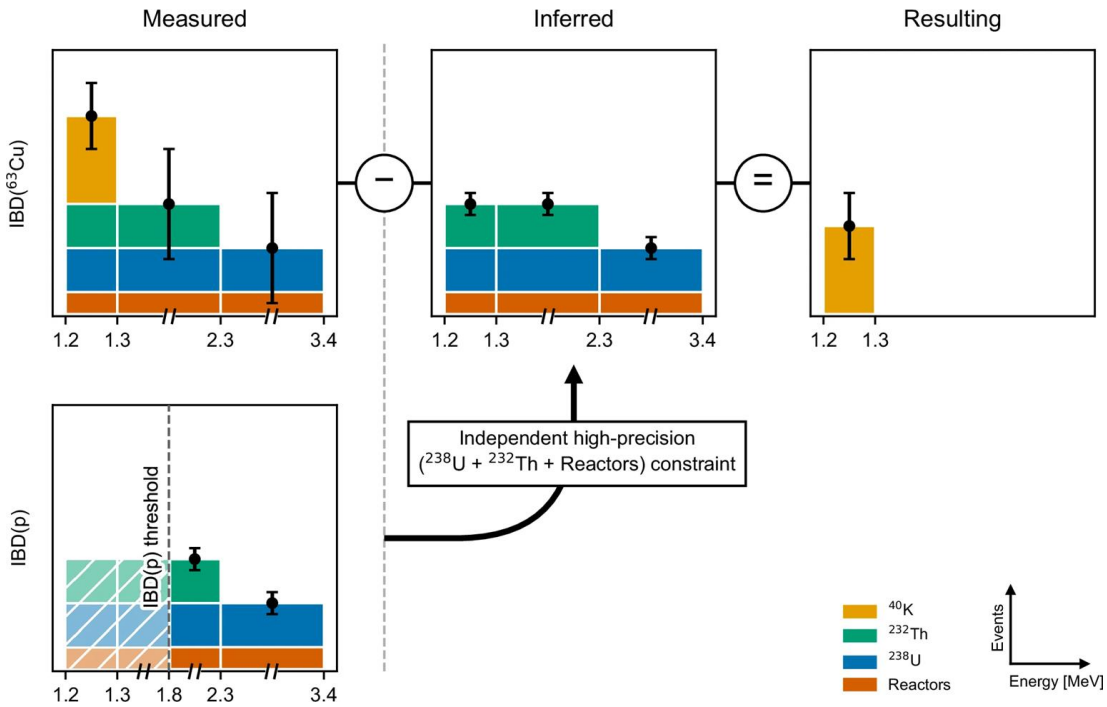
While antineutrinos from 238-U (3.27 MeV) and 232-Th (2.25 MeV) exceed this threshold, 40K do not, preventing their detection with conventional experiments.



Challenges: Backgrounds

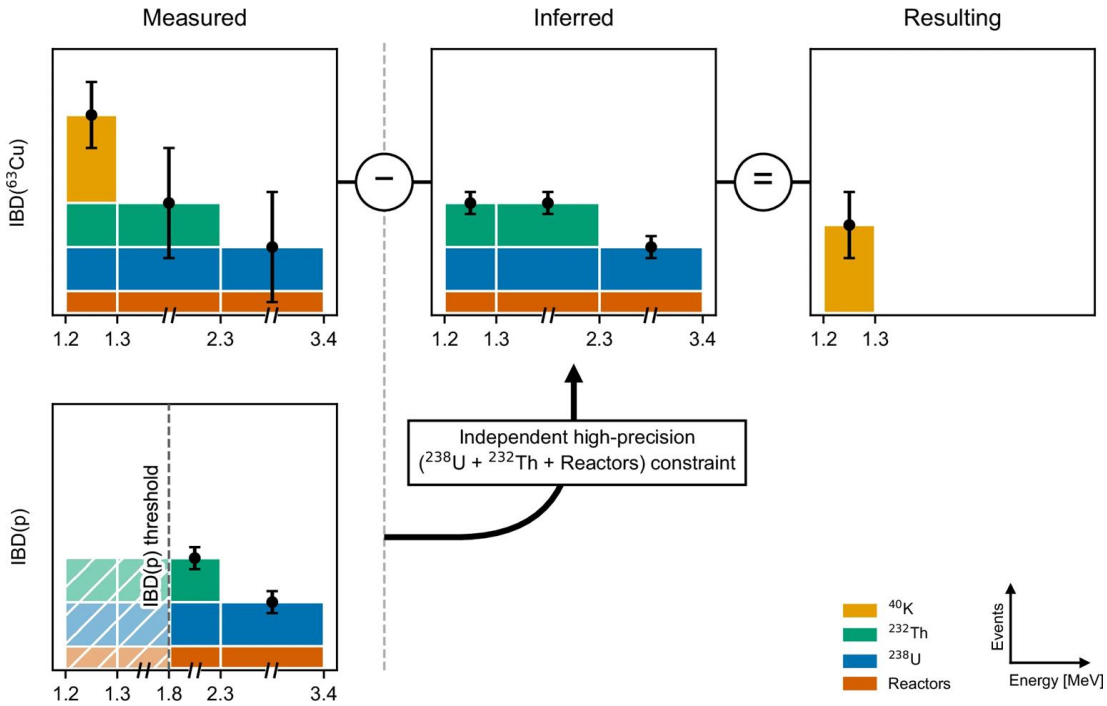
Experimental errors in geoneutrinos experiments are associated with low statistics and the presence of backgrounds.

Separating the geoneutrino signal from backgrounds distributions is one of the main challenges in current experiments



Challenges: Backgrounds

Experiments could extract the signal statistically from the measured energy spectrum rather that identifying individual geoneutrino events.



LiquidO: A proposed detection scheme using 63Cu

$$\bar{\nu}_e + {}^{63}\mathrm{Cu} \longrightarrow {}^{63}\mathrm{Ni}^* + e^+$$

$$e^+ + e^- \longrightarrow 2\gamma$$

$${}^{63}\mathrm{Ni}^* \longrightarrow {}^{63}\mathrm{Ni} + \gamma$$

$$\mathrm{E_{th}} = 1.176\ \mathrm{MeV}$$

The 63Cu interaction is sensitive to 40K geoneutrinos, owing to its lower reaction threshold of 1.176 MeV

LiquidO combines optical segmentation with a copper-loaded liquid scintillator

A. Cabrera *et al.* (LiquidO Collaboration), *Communications Physics* **9**, 95 (2026).