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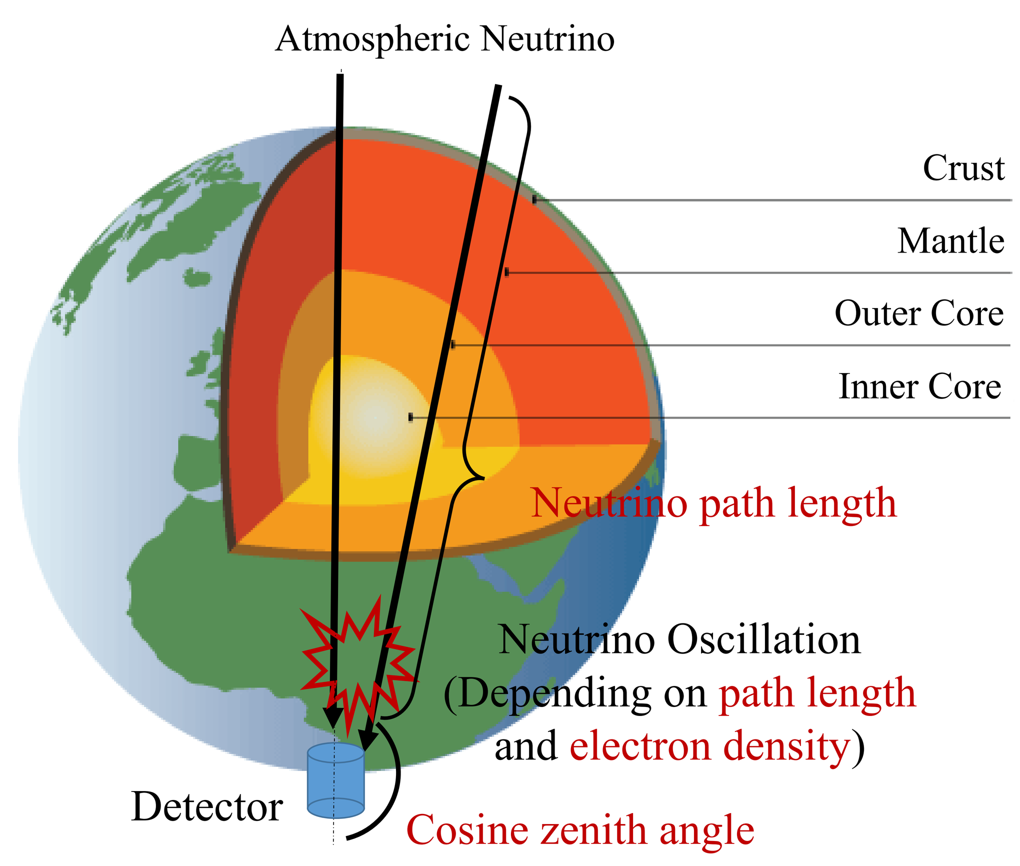
Earth Tomography Using Neutrino Oscillations

JongHyun Kim, Debanjan Bose

Abstract

Understanding the inner structure and composition of the Earth is fundamental to Earth science. Even though Earth's average density is very well known, the inner Earth composition is far more uncertain and has not been measured. Of particular interest is the composition of thermochemical piles in the mantle and the light element content in the outer core. Neutrinos, which are naturally produced in the atmosphere, traverse the Earth and undergo oscillations that depend on the Earth's electron density. Using neutrino oscillations in combination with seismic measurement, we can remotely determine the chemical composition of the Earth's structure. We explore the potential of the neutrino oscillation tomography with next-generation neutrino detectors

Motivation



Neutrino passing through the Earth

Formula

- Neutrino oscillates one flavor to another as it travels
- Neutrino when passes through matter [e.g. Earth] due to forward scattering of electron neutrinos neutrino oscillations are modified (MSW Effect)
- Exploiting this features, we can estimate electron density of the Earth's core

➢ Survival probability of $\nu_\mu \to \nu_\mu$

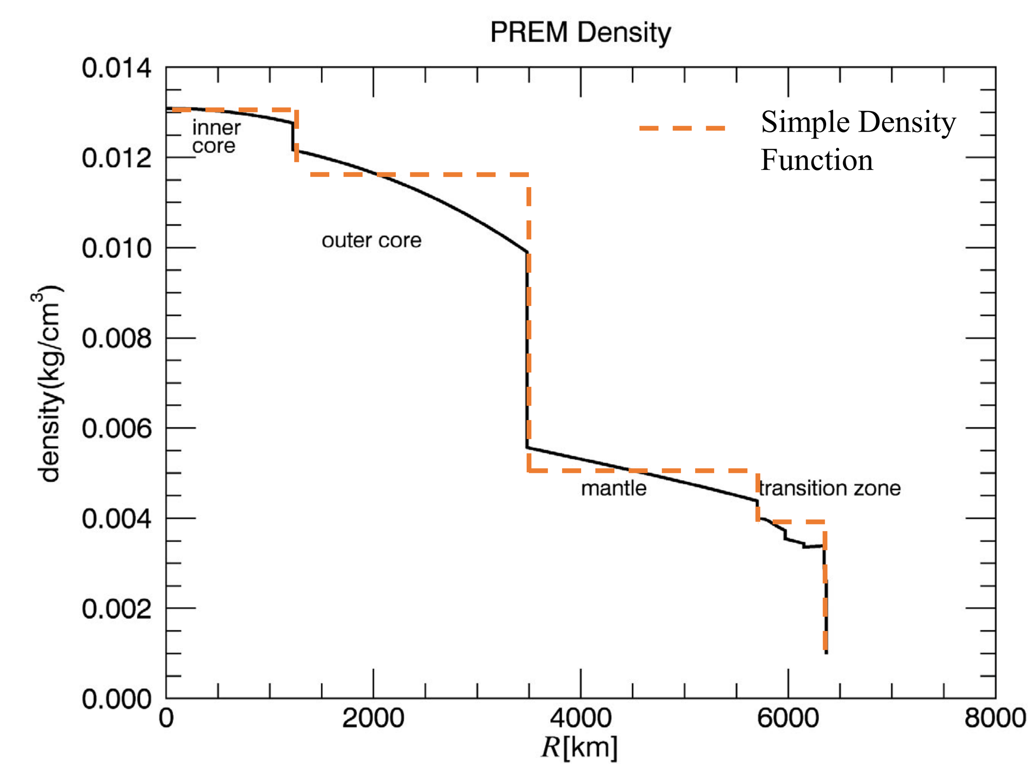
$$P(\nu_\mu \to \nu_\mu) \sim 1 - \sin^2\theta \, \sin^2\left(\frac{1.27\Delta m^2 L}{E_\nu}\right)$$

➢ Observed events calculation

$$N_{events} = Flux \cdot A_{eff}(E) \cdot P(\nu_\mu \to \nu_\mu) \cdot \; Livetime$$

Earth density profile and composition

- PREM(Preliminary Reference Earth Model)



- Chemical composition of the Earth

1) Mantle : Pyrolite

2) Core: Iron / Nickel alloy + light element

- Several models of the Earth's outer core

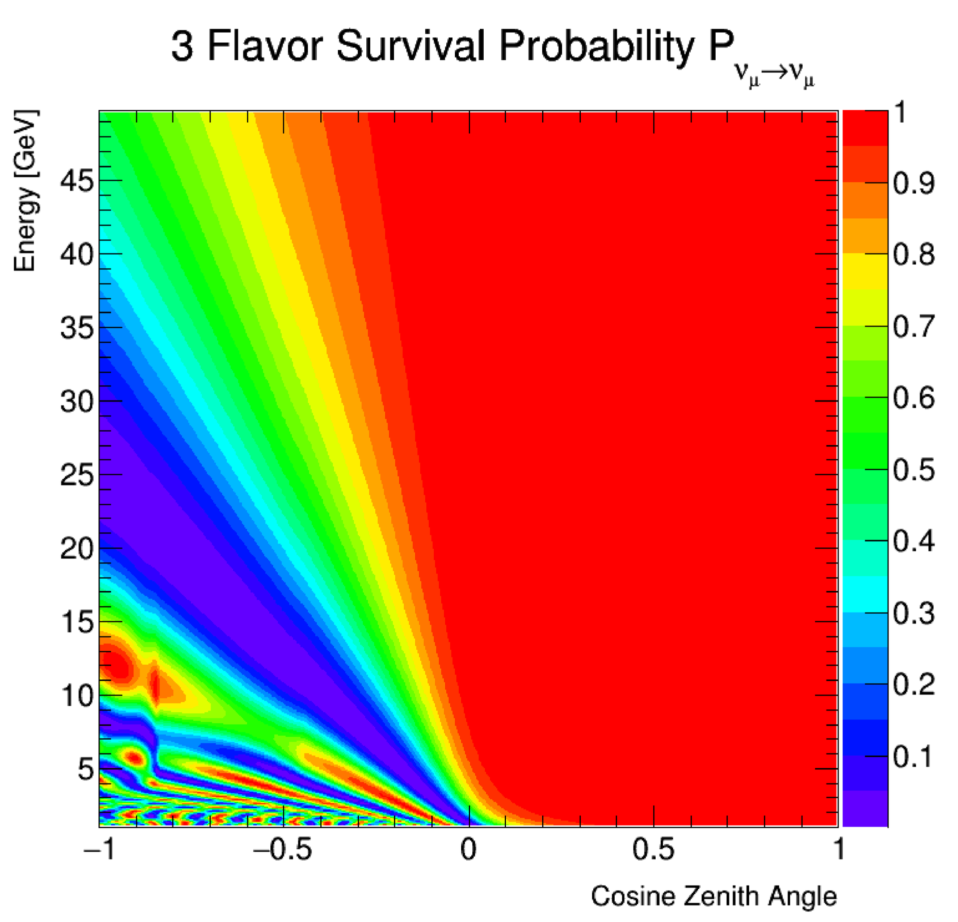
① Fe + 1wt% H → Z/A = 0.4709

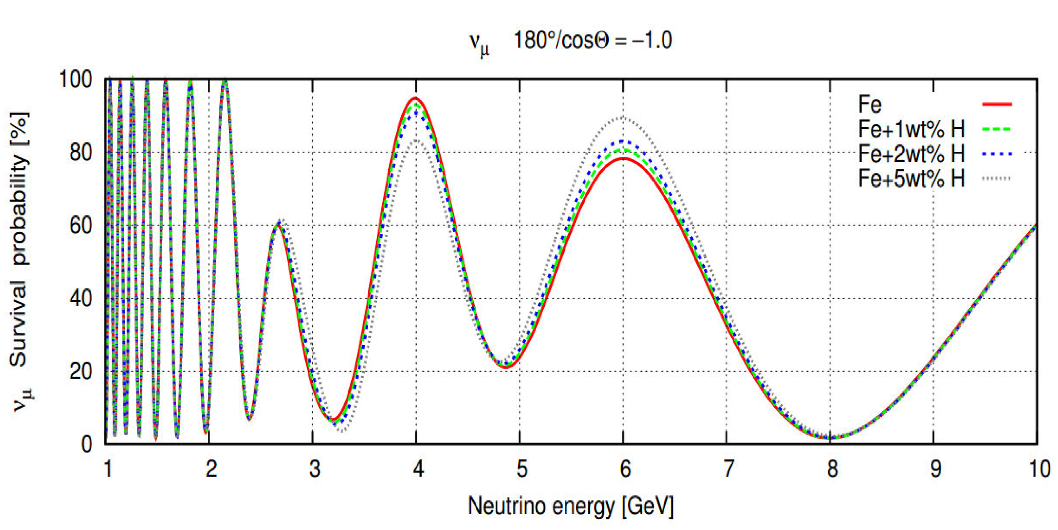
② Fe + 11wt% O → Z/A = 0.4693

③ McDonough 2000 → Z/A = 0.4682
(Fe + 6wt%Si + 1.9wt%S + 0.2wt%C + 0.06wt%H)

Z/A : Electron density per atom

Effect of neutrino oscillation

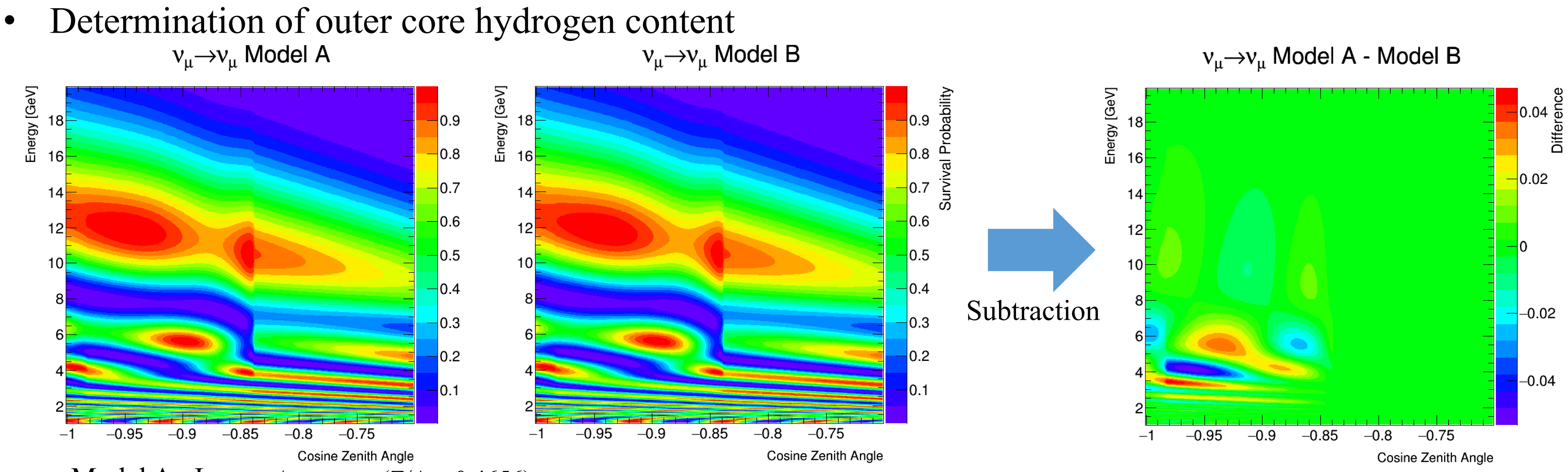




Survival probability of various model in fixed angle

Principle oscillation tomography

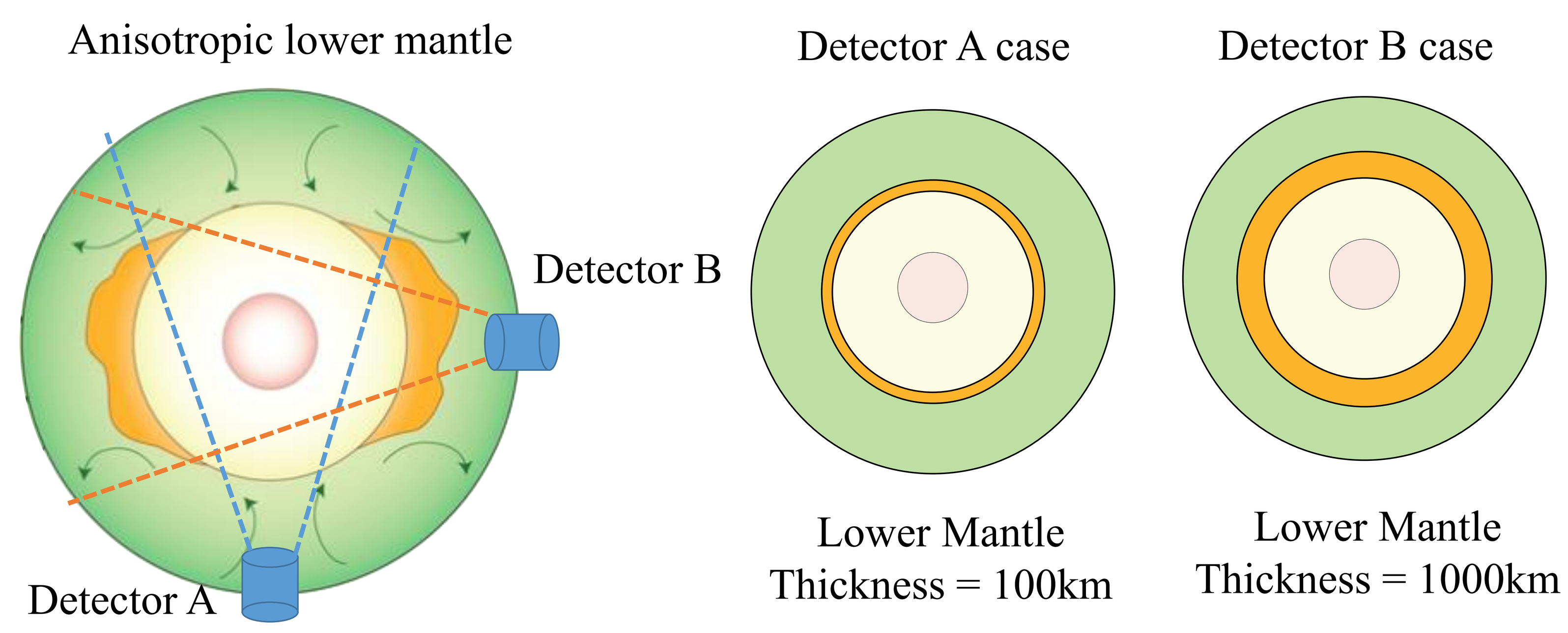
- Determination of outer core hydrogen content

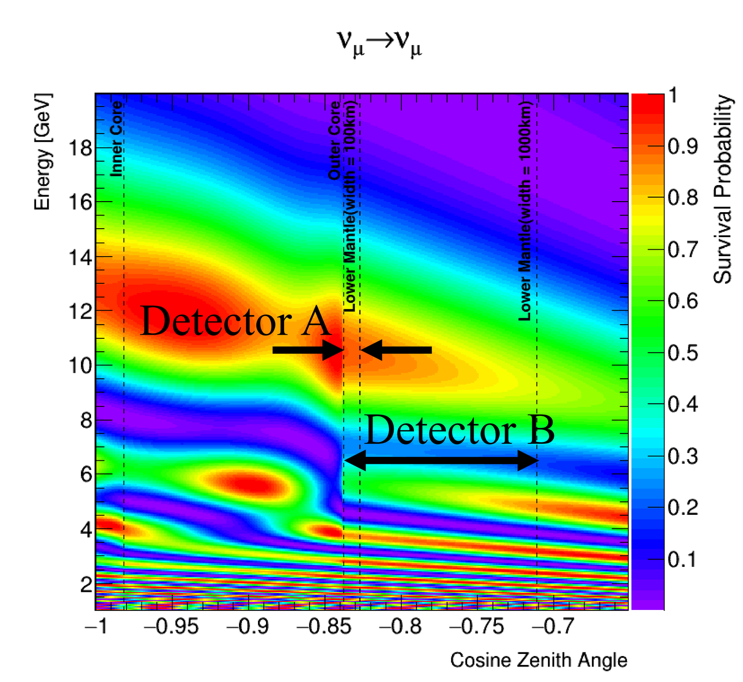


Model A : Iron outer core (Z/A = 0.4656)
Model B : Alloy of iron and 1wt% hydrogen (Z/A = 0.4709)

Probability difference between two models

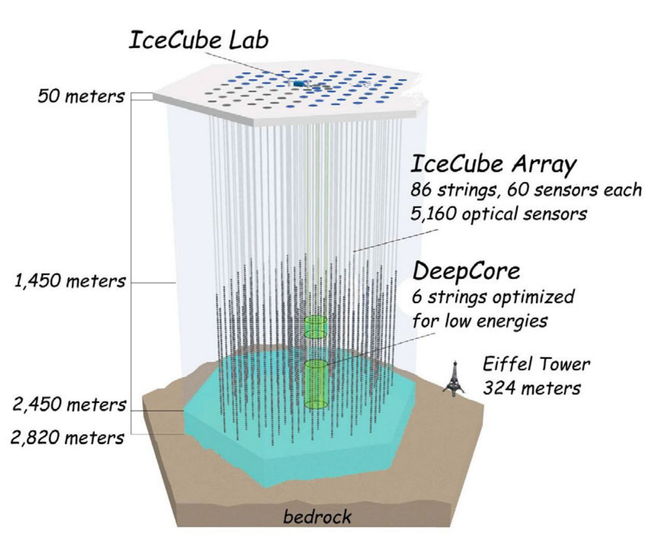
- Modeling of anisotropic mantle



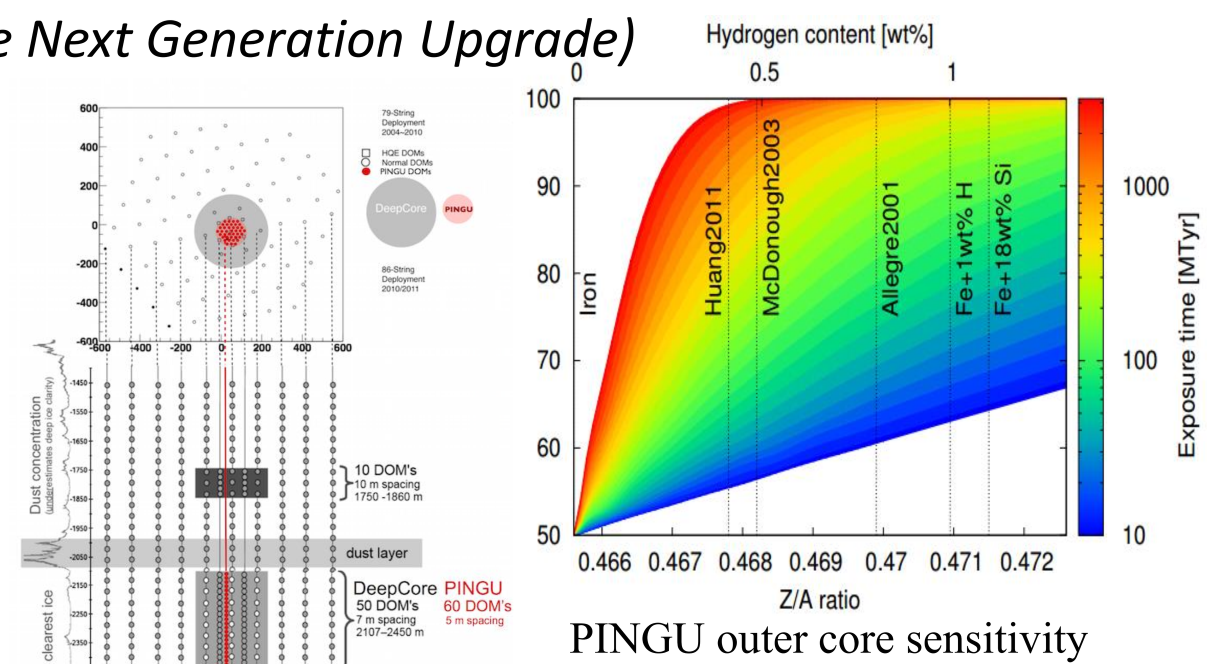


Next generation neutrino detectors and sensitivity

- PINGU(*Precision IceCube Next Generation Upgrade*)

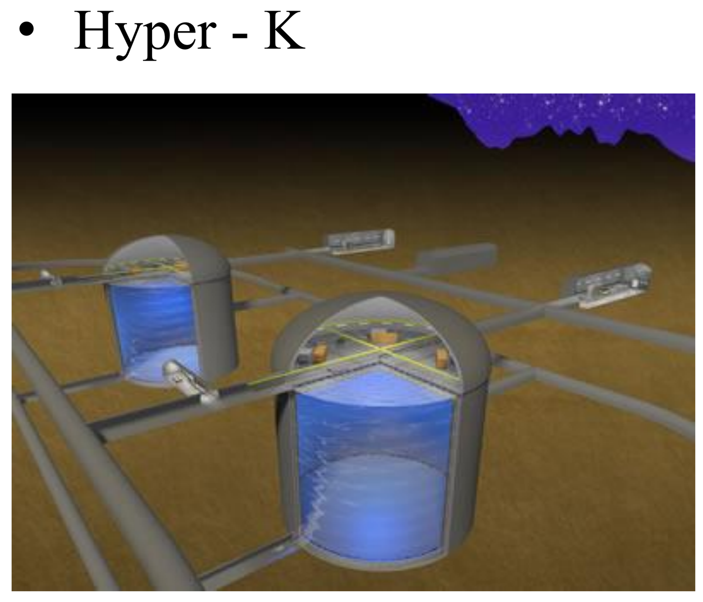


IceCube and PINGU

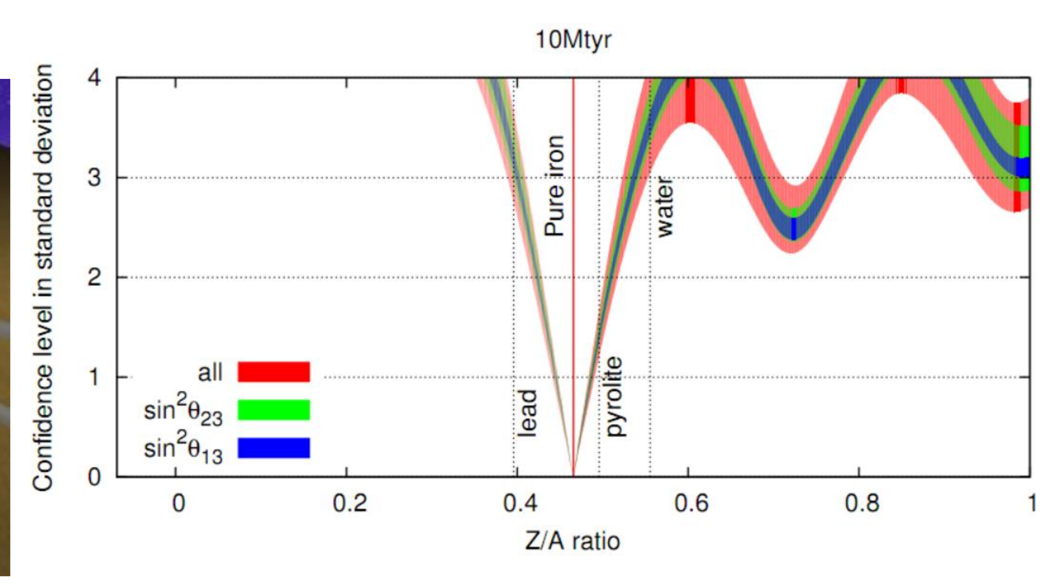


PINGU outer core sensitivity
(Energy threshold : few GeV)

- Hyper - K



Hyper-K illustration



Hyper-K outer core sensitivity
(Energy threshold : much lower energy)

Conclusion

- Neutrino Oscillation tomography is a new tool to investigate the Earth's structure
- Using the neutrino oscillation with seismic measurement, we can measure the Earth's chemical composition remotely
- Prospects to study anisotropic in the mantle
- With next generation neutrino detectors like PINGU and Hyper-K, we expect better understanding of the inner Earth composition and anisotropic mantle

Reference

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