John Learned,  University of Hawaii at Manoa
(& other colleagues at UH and elsewhere)

(HANOHANO consists of about 20 institutions, collaboration not yet official, including U. Tohoku, U. Maryland, U. Alabama, Stanford, Caltech, UC Davis, U. Munich, and more)
Outline

- **Neutrino Oscillation Physics**
  - Review KamLAND results
  - Mixing angles $\theta_{12}$ and $\theta_{13}$
  - Mass squared difference $\Delta m^2_{31}$
  - Mass hierarchy

- **Hanohano:**
  - **Deep ocean:** measure mantle neutrinos
  - **Mobile:** position off shore reactor at ideal distance(s)
  - Detector Studies

- **Neutrino Geophysics**
  - U & Th mantle flux
  - Th/U ratio
  - Georeactor search

- **Other studies, future**
MeV-Scale Electron Anti-Neutrino Detection

Production in reactors and natural decays

Key: 2 flashes, close in space and time, 2nd of known energy, eliminate background

Detection

- Standard inverse β-decay coincidence
- $E_\nu > 1.8$ MeV
- Rate and spectrum - no direction

Reines & Cowan
**$\nu_e$ Mixing Parameters: Present Knowledge**

- **KamLAND combined analysis:**
  \[
  \tan^2(\theta_{12}) = 0.40 (+0.10/-0.07)
  \]
  \[
  \Delta m^2_{21} = (7.9 \pm 0.7) \times 10^{-5} \text{ eV}^2
  \]
  (update on next slide)

- **CHOOZ limit:**
  \[
  \sin^2(2\theta_{13}) \leq 0.20
  \]

- **SuperK and K2K:**
  \[
  \Delta m^2_{31} = (2.5 \pm 0.5) \times 10^{-3} \text{ eV}^2
  \]
  Ashie et al., *Phys. Rev.* D64 (2005) 112005
Measurement of Reactor Antineutrinos in KamLAND

Japanese Reactors

Kashiwazaki

Takahama

Ohi

55 reactors

Reactors Isotopes

Antineutrino Detection in KamLAND

$\bar{\nu}_e + p \rightarrow e^+ + n$

through inverse $\beta$-decay

$235U : 238U : 239Pu : 241Pu = 0.570 : 0.078 : 0.0295 : 0.057$

reactor $\bar{\nu}$ flux $\sim 6 \times 10^6$/cm$^2$/sec

TAUP2007, Sendai, Japan, September 13, 2007
## Systematic Uncertainty

“full volume” calibration lowered the fiducial volume error

(4.7% in previous analysis)

<table>
<thead>
<tr>
<th>Detector related</th>
<th>Reactor related</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiducial volume</td>
<td>$\bar{\nu}_e$ spectra</td>
</tr>
<tr>
<td></td>
<td>1.8%</td>
</tr>
<tr>
<td>Energy scale</td>
<td>Reactor power</td>
</tr>
<tr>
<td></td>
<td>1.5%</td>
</tr>
<tr>
<td>L-selection eff.</td>
<td>Fuel composition</td>
</tr>
<tr>
<td></td>
<td>0.6%</td>
</tr>
<tr>
<td>OD veto</td>
<td>Long-lived nuclei</td>
</tr>
<tr>
<td></td>
<td>0.2%</td>
</tr>
<tr>
<td>Cross section</td>
<td>Time lag</td>
</tr>
<tr>
<td></td>
<td>0.2%</td>
</tr>
</tbody>
</table>

Total systematic uncertainty : 4.1%
Survival Probability: L/E Variation

Oscillations: 1st and 2nd reappearance!

Expected survival probability for point source at 180km baseline

L₀ = 180km flux-weighted average reactor distance

Definitely oscillations... alternatives not viable any more.

KamLAND data
best-fit osci.
best-fit osci. + Expected Geo \( \bar{\nu}_e \)
Oscillation Parameters

\[ \tan^2 \theta = 0.56^{+0.14}_{-0.09} \]
\[ \Delta m^2 = 7.58^{+0.21}_{-0.20} \times 10^{-5} \text{ eV}^2 \]

(KamLAND only)

SNO  KamLAND

Small matter effect

\[ \Delta \chi^2 \]

\[ \Delta m^2 (\text{eV}^2) \]

LMA II

3 neutrino effect

LMA 0

3 neutrino

2 neutrino

Same result for \( \Delta m^2 \)

Preliminary
Neutrino Oscillations Parameters Summary

Atmospheric Neutrinos

Solar & Reactor Neutrinos

(And forget the rest!)

http://hitoshi.berkeley.edu/neutrino
Dirty laundry or smudged glasses? The LSND-MiniBOONE Problem

Conclusion: Each experiment has an “anomaly” with spectrum like the background; together are incompatible with any oscillations interpretation.

What they want: More beamtime.

Best bet (JGL): Waste of time. But maybe not...
The State of the Neutrino Mixing Matrix (MNSP)

\[
U_{MNS} = \begin{pmatrix}
U_{e1} & U_{e2} & U_{e3} \\
U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\
U_{\tau 1} & U_{\tau 2} & U_{\tau 3}
\end{pmatrix} = \begin{pmatrix}
1 & c_{13} & s_{13}e^{-i\delta} \\
c_{23} & s_{23} & 1 \\
-s_{23} & c_{23} & -s_{13}e^{i\delta}
\end{pmatrix} \begin{pmatrix}
c_{12} & s_{12} \\
-s_{12} & c_{12}
\end{pmatrix}
\]

Normal hierarchy --- Inverted Hierarchy

\[
\begin{pmatrix}
0.8 & 0.5 \\
0.6 & 0.7
\end{pmatrix}
\]

Quarks

\[
V_{CKM} = \begin{pmatrix}
1 & 0.2 & 0.04 \\
0.2 & 1 & 0.04 \\
0.04 & 0.04 & 1
\end{pmatrix}
\]
Hanohano
a mobile deep ocean detector

10 kiloton liquid scintillation

Deploy and retrieve from barge
2 Candidate Off-shore Sites for Physics

San Onofre, California - $\sim6 \, \text{GW}_{\text{th}}$
Maanshan, Taiwan - $\sim5 \, \text{GW}_{\text{th}}$

Need study of backgrounds versus depth
Neutrino Oscillation Physics with Hanohano

- Precision measurement of mixing parameters needed (4 of 5 in Hanohano)
- World effort to determine $\theta_{13} (= \theta_{31})$ (Hanohano, unique method)
- Determination of mass hierarchy (Hanohano novel method)
- Neutrino properties relate to origin of matter, formation of heavy elements, and may be key to unified theory (pace Landscape folks).
3-ν Mixing: Reactor Neutrinos

\[ P_{ee} = 1 - \left\{ \cos^4(\theta_{13}) \sin^2(2\theta_{12}) \left[ 1 - \cos(\Delta m^2_{12} L/2E) \right] + \cos^2(\theta_{12}) \sin^2(2\theta_{13}) \left[ 1 - \cos(\Delta m^2_{13} L/2E) \right] + \sin^2(\theta_{12}) \sin^2(2\theta_{13}) \left[ 1 - \cos(\Delta m^2_{23} L/2E) \right] \right\} / 2 \]

- Survival probability: 3 oscillating terms each cycling in L/E space (\( \sim t \)) with own “periodicity” (\( \Delta m^2 \sim \omega \))
  - Amplitude ratios \( \sim 13.5 : 2.5 : 1.0 \)
  - Oscillation lengths \( \sim 110 \text{ km} \) (\( \Delta m^2_{12} \)) and \( \sim 4 \text{ km} \) (\( \Delta m^2_{13} \sim \Delta m^2_{23} \)) at reactor peak \( \sim 3.5 \text{ MeV} \)

- ½-cycle measurements can yield
  - Mixing angles, mass-squared differences

- Multi-cycle measurements can yield
  - Mixing angles, precise mass-squared differences
  - Mass hierarchy
  - **Less sensitivity to systematic errors**
Hanohano: Guaranteed Precise measurement for \(\frac{1}{2}\)-cycle \(\theta_{12} (= \theta_{21})\)

- Reactor experiment - \(\nu_e\) point source
- \(P(\nu_e \rightarrow \nu_e) \approx \sin^2(2\theta_{12})\sin^2(\Delta m_{21}^2L/4E)\)
- 60 GW·kt·y exposure at 50-70 km
  - \(\sim 4\%\) systematic error from near detector
  - \(\sin^2(\theta_{12})\) measured with \(\sim 2\%\) uncertainty

Minakata et al., hep-ph/0407326
Bandyopadhyay et al., hep-ph/0410283

oscillation maximum at \(\sim 50-60\) km
Reactor $\nu_e$ Spectra at 50 km

~4400 events per year from San Onofre

Fitting will give improved $\theta_{12}$

1,2 oscillations with $\sin^2(2\theta_{12})=0.82$ and $\Delta m^2_{21}=7.9 \times 10^{-5} \text{ eV}^2$

1,3 oscillations with $\sin^2(2\theta_{13})=0.10$ and $\Delta m^2_{31}=2.5 \times 10^{-3} \text{ eV}^2$
Fourier Transform on L/E to $\Delta m^2$

- $\Delta m^2_{32} < \Delta m^2_{31}$
- Normal hierarchy
- 0.0025 eV$^2$
  - Peak due to nonzero $\theta_{13}$

Spectrum with $\theta_{13}=0$

No Osc. Spectrum

Includes energy smearing

50 kt-y exposure at 50 km range

$\sin^2(2\theta_{13}) \geq 0.02$

$\Delta m^2_{31} = 0.0025$ eV$^2$ to 1% level

Learned, Dye, Pakvasa, Svoboda hep-ex/0612022
Measure $\Delta m^2_{31}$ by Fourier Transform & Determine $\nu$ Mass Hierarchy

Note asymmetry due to hierarchy

\[ \Delta m^2_{31} > \Delta m^2_{32} \quad |\Delta m^2_{31}| < |\Delta m^2_{32}| \]

Determination at ~50 km range

\[ \sin^2(2\theta_{13}) \geq 0.05 \text{ and } 10 \text{ kt-y} \]
\[ \sin^2(2\theta_{13}) \geq 0.02 \text{ and } 100 \text{ kt-y} \]

Learned, Dye, Pakvasa, and Svoboda, hep-ex/0612022
Hierarchic Determination

Ideal Case with 10 kiloton Detector, 1 year off San Onofre

Distance variation: 30, 40, 50, 60 km

Inverted hierarchy

Hierarchy tests employing Matched filter technique, for Both normal and inverted hierarchy on each of 1000 simulated one year experiments using 10 kiloton detector.

Normal Hierarchy

100 kt-yrs separates even at 0.02

Sensitive to energy resolution: probably need 3%/sqrt(E)
Misha’s New Simulation:

• Calculations of the expected Hanohano live-times to reach various physics goals were done under the assumptions of:

  -- 10 kt detector (fiducial)

  -- 5 GWt single power plant

  -- Same # of protons per mass as KamLAND

• Main points:

  -- Systematics considered:

    a) "general efficiency": fiducial volume, number of protons, eff. of cuts, etc.

    b) error in detector resolution estimation.

  -- Systematics ignored at this point:

    a) overall energy scale error

    b) background uncertainties
Precision Measurement of $\Theta_{12}$

- Solar Parameters: ~2 years at ~40 km baseline
  - $\sin^2(2\Theta_{12})$ down to 0.005
  - $\Delta m^2_{12}$ to 0.05E-5 eV$^2$
- 4x the current SNO/KL best value
- Mixing angle
  - more sensitive to the optimum choice of the baseline
  - some dependence on the small "efficiency" systematics
- $\Delta m^2_{12}$
  - less sensitive to baseline
  - doesn't depend on the systematics
  - May depend on the ignored energy scale error.
  - Neither depends much on energy resolution.
Measuring $\Theta_{13}$

- $\sin^2(2\Theta_{13})$:
  - can be measured to 0.02 in 2-3 years
  - baselines above 20 km are not optimal (# events dominate)
  - doesn’t depend strongly on the energy resolution of the detector
  - depends on the systematic uncertainty of energy resolution (esp. for longer baselines)
  - depends on the efficiency error (esp. shorter baselines)
  - doesn’t depend on the actual value of $\sin^2(2\Theta_{13})$: 0.05 vs 0.06 is as difficult as 0 vs 0.01
Atmospheric $\Delta m^2$

- shorter baselines better, but not as much as for $\Theta_{13}$
- relies on non-zero $\sin^2(2\Theta_{13})$
- accuracy degrades in case of small $\Theta_{13}$
- depends significantly but not critically on the detector resolution
- for $\sin^2(2\Theta_{13})=0.05$ and $\Delta E/E=0.025 \times \sqrt{(E_{\text{vis}}/\text{MeV})}$
- can be measured to $2.5\times10^{-5}$ eV$^2$ ($\sim 1\%$ of value)
  - < 2 years;
  - not much systematics-limited;
  - If hierarchy not known, splits into two possible solutions.
Mass Hierarchy Determination

- optimal baseline ~50 km
- strong dependence on the baseline
- relies on non-zero \( \sin^2(2\Theta_{13}) \)
  - accuracy degrades in case of small \( \Theta_{13} \)
  - depends critically on the detector resolution
  - resolution of 2%\(\sqrt{\text{Evis}}\) gives almost 2X statistical advantage over the 2.5% but not very realistic;
  - 3.5% vs 2.5% resolution is a 4x hit in statistics
  - for 2.5%\(\sqrt{\text{Evis}}\) and \( \sin^2(2\Theta_{13})=0.05 \) there it is possible to separate hierarchies to 1\(\sigma\) CL in 2.5 years;
  - weak systematics-limitation.
Estimation of the statistical significance for Hierarchy Determination

- Thousands of events necessary for reliable discrimination – big detector needed
- Longer baselines more sensitive to energy resolution; may be beneficial to adjust for actual detector performance

KamLAND: 0.065 MeV^{0.5}

Hanohano design goal: < 3% desirable, but maybe unrealistic E resolution

Thanks Misha Batygov
GeoNeutrinos

you’ve probably heard lots about this from Nikolai and Kazumi....
Big picture questions in Earth Sci

What drives plate tectonics?

What is the Earth’s energy budget?

What is the Th & U conc. of the Earth?

Energy source driving the Geodynamo?
Structure of the Earth

We do not know How much U & Th is in the mantle
Convection in the Earth

• The mantle convects.
• Plate tectonics operates via the production of oceanic crust at mid-ocean ridges and it is recycled at deep sea trenches.
How much Th, U and K is there in the Earth?

- Heat flow measurements
- Geochemical modeling
- Neutrino Geophysics

Inconsistent results
Radiogenic heat & “geoneutrinos”

K-decay chain

Th-decay chain

U-decay chain

\[ n \rightarrow p + e^- + \bar{\nu}_e \]

Detectable > 1.8 MeV
Data sources

Earth’s Total Heat Flow

- Conductive heat flow measured from bore-hole temperature gradient and conductivity

Total heat flow
Conventional view
44±1 TW
Challenged recently
31±1 TW

strongly model dependent
Urey Ratio and Mantle Convection Models

\[
\text{Urey ratio} = \frac{\text{radioactive heat production}}{\text{heat loss}}
\]

• Mantle convection models typically assume:
  mantle Urey ratio: 0.4 to 1.0, generally ~0.7

• Geochemical models predict:
  Urey ratio 0.4 to 0.5.

generally geologists believe these inconsistent
Discrepancy?

• Est. total heat flow, 44 or 31TW
  est. radiogenic heat production 19TW or 31TW
give Urey ratio ~0.4 to ~1
• Where are the problems?
  – Mantle convection models?
  – Total heat flow estimates?
  – Estimates of radiogenic heat production rate?
• Mantle geoneutrino measurements can constrain the planetary radiogenic heat production.
Chondritic Meteorites

- Estimated abundances of U and Th in the Earth are based on measurements of chondritic meteorites.
- Solar photosphere and chondrites possess similar ratios of non-volatile elements.
- Chondritic Th/U ratio is $3.9 \pm 0.3$.
- Earth’s Th/U ratio is known better than the absolute concentrations.
Two types of crust: Oceanic & Continental

Oceanic crust: single stage melting of the mantle
Continental crust: multi-stage melting processes

Compositionally distinct
U and Th Distribution in the Earth

• U and Th are thought to be absent from the core and present in the mantle and crust.
  – Core: Fe-Ni metal alloy
  – Crust and mantle: silicates

• U and Th concentrations are the highest in the continental crust.
  – Continents formed by melting of the mantle.
  – U and Th prefer to enter the melt phase

• Continental crust: insignificant in terms of mass but major reservoir for U, Th, K.
Mantle is depleted in some elements (e.g., Th & U) that are enriched in the continents.

-- models of mantle convection and element distribution
Natural Reactors?

• Suggested for core (Herndon) or near Core-Mantle Boundary (Rusov and deMeijer)
• 5-10 TW could help explain heating, convection, He3 anomaly, and some isotope curiosities.
• Both models disfavored strongly by geochemists (comments from dynamo people here today?)
• Due to high neutrino energies, easily tested.
• KamLAND limit on all unknown reactors is 6.2 TW (90% C.L.) at earth center equivalent range.
What Next for Geonus?

- Measure gross fluxes from crust and mantle
- Discover or set limits on georeactors.
- Explore lateral homogeneity
- Better earth models
- Use directionality for earth neutrino tomography
- Follow the science....
New KamLAND Results

- Fiducial Radius: 6.0 m (but uses L-selection cut to suppress accidental backgrounds)

- Livetime: 1491 days

- Exposure: \(2.44 \times 10^{32}\) proton-year
  (corresponding to 2881 ton-year)

- Energy resolution: 6.5%/ \(\sqrt{E}\) (MeV)

- Analysis threshold: 0.9 MeV

- Geonu flux from Enomoto et al. model: 16TW U+Th total

- U&Th strongly anti-correlated

- Mauve band from Enomoto geo model, shows 20% uncertainty (maybe too too small)

<table>
<thead>
<tr>
<th></th>
<th>Events</th>
<th>TNU</th>
<th>Flux x10^6/cm^2s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>56.6</td>
<td>29.2</td>
<td>2.24</td>
</tr>
<tr>
<td>U/Th</td>
<td>13.1</td>
<td>7.7</td>
<td>1.90</td>
</tr>
<tr>
<td>Best fit</td>
<td>25</td>
<td>12.6</td>
<td>2.10</td>
</tr>
<tr>
<td>U/Th</td>
<td>36</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fit with 3.9 ratio fixed</td>
<td>73±27</td>
<td>39±14</td>
<td>4.4±1.6</td>
</tr>
</tbody>
</table>

Thanks Patrick Decowski

22 May 2008 John Learned at KITP Santa Barbara
Conclusions at this time:
Data compatible with models, but does not constrain much yet, and virtually no constraints on mantle component.


Thanks Eligio Lisi
KamLAND New Results – Geonu Spectrum

1491 day data set

Thanks Patrick Decowski
Predicted Geoneutrino Flux

Reactor Flux - irreducible background

Geoneutrino flux determinations
- continental (Dusel, SNO+, LENA?)
- oceanic (Hanohano)

synergistic
Locations for Possible Geonu Experiments

Color indicates U/Th neutrino flux, mostly from crust
Reactor “Background”

- KamLAND was designed to measure reactor antineutrinos.
- Reactor antineutrinos are the most significant background.
Simulated Geoneutrino Origination Points

- 50% within 500km
- 25% from Mantle

KamLAND

Assumes homogeneous mantle & no core source

In Mid-Ocean
- 70% Mantle
- 30% Other
Why we need Geonu measurements in the deep ocean to measure the Mantle Contribution
More dramatically… Why one wants to go to the ocean to measure the mantle neutrinos.
Hanohano Engineering Studies
Makai Ocean Engineering

- Studied vessel design up to 100 kilotons, based upon cost, stability, and construction ease.
  - Construct in shipyard
  - Fill/test in port
  - Tow to site, can traverse Panama Canal
  - Deploy ~4-5 km depth
  - Recover, repair or relocate, and redeploy

Barge 112 m long x 23.3 wide

Descent/ascent 39 min

Deployment Sketch
Addressing Technology Issues

• Scintillating oil studies in lab
  – P=450 atm, T=0°C
  – Testing PC, PXE, LAB and dodecane
  – No problems so far, LAB favorite… optimization needed

• Implosion studies
  – Design with energy absorption
  – Computer modeling & at sea
  – No stoppers

• Power and comm, no problems
• Optical detector, prototypes OK
• Need second round design
Future Dreams: Directional Sensitivity

Directional information provides:
- Rejection of backgrounds
- Separation of crust and mantle
- Earth tomography by multiple detectors

Good News:
- Recoiled neutron remembers direction

Bad News:
- Thermalization blurs the info
- Gamma diffusion spoils the info
- Reconstruction resolution is too poor

Wish List:
- large neutron capture cross-section
- (heavy) charged particle emission & good resolution detector (~1cm)
Towards Directional Sensitivity 1

$^6\text{Li}$ loading helps preserving directional information

- $^6\text{Li} + n \rightarrow \alpha + T$ : no gamma-ray emission
- Natural abundance 7.59%
- Large neutron capture cross-section: 940 barn

Neutron Capture Position (MC)

Delayed Event Position (MC)

Various chemical forms for Li loading are being tested...
Towards Directional Sensitivity 2

~1M pixel imaging can achieve 1 cm resolution

- Proper optics need to be implemented
- Sensitivity to 1 p.e. and high-speed readout required

First step for LS imaging, just started...

10cm

LS
(Bis-MSB added)

image intensifier

CCD

Muon Event ???

Isotope Decay Event ???

Fresnel lens

Tohoku
Security Applications for Antineutrino Detectors

**Aboveground**
- 100 km distance
- 100 KT
- Technology: scintillator or water
- Status: Segmentation R&D needed

**SONGS1**
- 100 m distance
- 10 m depth
- 1 T
- Technology: scintillator
- Status: operational

**KamiLAND Style**
- 10 km distance
- 1 km depth
- 1 T
- Technology: scintillator
- Status: operational

**Hanohano**
- 50 km distance
- 1 km depth
- 10 KT
- Technology: scintillator
- Status: proposed

**Hyper-K**
- 1000 km distance
- 2 km depth
- 1000 KT
- Technology: water
- Status: proposed
Practical Application

- Remote monitoring of nuclear reactors
- Proliferation of reactors in near future
- Need to keep track of “special materials”
- Giant neutrino detector network will help.
- Network can detect bomb tests too.
Reactor Monitoring with Anti-Neutrinos

small 100 MWt reactor observed with 10MT detector
- daily ops out to ~60 km
- annual output to 1000 km

D~10 m unintrusive detector of ~1 ton, for IAEA?
AAPW, Paris December 2007


- 65 participants, much interest in neutrino reactor monitoring, including IAEA people.

- Very good meeting… much enthusiasm for neutrino monitoring of reactors, close to far.
Neutrino Monitoring Workshop, U. Maryland, 3-5 January 2008

• Brought together representatives from academe, nuclear monitoring community and intelligence community.
• Discussed future potential of nuclear reactor and bomb monitoring near and far.
• White paper produced making case for large scale, interdisciplinary National Antineutrino Science Center, as well as specific projects.
• Hanohano endorsed as flagship project, not to wait for NASC.
Summary of Expected Results
Hanohano- 10 kt-1 yr Exposure

- **Neutrino Geophysics- near Hawaii**
  - Mantle flux U geoneutrinos to ~10%
  - Heat flux ~15%
  - Measure Th/U ratio to ~20%
  - Rule out geo-reactor if P>0.3 TW

- **Neutrino Oscillation Physics- ~55 km from reactor**
  - Measure $\sin^2(\theta_{12})$ to few % w/ standard $\frac{1}{2}$-cycle
  - Measure $\sin^2(2\theta_{13})$ down to ~0.05 w/ multi-cycle
  - $\Delta m^2_{31}$ to less than 1% w/ multi-cycle
  - Mass hierarchy if $\theta_{13} \neq 0$ w/multi-cycle & no near detector; insensitive to background, systematic errors; complementary to Minos, Nova
  - **Lots to measure even if $\theta_{13}=0$**

- **Much other astrophysics and nucleon decay too....**
**Additional Physics/Astrophysics**

Hanohano will be biggest low energy neutrino detector (except for maybe LENA)

- **Nucleon Decay:** SUSY-favored kaon modes
- **Supernova Detection:** special $\nu_e$ ability
- **Relic SN Neutrinos**
- **GRBs and other rare impulsive sources**
- **Exotic objects** (monopoles, quark nuggets, etc.)
- **Long list of ancillary, non-interfering science, with strong discovery potential**

*Broad gauge science and technology, a program not just a single experiment.*
Hanohano Summary

- **Proposal** for portable, deep-ocean, 10 kiloton, liquid scintillation electron anti-neutrino detector.

- **Transformational geophysics, geochemistry, particle physics and astrophysics**: answers to key, big questions in multiple disciplines. Enormous discovery potential.

- Program under active **engineering**, Monte Carlo simulations, and studies in laboratory and at sea.

- **Collaboration** formed, aimed at decade or more multi-disciplinary program between physics and geology. Open to more collaborators.

- **Future**, much science and many applications for low energy neutrino detection with huge instruments.