Hanohano

Steve Dye
University of Hawaii
Hawaii Pacific University

For the
Hanohano Collaboration
Hanohano: mobile deep ocean antineutrino observatory

10-100 kiloton scintillating liquid

Deploy and recover with barge

for physics, geology, nuclear monitoring
Hanohano History

- **2004 Concept**: U Hawaii physics
  - Large, deep-ocean KamLAND: physics, geology, nuclear monitoring
- **2005 Design**: CEROS funded
  - $686k to Makai Ocean Engineering/University of Hawaii
- **2007 Collaboration**: international, >20 institutions
  - Advisory council: physics and geology
- **On-going Mission**: Develop capabilities
  - Physics, geology, nuclear monitoring
- **On-going Technology**: Scintillator studies
  - Transparency and light production vs temperature and pressure
- **On-going Sponsorship**: Pursue funding
  - NSF, DoE, DoD, etc…
Deployment and Recovery

- **Tow to site w/ detector empty**
- **Transfer fluids to detector**
- **Lower anchor to separate**
- **Transfer cable and release detector**

- **Recover for maintenance and redeployment**

- **Ascent rate**
  \( \sim 100 \text{ m per min} \)

- **Release anchor at end of operation**

- **Operate at depth: mission defines location**

- **Descent rate**
  \( \sim 100 \text{ m per min} \)

- **Touchdown w/ bounce and oscillations**
Oscillation Physics with Hanohano/Reactor Antineutrinos

✓ Precision (1%) measurements of solar mixing parameters
  (currently solar+KamLAND $\sin^2 2\theta_{12} \sim 4\%$ ; $\Delta m^2 \sim 3\%$)

? Measurement of $\sin^2(2\theta_{13}) > 0.05$ to ± 0.02
  (no near detector)

? Precision (1%) measurement of $\Delta m^2_{32} (\Delta m^2_{31})$
  for $\sin^2(2\theta_{13}) > 0.05$
  (currently Super-K $\Delta m^2 \sim 5\%$)

? Determination of mass hierarchy for $\sin^2(2\theta_{13}) > 0.05$
  (systematics insensitive)

Neutrino properties relate to origin of matter, formation of heavy elements, and may be key to unified theory
Two Candidate Off-shore Sites

San Onofre, California- \( \sim 6 \text{ GW}_\text{th} \)
Maanshan, Taiwan- \( \sim 5 \text{ GW}_\text{th} \)

Need study of background versus depth
1% $\sin^2(2\theta_{12})$, $\Delta m^2_{21}$ sensitivity curves

- Geo-neutrinos are an issue
- Not sensitive to detector resolution and systematics
- Can achieve 1% precision in $\sin^22\theta_{12}$, $\Delta m^2_{12}$ with exposure of $\sim300$ GW-kT-y at 65 km
68% CL $\sin^2(2\theta_{13}) \pm 0.02$ sensitivity curves

- Moderately sensitive to resolution and systematics
- Geo-neutrinos not an issue at short baselines
- Target sensitivity of $\pm 0.02$ in $\sin^2 2\theta_{13}$ insensitive to $\theta_{13}$ will probably be exceeded in 300 GW-kT-y
- Optimum baseline < 30 km

\[ \delta E = 2.5\% \sqrt{E_{\text{vis}}(\text{MeV})} \]
1% $\Delta m^2_{31}$ ($\Delta m^2_{32}$) sensitivity curves

- Very demanding of detector energy resolution
- Two families of solutions, for each hierarchy respectively, one somewhat favored over another
- Sensitivity depends on $\sin^2 2\theta_{13}$
- Optimum baseline $\sim < 30$ km

$\sin^2 2\theta_{13} = 0.05$ and $\delta E = 2.5\% \sqrt{E_{\text{vis}}}$ (MeV)
68% CL $\nu$ mass hierarchy sensitivity curves

- Strongly dependent on detector energy resolution
- Success depends on the actual value of $\theta_{13}$; unlikely to achieve considerable CL if $\sin^2 2\theta_{13}$ less than 0.05
- Optimum baselines $\sim$50 km

$\sin^2 2\theta_{13} = 0.05$ and $\delta E = 2.5\% \sqrt{E_{\text{vis}}}$ (MeV)

$\sin^2 2\theta_{13} = 0.05$
More physics…

Proton decay

• SUSY: \( p^+ \rightarrow \nu K^+ \)
  – SO(10), \( \tau \leq 2 \times 10^{34} \text{y} \)

• Water Č inefficient
  – \( K^+ \) below Č threshold, \( \varepsilon \sim 8.6\% \)
  – SK: \( \tau/B \geq 2.3 \times 10^{33} \text{y} \) (90% CL)

• LS efficient
  – \( K^+ \) resolved, \( \varepsilon \sim 65\% \)
  – \( \tau/B \geq 10^{34} \text{y} \) (90% CL) / 100 kt-y

Supernova neutrinos

• Galactic SN
  – 10 kpc, \( 3 \times 10^{53} \) ergs, equipartition of energy among neutrino types
  – \( \sim 5000/10s/10kt \) CC and NC events
  – Measure neutrino oscillation and SN parameters

• DSNB
  – 1-4 events/y/10kt
Geo-neutrinos: Terrestrial Antineutrinos

\[ \bar{\nu}_e + p^+ \rightarrow n + e^+ \]
Geo-neutrinos and Earth Models

**Crust**

<table>
<thead>
<tr>
<th>Crust Model</th>
<th>Ref.</th>
<th>S86</th>
<th>W94</th>
<th>RF95</th>
<th>WT84</th>
<th>TM85</th>
</tr>
</thead>
<tbody>
<tr>
<td>$h$ ($\mu W m^{-3}$)</td>
<td>1.03</td>
<td>1.31</td>
<td>1.25</td>
<td>0.93</td>
<td>0.92</td>
<td>0.58</td>
</tr>
<tr>
<td>$H$ (TW)</td>
<td>8.59</td>
<td>10.93</td>
<td>10.42</td>
<td>7.76</td>
<td>7.67</td>
<td>4.84</td>
</tr>
<tr>
<td>% difference</td>
<td>0</td>
<td>+31</td>
<td>+25</td>
<td>-7</td>
<td>-8</td>
<td>-42</td>
</tr>
</tbody>
</table>

**Mantle**

<table>
<thead>
<tr>
<th>Mantle Model</th>
<th>Ref.</th>
<th>TH05</th>
<th>TKH06</th>
<th>EOSI07</th>
<th>KT97</th>
<th>TPW01-II</th>
<th>TPW01-I</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H$(TW)</td>
<td>10.9</td>
<td>7.4</td>
<td>11.4</td>
<td>11.2</td>
<td>12.7</td>
<td>18.2</td>
<td>25.7</td>
</tr>
<tr>
<td>TNU</td>
<td>8.9</td>
<td>6.9</td>
<td>8.6</td>
<td>10.0</td>
<td>10.9</td>
<td>15.1</td>
<td>22.0</td>
</tr>
<tr>
<td>% difference</td>
<td>0</td>
<td>-22</td>
<td>-3</td>
<td>+12</td>
<td>+22</td>
<td>+70</td>
<td>+147</td>
</tr>
</tbody>
</table>
KamLAND Geo-nu Flux Measurement

U, Th Geo-nu Flux
(10^6 cm^-2 s^-1)

<table>
<thead>
<tr>
<th></th>
<th>Observed</th>
<th>Predicted</th>
</tr>
</thead>
<tbody>
<tr>
<td>KL-04</td>
<td>5.7 ± 4.2</td>
<td>4.14†</td>
</tr>
<tr>
<td>KL-08</td>
<td>4.4 ± 1.6</td>
<td>3.96‡</td>
</tr>
</tbody>
</table>

†Enomoto et al. 2007, ‡Mantovani et al. 2004

KamLAND flux measurement does not constrain models
Continental + Oceanic Observations

$$\Delta \frac{\Delta c}{c} = \sqrt{\frac{n_2/e_2 + n_1/e_1 + \sigma_r^2 (r_2^2 + r_1^2) + \sigma_e^2 (n_2^2 + n_1^2) + \sigma_o^2 (n_2^2 + n_1^2)}{(n_2 - n_1) - (r_2 - r_1)}}$$

Solid $\sigma_r = \sigma_e = \sigma_o = 0.03$; Dots $\sigma_r = \sigma_e = \sigma_o = 0.01$; Dash $\sigma_r = \sigma_e = \sigma_o = 0.05$
Summary

• Hanohano- a mobile 10-kt deep-ocean antineutrino observatory

• Neutrino oscillation physics
  – Reactor antineutrinos: deploy ~50 km offshore
    • Solar parameters guaranteed
    • Mass hierarchy & $\Delta m^2_{31}$ if $\theta_{13}$ big enough
  – $p \rightarrow \nu K^+$ and SN $\nu$
  – Neutrino beam potential: deploy in T2K beam

• Transformational geology: deploy mid-ocean

• Nuclear monitoring

• Needs funding!!!
extras
Laboratory Testing of LS at UH

1-m SS test cell
$1<P<240$ atm.
$1<T<22\, ^\circ C$

Differential timing measures refractive index consistent with specified value

No measureable effects due to low temperature and/or high pressure
N/B Hanohano

- Initial design study- Makai Ocean Eng.
- Draft < 10m; fits in harbors
- Tow to any ocean
- Onboard oil purification
- Onboard RO water for veto
- Full detector support onboard
- Basic design accommodates detector sizes to 100 kt of scintillating oil

- Detailed design study
  - 9 kt scintillating oil
  - fits Panama Canal
  - double hull construction
  - total cost of barge ~$9M

For details see: