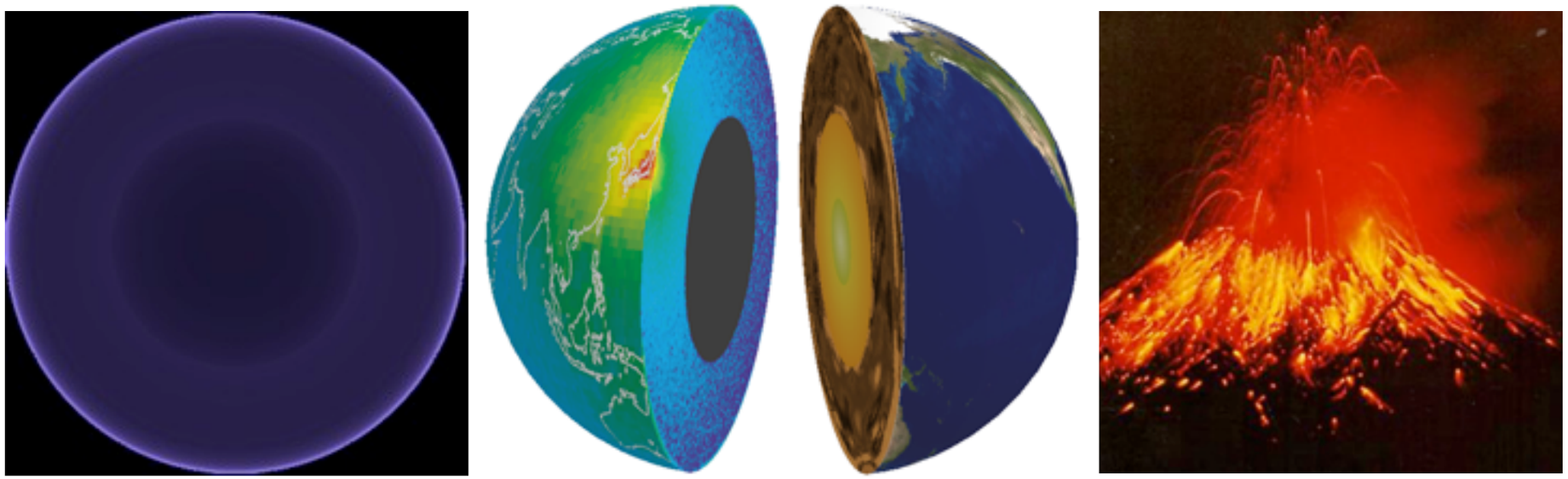
Geoneutrinos:
Journey to the Center of the Earth



Brian Fields
University of Illinois

CCAPP Symposium: April 5, 2011

Revealing the Invisible with Neutrinos:
An Impressionist's View

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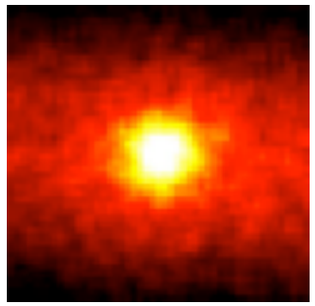

- **solar neutrinos**

  direct probe of solar energy generation

  beta decays of fusion products

- **supernova (anti)neutrinos**

  direct probe of core collapse energy release

  thermal production

- **geoneutrinos**

  direct probe of geothermal energy generation

  beta decays in U & Th chains

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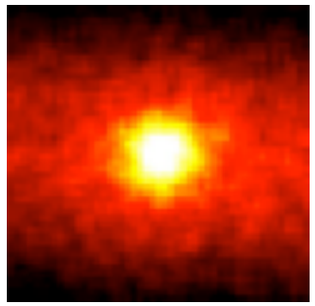

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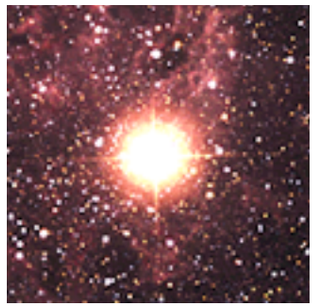

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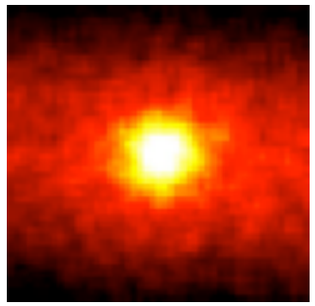

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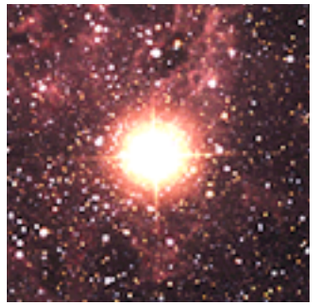

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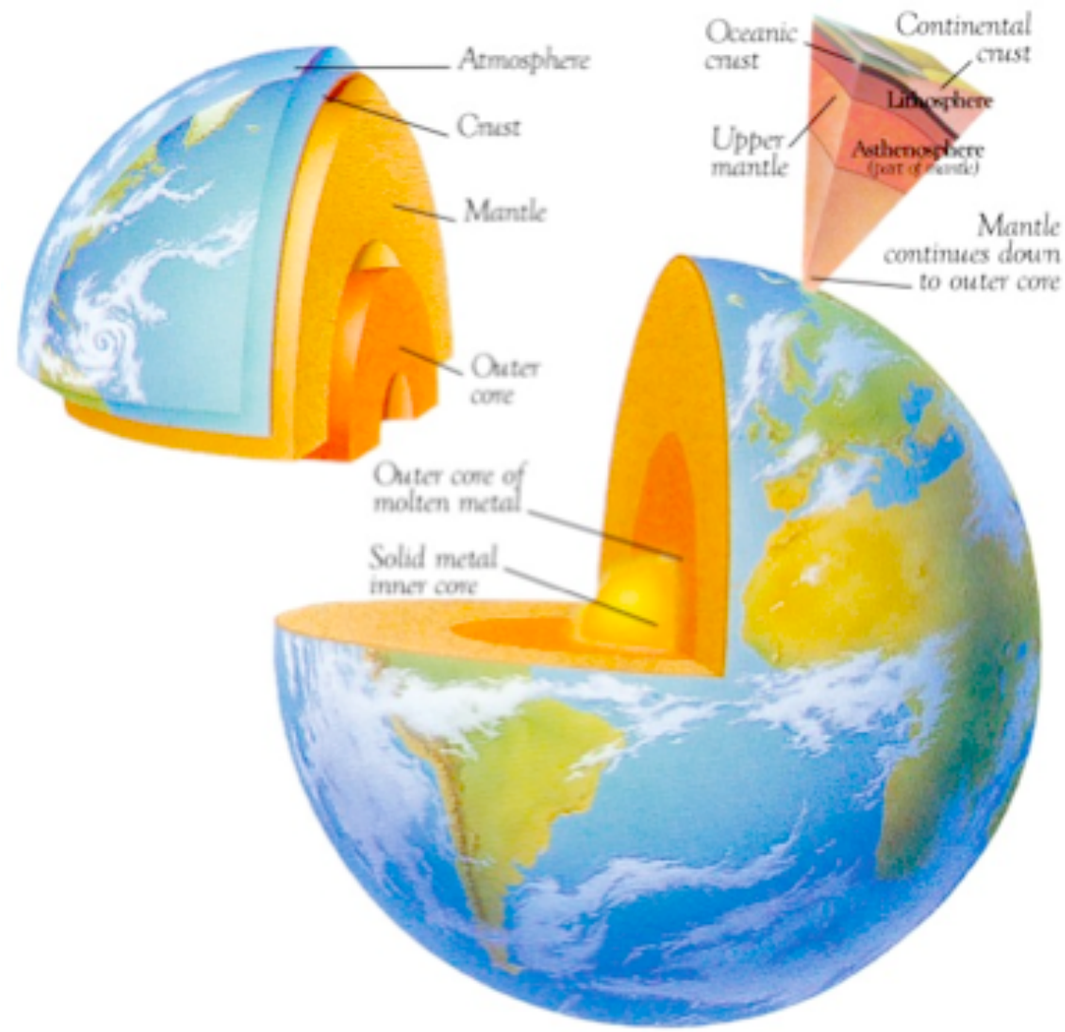
Geothermal Heat

- heat flux measured from thermal gradient

  deepest drill core:

  ~12 km = 0.002 R_{Earth}



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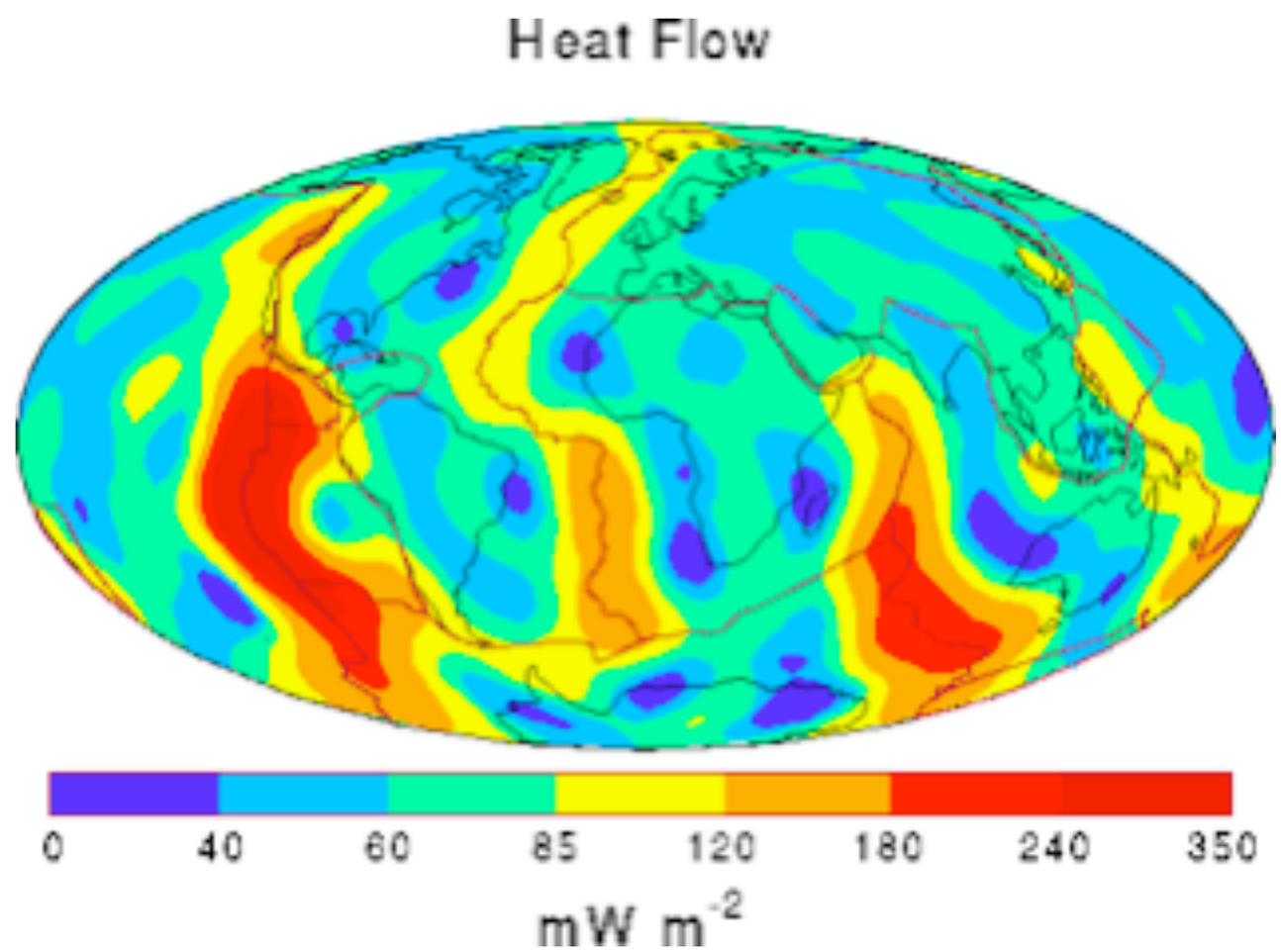

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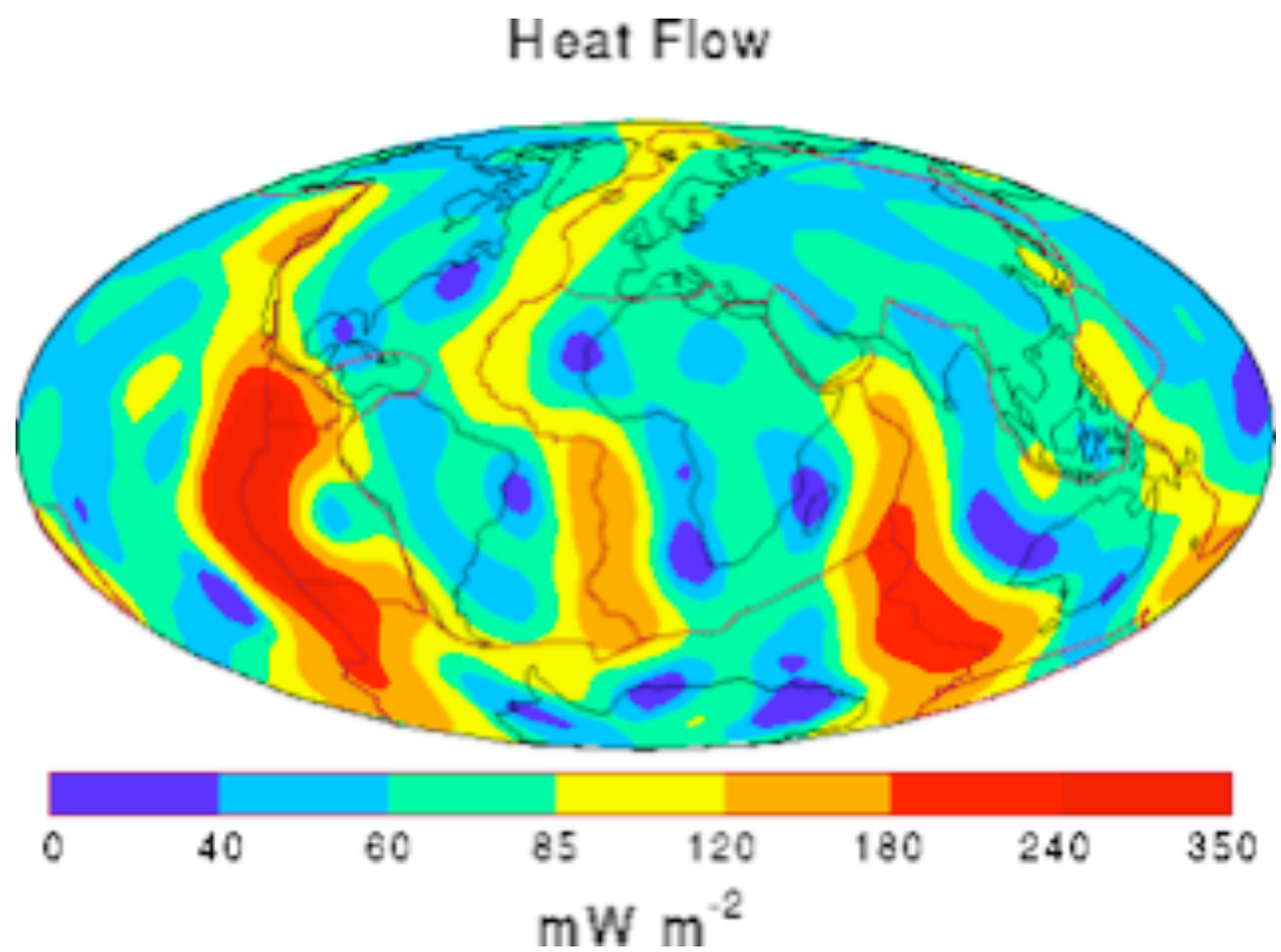

Geothermal Heat

- heat flux measured from thermal gradient

  deepest drill core:

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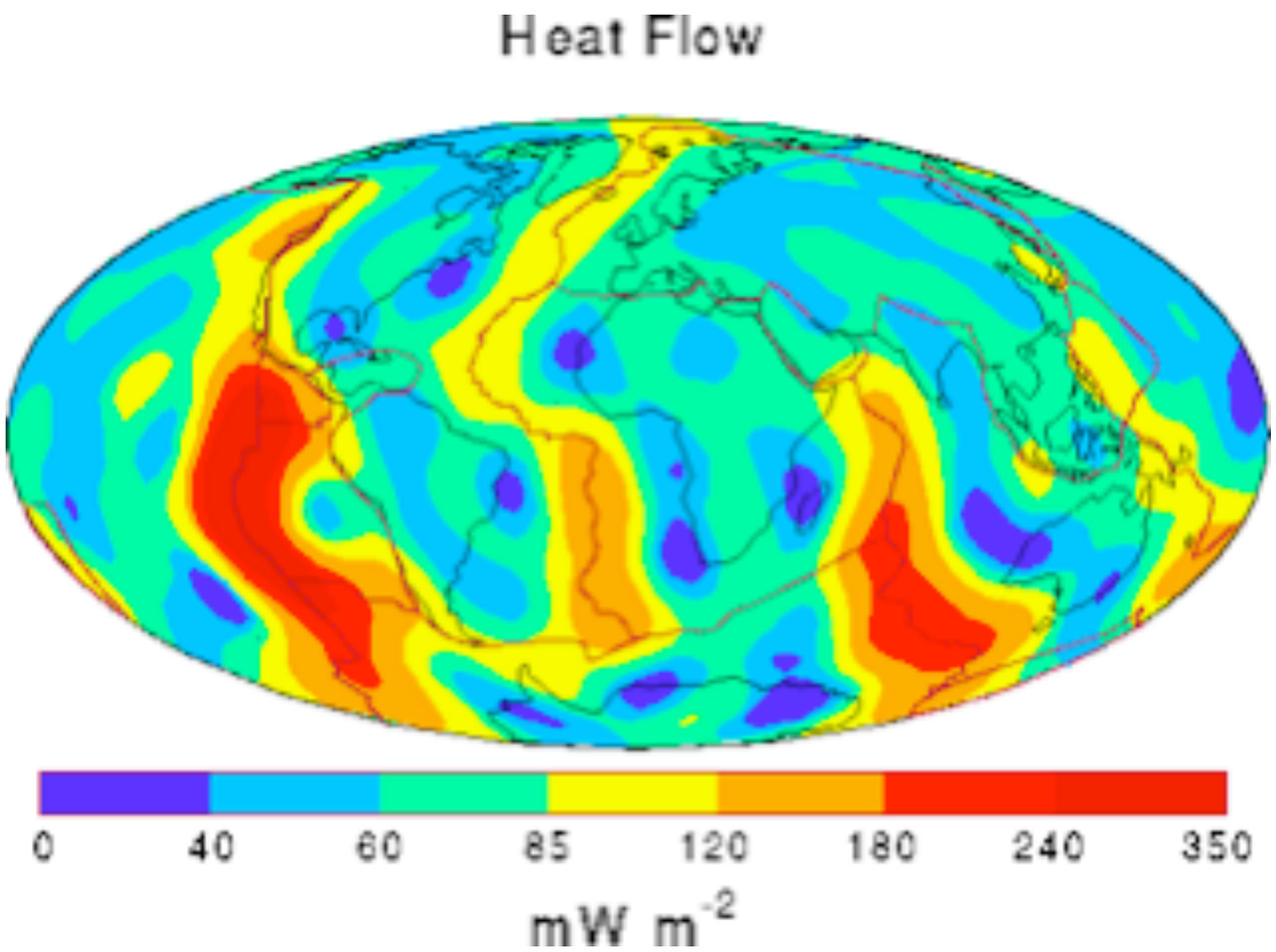
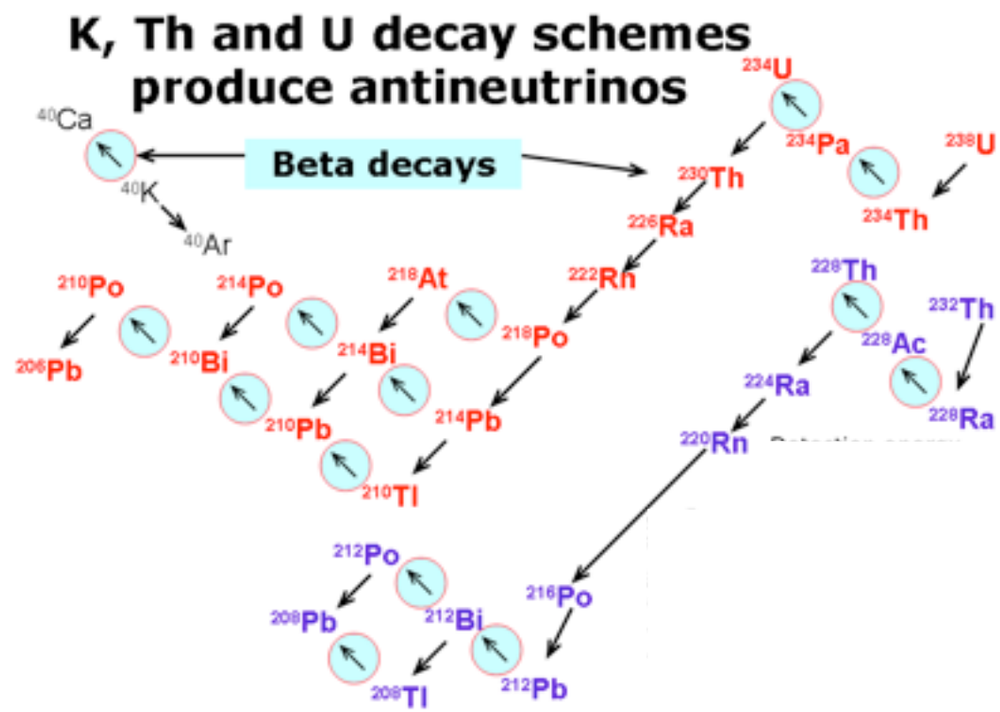
- anisotropic flux
- net luminosity ~ 40 TW
- energy source?
  - ✓ "primordial" heat
  - ✓ radioactive decays: ^{238}U, ^{232}Th, ^{40}K

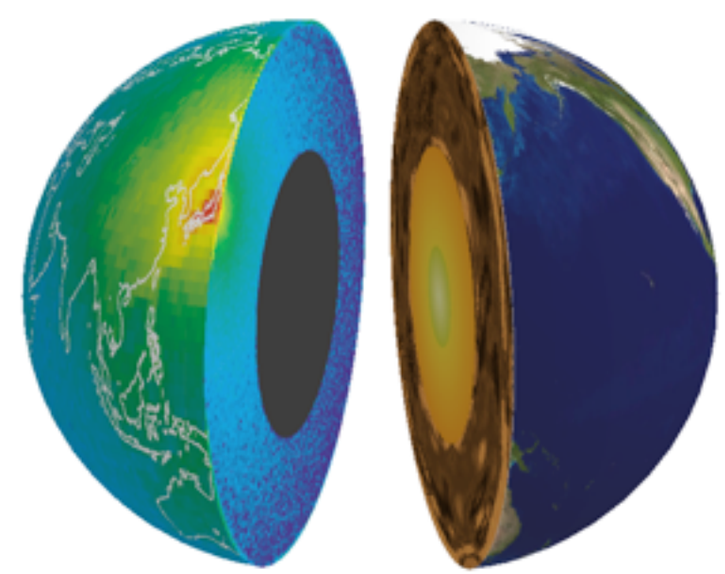


The Radioactive Earth

- U, Th chemically "lithophile"
  - bind to silicates
  - found in crust, not core!
- K also in crust, but maybe core?
- Urey ratio



$$= \frac{L_{\oplus,\mathrm{radioactive}}}{L_{\oplus,\mathrm{tot}}} \sim 0.2 - 0.7$$



Geoneutrino Spectrum

Eder 1966, Krauss et al 1984, Fiorentini et al

- **beta decays: antineutrinos** $\bar{\nu}_e$
- **flux:**

$$\Phi_{\nu,\oplus} \sim \frac{F_{\mathrm{heat}}}{Q}$$

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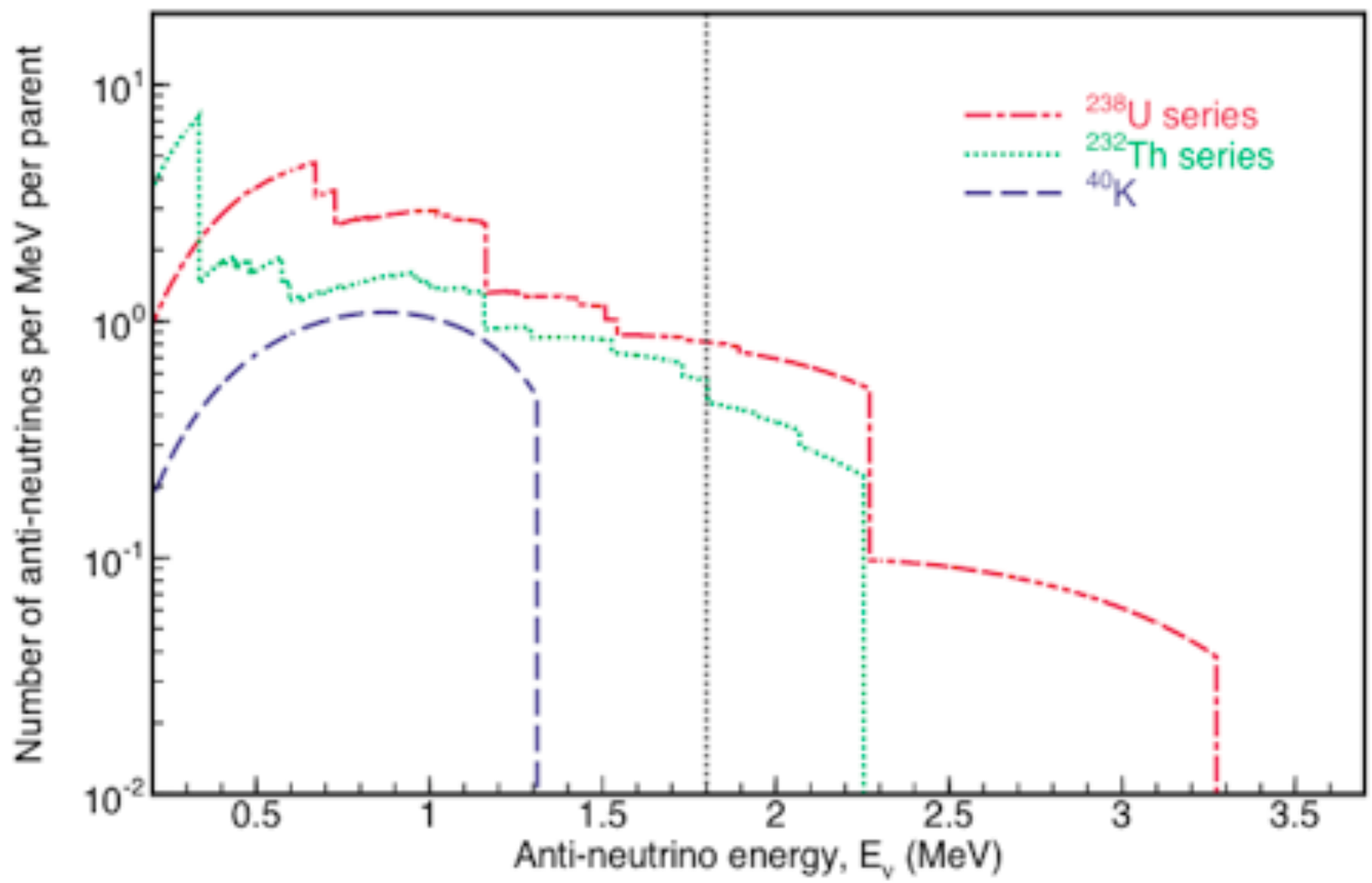

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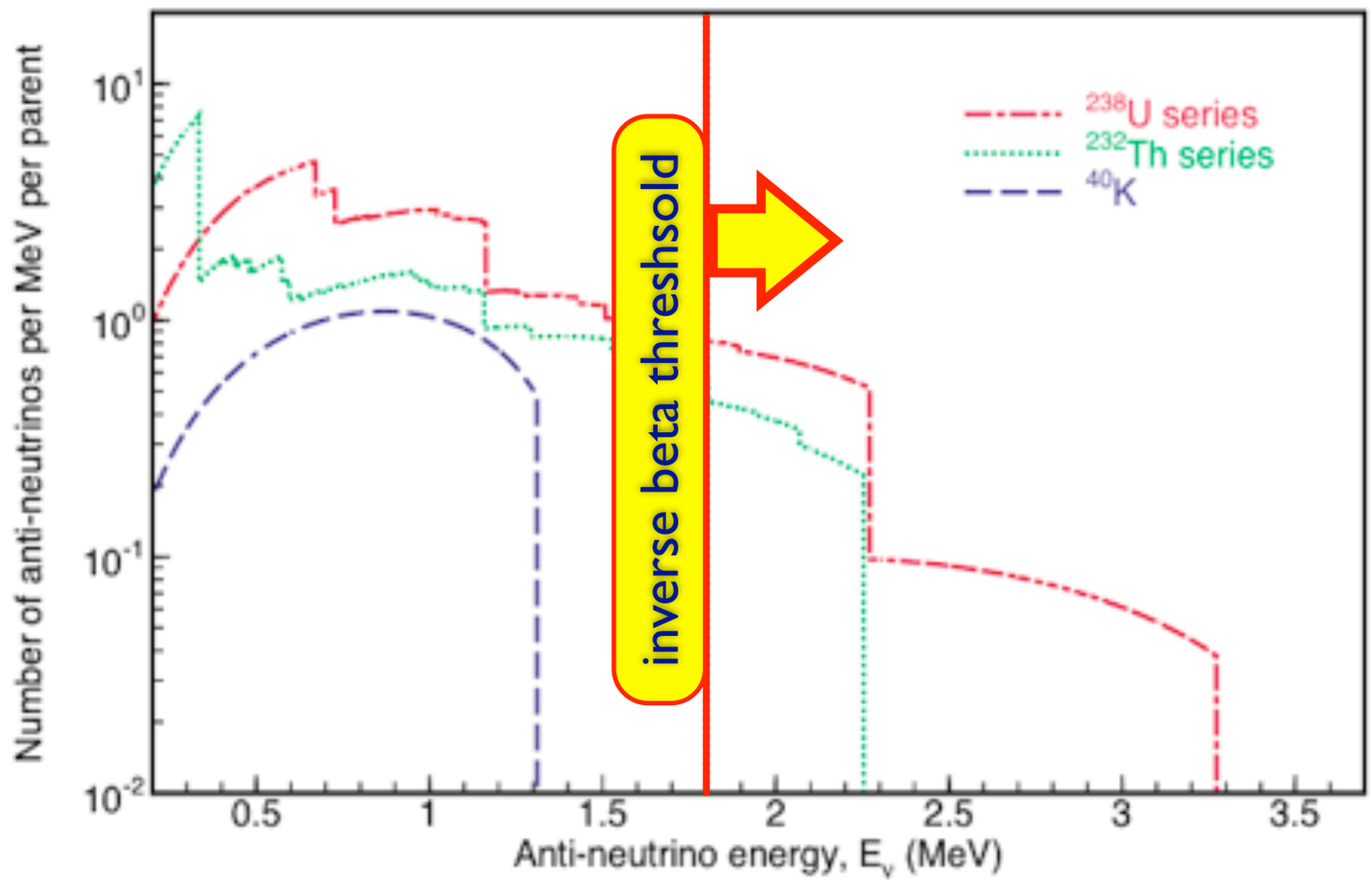
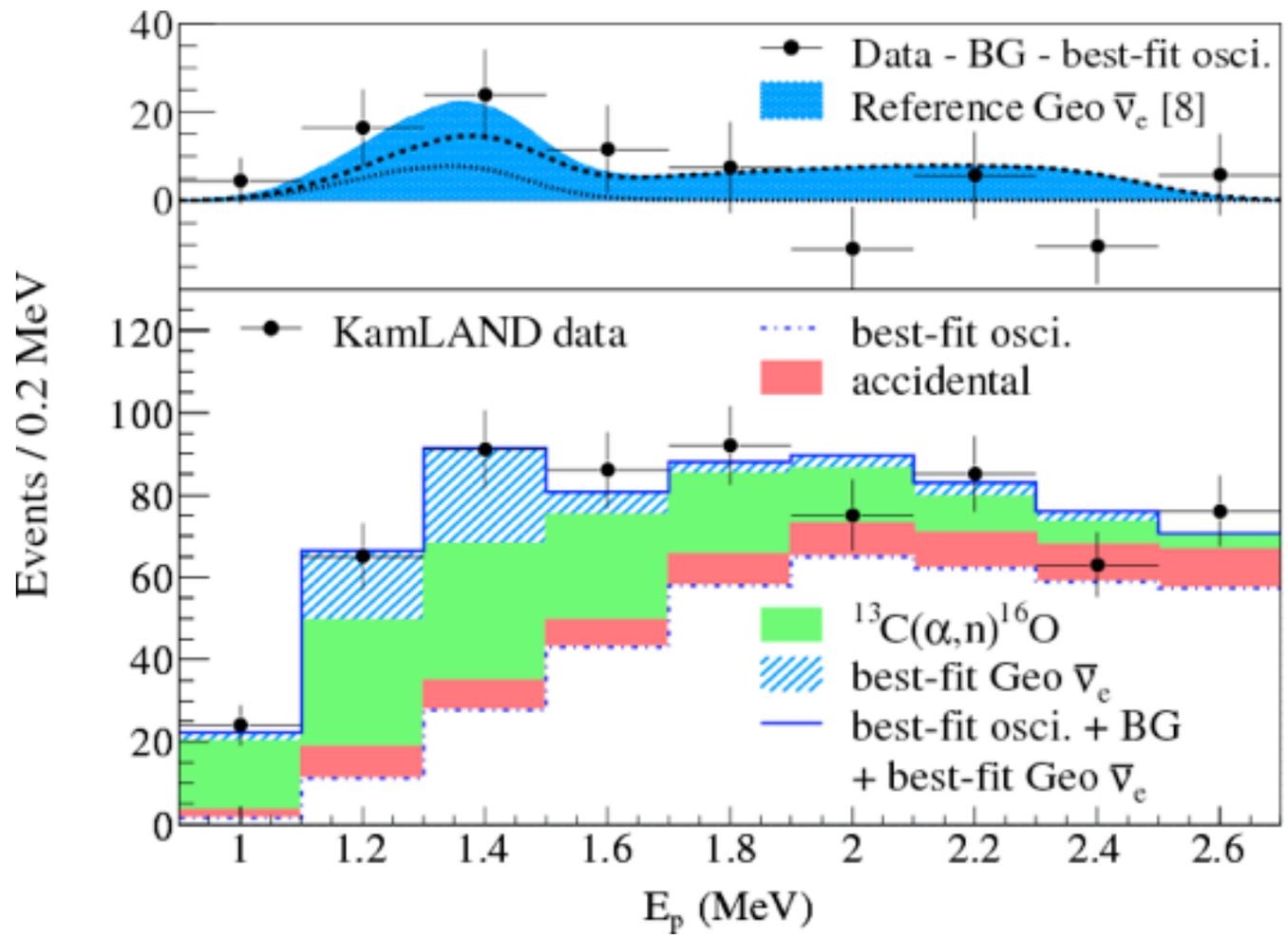
- 1.8 MeV inverse beta detection threshold excludes all ^{40}K events, most U & Th events

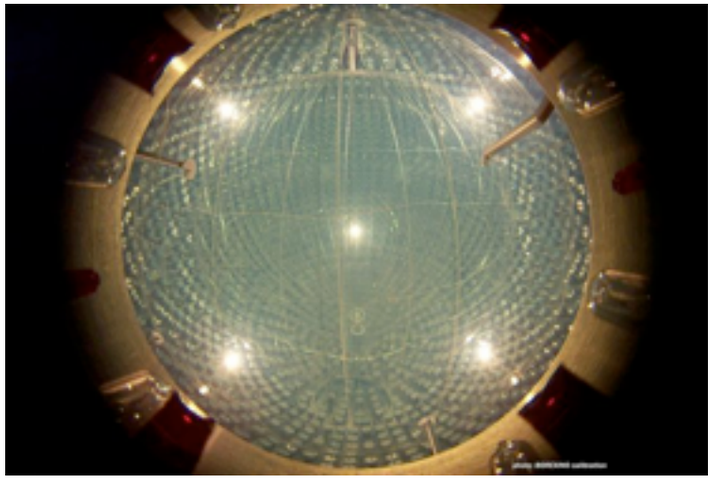


2005:
KamLAND Discovery

- 1 kTon liquid scintillator
  $\bar{\nu}_e + p \rightarrow n + e^+$
- Low-energy signal exceeds reactor flux
- ~4-54 geonu counts (90% CL range)
- heat flux limit < 60 TW
- radioactivity an important geothermal energy source!



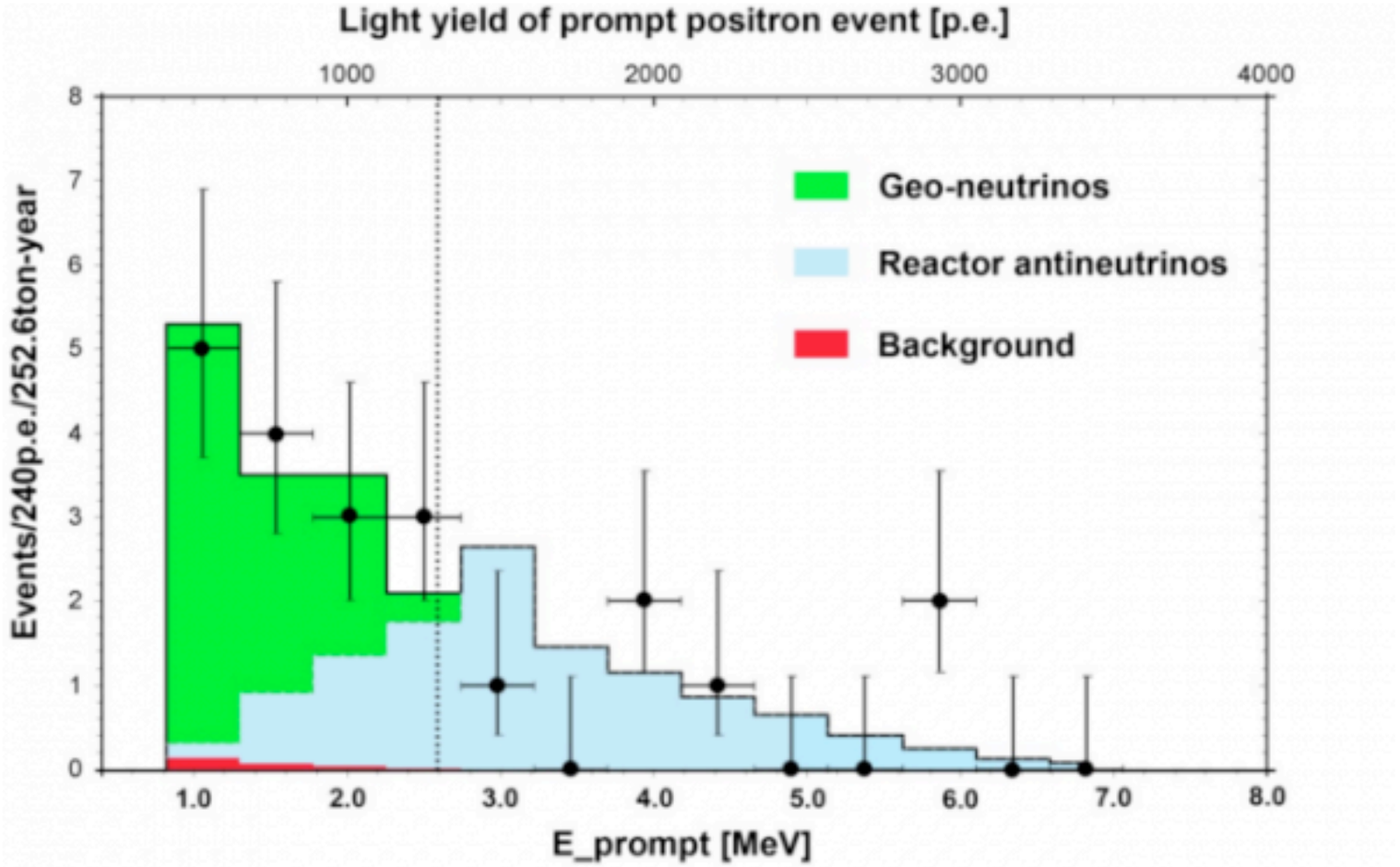
2010:
Borexino Confirmation



- 0.3 kTon liquid scintillator
- geonu detection

  $9.9^{+14.6}_{-8.2}$ events (99.73%CL)
- consistent with KamLAND (within large errors)
- georeactor < 3 TW
- combined KamLAND and Borexino: reject no-geo at >5sigma

  Fogli et al 2010



Geoneutrino Angular Distribution: Imaging the Earth

BDF & Hochmuth 2006

Future-looking:

imagine directional information

- **can resolve geonu image**
- **intensity ~ sightline column**

$$I = \int_{\rm los} q \; d\ell \propto n_{\rm radioactive} \ell$$

- **largest emission at largest column**
- **since most U & Th in crust, signal max at ~ horizon**
- **image gives 3-D map (tomography) of radioactive earth!**

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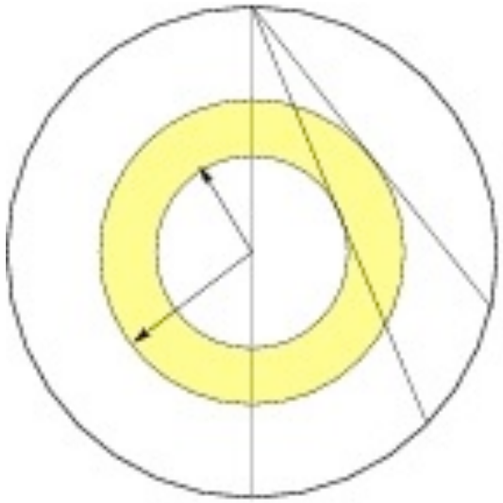

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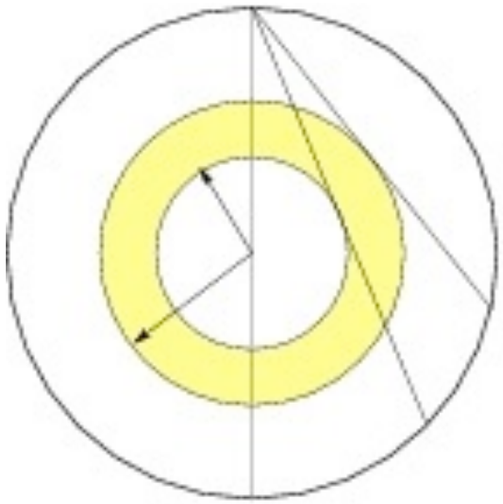

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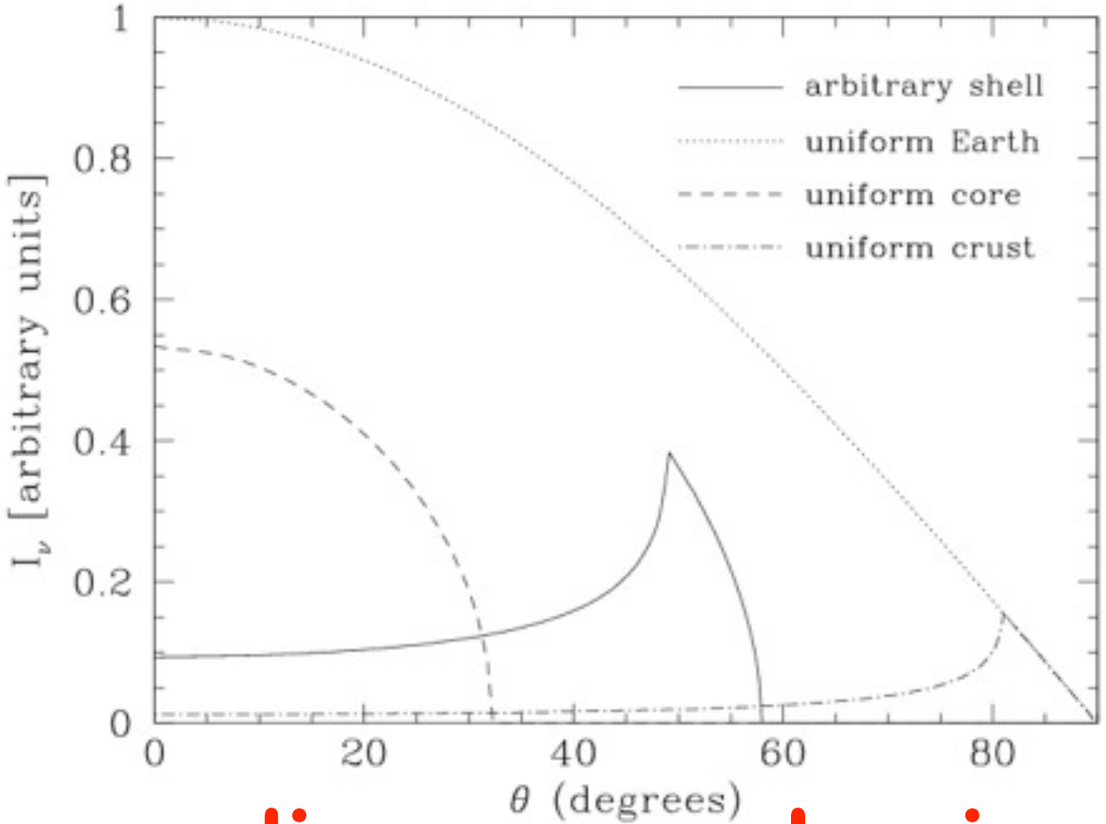

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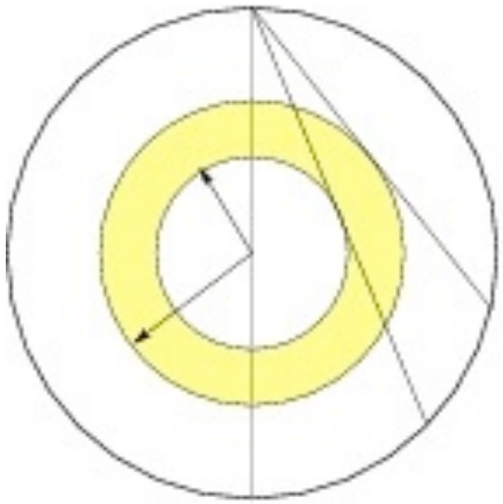

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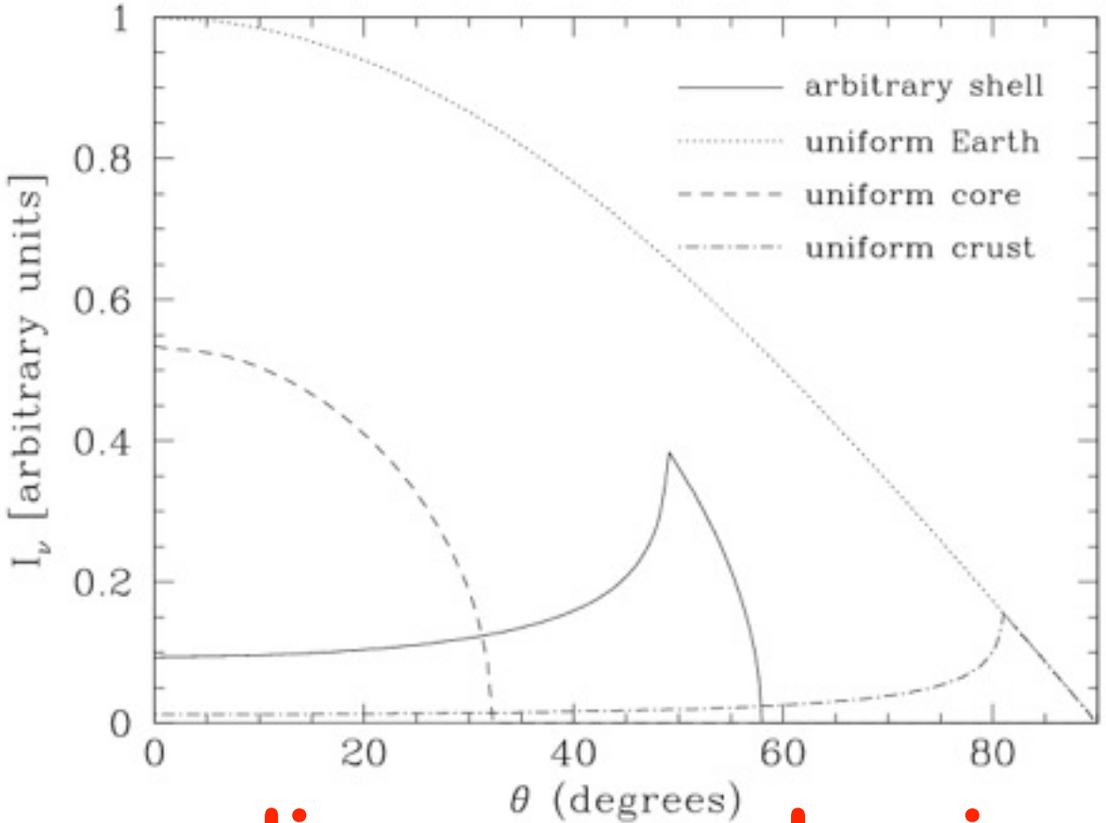

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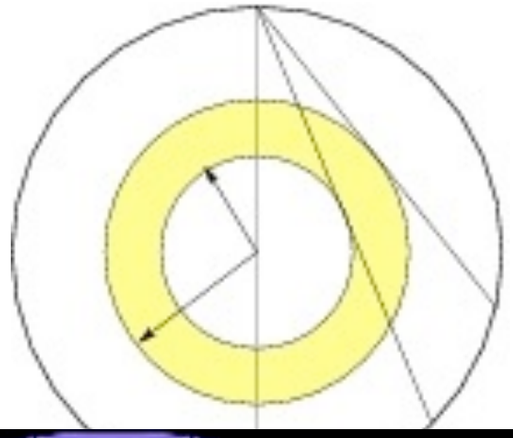

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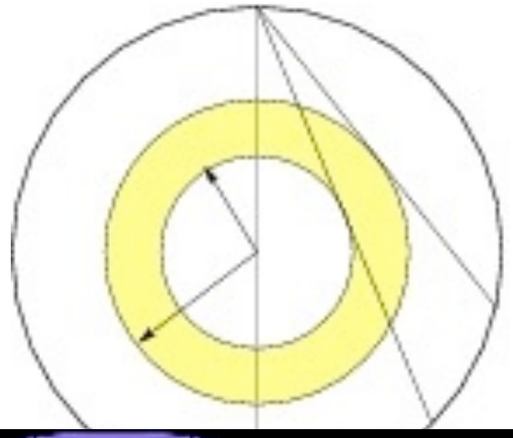

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Geo/Diffuse Supernova Lessons & Links

- frontier of antineutrino astronomy

  detection solid, but physics murky

  linked since Krauss, Galshow, & Schramm 1984

  every source precious!

- understanding back/foregrounds crucial
- large detectors & directional information transformative: open era of nucleo-astro-geo-particle physics

Conclusions

- Geoneutrinos probe radioactive earth and terrestrial energy budget
- Geoneutrinos detected (KamLAND) and confirmed (Borexino)
- Nuclear physics a substantial geothermal power source

Future

- Spectral resolution: separate U, Th inventory
- Directional information: 3-D map of radioactive earth