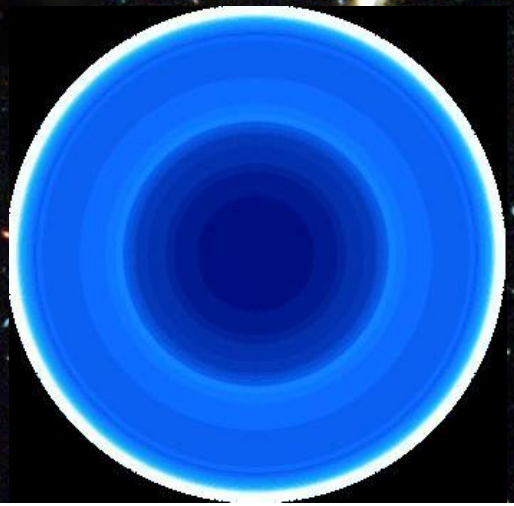
Taking a picture of the Earth's Interior with Geoneutrinos



Ringberg Meeting

18.-22.07.2005

Kathrin A. Hochmuth

Outline:

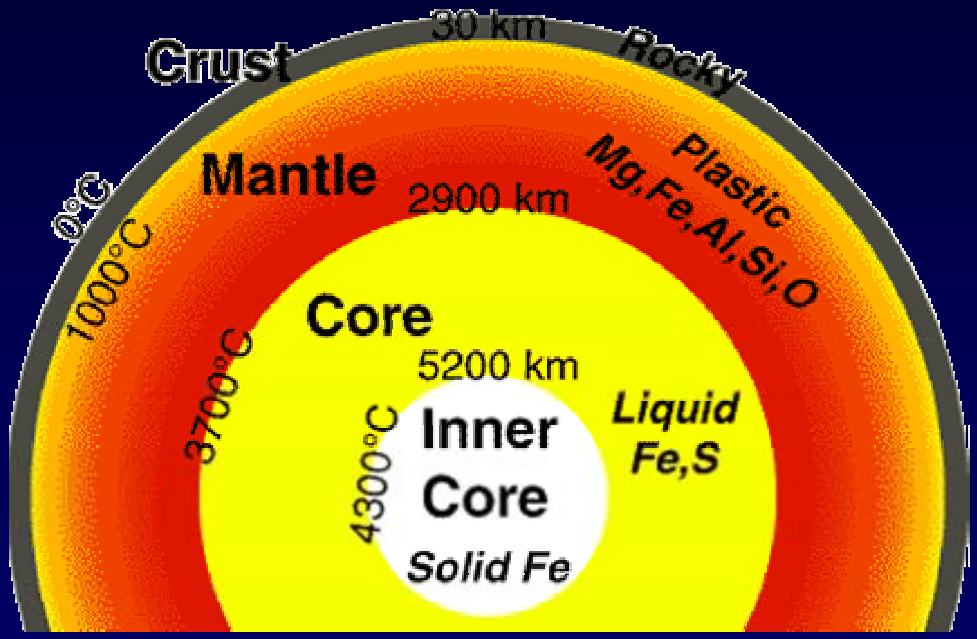
The earth`s interior

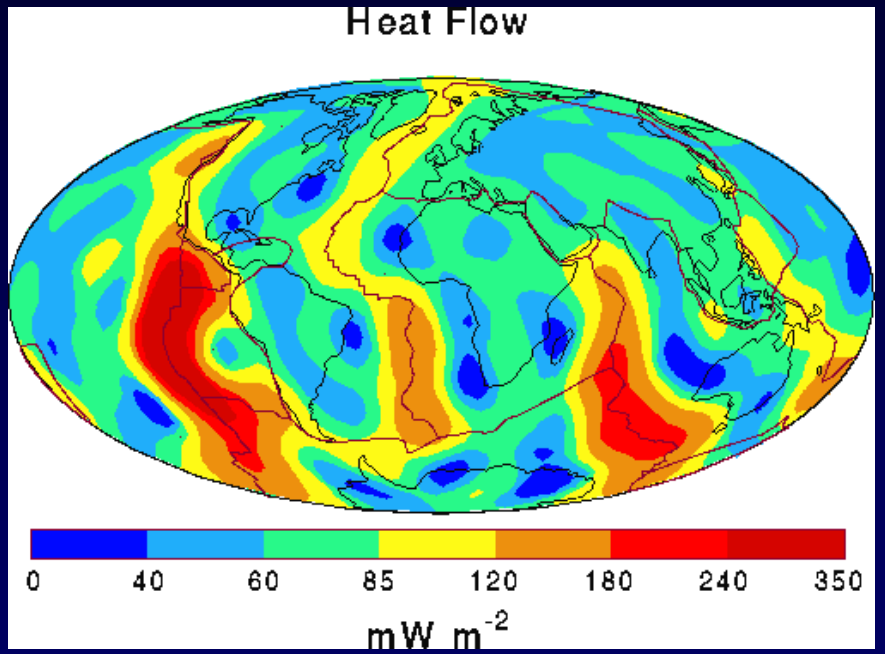
Theoretical angular distribution of geoneutrinos

Measuring geoneutrinos with liquid scintillation detectors (LENA)

Angular spectra in LENA

The Earth's Interior

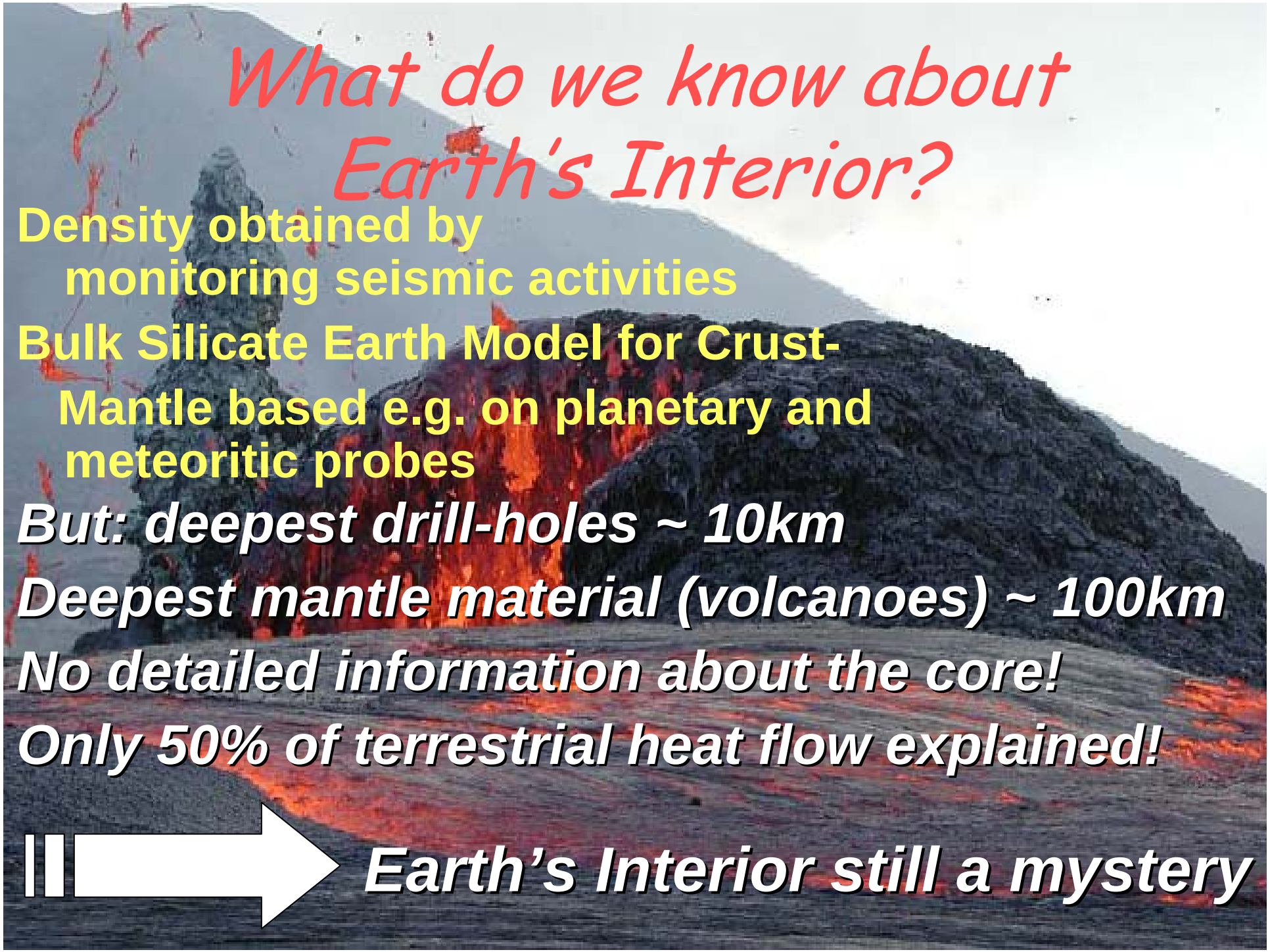




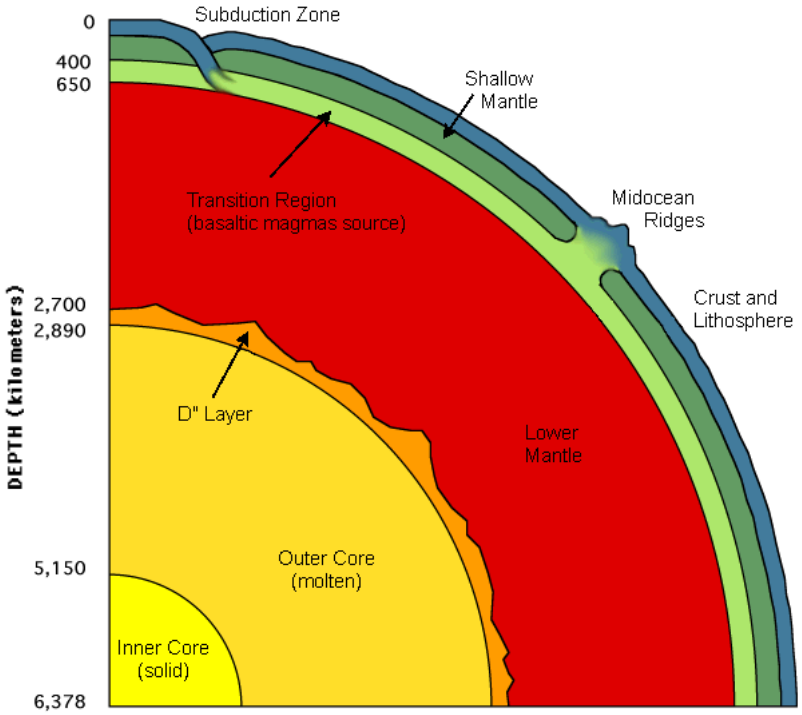
http://www.seismo.unr.edu/ftp/pub/louie/class/100/interior.html

Radioactive Elements

Element	mean life (Gyr)	# of neutrinos	Isotopic abundance	Energy released
^{40}K	1.84	1	0.0117%	~1.4 MeV
^{238}U	6.45	6	99.2745%	51.7 MeV
^{232}Th	20.3	4	100%	42.5 MeV


What do we know about Earth's Interior?
Density obtained by monitoring seismic activities
Bulk Silicate Earth Model for Crust-Mantle based e.g. on planetary and meteoritic probes
But: deepest drill-holes ~ 10km
Deepest mantle material (volcanoes) ~ 100km
No detailed information about the core!
Only 50% of terrestrial heat flow explained!
Earth's Interior still a mystery

What to use …

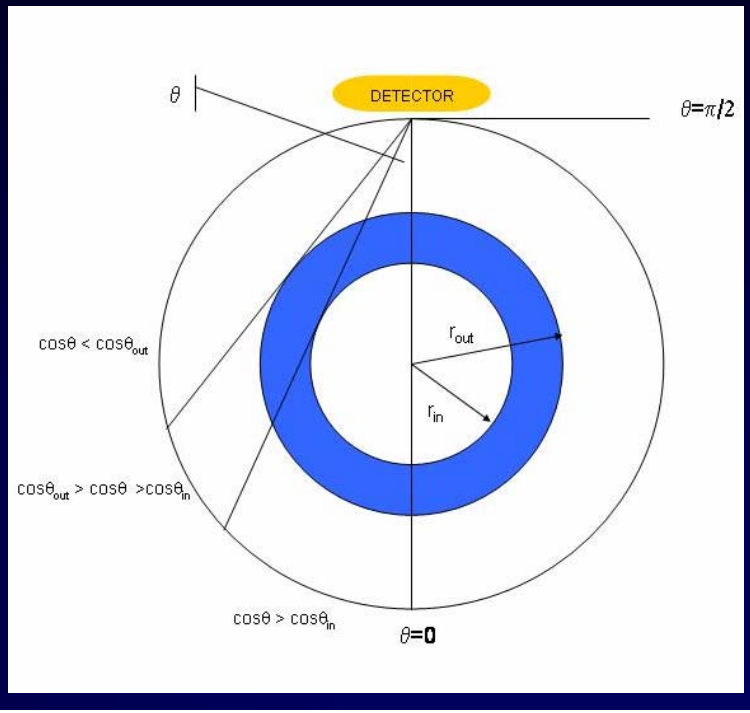


http://www.edu.pe.ca/southernkings/compositionch.htm

- Bulk Silicate Earth Model
- Preliminary Reference Earth Model
- Laboratory Experiments suggesting potassium-iron alloys in the core

First steps to get a neutrino picture of the earth

Using the density profile given in the Preliminary Reference Earth Model to Divide Earth into shells of constant density

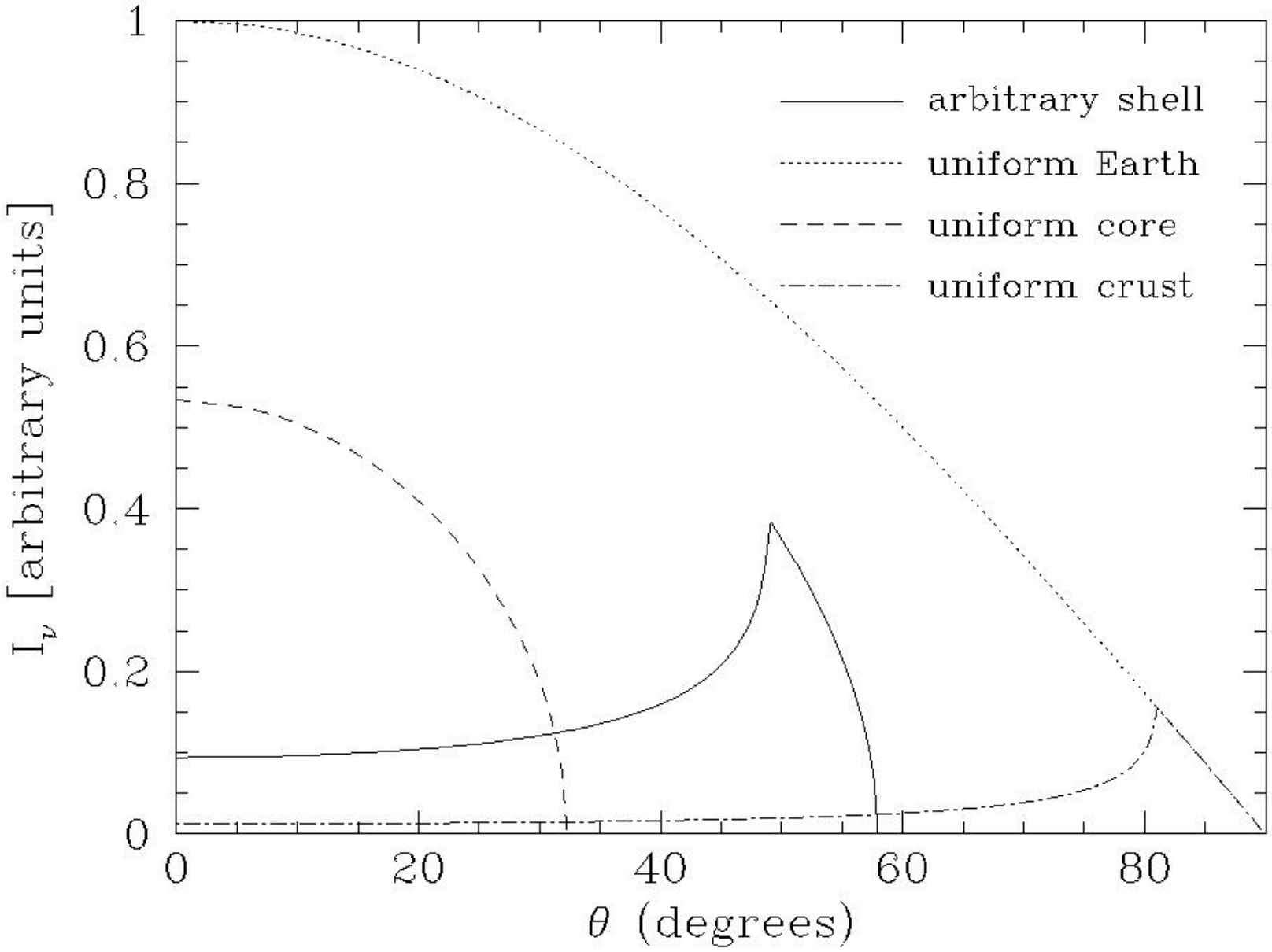


$$I_i(\vartheta) = I_{i,0}\, g(\vartheta)$$

with

$$I_{i,o} = 2\frac{N_i a_i \rho R_\oplus}{4\pi A_i m_u \tau_i}$$

Simple Illustrations



Towards a real model

Bulk Silicate Earth Model

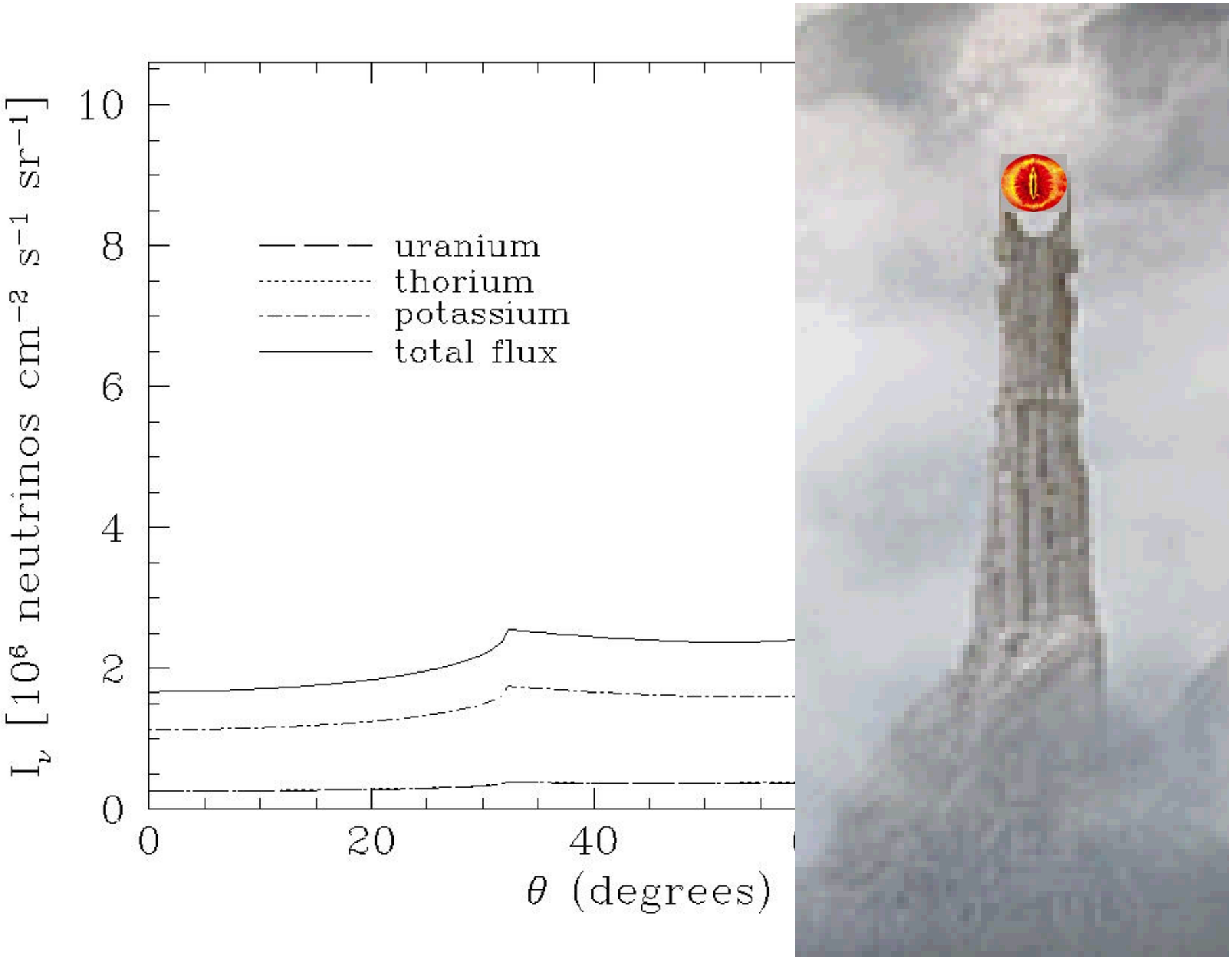
Preliminary reference earth model

Neutrino Oscillations:

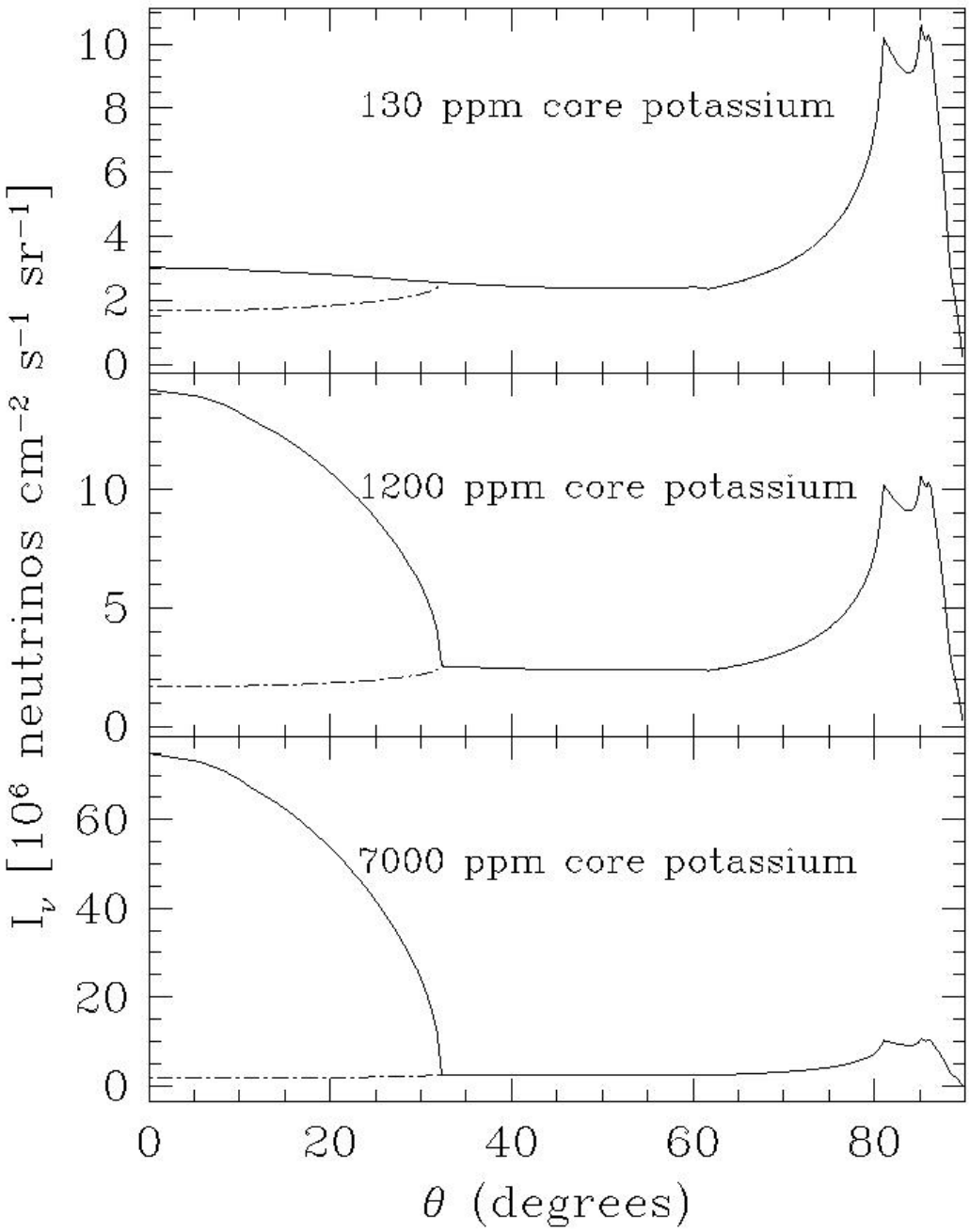
$L_V \sim 10 km$ vs. $L_M \sim 1000 km$

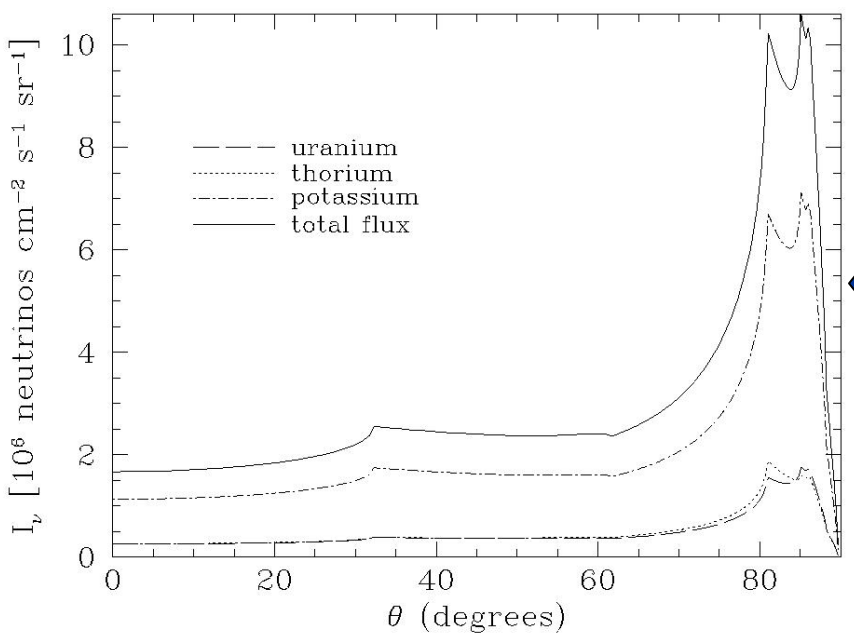
➡ Neglect matter effects

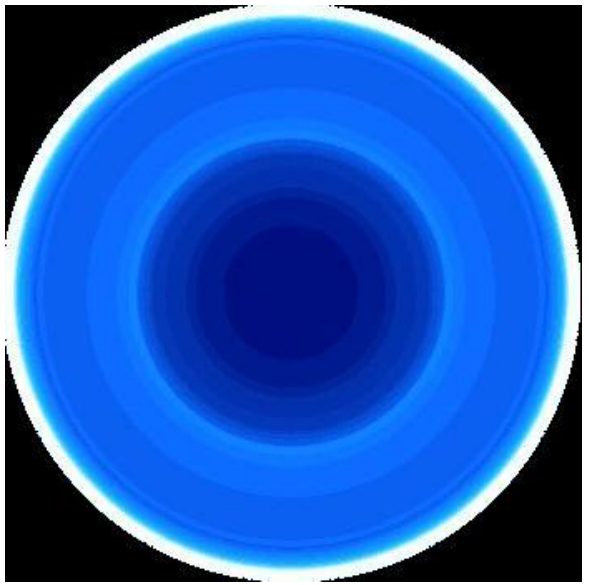
$$1 - \frac{1}{2}\sin 2\vartheta \sim 0.58$$

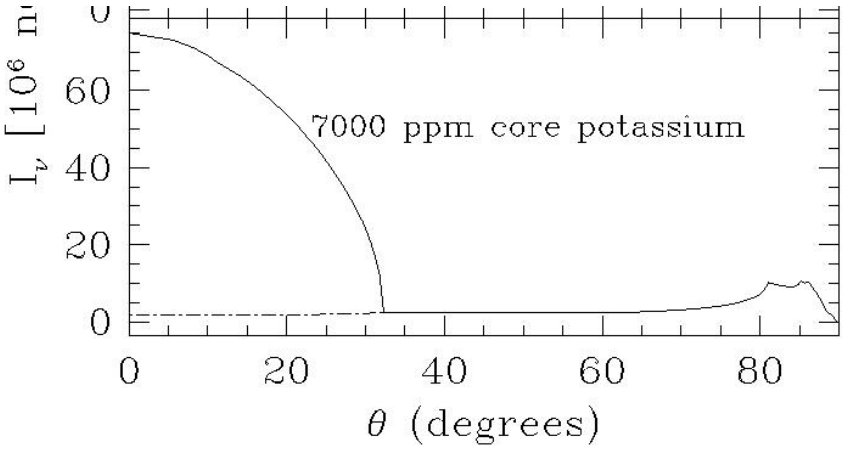

uranium
thorium
potassium
total flux
I_ν [10^6 neutrinos cm^{-2} s^{-1} sr^{-1}]
0
2
4
6
8
10
0
20
40
θ (degrees)

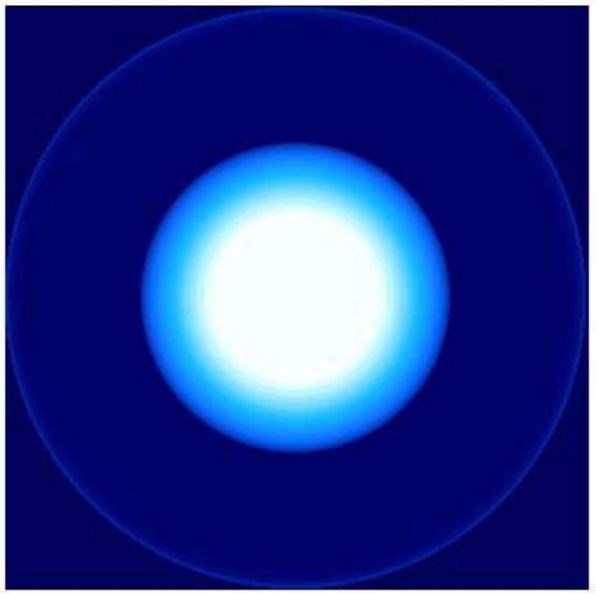
With Core……


130 ppm core potassium
1200 ppm core potassium
7000 ppm core potassium
I_ν [10^6 neutrinos cm^{-2} s^{-1} sr^{-1}]
θ (degrees)
0
20
40
60
80
0
2
4
6
8
10
0
5
10
0
20
40
60

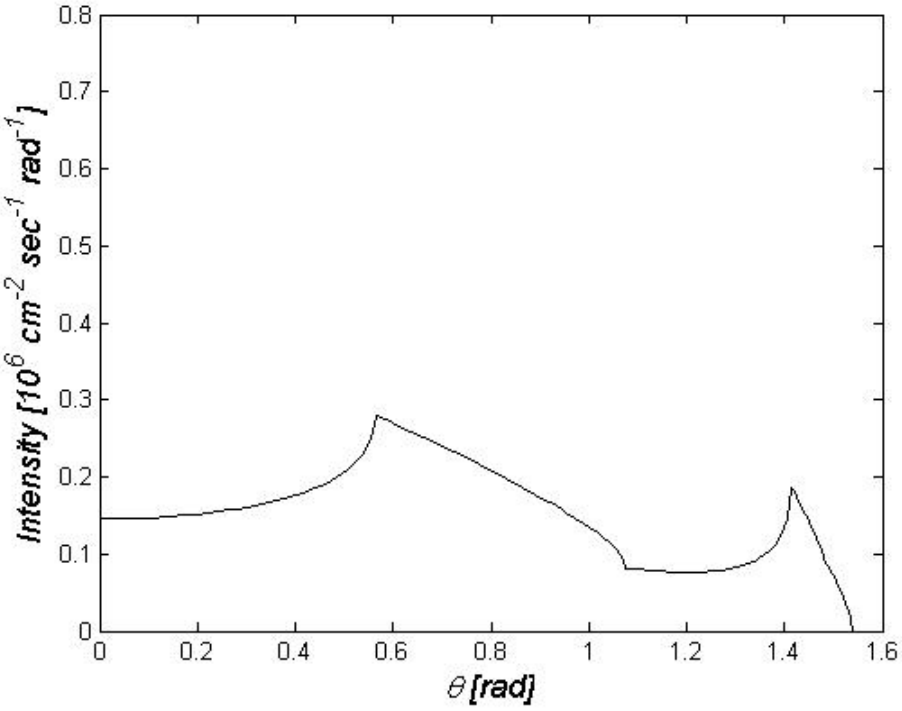

uranium
thorium
potassium
total flux
I_ν [10^6 neutrinos cm^{-2} s^{-1} sr^{-1}]
θ (degrees)

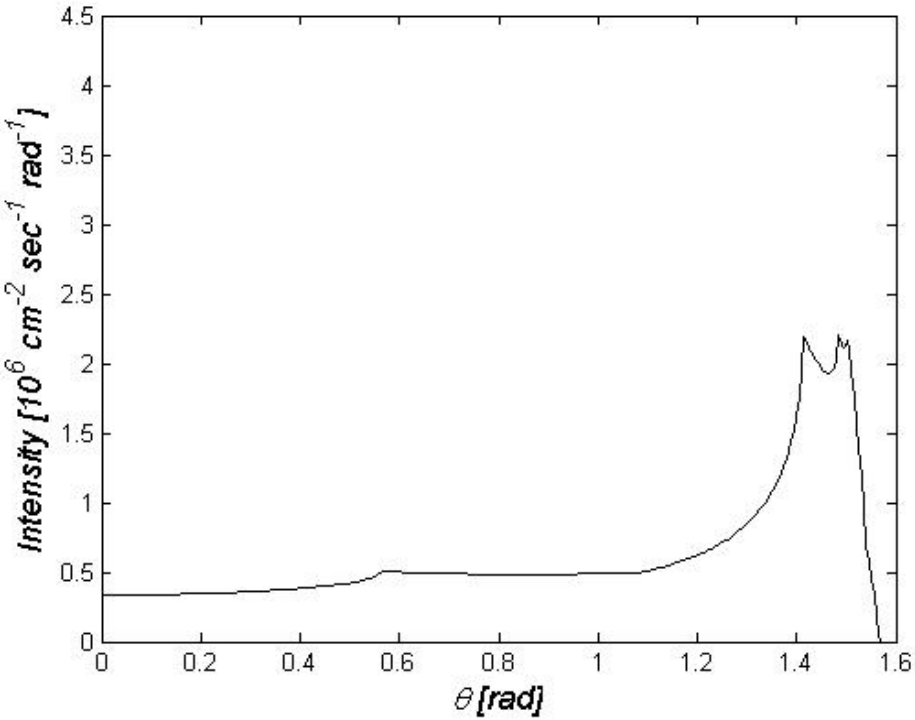



7000 ppm core potassium
I_ν [10^6 n
θ (degrees)

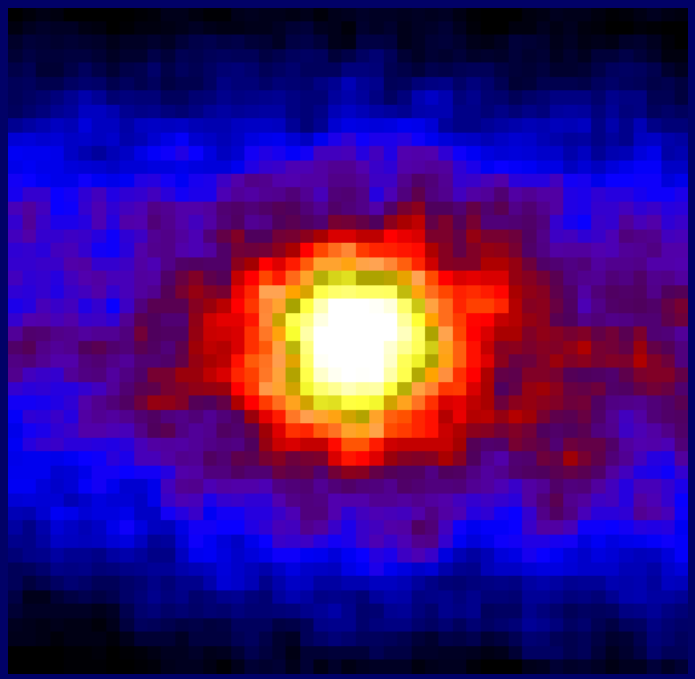


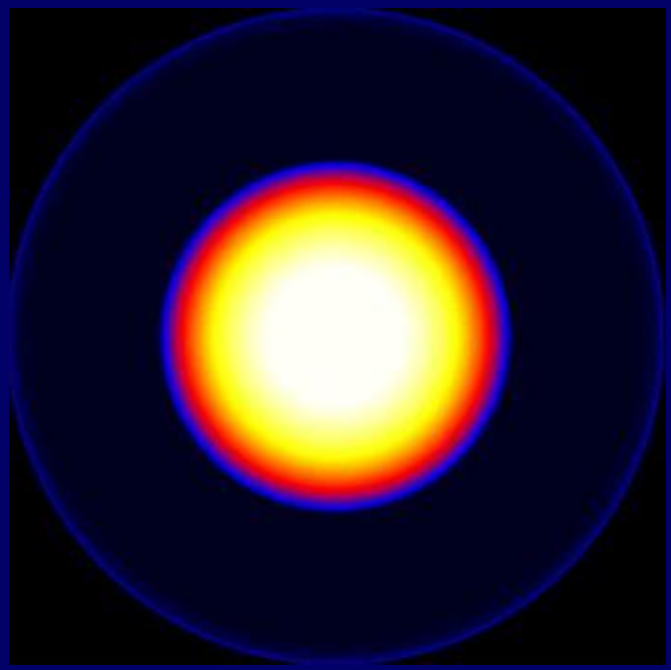
Other options- Hawaii:





Sun vs. Earth

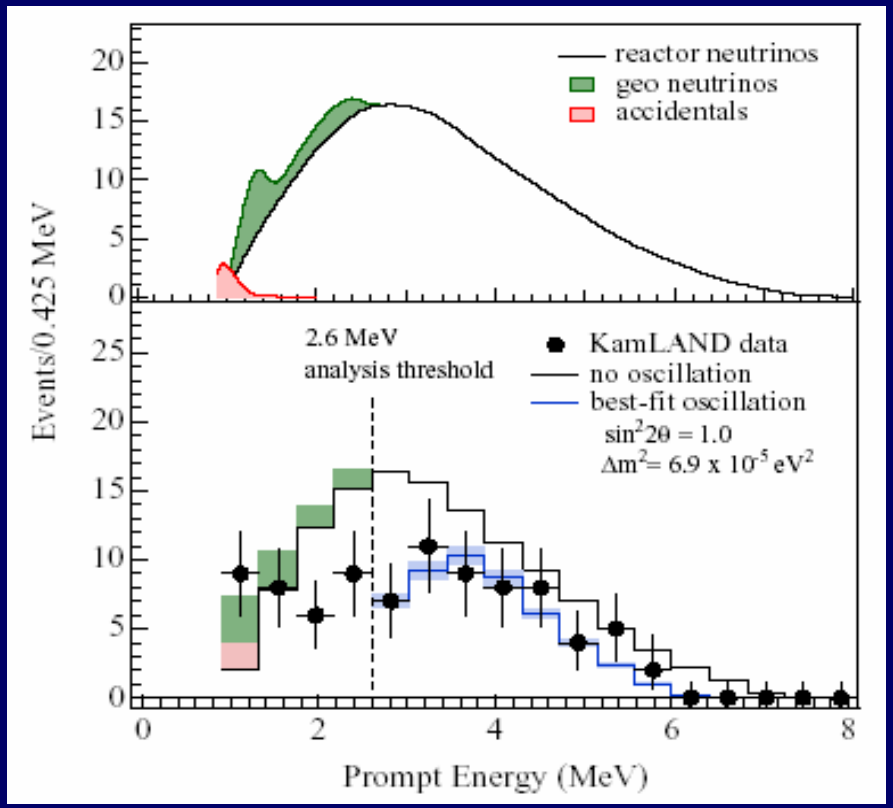




http://elvis.phys.lsu.edu/svoboda/superk.html

Detection via $p + \overline{\nu}_e \longrightarrow n + e^+$

First events from KamLAND (1kton):

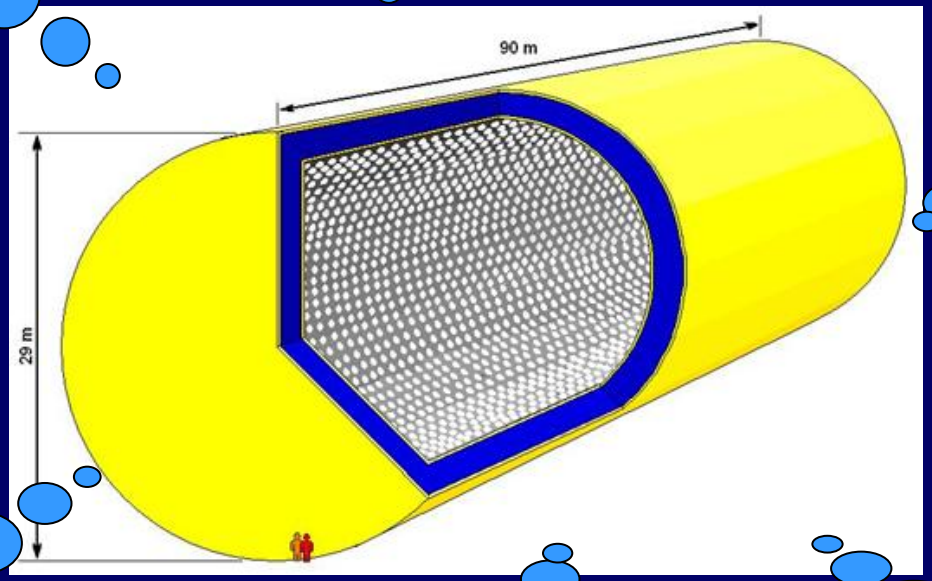


Next generation: 50 kton liquid scintillation detector: LENA

Supernova Neutrinos

Proton Decay

Long Baseline Experiments



Relic Supernova Neutrino Background

Solar Neutrino Spectroscopy

Geoneutrinos

Angular resolution in LENA

Momentum conservation
(proton at rest)

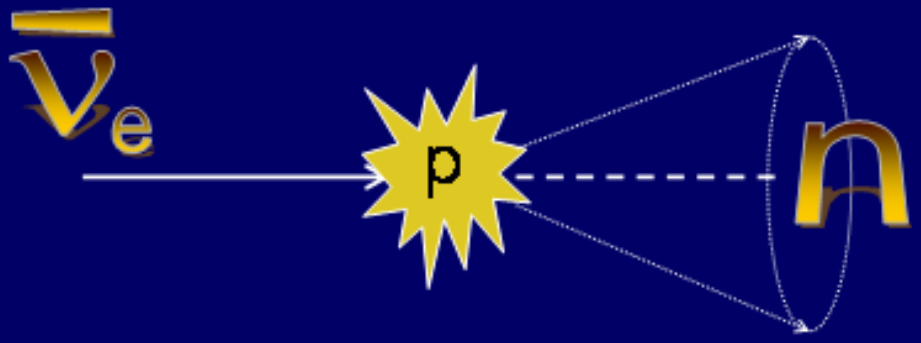
$$\overrightarrow{p_\nu} = \overrightarrow{p_e} + \overrightarrow{p_n}$$

$$\cos\vartheta_{\max} = \frac{\sqrt{2E_\nu\Delta - (\Delta^2 - m_e^2)}}{E_\nu}$$

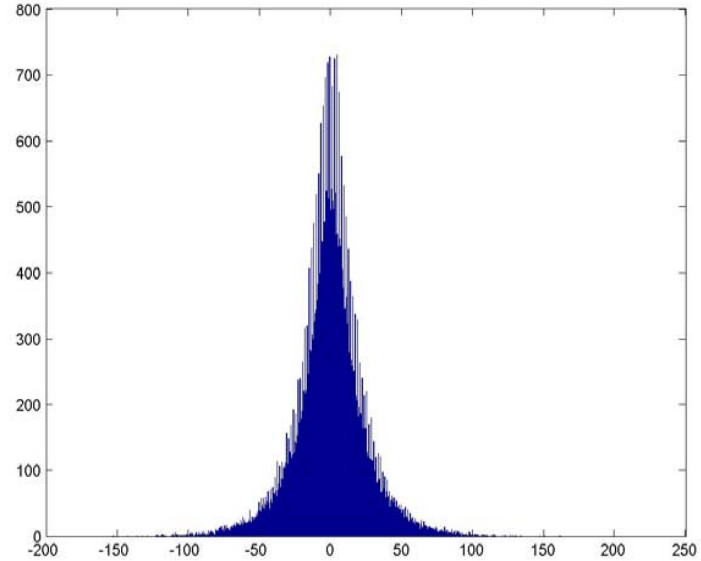
2 MeV ➔ $\cos\theta = 0.95$

3.2 MeV ➔ $\cos\theta = 0.79$

Angular Resolution

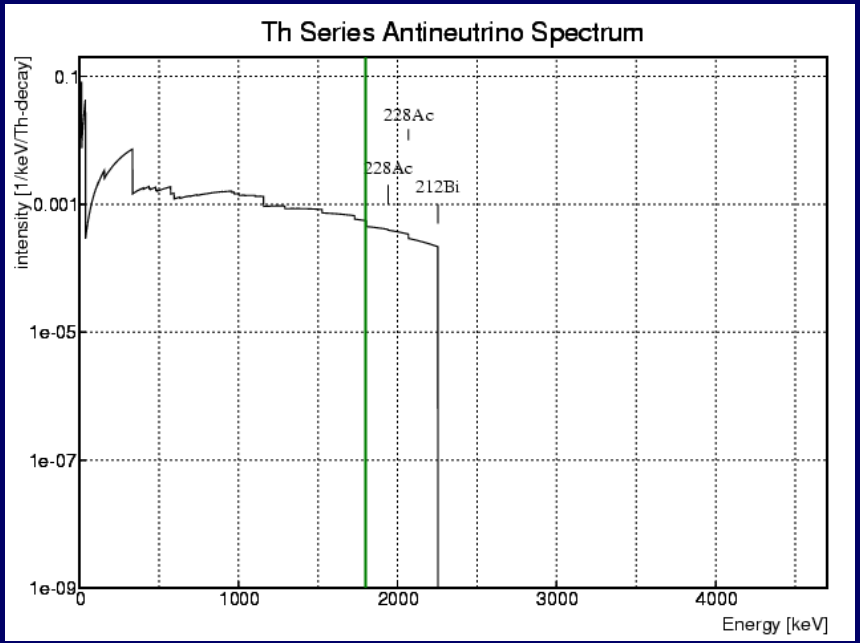


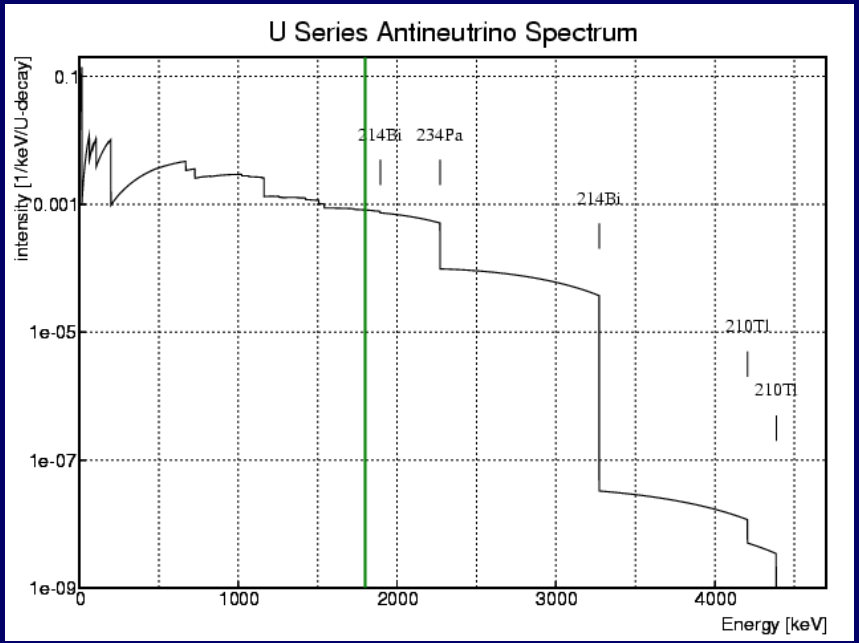
Sensitivity of LENA + resolution of CHOOZ (18°)



➔ Angular resolution of LENA: ~26° (half-cone aperture)

Measurable Spectra

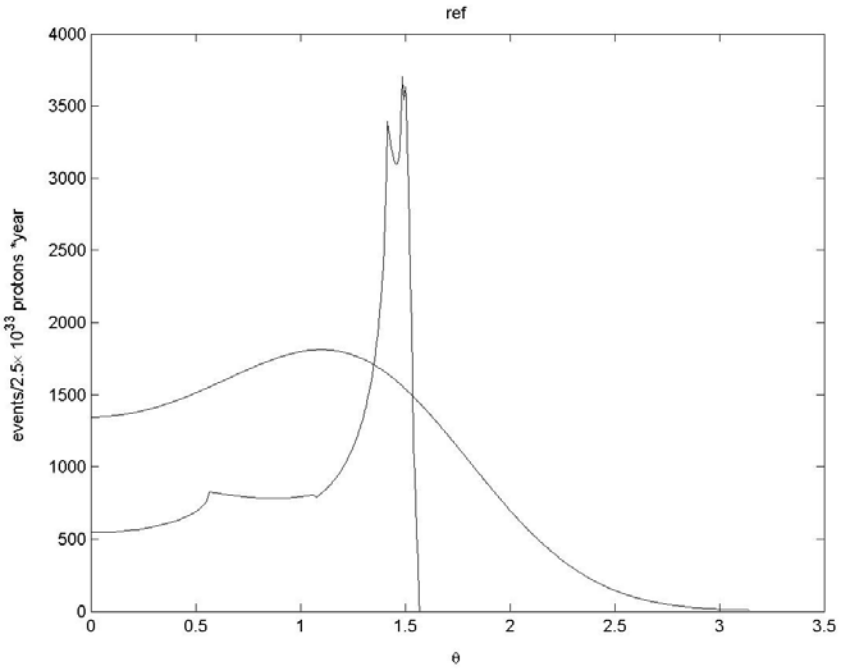


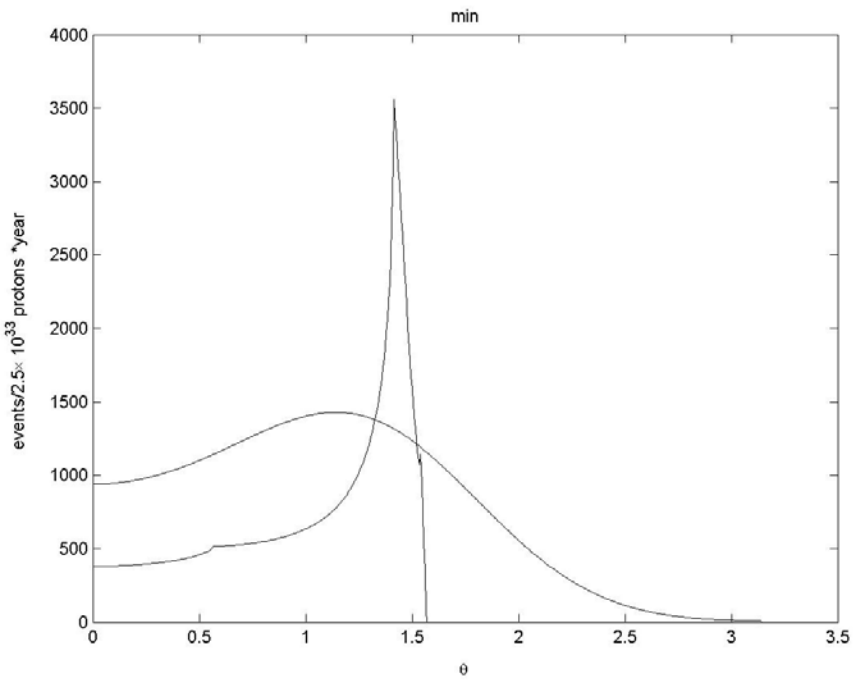


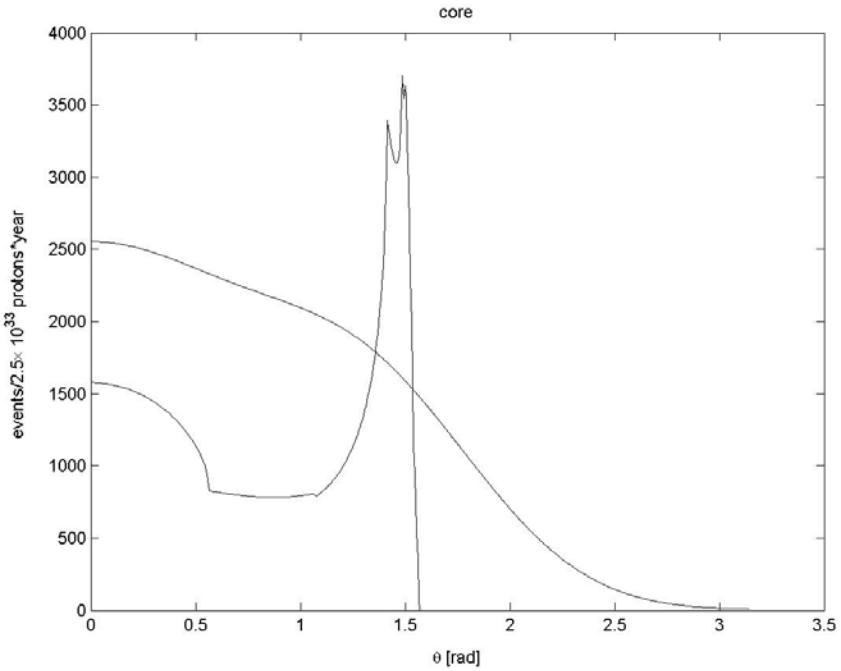
U/Th ratio measurable

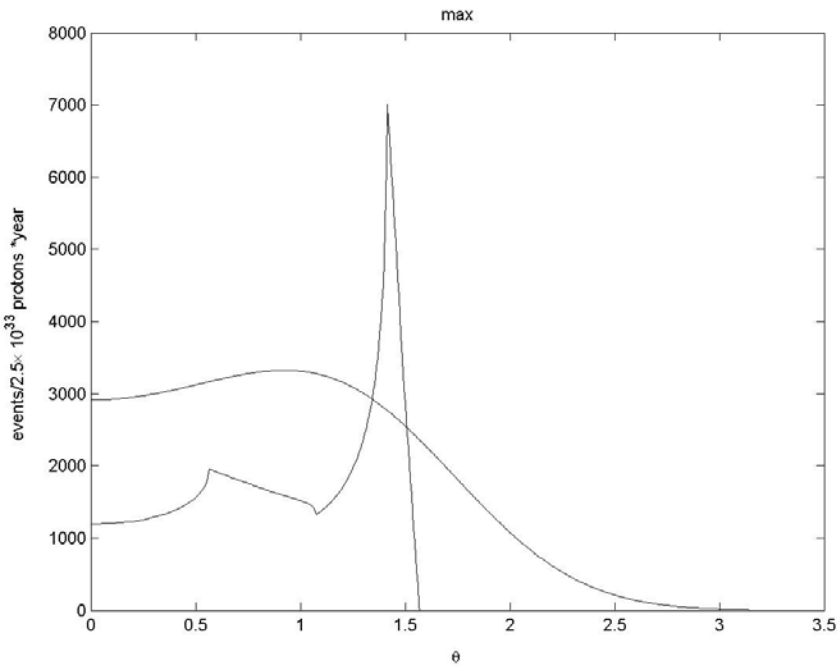
Conclusions for K abundance possible

Note: Only 13% of uranium neutrinos and 9% of thorium above 1.8 MeV


ref
events/2.5× 10^33 protons *year
θ

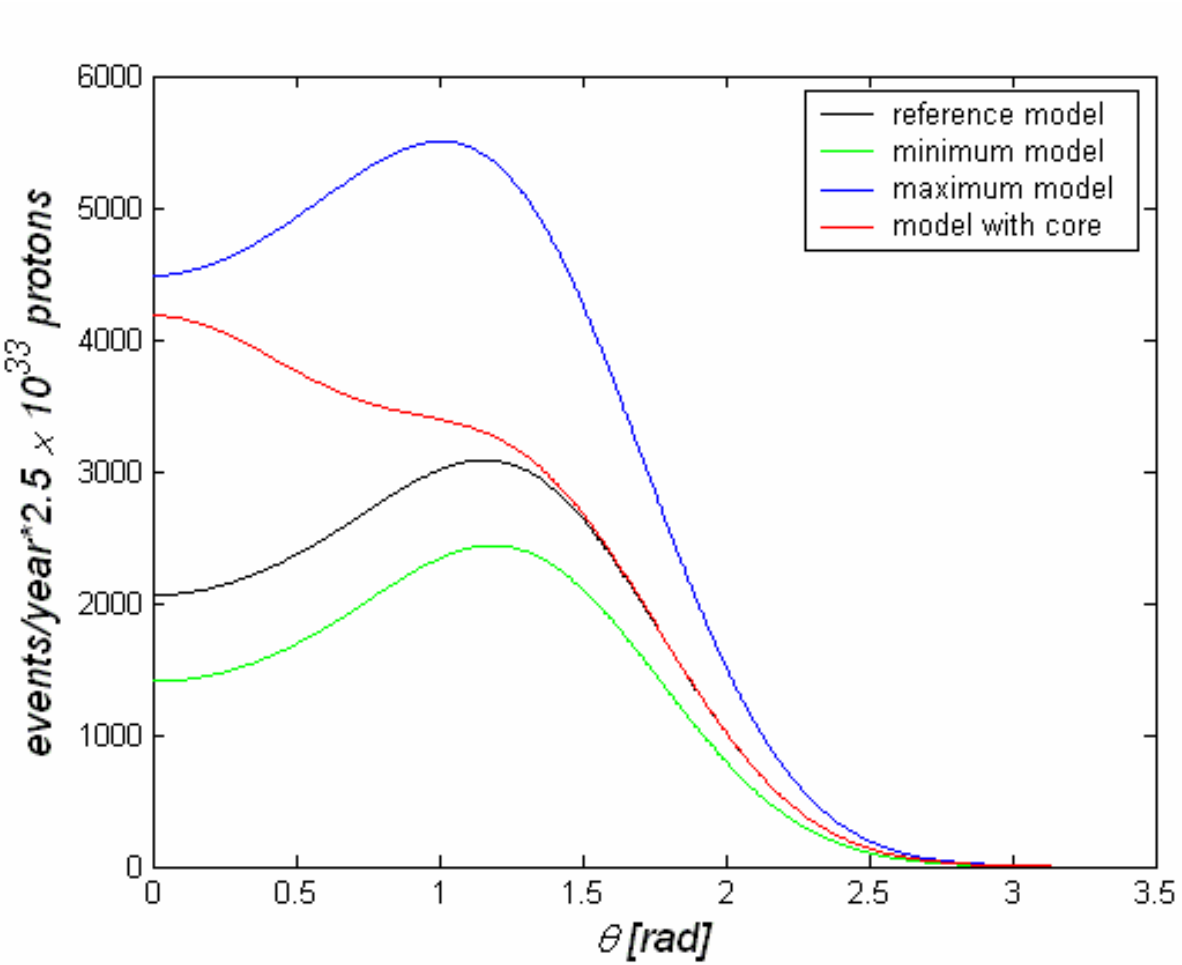

min
events/2.5× 10^33 protons *year
θ


core
events/2.5× 10^33 protons*year
θ [rad]


max
events/2.5× 10^33 protons *year
θ

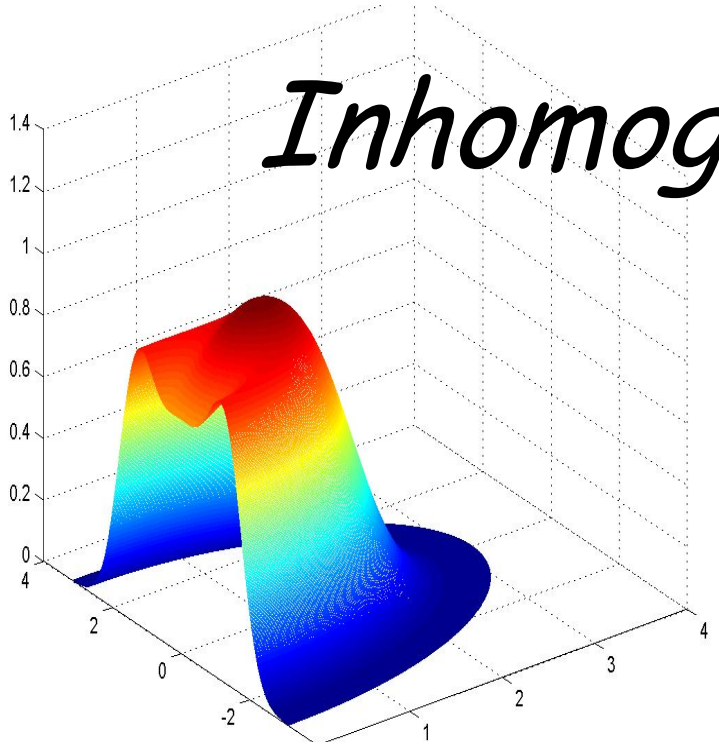
Continental Crust Models

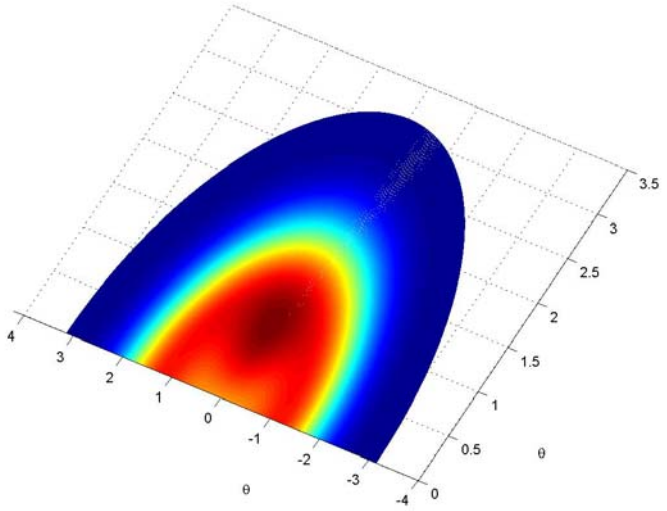
Direct Comparison :

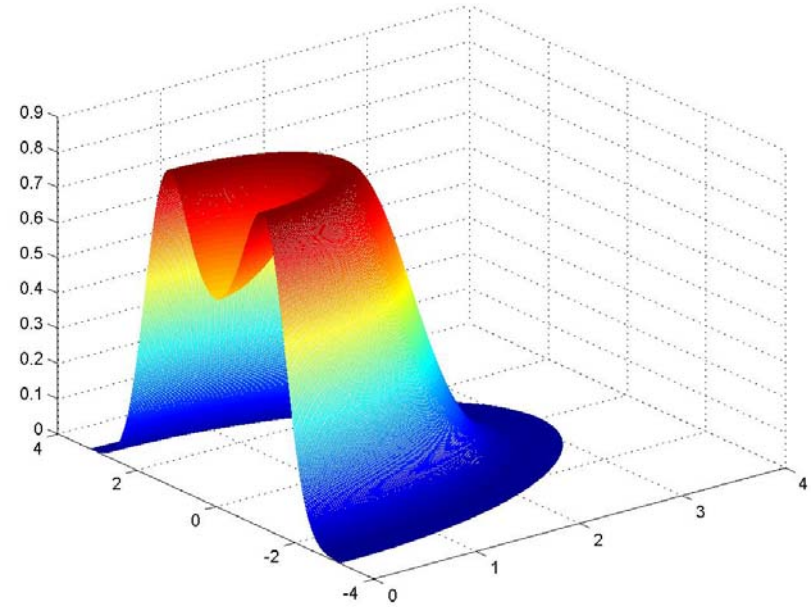


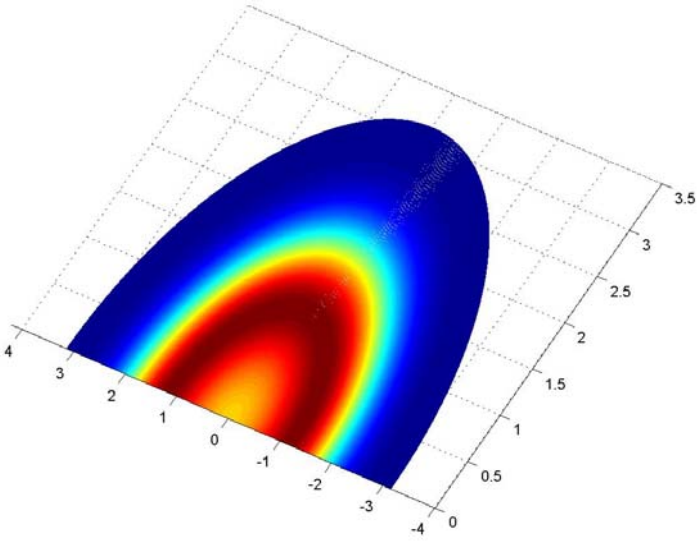
	$0° < \theta < 30°$	$30° < \theta$	total	ratio
ref	1081 ± 33	4020± 63	5102 ± 71	0.27 ± 0.01
min	750 ± 27	3195 ± 56	3945 ± 63	0.33 ± 0.01
max	2321 ± 48	7015± 84	9336 ± 97	0.24 ± 0.01
core	2011 ± 45	4537 ± 67	6548 ± 81	0.44 ± 0.01

Inhomogenous Earth

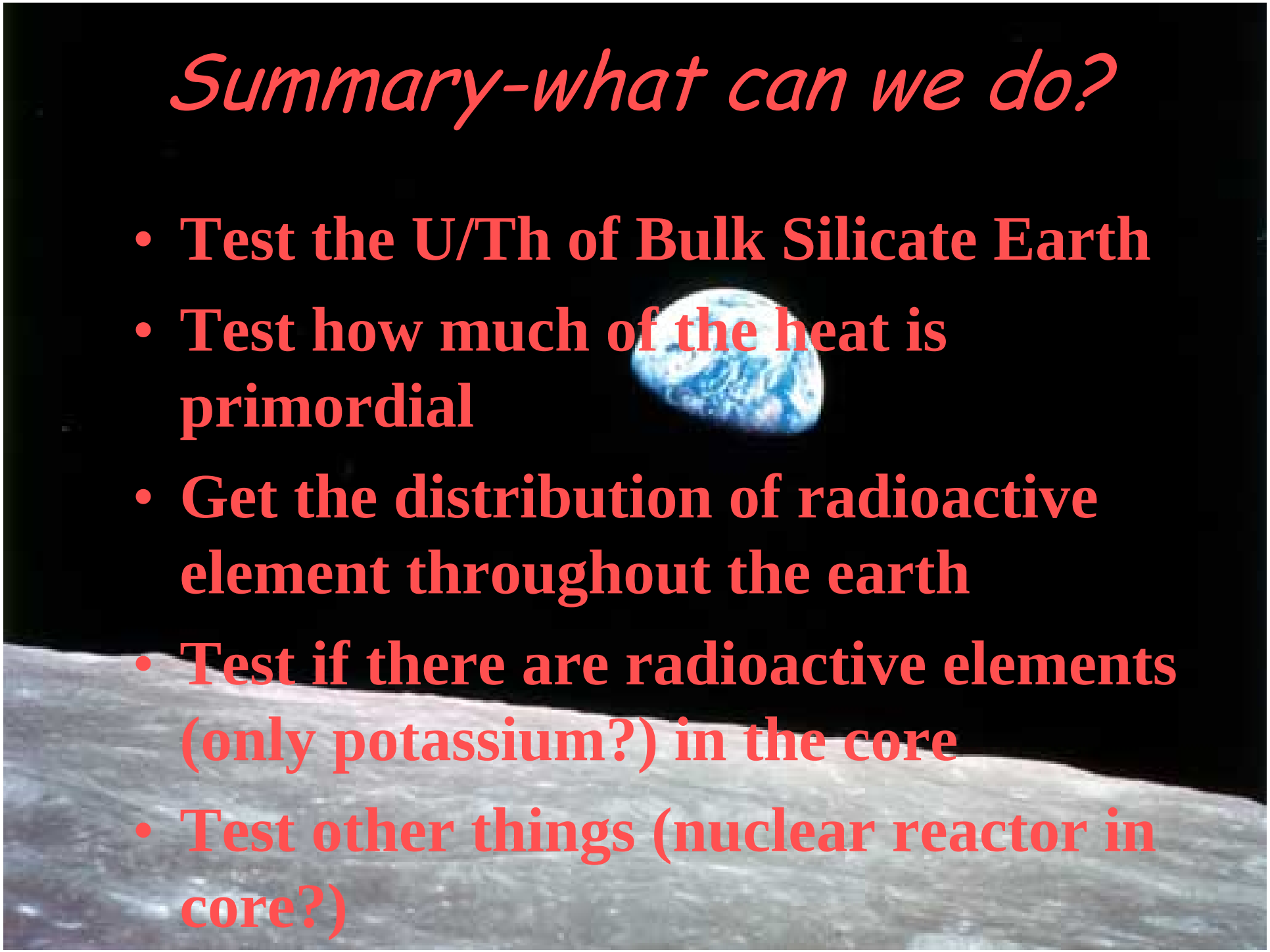








Summary-what can we do?



- **Test the U/Th of Bulk Silicate Earth**
- **Test how much of the heat is primordial**
- **Get the distribution of radioactive element throughout the earth**
- **Test if there are radioactive elements (only potassium?) in the core**
- **Test other things (nuclear reactor in core?)**

Conclusions

Angular resolution of LENA 26°

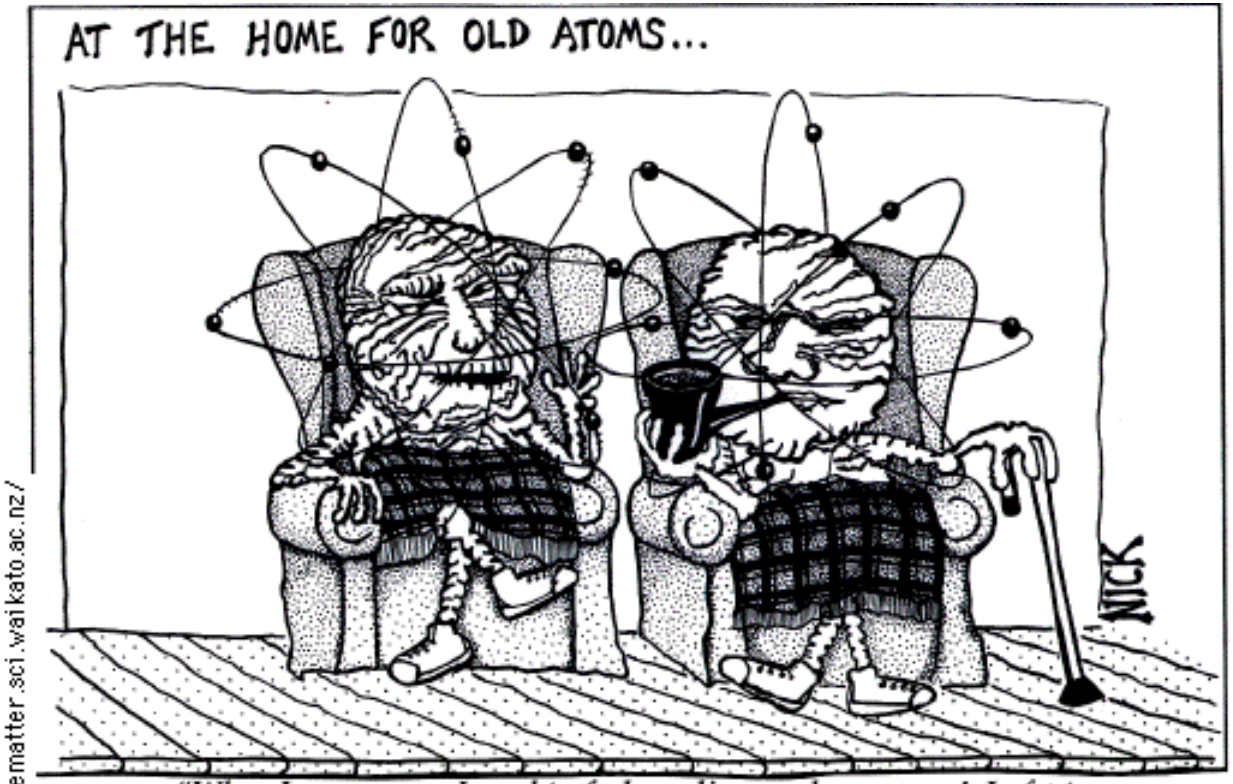
Distinction between different geological models possible!!

Chance for location of non-visible galactic SN

References:

- Fields, Hochmuth [hep-ph/0406001]
- Mantovani, Carmignani, Fiorentini, Lissia [hep-ph/0309013]
- Rama Murthy, van Westrenen, Fei, Nature 423 (2003)
- Gessmann, Wood, Earth Planet Sci Lett, 200 (2002)
- Lee, Jeanloz, Geophys Res Lett, 30 (2003)
- Dziewonski, Anderson, Phys Earth Plan Int 25, 297 (1981)
- Table of Nuclides: http://atom.kaeri.re.kr/index.html
- Super-K: http://elvis.phys.lsu.edu/svoboda/superk.html
- Vogel, Beacom: arxiv:hep-ph/9903554
- Chooz:arxiv:hep-ex/9906011
- http://arxiv.org/abs/hep-ph/0401221
- http://kamland.lbl.gov/Pictures/
- http://www.greeklandscapes.com/maps/satellite.html
- http://virtual.finland.fi/netcomm/news/showarticle.asp?intNWSAID=27070

Thank you!



"When I was young I used to feel so alive, so dangerous..! In fact, would you believe that I started out life as a Uranium-238 ? Then one day I accidentally ejected an alpha particle, and that's where it all began. Now look at me, a spent old atom of Lead-206. It seems that all my life since then has been nothing but decay, decay, decay...."