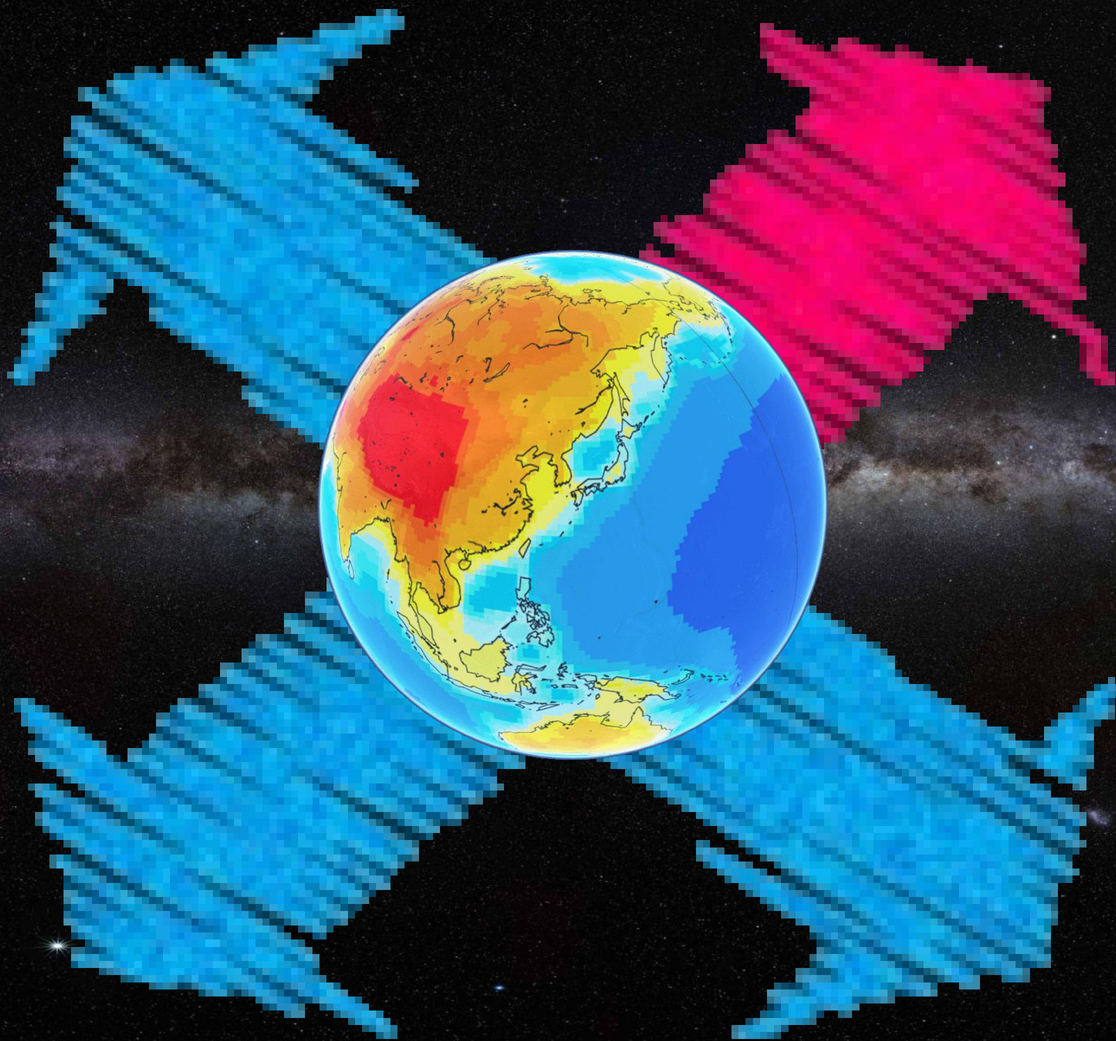
Antineutrini da reattori e geoneutrini in JUNO

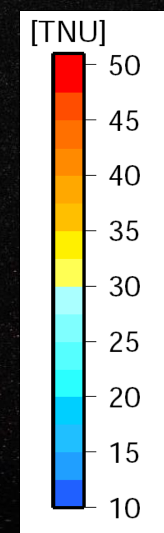
Fabio Mantovani – University of Ferrara & INFN - Italy

Geoneutrinos: what next?



SUMMARY

- **Cosa è stato fatto…**
- **Cosa si sta facendo…**
- **Cosa si potrebbe fare..**



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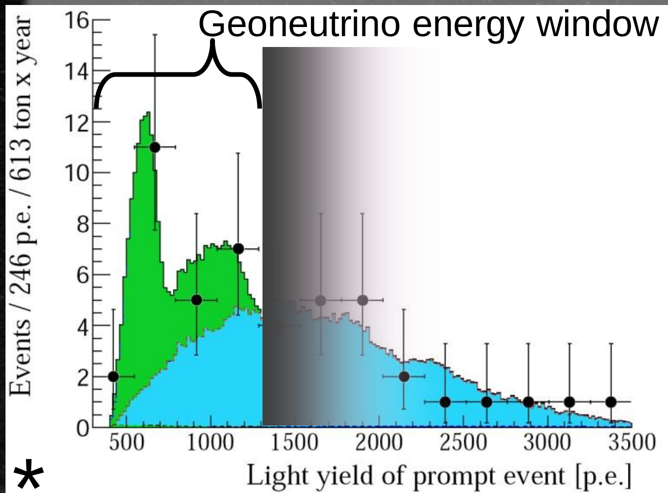
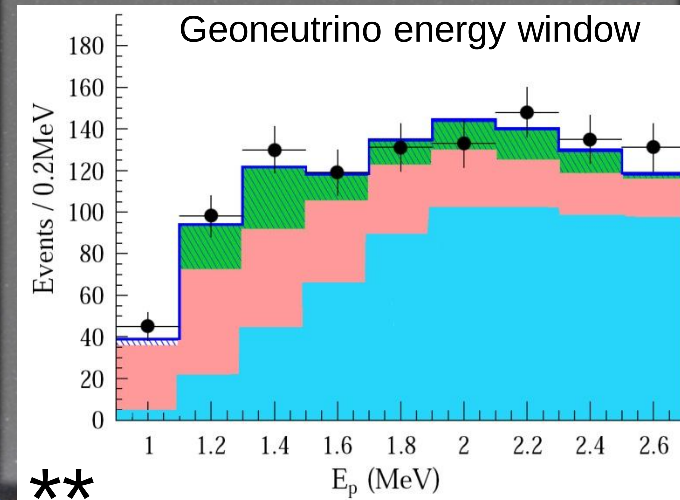
Borexino and KamLAND results

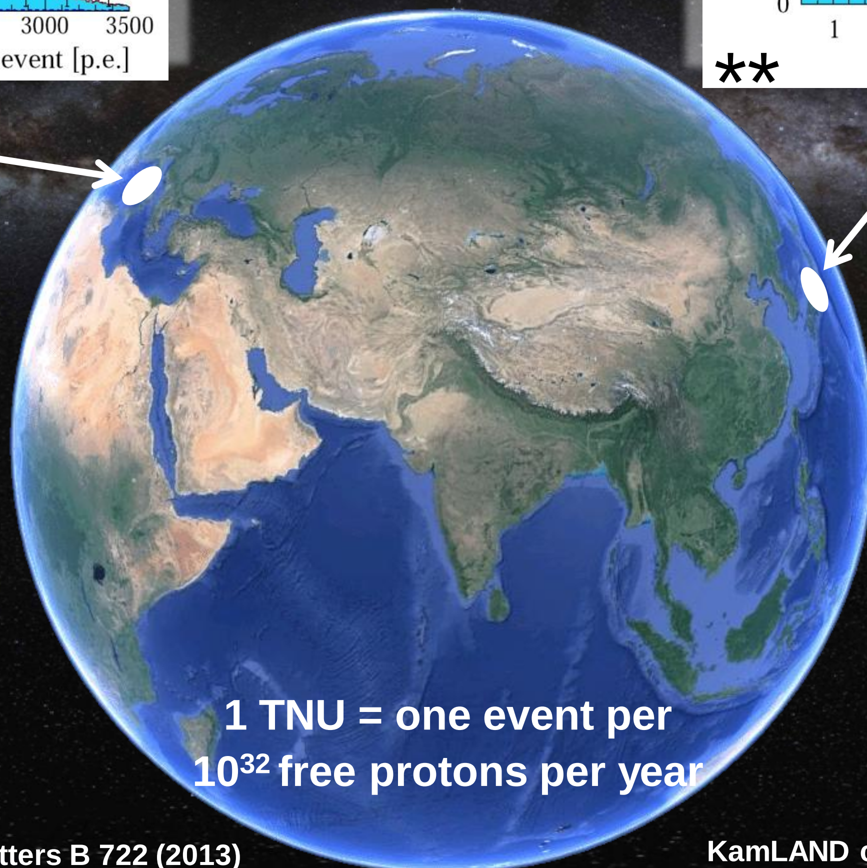


Geoneutrinos

Background

Reactor antineutrinos





Borexino

- Period: 2007 – 2012
- Geo-ν events: 14^{+4}_{-4}
- Signal: 39 ± 12 TNU

KamLAND

- Period: 2002 – 2012
- Geo-ν events: 116^{+28}_{-27}
- Signal: 30 ± 7 TNU

1 TNU = one event per 10^{32} free protons per year

* arXiv:1303.2571v2
Borexino collaboration - Physics Letters B 722 (2013)

** arXiv:1303.4667v2
KamLAND collaboration - Phys. Rev. D 88 (2013)

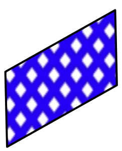
KL and BX results and radiogenic heat

In the plane (S,H), a region containing all models consistent with geochemical and geophysical data can be defined:

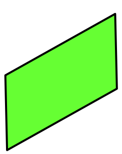
✓ the "slope" is universal

✓ the intercept depends on the site

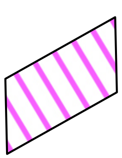
✓ the width depends on the site (crust effect)



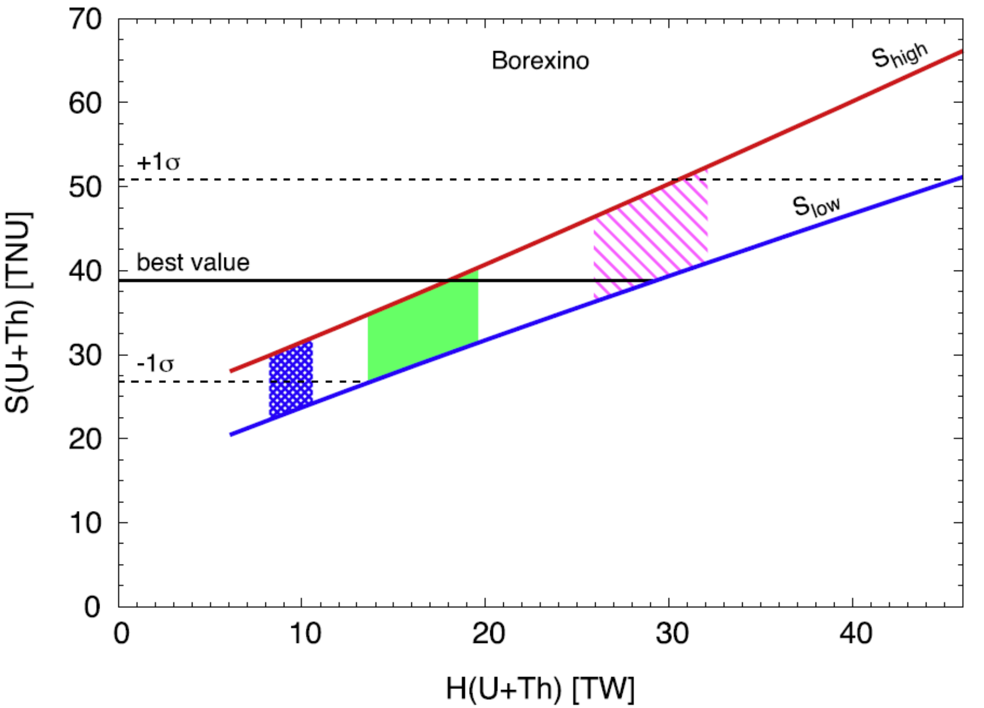
Cosmochemical BSE models:
$m_{PRIM}(U) = 0.5 \pm 0.1\ 10^{17}$ kg
Th/U = 3.5

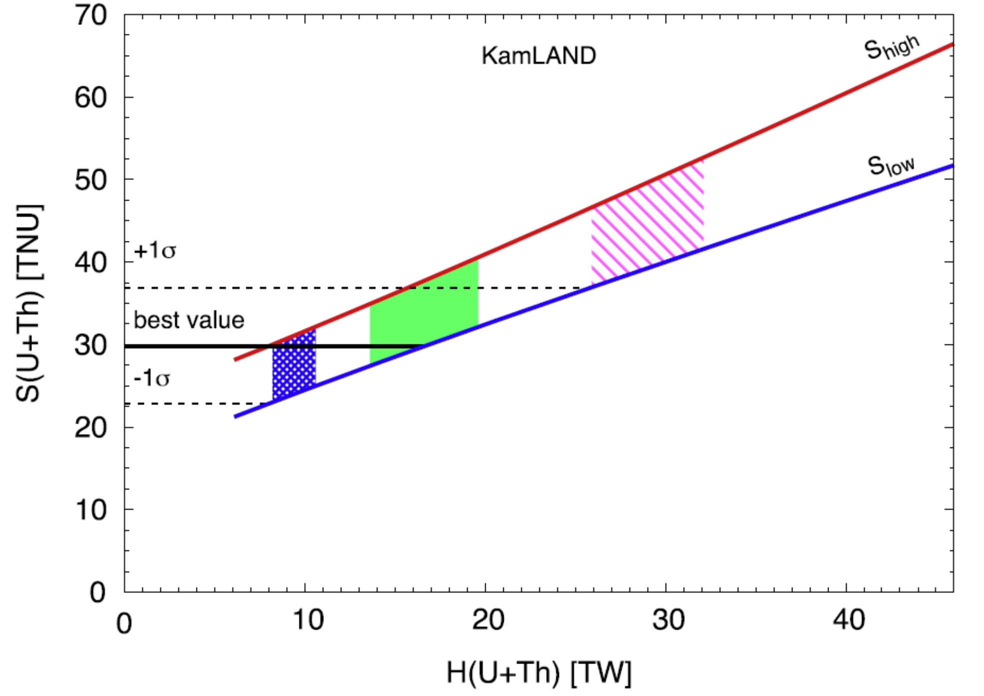


Geochemical BSE models:
$m_{PRIM}(U) = 0.8 \pm 0.2\ 10^{17}$ kg
Th/U = 4



Geodynamical BSE models:
$m_{PRIM}(U) = 1.4 \pm 0.2\ 10^{17}$ kg
Th/U = 4

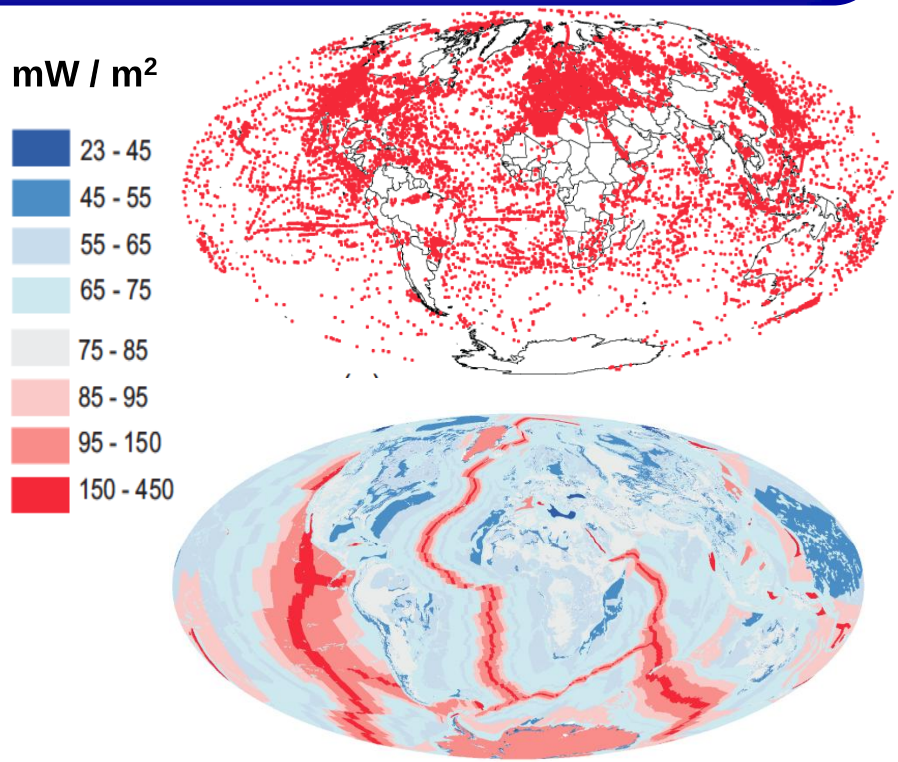




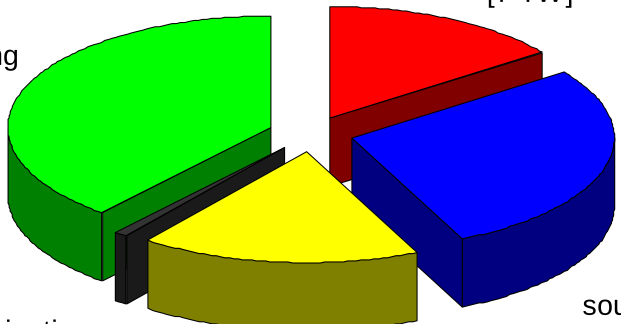
Implications of KL and BX on terrestrial radiogenic heat

	Global heat loss [TW]
Williams and von Herzen [1974]	43
Davies [1980]	41
Sclater et al. [1980]	42
Pollack et al. [1993]	44 ± 1
Hofmeister et al. [2005]	31 ± 1
Jaupart et al. [2007] *	46 ± 3
Davies and Davies [2010]	47 ± 2

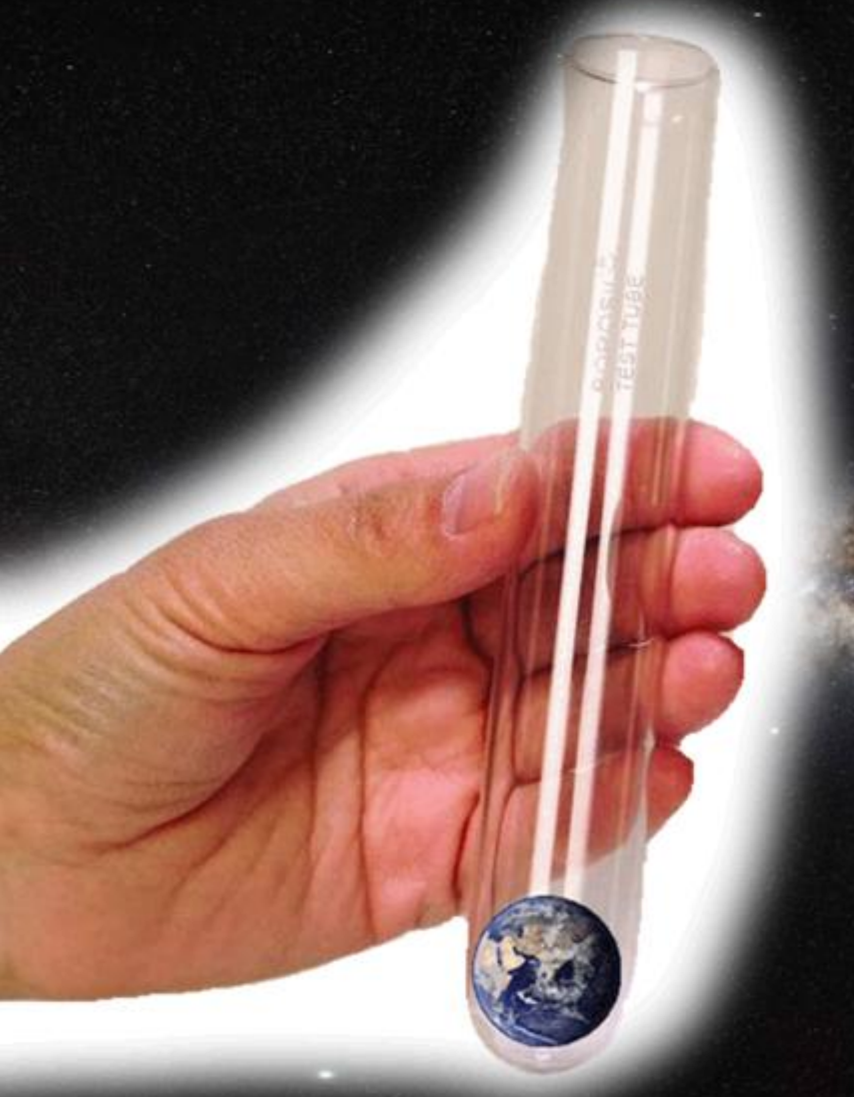
- New results based on ~40.000 measurements in deep bore-holes (55% more than used in previous estimates)
- Heat loss through the sea floor is estimated by half space model.



	H(U+Th) [TW]*
KamLAND	13 ± 9
Borexino	23 ± 14



* Bellini et al 2013 - Prog Part Nucl Phys - arXiv:1310.3732



Two independent and pioneering experiments, far ~10^4 km one from another, are measuring a geoneutrino signal in good agreement with the expectations

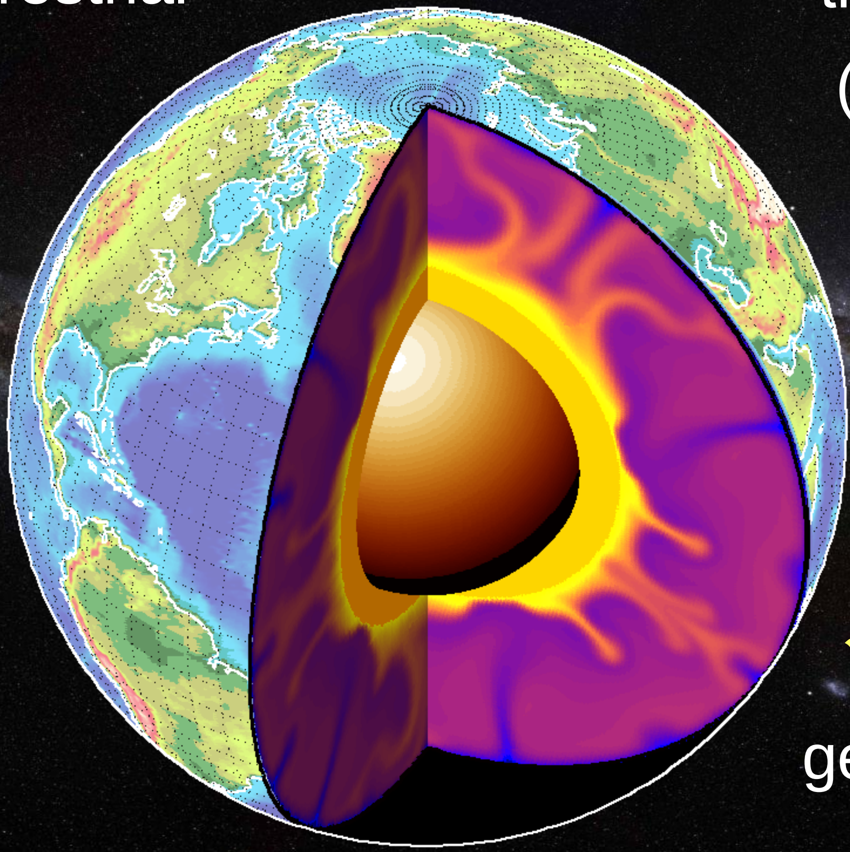
Geoneutrinos are bringing to Earth's surface information about the chemical composition of the whole planet

Open questions about natural radioactivity in the Earth

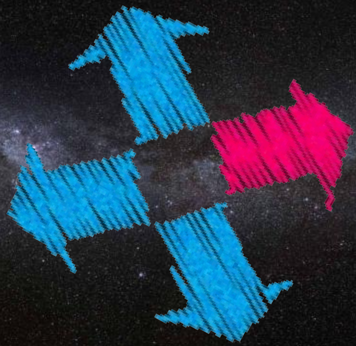
✓ What is the radiogenic contribution to terrestrial heat production?

✓ How much U and Th in the crust and in the mantle?

✓ What is the distribution of radioactivity in the mantle?



✓ What is hidden in the Earth's core? (geo-reactors…)



✓ Is the standard geochemical model (BSE) consistent with geo-neutrino data?

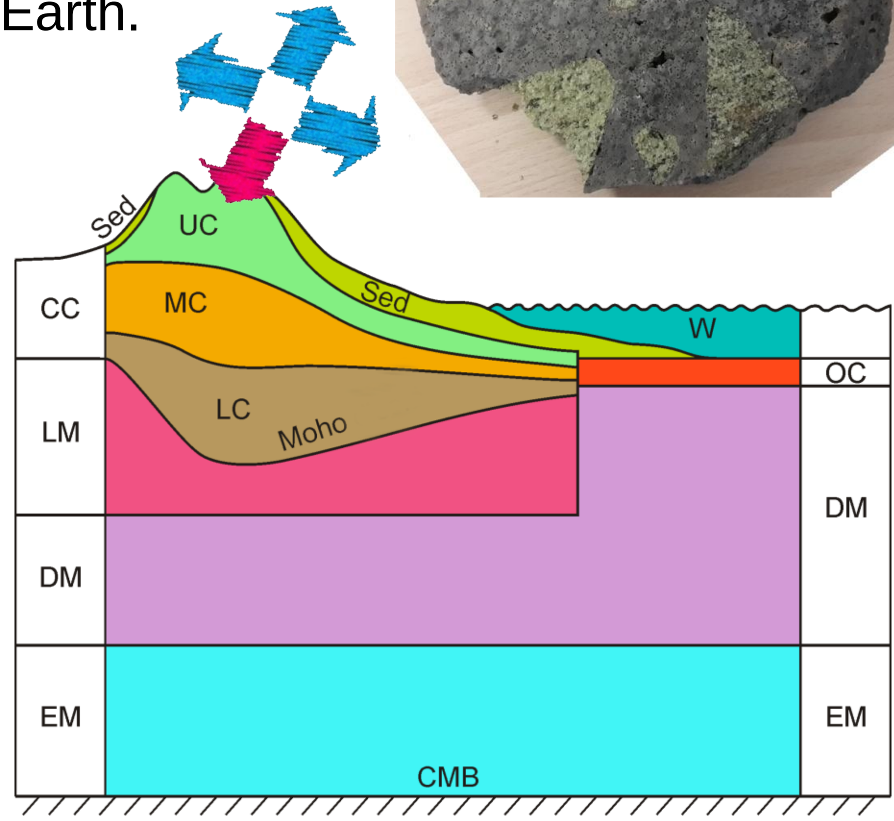
Terra incognita

- Deepest hole is about 12 km
- Samples from the crust (and the upper portion of mantle) are available for geochemical analysis.

- Seismology reconstructs density profile (not composition) throughout all Earth.

Recent novelties[2]:

- a refined geophysical structure of CC and new compilations of geochemical data
- a new approach for evaluating the composition of MC and LC
- the contributions from Lithospheric Mantle and from 3 classes of BSE compositional models (cosmochemical, geochemical and geodynamical)

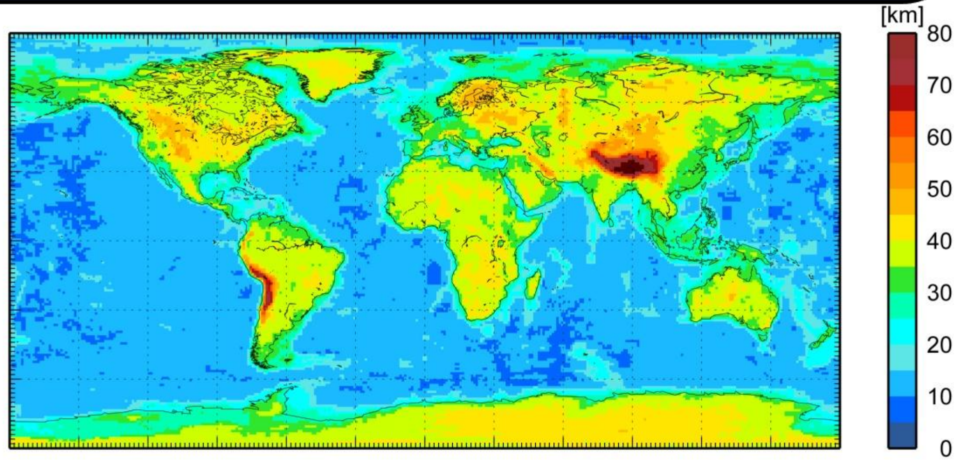


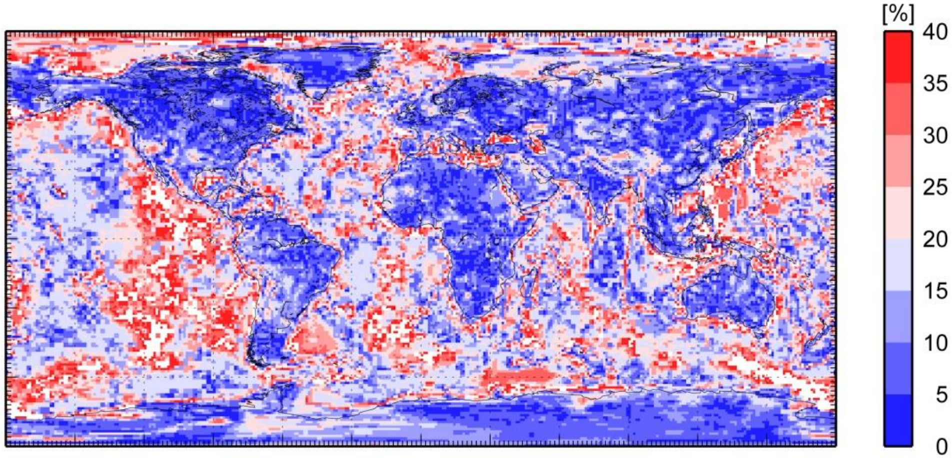
[2] Sràmek et al. 2012 + Huang et al. 2013

Geophysical model and its uncertainties

Crustal reference model[1]: 64.800 1°x1° voxels divided in CC and OC.

- CRUST2.0[2]: reflection and refraction seismic data
- CUB2.0[3]: surface seismic waves
- GEMMA[4]: gravitational potential field





- First uncertainty estimate of global crustal thickness
- ~10% uncertainty in continents
- Larger uncertainty in oceans and continental margins

		CRUST2	CUB2	GEM	RM
Mass (10^{21} kg)	CC	21.4	20.9	19.6	20.6 ± 2.5
	OC	6.3	6.4	7.4	6.7 ± 2.3

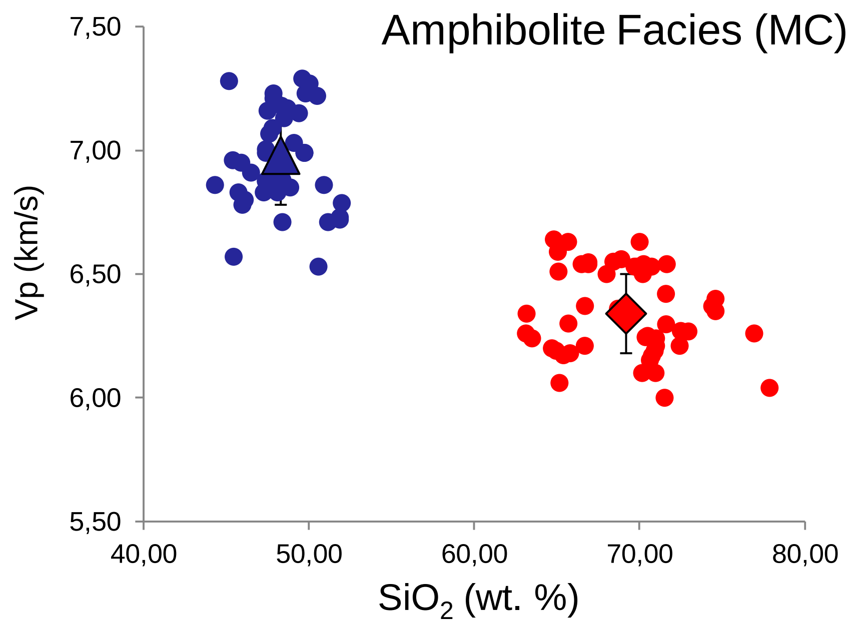
[1] Huang, Y., et al. – 2013
[2] Bassin et al. - 2000
[3] Shapiro and Ritzwoller - 2002
[4] Negretti et al. - 2012

Seismic argument for estimating Felsic/Mafic in MC and LC

- **Felsic** and **mafic** rocks can be distinguished on the basis of P and S waves velocities

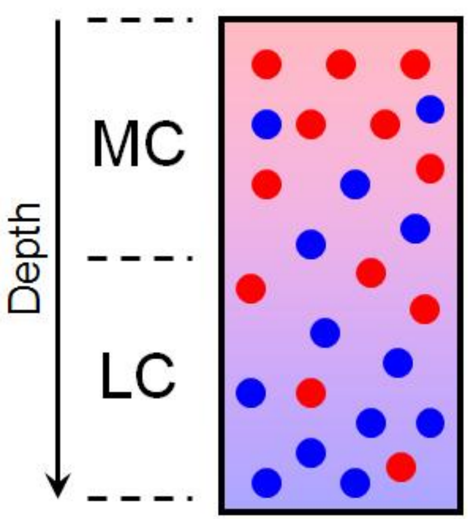
- Ultrasonic velocity measurements of deep crustal rocks **provide a link** between seismic velocity and lithology.

- The fractions of **felsic** (**f**) and **mafic** (**m**) rocks in the MC and LC of RRM are estimated solving:



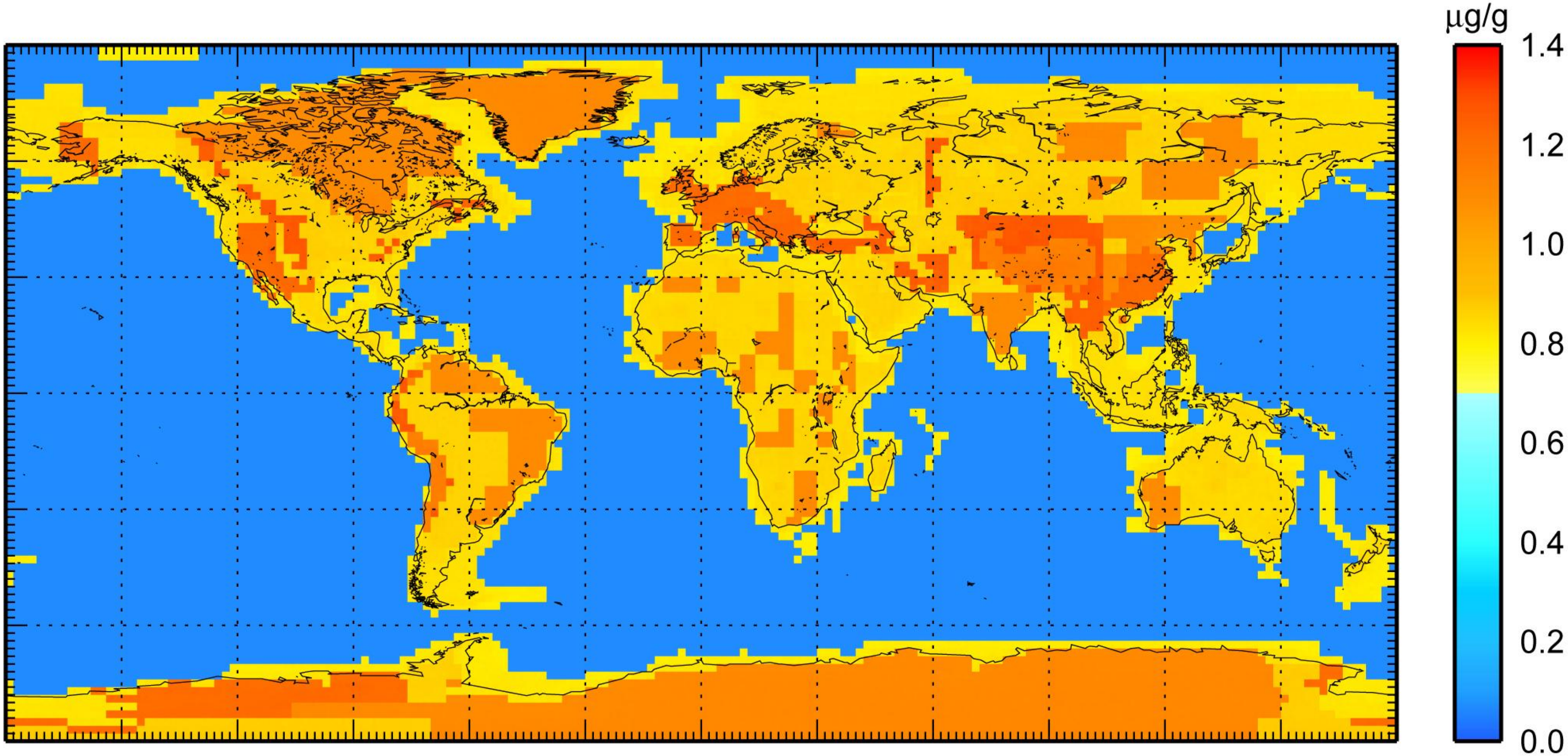
$$\begin{cases} f + m = 1 \\ v_C = m v_m + f\, v_f \\ a = m a_m + f\, a_f \end{cases}$$

		a (U) µg/g
MC	Fels.	$1.4_{-0.6}^{+1.0}$
	Mafic	$0.4_{-0.2}^{+0.4}$
LC	Fels.	$0.4_{-0.2}^{+0.4}$
	Mafic	$0.1_{-0.1}^{+0.1}$



v_C = seismic velocity measured in MC and LC (CRUST2.0)
$v_{f;m}$ = lab. measurements of felsic and mafic rock velocity
$a_{f;m}$ = U (and Th) abundance in felsic and mafic rocks
a = U (and Th) abundance in MC and LC

Heterogeneous distribution of U in MC

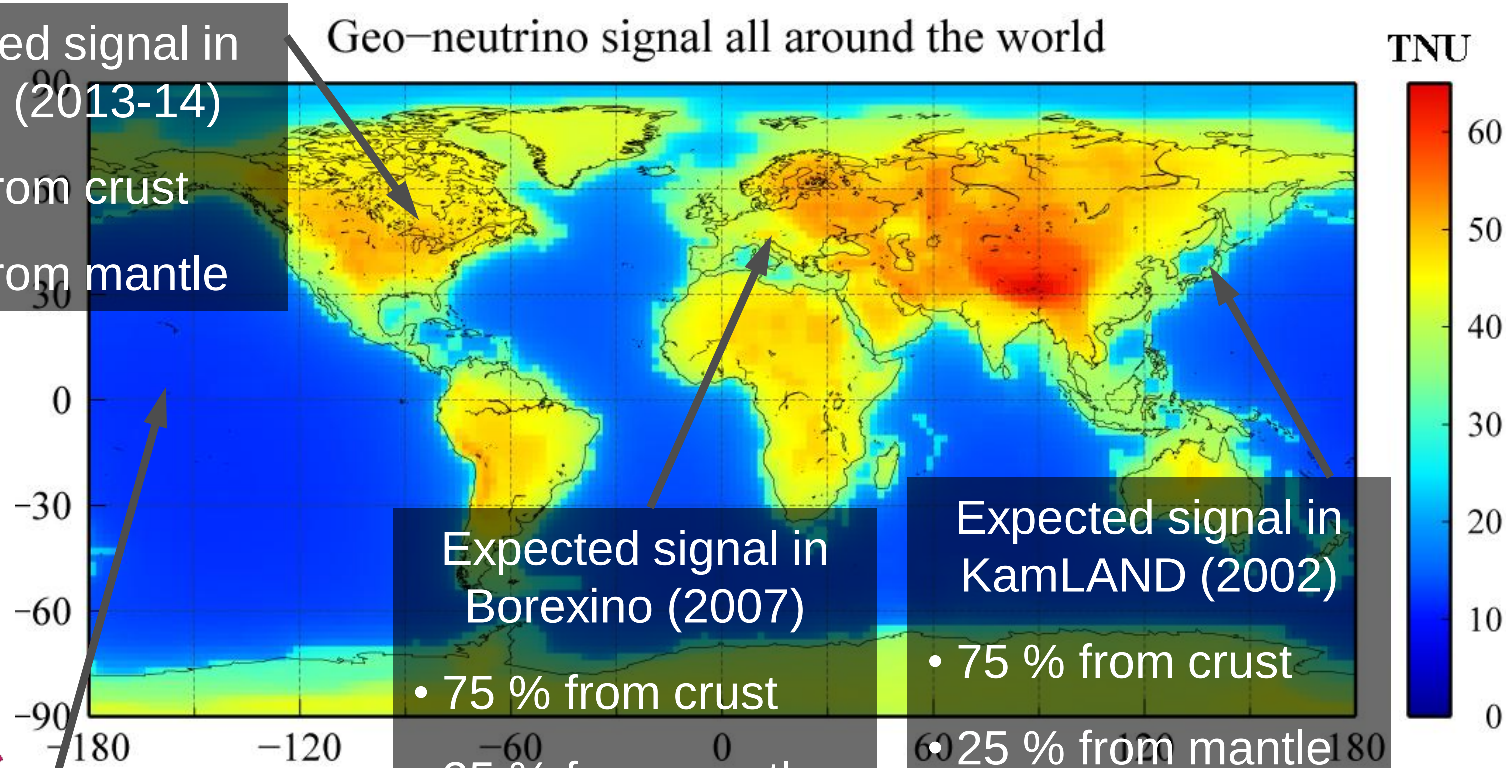


	MC		LC		Bulk CC		
	a(U) [μg/g]	*a*(Th) [μg/g]	*a*(U) [μg/g]	*a*(Th) [μg/g]	*a*(U) [μg/g]	*a*(Th) [μg/g]	P (TW)
R&G (03)	**1.3**	**6.5**	**0.2**	**1.2**	**1.4**	**6.2**	**7.4**
Huang et al (13)	**$1.0^{+0.6}_{-0.4}$**	**$4.9^{+4.3}_{-2.3}$**	**$0.2^{+0.1}_{-0.1}$**	**$1.0^{+1.2}_{-0.5}$**	**$1.3^{+0.3}_{-0.3}$**	**$5.6^{+1.6}_{-0.9}$**	**$6.8^{+1.4}_{-1.0}$**

How to look into the deep Earth?

Expected signal in SNO+ (2013-14)

- 82 % from crust
- 18 % from mantle



Expected signal in Borexino (2007)

- 75 % from crust
- 25 % from mantle

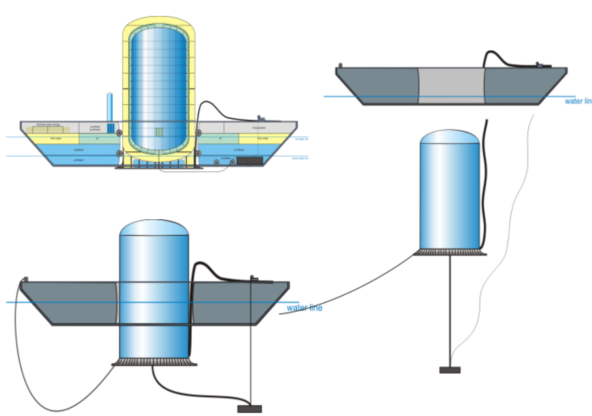
Expected signal in KamLAND (2002)

- 75 % from crust
- 25 % from mantle

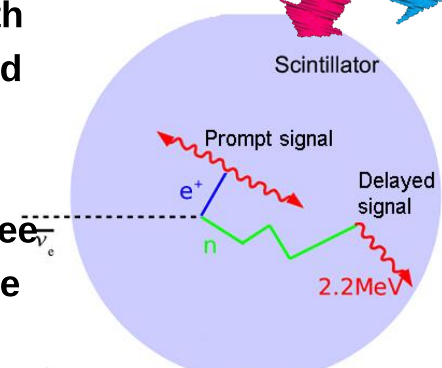
Expected signal in Hawaii

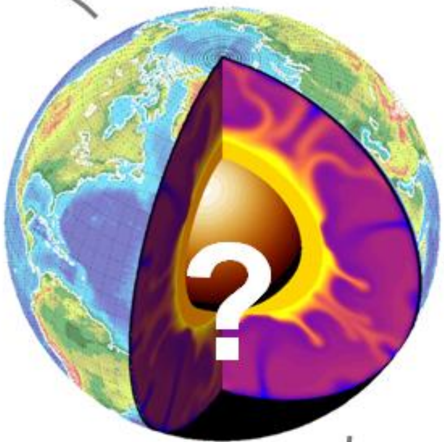
- 28 % from crust
- 72 % from mantle

See Jocher et al. 2013



Reconstruction of geo-ν direction with Gd, Li and B loaded LS is being investigated by several groups. (See Tanaka & Watanabe 14, Shimizu 07, Domogatsky et al. 06)





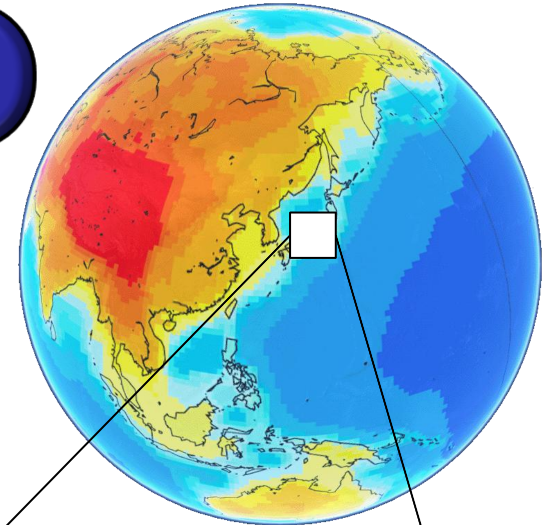
PHYSICAL REVIEW D **86**, 033004 (2012)

Mantle geoneutrinos in KamLAND and Borexino

G. Fiorentini,[1,2,3] G. L. Fogli,[4,5] E. Lisi,[5] F. Mantovani,[1,3] and A. M. Rotunno[4]

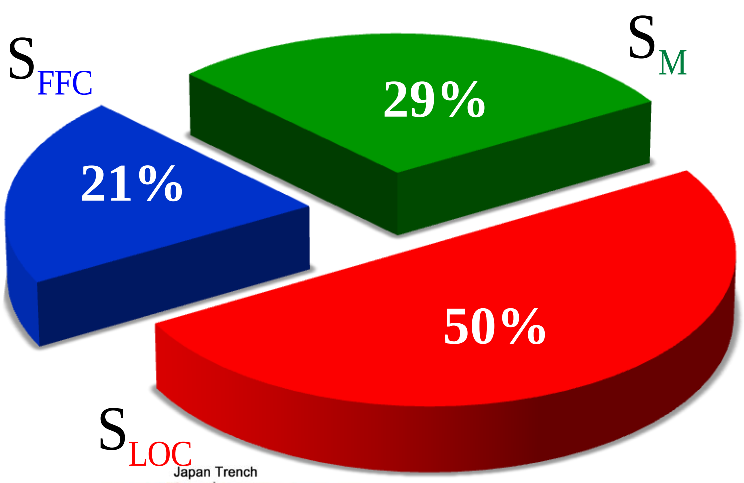
$$S_{\text{Expected}} = S_{\text{LOCal}} + S_{\text{Far Field Crust}} + S_{\text{Mantle}}$$

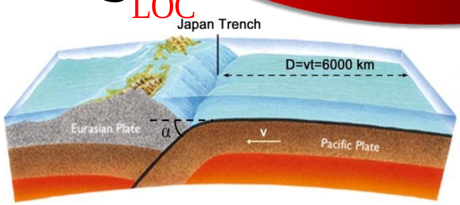
KamLAND: theory vs experiment



For each element (U, Th) the expected geo-neutrino signal S in one site on the Earth's surface is the sum of three contributions:

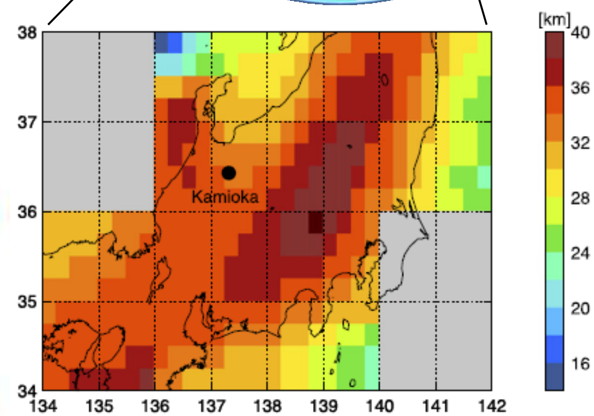
$$S_{Expected} = S_{LOCal} + S_{Far\ Field\ Crust} + S_{Mantle}$$





Contributions to the S_{LOC} in KamLAND are given by U and Th in:

	S(TNU)
Local geology	14.4 ± 1.0
Subducting slab	2.9 ± 0.9
Crust of Japan Sea	0.4 ± 0.1
Total S_{LOC}	17.7 ± 1.4



~ 500 km x 500 km

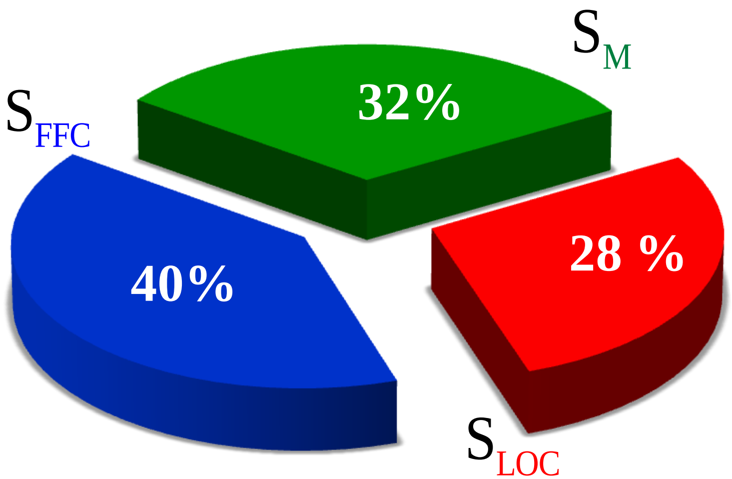
	LOC[1]	FFC[2]	CLM[2]	Mantle[2]	Total (theory)	Experiment (KL 2013)[3]
S(U+Th) [TNU]	17.7 ± 1.4	7.3 ± 1.4	1.6 ± 1.6	8.8	35.4 ± 2.5	30 ± 7

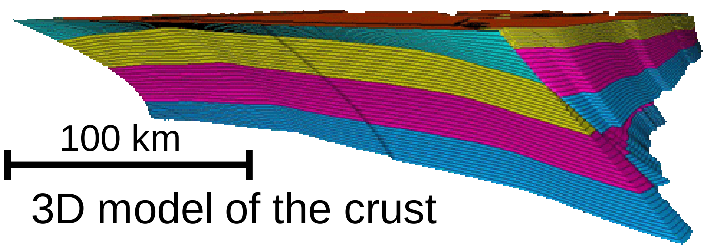
Including a refined local model, in Enomoto et al. (2007) the expected signal in KamLAND is 35.2 TNU.

[1] Fiorentini et al. - 2012
[2] Huang, Y., et al. - 2013 - arXiv:1301.0365v2
[3] KamLAND collaboration - Phys. Rev. D 88 - 2013

Borexino: theory vs experiment

$$S_{Expected} = S_{LOCal} + S_{Far\ Field\ Crust} + S_{Mantle}$$

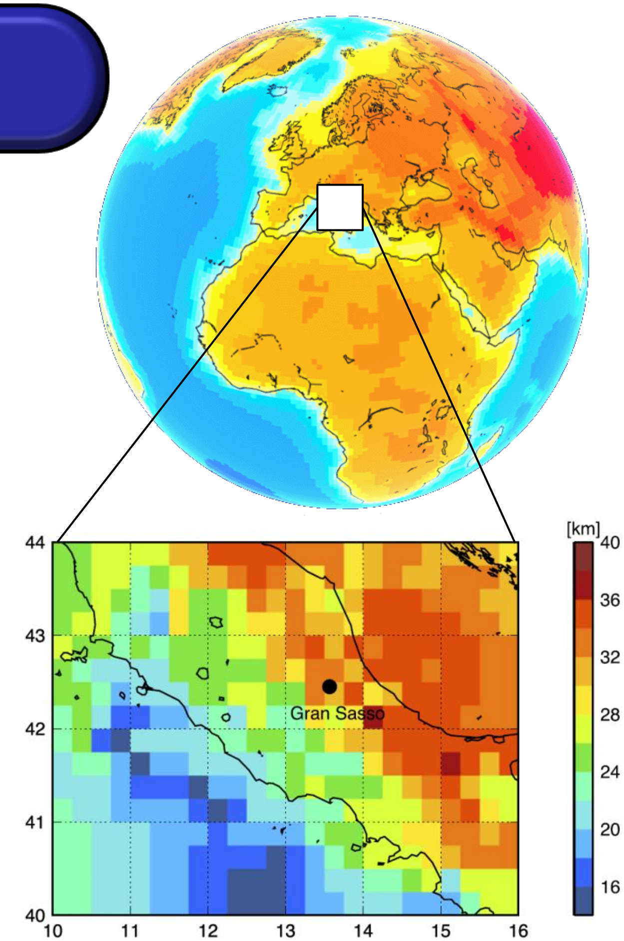




3D model of the crust around Gran Sasso Lab

Contributions to the S_{LOC} Borexino are given by U and Th in:

	S_{LOC} (TNU)
Sediments	2.9 ± 0.3
Loc UC	6.2 ± 1.2
Loc LC	0.6 ± 0.2
Total S_{LOC}	9.7 ± 1.3

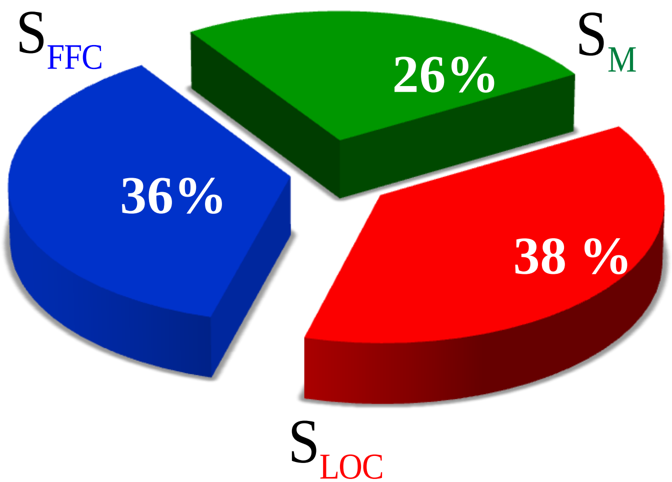


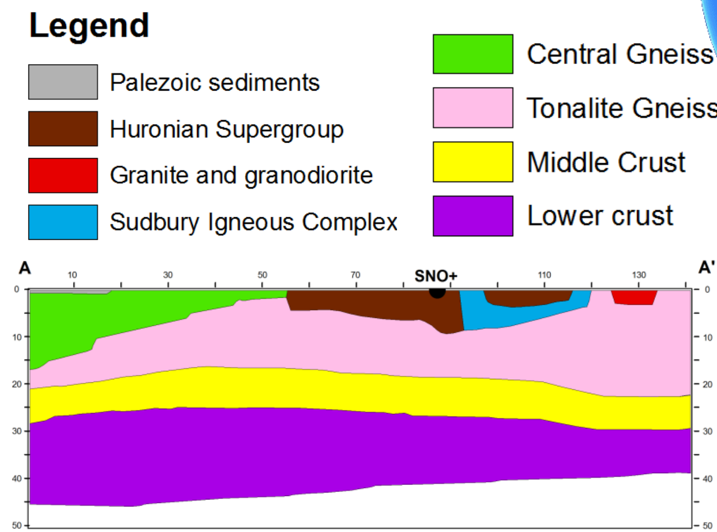
	LOC[1]	FFC[2]	CLM[2]	Mantle[2]	Total (theory)	Experiment (BX 2013)[3]
S(U+Th) [TNU]	9.7 ± 1.3	13.7 ± 2.5	2.2 ± 2.2	8.7	34.3 ± 3.6	39 ± 12

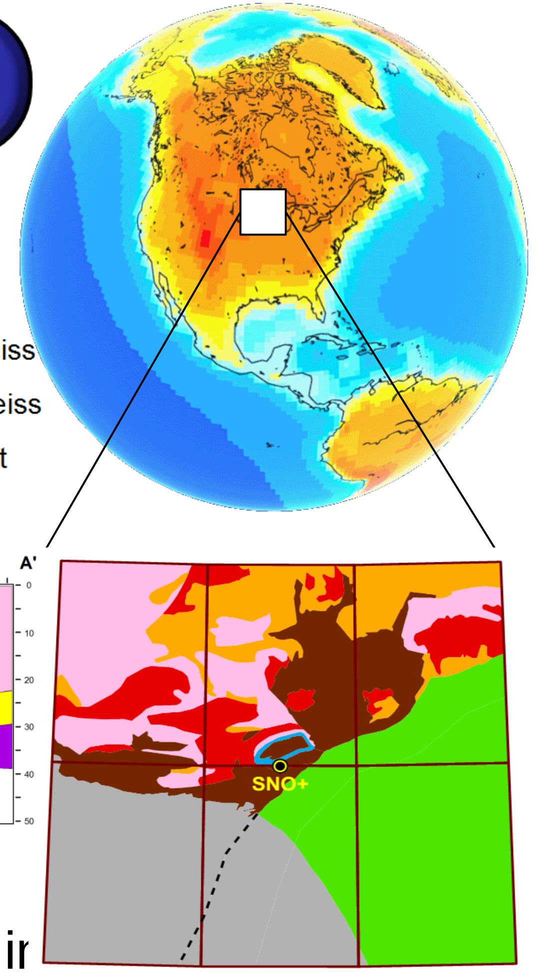
[1] Fiorentini et al. – 2012 // [2] Huang, Y., et al. - 2013 - arXiv:1301.0365v2 // [3] Borexino collaboration - Physics Letters B 722 - 2013

SNO+: theory vs experiment

$$S_{Expected} = S_{LOCal} + S_{Far\ Field\ Crust} + S_{Mantle}$$





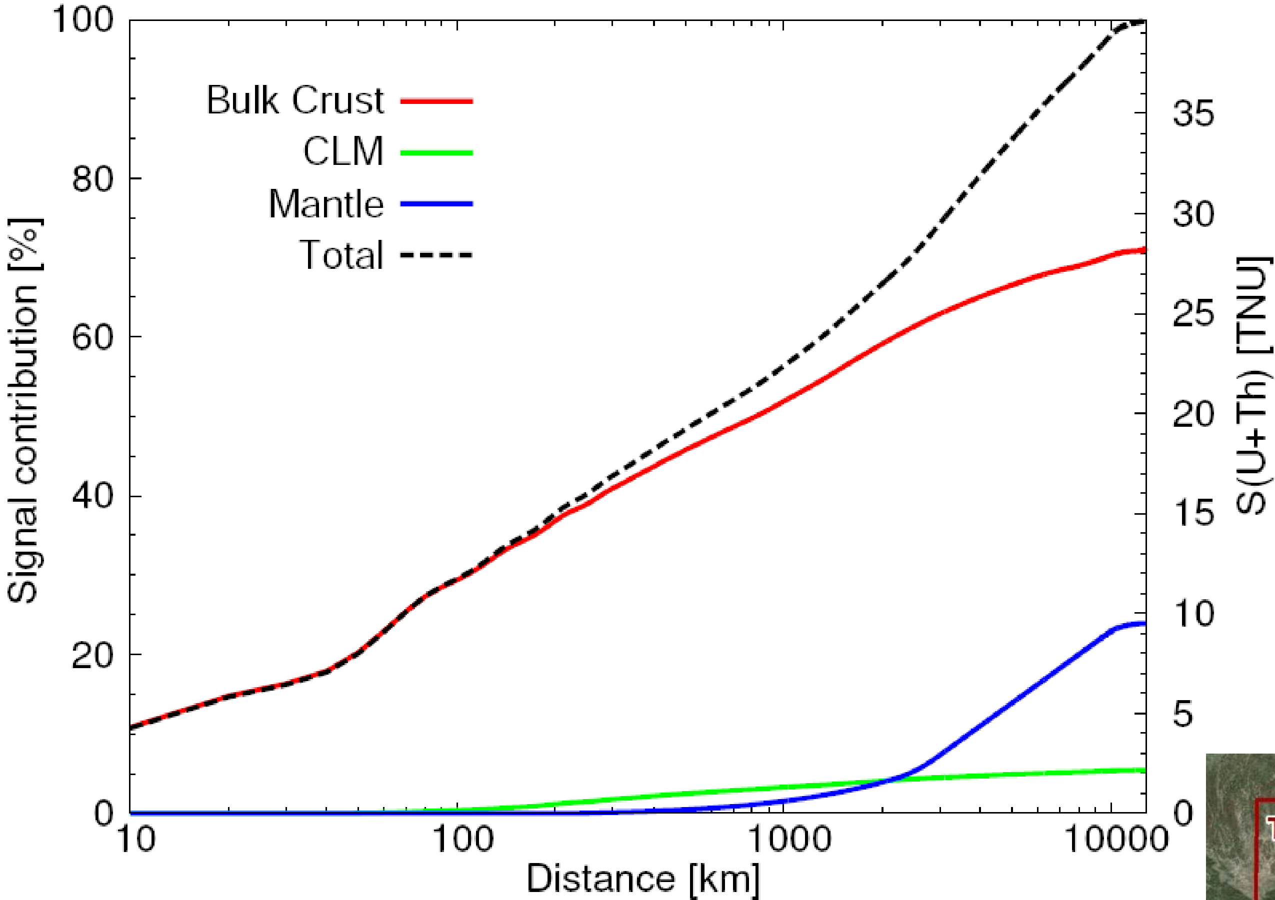


- The local UC is divided into 7 dominant lithologic units
- 3146 samples used for estimating U and Th abundance ir
- Local 3D geophysical model based on ~400 seismic control points

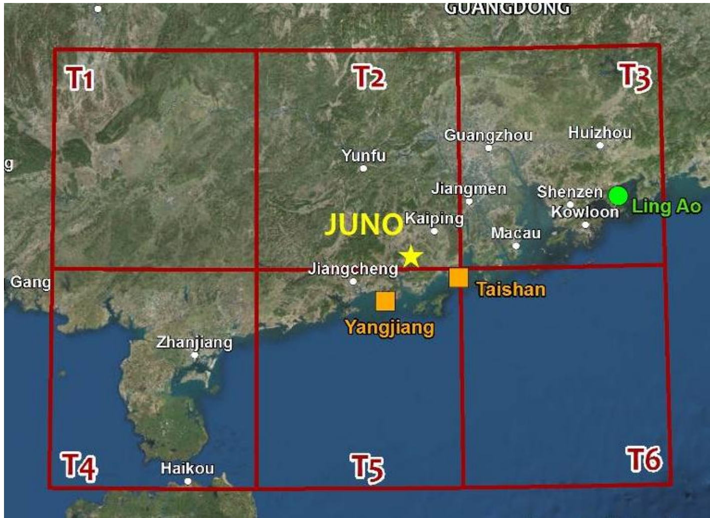
	LOC[1]	FFC[2]	CLM[2]	Mantle[2]	Total Expected	Experiment
S(U+Th) [TNU]	15.6 ± 4.3	15.1 ± 2.6	2.1 ± 2.1	8.7	41.5 ± 5.4	(2016?)

[1] Huang, Y., et al. - 2014 - arXiv:1404.6692 // [2] Huang, Y., et al. - 2013 - arXiv:1301.0365v2

Geoneutrinos signal in JUNO

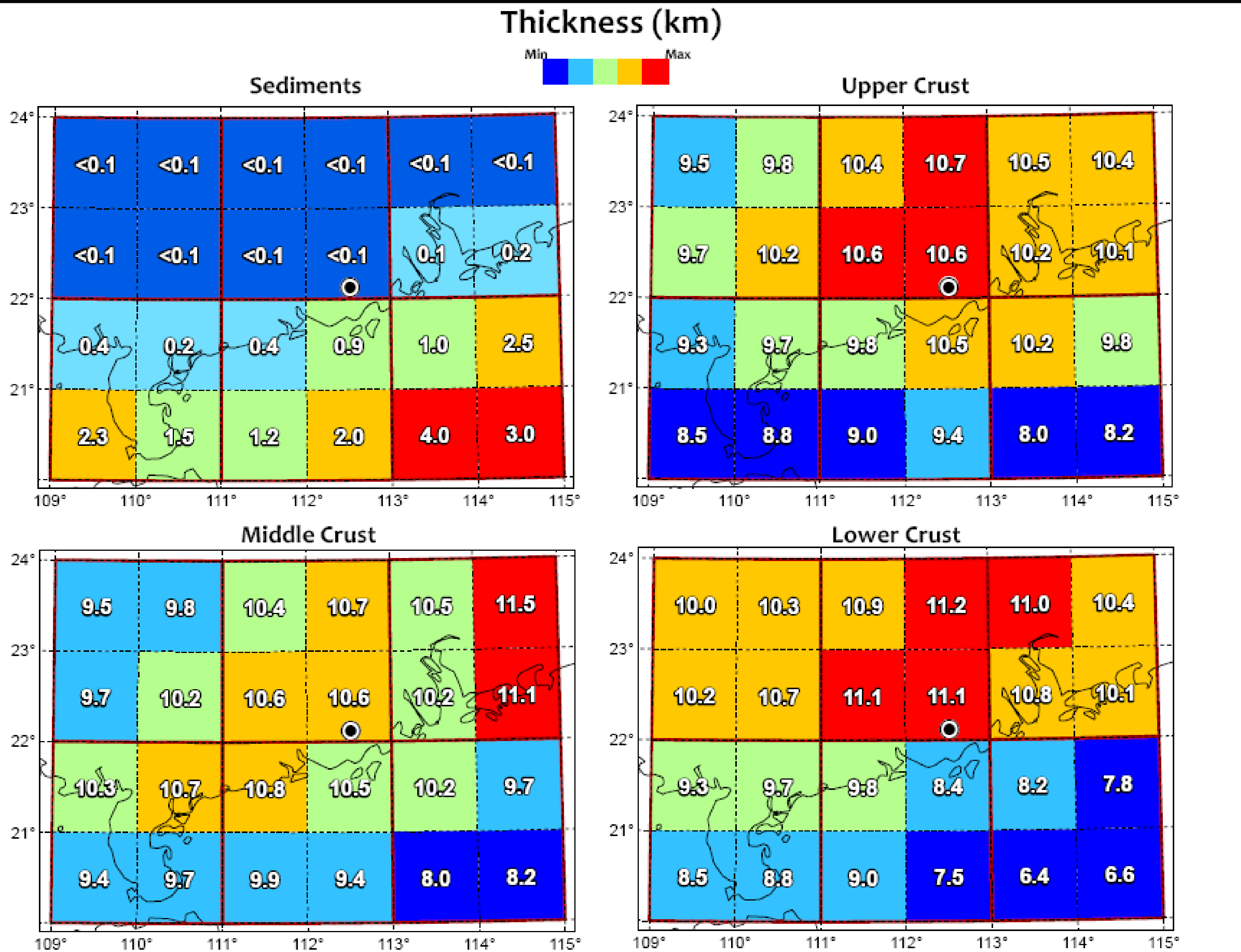


Tile	S (U+Th)
T1	$0.53^{+0.13}_{-0.10}$
T2	$10.77^{+2.09}_{-1.78}$
T3	$1.48^{+0.33}_{-0.25}$
T4	$0.38^{+0.09}_{-0.07}$
T5	$3.16^{+0.56}_{-0.49}$
T6	$1.02^{+0.23}_{-0.17}$

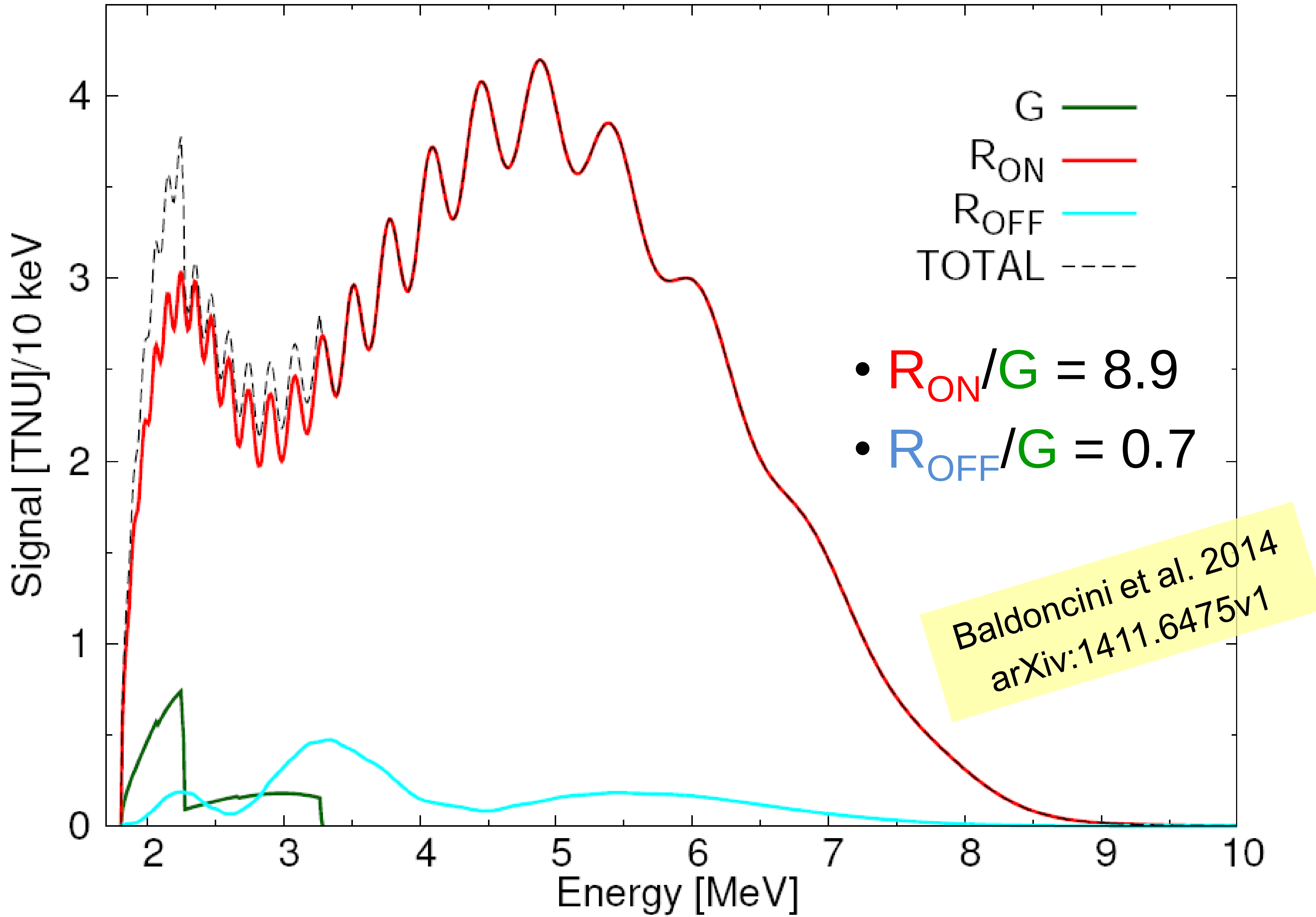


The 50% of the total signal comes from U and Th in the crust of the region within 860 km from the detector.

Crust surrounding JUNO



Reactors antineutrinos and geoneutrinos in JUNO

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