Geoneutrino measurements with Borexino: implications for geoscience

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on behalf of the Borexino Collaboration

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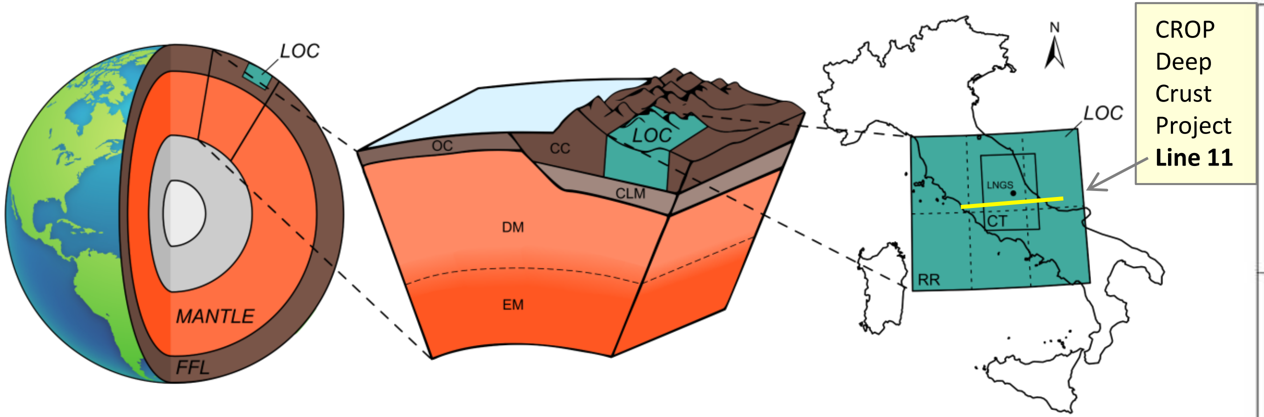
Expected geoneutrinos from lithosphere



*		
Vp: <6.0 Km/sec Thickness of the layer: 7.0 Km Depth of the lower boundary: 7.0 Km	Plio-Pleistocene deposits	Lower boundary: 1.8 sec TWT Δt: 1.7 sec TWT Vp: 2.0 Km/sec Thickness of the unit: 1.7 Km Depth of the lower boundary: 1.7 Km
	Messinian-Jurassic shallow-marine deposits	Lower boundary: 3.4 sec TWT Δt: 1.6 sec TWT Vp: 5.5 Km/sec Thickness of the unit: 4.4 Km Depth of the lower boundary: 6.1 Km
Vp: increasing up to 6.7 Km/sec Thickness of the layer: 5.0 Km Depth of the lower boundary: 12 Km	Upper Triassic dolomites	Lower boundary: 3.8 sec TWT Δt: 0.4 sec TWT Vp: 6.0 Km/sec Thickness of the unit: 1.2 Km Depth of the lower boundary: 7.3 Km
	Upper Triassic anhydrites	Lower boundary: 4.4 sec TWT Δt: 0.6 sec TWT Vp: 6.7 Km/sec Thickness of the unit: 2.0 Km Depth of the lower boundary: 9.3 Km
Vp: 6.2 Km/sec Thickness of the layer: 10 Km Depth of the lower boundary: 22 Km	Sedimentary unit underlying the upper Triassic anhydrites	Lower boundary: 7.8 sec TWT Δt: 3.4 sec TWT Vp: 4.5 Km/sec Thickness of the unit: 7.6 Km Depth of the lower boundary: 16.9 Km
	Crystalline upper crust	Lower boundary: 9.7 sec TWT Δt: 1.9 sec TWT Vp: 6.2 Km/sec Thickness of the unit: 5.9 Km Depth of the lower boundary: 22.8 Km
Vp: 7.0 Km/sec Thickness of the layer: 10 Km Depth of the lower boundary: 32 Km	Layered lower crust	Lower boundary: 12 sec TWT Δt: 2.3 sec TWT Vp: 7.0 Km/sec Thickness of the unit: 8.0 Km Depth of the lower boundary: 30.8 Km

The expected geoneutrino signal at Borexino (BX) is calculated considering the contributions of three components:
the local crust (**LOC**), the far field lithosphere (**FFL**), and the mantle.

	S (U+Th) [TNU]
Local Crust (LOC)	9.2 ± 1.2
Far Field Lithosphere (FFL)	$16.3^{+4.8}_{-3.7}$
Lithosphere (LS)	$25.9^{+4.9}_{-4.1}$

* Patacca et al. Tectonics 27, 1–36, TC3006 (2008).

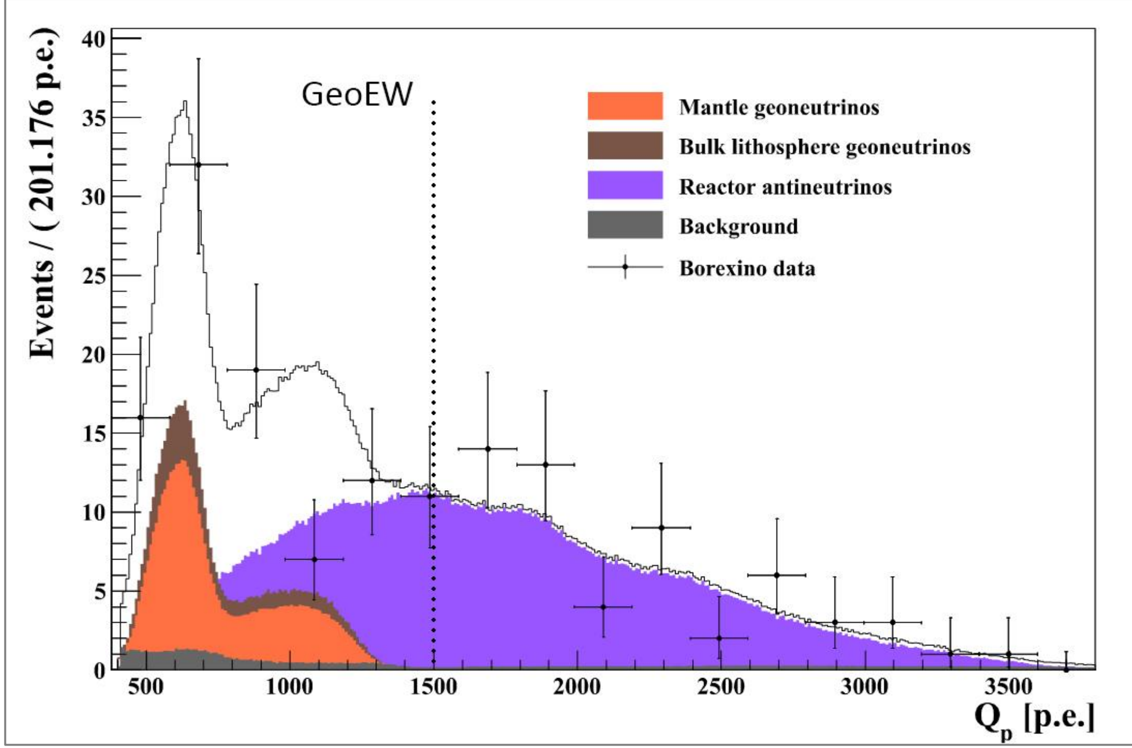
Borexino results

• In 3262.74 days BX measured 154 antineutrinos candidates, with 8.3 ± 1.0 estimated **background events**.

• In GeoEW [1.8-3.3 MeV] the reconstructed **reactor events** are 39.5 ± 0.7.

• Assuming a Th/U = 3.9, the **geoneutrino events** are $52.6^{+9.6}_{-9.0}$

• Constraining the contribution from the **bulk lithosphere** (28.8 ± 5.6 events), the **extracted mantle** events are $23.7^{+10.7}_{-10.1}$



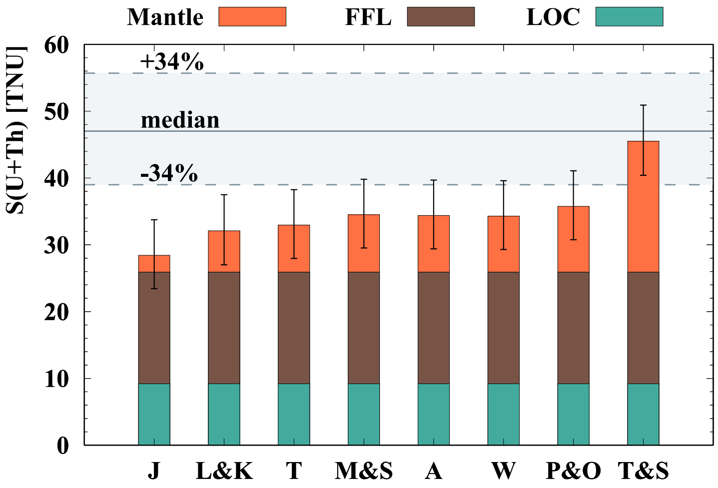
• Considering the effective exposure ε' = 1.12 10^{32} free protons x yr, one can calculate the signal in TNU:

$$S[TNU] = N_{Eve} * (10^{32}/ \varepsilon')$$

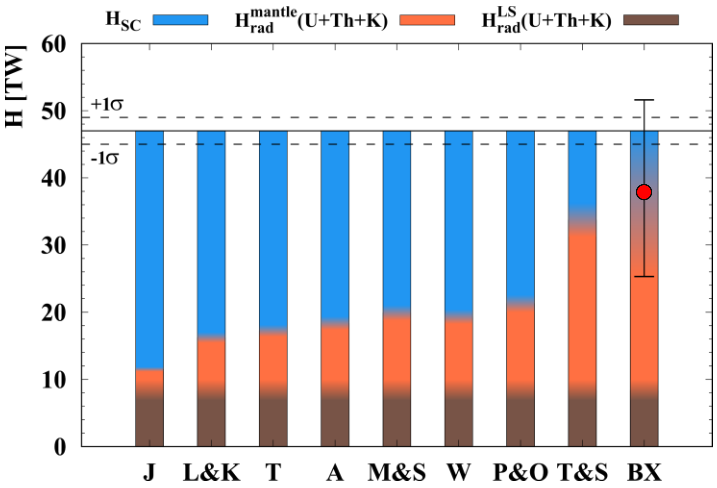
Borexino measurement and BSE models

- BX signal $S(U+Th) = 47.0^{+8.6}_{-8.1}$ TNU can be compared with the expectations calculated for different BSE models:

J = M. Javoy et al., EPSL 293, (2010).
L&K = T. Lyubetskaya and J. Korenaga, J. Geoph. Res. Sol. Earth, 112 (2007)
T = S. Taylor, Proc. Lunar Planet. Sci. Conf. 11, 333 (1980)
M&S = W. F. McDonough and S. Sun, Chem. Geol. 120, (1995)
A = D. L. Anderson, Cambridge University Press, (2007)
W = H. S. Wang et al., Icarus 299, (2018)
P&O = H. Palme and H. O'Neill, Treatise of Geochemistry, (2003)
T&S = D. L. Turcotte and G. Schubert, Cambridge University Press, (2002)



- Adopting a **lithospheric heat power** $H_{Lith}(U+Th+K) = 8.1^{+1.9}_{-1.4}$ TW and $H_{mantle}(K) = 0.18\ H_{mantle}(U+Th+K)$, the total radiogenic heat power inferred by **BX measurement** is $H_{BX}(U+Th+K) = 38^{+14}_{-13}$ TW
- Knowing the terrestrial heat power H = 47 ± 2 TW, **secular cooling** and radiogenic power are calculated for different BSE models and BX measurement



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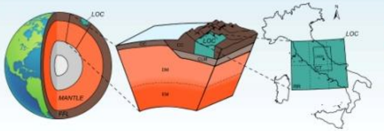
LITHOSPHERE

The expected geoneutrino signal at Borexino (BX) is calculated considering the contributions of three components: the local crust (LOC), the far field lithosphere (FFL), and the mantle.



The LOC[1] is the 6° × 4° crustal area surrounding BX. The FFL[2] includes the continental lithospheric mantle (CLM) and the remaining crust obtained after the removal of the LOC.

	S (U+Th) [TNU]
Local Crust (LOC)	9.2 ± 1.2
Far Field Lithosphere (FFL)	$16.3^{+4.8}_{-3.7}$
Lithosphere (LS)	$25.9^{+4.9}_{-4.1}$

The signal reduction of ~ 6 TNU with respect to the estimations of the global reference model is due to the presence of thick sedimentary deposits composed primarily of U- and Th-poor carbonate rocks.

MANTLE

Bulk Silicate Earth models predictions

The radiogenic heat and the geoneutrino signal expected for the mantle are obtained subtracting the Lithosphere contributions ($H_{rad}^{LS} = 8.1^{+1.9}_{-1.4}$ TW and $S_{LS} = 25.9^{+4.9}_{-4.1}$ TNU) from the predictions of different BSE models.

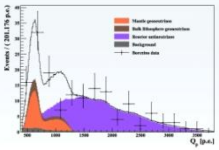
		S_{mantle}(U+Th) [TNU]	H_{rad}^{mantle}(U+Th+K) [TW]
J	Javoy et al., 2010[3]	0.9 – 4.1	1.2 – 4.7
L&K	Lyubetskaya & Korenaga, 2007[4]	3.9 – 8.0	5.5 – 9.4
T	Taylor, 1980[5]	4.7 – 8.9	6.5 – 10.4
M&S	McDonough & Sun, 1995[6]	6.0 – 10.6	9.2 – 13.1
A	Anderson, 2007[7]	5.9 – 10.5	7.7 – 11.6
W	Wang et al., 2018[8]	5.8 – 10.4	8.6 – 12.5
P&O	Palme and O'Neil, 2003[9]	7.1 – 12.0	10.6 – 14.5
T&S	Turcotte & Schubert, 2002[10]	15.7 – 22.4	23.5 – 26.9
CC	Cosmochemical[11]	0.9 – 4.1	1.2 – 4.7
GC	Geochemical[11]	6.0 – 10.6	9.7 – 13.6
GD	Geodynamical[11]	15.7 – 22.4	23.0 – 26.9
FR	Fully radiogenic[11]	24.2 – 33.0	36.5 – 39.8

CC: model based on the Earth's composition on enstatite chondrites
GC: model adopting the relative abundances of refractory lithophile elements as in CI chondrites and constraining the absolute abundances with terrestrial samples
GD: model based on the energetics of mantle convection and the observed surface heat loss
FR: extreme model where the terrestrial heat is assumed to be fully accounted for by radiogenic production

Experimental results

Keeping the masses of HPEs in the unexplored mantle as free parameters, constraints on the mantle signal can be provided based on experimental signal measured by Borexino.
The mantle signal was extracted from the spectral fit by constraining the contribution from the bulk lithosphere according to the expectation.

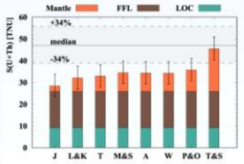
$$S_{mantle} = S_{BX} - S_{LS} - S_{Reactor} - S_{Background} = 21.2^{+9.6}_{-9.0}\ TNU$$



EXPERIMENT vs EXPECTATION

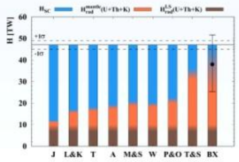
Geoneutrino signals

Borexino geoneutrino measurements ($S_{BX} = 47.0^{+8.6}_{-8.1}$ TNU) can be compared with the expected signals obtained summing the contributions from LOC, FFL and mantle according to different BSE models.



Terrestrial heat power

The radiogenic power from lithosphere ($H_{rad}^{LS} = 8.1^{+1.9}_{-1.4}$ TW) and mantle ($H_{rad}^{mantle} = 30.0^{+13.5}_{-12.7}$ TW) together with secular cooling (H_{SC}) give terrestrial heat power (47 ± 2 TW). The black dot represents the radiogenic power inferred from Borexino measurement ($H_{rad}^{BX} = 38.0^{+13.6}_{-12.7}$ TW)

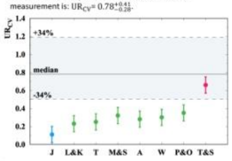


Convective Urey Ratio

The Convective Urey Ratio is: $UR_{CV} = \frac{H_{rad} - H_{rad}^{cc}}{H_{tot} - H_{rad}^{cc}}$

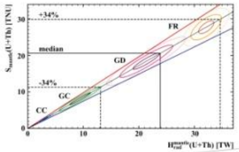
where $H_{tot} = 47 \pm 2$ TW, $H_{rad}^{cc} = 6.8^{+1.4}_{-1.1}$ TW and the total radiogenic power H_{rad} is model dependent.

The convective Urey Ration derived from Borexino measurement is: $UR_{CV} = 0.78^{+0.41}_{-0.28}$.



Mantle radiogenic power

The red and blue lines constrain the mantle signal $S_{mantle}(U + Th)$ as a function of $H_{rad}^{mantle}(U + Th)$ adopting two extreme scenarios having an homogeneous mantle and a unique rich layer just above the Core Mantle Boundary. According to the predictions of 4 BSE class models, the geoneutrino signal is confined in the blue, green, red, and yellow ellipses with darker to lighter shades representing 1, 2, and 3σ contours.



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