

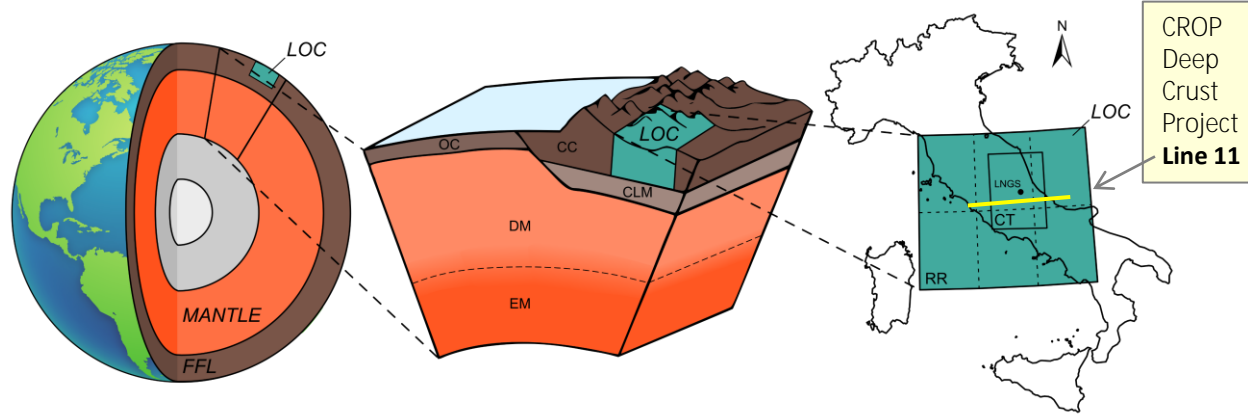
Geoneutrino measurements with Borexino: implications for geoscience



Fabio Mantovani
on behalf of the Borexino Collaboration



Expected geoneutrinos from lithosphere



CROP
Deep
Crust
Project
Line 11

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}

* Vp: <6.0 Km/sec Thickness of the layer: 7.0 Km Depth of the lower boundary: 7.0 Km	Pilo-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

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

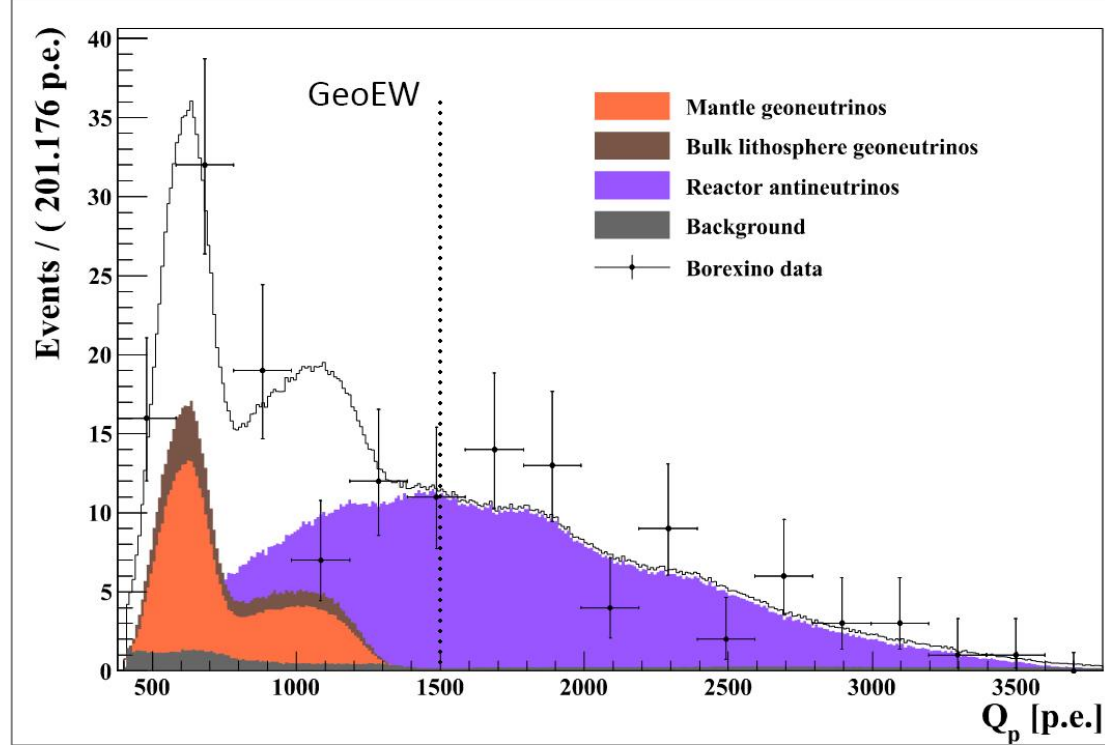
Borexino results

“ 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 Y 10^{32} free protons x yr, one can calculate the signal in TNU:

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

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)

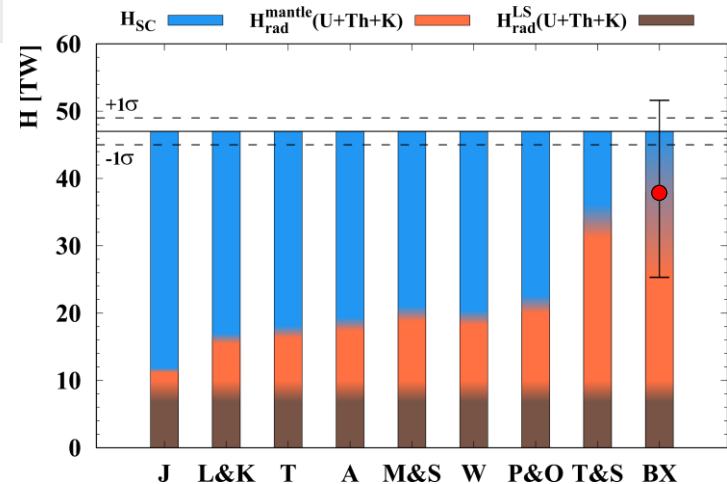
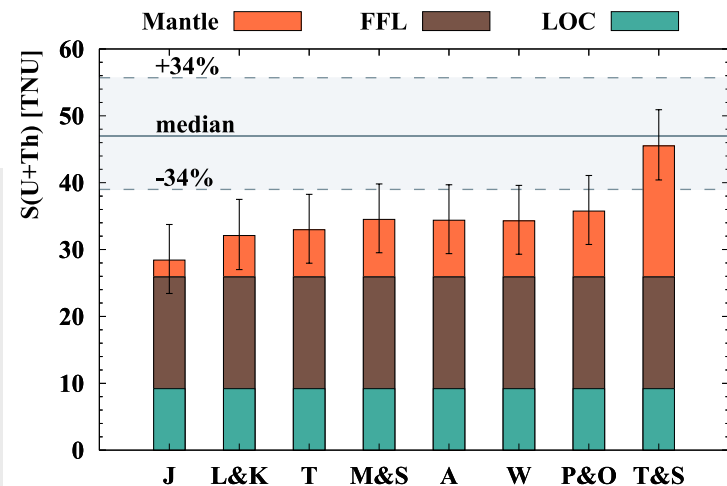
W = H. S. Wang et al., Icarus 299, (2018)

P&O = H. Palme and H. V. 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 $H = 47 \pm 2$ TW, **secular cooling** and radiogenic power are calculated for different BSE models and BX measurement





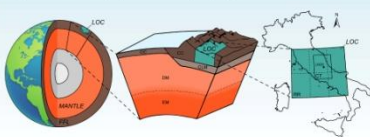
Geoneutrino measurements with Borexino

implications for geoscience
Fabio Mantovani on behalf of the Borexino Collaboration



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 LOC¹ is the 6° × 4° crustal area surrounding BX. The FFL² 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} _{-3.2}
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 ($H_{LS}^{238U} = 8.1^{+1.2}_{-1.1}$ TW and $S_{LS}^{238U} = 25.9^{+4.9}_{-4.1}$ TNu) from the predictions of different BSE³ models.

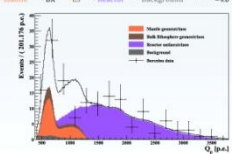
J	H_{Mantle}^{238U} [TW]	S_{Mantle}^{238U} [TNu]
J (Jiang et al., 2005) ⁴	0.0 - 4.1	3.2 - 4.7
LAK (Lythell & Kopp, 2005) ⁵	3.0 - 8.0	5.5 - 8.4
T (Tosca, 2007) ⁶	4.7 - 8.9	6.9 - 10.4
MMS (McDermott & Sun, 1995) ⁷	6.0 - 20.6	9.2 - 13.1
A (Anderson, 2007) ⁸	0.0 - 10.5	7.7 - 13.6
W (Wendt et al., 2005) ⁹	0.0 - 9.4	8.6 - 12.5
PAO (Parker and O'Neill, 2003) ¹⁰	7.1 - 12.0	10.6 - 14.5
TS (Turek & Scherer, 2002) ¹¹	16.7 - 22.4	23.8 - 26.9
CC (Cochran & Cheng, 2002) ¹²	0.0 - 4.1	3.2 - 4.7
GD (Geonema et al. ¹³)	6.0 - 10.6	9.7 - 13.6
GD (Geonema et al. ¹³)	10.7 - 12.4	13.6 - 16.9
FR (Fully redigene) ¹⁴	24.2 - 33.0	36.5 - 39.8

CC: model based on the Earth's composition on enstatite chondrites
GD: model adopting the relative abundances of refractory lithophile elements as in chondrites and constraining the absolute abundances with terrestrial samples
FR: model based on the energetic U-Th ratio correction and the observed surface heat flux
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.

$$S_{Mantle} = S_{BX} - S_{LS} - S_{Reactor} - S_{Background} = 21.2^{+2.0}_{-1.9} \text{ TNu}$$



Geoneutrino signals

Borexino geoneutrino measurements ($S_{BX} = 47.0^{+1.1}_{-1.1}$ TNu) can be compared with the expected signals obtained subtracting the contributions from LOC, FFL and mantle according to different BSE models.

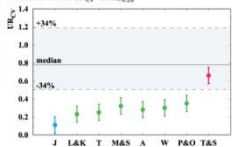


Convective Urey Ratio

$$\text{The Convective Urey Ratio is: } UR_{CV} = \frac{H_{rad} - H_{rad}^{LOC}}{H_{rad}^{Mantle}}$$

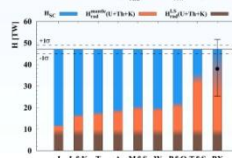
where $H_{rad} = 47.2$ TW, $H_{rad}^{LOC} = 6.8^{+1.1}_{-1.1}$ TW and the total radiogenic power H_{rad}^{Mantle} is model dependent.

The convective Urey Ratio derived from Borexino measurement is: $UR_{CV} = 0.78^{+0.11}_{-0.11}$



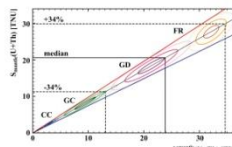
Terrestrial heat power

The radiogenic power from lithosphere ($H_{LS}^{238U} = 8.1^{+1.2}_{-1.1}$ TW) and mantle ($H_{Mantle}^{238U} = 30.0^{+1.1}_{-1.1}$ TW) together with secular cooling ($H_{sec} = 17.2$ TW). The black dot represents the radiogenic power inferred from Borexino measurement ($H_{rad}^{238U} = 38.0^{+1.1}_{-1.1}$ TW).



Mantle radiogenic power

The red and blue lines constrain the mantle signal $S_{Mantle}(U+Th)$ as a function of $H_{Mantle}^{238U}(U+Th)$ 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 L, 2, and 3σ contours.



EXPERIMENT VS EXPECTATION

¹ N. Colino et al., *Geochimica et Cosmochimica Acta*, 75, 2071 (2011), ePrint: 1003.1350 [astro-ph/0705001]
² Wang, D., *Geochimica et Cosmochimica Acta*, 71, 2673 (2007), ePrint: 0705.1001 [astro-ph/0705001]
³ J. Jiang et al., *Earth and Planetary Science Letters*, 235, 279 (2005)
⁴ J. Jiang et al., *Earth and Planetary Science Letters*, 235, 279 (2005)
⁵ J. Jiang et al., *Earth and Planetary Science Letters*, 235, 279 (2005)
⁶ J. Jiang et al., *Earth and Planetary Science Letters*, 235, 279 (2005)
⁷ J. Jiang et al., *Earth and Planetary Science Letters*, 235, 279 (2005)
⁸ J. Jiang et al., *Earth and Planetary Science Letters*, 235, 279 (2005)
⁹ J. Jiang et al., *Earth and Planetary Science Letters*, 235, 279 (2005)
¹⁰ J. Jiang et al., *Earth and Planetary Science Letters*, 235, 279 (2005)
¹¹ J. Jiang et al., *Earth and Planetary Science Letters*, 235, 279 (2005)
¹² J. Jiang et al., *Earth and Planetary Science Letters*, 235, 279 (2005)
¹³ J. Jiang et al., *Earth and Planetary Science Letters*, 235, 279 (2005)
¹⁴ J. Jiang et al., *Earth and Planetary Science Letters*, 235, 279 (2005)

¹ S. Wang, C. H. Johnson, and J. S. H. Lee, *Earth and Planetary Science Letters*, 235, 279 (2005)
² J. Jiang et al., *Earth and Planetary Science Letters*, 235, 279 (2005)
³ J. Jiang et al., *Earth and Planetary Science Letters*, 235, 279 (2005)
⁴ J. Jiang et al., *Earth and Planetary Science Letters*, 235, 279 (2005)
⁵ J. Jiang et al., *Earth and Planetary Science Letters*, 235, 279 (2005)
⁶ J. Jiang et al., *Earth and Planetary Science Letters*, 235, 279 (2005)
⁷ J. Jiang et al., *Earth and Planetary Science Letters*, 235, 279 (2005)
⁸ J. Jiang et al., *Earth and Planetary Science Letters*, 235, 279 (2005)
⁹ J. Jiang et al., *Earth and Planetary Science Letters*, 235, 279 (2005)
¹⁰ J. Jiang et al., *Earth and Planetary Science Letters*, 235, 279 (2005)
¹¹ J. Jiang et al., *Earth and Planetary Science Letters*, 235, 279 (2005)
¹² J. Jiang et al., *Earth and Planetary Science Letters*, 235, 279 (2005)
¹³ J. Jiang et al., *Earth and Planetary Science Letters*, 235, 279 (2005)
¹⁴ J. Jiang et al., *Earth and Planetary Science Letters*, 235, 279 (2005)