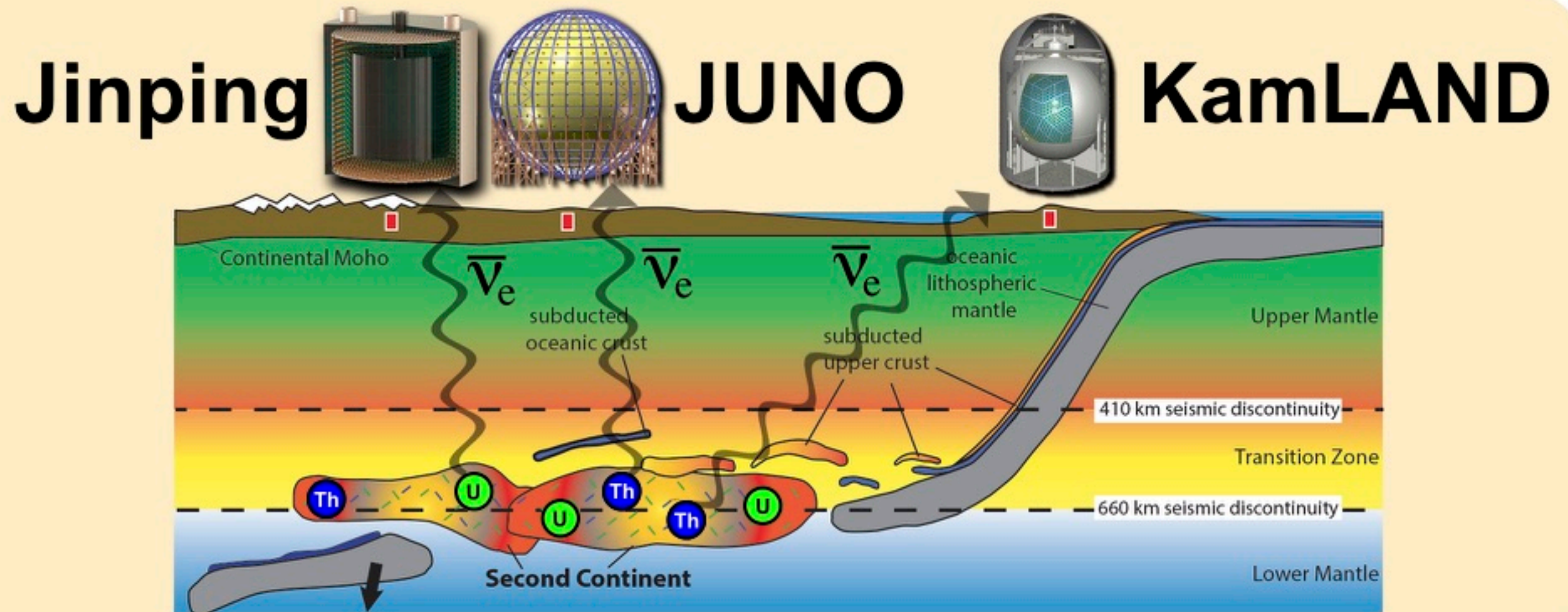
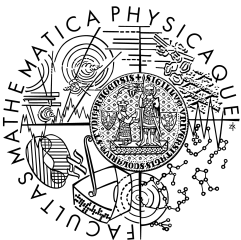


Testing a proposed “second continent” beneath eastern China using geoneutrino measurements



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Collaboration with: Bedřich Roskovec, Bill McDonough



Testing a proposed "second continent" beneath eastern China using geoneutrino measurements

Bedrich Roskovec, Ondrej Sramek, William F. McDonough

(Submitted on 25 Oct 2018)

Models that envisage successful subduction channel transport of upper crustal materials below 300 km depth, past a critical phase transition in buoyant crustal lithologies, are capable of accumulating and assembling these materials into so-called "second continents" that are gravitationally stabilized at the base of the Transition Zone, at some 600 to 700 km depth. Global scale, Pacific-type subduction (ocean-ocean and ocean-continent convergence), which lead to super continent assembly, were hypothesized to produce second continents that scale to about the size of Australia, with continental upper crustal concentration levels of radiogenic power. Seismological techniques are incapable of imaging these second continents because of their negligible difference in seismic wave velocities with the surrounding mantle. We can image the geoneutrino flux linked to the radioactive decays in these second continents with land and/or ocean-based detectors. We present predictions of the geoneutrino flux of second continents, assuming different scaled models and we discuss the potential of current and future neutrino experiments to discover or constrain second continents. The power emissions from second continents were proposed to be drivers of super continental cycles. Thus, testing models for the existence of second continents will place constraints on mantle and plate dynamics when using land and ocean-based geoneutrino detectors deployed at strategic locations.

Subjects: **Geophysics (physics.geo-ph)**

Cite as: **arXiv:1810.10914 [physics.geo-ph]**

(or **arXiv:1810.10914v1 [physics.geo-ph]** for this version)

Submission history

From: Bedřich Roskovec [[view email](#)]

[v1] Thu, 25 Oct 2018 15:02:45 UTC (320 KB)

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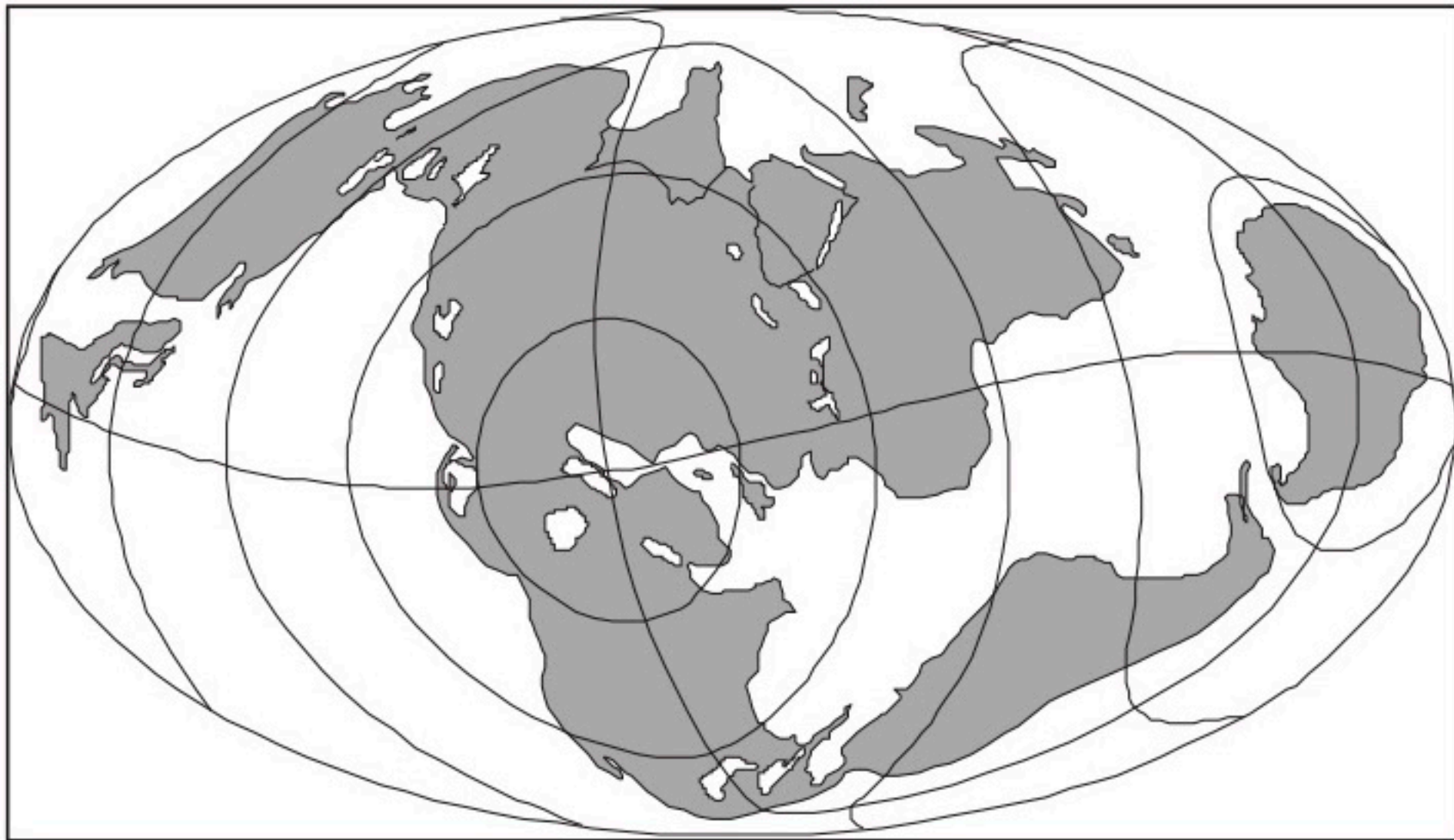
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What is “(first) continent”?

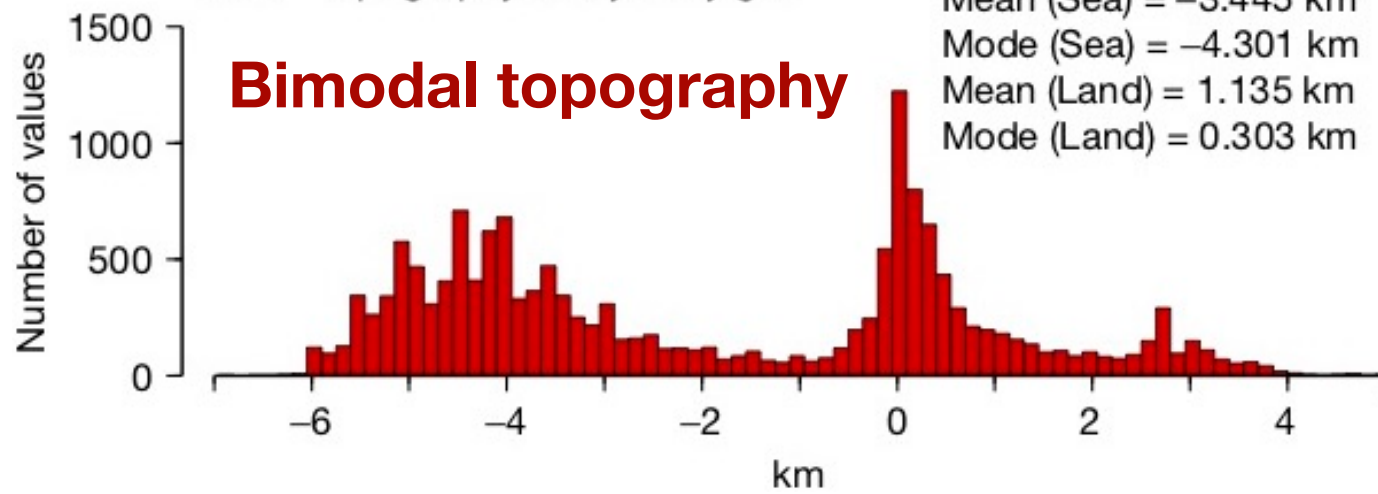


GEBCO

2 x 2° topography/bathymetry grid

Bimodal topography

Mean (Sea) = -3.445 km
Mode (Sea) = -4.301 km
Mean (Land) = 1.135 km
Mode (Land) = 0.303 km

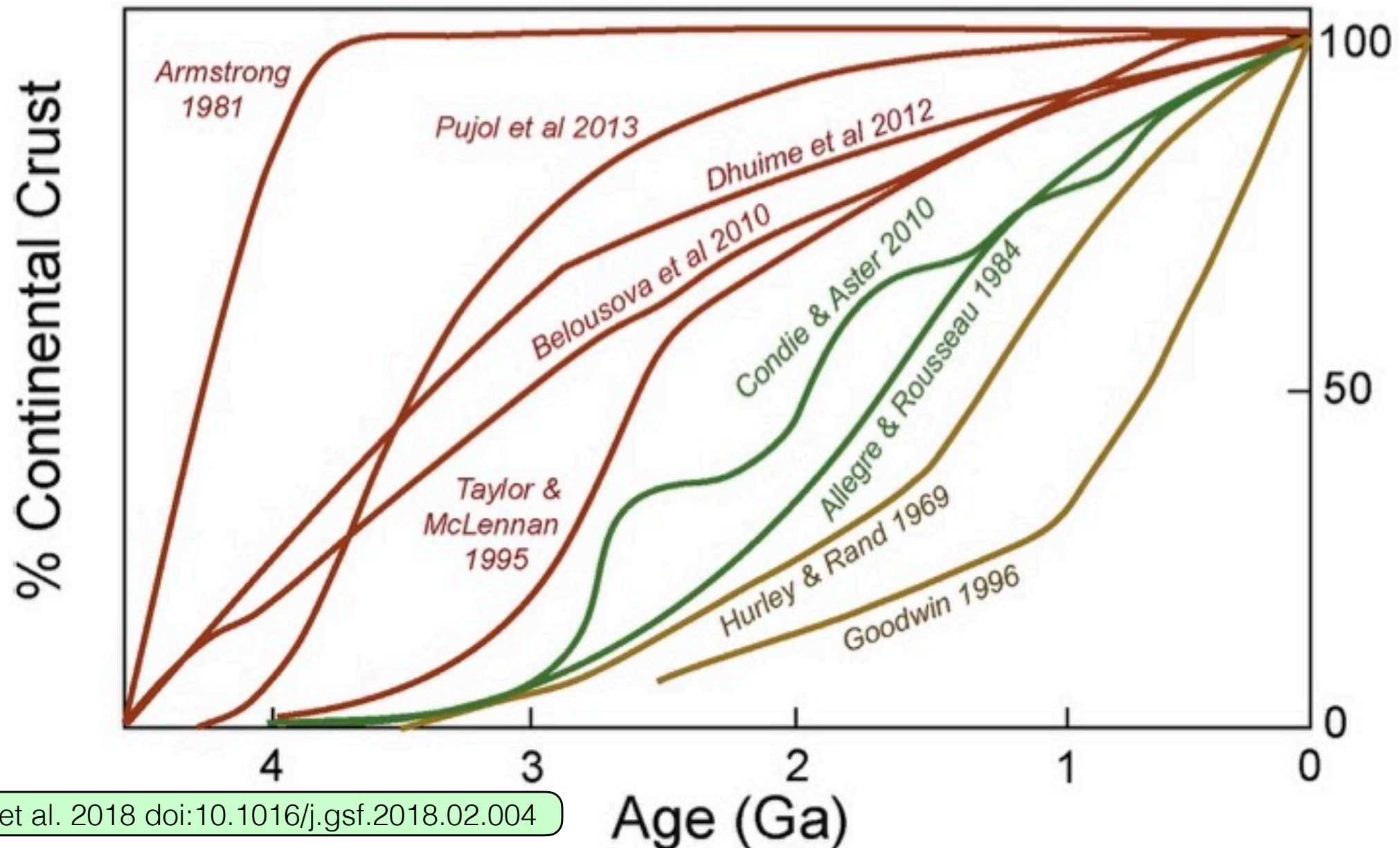


Hypsometric curve + Isostasy:
Thick Continental Crust ~40 km
(Thin Oceanic Crust ~7 km)
Diverse lithologies
Compositionally heterogeneous
Vertical compositional gradient (layers)

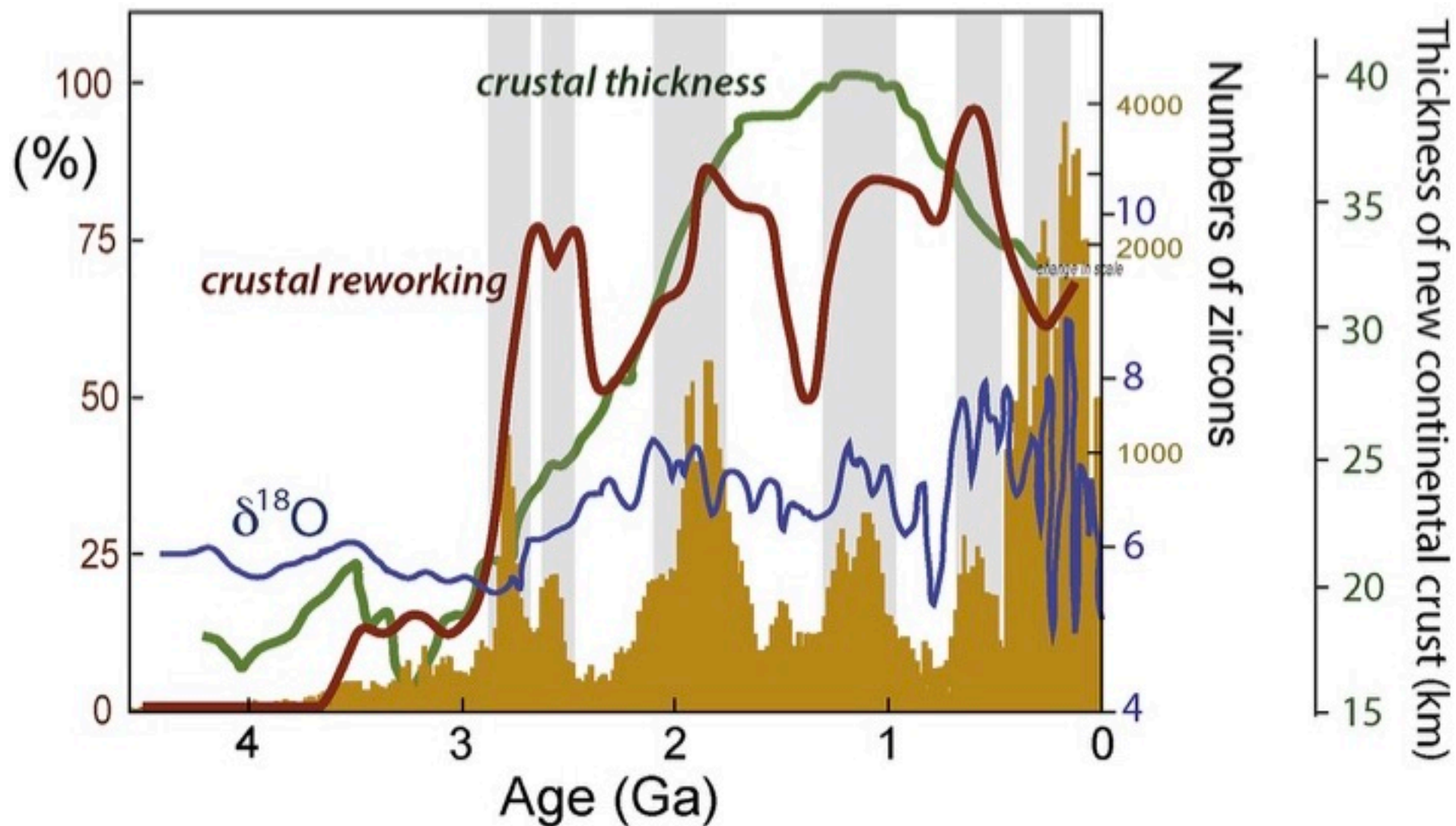
Continental growth

Methods to construct crustal growth models:

1. From distribution of rocks of different ages presently preserved on Earth
2. From distribution of rocks of different model ages (when derived from the mantle)
3. Using arguments about volume of crust over time even if no longer preserved (thermal arguments; argon isotope systematics; trace element ratios of mafic basalts; Hf isotopes in zircons)



Continental growth

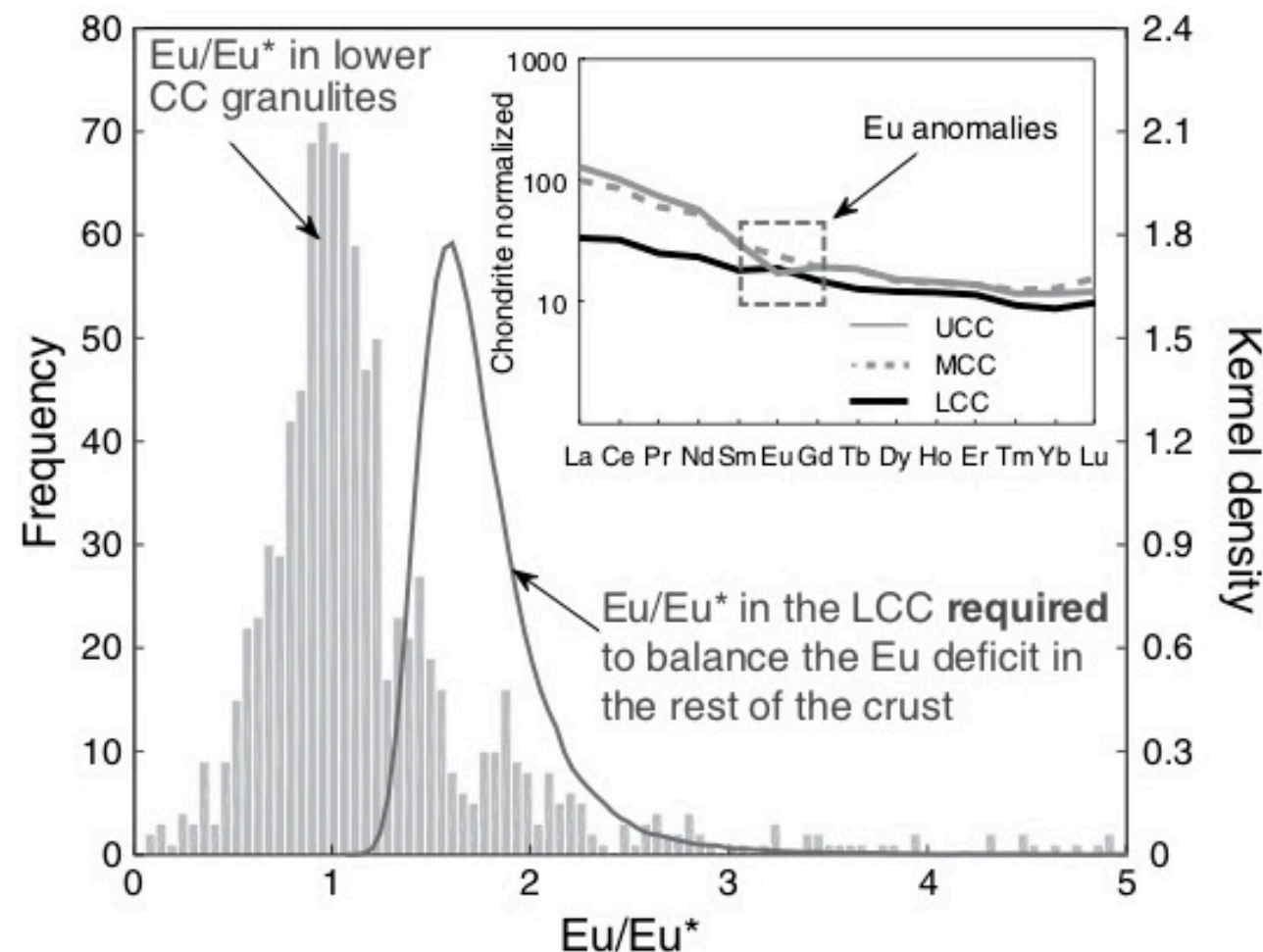


- By ~3 Ga the volume of continental crust was 65–70% of its present day volume
- Reduction in growth rates of continental crust
- Little evidence for reduction continental crust generation rates
- Interpreted as increase in continental crust destruction rates
- Related to onset of plate tectonics at around 3 Ga (?)

Continental destruction

One indication of significant recycling of lower Continental Crust back into mantle

- Based on Sm–Eu–Gd analyses of upper/middle/lower CC samples
- Lower CC enriched in Eu
- Upper CC strongly depleted in Eu
- Overall CC depleted in Eu relative to mantle-derived basalts (its building blocks)
- Interpreted as recycling of lower CC back into the mantle

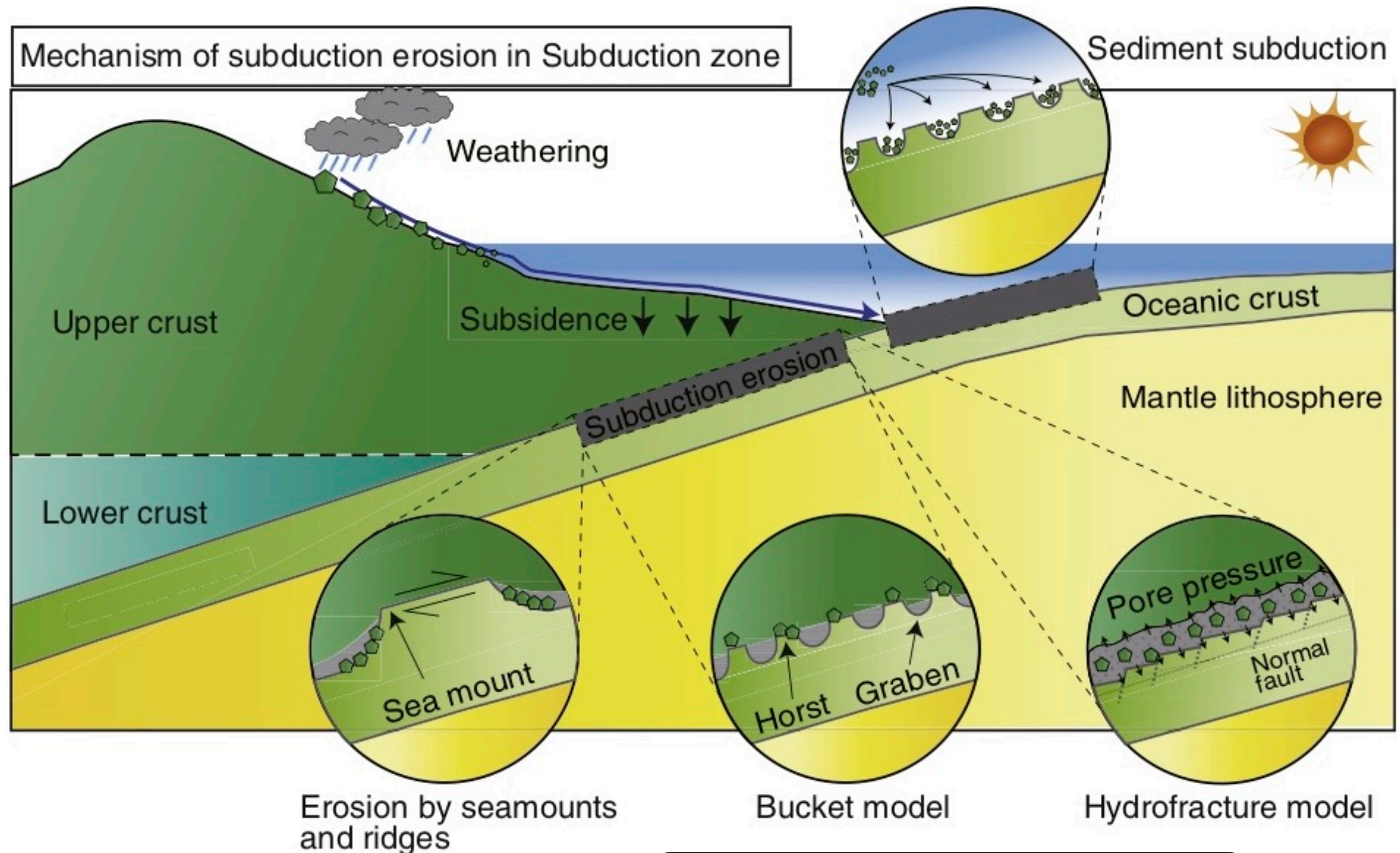


At least 2.9 crustal masses have been lost to the mantle via lower crustal recycling

Total continental crust mass created over age of the Earth could be 4 × present-day mass.

Continental destruction

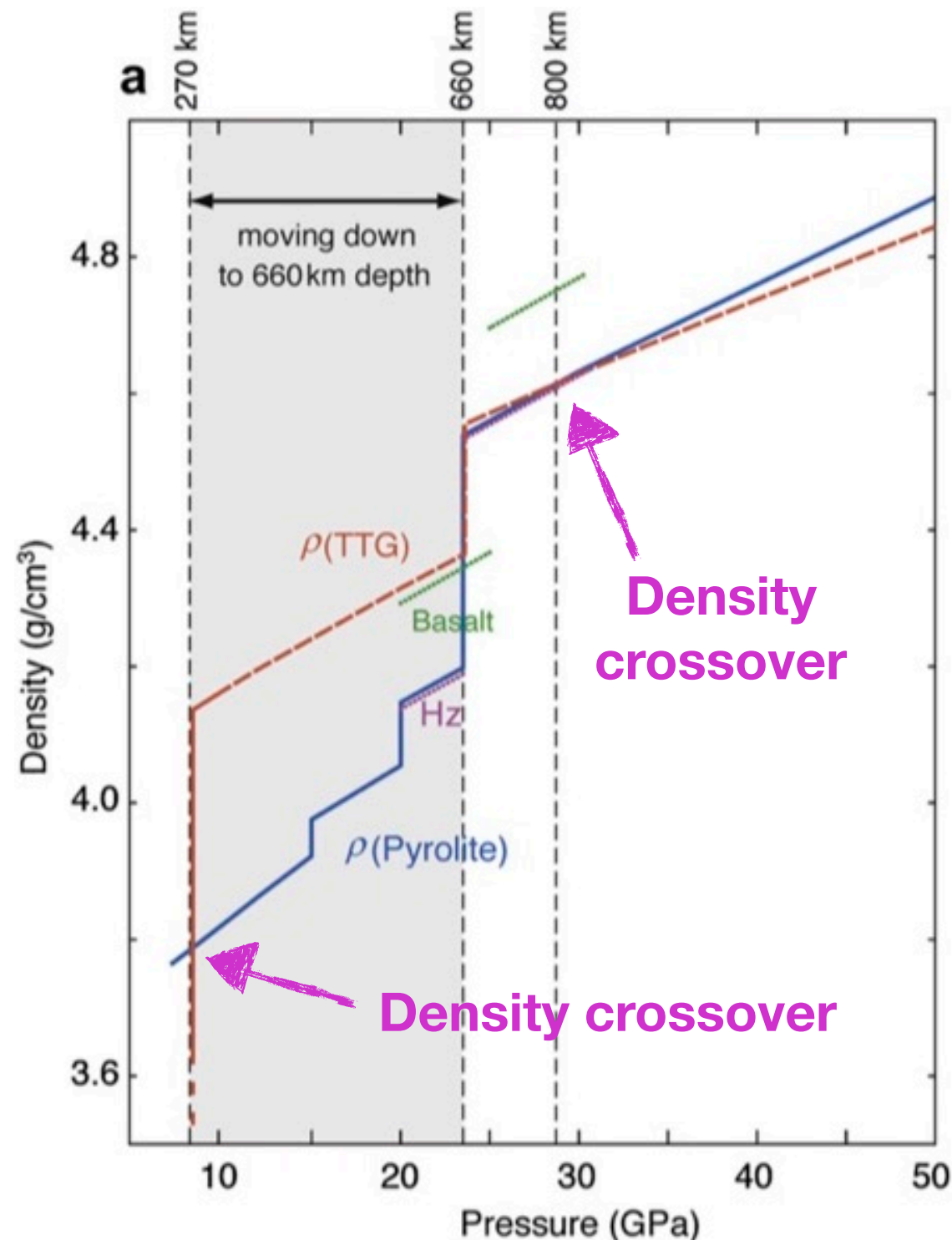
Sediment subduction and subduction erosion of Upper Continental Crust



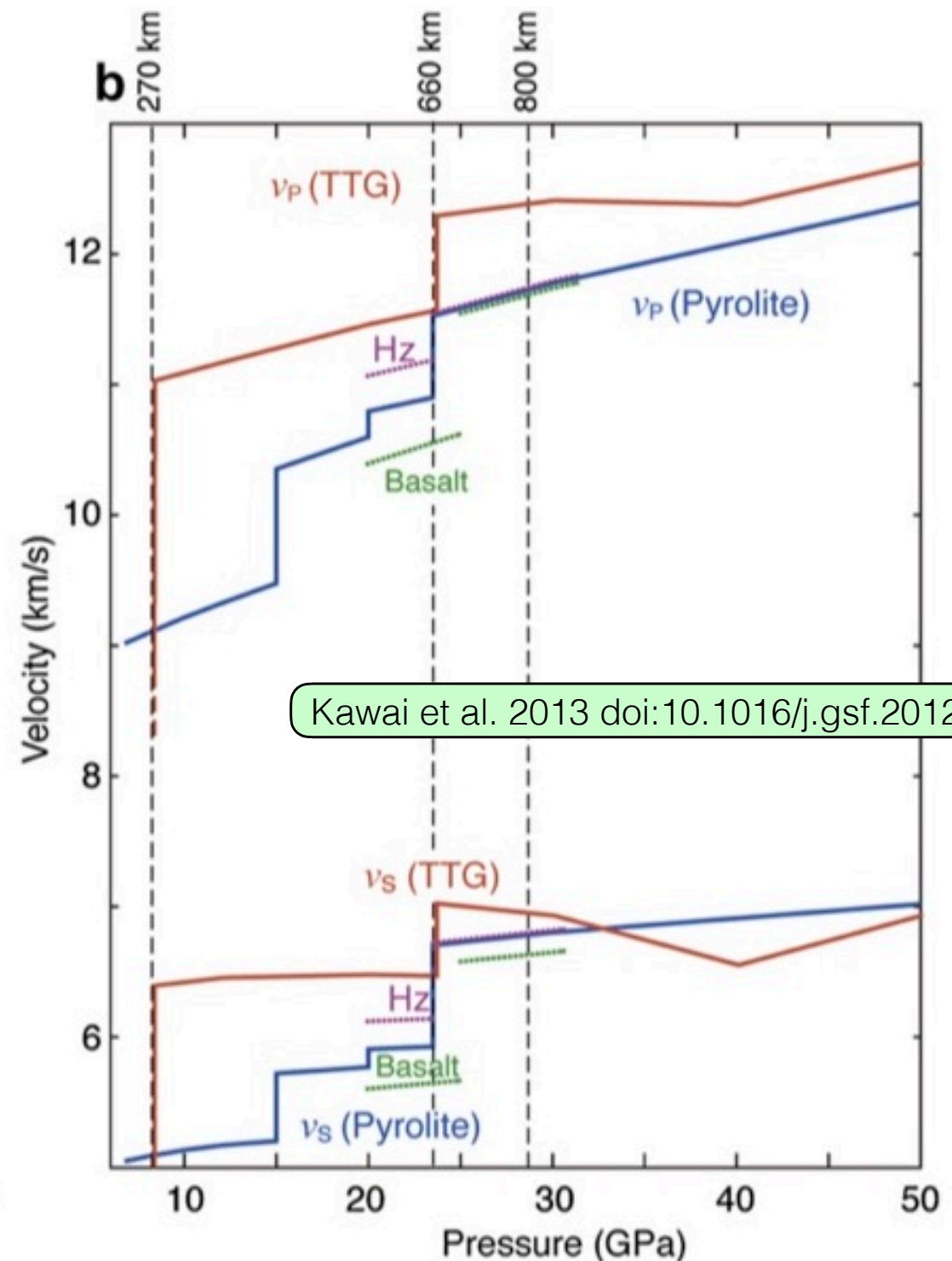
What happens to subducted material?

esp. Upper Crustal granitic rocks (TTG = tonalite-trondhjemite-granodiorite)

Density ρ



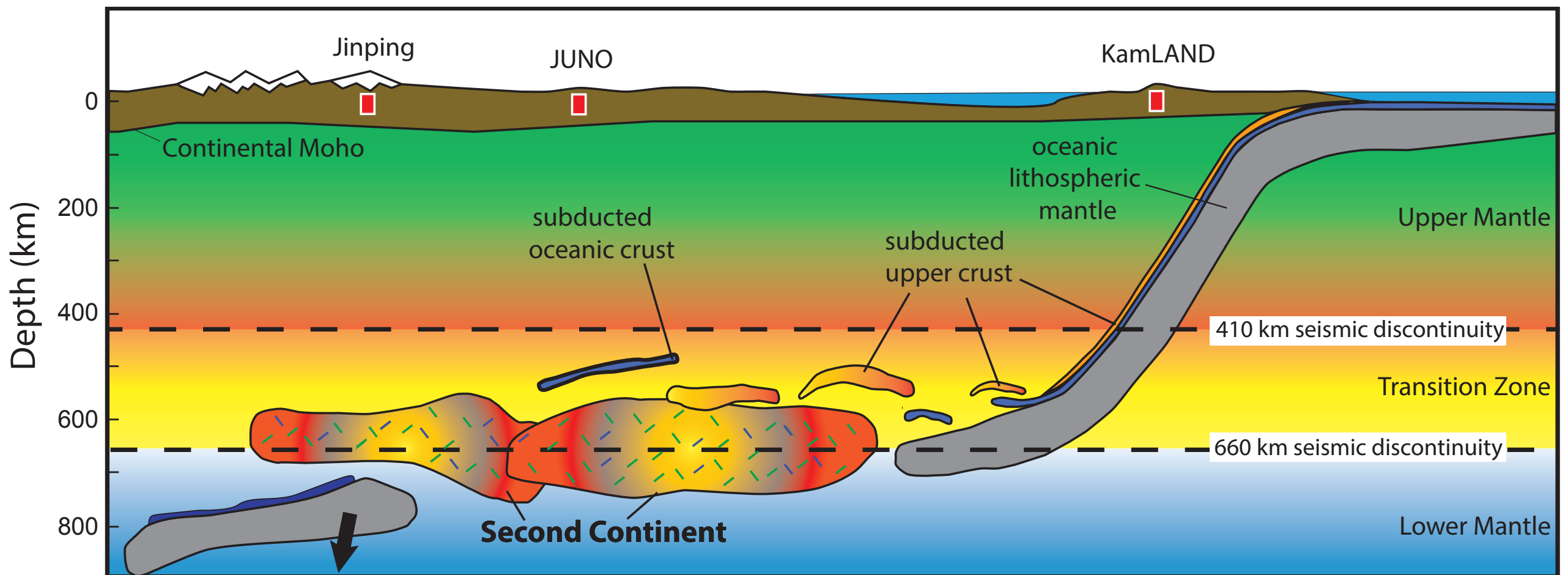
Seismic speeds v_P , v_S



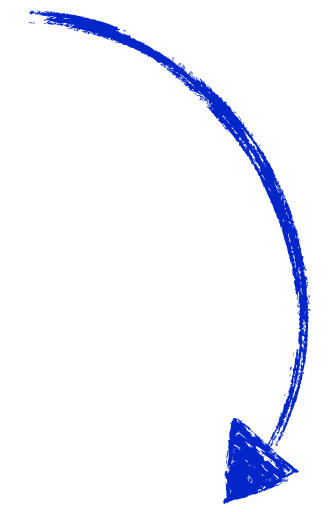
“Second continent” hypothesis

- Material of Upper Continental Crust is entrained and subducted in oceanic plate subduction setting, and accumulates at the base of the Transition Zone, where it forms a Second Continent

Kawai et al. 2009 doi:10.1016/j.gr.2009.05.012
Maruyama et al. 2011 doi:10.5026/jgeography.120.115
Kawai et al. 2013 doi:10.1016/j.gsf.2012.08.003



Testing Second Continent

- As such Second Continent is made of Upper Crustal material, which is enriched in K, Th, U by a factor of up to ~1000 relative to ambient mantle, it would be:
 - a bright geoneutrino emitter → we could “see” it
 - strongly internally heated → consequences for dynamics
- 

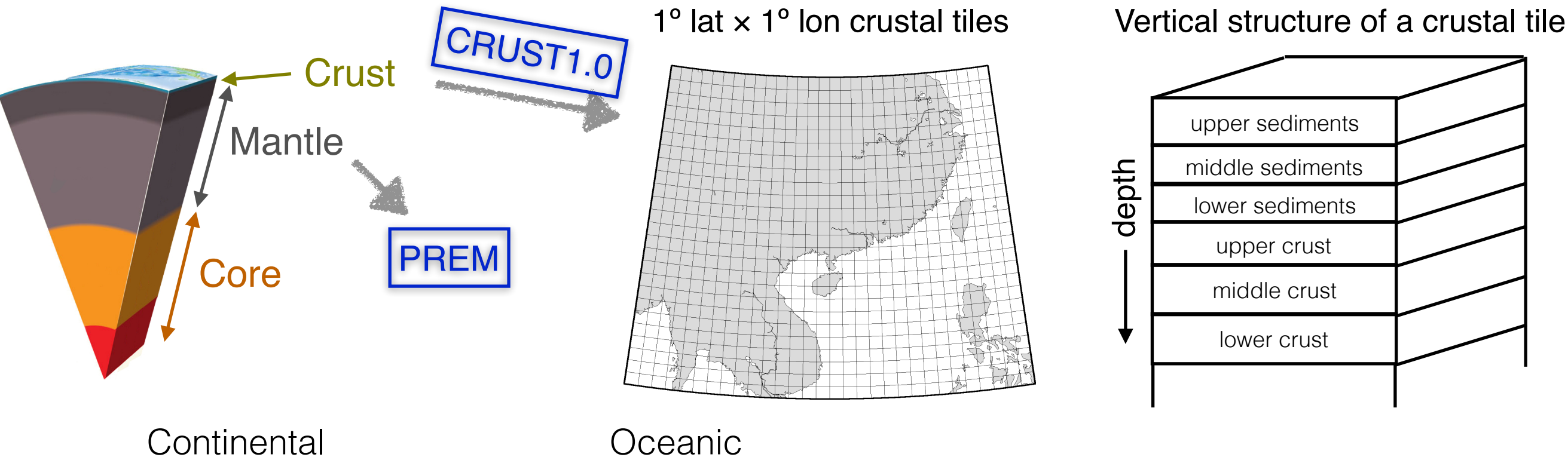
Construct models of Earth's geoneutrino emission with and without SC, ask whether the difference is detectable with current and future neutrino experiments.

Background “classical Earth” geoneutrinos + SC geoneutrinos

Background geoneutrino emission model

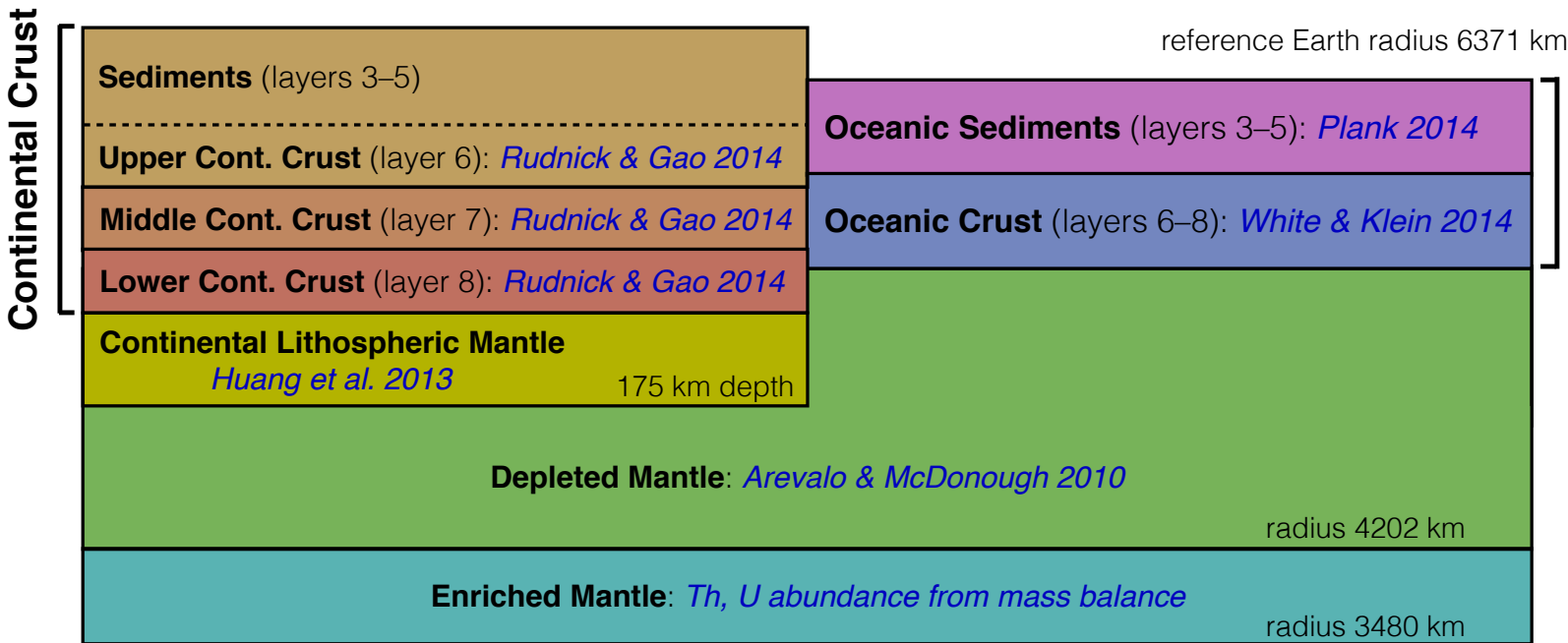
- Model of crustal geometry and material density from **CRUST1.0** model (*Laske et al.*)
- Material density in the mantle from **PREM** model (*Dziewonski & Anderson 1981*)
- Assume negligible Th, U in the core
- Total amount of Th, U in **Silicate Earth** from estimate by *Arevalo et al. 2009*, **20±4 TW** radiogenic power)

Šrámek et al 2016 doi:10.1038/srep33034



Continental

Oceanic

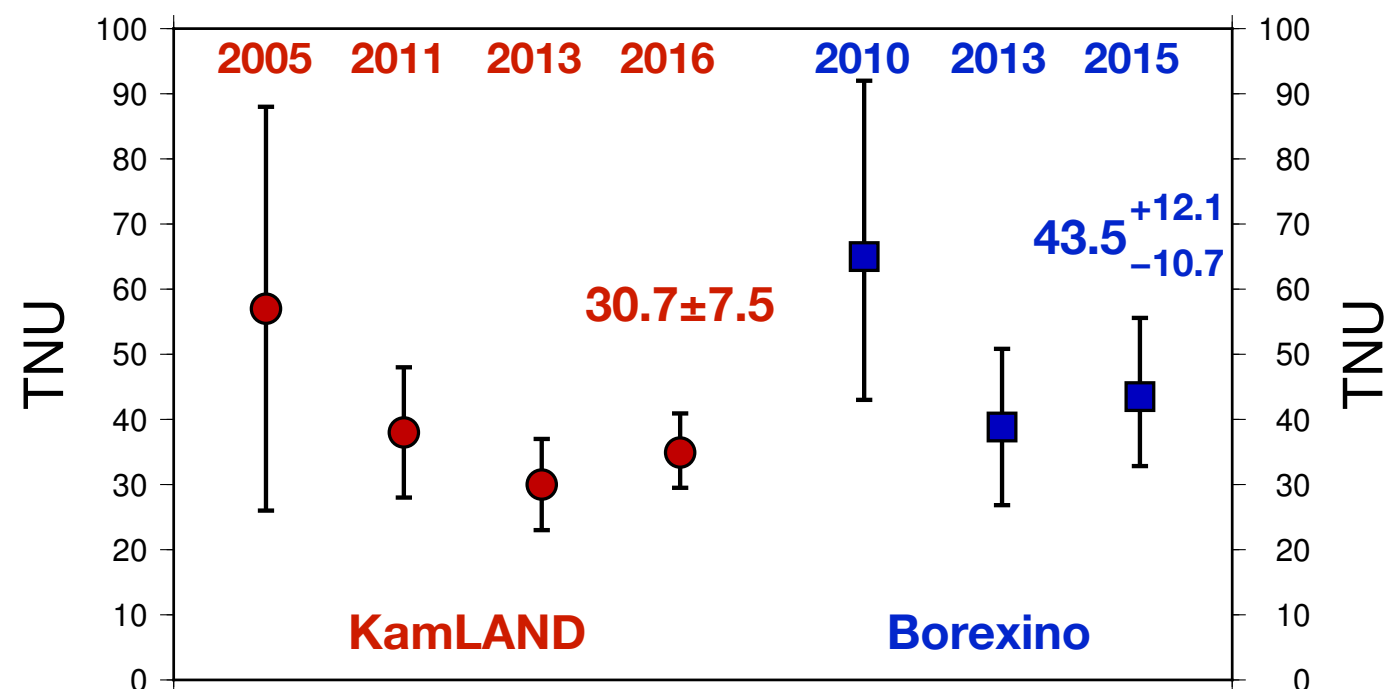


Mass fractions of Th and U

	Th	U
Upper CC + sediments	$(10.5 \pm 10\%) \times 10^{-6}$	$(2.7 \pm 21\%) \times 10^{-6}$
Middle CC	$(6.5 \pm 8\%) \times 10^{-6}$	$(1.3 \pm 31\%) \times 10^{-6}$
Lower CC	$(1.2 \pm 30\%) \times 10^{-6}$	$(0.2 \pm 30\%) \times 10^{-6}$
OC sediments	$(8.10 \pm 7\%) \times 10^{-6}$	$(1.73 \pm 5\%) \times 10^{-6}$
OC crust	$(0.21 \pm 30\%) \times 10^{-6}$	$(0.07 \pm 30\%) \times 10^{-6}$
CLM	$150^{+277}_{-97} \times 10^{-9}$	$33^{+49}_{-20} \times 10^{-9}$
Depleted Mantle	$(21.9 \pm 20\%) \times 10^{-9}$	$(8.0 \pm 20\%) \times 10^{-9}$
Enriched Mantle*	$147^{+74}_{-57} \times 10^{-9}$	$30^{+24}_{-18} \times 10^{-9}$
Bulk Silicate Earth	$(80 \pm 15\%) \times 10^{-9}$	$(20 \pm 20\%) \times 10^{-9}$

Global SC model 1a (crazy...)

- Let us assume an old SC which has accumulated+dispersed over >1 Gyr
→ formed a global layer between 600–700 km depth, with UCC (= upper Continental crust) abundances of Th, U
- Such model predicts additional 107 TW of radiogenic power and 93 TNU of geoneutrino signal.
- This is ruled out by heat flow measurements (46 ± 3 TW) and by current geoneutrino measurements:



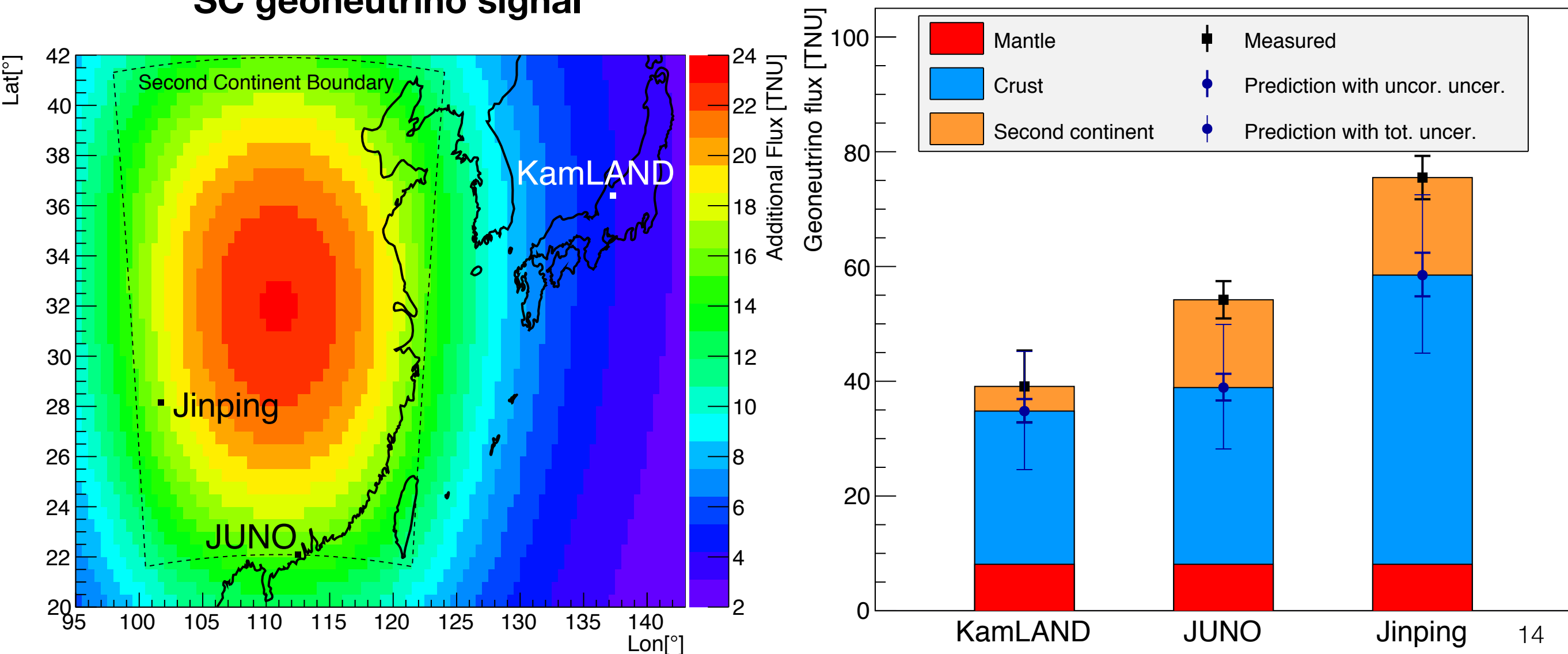
Global SC model 1b (upper limit)

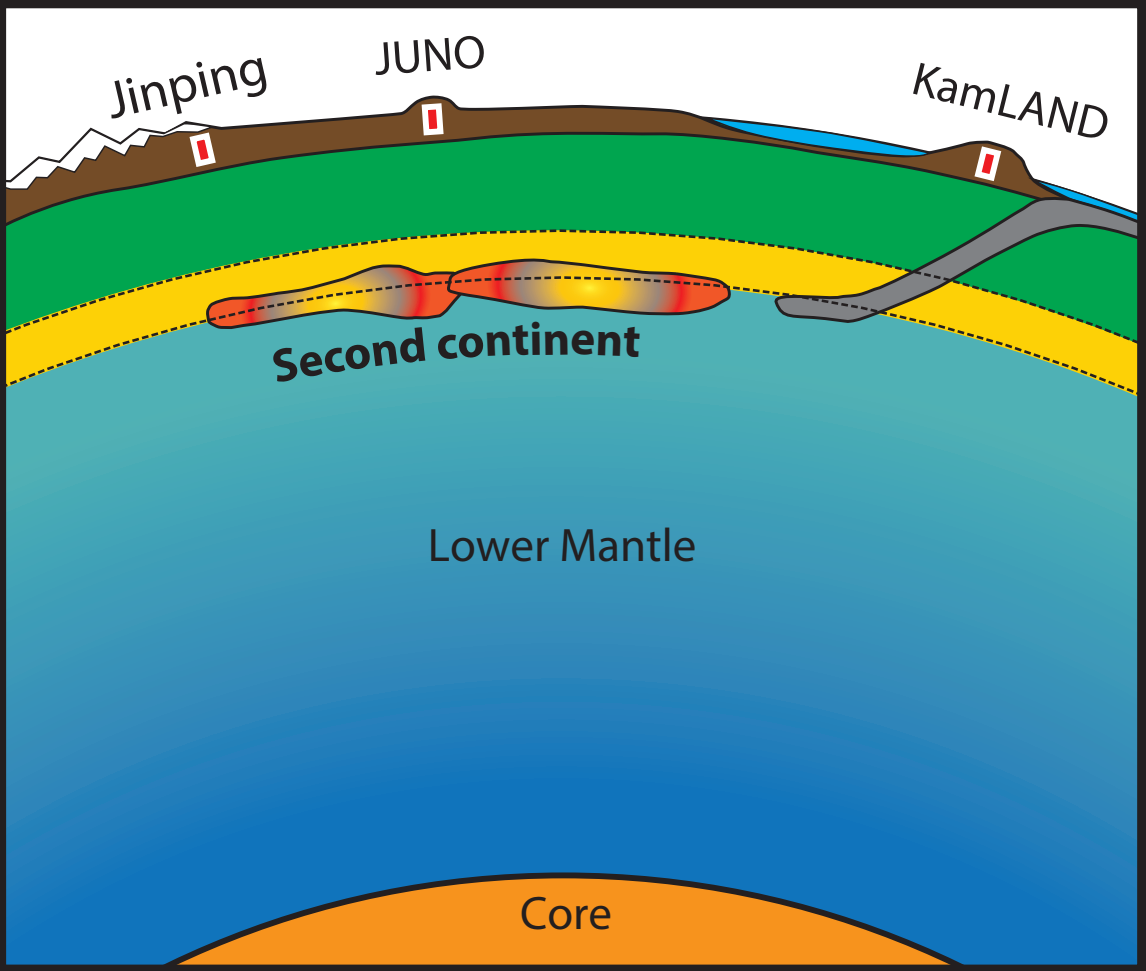
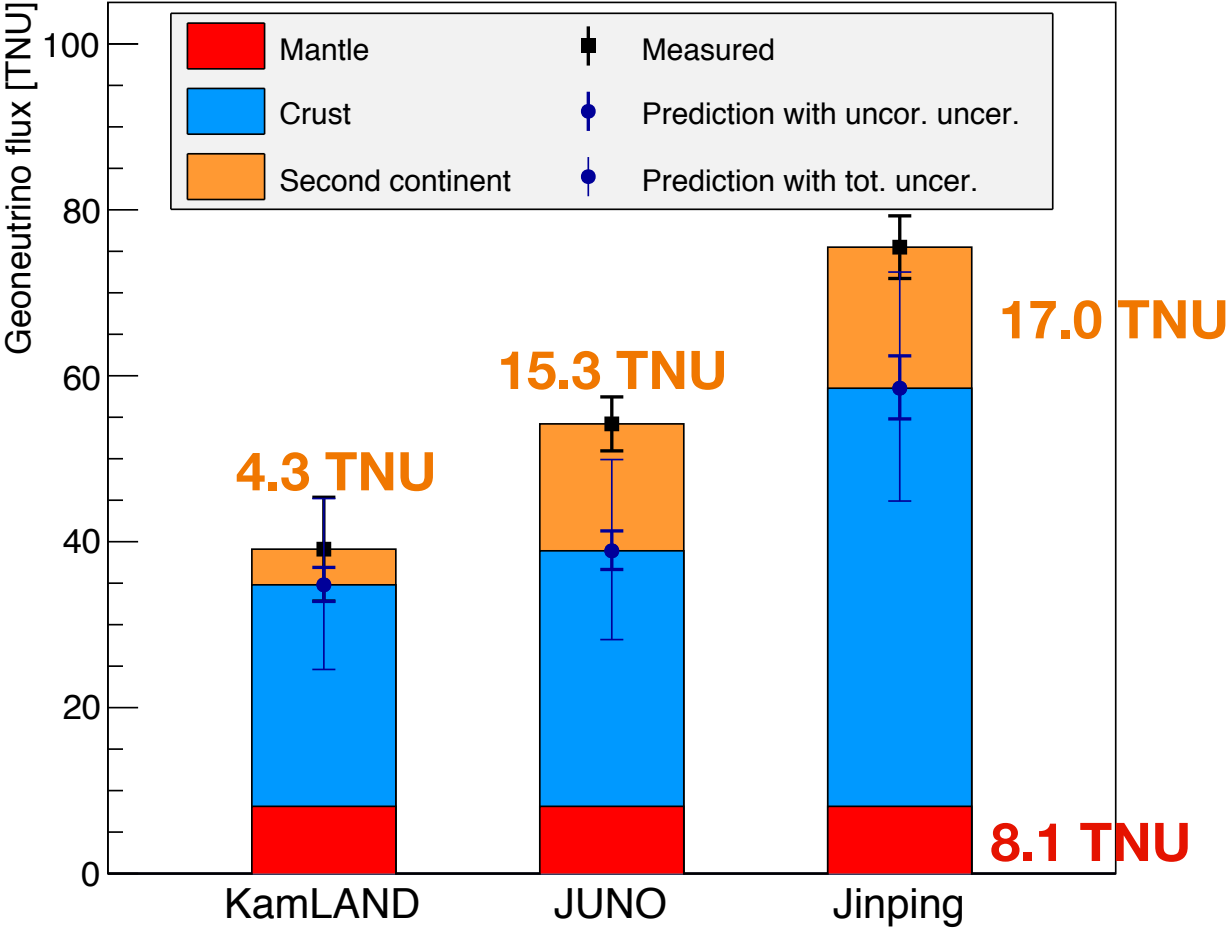
- Global layer at 600–700 km depth as in previous model
- Th, U concentration such that all mantle content of Th, U of a 20 TW (radiogenic) Earth is concentrated in this SC
- This results in a 1.6 TNU difference relative to a “classical” case
- This is too small a difference to be resolved by geoneutrino measurements (smaller than experimental uncertainties)
- Vertical distribution not resolvable by geoneutrinos ... reference mantle signal ~8.1 TNU; putting all emitters at CMB gives ~6.2 TNU; all emitter in SC give ~9.7 TNU

Regional SC model 2: SE Asia

- A young SC (few 100 My), created by Pacific plate subduction under Asia, location under SE China follows from subduction geometry, 2000 km × 2000 km laterally (~Australia-sized), UCC concentrations of Th, U

SC geoneutrino signal





Experiment	Location	Predicted flux [TNU]	Predicted flux with SC [TNU]	Measured flux [TNU]	Measurement uncertainty
KamLAND	36.4°N 137.3°E	$34.8^{+4.2}_{-4.0}$	$39.1^{+4.2a}_{-4.0}$	30.7 ± 7.5	16%
JUNO	22.1°N 112.5°E	$38.9^{+4.8}_{-4.5}$	$54.2^{+4.8a}_{-4.5}$	-	6%
Borexino	42.5°N 13.6°E	$41.4^{+5.1}_{-4.8}$	-	$43.5^{+12.1}_{-10.7}$	15%
ANDES	30.2°S 69.8°W	$41.7^{+4.8}_{-4.7}$	$45.8^{+4.8b}_{-4.7}$	-	5%
SNO+	46.5°N 81.2°W	$44.2^{+5.3}_{-5.1}$	-	-	9%
Jinping	28.2°N 101.7°E	$58.5^{+7.4}_{-7.2}$	$75.5^{+7.4a}_{-7.2}$	-	4%
OBD I	44.0°S 47.0°W	$15.5^{+2.4}_{-2.6}$	$38.6^{+2.4b}_{-2.6}$	-	10%
OBD II	44.0°S 19.0°W	$12.7^{+2.4}_{-2.6}$	$17.8^{+2.4b}_{-2.6}$	-	10%

^a Assuming SC Model II ^b Assuming SC Model III

Single detector

🙄

Compare signals between KamLAND, JUNO, Jinping

😊

Quantifying the discovery potential

Total signal with SC contribution

Total signal without SC contribution

$$\chi^2 = \sum_{i=1,2,3} \left(\frac{S_{\text{wSC}}^i - S_{\text{woSC}}^i}{\sqrt{(\sigma_m^i)^2 + (\sigma_p^i)^2}} \right)^2 = \sum_{i=1,2,3} \left(\frac{S_{\text{SC}}^i}{\sqrt{(\sigma_m^i)^2 + (\sigma_p^i)^2}} \right)^2$$

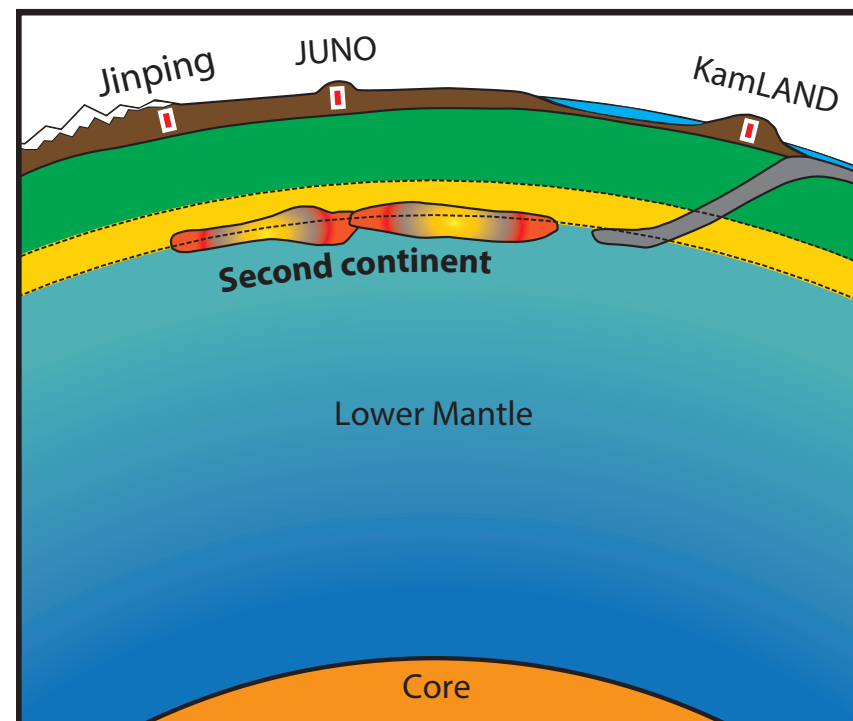
Expected measurement uncertainties

Uncorrelated part of prediction uncertainties

$$\sqrt{\chi^2} = 5.0$$



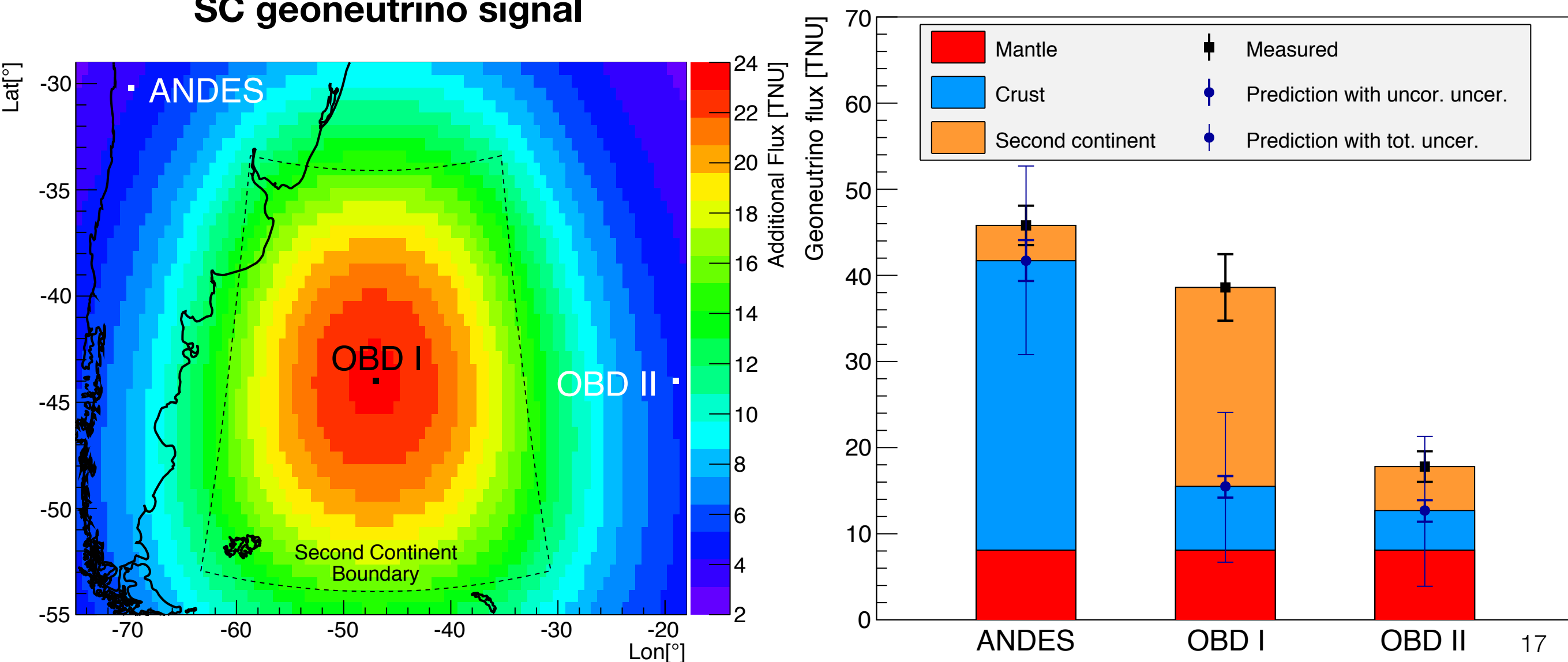
“Model 2” SC can be discovered at 5.0 σ level

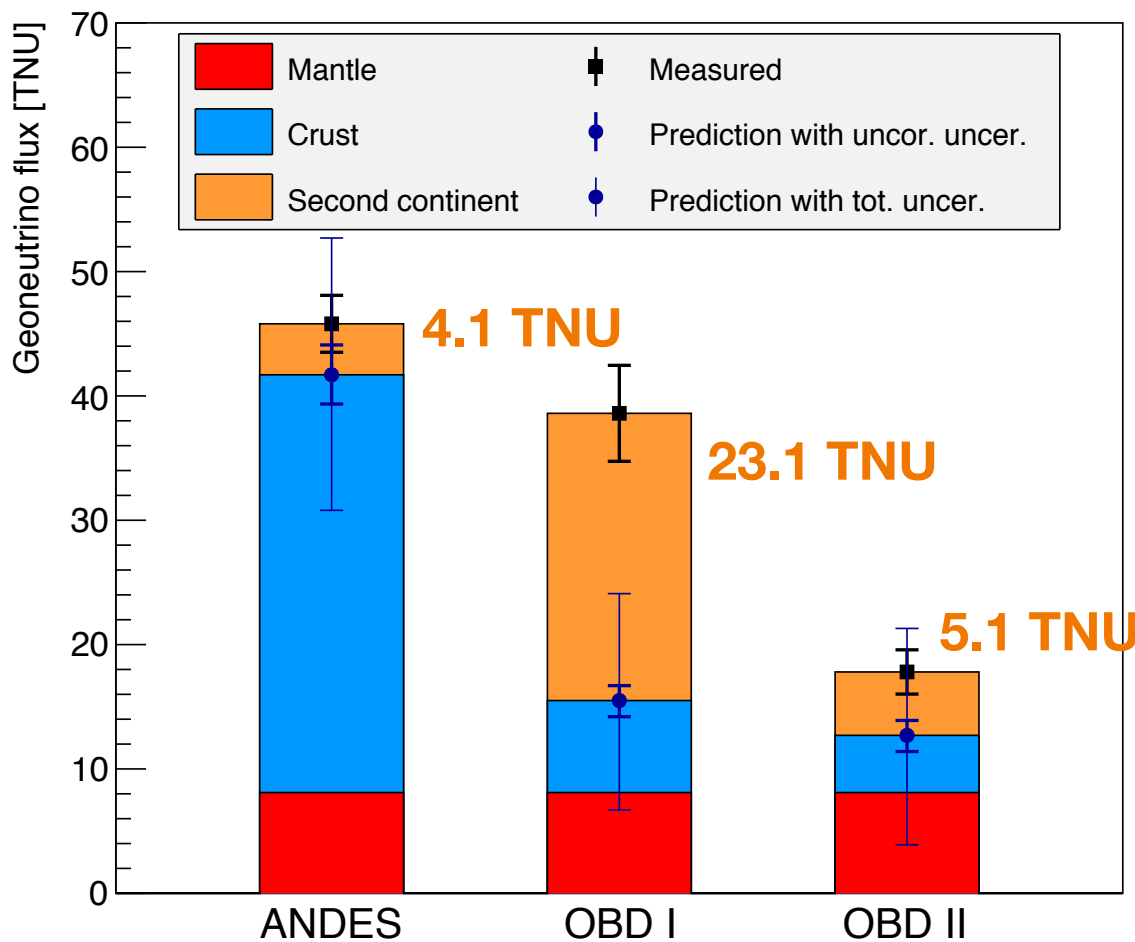


Regional SC model 3: South Atlantic

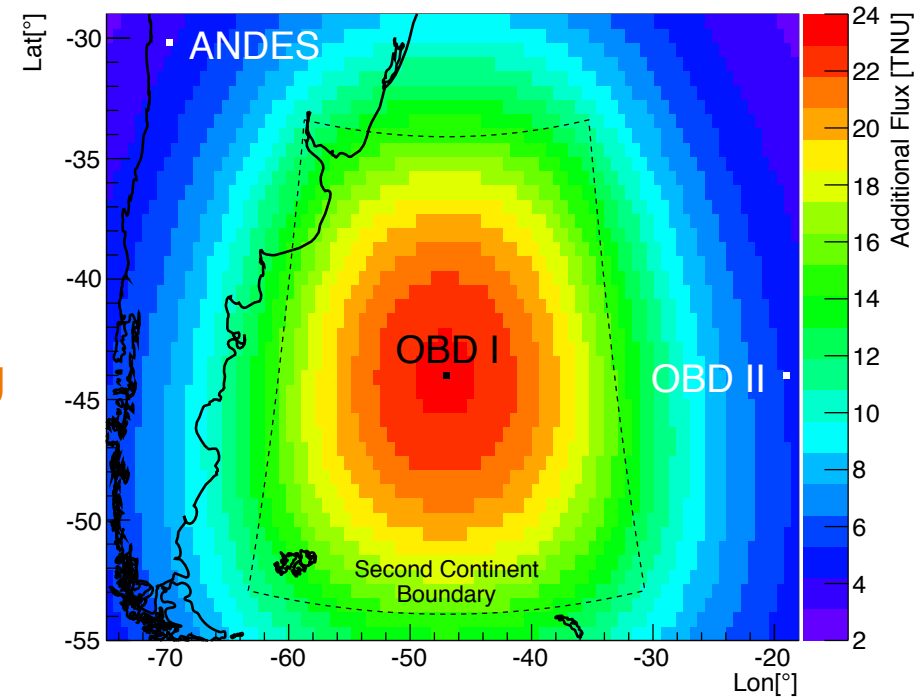
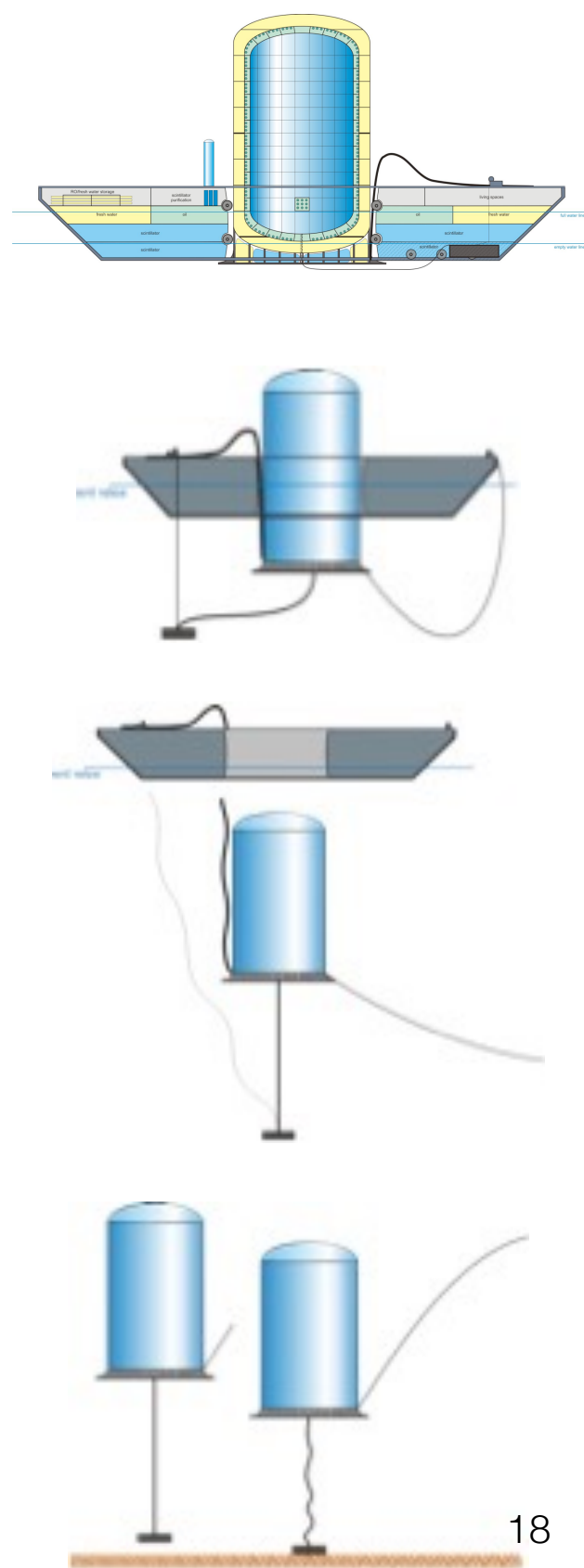
- A young SC (few 100 My), created by Pacific plate subduction below South America, located under South Atlantic, same geometry and composition as in model 2

SC geoneutrino signal





OBD = Ocean Bottom Detector

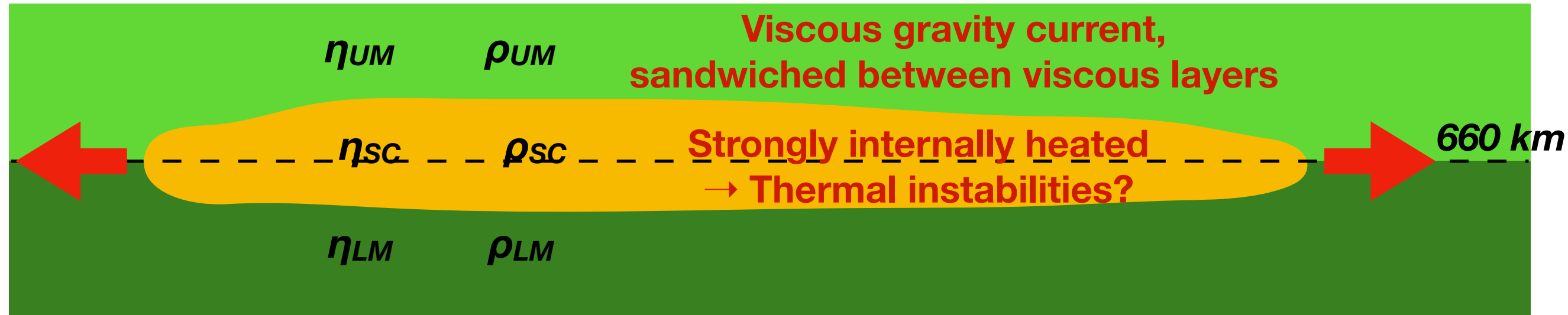
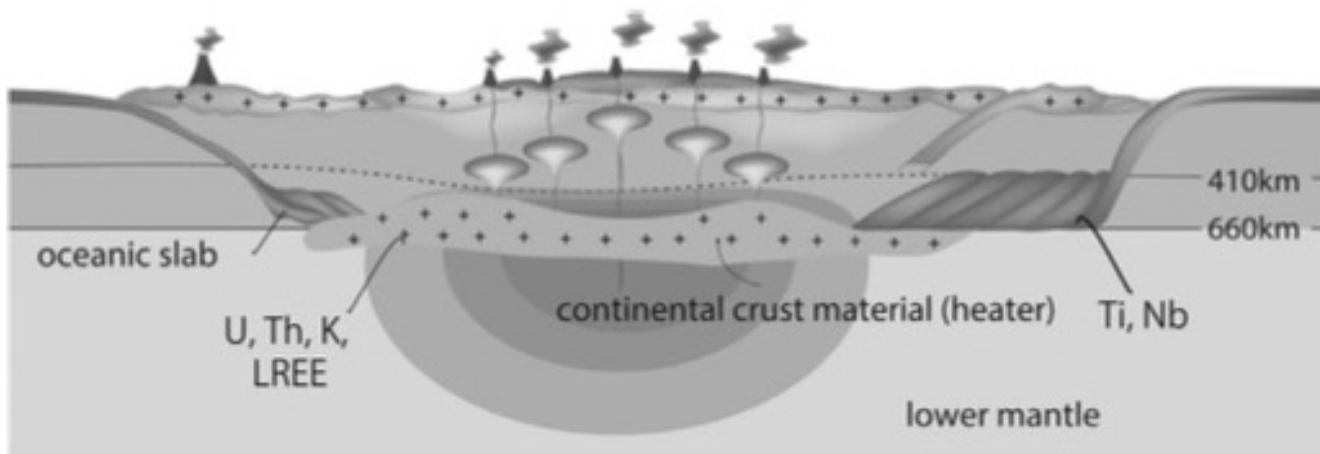


Experiment	Location	Predicted flux [TNU]	Predicted flux with SC [TNU]	Measured flux [TNU]	Measurement uncertainty
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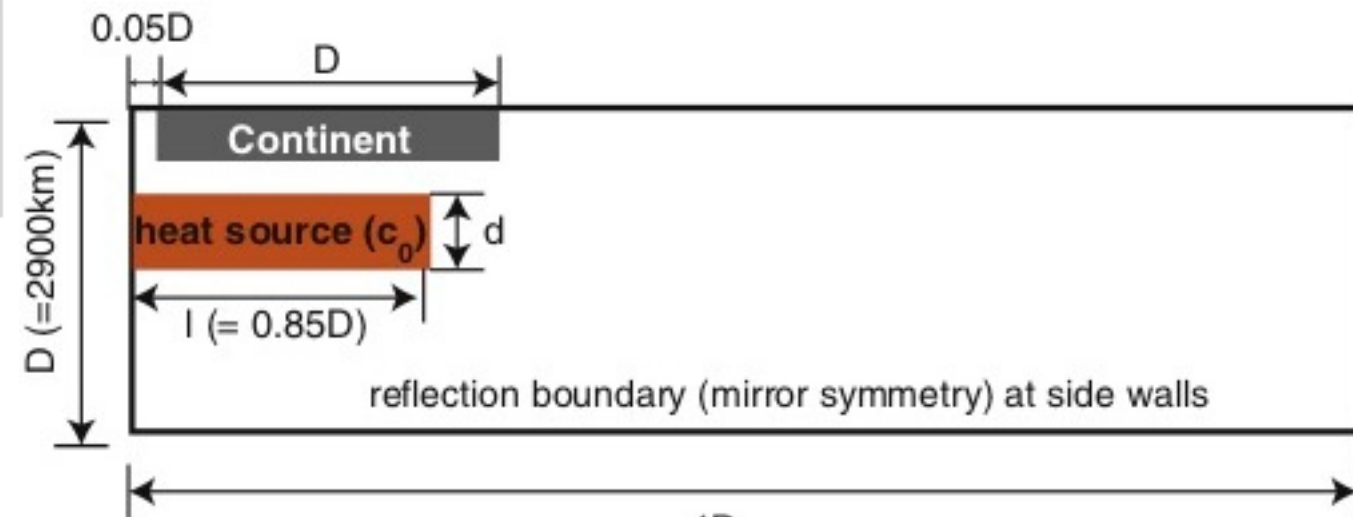
^a Assuming SC Model II ^b Assuming SC Model III

SC discovery potential is 6.2σ

Dynamics of Second Continent?



Safonova et al 2015 doi:10.1016/j.gsf.2014.11.004



Ichikawa et al 2013 doi:10.1016/j.gr.2013.02.001

Summary

- Second Continent hypothesis is testable by geoneutrino measurements ... either discover a SC or put upper limit on its (mass $\times$ enrichment / distance²)
- SE China location will benefit from three land-based detectors
- Ocean-bottom detector required for ocean-located SC (e.g, South Atlantic)
- Curious dynamical implications to explore

Neutrino Geoscience 2019 Prague

PRELIMINARY

- Neutrino geophysics, esp. geoneutrino themed meeting
- Probably on 21–23 October 2019 at Novotného Lávka
- Hoping to attract folks in the field, both neutrino physicists and geoscientists
- Past meetings:
 - Neutrino Sciences 2005, Neutrino Geophysics, Honolulu, Hawaii, 14–16 December 2005
 - Neutrino Sciences 2007, Deep Ocean Anti-Neutrino Observatory Workshop, Honolulu, Hawaii, 23–25 March 2007
 - Neutrino Geoscience 2008 at SNOLAB, Sudbury, Ontario, Canada, 17–19 September 2008
 - Neutrino Geoscience 2010, Gran Sasso National Laboratory, Italy, 6–8 October 2010
 - Neutrino Geoscience 2013, Takayama, Japan, 21–23 March 2013
 - Neutrino Geoscience 2015, IPG Paris, France, 15–17 June 2015
 - Neutrino Research and Thermal Evolution of the Earth, Tohoku University, Sendai, Japan, 25–27 October 2016
- Working with AMCA and MFF UK
- Need to raise some funds... **[Advice??]**

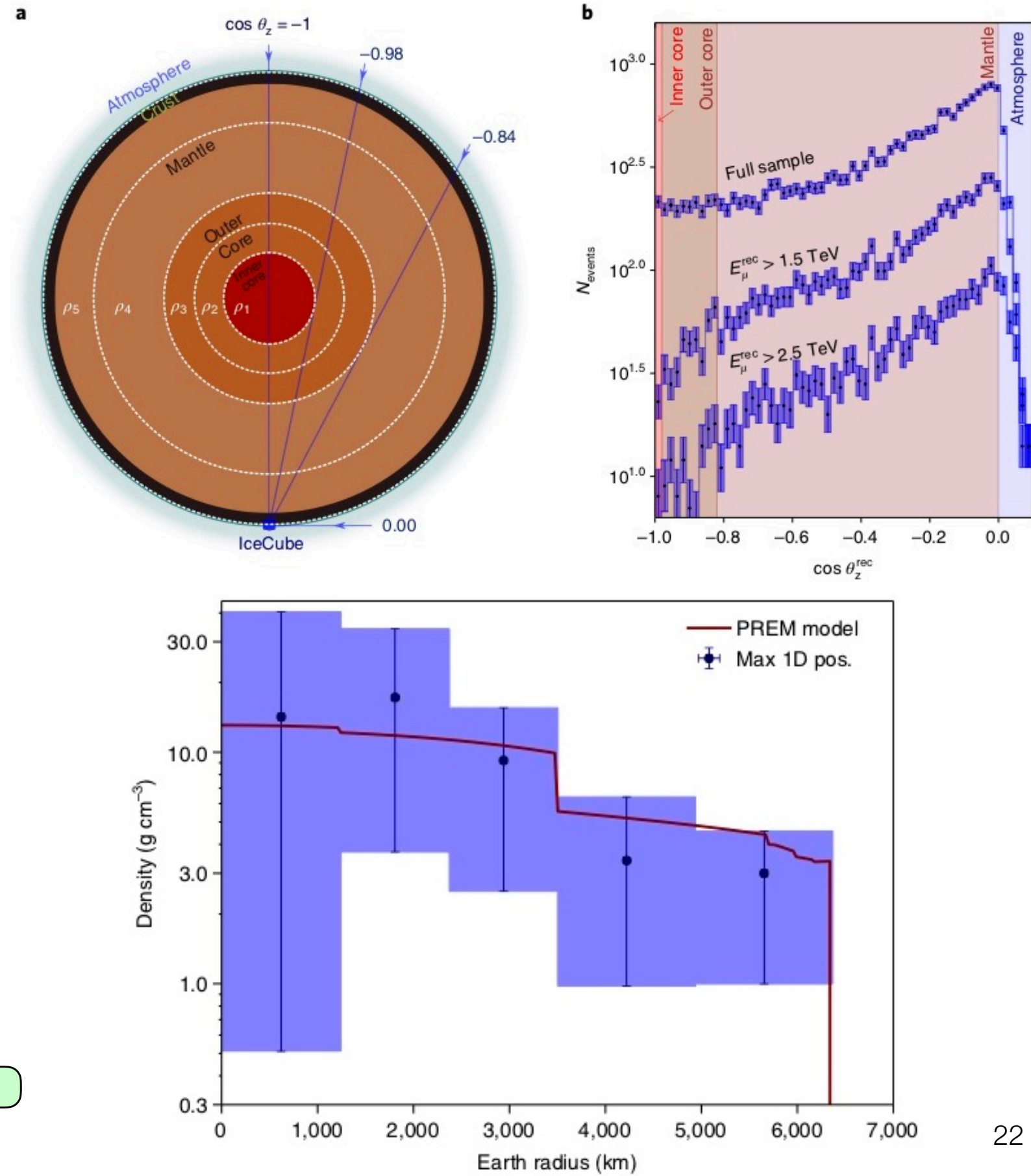


Neutrino tomography of Earth

Andrea Donini¹, Sergio Palomares-Ruiz^{1*} and Jordi Salvado^{1,2}

Cosmic-ray interactions with the atmosphere produce a flux of neutrinos in all directions with energies extending above the TeV scale¹. The Earth is not a fully transparent medium for neutrinos with energies above a few TeV, as the neutrino-nucleon cross-section is large enough to make the absorption probability non-negligible². Since absorption depends on energy and distance travelled, studying the distribution of the TeV atmospheric neutrinos passing through the Earth offers an opportunity to infer its density profile^{3–7}. This has never been done, however, due to the lack of relevant data. Here we perform a neutrino-based tomography of the Earth using actual data—one-year of through-going muon atmospheric neutrino data collected by the IceCube telescope⁸. Using only weak interactions, in a way that is completely independent of gravitational measurements, we are able to determine the mass of the Earth and its core, its moment of inertia, and to establish that the core is denser than the mantle. Our results demonstrate the feasibility of this approach to study the Earth's internal structure, which is complementary to traditional geophysics methods. Neutrino tomography could become more competitive as soon as more statistics is available, provided that the sources of systematic uncertainties are fully under control.

$$M_{\oplus}^{\nu} = (6.0_{-1.3}^{+1.6}) \times 10^{24} \text{ kg}$$





Thank you.