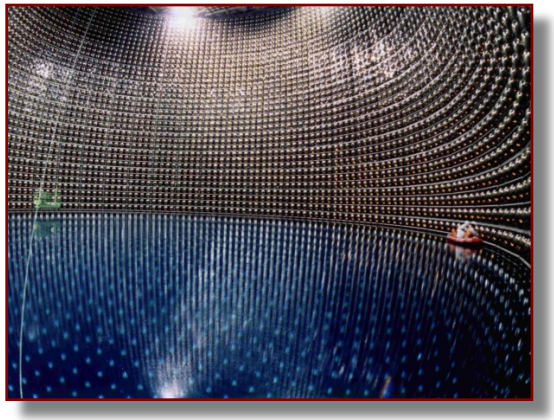
Particle Geophysics

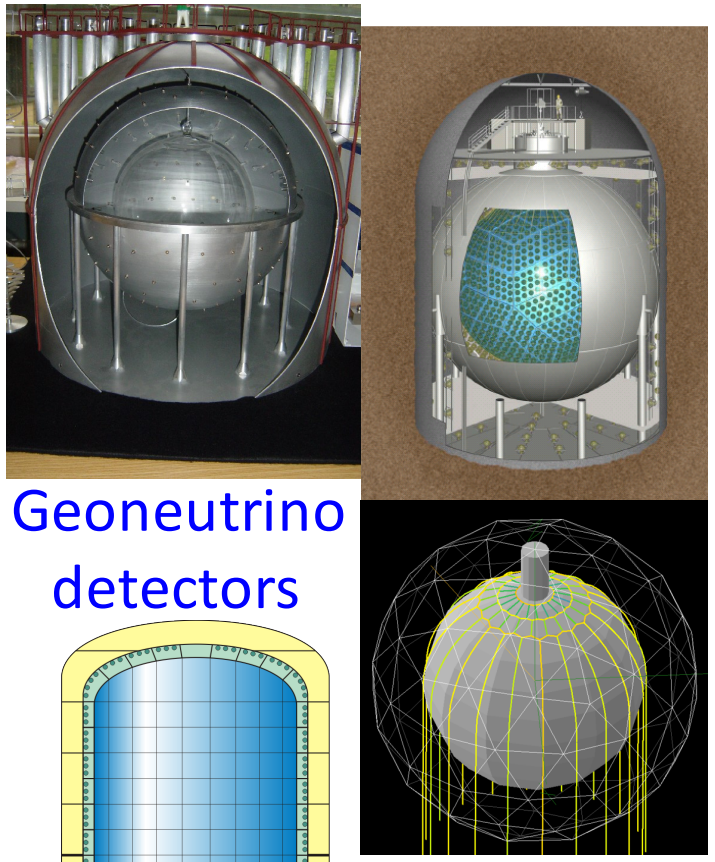
Probing Earth with neutrinos

IceCube -> PINGU

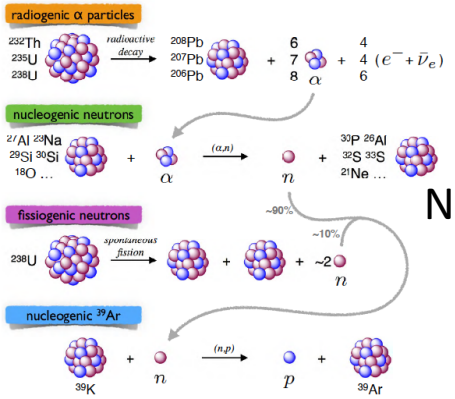
- Geoneutrinos
- neutrino oscillation

Next gen: Hyper-K





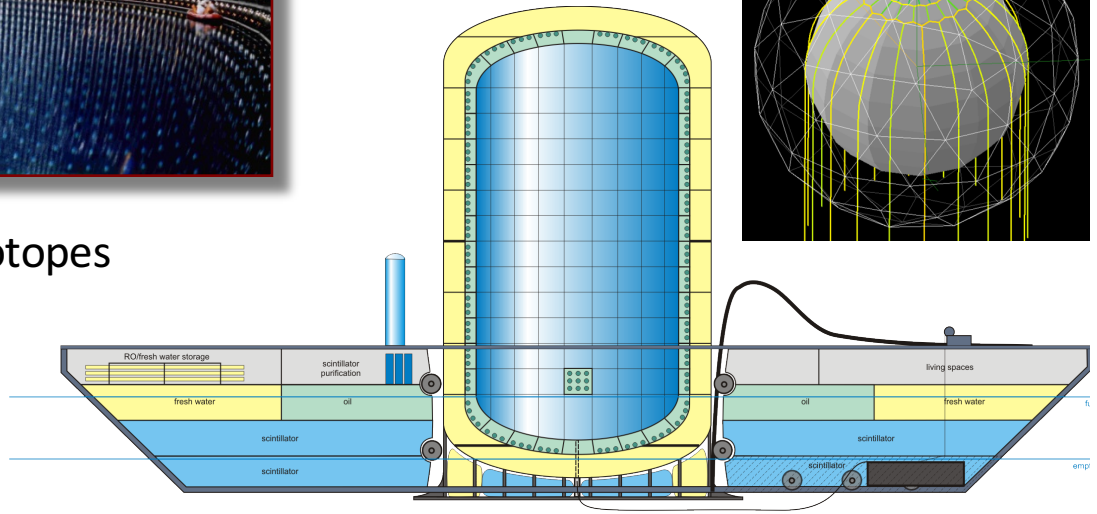
Geoneutrino detectors



Cosmogenic isotopes

Noble gases:

A(α,n)B rxn



5 Big Questions:

- What is the Planetary K/U ratio?

planetary volatility curve

- Radiogenic contribution to heat flow?

secular cooling

- Composition of the deep mantle?

whole vs layered convection

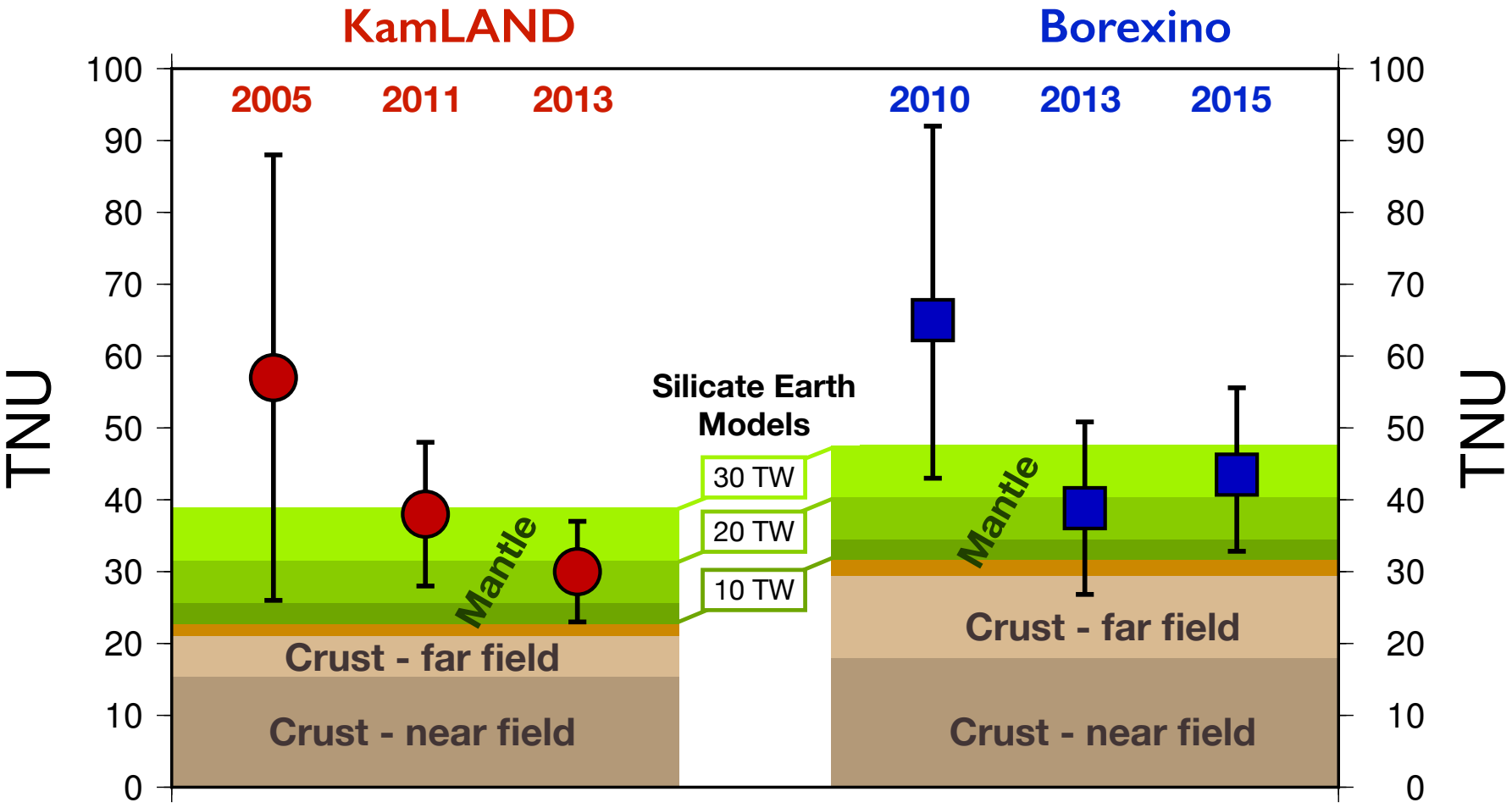
- Elements in the core?

Radioactive & light element budgets

- Nature of the Core-Mantle Boundary?

hidden reservoirs

Summary of geoneutrino results



SILICATE EARTH MODELS

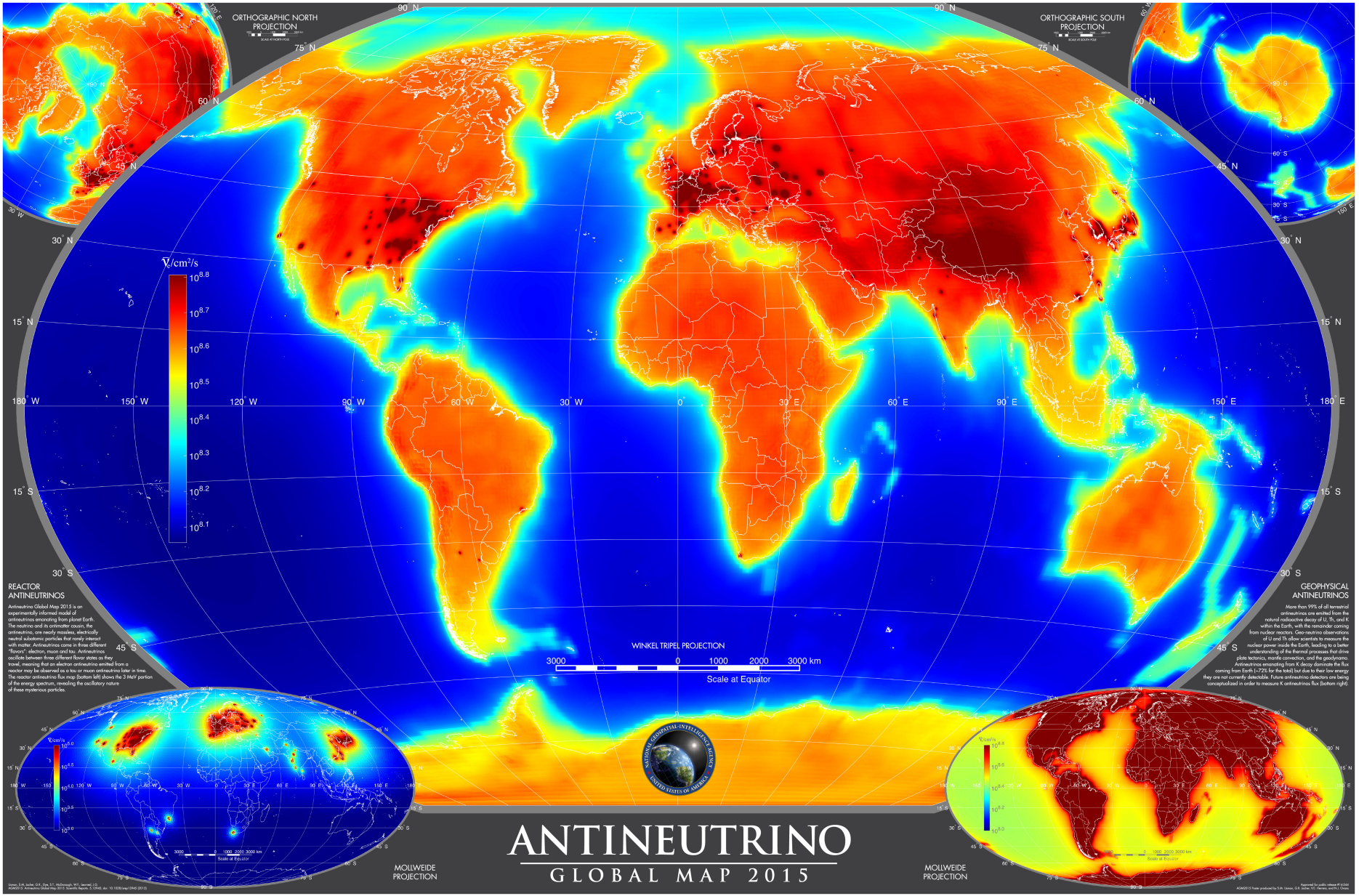
Cosmochemical: uses meteorites – 10 TW

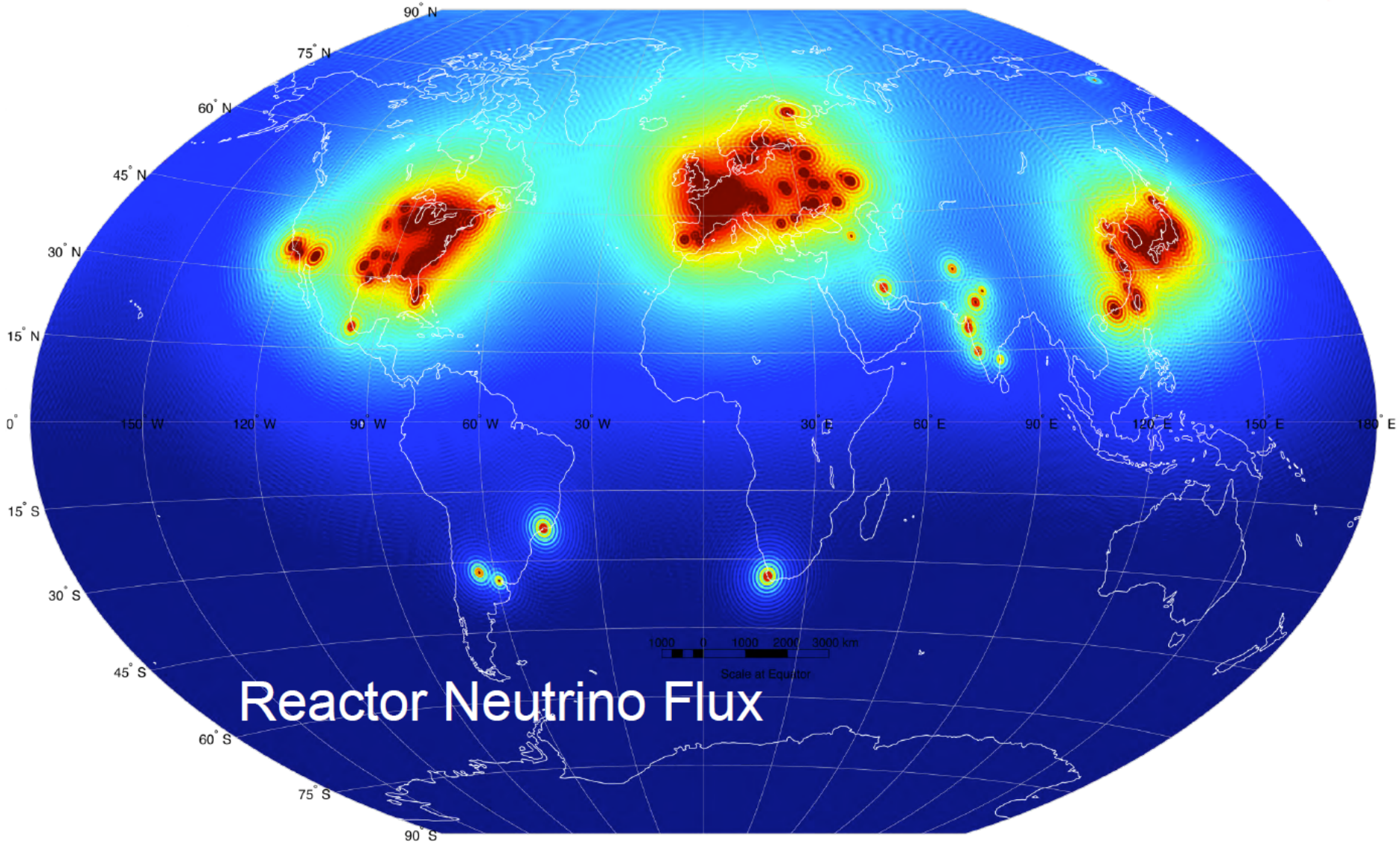
Geochemical: uses terrestrial rocks –20 TW

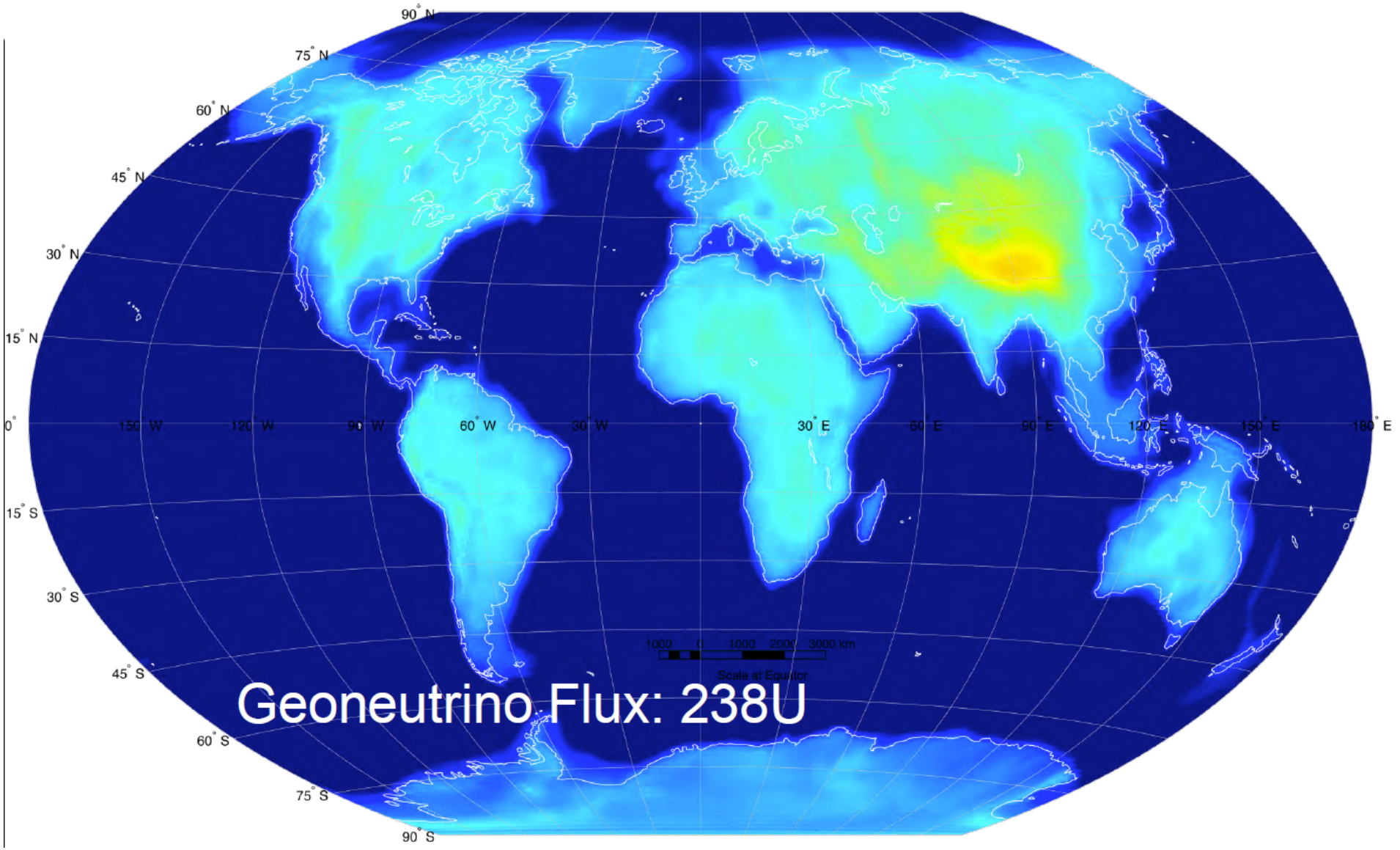
Geodynamical: parameterized convection – 30 TW

TNU: geo-ν event seen by a kiloton detector in a year

Antineutrino Map: geoneutrinos + reactor neutrinos




90° N
75° N
60° N
45° N
30° N
15° N
0°
15° S
30° S
45° S
60° S
75° S
90° S
150° W
120° W
90° W
60° W
30° W
30° E
60° E
90° E
120° E
150° E
180° E
1000 0 1000 2000 3000 km
Scale at Equator
Reactor Neutrino Flux


90° N
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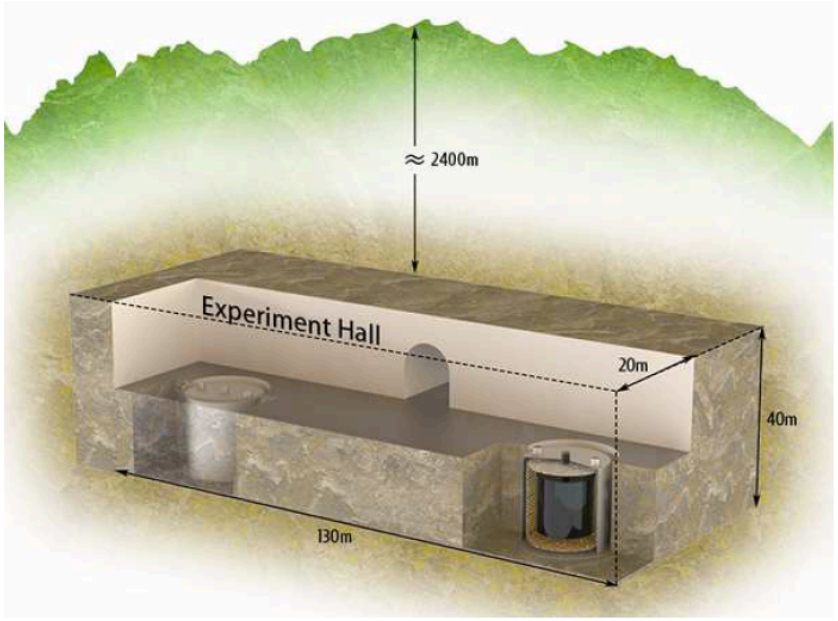
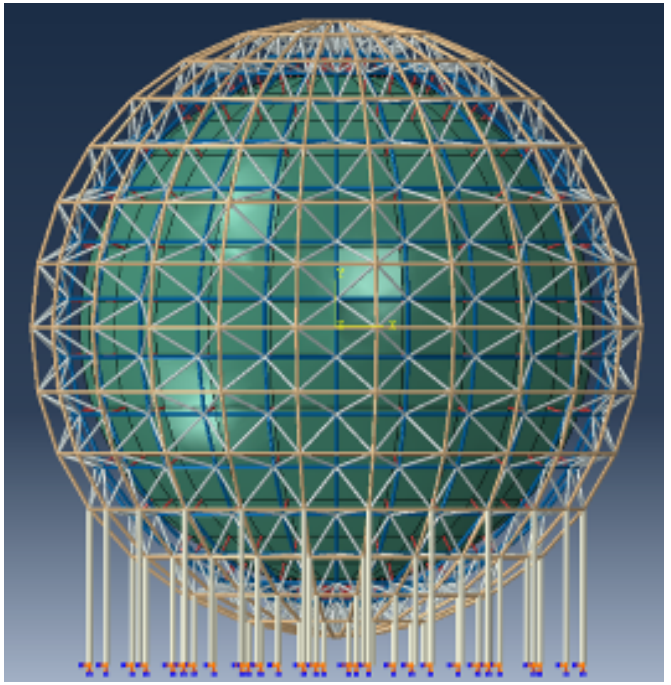
30° S
45° S
60° S
75° S
90° S
150° W
120° W
90° W
60° W
30° W
30° E
60° E
90° E
120° E
150° E
180° E
1000 0 1000 2000 3000 km
Scale at Equator
Geoneutrino Flux: 238U

Future detectors

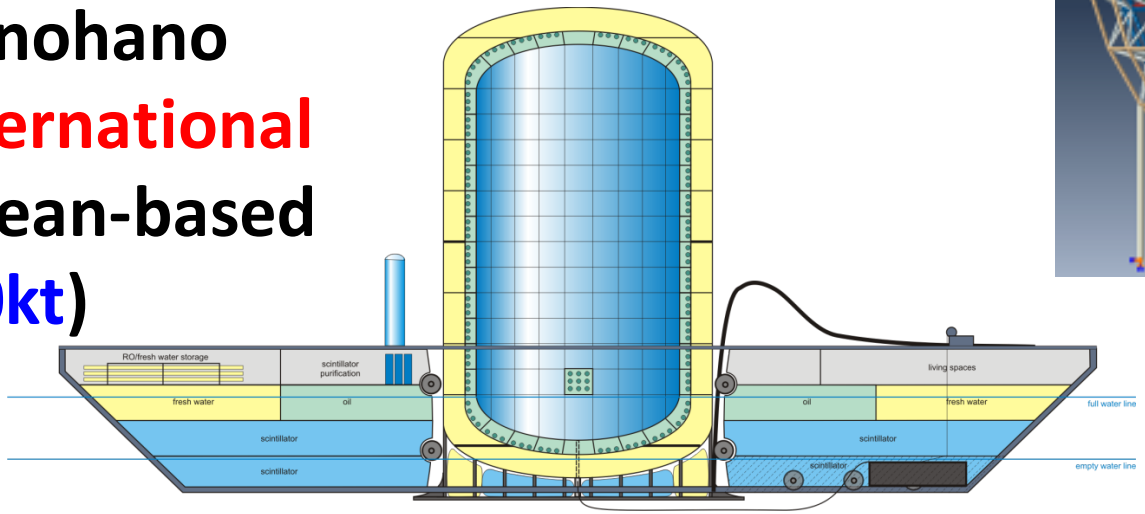


Jinping, China (3kt)

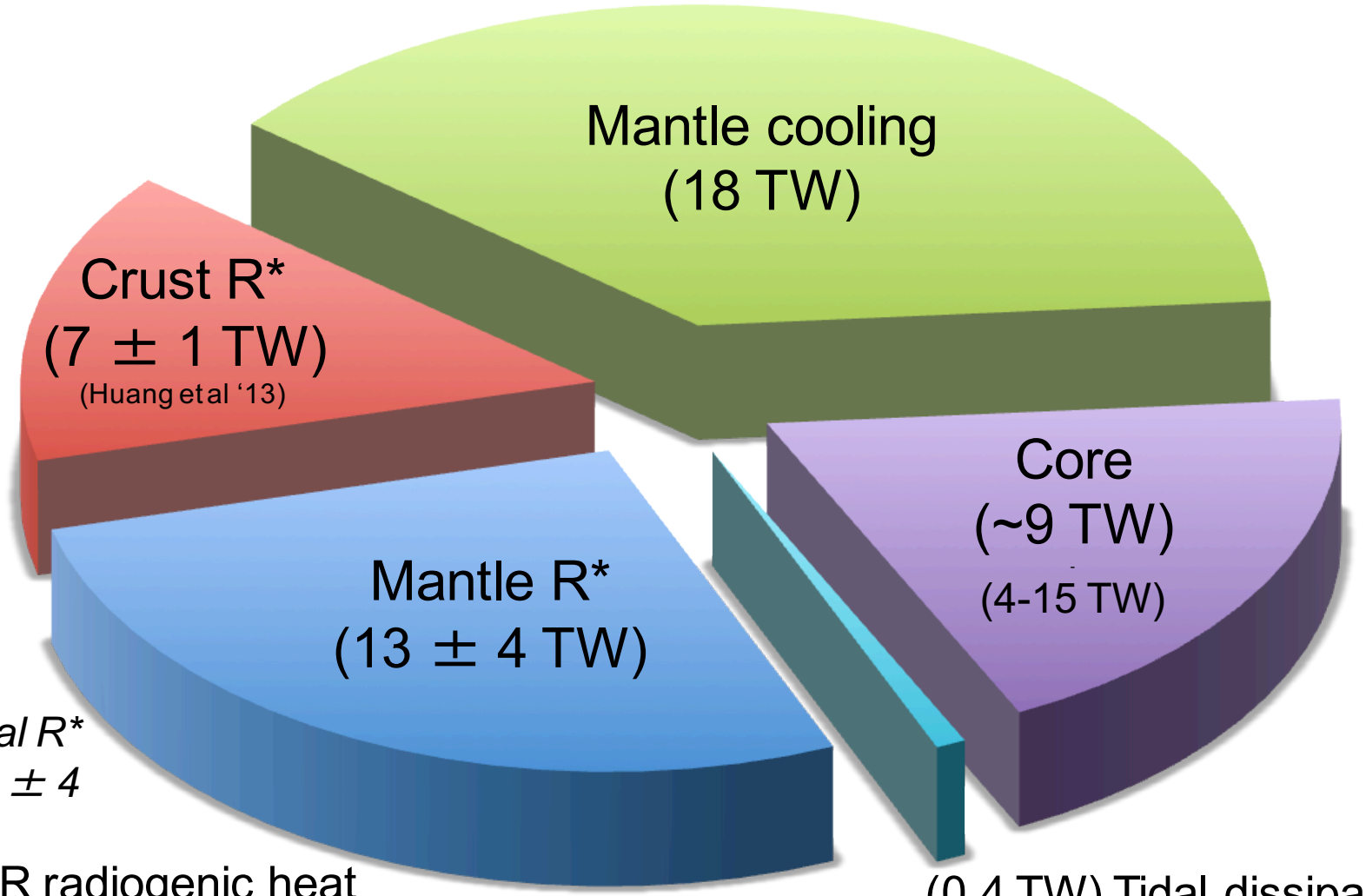
JUNO China (20kt)



Hanohano International ocean-based (10kt)



Earth's surface heat flow 46 ± 3 (47 ± 1) TW



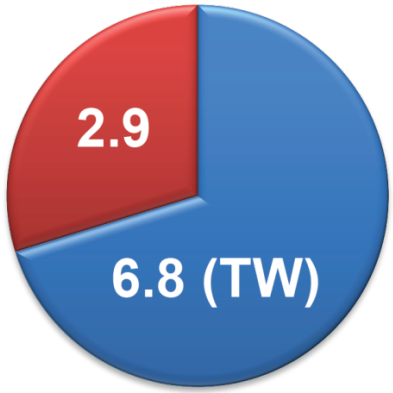
*total R**
20 ± 4

*R radiogenic heat
(after McDonough & Sun '95)

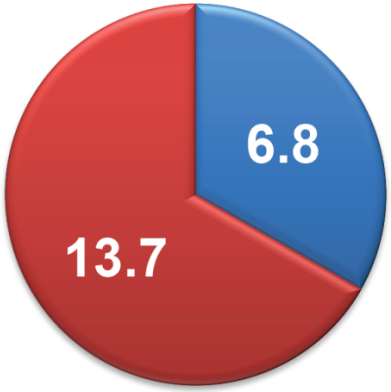
(0.4 TW) Tidal dissipation
Chemical differentiation

after Jaupart et al 2008 Treatise of Geophysics

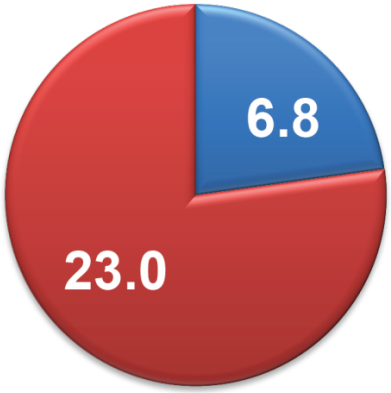
Bulk Silicate Earth Models



Cosmochemical
(10 TW)
(O'Neill & Palme '07)



Geochemical
(20 TW)
(McDonough & Sun '95)



Geodynamic
(30 TW)
(Turcotte & Schubert '02)

Cont. Crust
Modern Mantle

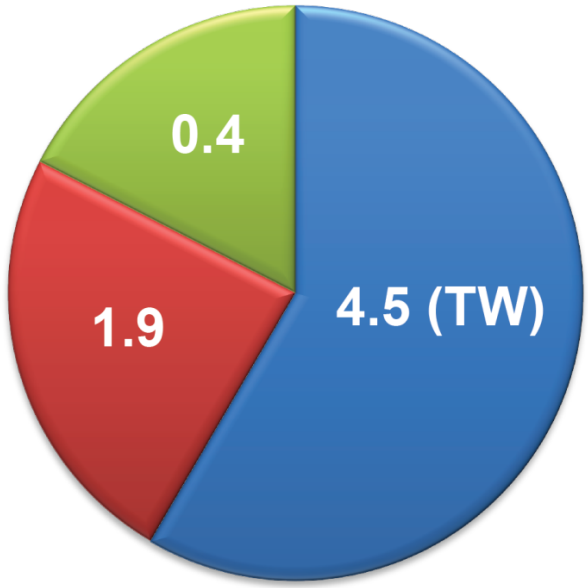
Th/U = 4

K/U = 1.4 x 10^4

Internal Heat?

Continental Crust

(Huang et al 2013)

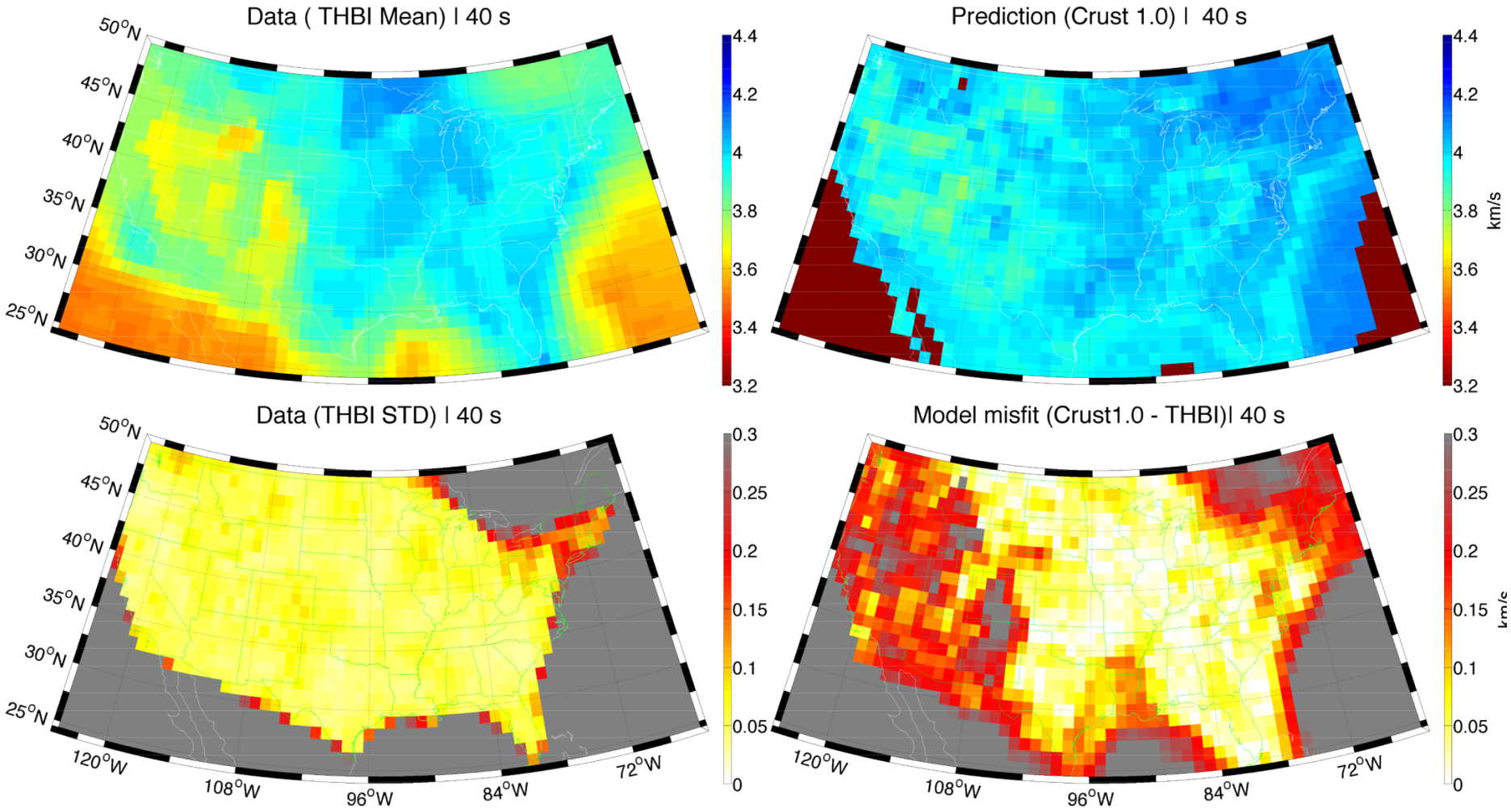


Upper Crust
Middle Crust
Lower Crust

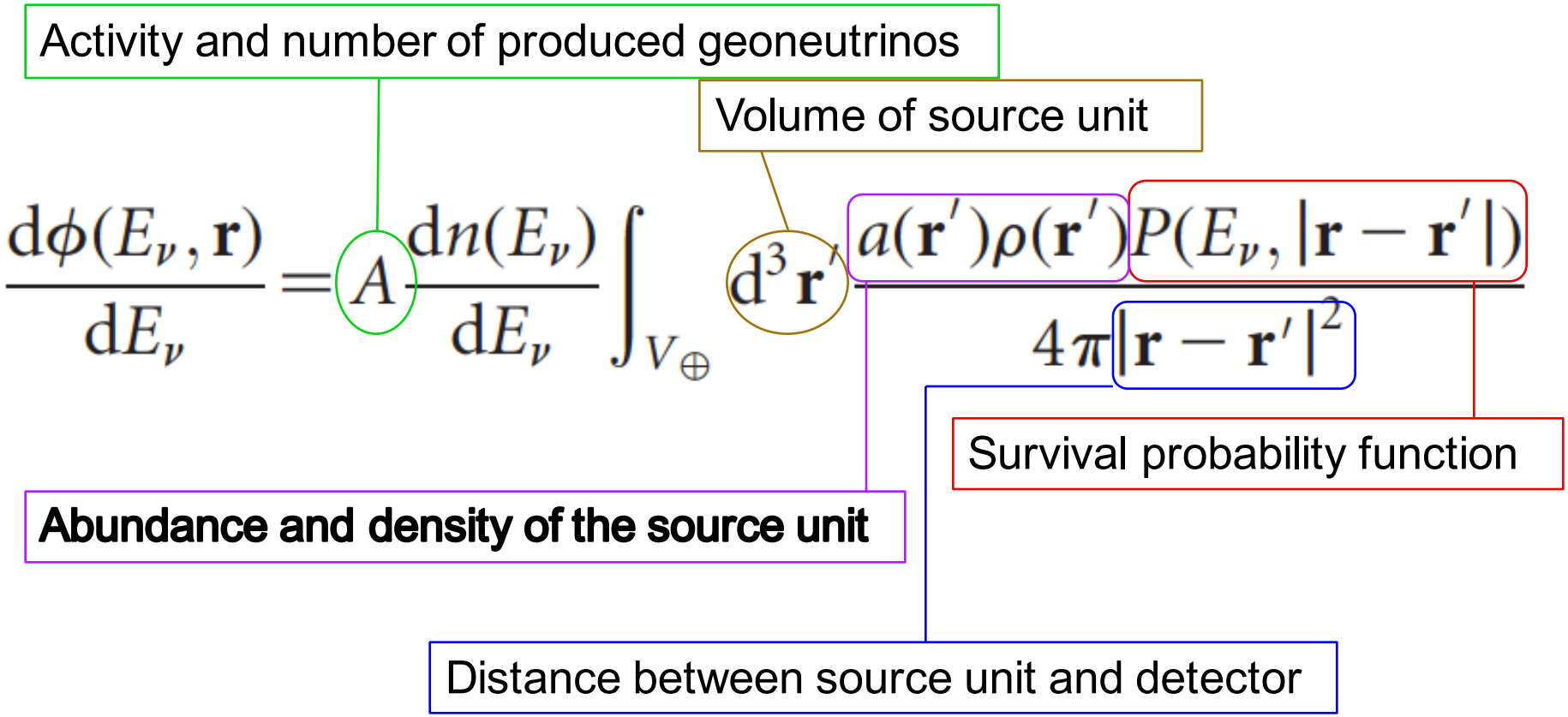
Rayleigh wave phase velocity: @ ~40 km

THBI: — *VS* — **CRUST 1.0**

Transdimensional Hierarchical Bayesian Inverse



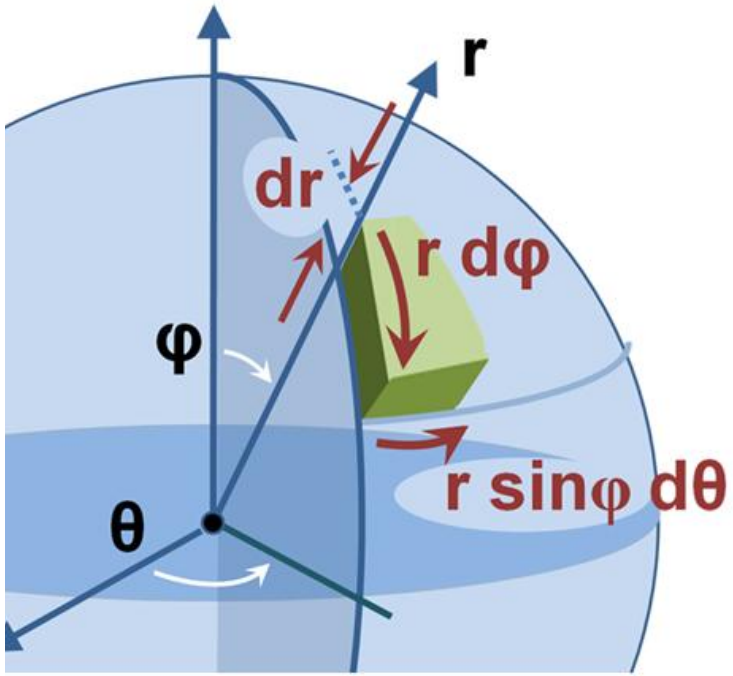
Geoneutrino Flux on Earth Surface

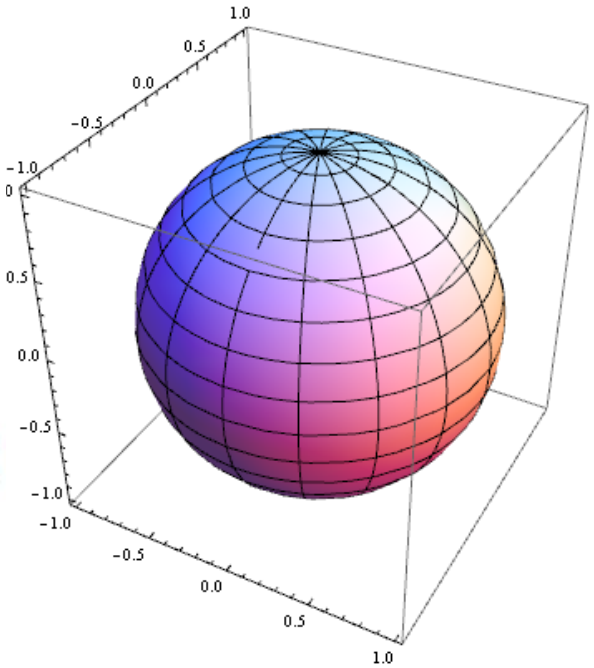


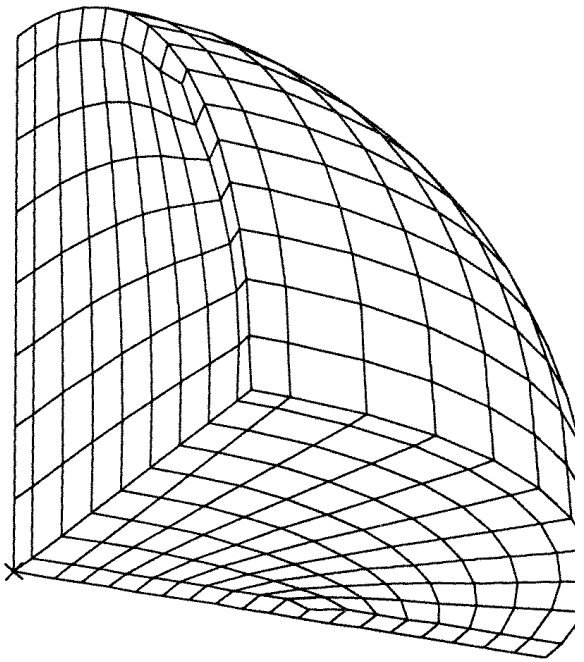
Earth structure (ρ and L) and **chemical composition** (a)

Constructing a 3-D reference model Earth

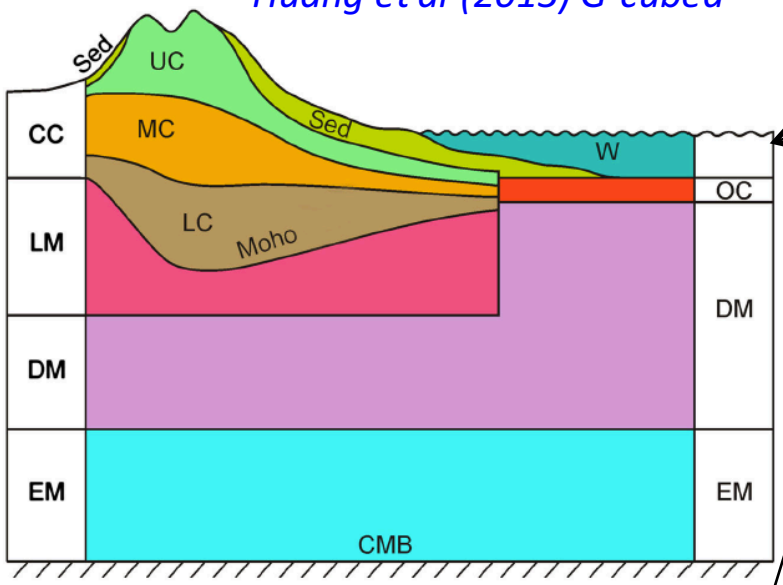
assigning chemical and physical states to Earth voxels





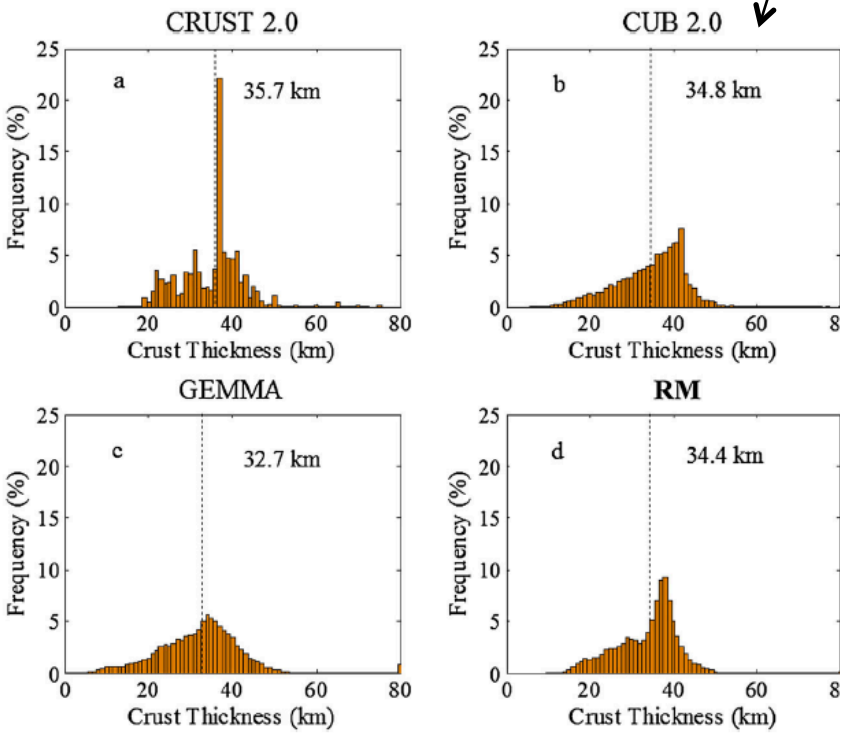


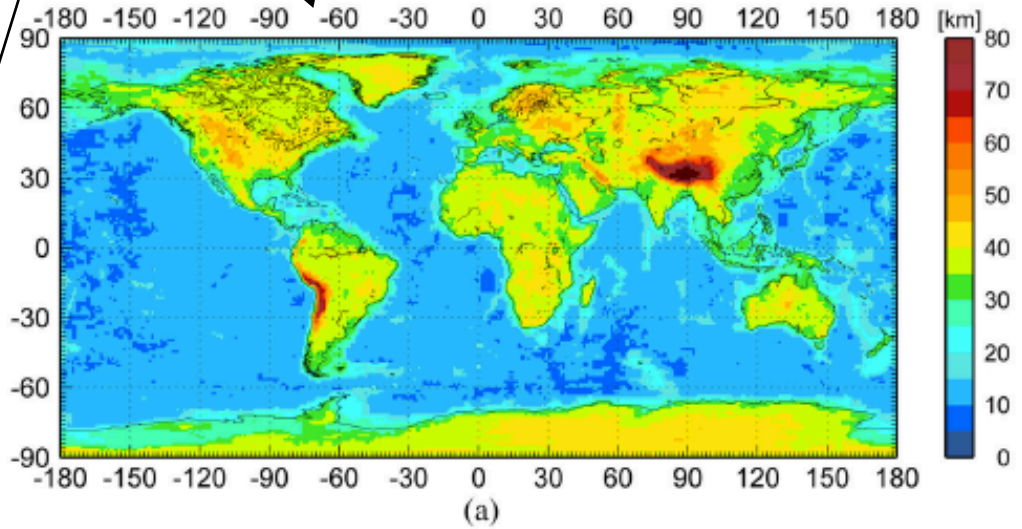
Huang et al (2013) G-cubed

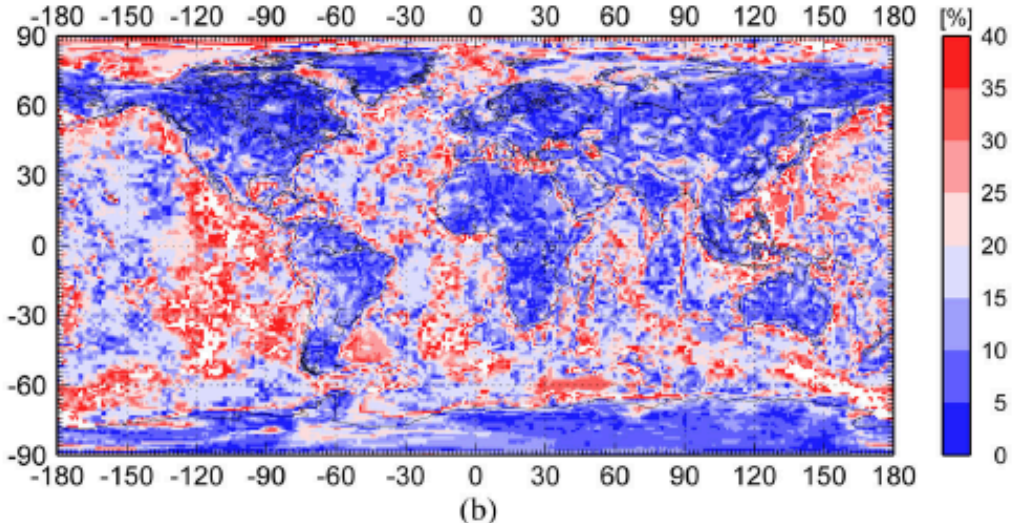


Global Earth Reference Model

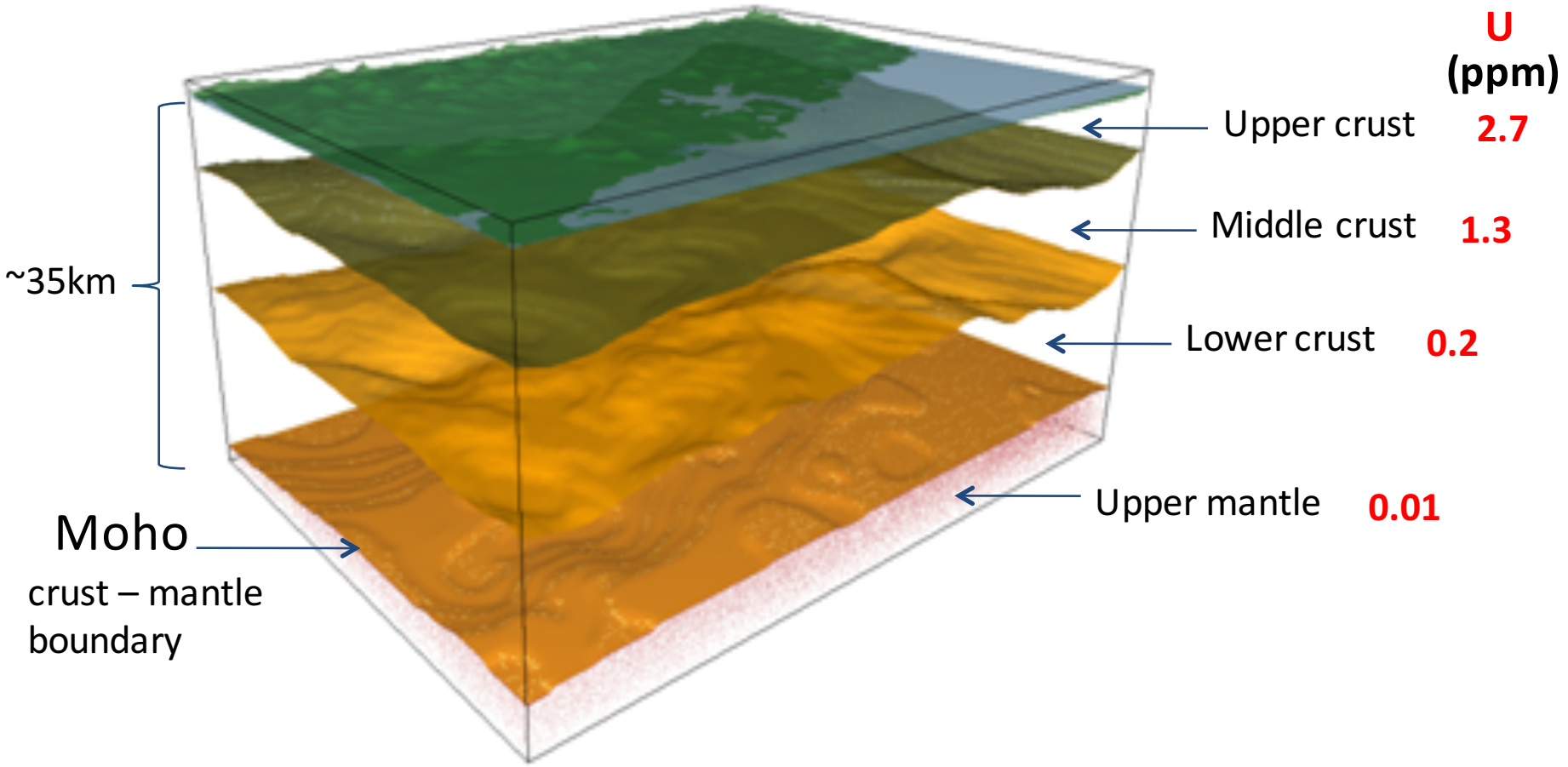
- 7 layers for the top 200 km
- Integrate 3 global models for the crust
- New crust model with uncertainties





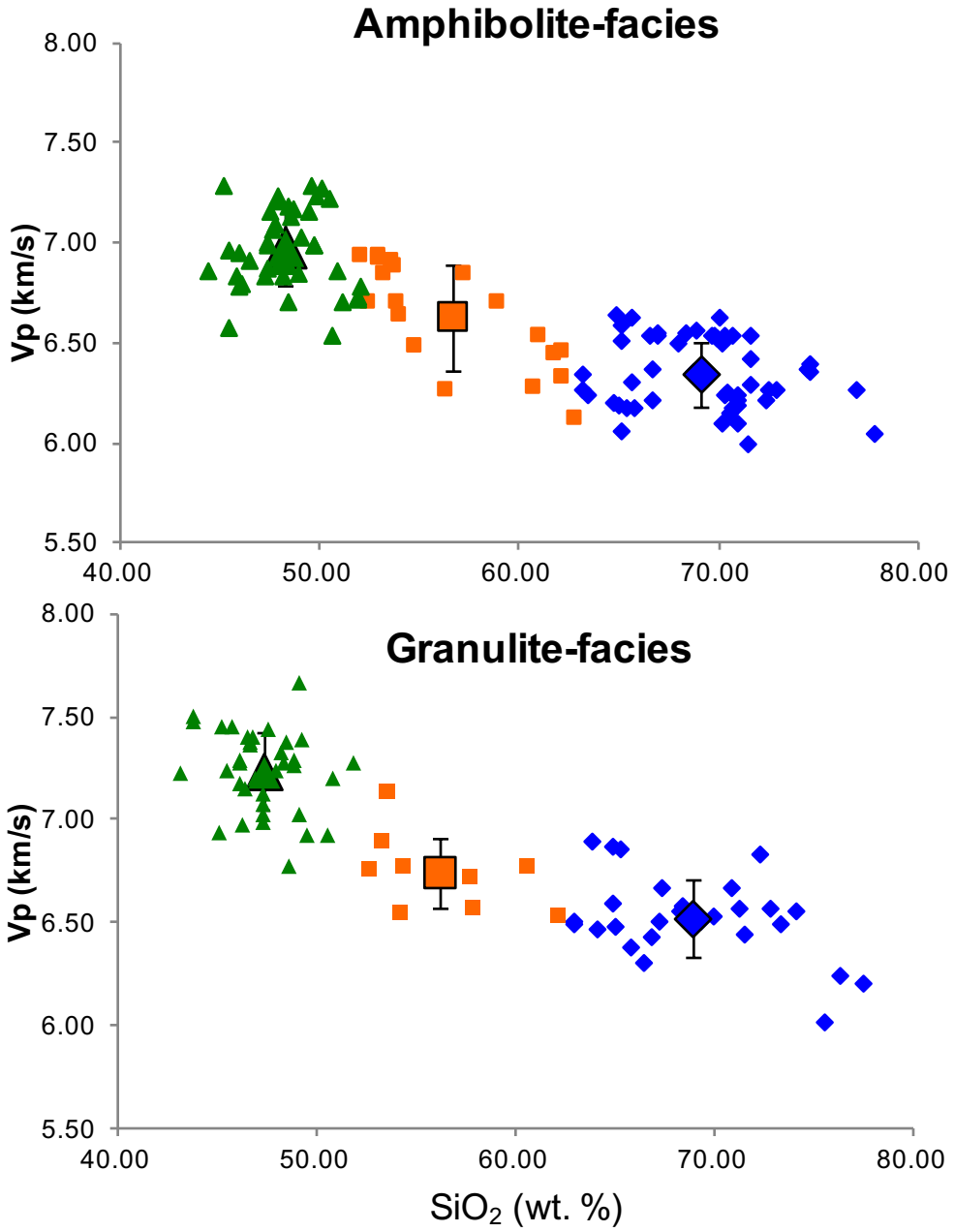


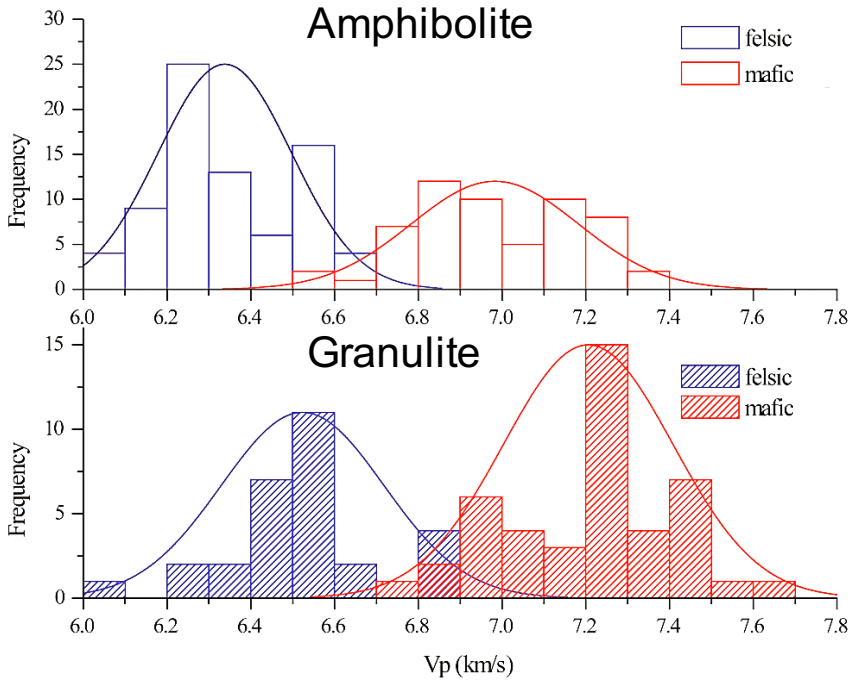
Geological model – Continental Crust



Surfaces of each layer is defined by geophysical data (i.e., gravity and seismic)

Seismic Velocities of Deep Crustal Rocks

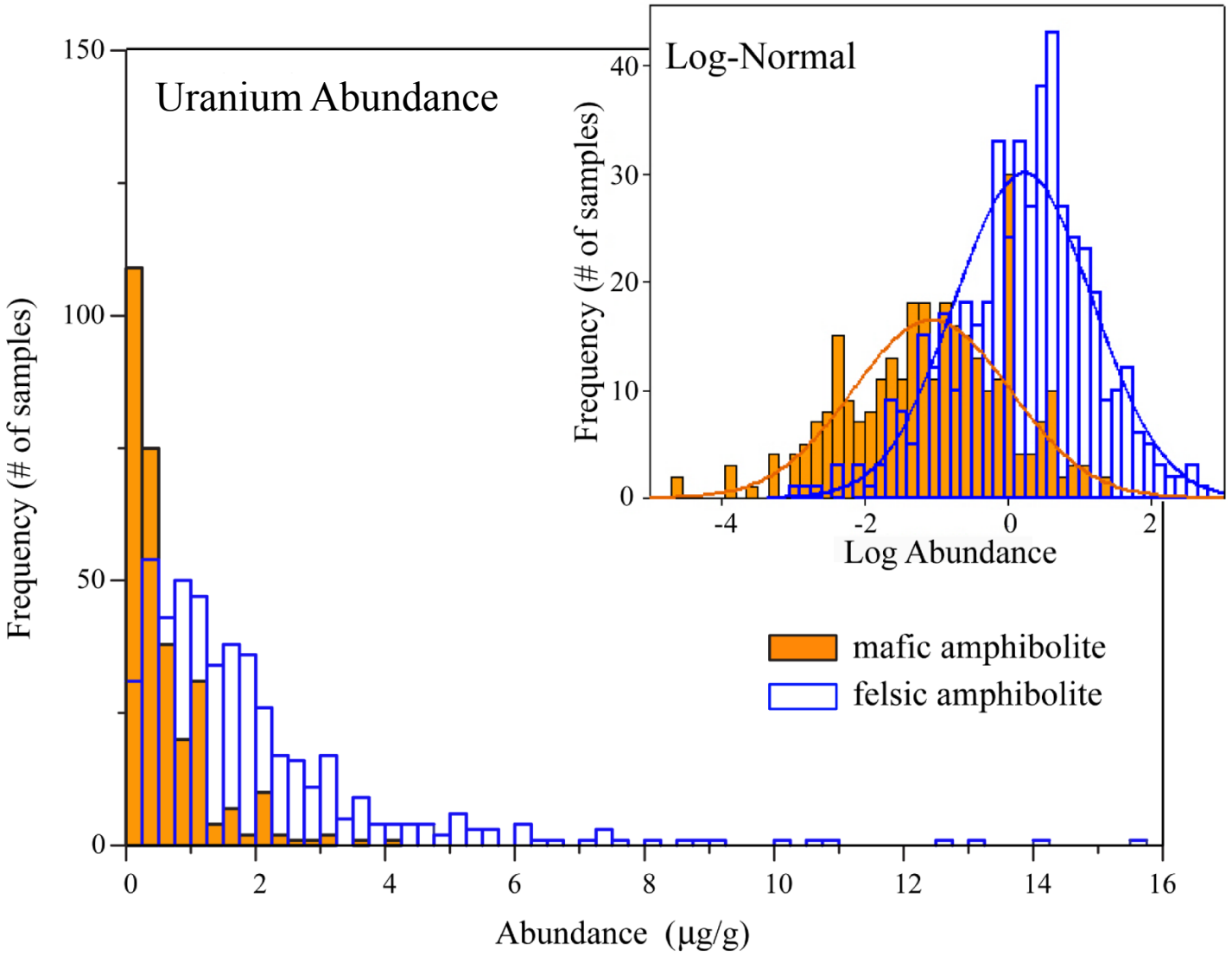




- ✓ Two components mixing in MC and LC: felsic and mafic
- ✓ Distinguishable by Vp (1-sigma)
- ✓ Close to linear relationship (Vp vs. SiO_2)

Composition of *Mafic* & *Felsic* Components

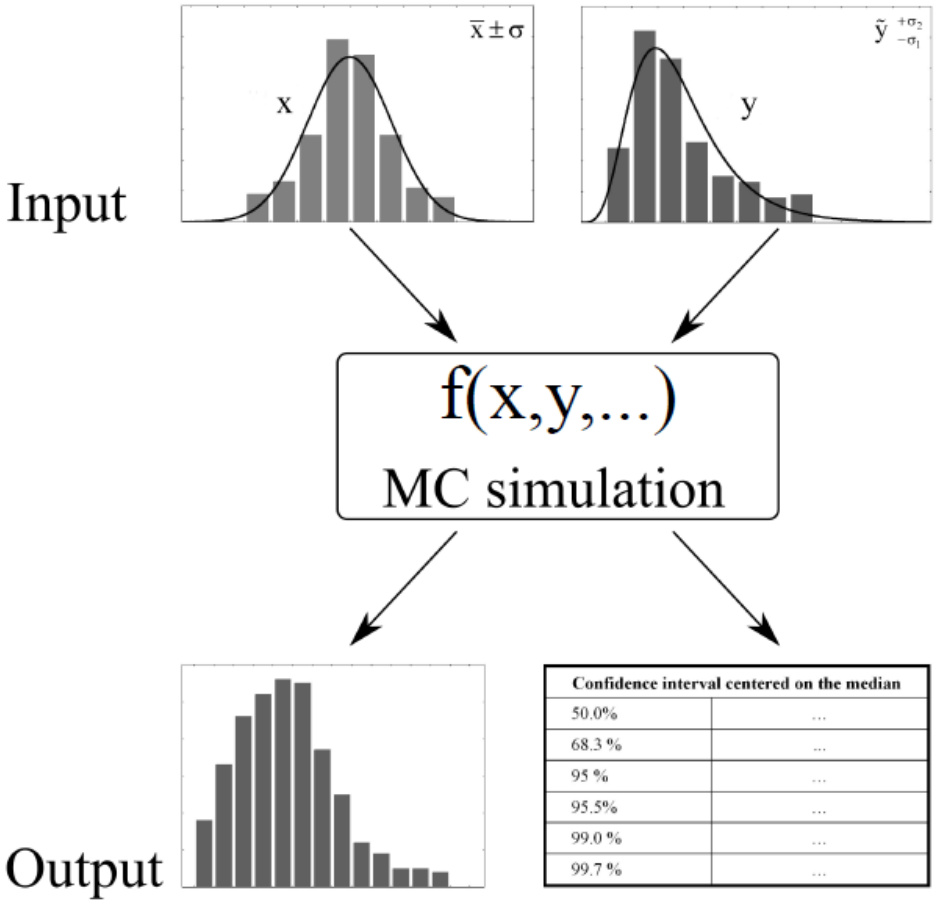
Non-Gaussian distributions



How to Track Uncertainty?

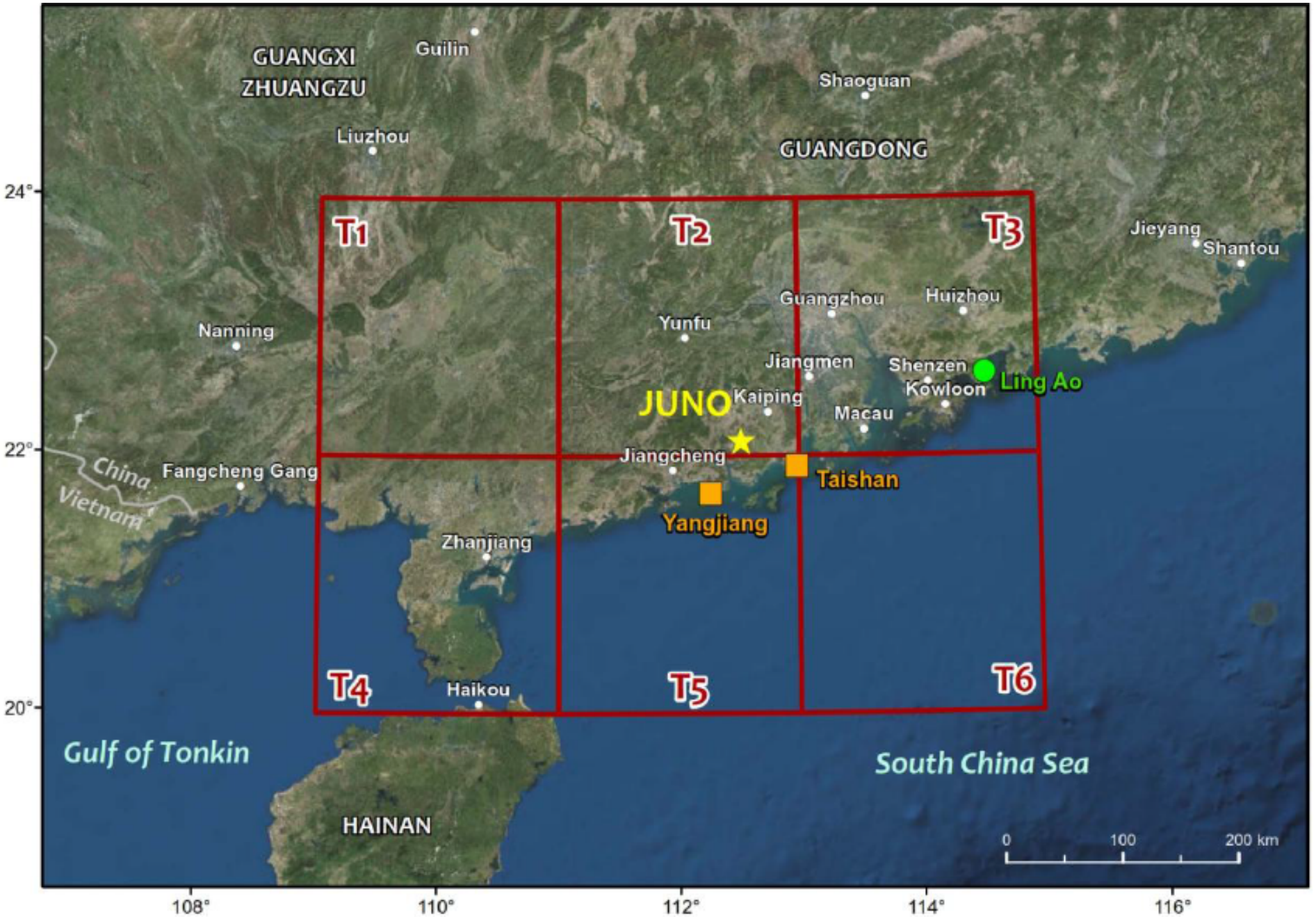
Monte Carlo simulation: highly desired for the propagation of asymmetric uncertainties

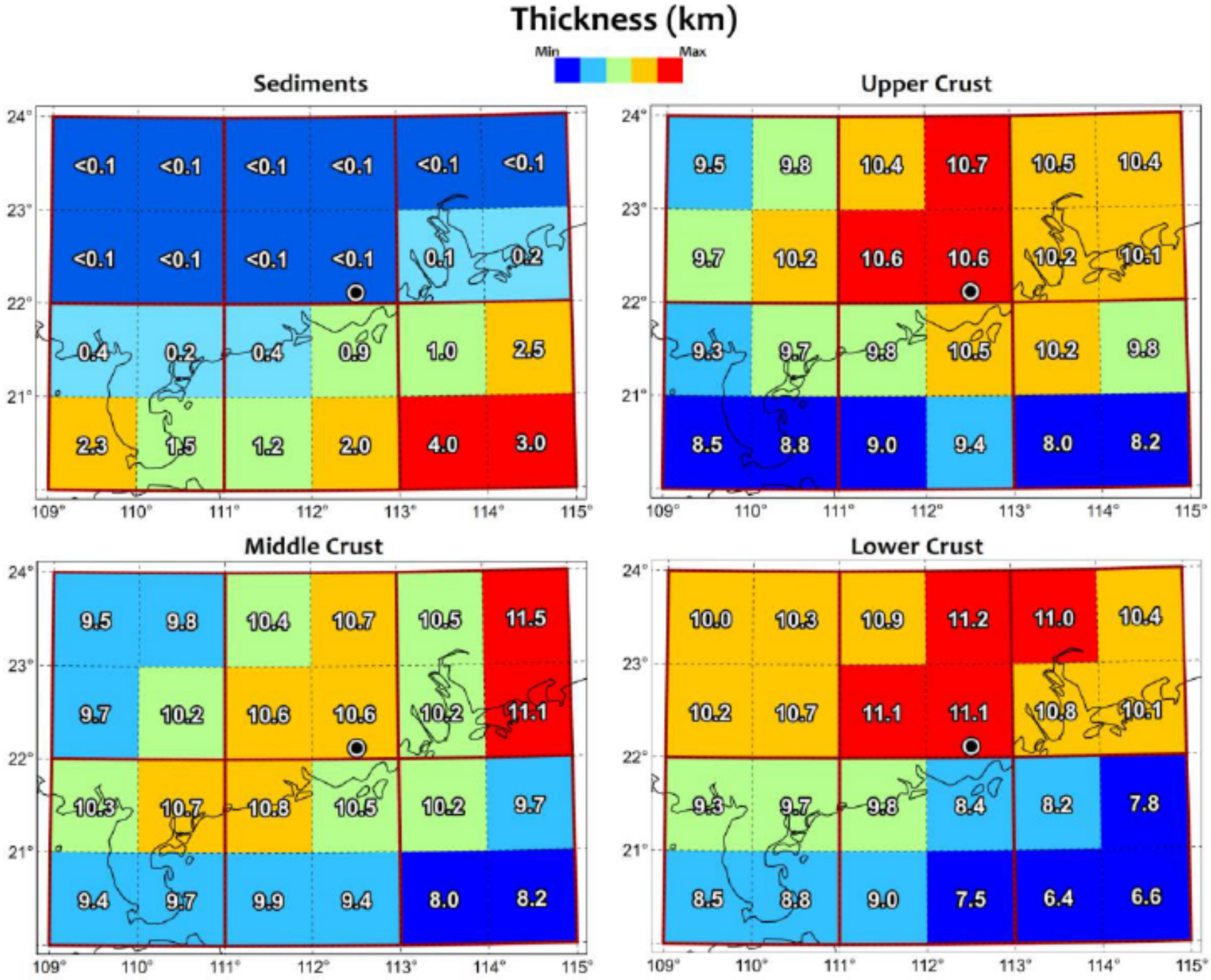
Requirement : the PDFs of all inputs are known



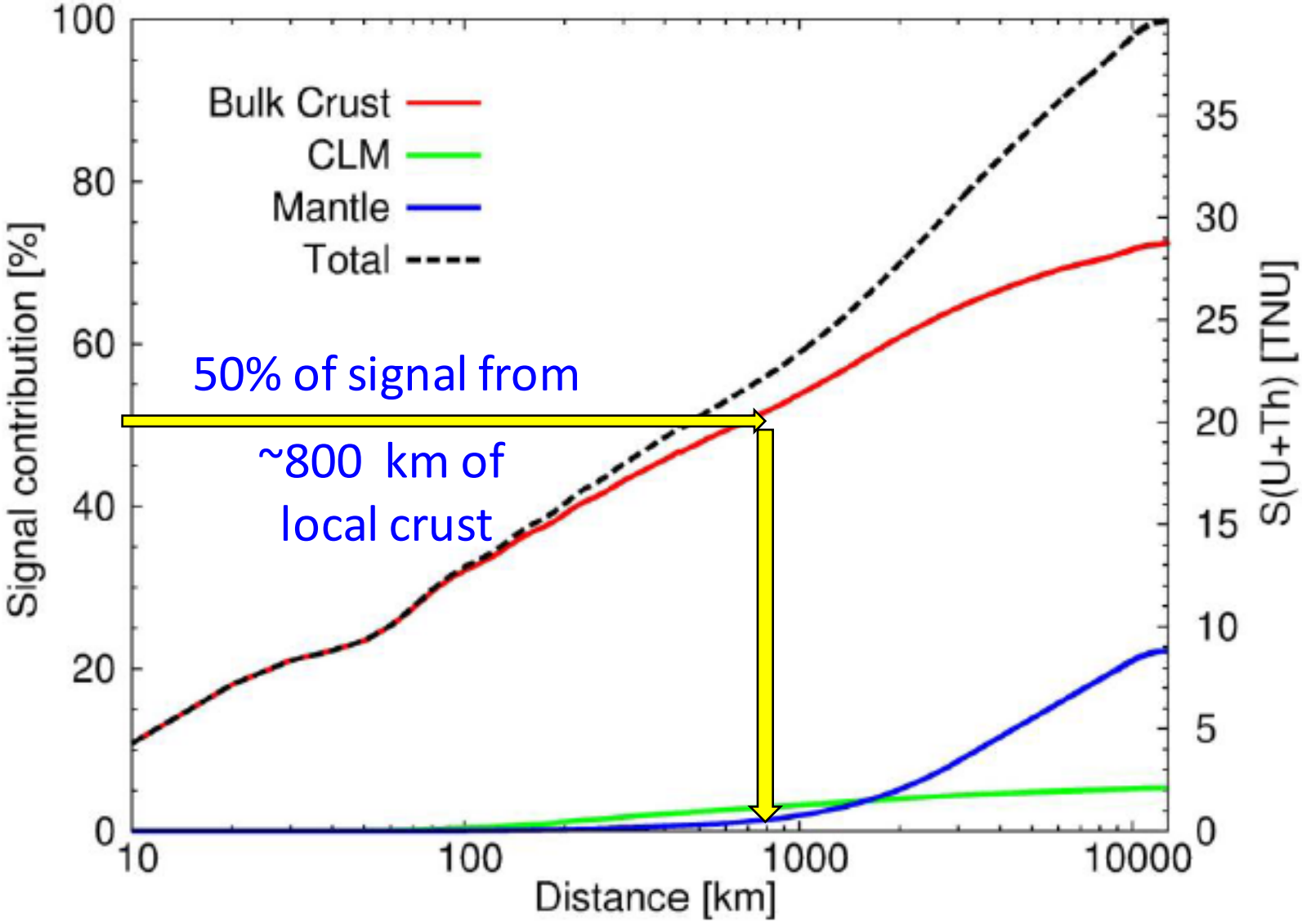
- ✓ Generate random samples for inputs, including correlation
- ✓ Calculate output variables
- ✓ Statistical analysis

Huang et al., 2013, under preparation


GUANGXI ZHUANGZU
Guilin
Liuzhou
Shaoguan
GUANGDONG
Jieyang
Shantou
T1
T2
T3
Nanning
Yunfu
Guangzhou
Huizhou
Jiangmen
Shenzen
Kowloon
Ling Ao
JUNO
Kaiping
Macau
Jiangcheng
Taishan
Yangjiang
China
Vietnam
Fangcheng Gang
Zhanjiang
T4
Haikou
T5
T6
Gulf of Tonkin
South China Sea
HAINAN
0
100
200 km
24°
22°
20°
108°
110°
112°
114°
116°


Thickness (km)
Min
Max
Sediments
<0.1 <0.1 <0.1 <0.1 <0.1 <0.1
<0.1 <0.1 <0.1 <0.1 0.1 0.2
0.4 0.2 0.4 0.9 1.0 2.5
2.3 1.5 1.2 2.0 4.0 3.0
Upper Crust
9.5 9.8 10.4 10.7 10.5 10.4
9.7 10.2 10.6 10.6 10.2 10.1
9.3 9.7 9.8 10.5 10.2 9.8
8.5 8.8 9.0 9.4 8.0 8.2
Middle Crust
9.5 9.8 10.4 10.7 10.5 11.5
9.7 10.2 10.6 10.6 10.2 11.1
10.3 10.7 10.8 10.5 10.2 9.7
9.4 9.7 9.9 9.4 8.0 8.2
Lower Crust
10.0 10.3 10.9 11.2 11.0 10.4
10.2 10.7 11.1 11.1 10.8 10.1
9.3 9.7 9.8 8.4 8.2 7.8
8.5 8.8 9.0 7.5 6.4 6.6
24°
23°
22°
21°
109° 110° 111° 112° 113° 114° 115°

JUNO : the signal



JUNO : the signal

	S [TNU]
Local contribution	$17.4^{+3.3}_{-2.8}$
Far Field Crust	$13.4^{+3.3}_{-2.4}$
Mantle	8.8
Gran total geoneutrinos	$39.7^{+6.5}_{-5.2}$
Reactors OFF	$26.0^{+2.2}_{-2.3}$
Reactors ON	354^{+45}_{-41}

role for Chinese geologists

big goal for geology

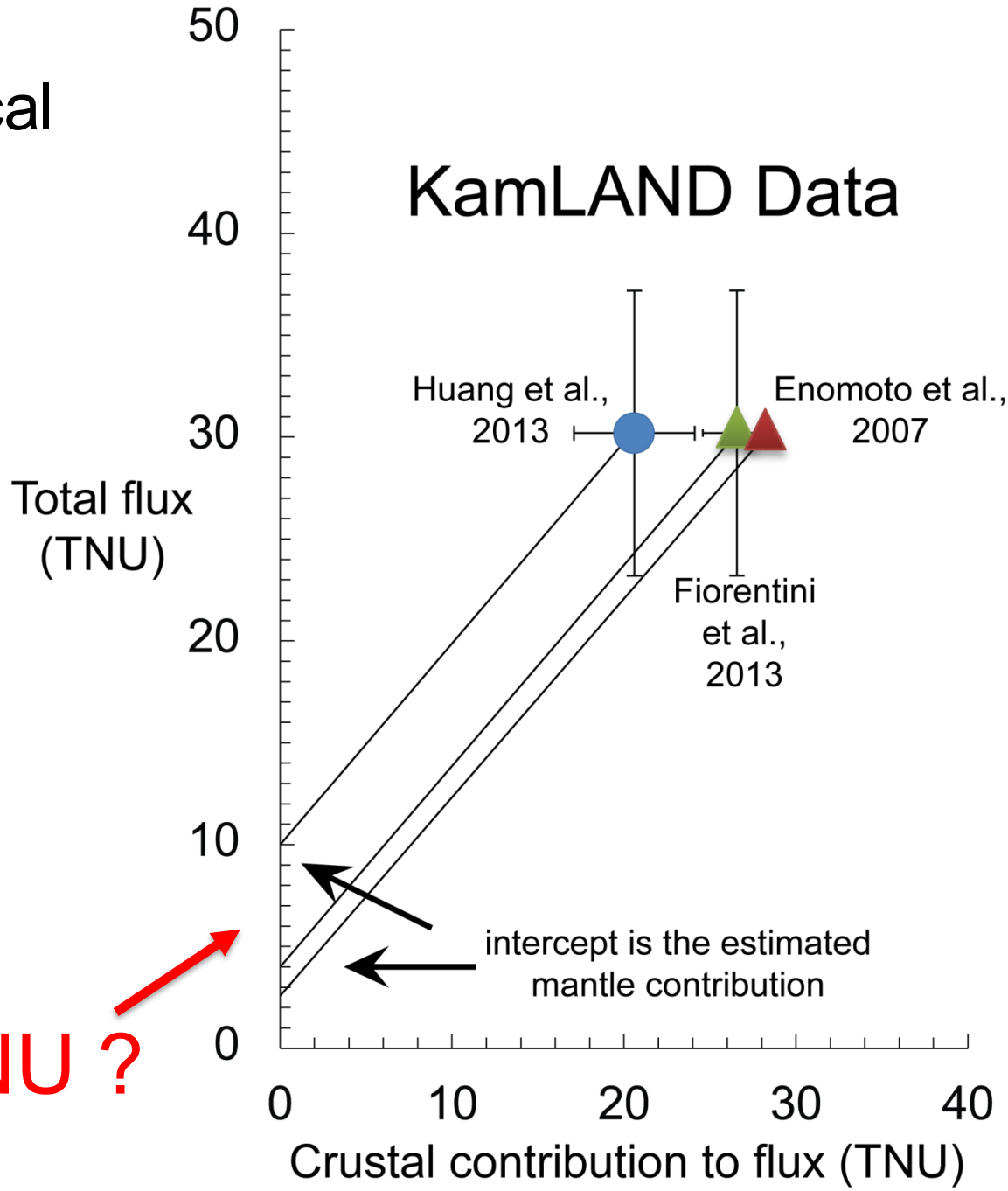
LARGE reactor signal

Different Geological models

Y-axis data is strictly from physics

X-axis data is strictly from geology

Intercept is mantle contribution



2, 4 and 10 TNU ?

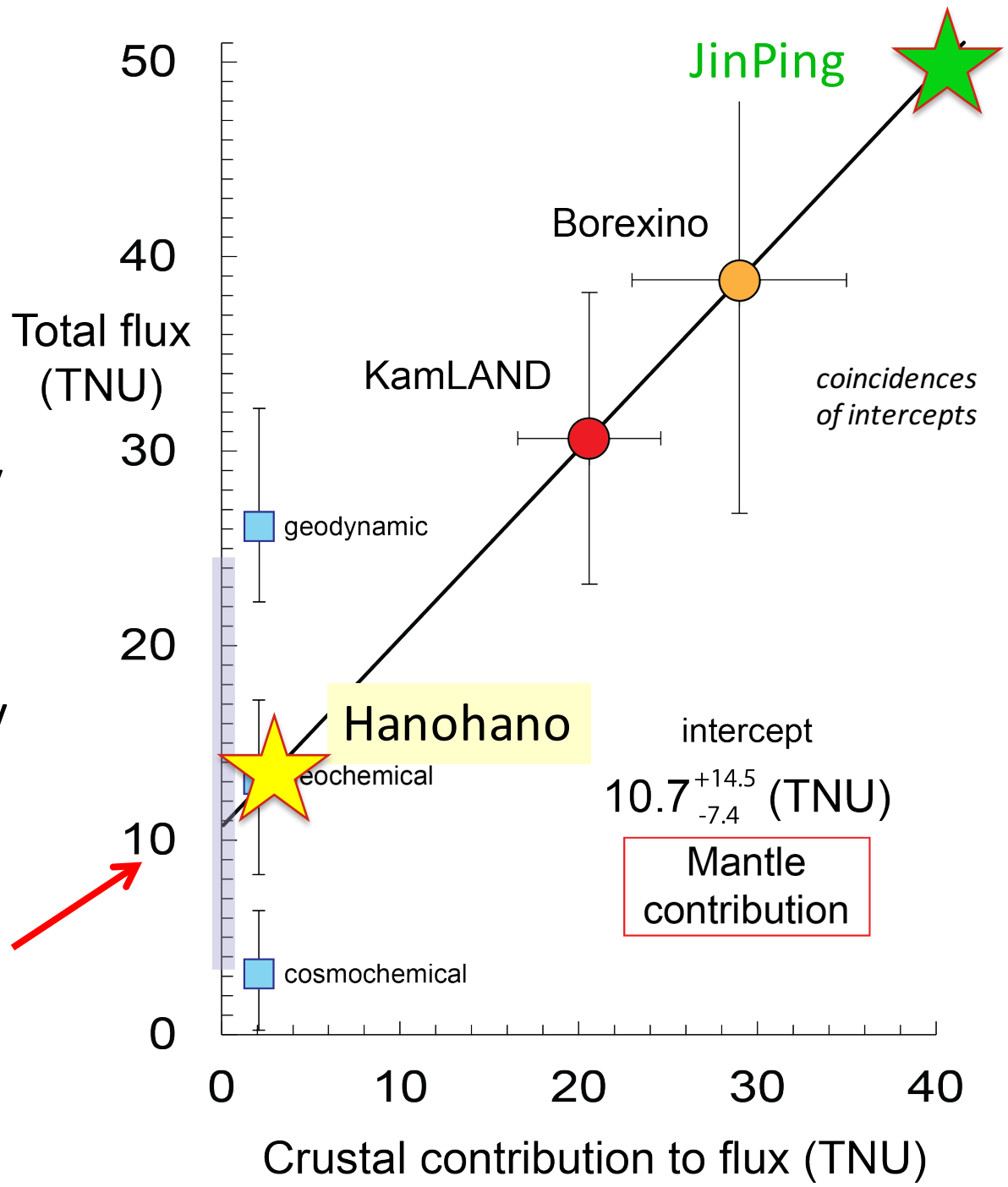
Existing data

squeezing @ limit

Y-axis data is strictly from physics

X-axis data is strictly from geology

Intercept is mantle contribution



SUMMARY

Earth's radiogenic (Th & U) power

28^{+24}_{-17} TW - Borexino $11.2^{+7.9}_{-5.1}$ TW – KamLAND

Prediction: models range from 8 to 28 TW (for Th & U)

Borexino: **MANTLE signal** 21^{+15}_{-10} TNU (~14 TW)

On-line and next generation GEO-NEUTRINO experiments:

- **SNO+** online 2017 ☺
- **JUNO**: 2020, enormous detector & background…
- **Jinping**: 202X, superb experiment, great for crust & mantle
- **Hanohano**: this is how to look at the mantle-only

IMPORTANT CONSIDERATIONS: **WbLS and directionality**