GIGJ: a crustal gravity model for predicting the geoneutrino signal at the JUNO experiment

Marica Baldoncini
Fabio Mantovani
Virginia Strati

Frascati, 15 March 2018

Outline

GIGJ: a crustal gravity model of the Guangdong Province for predicting the geoneutrino signal at the JUNO experiment

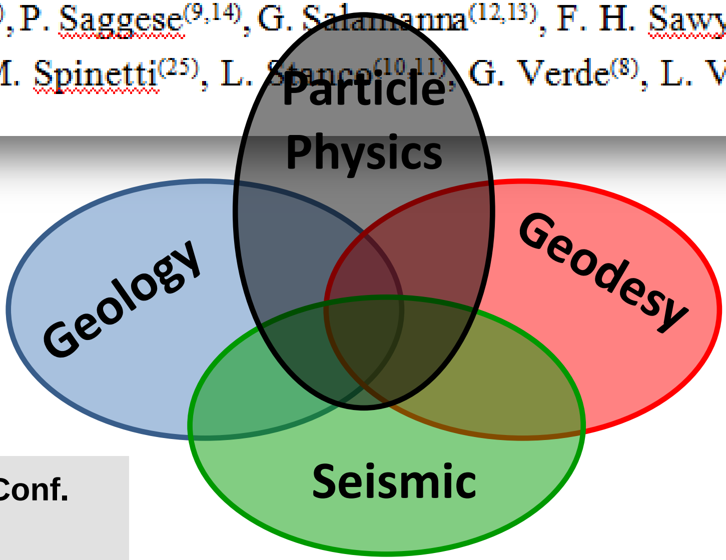
L. Rossi[1], M. Reguzzoni[1,3,6], M. Baldoncini[3,6], I. Callegari[4], P. Poli[7], D. Sampietro[7], V. Strati[3,5], F. Mantovani[3,5], G. Andronico[8], V. Antonelli[9], M. Bellato[10,11], E. Bernieri[12,13], A. Brigatti[9,14], R.
...3), M. Buscemi[8,15], S. Bussino[12,13], R. Caruso[8,15], D. Chiesa[16,17], D. Corti[11],
...ing[9,18], S. Dusini[10,11], A. Fabbri[12,13], G. Fiorentini[3,5], R. Ford[19,9], A.
...0,11), A. Garfagnini[10,11], M. Giammarchi[9,14], A. Giaz[10,11], M. Grassi[22], A.
...), I. Lippi[10,11], F. Longhitano[8], D. Lo Presti[8,15], P. Lombardi[9,14], Y.
...1), S. M. Mari[12,13], C. Martellini[12,13], E. Meroni[9,14], M. Mezzetto[11], L.
...e[8], M. Montuschi[3,5], M. Nastasi[16,17], F. Ortica[23,24], A. Paoloni[25], S.
...26,6), N. Pelliccia[23,24], R. Pompilio[9,14], E. Previtali[16,17], G. Ranucci[9,14], A. C.
...ni[23,24], P. Saggese[9,14], G. Salamanna[12,13], F. H. Sawy[10,11], G. Settanta[12,13],
...0,11), M. Spinetti[25], L. Stanco[10,11], G. Verde[8], L. Votano[25].

POLITECNICO DI MILANO
Department of Environmental and Civil Engineering
Doctoral programme in Environmental and Infrastructure Engineering

Bayesian gravity inversion by Monte Carlo methods

Doctoral dissertation by:
Lorenzo Rossi
820437

Supervisor:
Dr. Mirko Reguzzoni
Tutor:
Prof. Giovanna Venuti
The Chair of Doctoral programme:
Prof. Alberto Guadagnini



"Geoneutrino" is an interdisciplinary topic

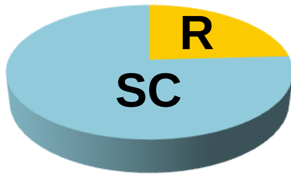
Lorenzo talk @ European Geophysical Union Conf.
Vienna - Austria (8 - 13 April 18)

How much uranium is in the Earth?

- **What is the radiogenic contribution to the heat flux?**

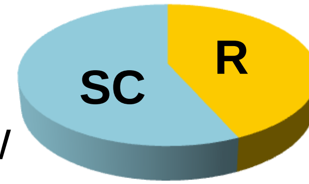
BULK SILICATE EARTH MODELS:

COSMOCHEMICAL MODEL



M_U = 5 x10^{16} kg
Radiogenic = **11 TW**
Secular **C**ooling ~ 36 W

GEOCHEMICAL MODEL



M_U = 8 x10^{16} kg
Radiogenic = **20 TW**
Secular **C**ooling ~ 27 W

- **Which are the building blocks (chondritic meteorites) of our planet?**

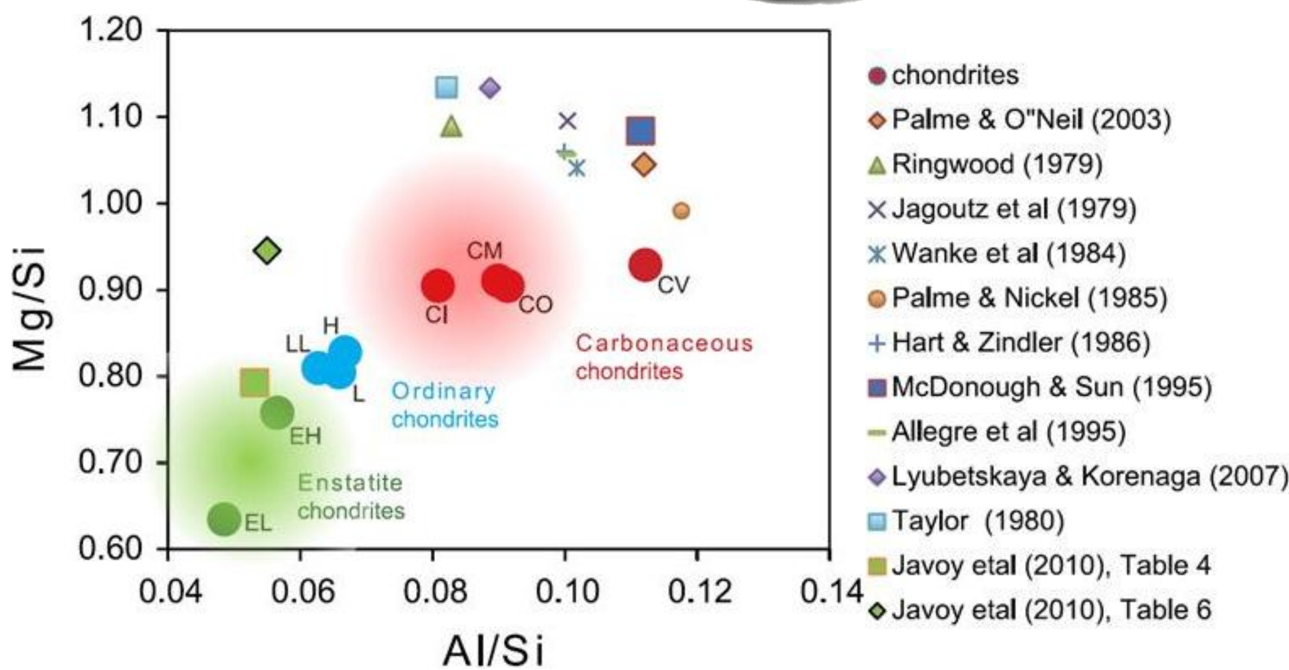
Enstatites Chondrites

A_U = 12 ppb
Th/U = 3.6

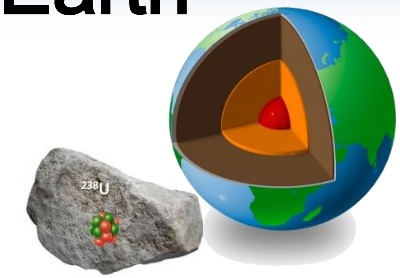
Carbonaceous Chondrites

A_U = 20 ppb
Th/U = 4

- **What kind of mechanical and thermal processes affected the early stages of the Earth formation?**



Geoneutrino: antineutrino from the Earth



U, Th and ^{40}K in the Earth release heat together with anti-neutrinos, in a well fixed ratio:

	Type of decays	$T_{1/2}$ [Gyr]	ε_ν [$kg^{-1}s^{-1}$]	Q [MeV]	ε_H [μW/kg]
^{238}U	α, β, βγ	4.5	7.46×10^7	51.7	95
^{232}Th	α, β, βγ	14.0	1.62×10^7	42.7	27
^{40}K	βγ (89%)	1.3	2.32×10^8	1.3	22

- Earth emits (mainly) antineutrinos $(\phi_{\bar{\nu}} \sim 10^6 \, cm^{-2} s^{-1})$ whereas Sun shines in neutrinos.

- A fraction of geo-neutrinos from U and Th (not from ^{40}K) are above threshold for inverse β on protons: $\bar{\nu} + p \rightarrow e^+ + n - 1.8 \text{ MeV}$

- Different components can be distinguished due to different energy spectra (e.g. anti-n with highest energy are from Uranium)

Geoneutrinos: a probe for investigating the deep Earth

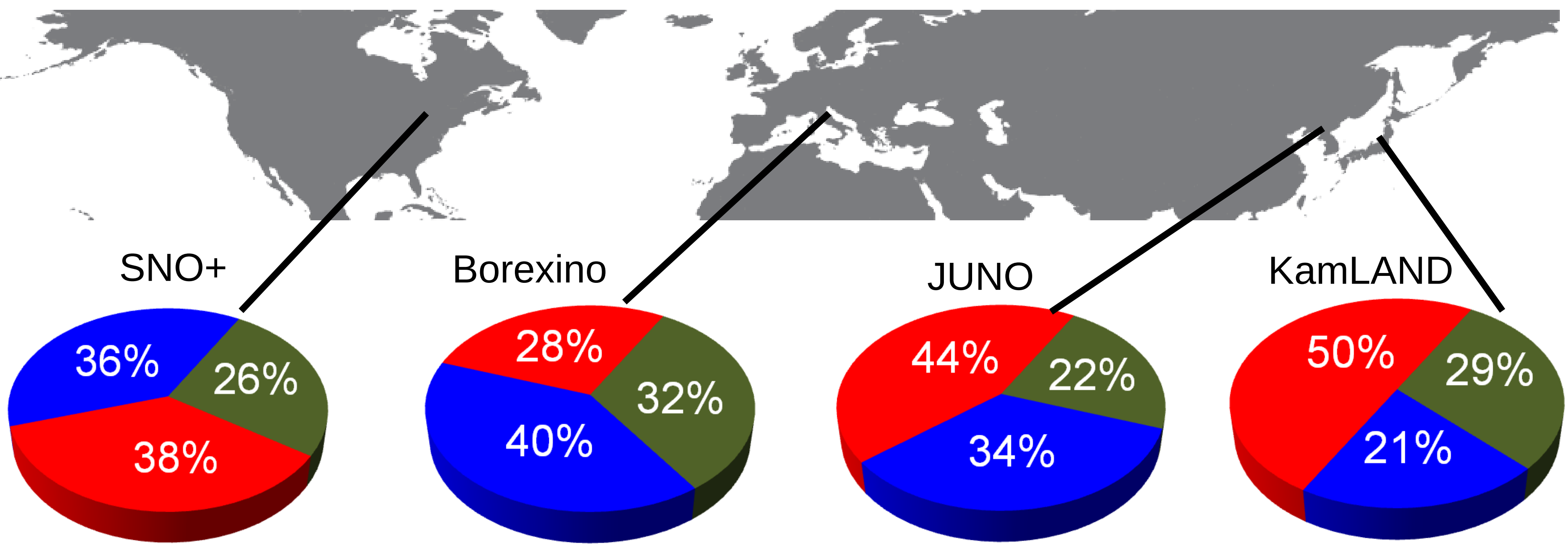
With a direct measurement of mantle radioactivity we can…

- estimate the radiogenic heat power
- exclude some BSE models
- understand the early stages of Earth formation

$$S_{EXP} = (S_{LOC} + S_{FFC}) + S_{Mantle}$$

S_{EXP} = experimental signals from KamLAND, Borexino, SNO+, JUNO

S_{LOC} + **S_{FFC}** = signals from local and far field crust estimated using geophysical and geochemical direct measurements



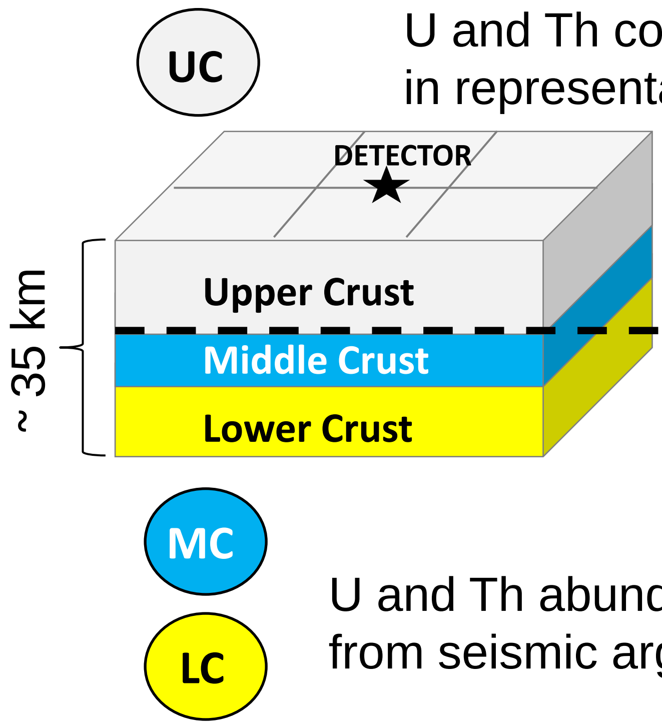
Calculation of geoneutrino flux and signal

The geoneutrino flux

$$\Phi(X) = \frac{\varepsilon_{\bar{\nu}_X}}{4\pi}\int_V \frac{\rho(\vec{r}')\,a_X(\vec{r}')}{\left|\vec{R}-\vec{r}'\right|^2}\,d\vec{r}'$$

Depends on X abundance, rock density, the number of antineutrinos per unit mass and inverse square distance of rocky reservoir

The signal (event rate in a detector) is expressed in Terrestrial Neutrino Unit (TNU), defined as one event per 10^{32} target nuclei per year.



U and Th content measured in representative samples

Literature data, geological maps and interpreted seismic profiles

$\Phi\,(a\;;\;\rho\;;\;dV)$

U and Th abundances inferred from seismic arguments

Estimations from seismic velocities and other geophysical data

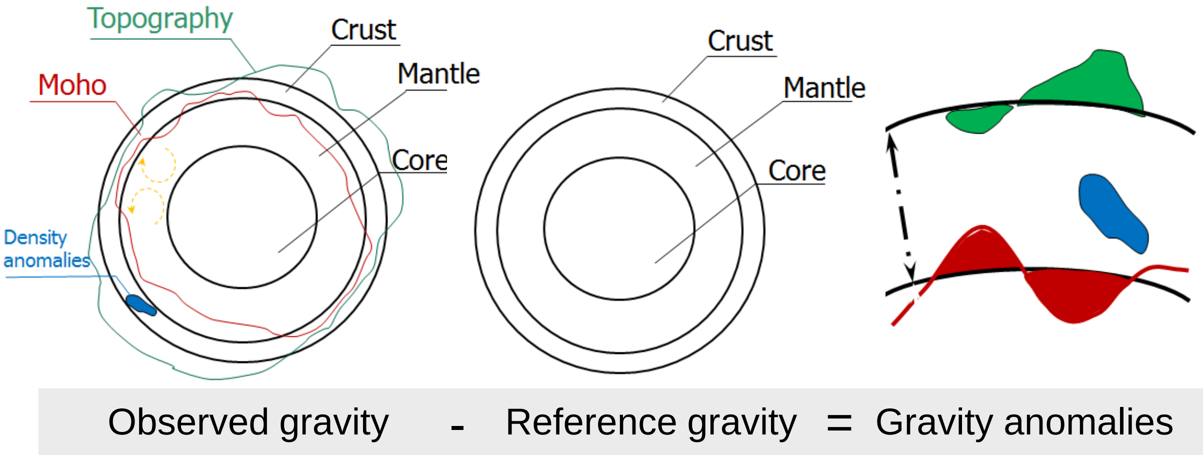
Geochemical uncertainties > 15%

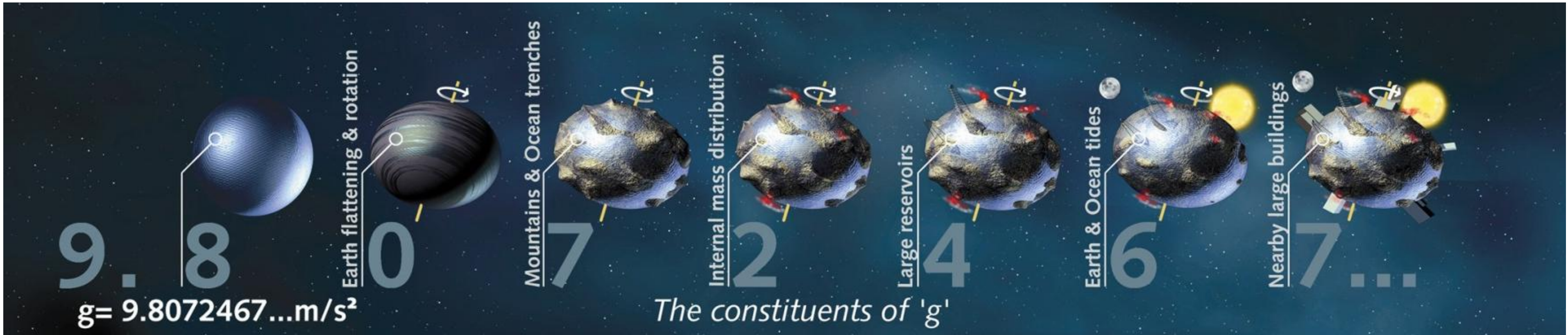
Geophysical uncertainties < 5%

A few pills on gravimetry

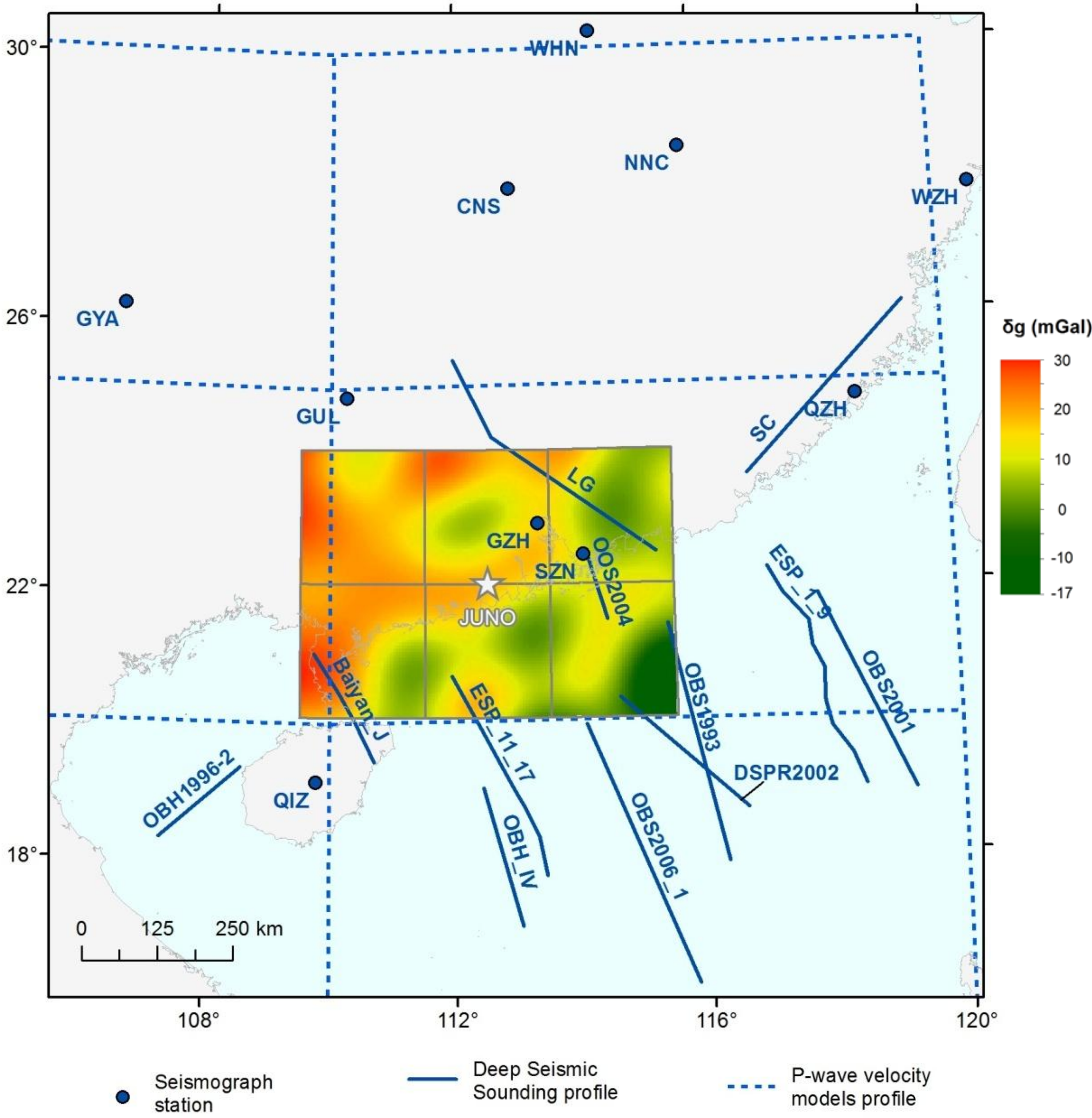
- Measuring the Earth's gravitational field from the ESA GOCE satellite benefits from:
  - ✓ high **observation accuracy**
  - ✓ **homogeneous** data distribution
  - ✓ good **spatial resolution**

- Gravimetric inversion solves for **anomalies** δg (1 mGal = 10^{-5} m/s^2) with respect to a reference Earth signal





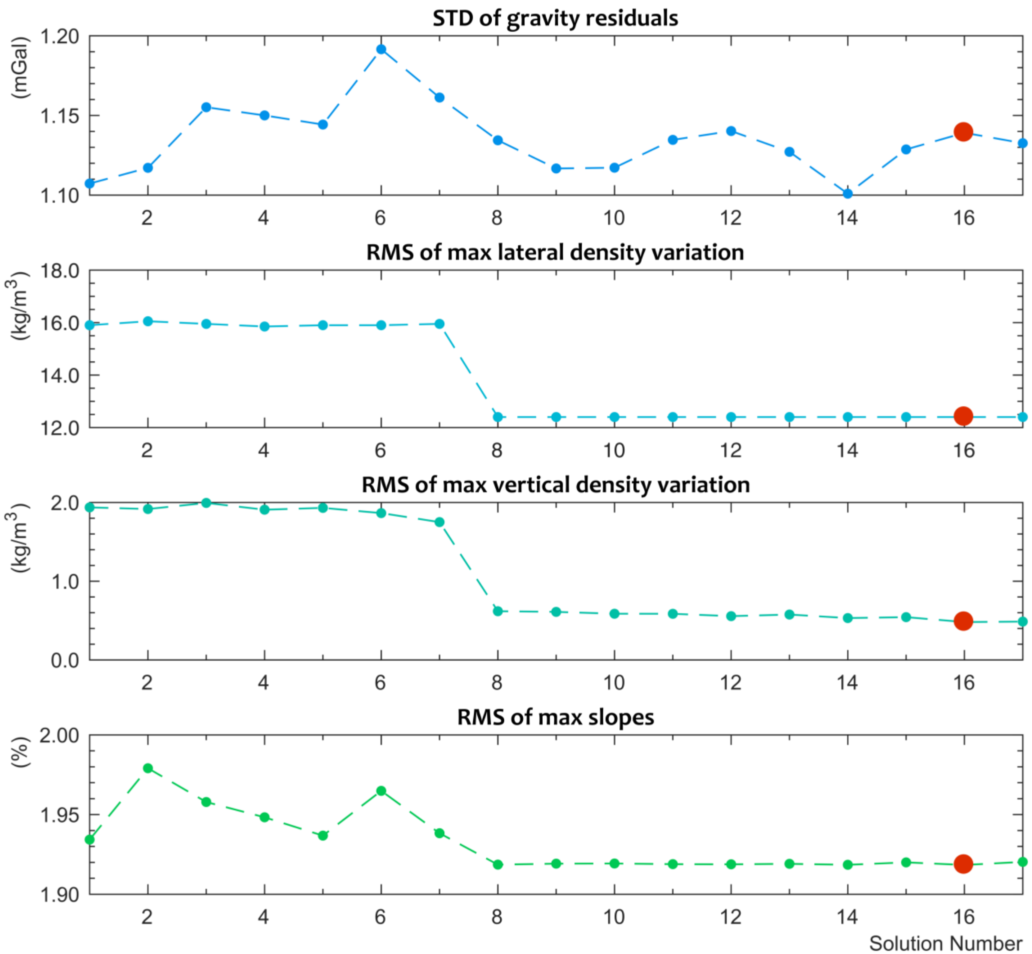
Gravimetry is dumb without seismic!

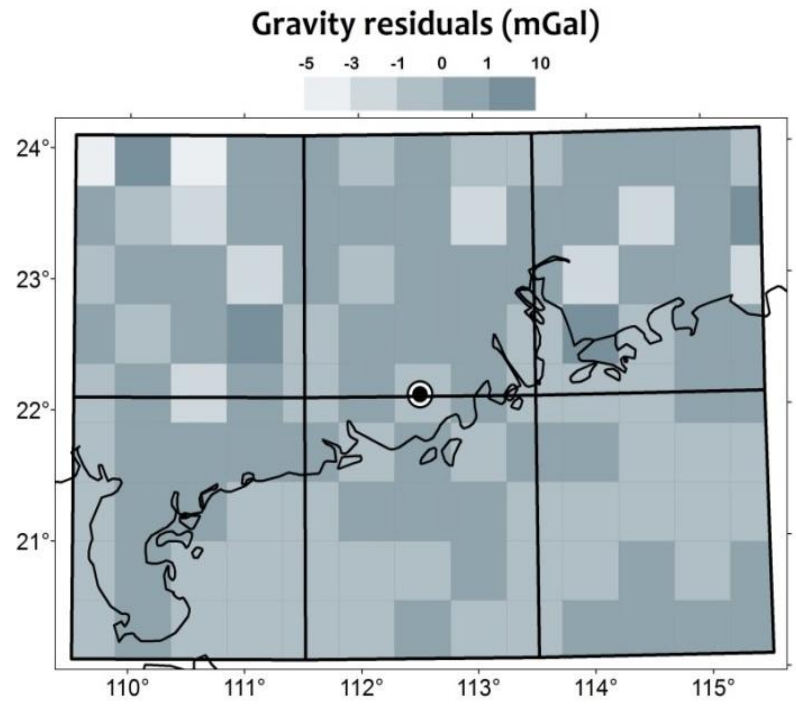


- Gravimetric inversion is generally an **ill-posed** problem having **non-unique** solution
- Gravimetric inversion needs an **a-priori model**, including a fixed sedimentary layer and **seismic data** combined according to their **accuracy** and **spatial resolution**
- Heterogeneous information from 2D and 1D seismic data, together with Moho depth maps are wisely integrated in a **unique** and **coherent** a priori geological model

The GIGJ (GOCE Inversion for Geoneutrinos at JUNO) model

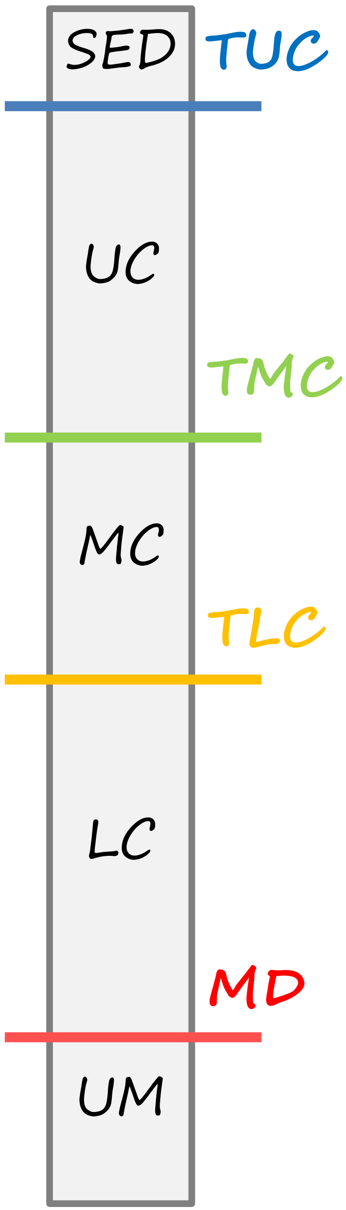
- GIGJ is a **3D numerical model** made up of **2688 voxels** of 50 km × 50 km × 0.1 km
- GIGJ fits GOCE gravity data with a 1.13 mGal standard deviation of the residuals, compatible with the observation accuracy

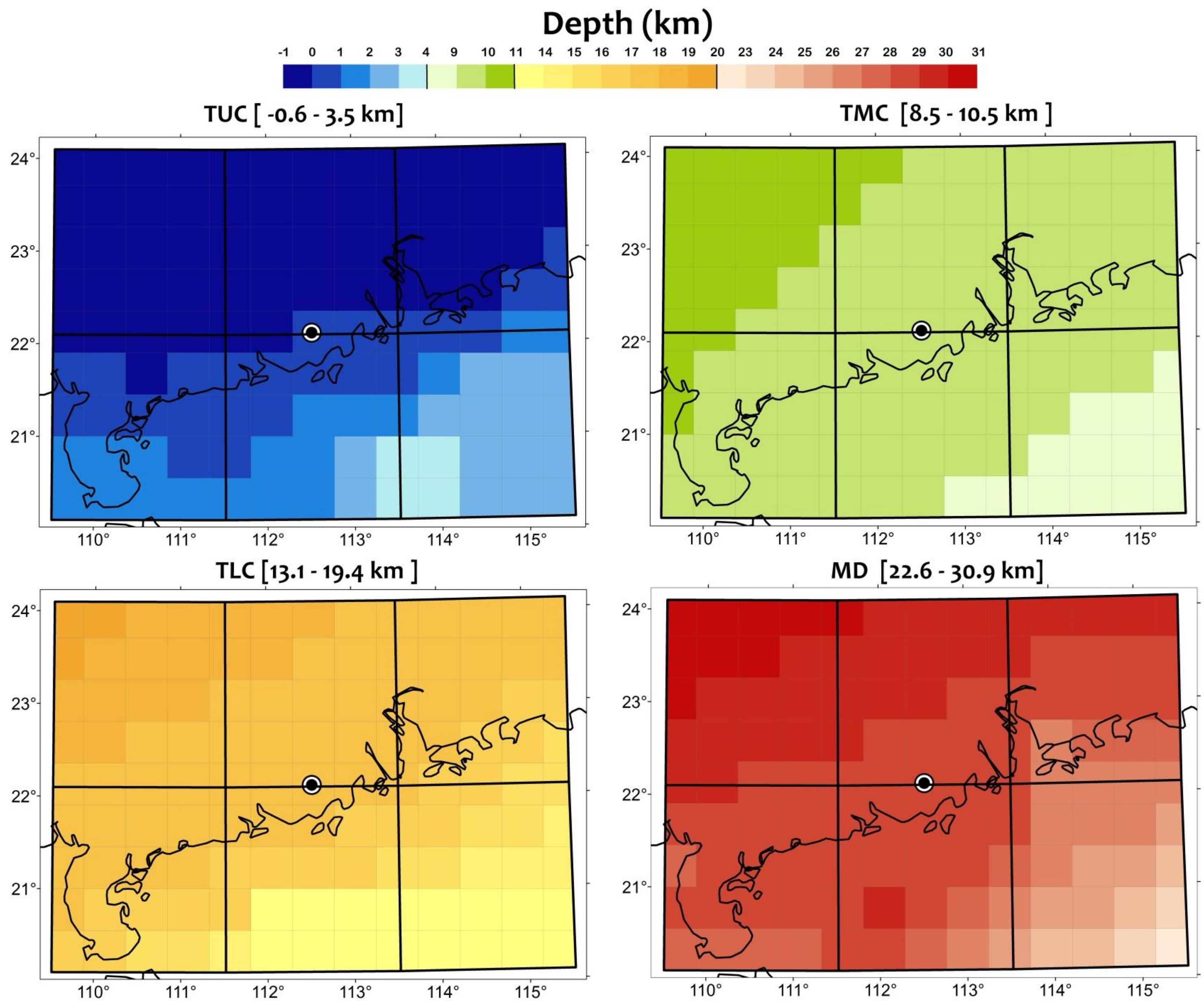




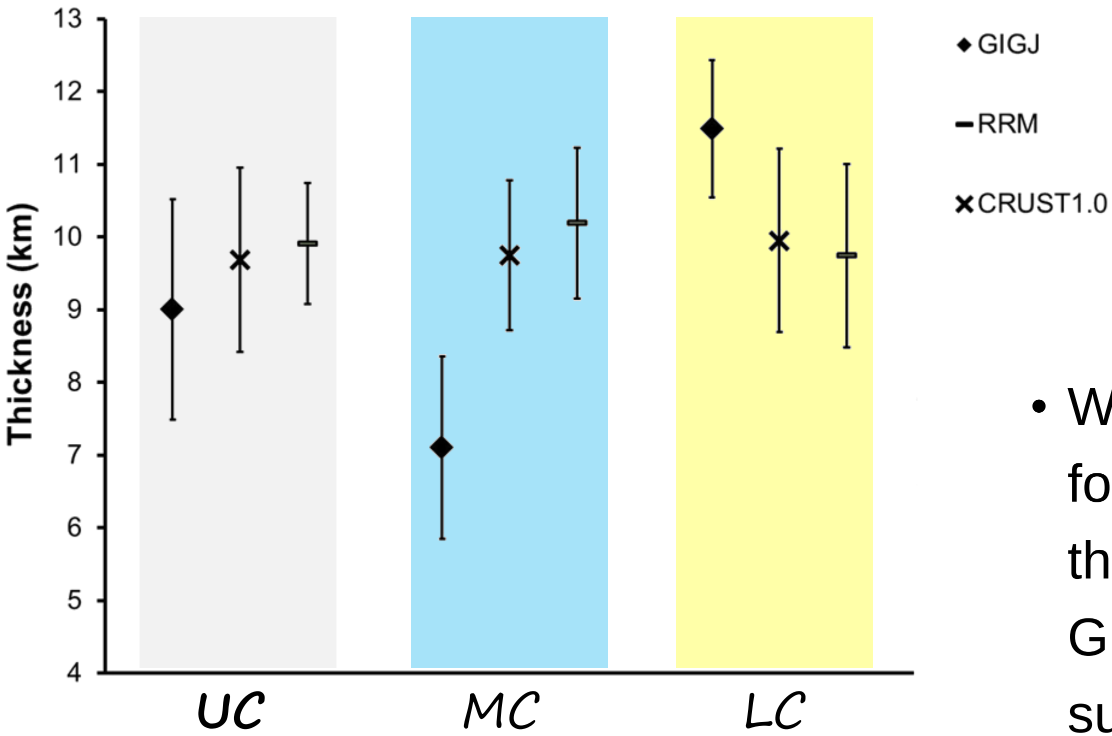
- The applied **Bayesian method** allows for fitting gravimetric observations integrating at the same time **local prior distribution** with **regularization conditions** (density and geometry smoothness)

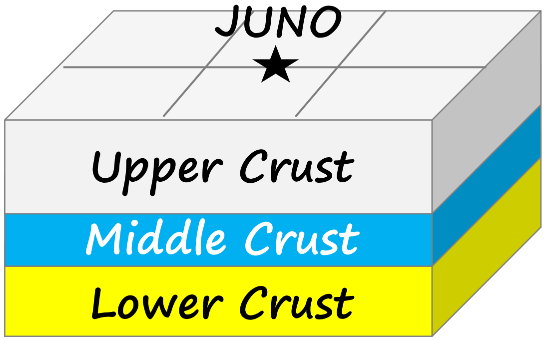
Depth maps of the geophysical discontinuities





GIGJ improves the definition of the crustal layers





- While global crustal models report for UC, MC and LC an equal thickness (33% of the total crust) GIGJ provides a site-specific subdivision of the crust

- Mass uncertainties include estimation errors, associated to the solution of the inverse gravimetric problem, and systematic uncertainties, due to the adoption of fixed sediments

	Mass (10^{16} kg)
UC	697.8 ± 2.2 (± 13.5)
MC	585.0 ± 15.9 (± 0.8)
LC	1001.2 ± 9.3 (± 0.7)

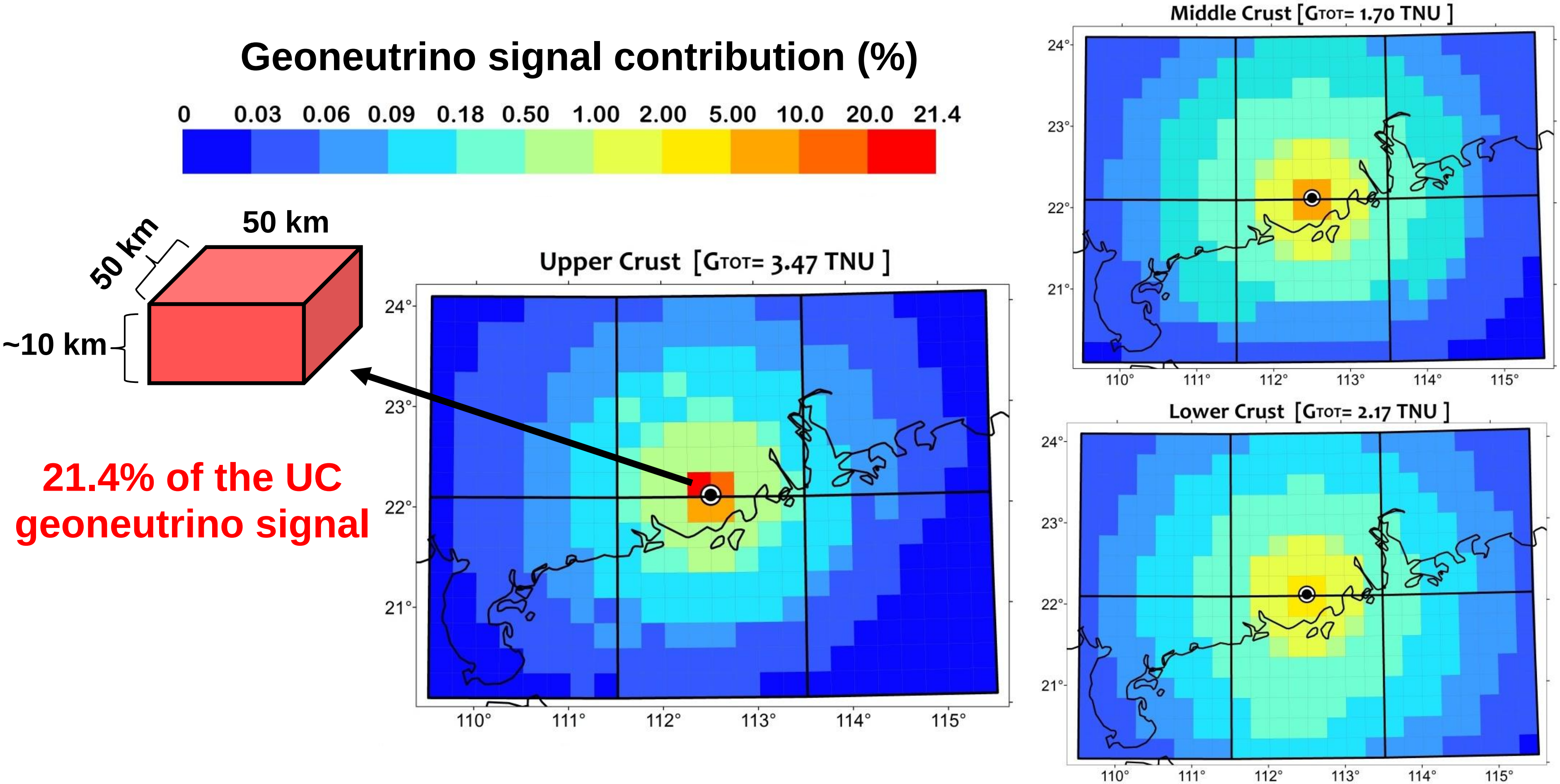
Results of geoneutrino signal calculation

	GIGJ (2018)	**CRUST1.0 (2014)**	**RRM (2013)**
	G_{TOT} (TNU)	G_{TOT} (TNU)	G_{TOT} (TNU)
UC	3.47 ± 0.08	3.56	3.72 ± 0.22
MC	1.70 ± 0.05	2.09	2.20 ± 0.11
LC	2.17 ± 0.02	1.73	1.77 ± 0.09

$\mathbf{G_{TOT}}$ = geoneutrino signal in TNU expected at JUNO produced by U and Th abundances (1µg/g) distributed in UC, MC e LC.

- We predicted a **reduction** (~21%) and an **increase** (~24%) of the **MC** and **LC** signal respectively.
- The main outcome of this study is the 63%, 55% and 78% reduction of the UC, MC and LC **signal uncertainty**.

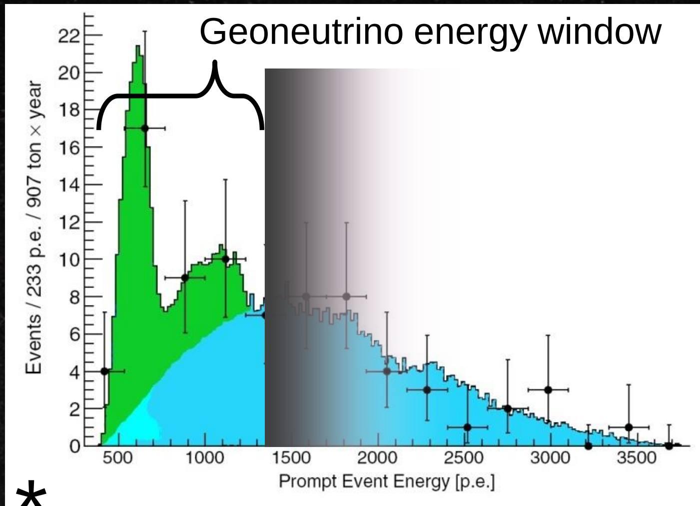
Why this work is relevant for the future?



• Focusing on the 100 km × 100 km area centered at JUNO, we highlight an evident **N-S anisotropy** in the UC geoneutrino signal.

• In the perspective of a geophysical and geochemical refinement, this is a relevant information for planning **future surveys.**

Geoneutrinos events in JUNO (compared to BX and KL)

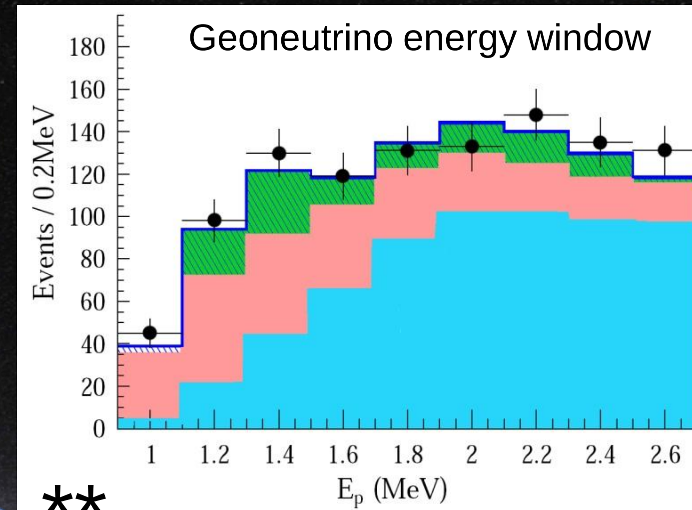


*

Geoneutrinos

Background

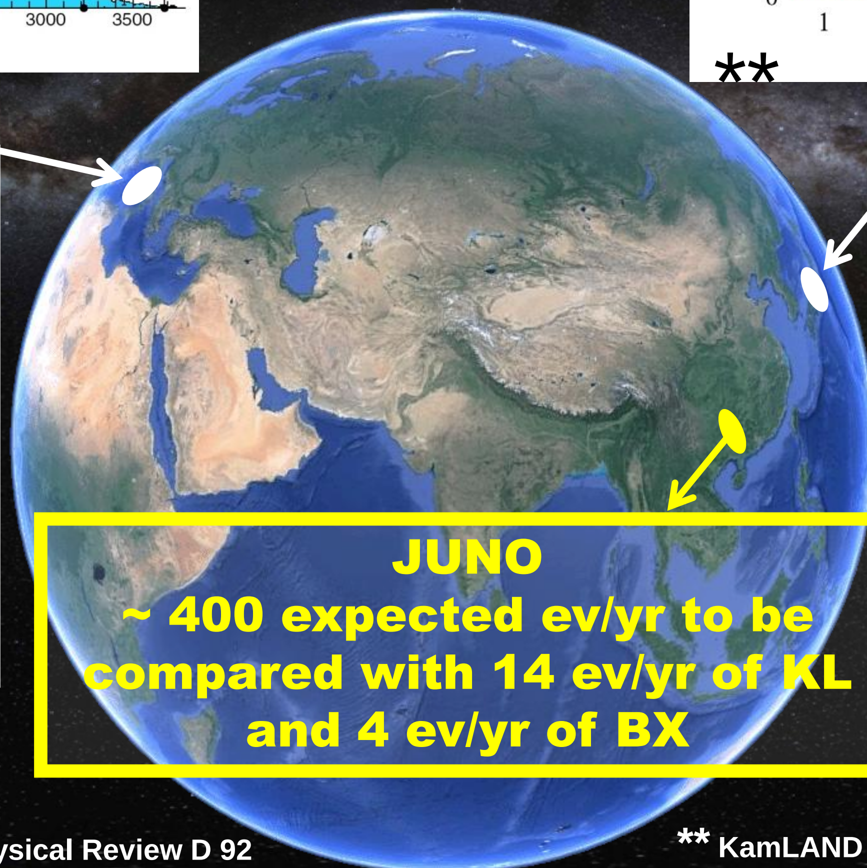
Reactor antineutrinos



**

Borexino

- Period: 2007 – 2015
- Geo-ν events: $23.7^{+7.4}_{-6.3}$
- Signal: $43.5^{+14.5}_{-12.8}$ TNU



JUNO
~ 400 expected ev/yr to be compared with 14 ev/yr of KL and 4 ev/yr of BX

KamLAND

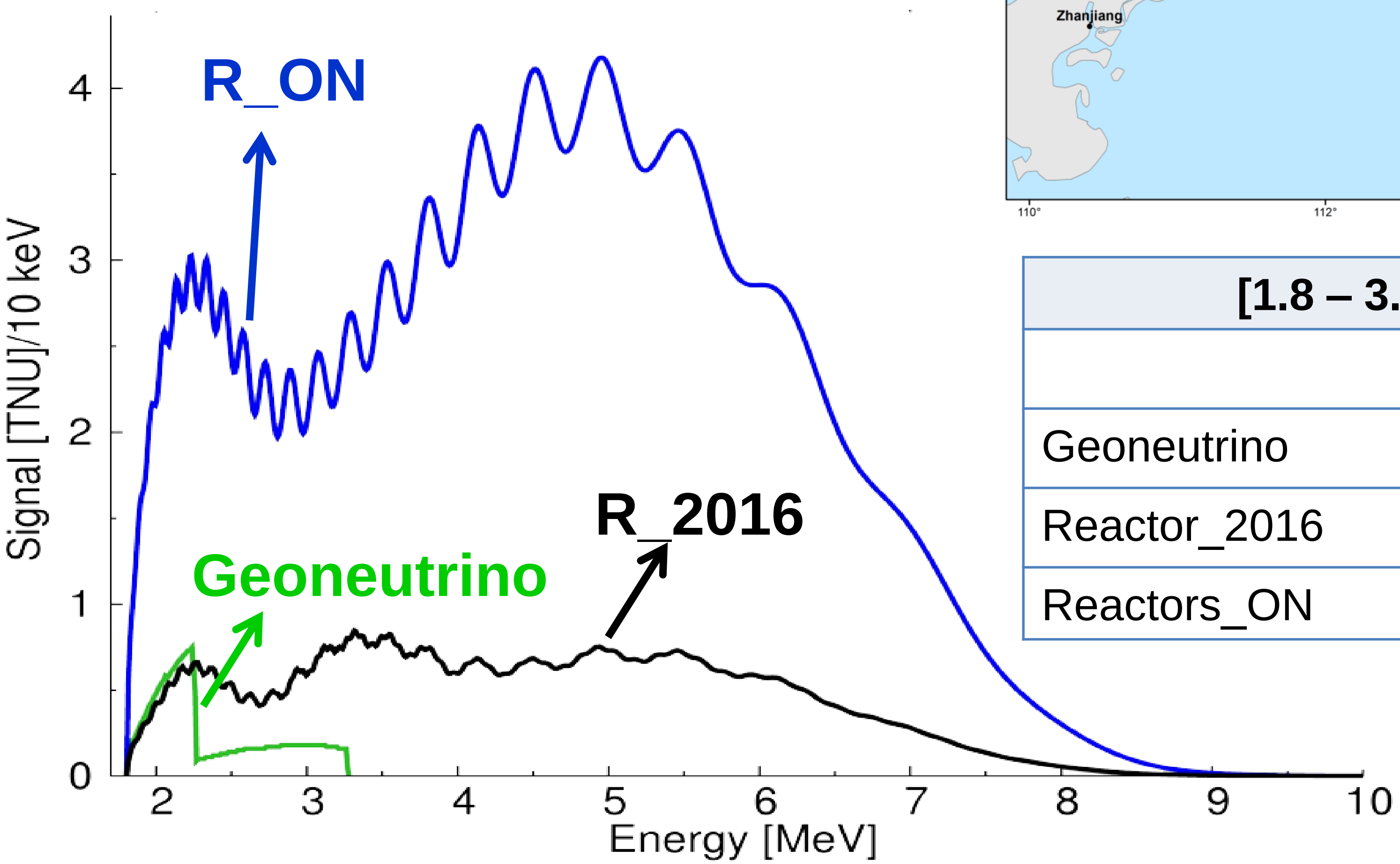
- Period: 2002 – 2012
- Geo-ν events: 116^{+28}_{-27}
- Signal: 30 ± 7 TNU

* Borexino collaboration, 2015 - Physical Review D 92

** KamLAND collaboration, 2013 - Phys. Rev. D 88

Antineutrino spectra at JUNO

	N°of cores (planned)	Load Factor (2016)	Planned P_{Th}
Yangjiang	3 (6)	82%	6 × 2.9 GW
Taishan	0 (4)	0%	4 × 4.6 GW



[1.8 – 3.3] MeV	
	S [TNU]
Geoneutrino	$39.7^{+6.5}_{-5.2}$
Reactor_2016	$117.5^{+6.3}_{-5.7}$
Reactors_ON	354^{+45}_{-41}

A look to Nuclear Power Stations

Site	Reactor	Construct. Start Date	First Grid Connection	Model	Gross GW_{El}
YANGJIANG	1	Dec. 08	Dec. 13	CPR-1000	1.1
	2	Jun. 09	Mar. 15	CPR-1000	1.1
	3	Nov. 10	Oct. 15	CPR-1000	1.1
	4	Nov. 12	Jan. 17	CPR-1000	1.1
	5	Sept. 13	Fall 18	ACPR-1000	1.1
	6	Dec. 13	Winter 18	ACPR-1000	1.1
TAISHAN	1	Nov. 09	Soon ?	EPR-1750	1.75
	2	Apr. 10	Soon ?	EPR-1750	1.75

- “Negotiations for Taishan-3 and -4 are expected to restart soon following the suspension of new-build authorizations after the Fukushima accident” (Soon?...)
- Before 2022 it’s reasonable to expect 8 reactors on line, with a total ~ 30 GW_{Th}
- With this constraint and an average load factor of 80%, we expect S_{rea} / S_{geo} = ~ 7

Source PRIS – IAEA – March 2018

TAISHAN Nuclear Power Plant

Using Particle Physics to Understand and Image the Earth

2-12 July 2018

University of Ferrara - Institute for Higher Studies, IUSS - Ferrara 1391 (Italy)

Europe/Rome timezone

Search...

- Overview
- Motivations
- Scientific Programme

Università degli Studi di Ferrara – Ex labore fructus –

INFN Istituto Nazionale di Fisica Nucleare

JÜLICH Forschungszentrum

https://indico.cern.ch/event/660892/

Thank you