Geoneutrinos: status and strategy

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JUNO Italia - meeting – 27/28 March 2023

Outline

- The Geoneutrino modeling Physics Working Group
- Geoneutrinos in JUNO
- Status & Next focuses
- Final considerations

The Physics Working Groups

Scope (brief description)	Physics Working Groups (PWG)	Satellite Groups
Topics with the neutrinos from reactors and the Earth, e.g., oscillation, flux/spectrum of both neutrino sources	Reactor ν (TAO sub-group)	Geological model
Topics with the solar neutrinos from both the pp-chain and CNO cycle (oscillations, flux/spectra, solar model, etc).	Solar ν	
Topics where atmospheric neutrinos as signal (oscillations) OR background (DSNB, proton decay, dark matter, and other rare event searches)	Atmospheric ν	ν interaction generators (GANYMEDE)
Topics with core-collapse supernova neutrinos	CCSN	
Topics with transient neutrinos associated with extreme astronomical events (gravitational waves, gamma ray burst, neutron star merger, fast radio bursts, etc)	Multi-messenger	

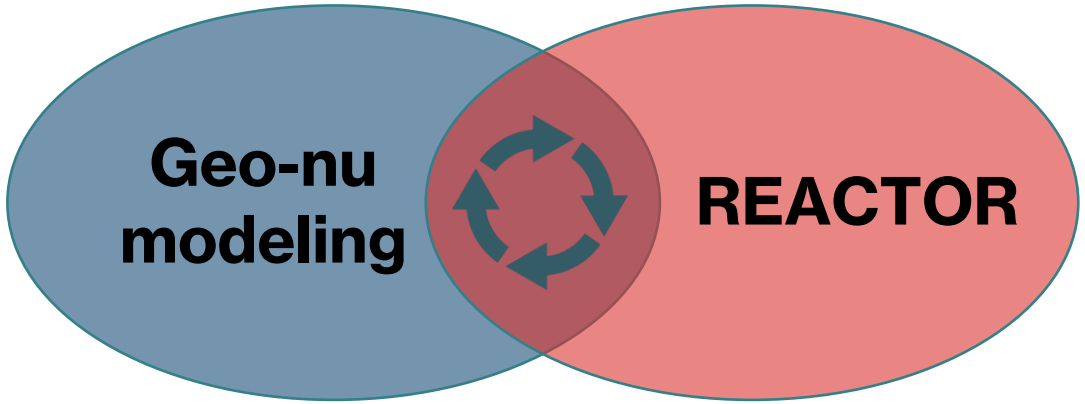
Conveners:
Virginia Strati & Ruohan Gao

Develop state-of-the-art LOCAL crust model, including structure, density and U/Th abundance. Calculate geo-ν flux and evaluate the uncertainties

Provide state-of-the-art neutrino interactions models, by tuning GENIE, GiBUU, NuWro or even NEUT with external data and future JUNO data.

The **Satellite group** is relatively independently from the associated PWG, but closely interact with the PWG

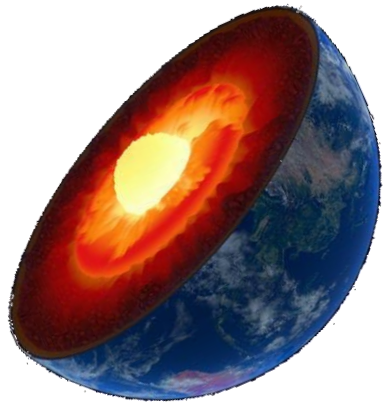
Tasks of the PWG



- Geophysical and geochemical model of the local crust
- Geonu flux (local crust and from rest of the crust)
- Signal ratio Th/U

IBD cross section, oscillation probability and geoneutrino detection efficiency (from unoscillated flux to signal)

- Geonu signal (local crust and from rest of the crust)
- Geonu signal from the mantles
- Geological results interpretations



Sensitivity to mantle geoneutrino signals

Past, present and future

Kick-off: 30 November 2022: aim & scopes, research groups

2° Meeting: 22 December 2022: recognition of geophysical and geochemical models

3° Meeting: 18 January 2023: definition of strategy for modeling of geoneutrinos signals

GM Meeting: 8 February 2023: first results of geoneutrinos signals predictions

Workshop: 3 March 2023: focus on JULOC-I and heat flux, geoneutrino spectra and oscillations, signals and uncertainties combinations

4° Meeting: 3 April 2023: updates of the models and geonu predictions

Summer 2023: final inputs for the geoneutrinos sensitivity paper

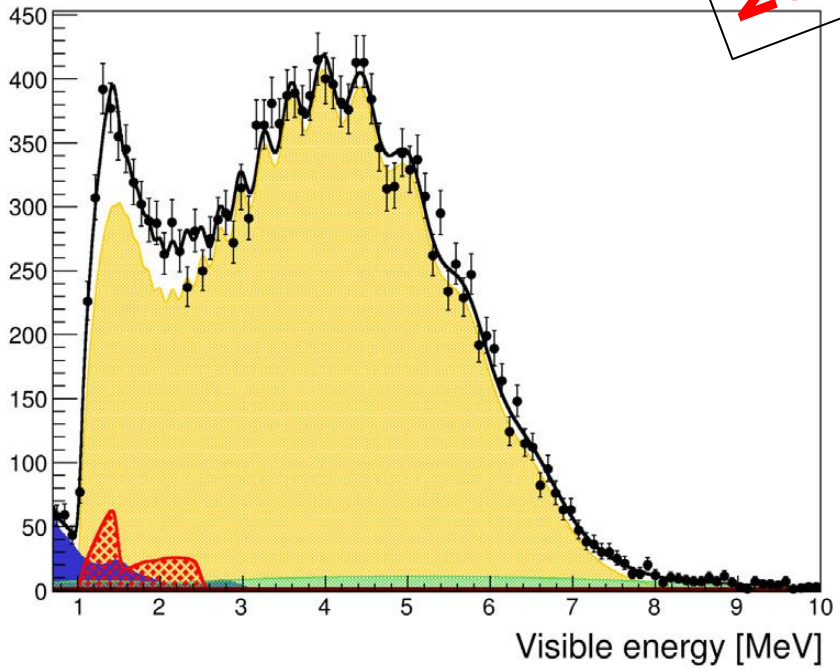
Status

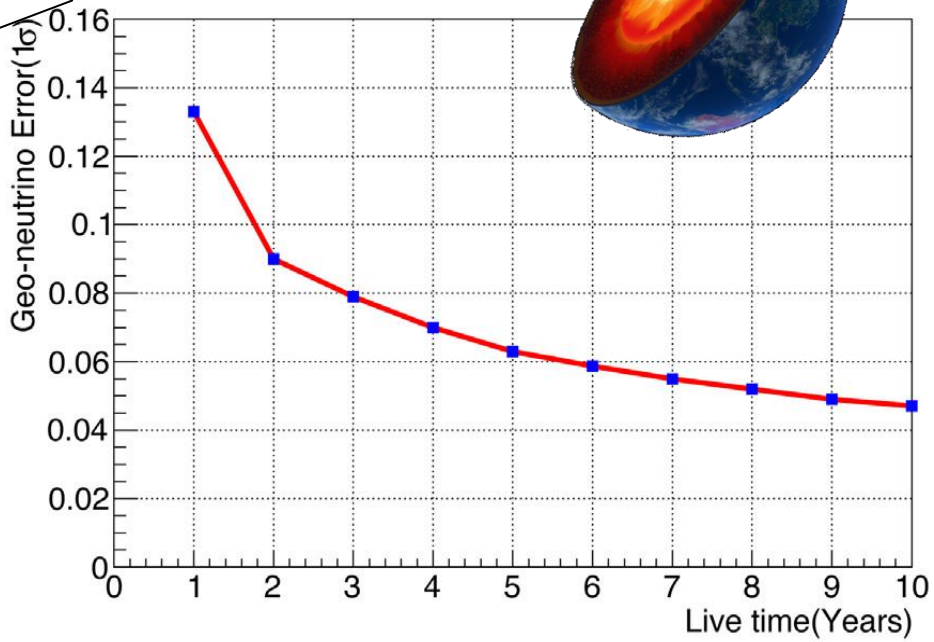
What we have dove

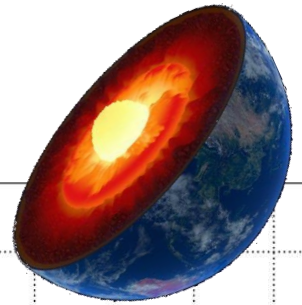
Geoneutrinos in JUNO

- Considering global Earth's reference models, **~ 400 geoneutrinos** per year are expected in JUNO
- Expected 1σ uncertainty of **14%** after 1 year of data taking to be compared with 18% of KamLAND after 18 years

2016







2023 - 2024

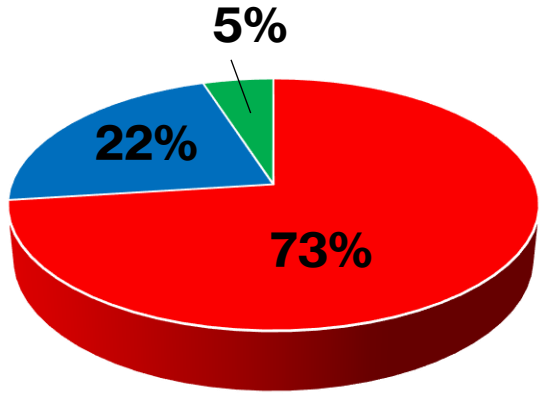
- New geoneutrino signal prediction
- Sensitivity of mantle geoneutrino

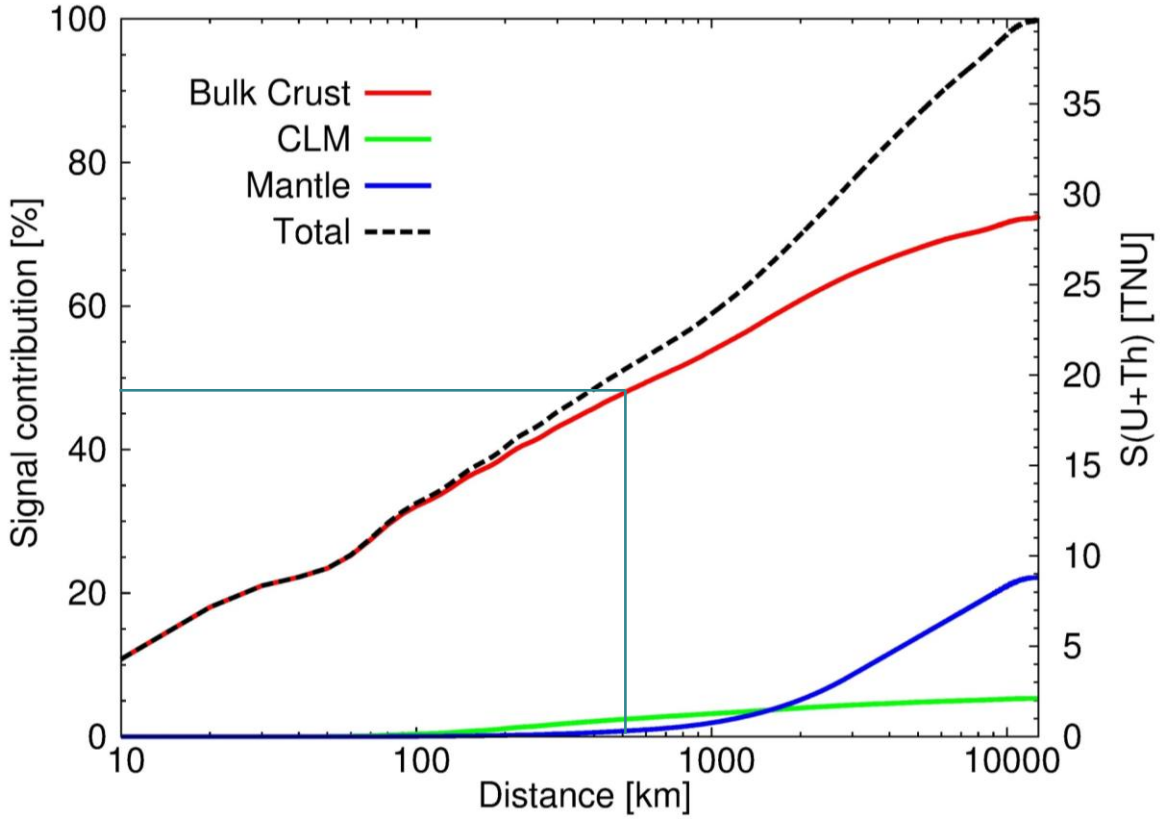
GEONEUTRINO SENSITIVITY PAPER

Where do geoeneutrinos measured at JUNO come from?

$$S_{EXP} = S_{\text{Bulk Crust}} + S_{CLM} + S_{Mantle}$$

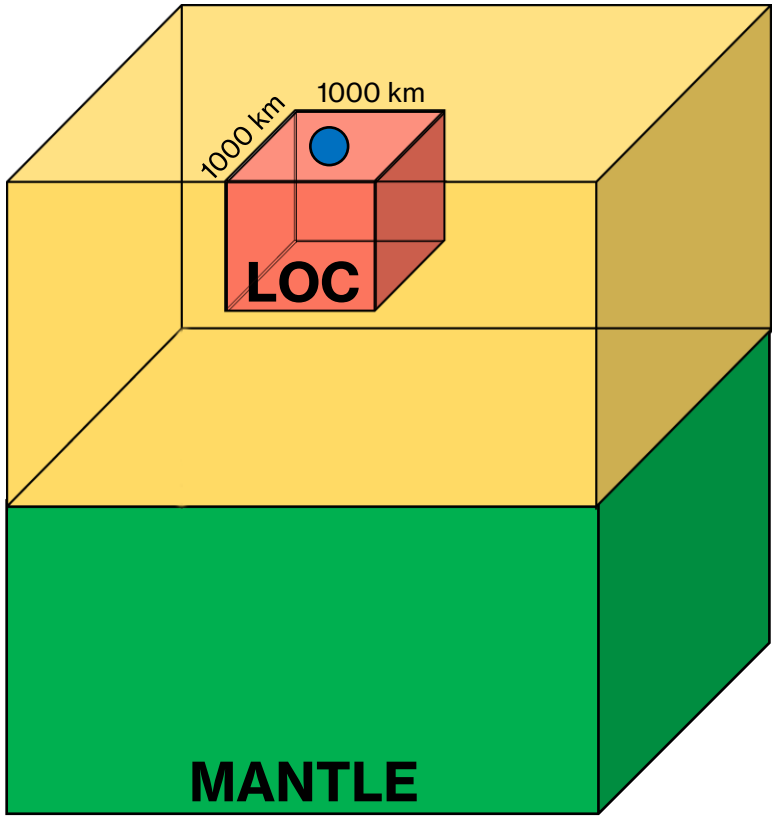
$$S_{Mantle} = S_{EXP} - S_{\text{Bulk Crust}} - S_{CLM}$$





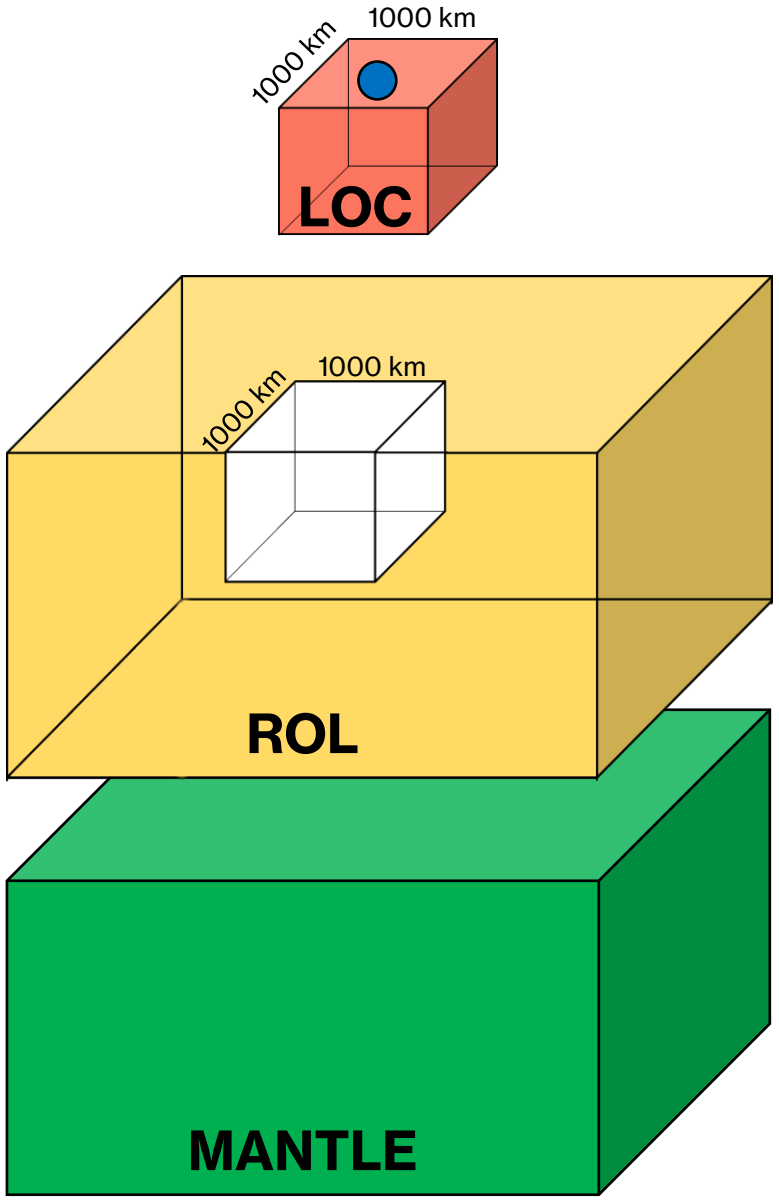
- About **50%** of the crustal signal comes from the area within ~500 km radial distance from the detector
- A **local crustal model** with refined geophysical and geochemical inputs is mandatory to interpret future geoneutrinos results

The strategy for the signal modeling



- **LOcal Crust** (**LOC**): the portion of crust centred in JUNO of dimension 10° x 10° (~ 1000 km x 1000 km)
- **Rest Of Lithosphere** (**ROL**): the Continental Lithospheric Mantle and the remaining crust subtracting the Local crust
- **Mantle:** sublithospheric mantle

Local crust vs Rest Of Lithosphere



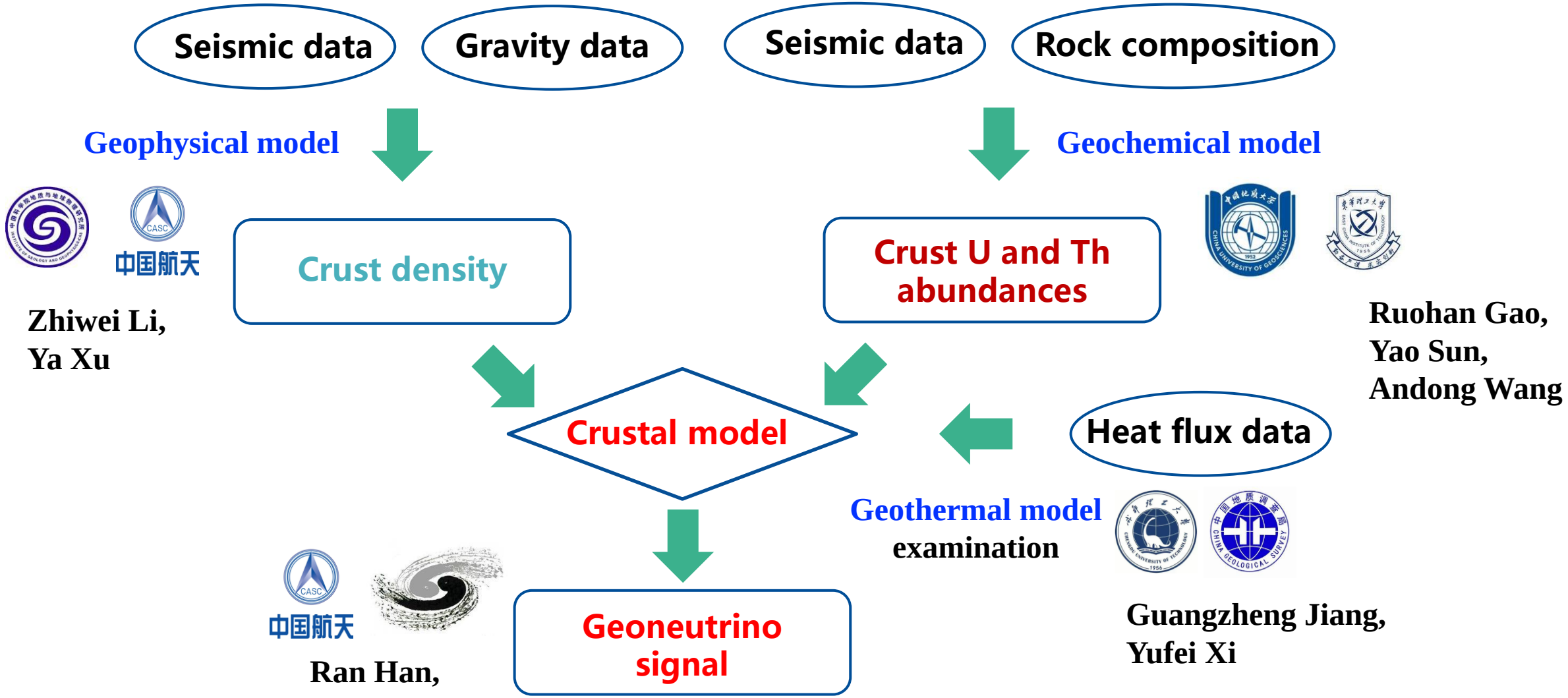
Refined crustal model: JULOC-I
10° x 10° (1000 km x 1000 km)
(Next talk by Ruohan Gao)

Global model:
The Reference EaRth Model*

Bulk Silicate Earth models

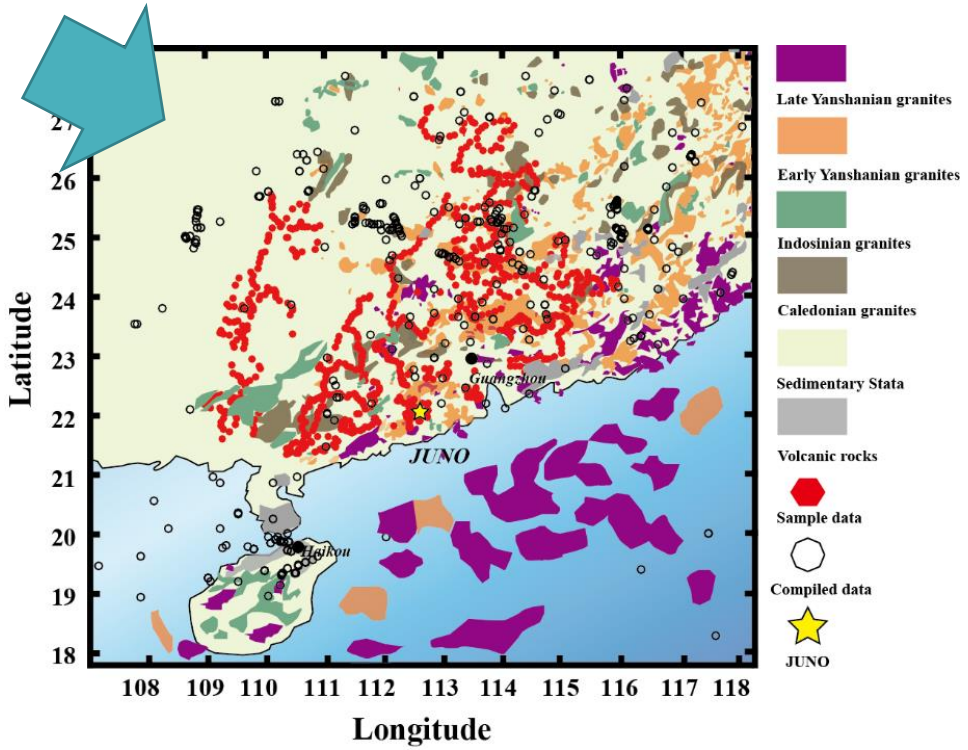
* [Huang, Y., et al. (2013) A reference Earth model for the heat-producing elements and associated geoneutrino flux. Geochemistry, Geophysics, Geosystems, 14

The JULOC-I model



Geoneutrino signals from local crust

- Compiled data (~2000)
- Analyzed sample (500)

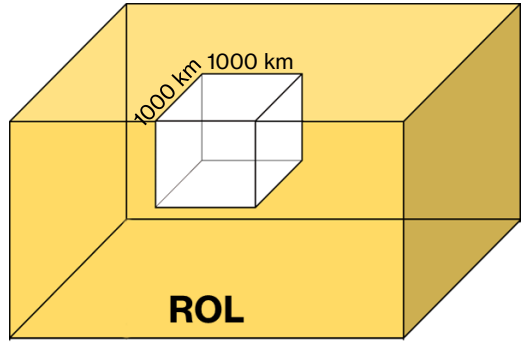


	$S_U \pm \sigma$	$S_{Th} \pm \sigma$	$S_{U+Th} \pm \sigma$
UC	17.2 ± 1.3	5.0 ± 0.3	22.3 ± 1.4
MC	$5.4^{+3.8}_{-2.2}$	$0.4^{+0.4}_{-0.2}$	$6.0^{+3.4}_{-2.2}$
LC	$1.5^{+0.3}_{-0.2}$	$0.1^{+0.05}_{-0.04}$	$1.7^{+0.3}_{-0.2}$
Continental Crust	24.5 ± 3.3	5.7 ± 0.4	30.4 ± 3.2
Oceanic Crust	0.2 ± 0.05	0.1 ± 0.01	0.3 ± 0.05
Total Crust	24.7 ± 3.3	5.8 ± 0.4	30.7 ± 3.2

JUNO: ~22° N, 112.5° E

Research area: 18-28° N, 106-118° E

Geoneutrino signals from the ROL



[Rest Of Lithosphere (**ROL**): the Continental Lithospheric Mantle and the remaining crust subtracting the Local crust (1000 km x 1000 km)]

- Half of the total geoneutrinos signal of the ROL is produced by the Upper Crust (**UC)**
- The contribution of the Continental Lithospheric Mantle (**CLM)** is 15%
- The relative uncertainty on the S(U+Th) of the ROL is about 25%
- Given an average ratio a(Th)/a(U) = 4.5 in the ROL, the **S(Th)/S(U)** is **0.31**

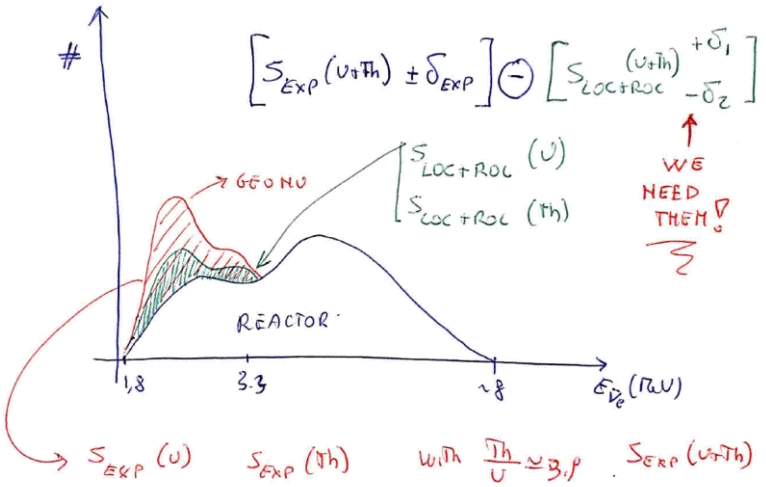
	Signal [TNU]			S(Th)/S(U)
	U	**Th**	**U + Th**	
Sed	0.37 ± 0.06	0.12 ± 0.02	0.40 ± 0.04	0.33
UC	$4.32^{+1.03}_{-1.00}$	$1.17^{+0.16}_{-0.15}$	$5.49^{+1.04}_{-1.01}$	0.27
MC	$1.70^{+1.08}_{-0.66}$	$0.60^{+0.56}_{-0.28}$	$2.43^{+1.23}_{-0.80}$	0.36
LC	$0.26^{+0.23}_{-0.12}$	$0.12^{+0.02}_{-0.02}$	$0.42^{+0.30}_{-0.16}$	0.45
OC	0.05 ± 0.02	0.01 ± 0.01	0.06 ± 0.02	0.21
Bulk Crust	$6.84^{+1.57}_{-1.34}$	$2.09^{+0.65}_{-0.39}$	$9.07^{+1.70}_{-1.48}$	0.31
CLM	$1.32^{+2.52}_{-0.91}$	$0.42^{+0.96}_{-0.30}$	$2.15^{+2.92}_{-1.28}$	0.31
ROL	$\mathbf{8.56^{+3.24}_{-2.01}}$	$\mathbf{2.68^{+1.27}_{-0.70}}$	$\mathbf{11.55^{+3.60}_{-2.32}}$	**0.31**

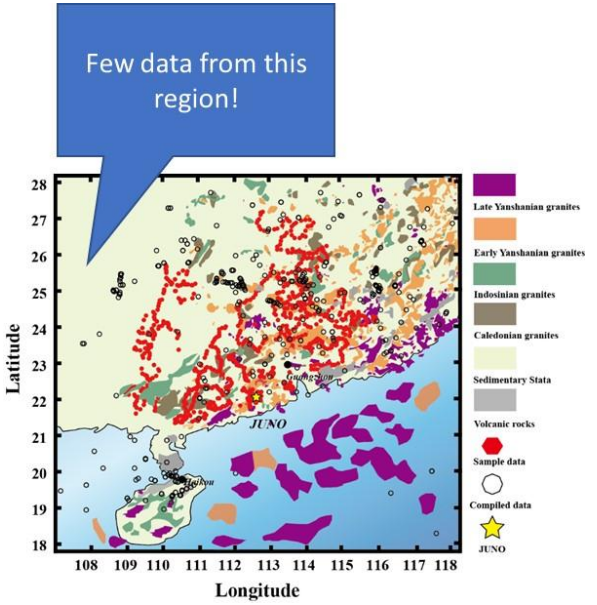
Next steps

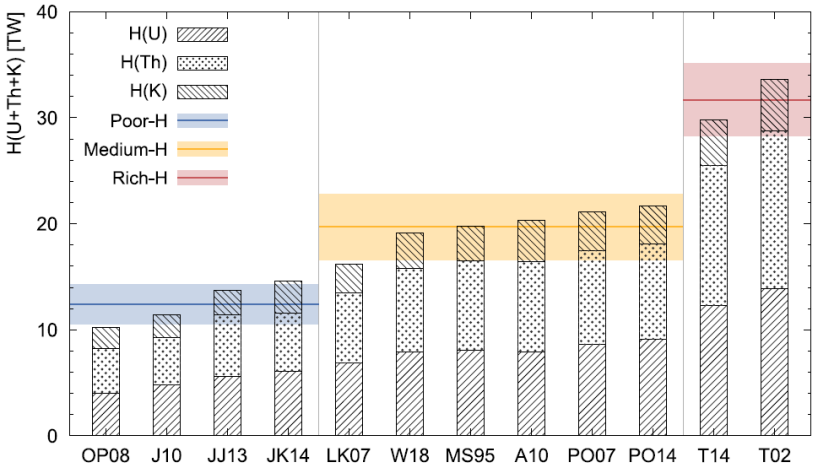
What we have to do

Next steps

- **Final models** for LOC and ROL
- **Final geonu predictions** for LOC and ROL
- **Combinations** of the signals: study of uncertainties
- Geoneutrinos signals from **mantles:** study of different models
- Earth **density** profiles







Final considerations

- Geoneutrinos are a central topic in JUNO
- Significative progresses in data sharing
- Constructive collaboration among groups

Next meeting: 3 April, 8.30 – 10.30 (IT)

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Thank you

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JUNO Italia meeting