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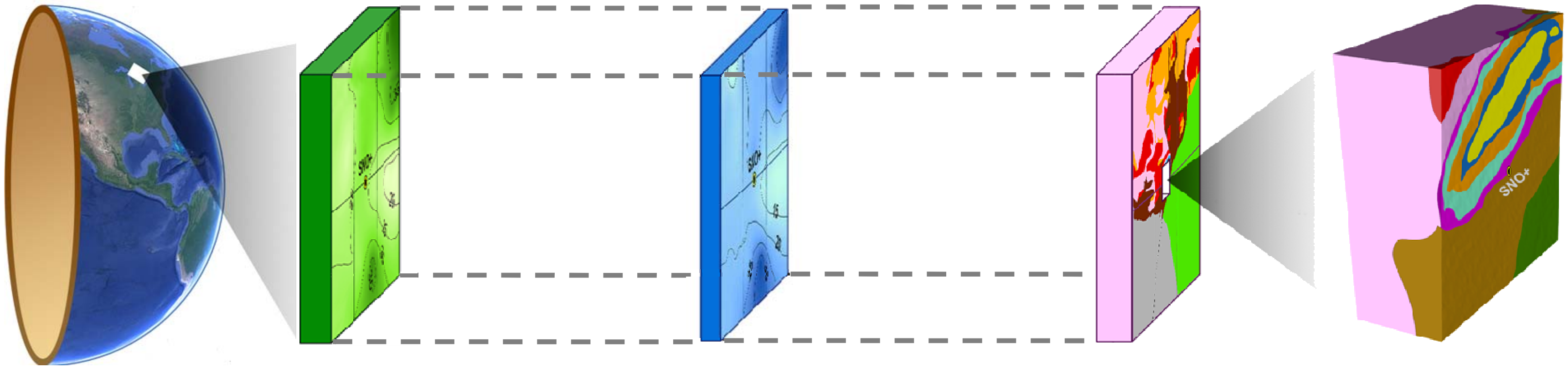
Crustal geoneutrino signal expected at SNO+

Marica Baldoncini

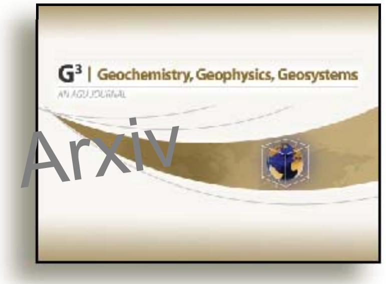
In collaboration with Virginia Strati, Scott A. Wipperfurth, William Mc Donough and Fabio Mantovani

Topics in Astroparticle and Underground Physics – Sudbury 27 July 2017

Outline



- Three question marks for geoneutrinos
- State of the art in crustal modeling for geoneutrino predictions at SNO+
- Building a refined 3D model in the SNO+ Close Upper Crust
- Geoneutrino signal predictions and uncertainties
- Conclusions and perspectives

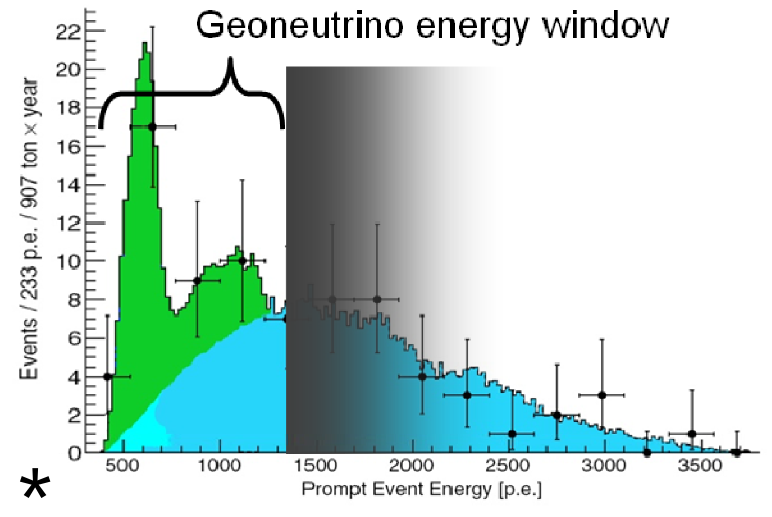


Submitted – Soon in Arxiv

Perceiving the crust in 3D: a model integrating geological, geochemical, and geophysical data

Virginia Strati[1,2], Scott A. Wipperfurth[3], Marica Baldoncini[2,4], William F. McDonough[3,5], Fabio Mantovani[2,4]

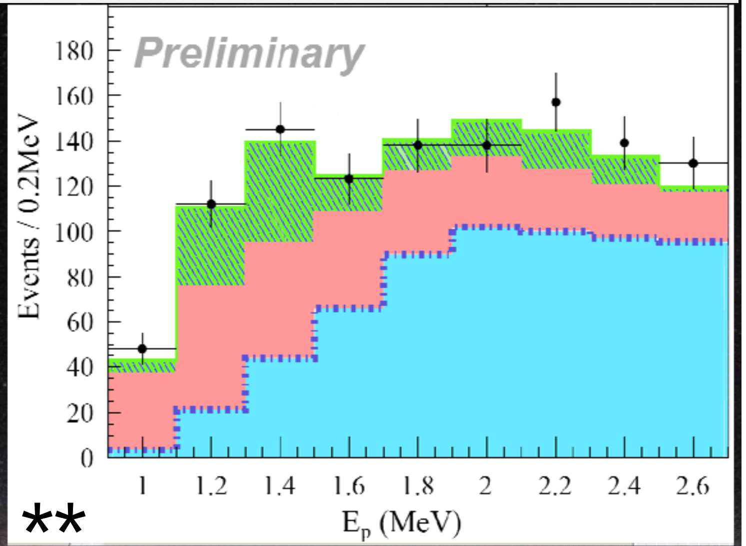
Geoneutrinos measured around the world



Geoneutrinos

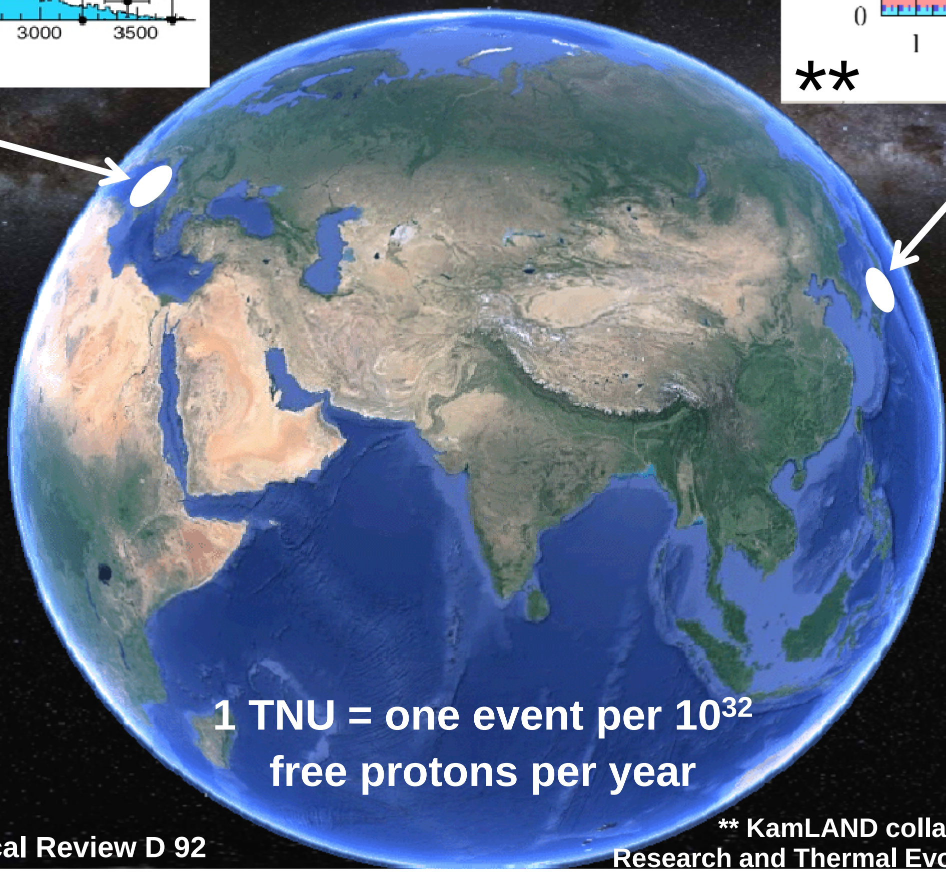
Background

Reactor antineutrinos



Borexino

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



KamLAND

- Period: 2002 – 2016
- Geo-ν events: 164^{+28}_{-25}
- Signal: $34.9\ ^{+6.0}_{-5.4}$ TNU

1 TNU = one event per 10^{32} free protons per year

* Borexino collaboration, 2015 - Physical Review D 92

** KamLAND collaboration - International Workshop: Neutrino Research and Thermal Evolution of the Earth - Sendai, Oct 25-27, 2016

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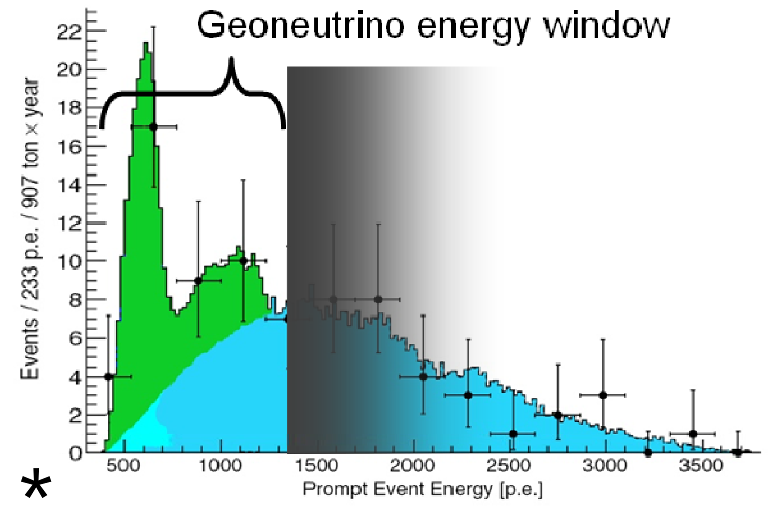

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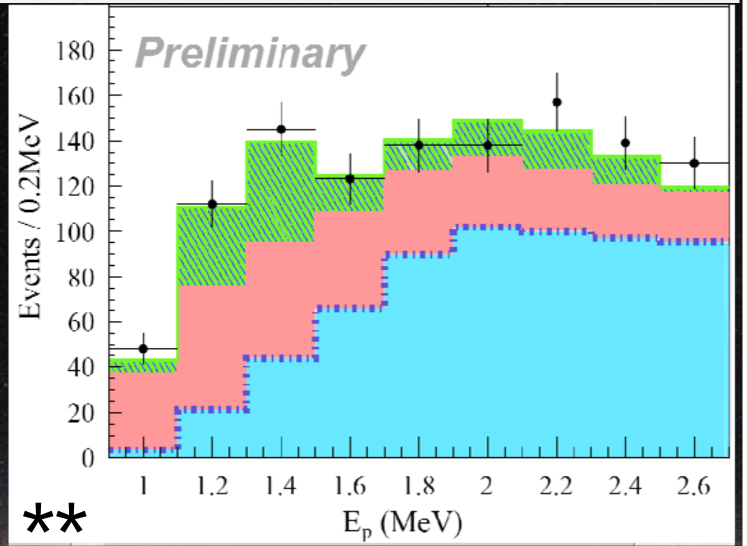

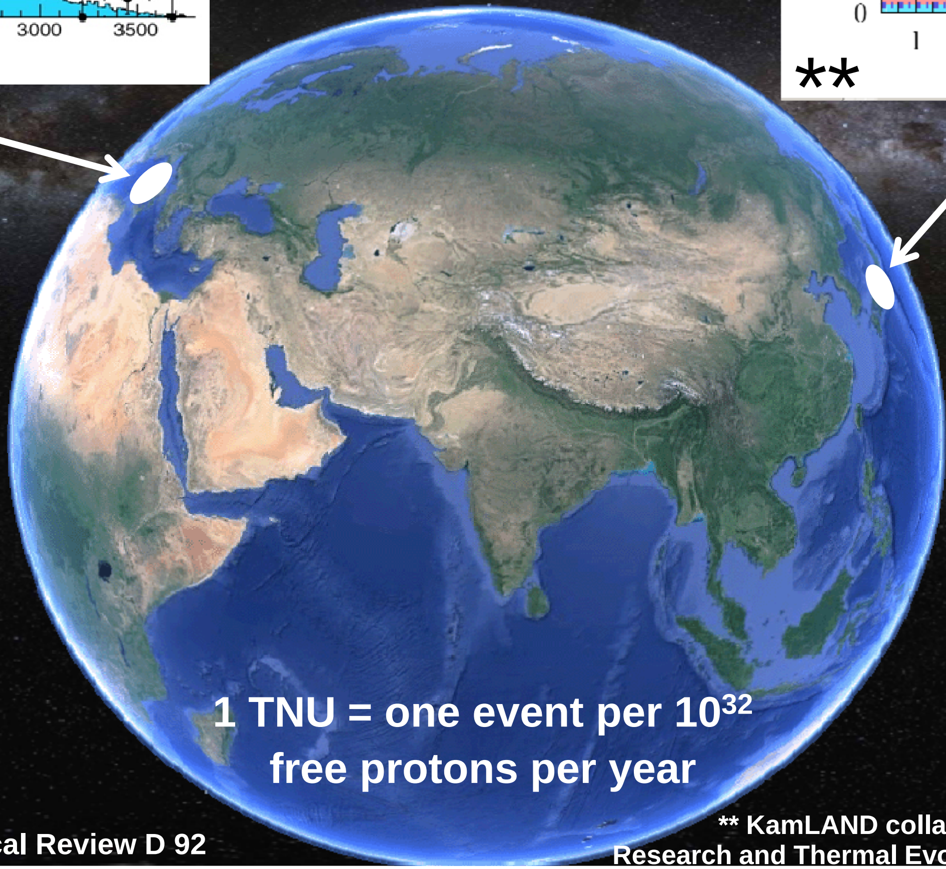

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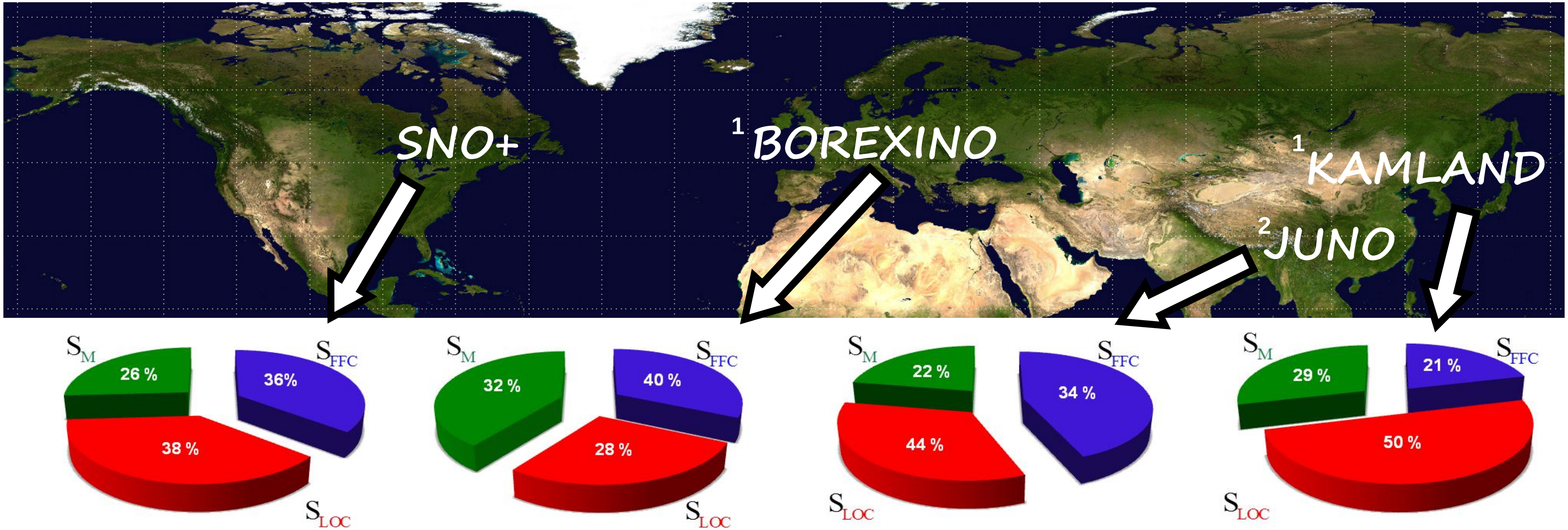
A stereoscopic geoneutrino picture

In one site, for each radioisotope (^{238}U, ^{232}Th) the expected geoneutrino signal can be seen as the sum of three contributions(1):

$$S_{Expected} = S_{LOCal} + S_{Far\ Field\ Crust} + S_{Mantle}$$



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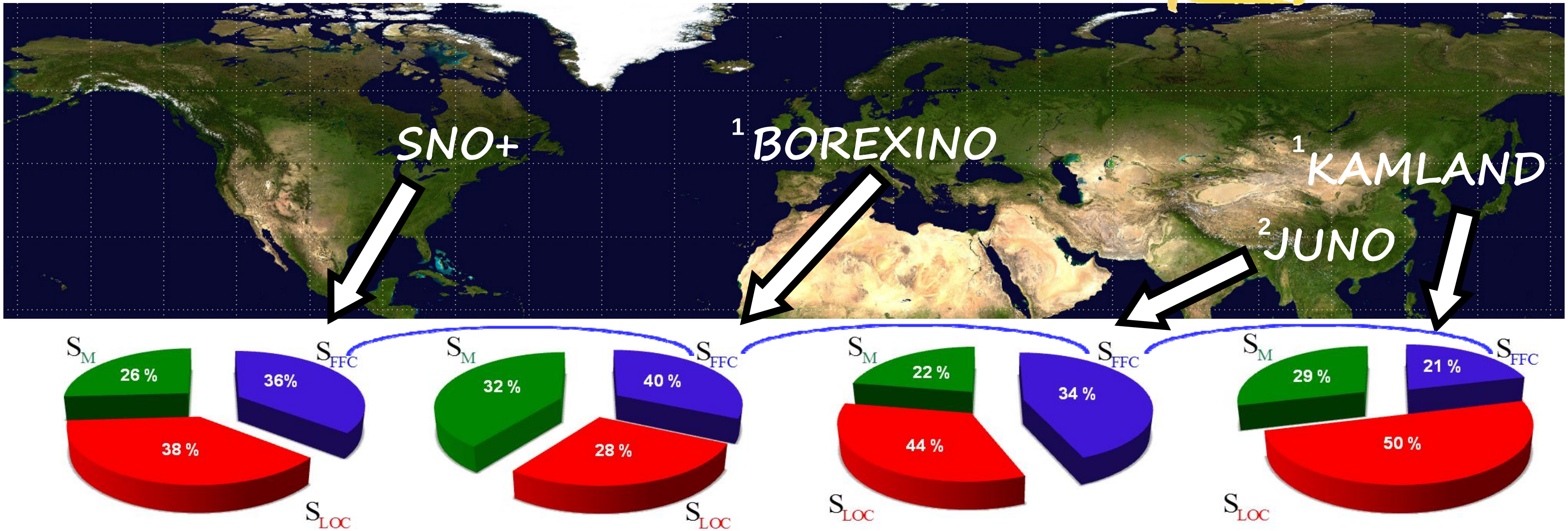

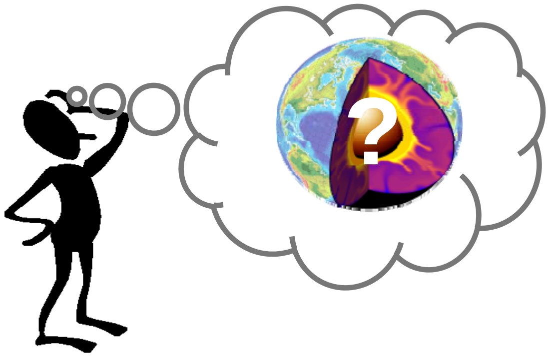

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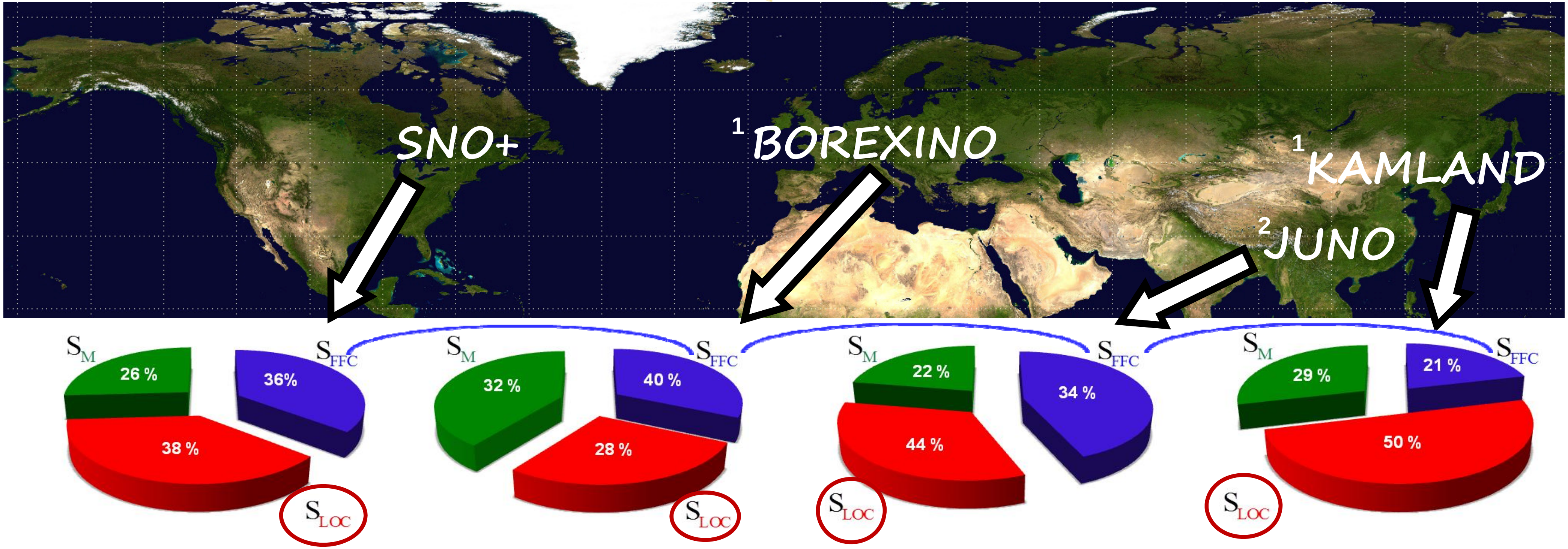

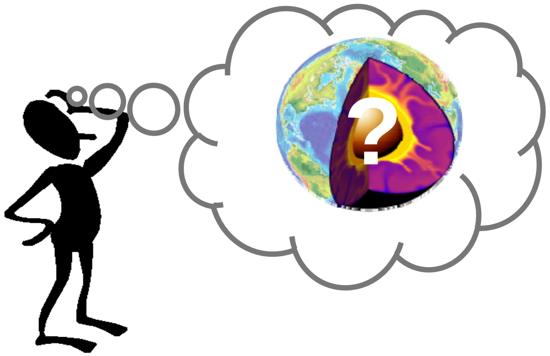

- By combining results from multiple experiments we would possibly discriminate/exclude some geochemical models of the Earth.
- To infer S_{Mantle} from geoν measurements, the contribution from S_{LOC} (~500 km) is supposed to be well known.

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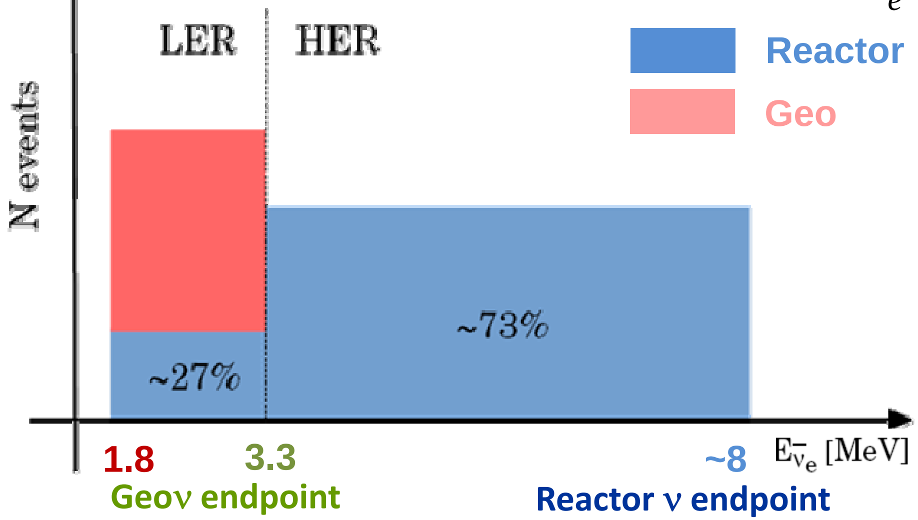
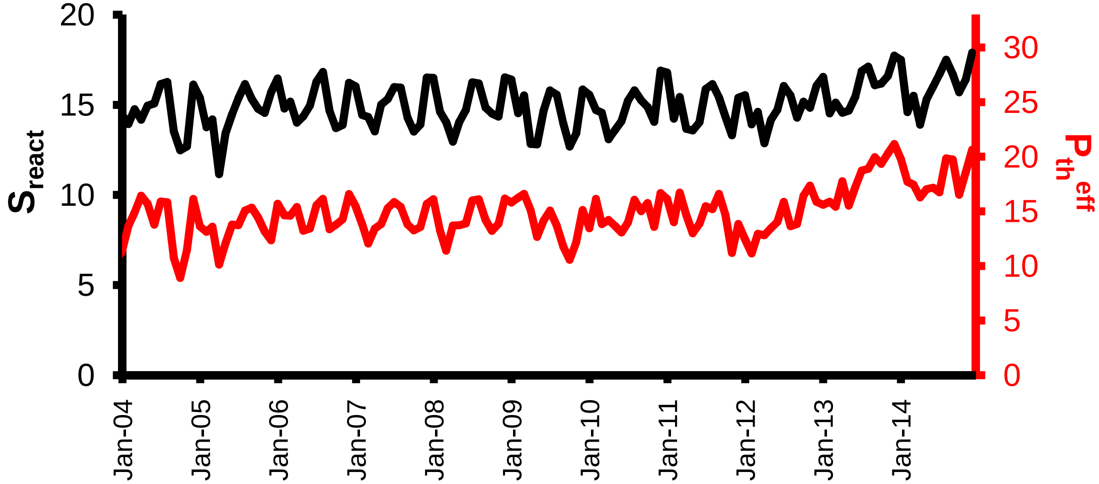
Keeping an eye out for reactor antineutrinos

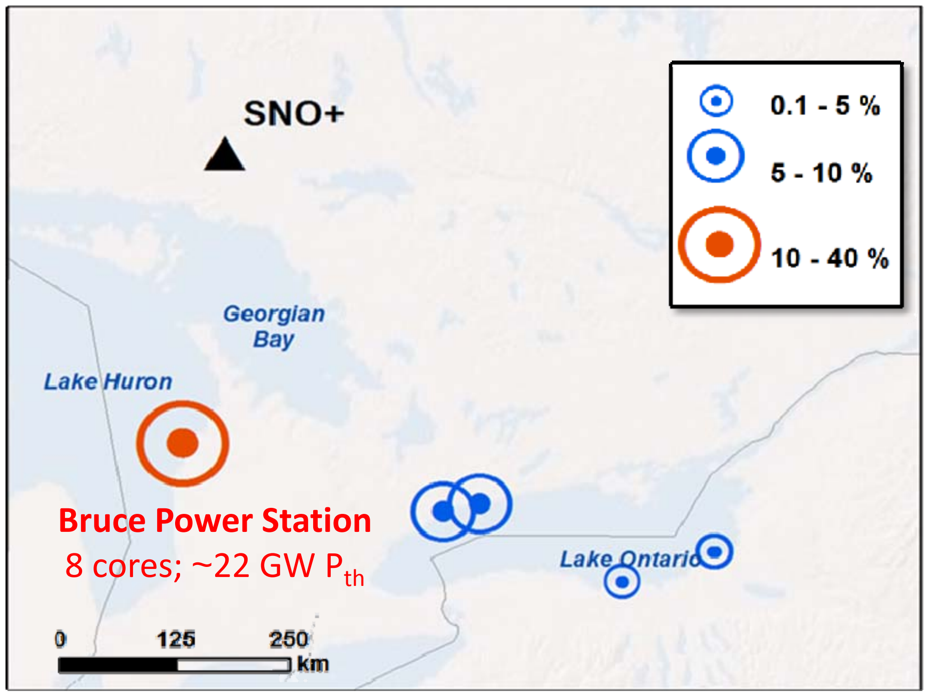
Inverse Beta Decay (**IBD**) Reaction $\bar{\nu}_e + p \rightarrow e^+ + n$ ***- 1.806 MeV***





- The **temporal fluctuations** (~10%) of S_{React} resemble the temporal profile of the Bruce Power Station P_{th}^{eff}.
- Although the thermal power of Bruce reactors corresponds to 1.9% of the global thermal power, they contribute to **~38%** of $\mathbf{S_{React}}$ at SNO+.
- The overlap in the **L**ow **E**nergy **R**egion (**LER**) between reactor and geoν spectra provides a signal ratio $\mathbf{S_{LER}/S_{Geo}}$ **~ 1** from both a local and a global perspective.

	S_{LER}[2]	S_{GEO}[1]	$S_{LER}(t)/S_{GEO}$
LOCAL	$17.3^{+1.0}_{-0.7}$	$15.6^{+5.3}_{-3.4}$	1.1
GLOBAL	$48.5^{+1.8}_{-1.5}$	40^{+6}_{-4}	1.2



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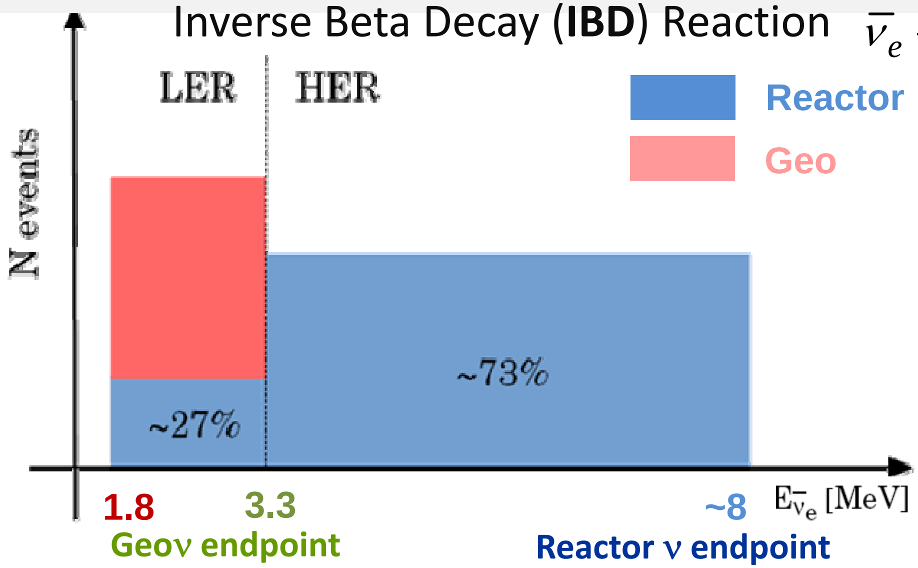

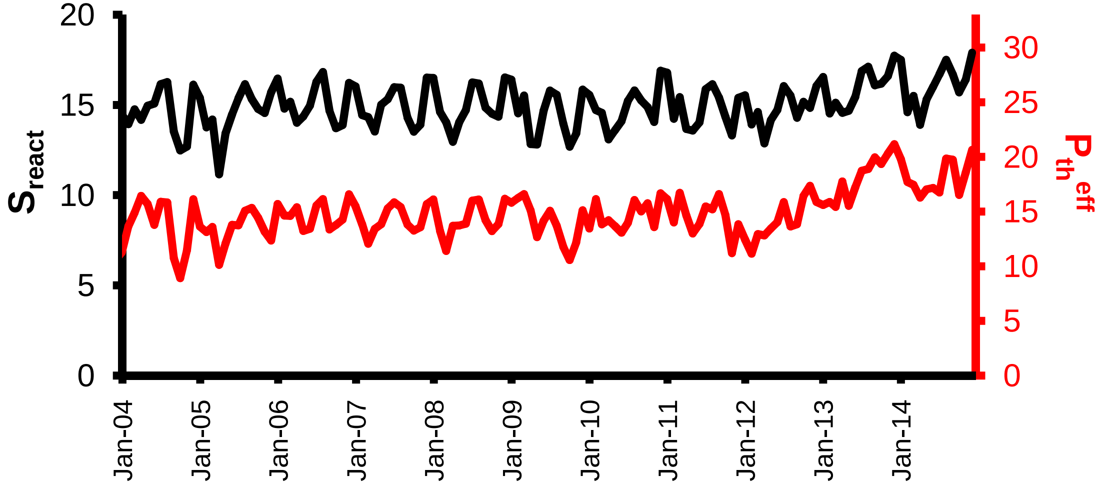

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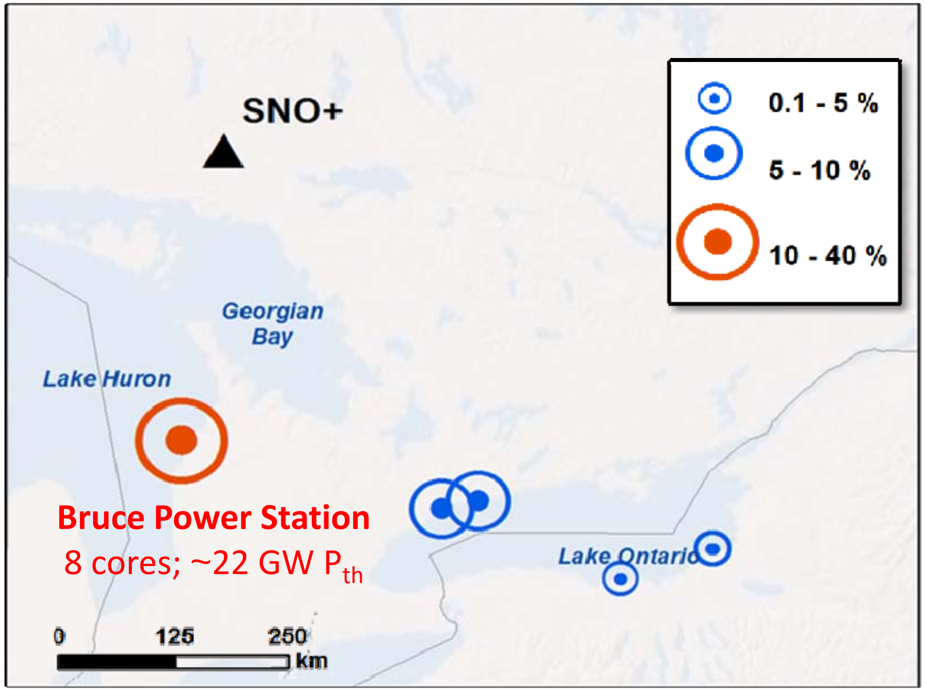

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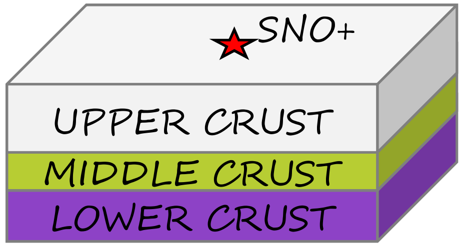
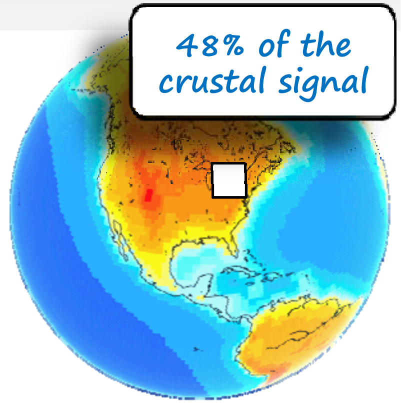
Getting closer and closer…

Huang et al 2013 – Global crustal model

- Geophysical and geochemical attributes of the crust reservoirs inferred from Earth-scale input data.





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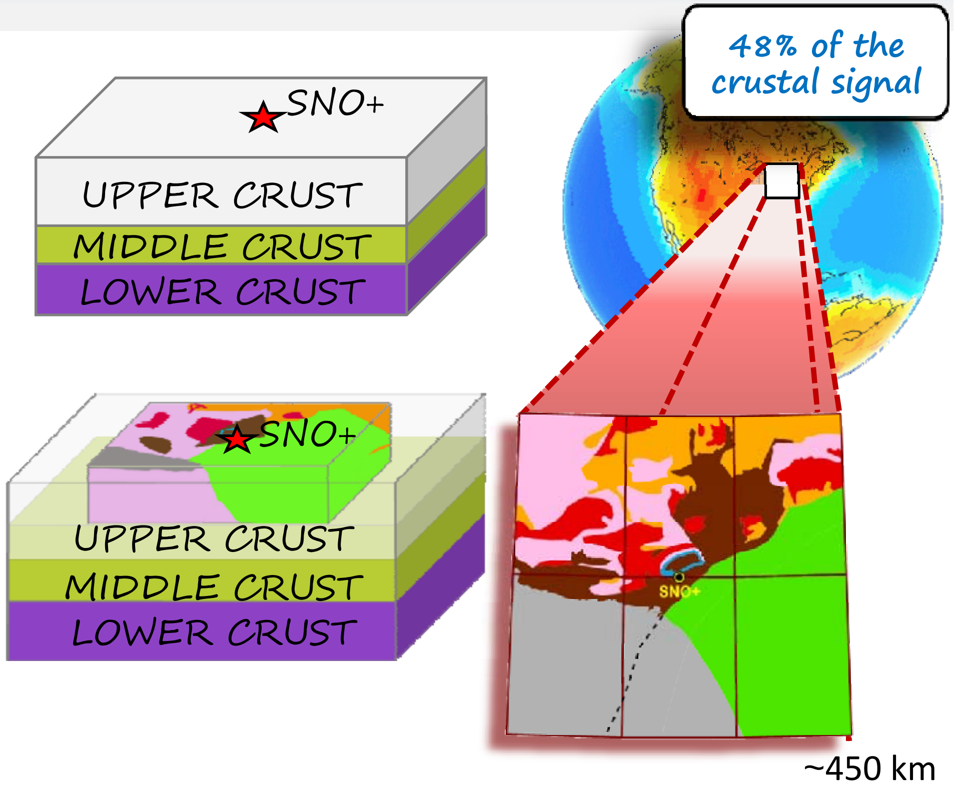
- Homogeneity of the UC broken down into a multifaceted picture mirroring the local geology → identification of 7 dominant lithologic units in the UC
- The higher spatial resolution revealed the complexity and heterogenity of the SNO+ local upper crust



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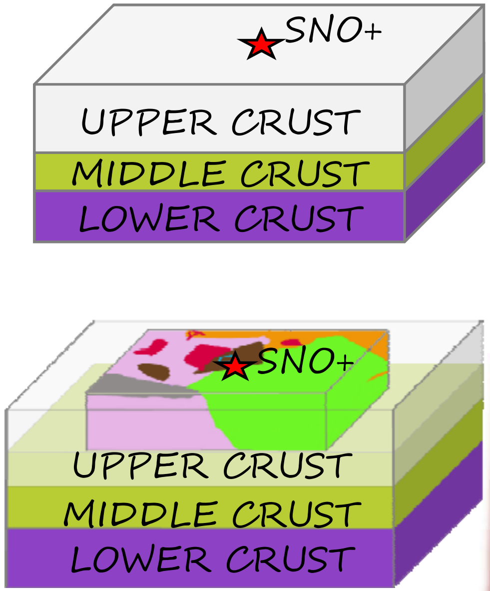

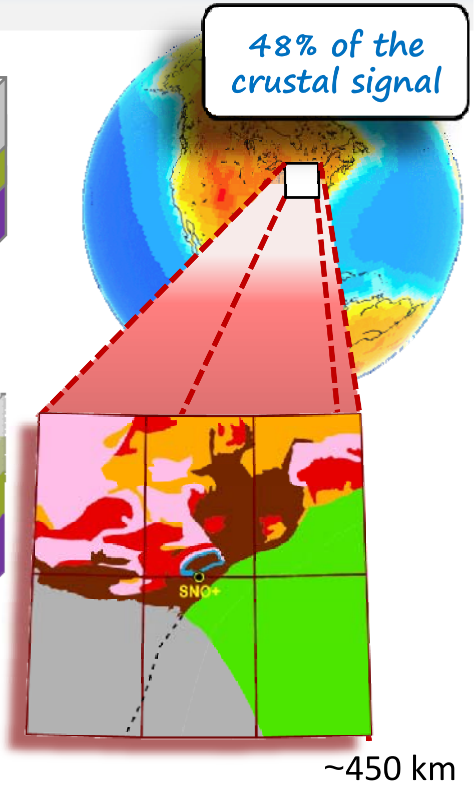

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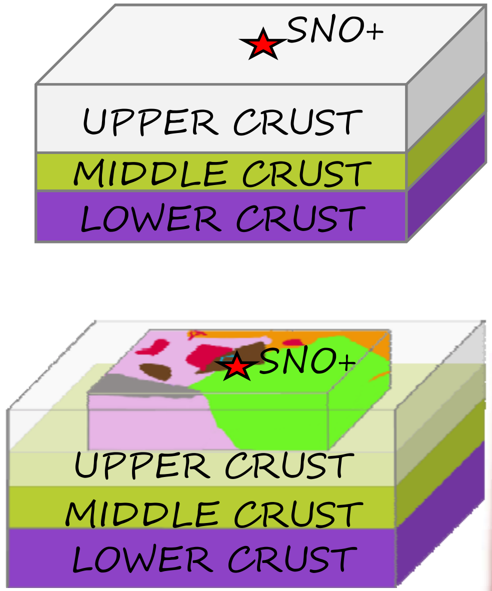
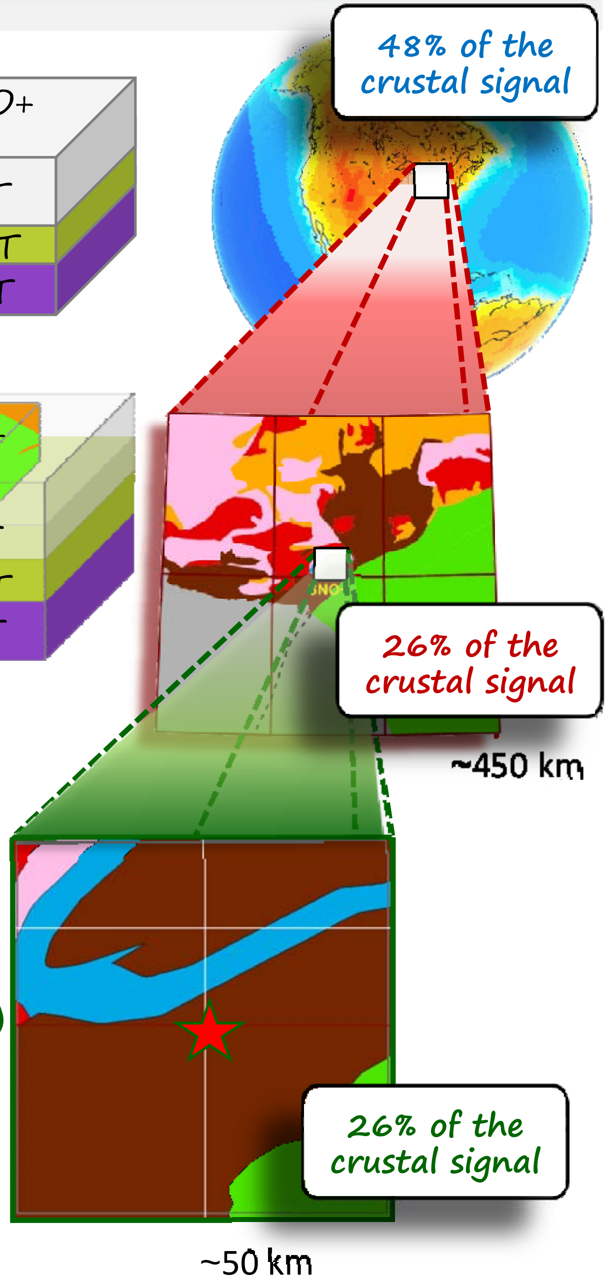


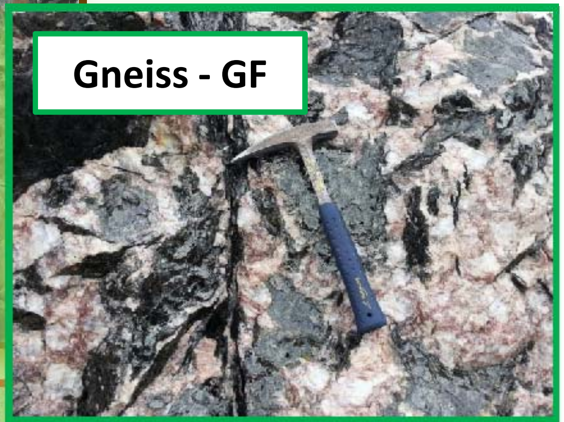


Strati et al 2017 – CLose Crustal model

- Geophysical and geochemical refinement of the *Close Upper Crust (CUC)*
- Systematic rock sampling of the main lithologies of the CUC specifically targeted to geoν studies
- Integration of local geophysical and geochemical data into a coherent 3D picture

Assignign colors to the rocks

Identification of 9 **UNITS** in the Upper Crust on the basis of lithology, metamorphism, tectonic events and evolutional history



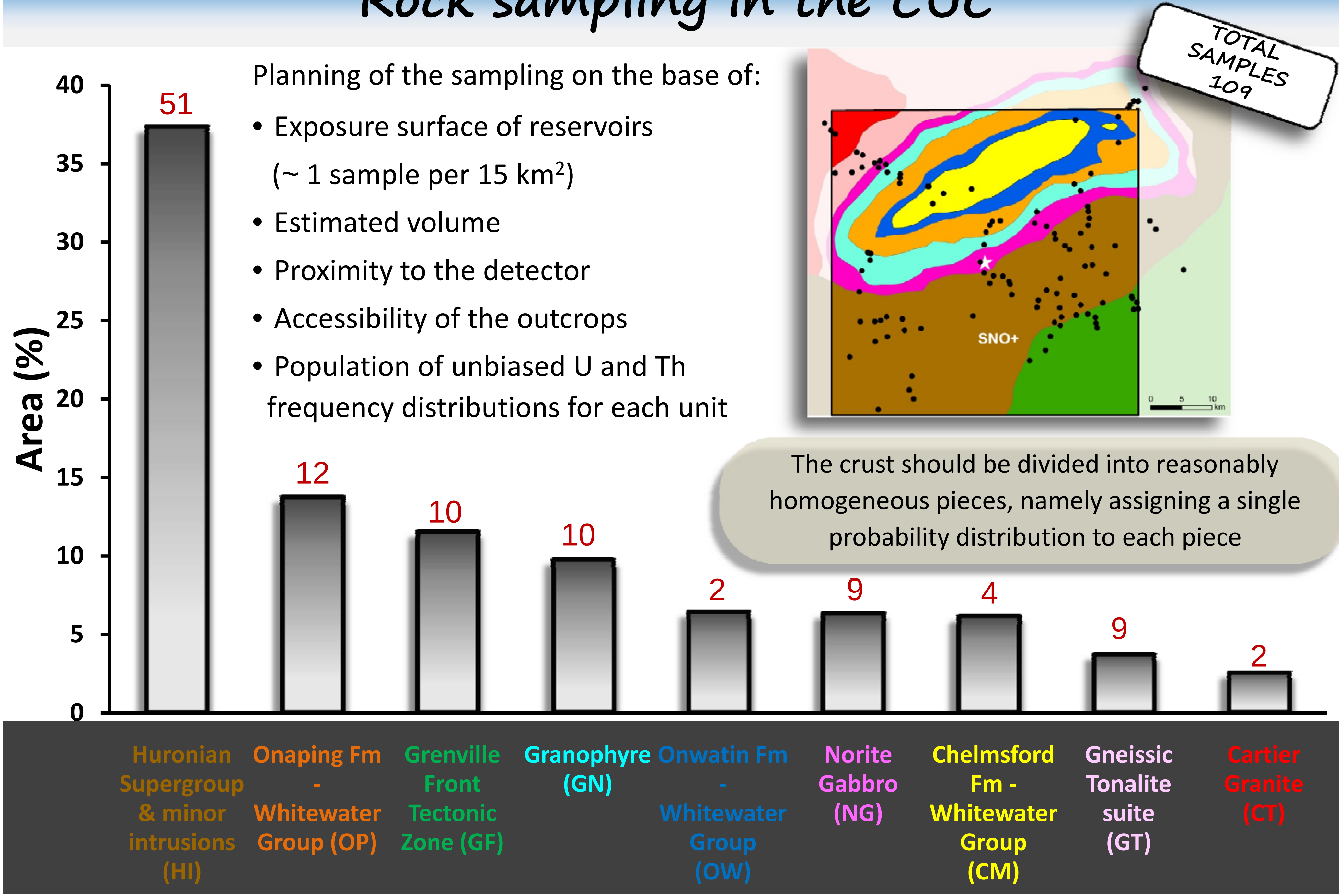
- **NG** – Norite Gabbro (Sudbury Igneous Complex)
- **GN** – Granophyre (Sudbury Igneous Complex)
- **OP** – Onaping Fm (Whitewater Group)
- **OW** – Onwatin Fm (Whitewater Group)
- **CM** – Chelmsford Fm (Whitewater Group)
- **GT** – Gneissic Tonalite Suite
- **CT** – Cartier Granite
- **HI** – Huronian Supergroup & minor intrusions
- **GF** – Grenville Front Tectonic Zone

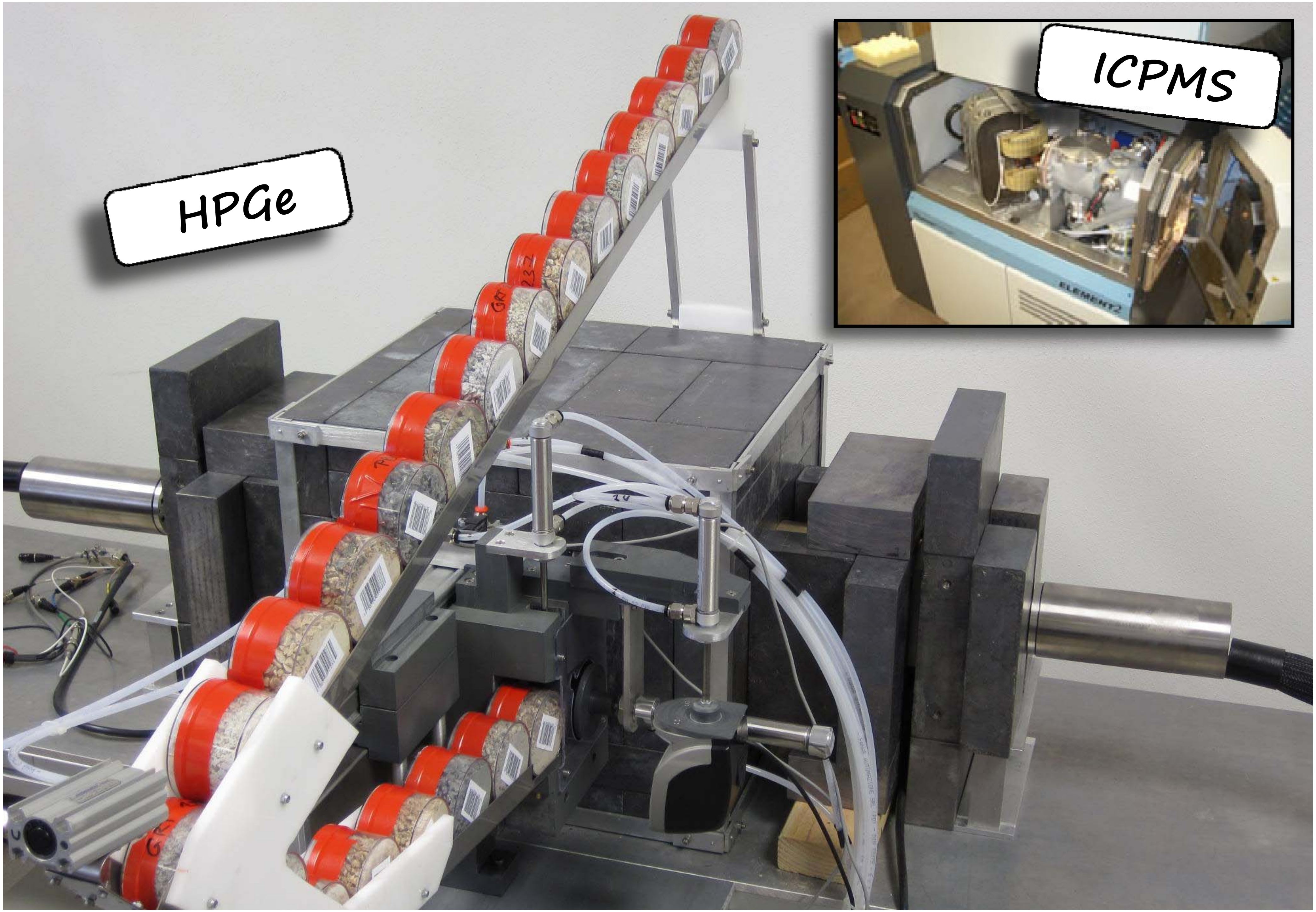
Rock sampling in the CUC

Planning of the sampling on the base of:

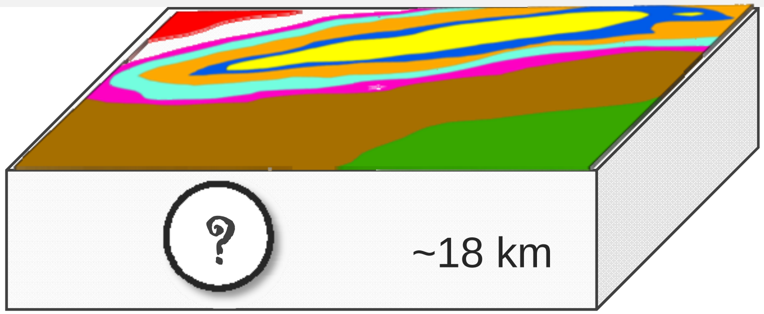
- Exposure surface of reservoirs (~ 1 sample per 15 km^2)
- Estimated volume
- Proximity to the detector
- Accessibility of the outcrops
- Population of unbiased U and Th frequency distributions for each unit

The crust should be divided into reasonably homogeneous pieces, namely assigning a single probability distribution to each piece



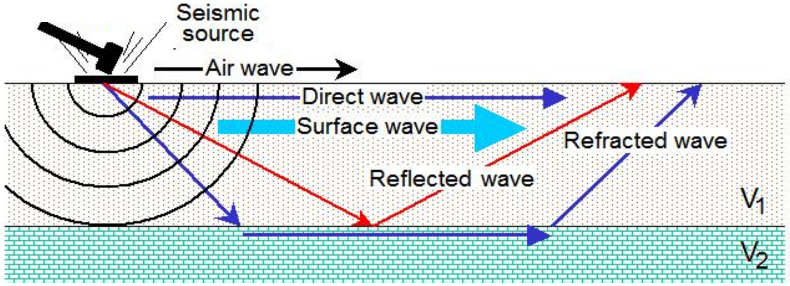

HPGe
ICPMS
ELEMENT2

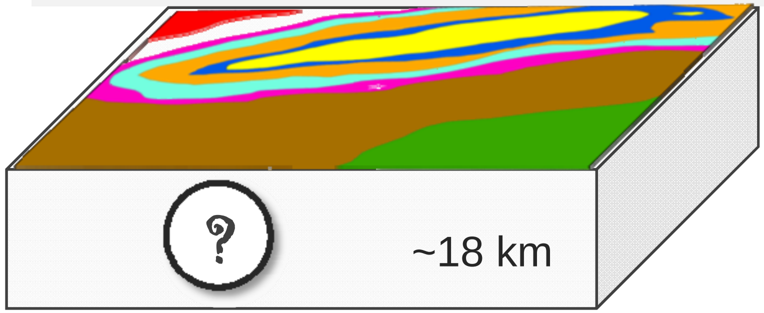
Building a 3D model



Building a 3D model

The boundaries among different units can be identified by means of interpreted geological cross sections based on gravimetric and seismic profiles





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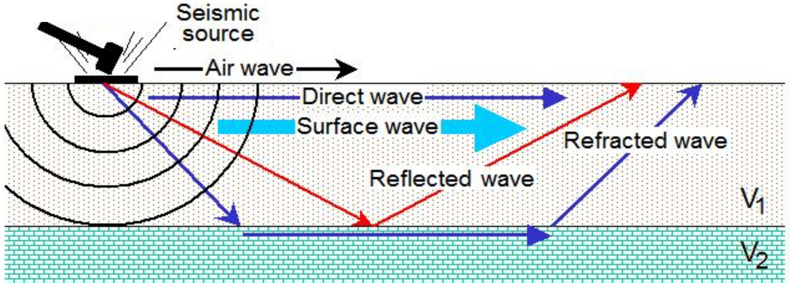
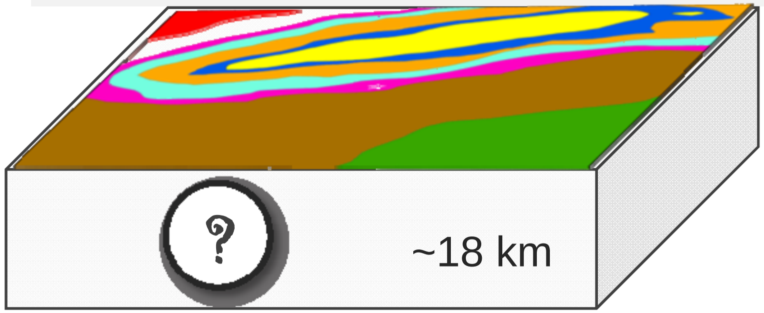


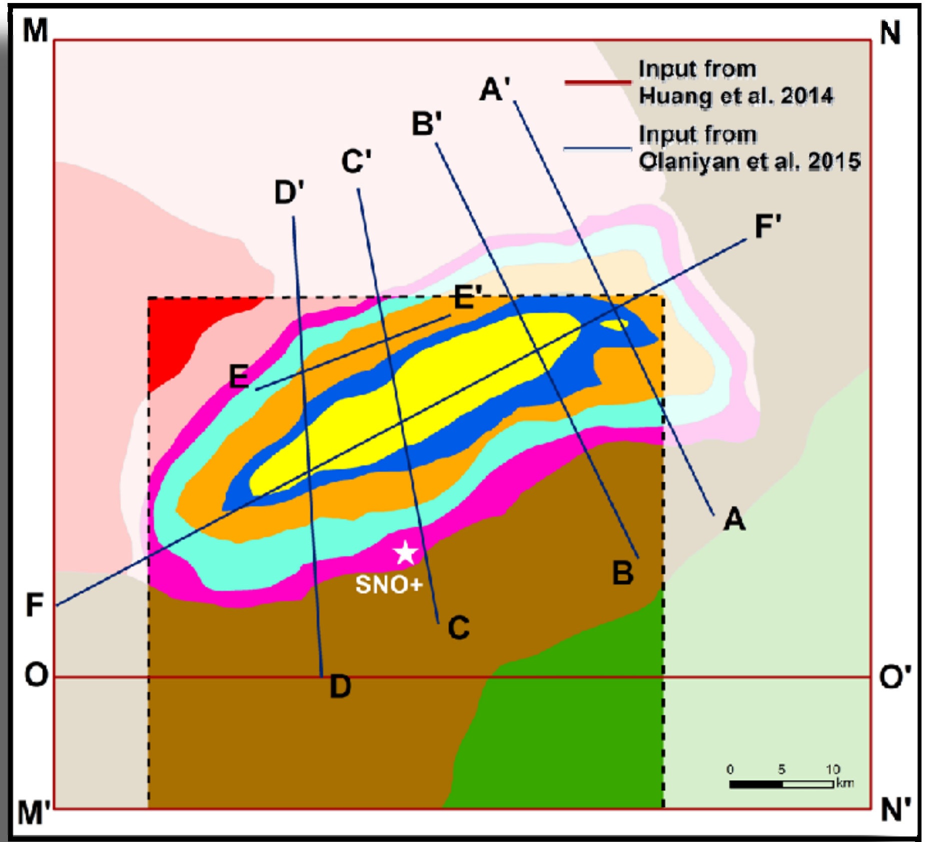


Geophysical uncertainties ~ 5%

Input

- Bedrock Geology of Ontario 1:250000 scale conveniently simplified
- 6 interpreted seismic profiles of the Sudbury Structure [(1)]
- 5 virtual cross sections [(2)]
- Orientation and structural data

Unit	ρ (g/cm³)
GT	2.73 ± 0.08
HI	2.75 ± 0.04
NG	2.83 ± 0.10
GN	2.70 ± 0.10
OP	2.77 ± 0.04
GF	2.73 ± 0.08
OW	2.68 ± 0.04
CM	2.75 ± 0.04
CT	2.65 ± 0.08

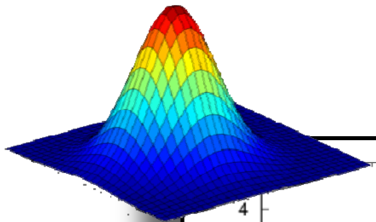


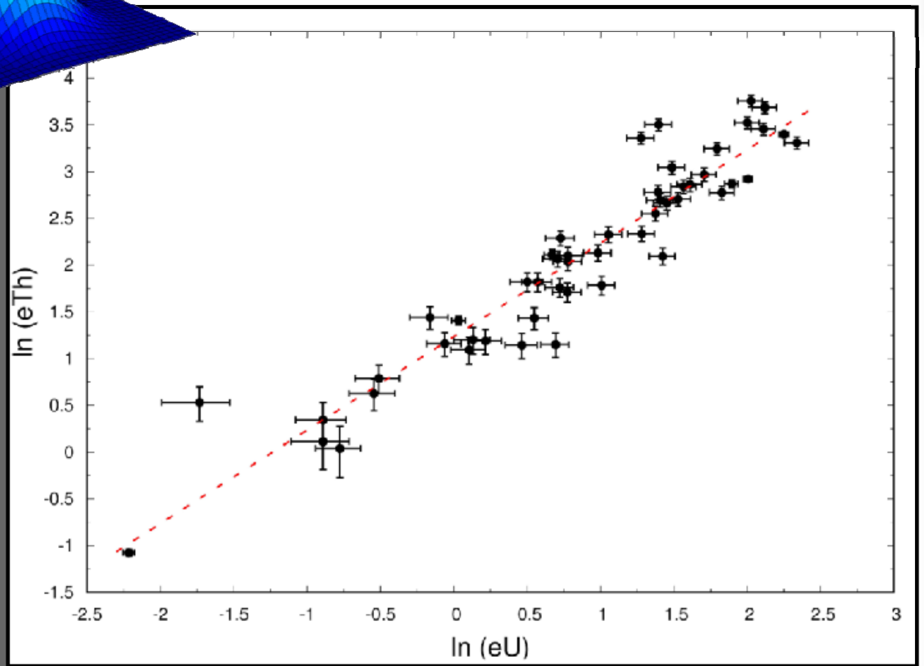
1 – Olanyian et al. 2015, Interpretation. 2 - Huang et al. 2014 Geoch. Geoph. Geosys

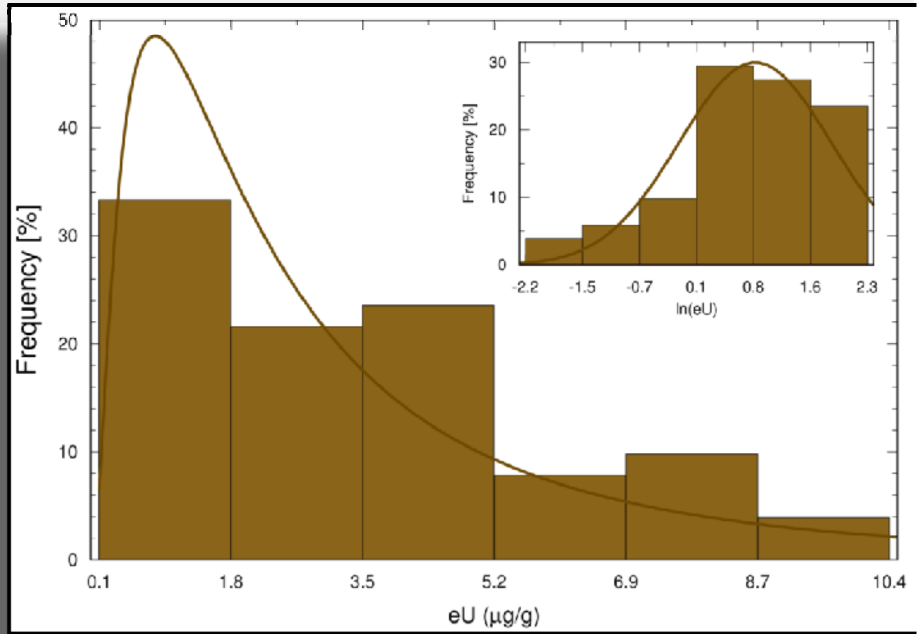
The geochemical characterization of the CUC

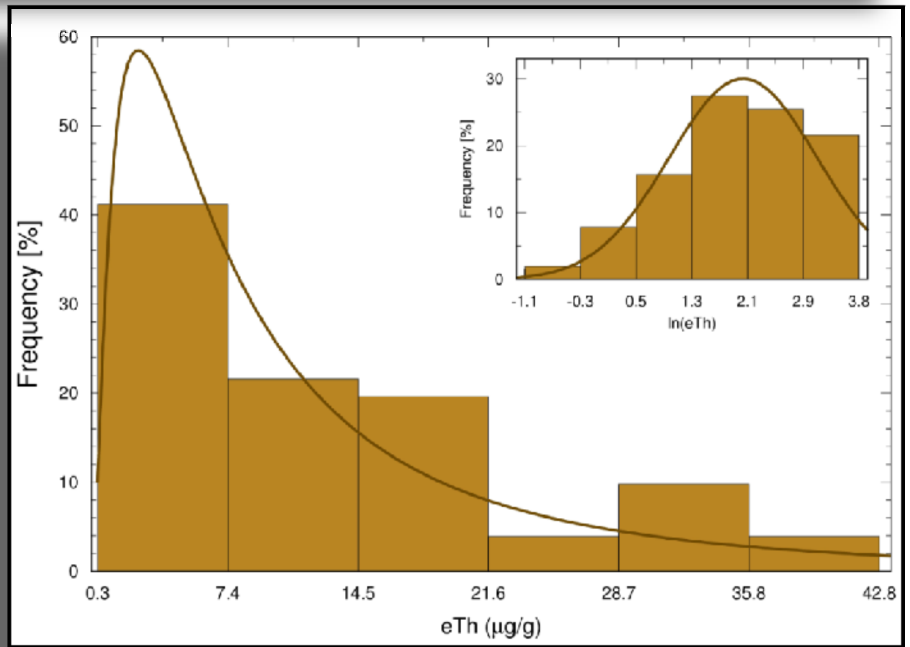
- For units with $N_{sample} > 10$ U and Th frequency distributions have been studied.
- Trace elements abundance are frequently characterized by right skewed distributions: investigation of Gaussian and Log-normal PDFs.
- In case of manifest (U, Th) correlation the calculation of geoν signal and its uncertainty on the basis of bivariate PDFs is mandatory

	U (ppm)	Th (ppm)	Corr. Coeff.
HI	$2.3^{+4.0}_{-1.5}$	$8.0^{+15.3}_{-5.3}$	0.95

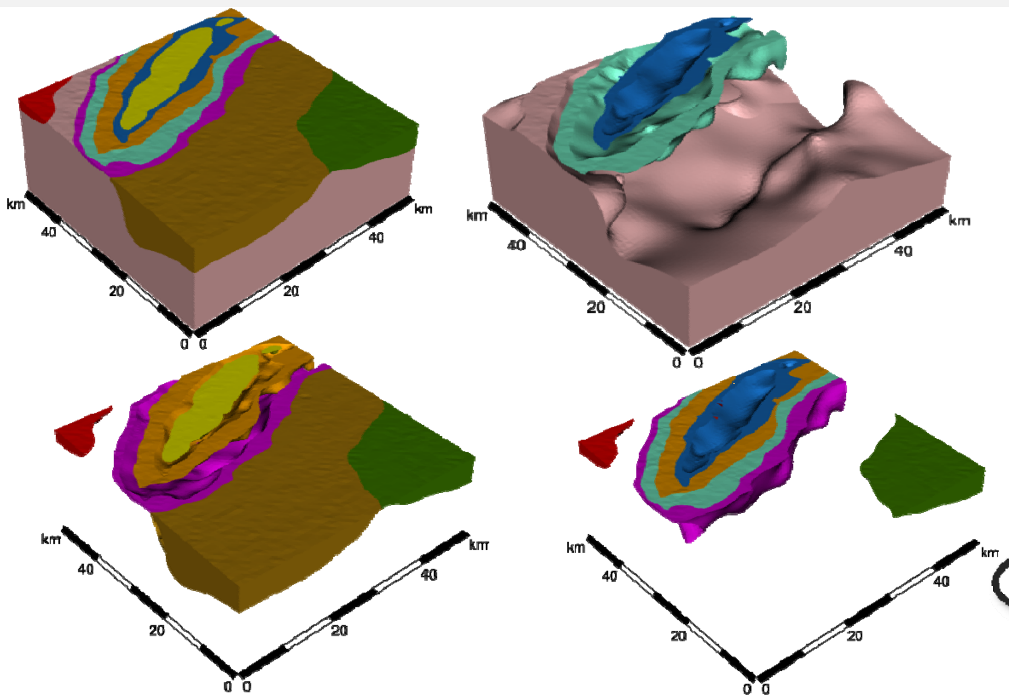


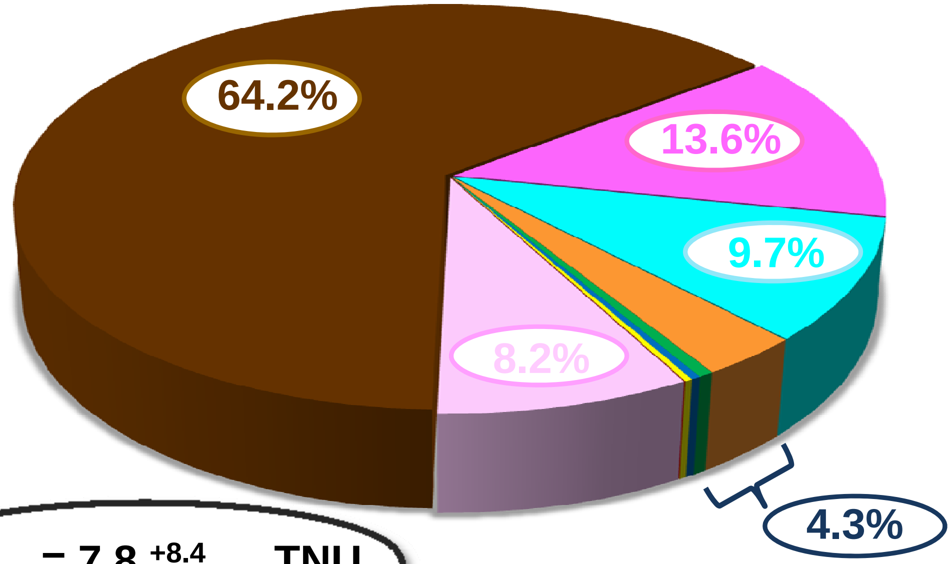






Geoneutrino signal from the CUC





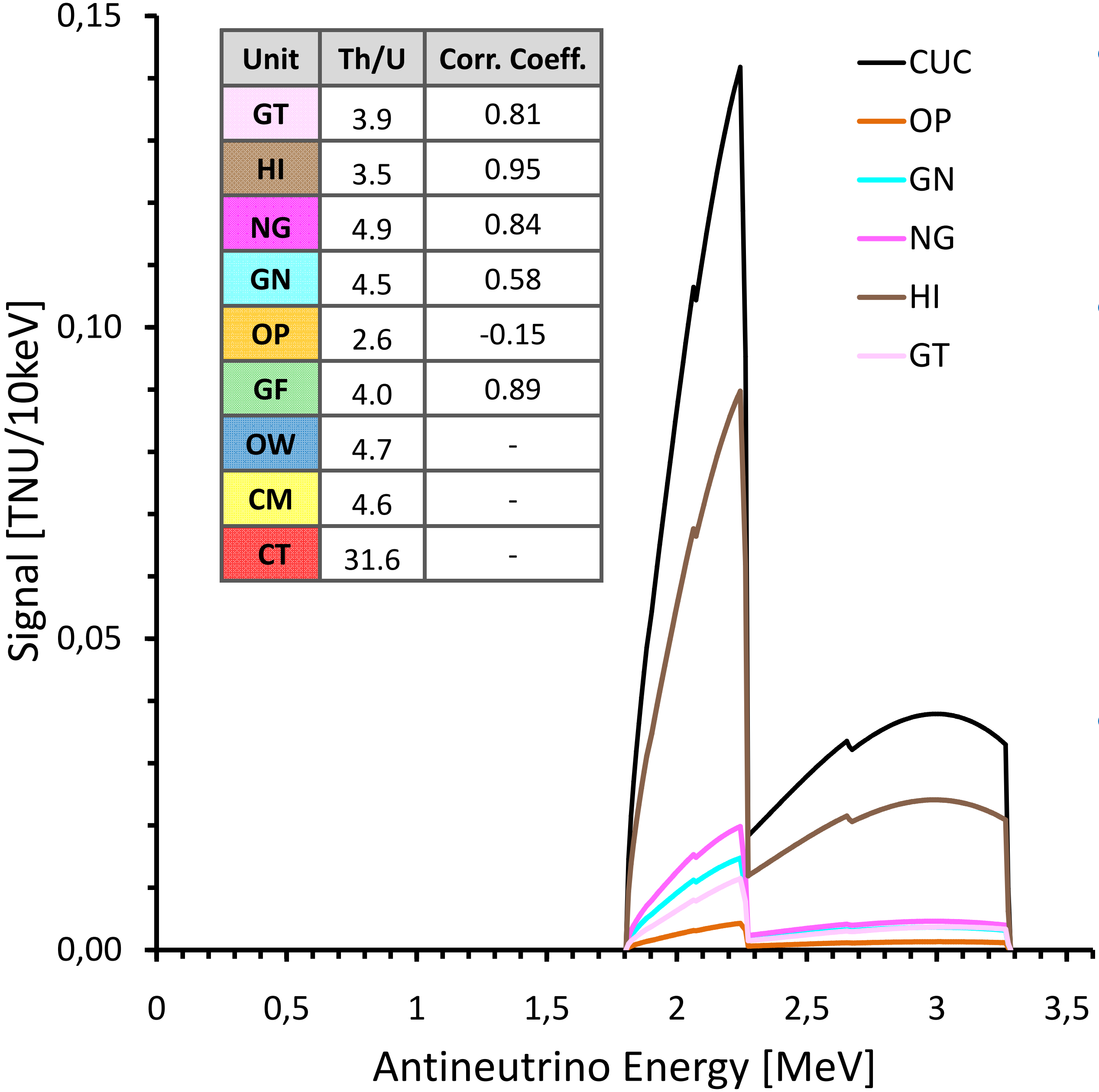
$S_{CUC} = 7.8\ ^{+8.4}_{-3.2}$ TNU

- The 5 smallest units (**CT** + **CM** + **OW** + **OP** + **GF**) accounting for ~5% of the CUC volume provide ~5% of the geoν signal from the CUC.
- Although the **GT** unit occupies > 60% of the CUC volume it produces <10% of the geoν signal from the CUC.
- The **HI** unit dominates the CUC geoν signal as well as its uncertainty.

Unit	Vol (%)	S (U+Th) [TNU]
GT	63.7	$0.6^{+0.9}_{-0.4}$
HI	22.6	$4.7\ ^{+8.4}_{-3.0}$
NG	5.7	$1.0\ ^{+0.4}_{-0.3}$
GN	3.1	0.71 ± 0.08
OP	2.0	0.24± 0.04
GF	1.8	$(3.6\ ^{+4.5}_{-2.1})\cdot 10^{-2}$
OW	0.6	$(2.2\pm 0.2)\cdot 10^{-2}$
CM	0.5	$(1.8\pm 0.2)\cdot 10^{-2}$
CT	0.1	$(1.0\pm 0.4)\cdot 10^{-4}$

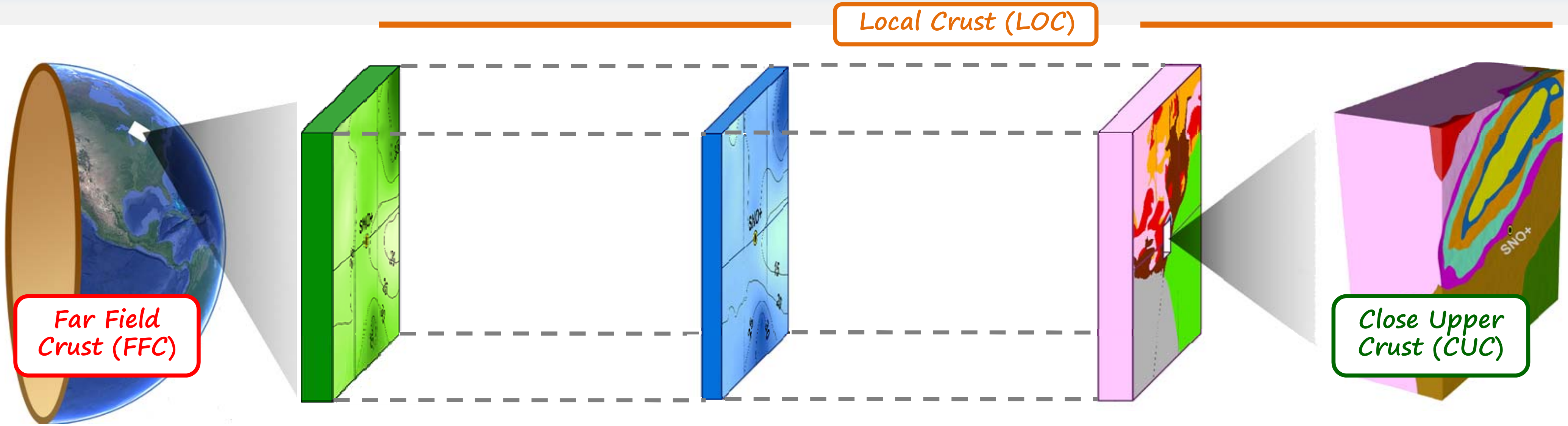
Geoneutrino spectrum from the CUC

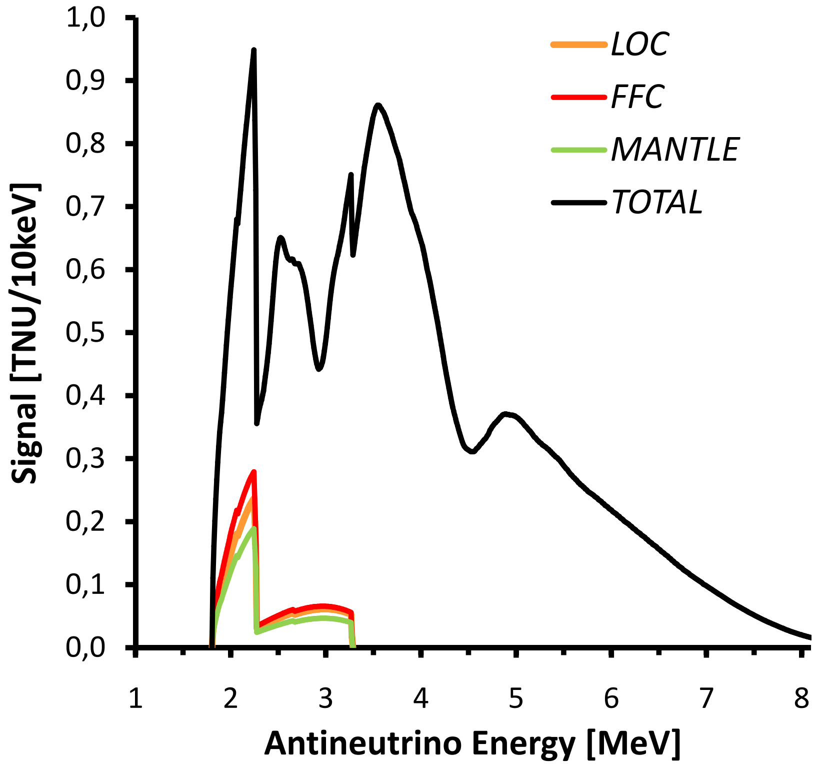
Unit	Th/U	Corr. Coeff.
GT	3.9	0.81
HI	3.5	0.95
NG	4.9	0.84
GN	4.5	0.58
OP	2.6	-0.15
GF	4.0	0.89
OW	4.7	-
CM	4.6	-
CT	31.6	-



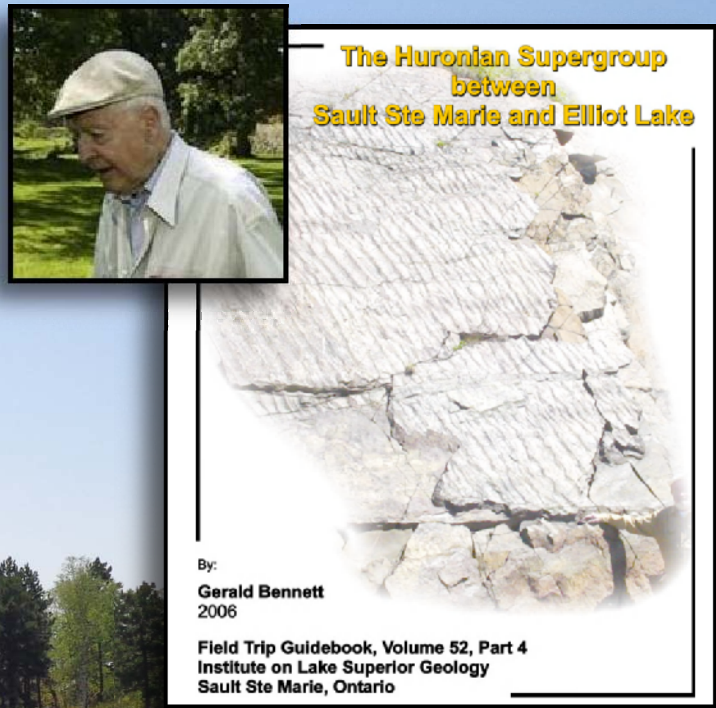
- Not all the units of the CUC exhibit a good correlation between U and Th contents.
- When a good correlation is observed it is not always true that U and Th abundances reproduce the Th/U = 3.9 chondritic ratio.
- When interpreting SNO+ experimental data possible deviations from a fixed chondritic ratio should be kept in mind

Conclusions and perspectives





- A refined model of the ***Close Upper Crust (CUC)*** around SNO+ is obtained by integrating regional geophysical and geochemical data of the area in a coherent crustal 3D picture
- U and Th in the ***CUC*** provide ~**50%** of the ***LOC*** signal
- The 1σ uncertainty on S_{CUC} is essentially given by the uncertainty on the **HI** signal, which is of the same order of the mantle signal spread according to different models
- The shape of the geoν spectrum can reflect different **Th/U ratios** which could be taken into account in the analysis of SNO+ experimental data



The Huronian Supergroup
between
Sault Ste Marie and Elliot Lake

By:

Gerald Bennett
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Field Trip Guidebook, Volume 52, Part 4
Institute on Lake Superior Geology
Sault Ste Marie, Ontario

"I would like to acknowledge the rocks of the Huronian Supergroup for providing me with so many years stimulating and rewarding work and for teaching me so much, only to eventually show me how much more there was to learn"