Integrating geological, geochemical and geophysical data and uncertainties into a coherent 3D model

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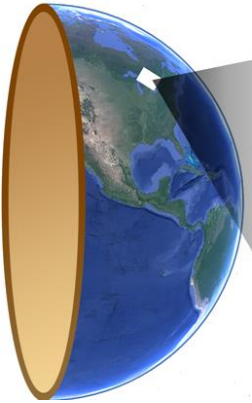
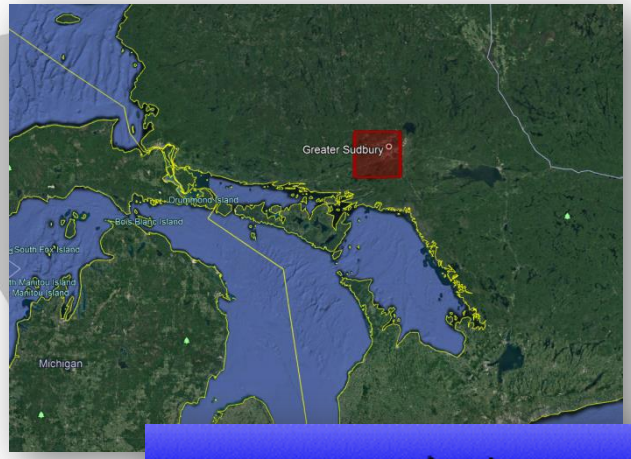
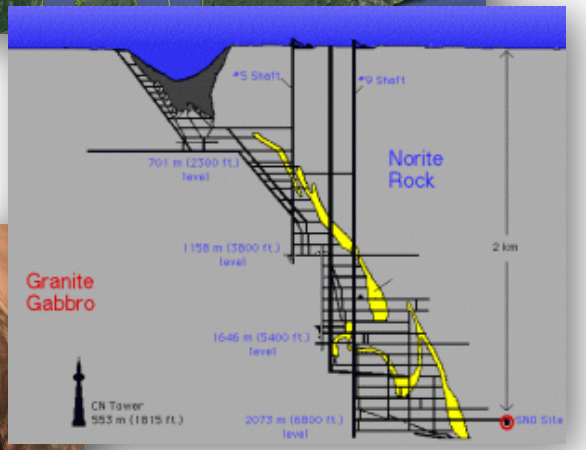
A 3D crustal model for the SNO+ experiment





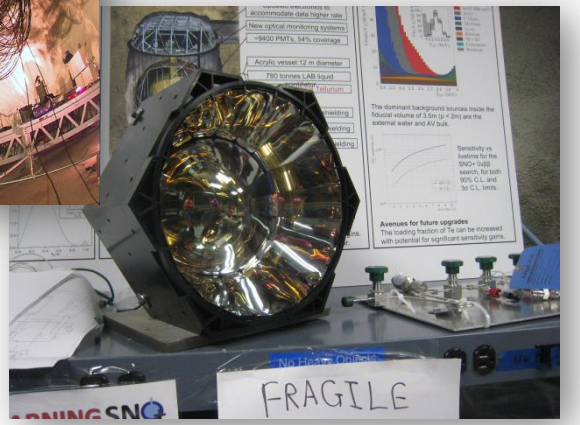
STUDY AREA

The **50 x 50 km** area centered at **SNOLAB**, an underground (2092 m) physics laboratory at Sudbury (Ontario, Canada).



THE SNO+ EXPERIMENT

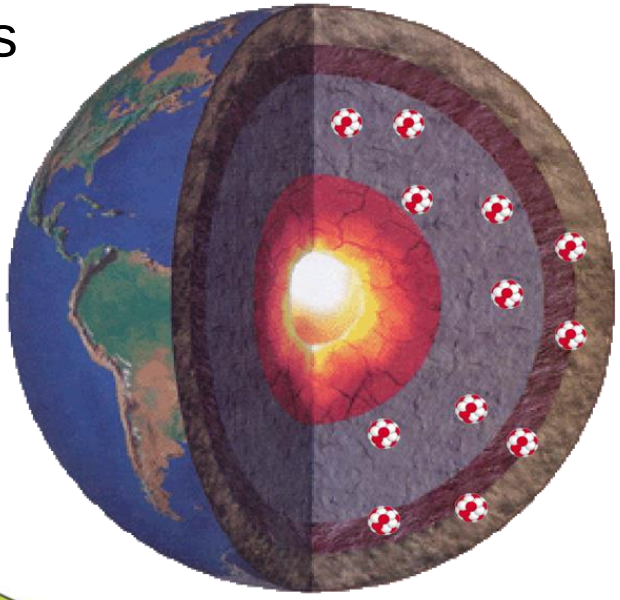
- 12 m diameter Acrylic Vessel
- 1000 tons of Liquid scintillator
- 9438 Photomultiplier Tubes of 20 cm diameter
- Investigate the properties of neutrinos and of their sources…
- …in particular **GEONEUTRINOS** the antineutrinos from the Earth



Geoneutrinos: a new probe for Earth interior

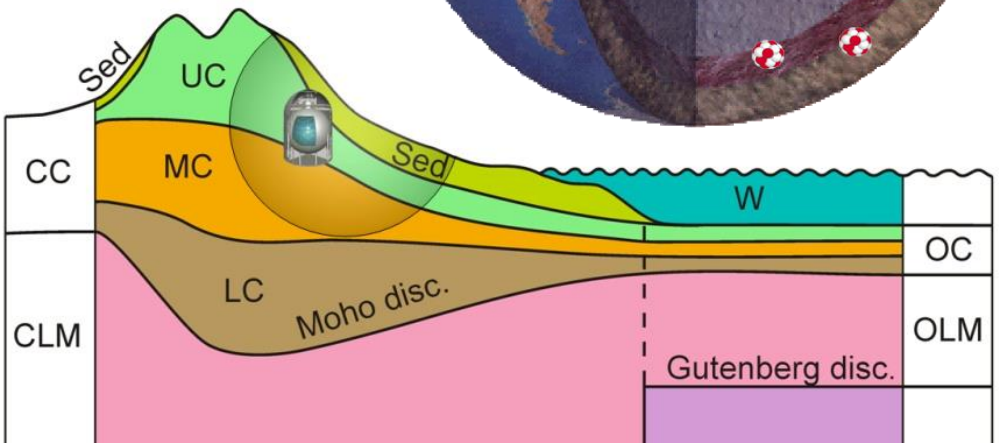
• Electron antineutrinos produced in beta minus decays of naturally occurring radioactive isotopes (U & Th) in the Earth

$$\phi_{\bar{\nu}} \sim 10^{6}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$$



$$dS(U) \sim \frac{\rho \cdot dV \cdot a(U)}{r^2}$$

• The cross section of geoneutrinos is very low: they could straight through more than a trillion kilometers of lead



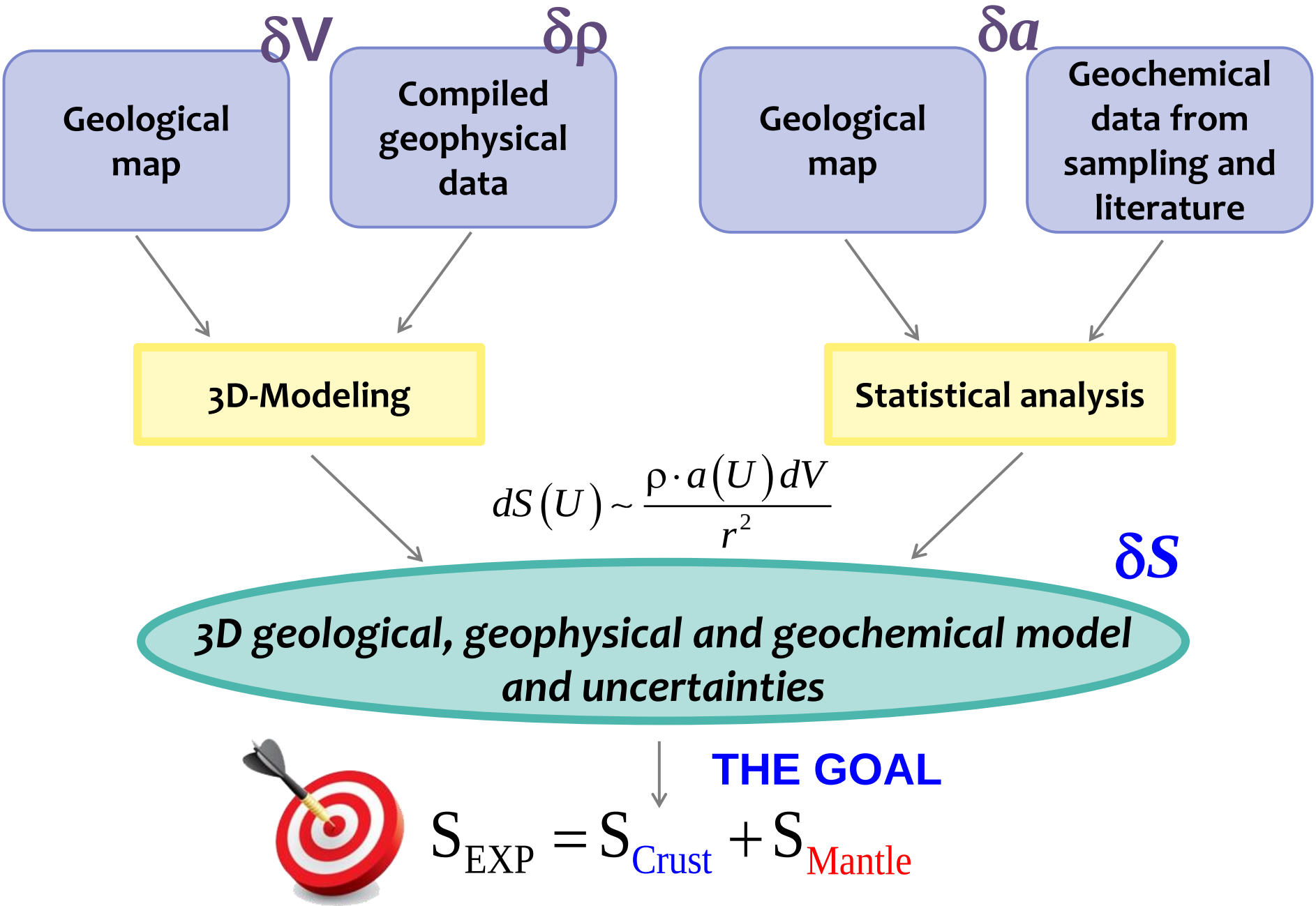
$$S_{EXP} = S_{Crust} + S_{Mantle}$$

EXPerimental signal — Modeled signal

With a measurement of mantle radioactivity we can…

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

A integrated approach for modeling the crust

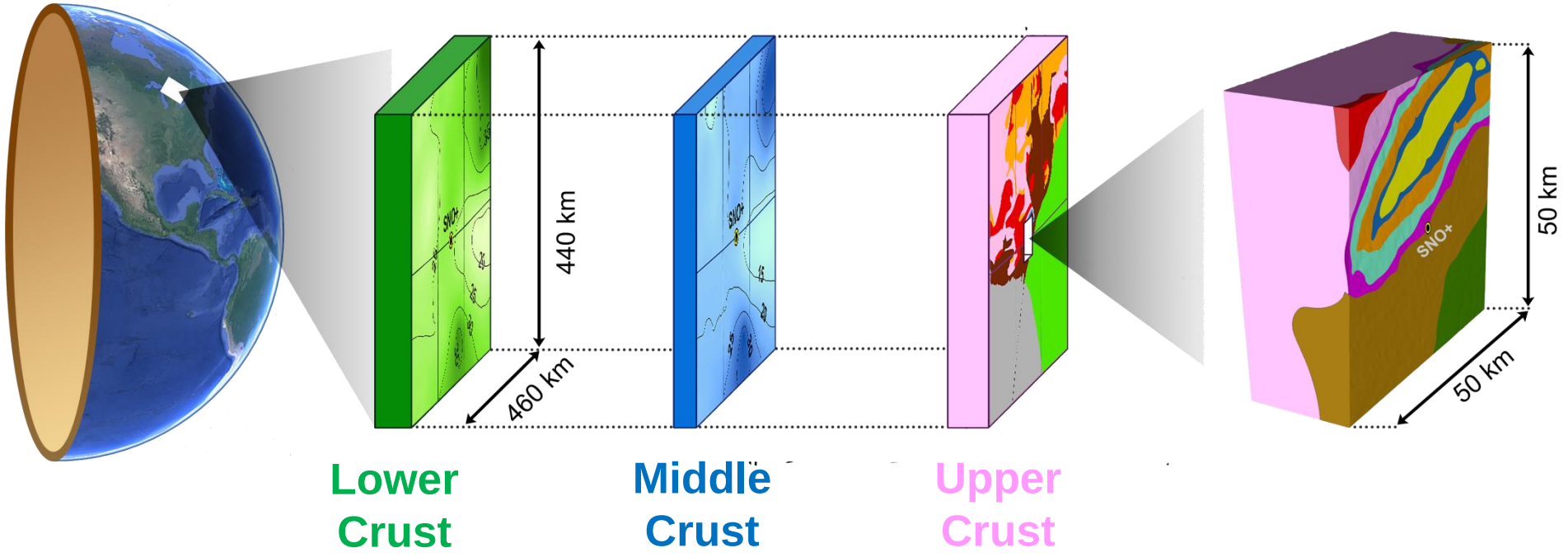


Contributions to the crustal geoneutrino signal

49 %
Far field crust

26 %
LOcal Crust (LOC)

25 %
Close Upper Crust (CUC)



Lower Crust

Middle Crust

Upper Crust

NEW

1st refined crustal model with geophysical uncertainties

Huang Y et al. (2014) Geoch., Geoph, Geosys.

NEW

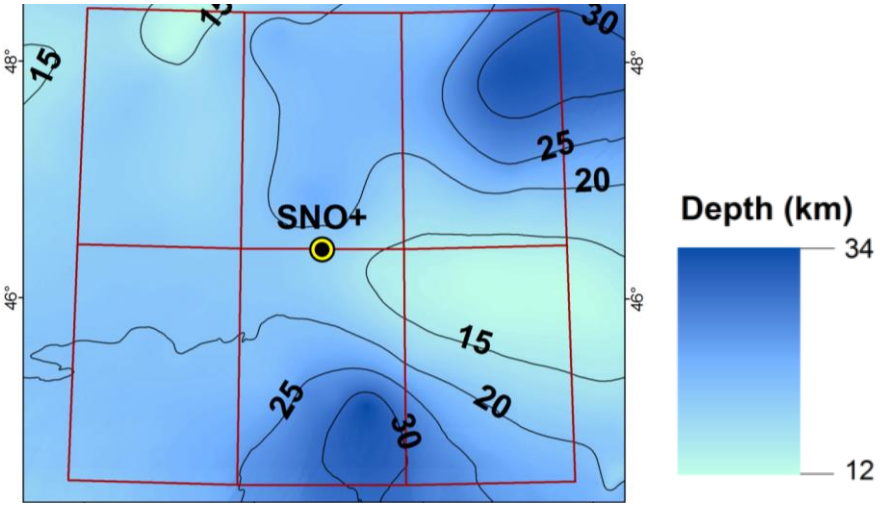
Focus on the upper crust: rock sampling

Strati V et al. (2017) Geoch., Geoph, Geosys.

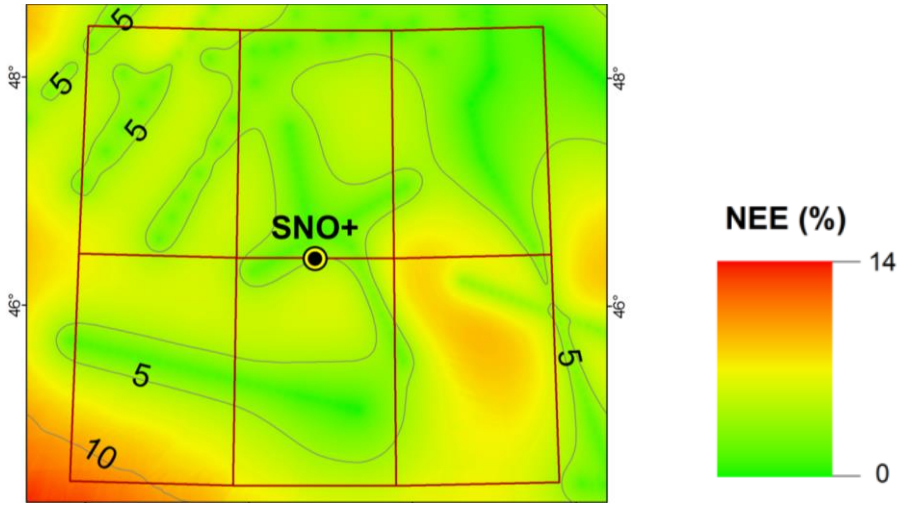
The geophysical model of the LOC

- Modeling of the **440 km x 460 km area** using **compiled seismic data**
- **Spatial interpolation** of depth control points with the Ordinary Kriging

Top of the Middle Crust



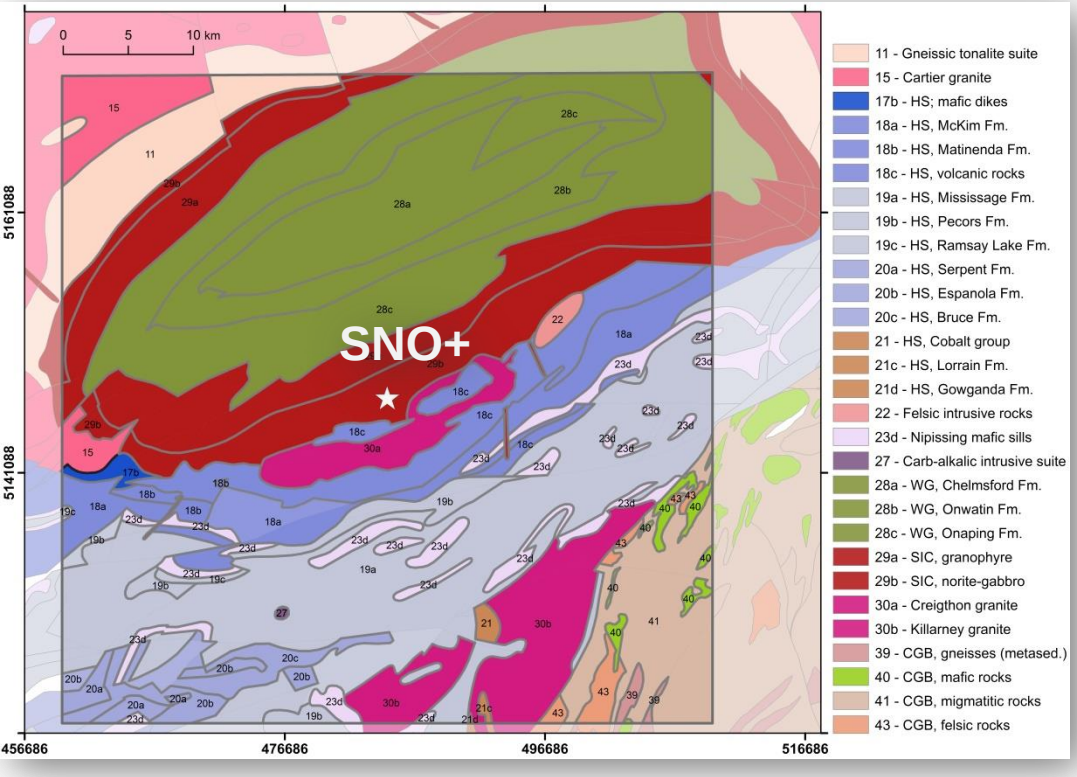
Estimation error map



	CRUST 1.0	Huang et al. 2014[1]		
	M [10^{18} kg]	Volume [10^{6} km^3]	Density [10^{3} kg/m^3]	M [10^{18} kg]
UC	**6.6**	**4.2 ± 0.2**	**2.73 ± 0.08**	**11.5 ± 0.6**
MC	**8.1**	**1.3 ± 0.1**	**2.96 ± 0.03**	**3.8 ± 0.3**
LC	**8.0**	**3.2 ± 0.2**	**3.08 ± 0.06**	**9.9 ± 0.6**
Total	**22.7**	8.7 ± 0.5	-	**25.2 ±1.6**

The identification of the units of the CUC

Bedrock Geology of Ontario map 1:250,000 scale



Simplified geological map: 9 lithologic units

Gneissic Tonalite suite (3.0 Ga)

Grenville Front Tectonic zone (1.5 Ga)

Cartier Granite (2.5 Ga)

Huronian Supergroup and intrusions (2.4 Ga)

Sudbury Igneous Complex (1.85 Ga)

Granophyre

Norite-gabbro

Whitewater Group (1.6 Ga)

Chelmsford Fm.

Onwatin Fm.

Onaping Fm.

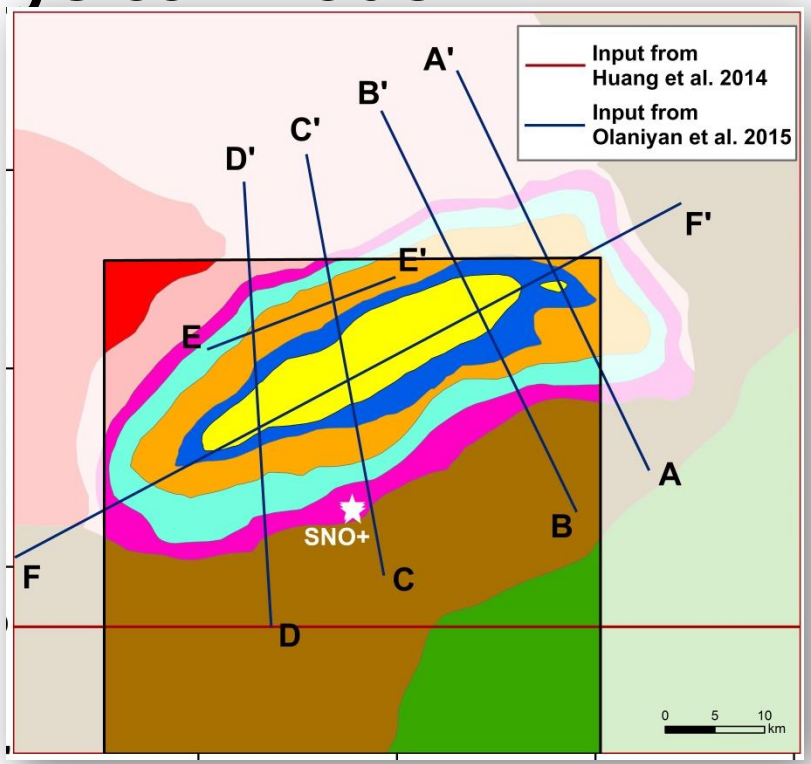
CRITERIA FOR CLUSTERING THE UNITS

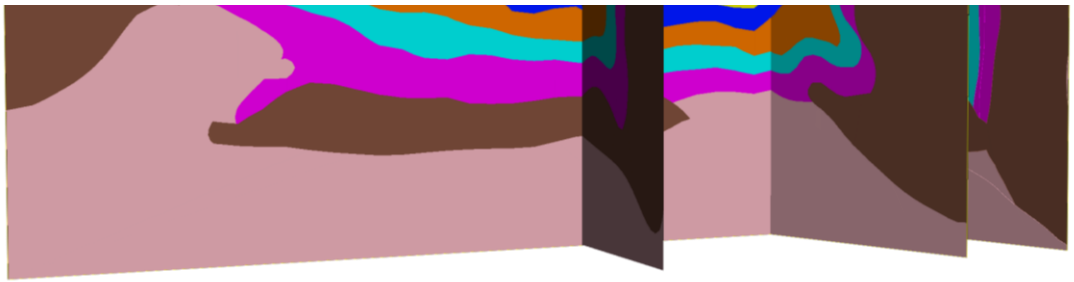
- spatial resolution of the available information about crustal structure
- lithology, tectonic events, and evolutional history

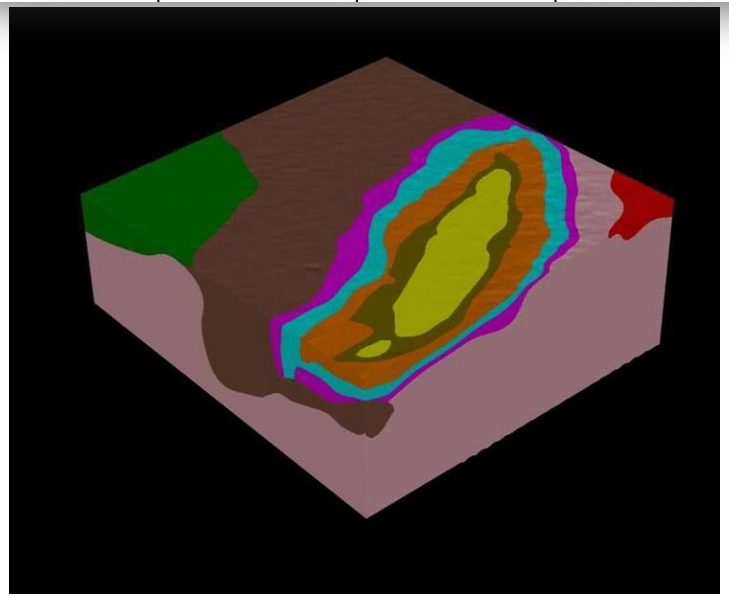
Building the 3D geophysical model

3D interpolator method based on potential field theory using hard geological constraints.

- 6 interpreted seismic/gravimetric profiles[1]
- 5 virtual cross sections[2]
- Simplified geological map
- Digital elevation model
- Orientation and structural data
- Stratigraphic succession of geological formations







Density values with uncertainties from gravimetric data[1] and compiled databases[2]

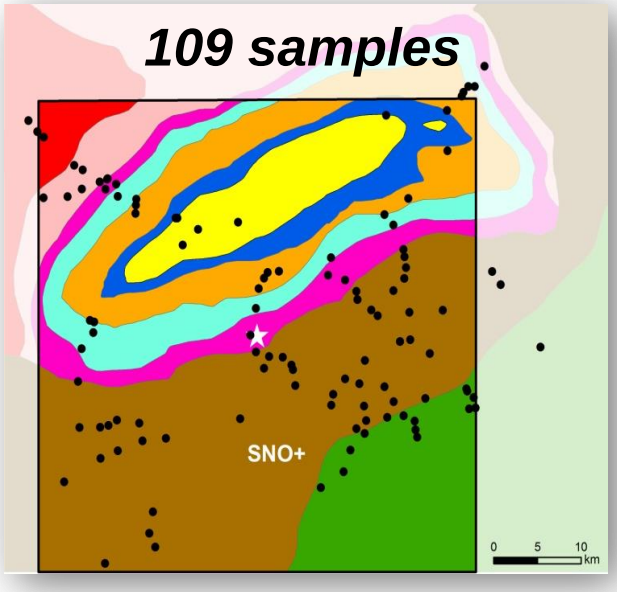
1 – Olanyian et al. 2015, Can. J. Earth Sci
2 - Huang Y et al. (2014), Geoch, Geoph, Geosys.

Geochemical data: ad hoc rock sampling

Planning of the sampling:

- Exposure surface of geological formations (~ 1 sample per 15 km^2)
- Estimated volume
- Proximity to the detector
- Accessibility of the outcrops

U and Th abundances from gamma-ray spectroscopy (HPGe) and ICPMS analysis

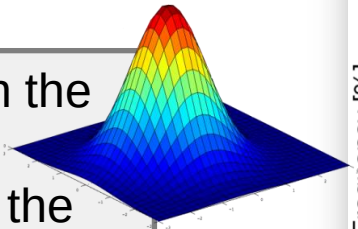


Population of unbiased U and Th frequency distributions for each unit

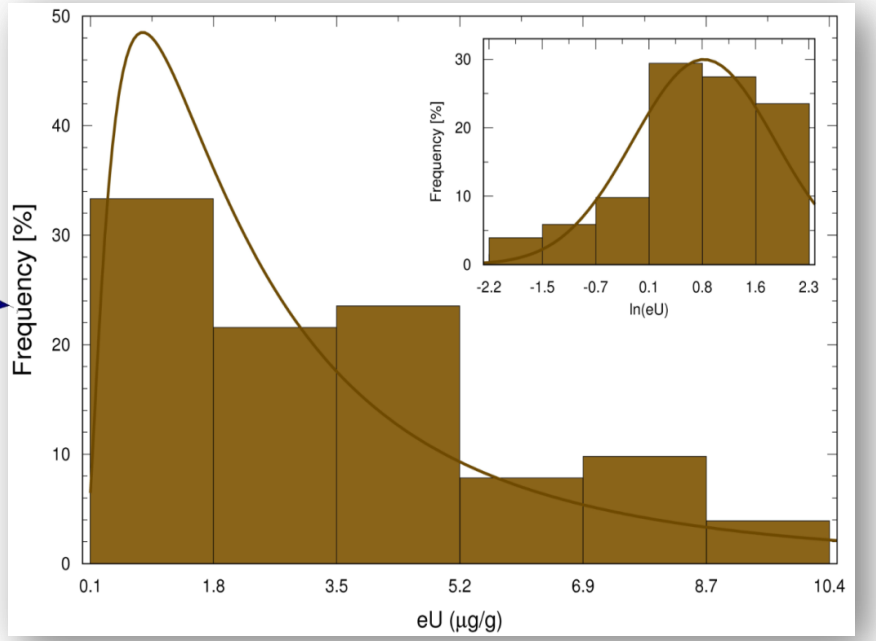
Geochemical data: statistical analysis

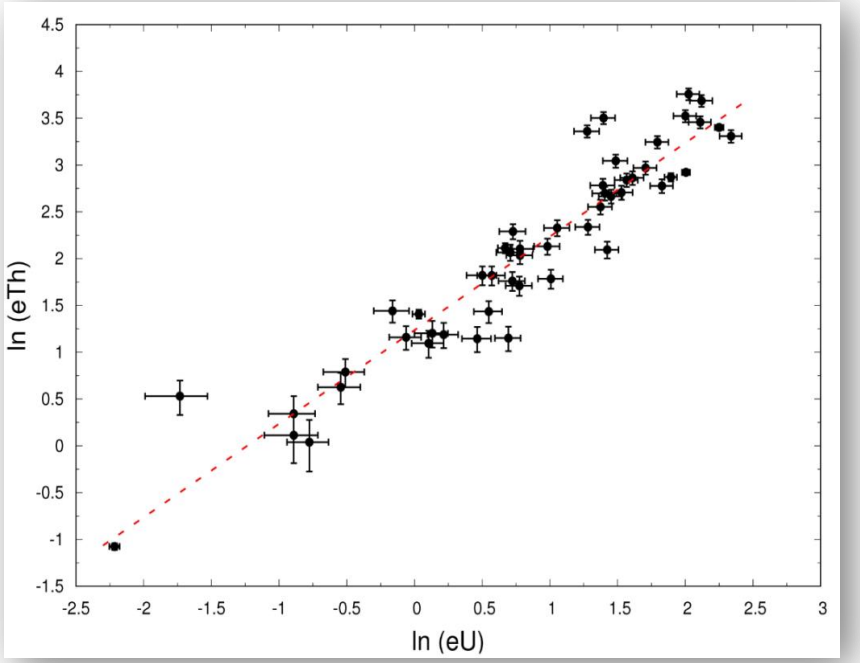
N_{sample} > 10: study of U and Th frequency distributions: investigation of Gaussian and Log-normal PDFs

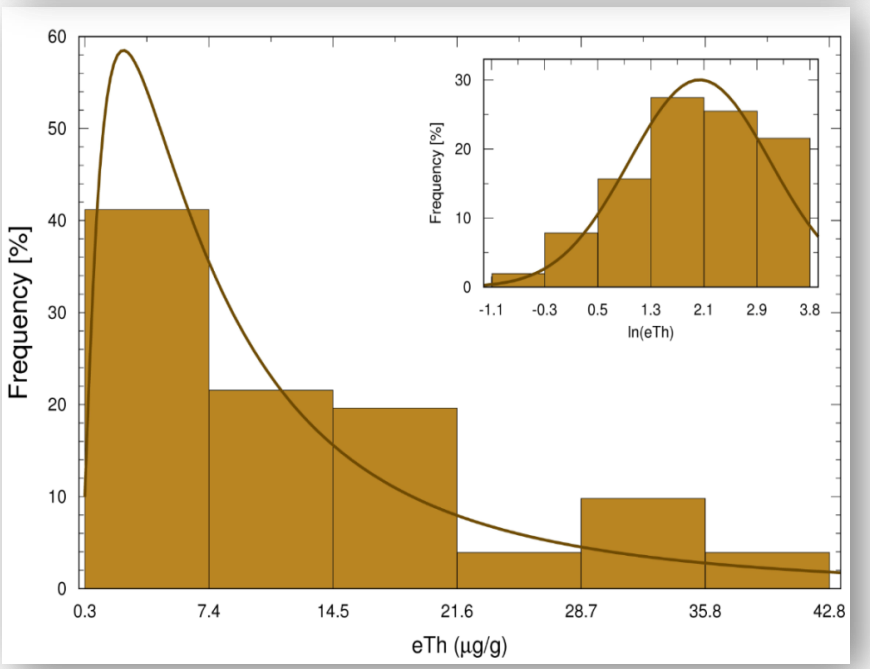
For manifest (U, Th) correlation the total geoneutrino signal and its uncertainty were calculated on the basis of bivariate PDFs



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



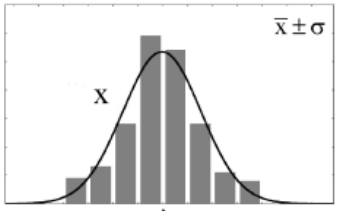


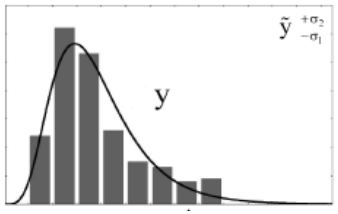


Geoneutrino signals calculation

INPUT

Geophysical data
Normal distribution





INPUT

Geochemical data
Lognormal distribution

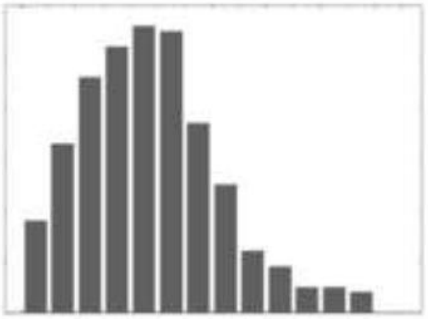
95% of Volume

Unit	Density [g/cm^3]	Volume [10^3km^3]
GT	2.73 ± 0.08	29.69 ± 1.40
HI	2.75 ± 0.04	10.52 ± 0.49
NG	2.83 ± 0.10	2.64 ± 0.12
GN	2.70 ± 0.10	1.43 ± 0.07

Unit	*a*(U) [μg/g]	*a*(Th) [μg/g]
GT	$0.7^{+1.0}_{-0.4}$	$2.7^{+6.0}_{-1.9}$
HI	$2.3^{+4.0}_{-1.5}$	$8.0^{+15.3}_{-5.3}$
NG	$1.2^{+0.6}_{-0.4}$	$5.9^{+2.1}_{-1.6}$
GN	3.3 ± 0.3	15.0 ± 1.5

Monte Carlo uncertainty propagation procedure
with known distributions (not limited to Gaussian) and correlations

OUTPUT

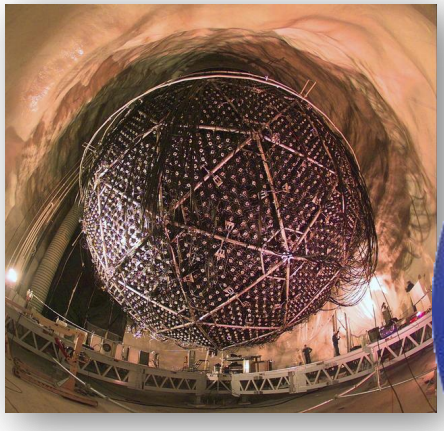


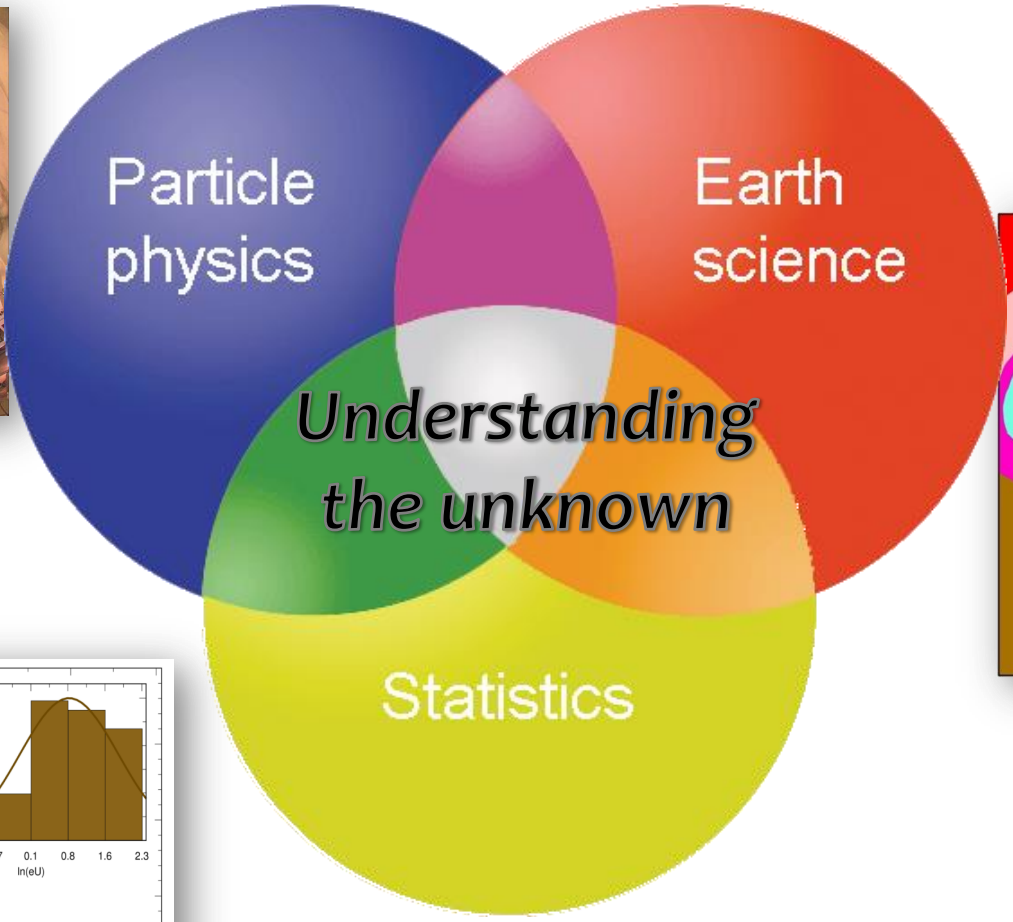
Unit	Signal (U+Th) [TNU]
GT	$0.6^{+0.9}_{-0.4}$
HI	$4.7^{+8.4}_{-3.0}$
NG	$1.0^{+0.4}_{-0.3}$
GN	0.71 ± 0.08

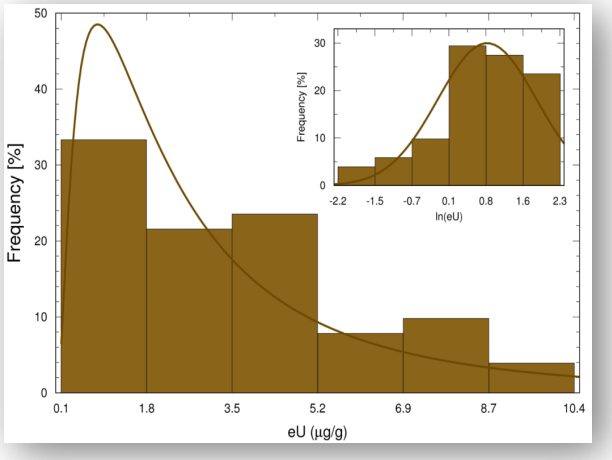
GEONEUTRINO SIGNAL @ SNO+

In short words…

Geoneutrinos results are the melting of three disciplines







Different sources of uncertainty have to be combined for building a homogenous picture of the Earth

Thank you