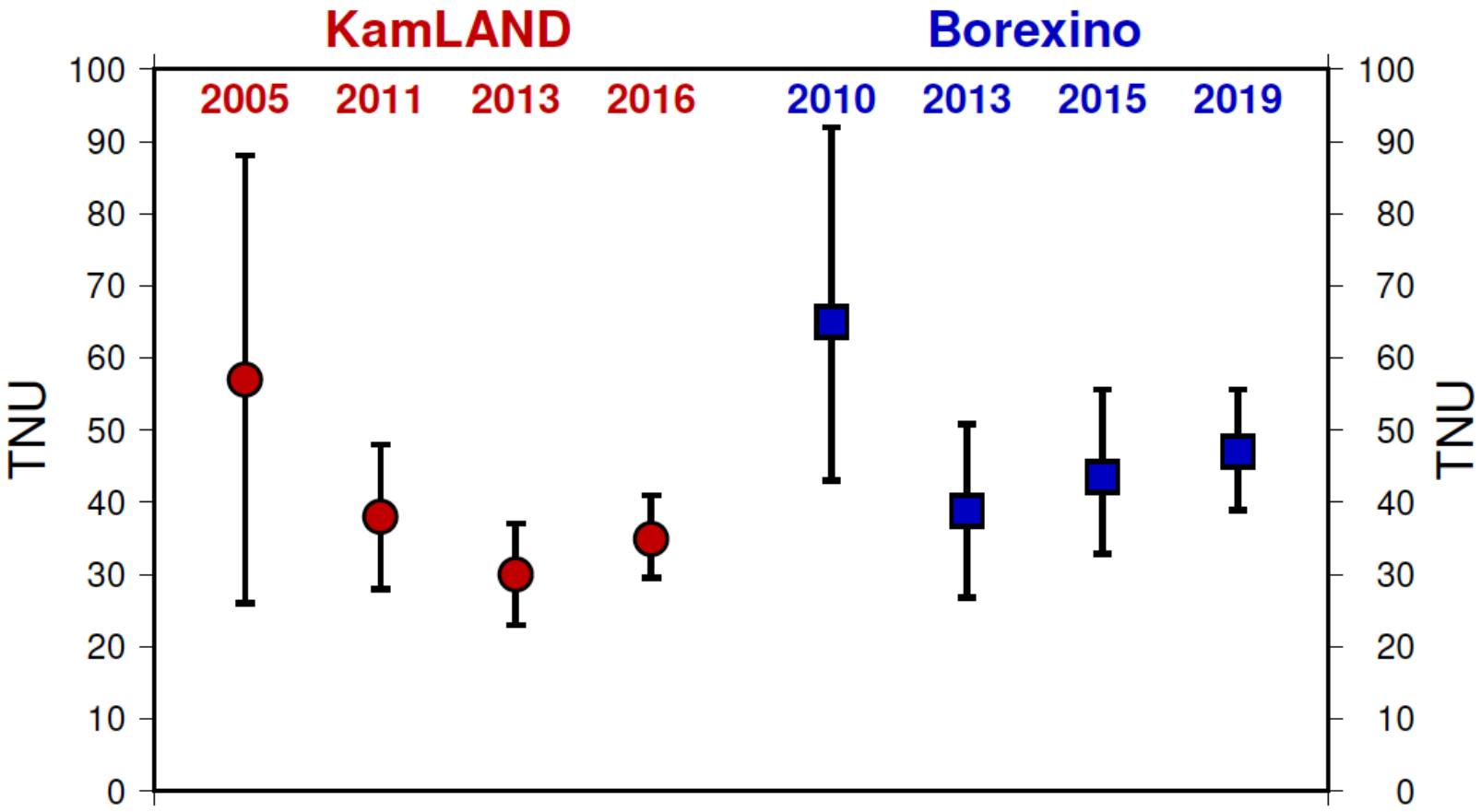
Geo-neutrinos in SNO+

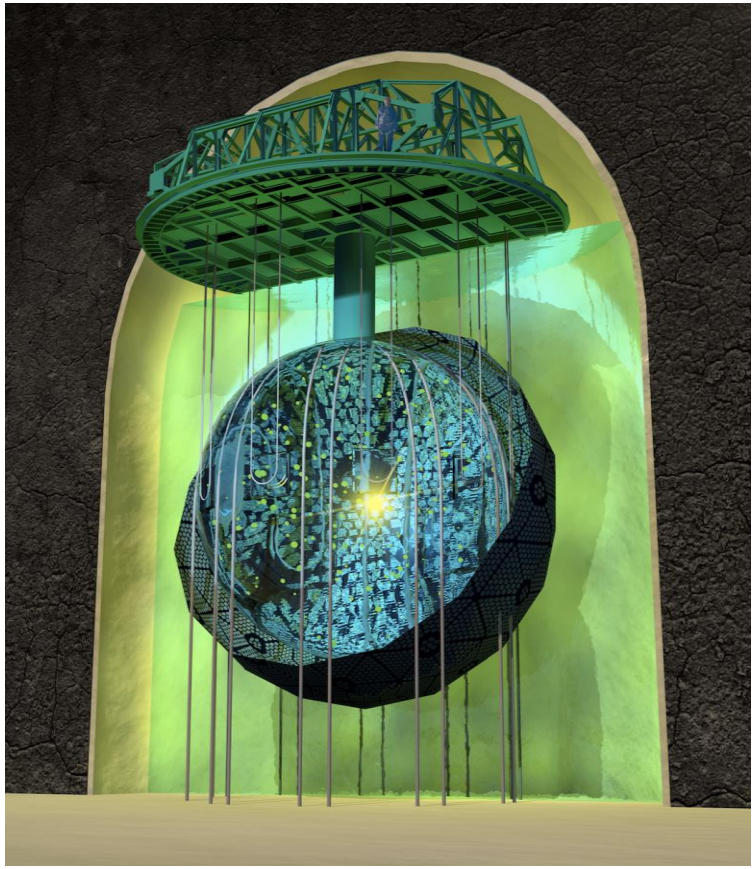
Ingrida Semenec
SNO+ collaboration
Queen’s University



courtesy of O.Šrámek

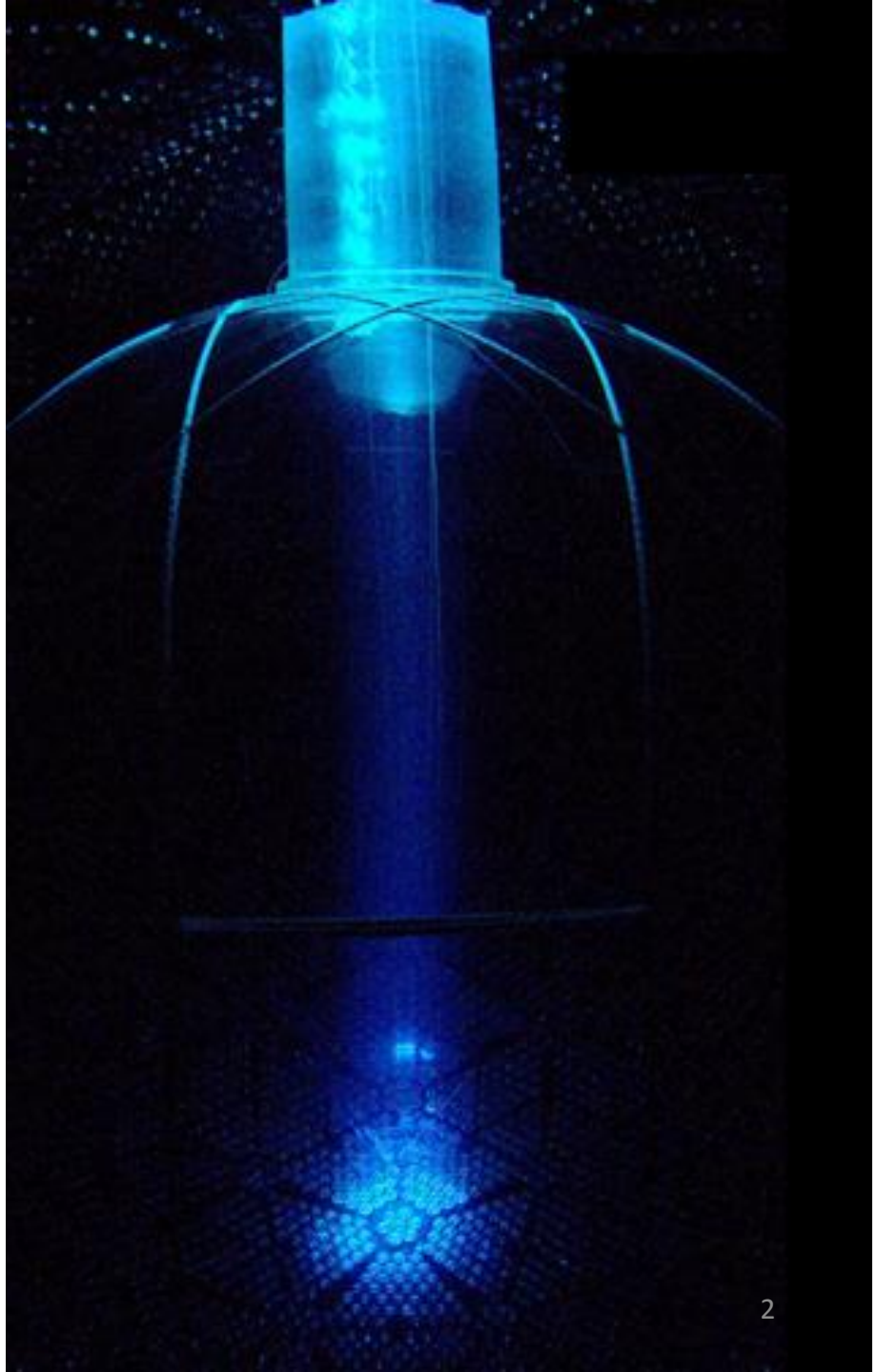
SNO+ ???

Start taking geoneutrino data 2020



Overview

- SNOLAB and SNO+
- Physics program
- Water phase results
- Current status
- Geo-neutrinos



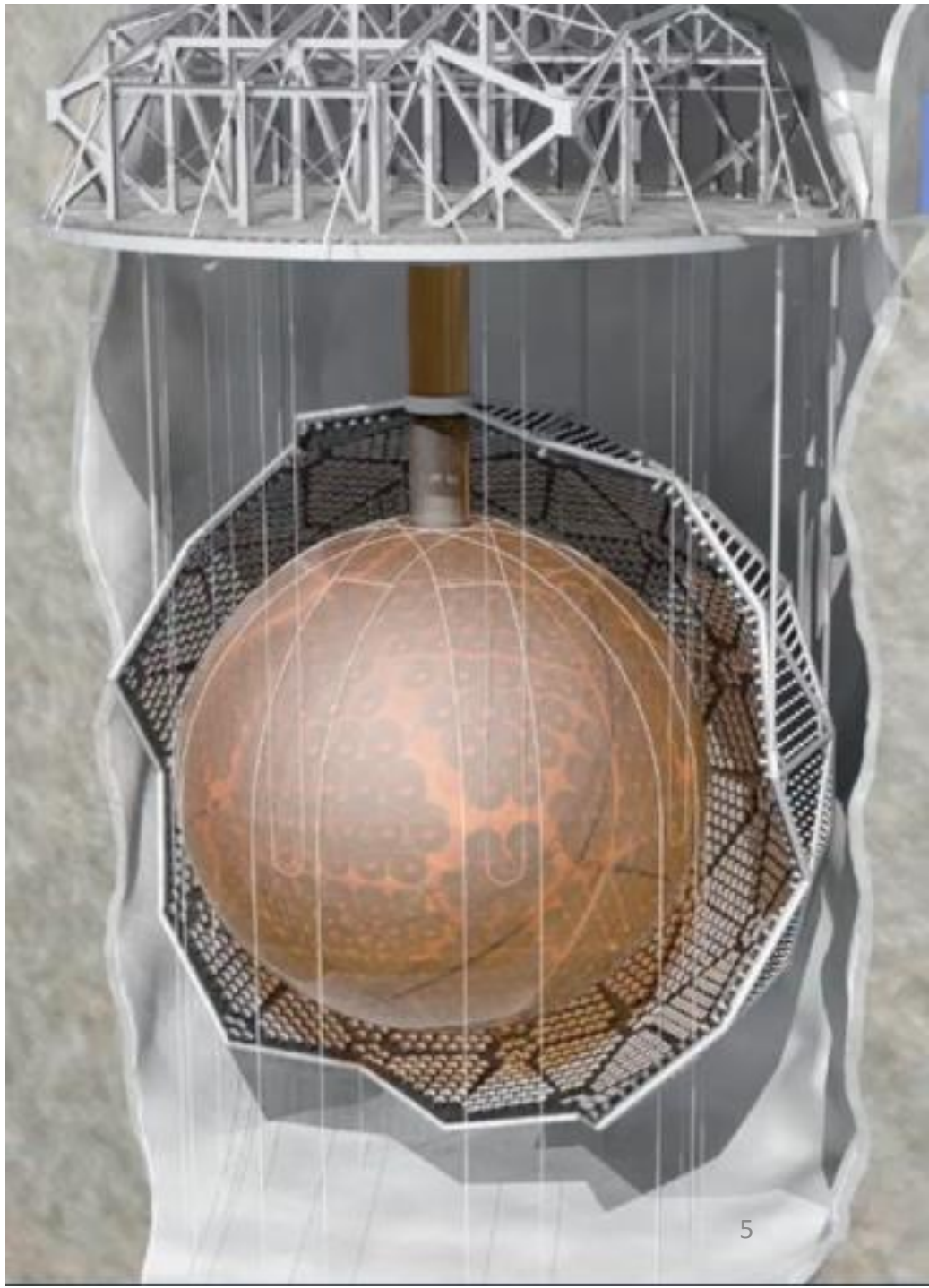
SNOLAB

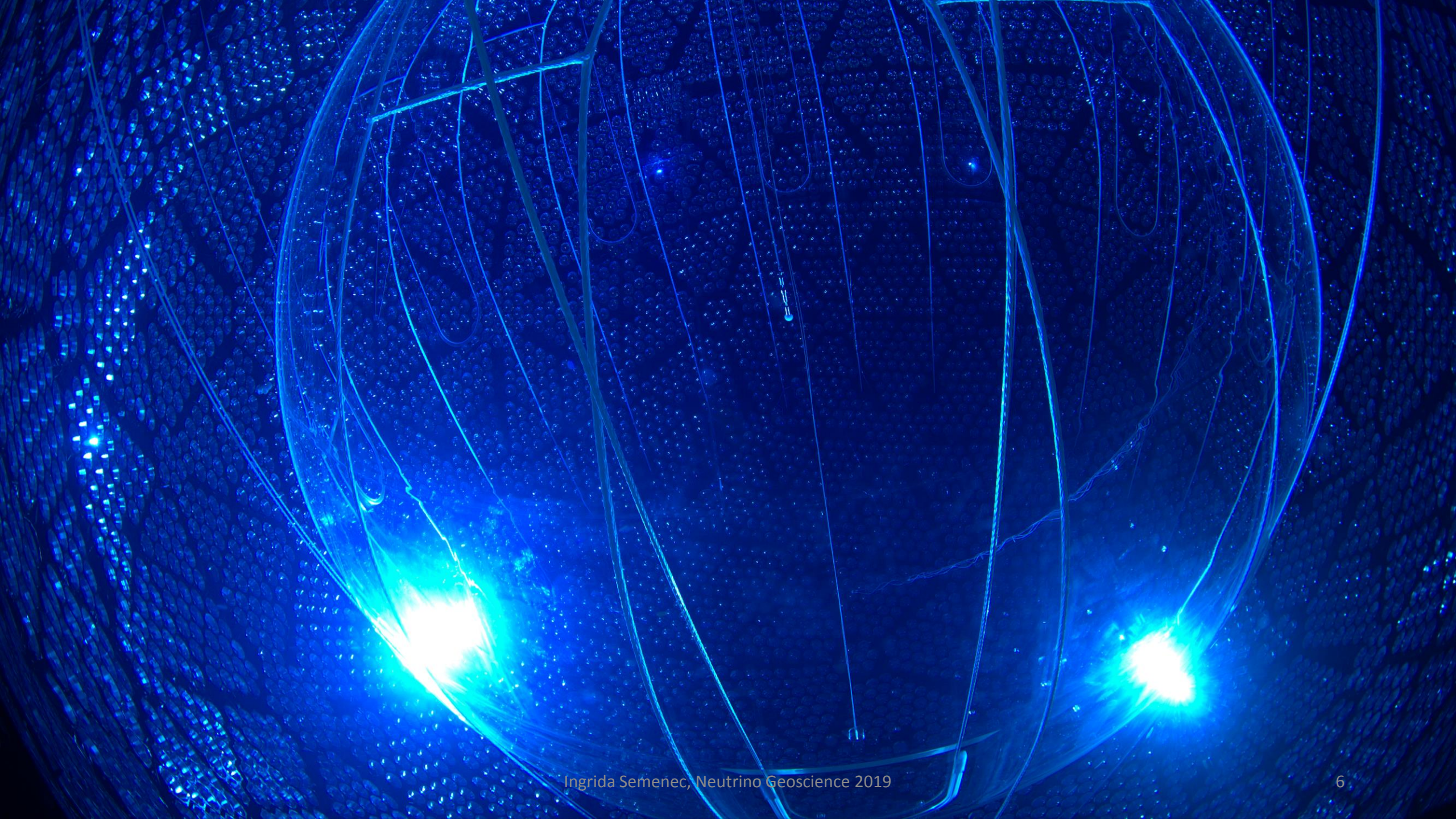
- Located in Creighton Mine, Sudbury, Canada
- ~2070 m underground!

SNO+ Collaboration

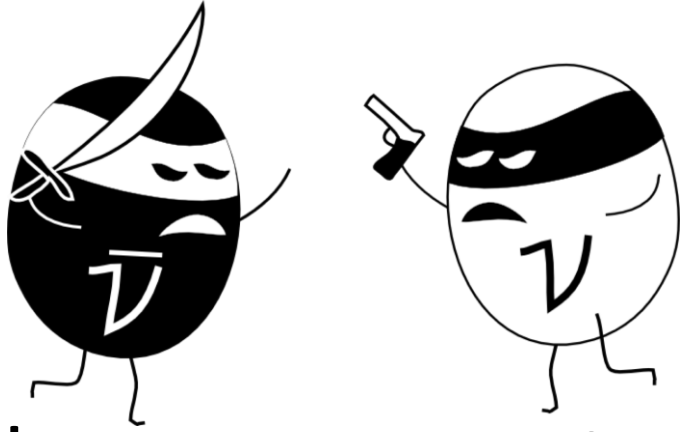
SNO+

- Successor experiment to Sudbury Neutrino Observatory (SNO)
- 780 tonnes of liquid scintillator (LAB) inside a 12 m diameter acrylic vessel. LAB to be loaded with PPO+3.9 tonnes of Tellurium.
- Hold-down rope system to restrain buoyant force
- ~9400 PMTs, ~54% effective coverage
- 7000 tonnes of ultra-pure water shielding





Physics program



Water phase

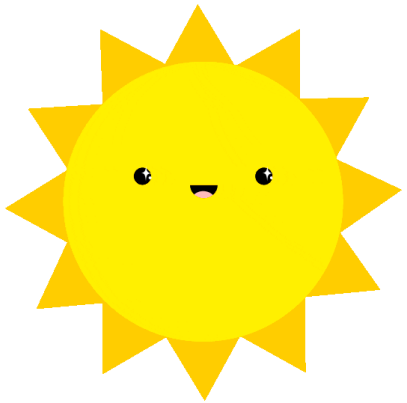
- Detector calibration
- Background measurements
- Nucleon decay searches
- ^{8}B solar neutrino flux

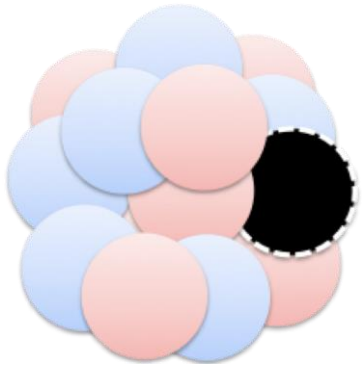
Scintillator phase

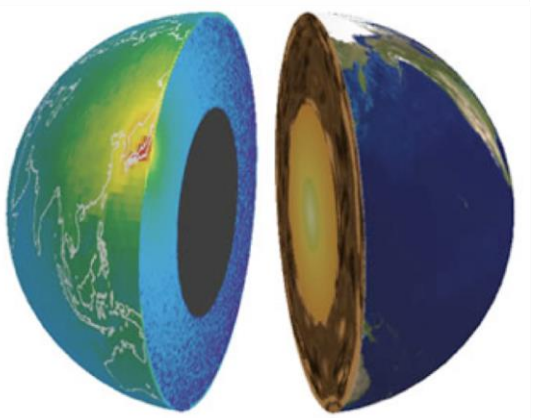
- Background measurements
- Low energy solar neutrinos
- Geo and reactor antineutrinos

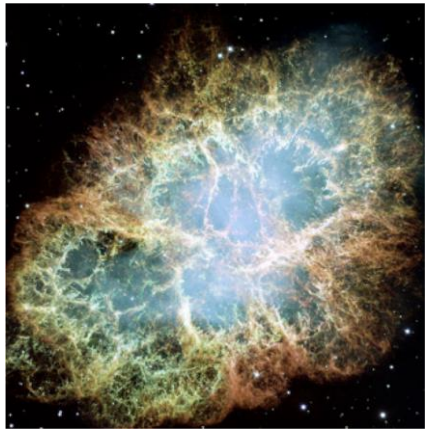
Te-loaded phase

- $2\nu\beta\beta$ decay lifetime of ^{130}Te
- $0\nu\beta\beta$ decay search with ^{130}Te
- Geo and reactor antineutrinos









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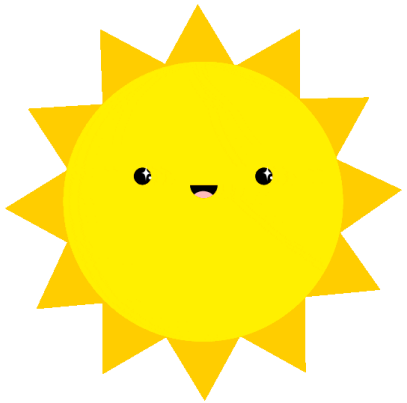
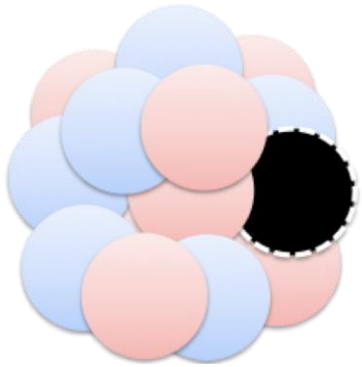
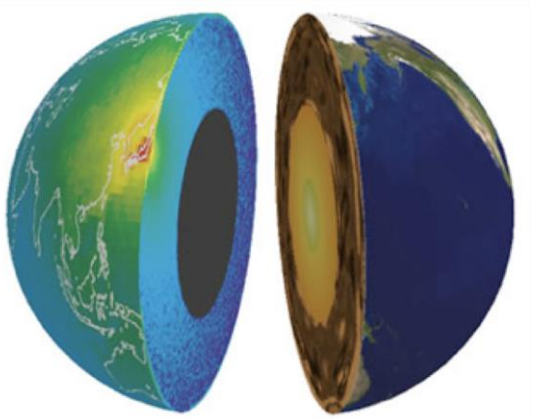
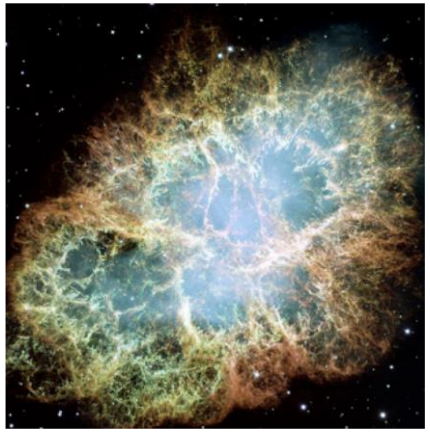
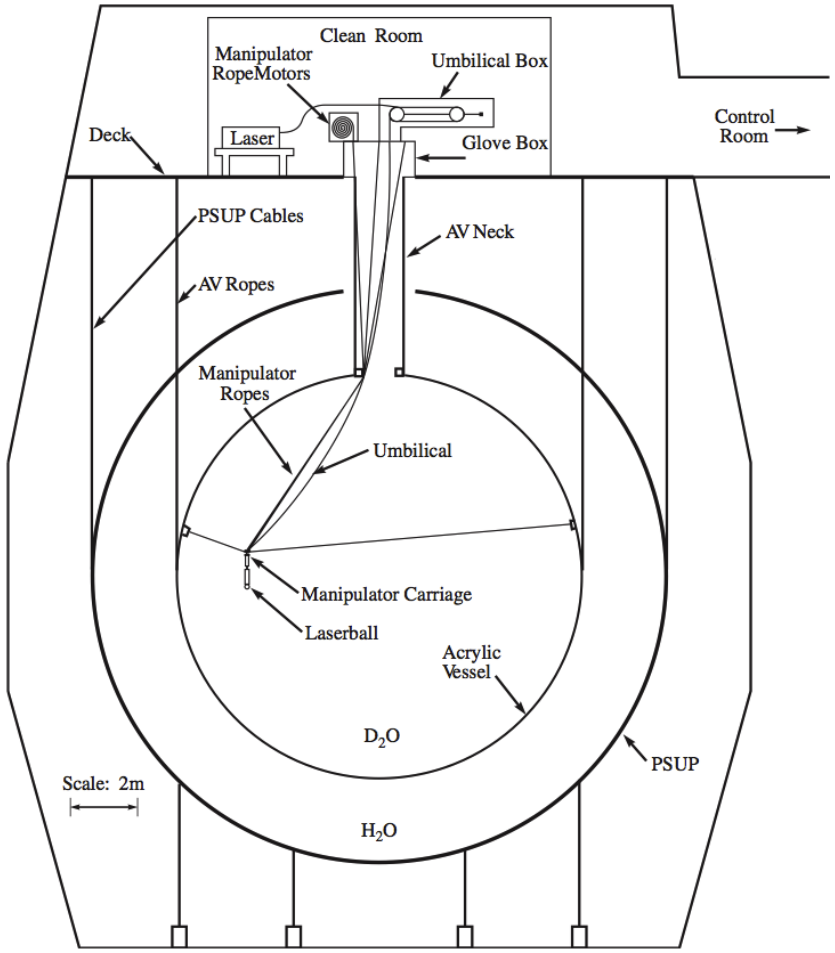




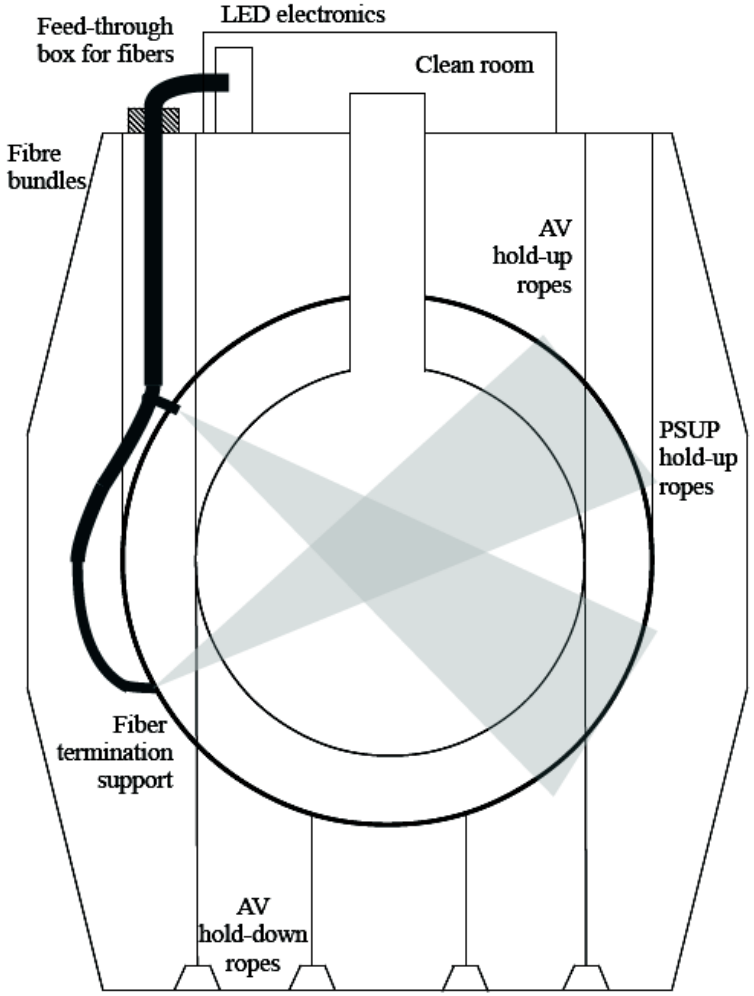




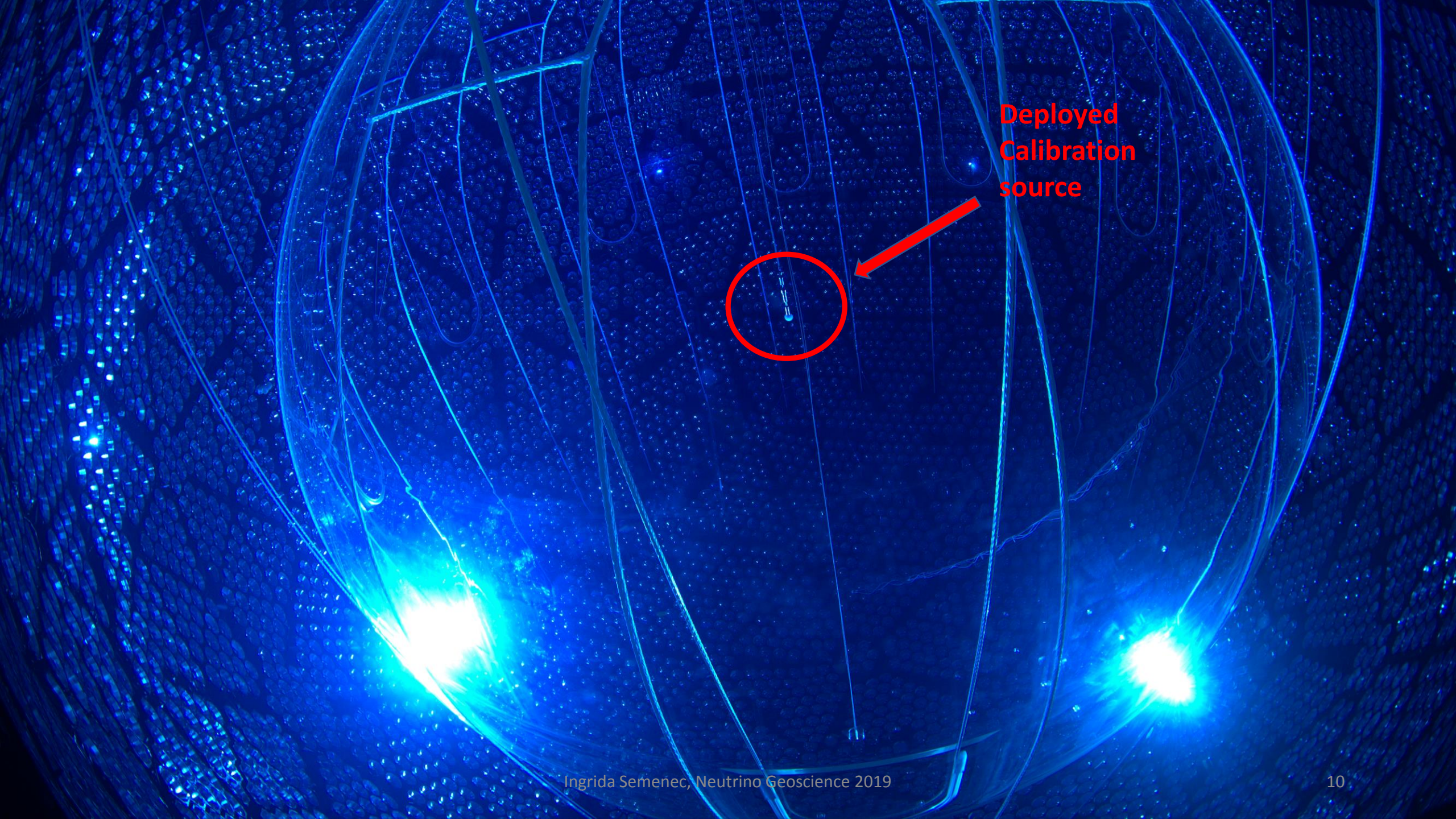
Calibration systems



Internal source deployment

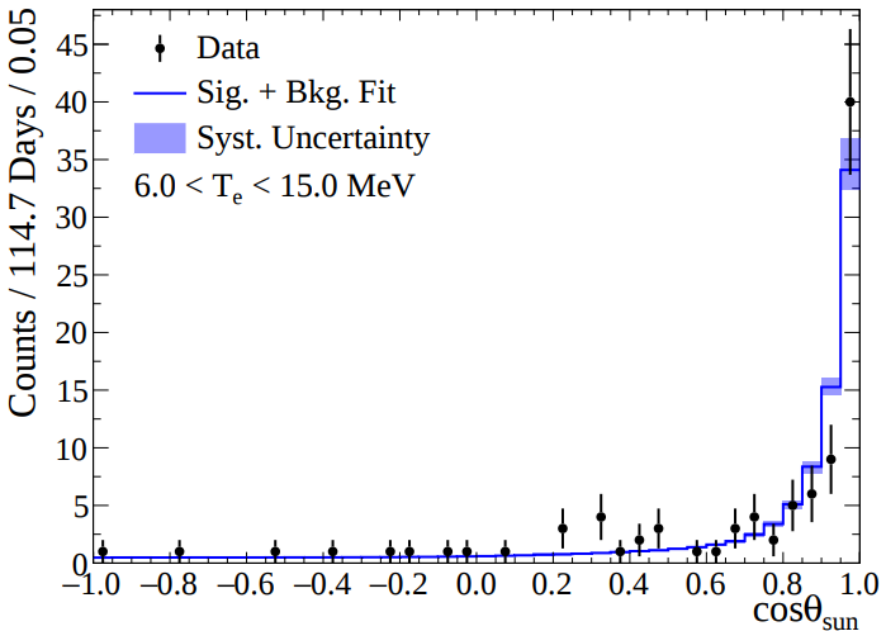


External source deployment


Deployed
Calibration
source

Water phase results

^{8}B solar neutrino flux

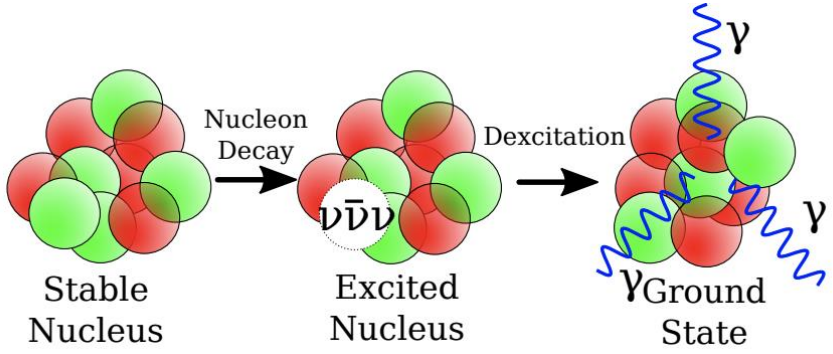


Observed solar ^{8}B neutrino flux with very low backgrounds

$$2.53^{+0.31}_{-0.28}(stat.)^{+0.13}_{-0.10}(syst.)\times 10^{6} cm^{-2} s^{-1}$$

https://arxiv.org/pdf/1812.03355.pdf

Invisible nucleon decay



- Set limits on the p, pn and pp decay modes
- Factor of 2 improvement on p decay mode.
- Almost three orders of magnitude improvement on pn and pp modes.

	Spectral analysis	Counting analysis
n	2.5×10^{29} y	2.6×10^{29} y
p	3.6×10^{29} y	3.4×10^{29} y
pp	4.7×10^{28} y	4.1×10^{28} y
pn	2.6×10^{28} y	2.3×10^{28} y
nn	1.3×10^{28} y	0.6×10^{28} y

https://arxiv.org/pdf/1812.05552.pdf

SNO+ Current Status

- Scintillator fill ongoing
  - Several delays due to minor problems in the distillation plant
  - Completion of scintillator fill planned for end of 2019
  - Counting scintillator backgrounds now
- Tellurium process systems fully installed underground
  - Preparing for Te loading in 2020 (for double beta decay)
- SNO+ geo-neutrino measurement starts after scintillator fill
  - continues after tellurium addition

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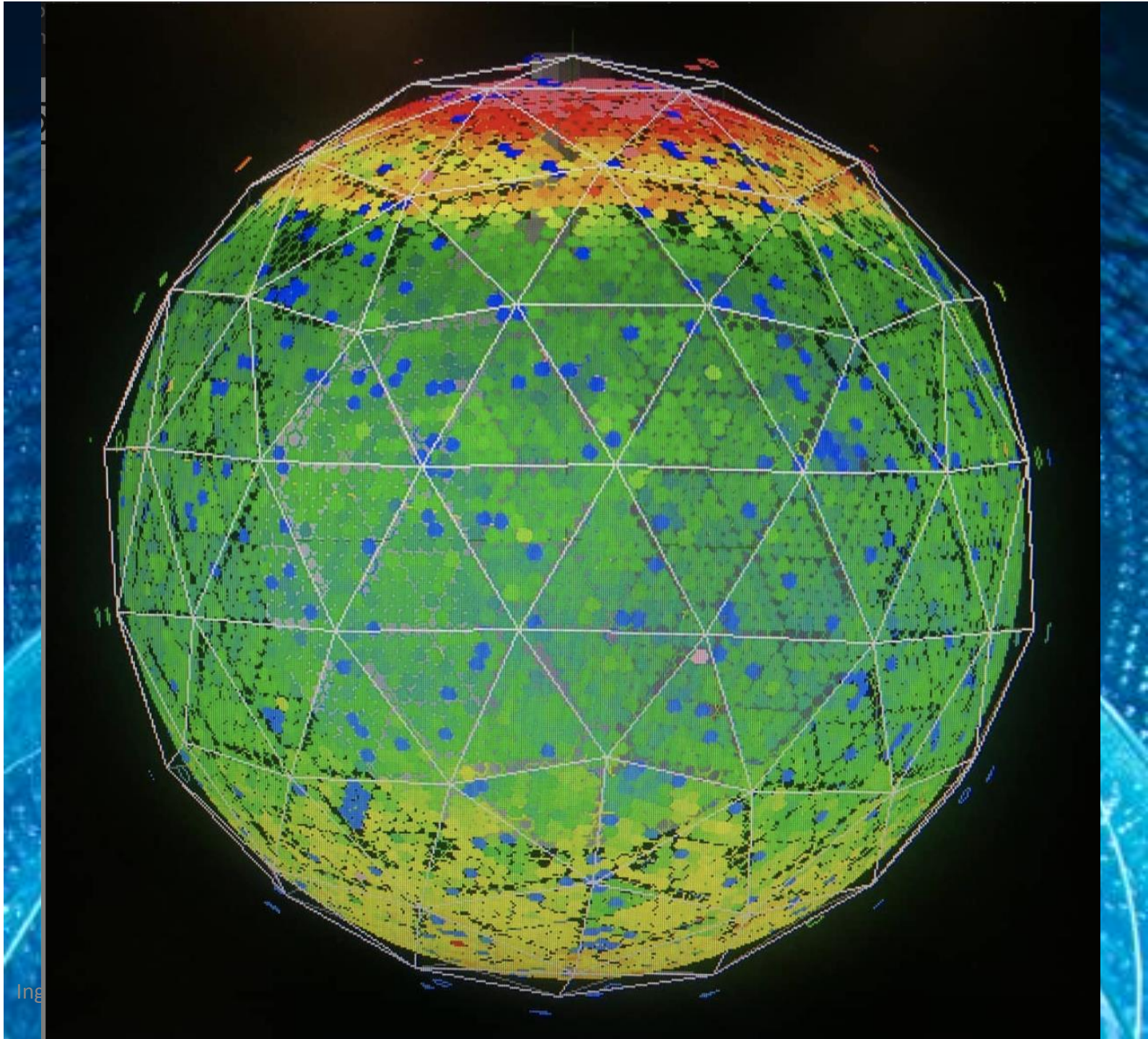
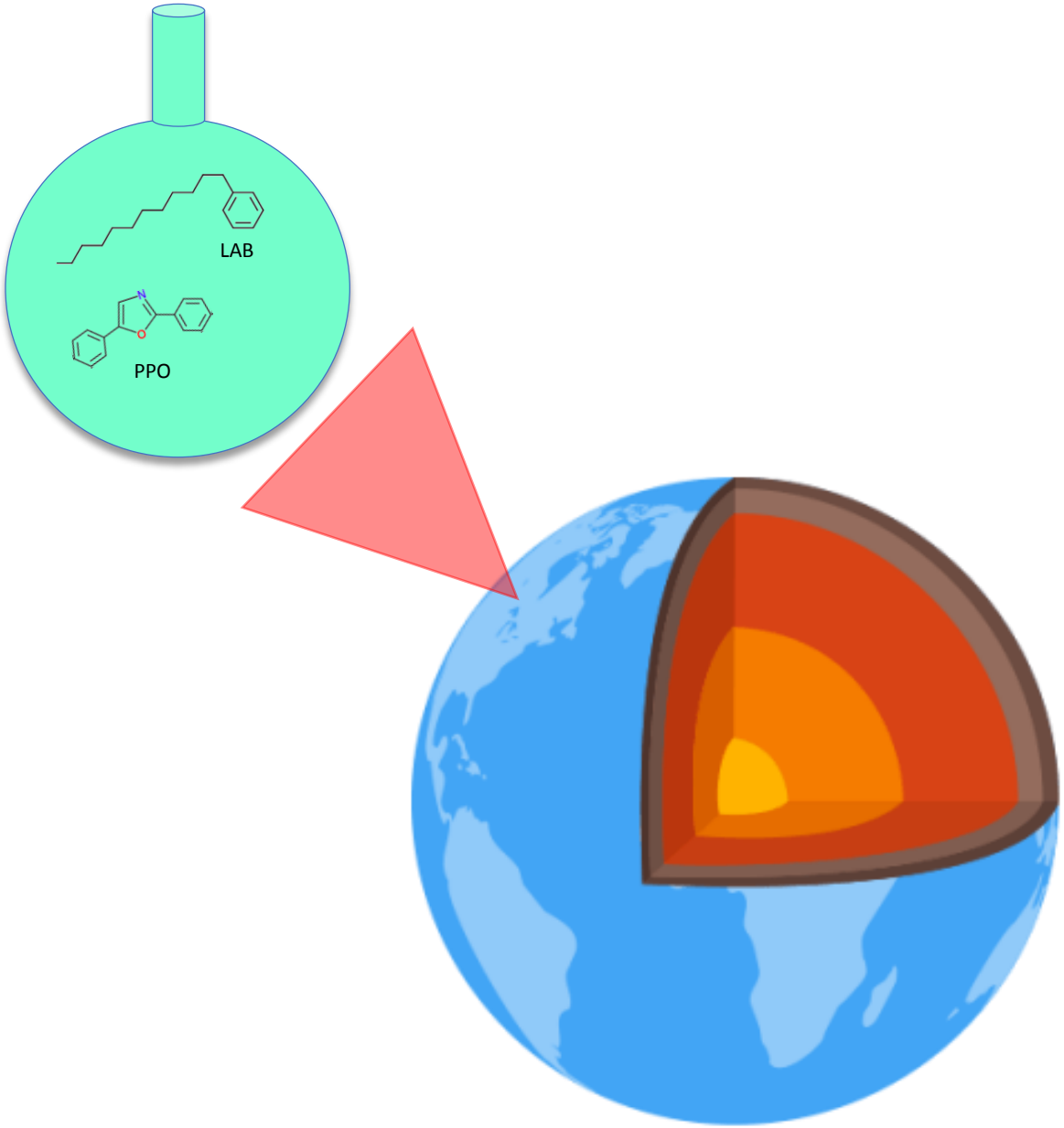
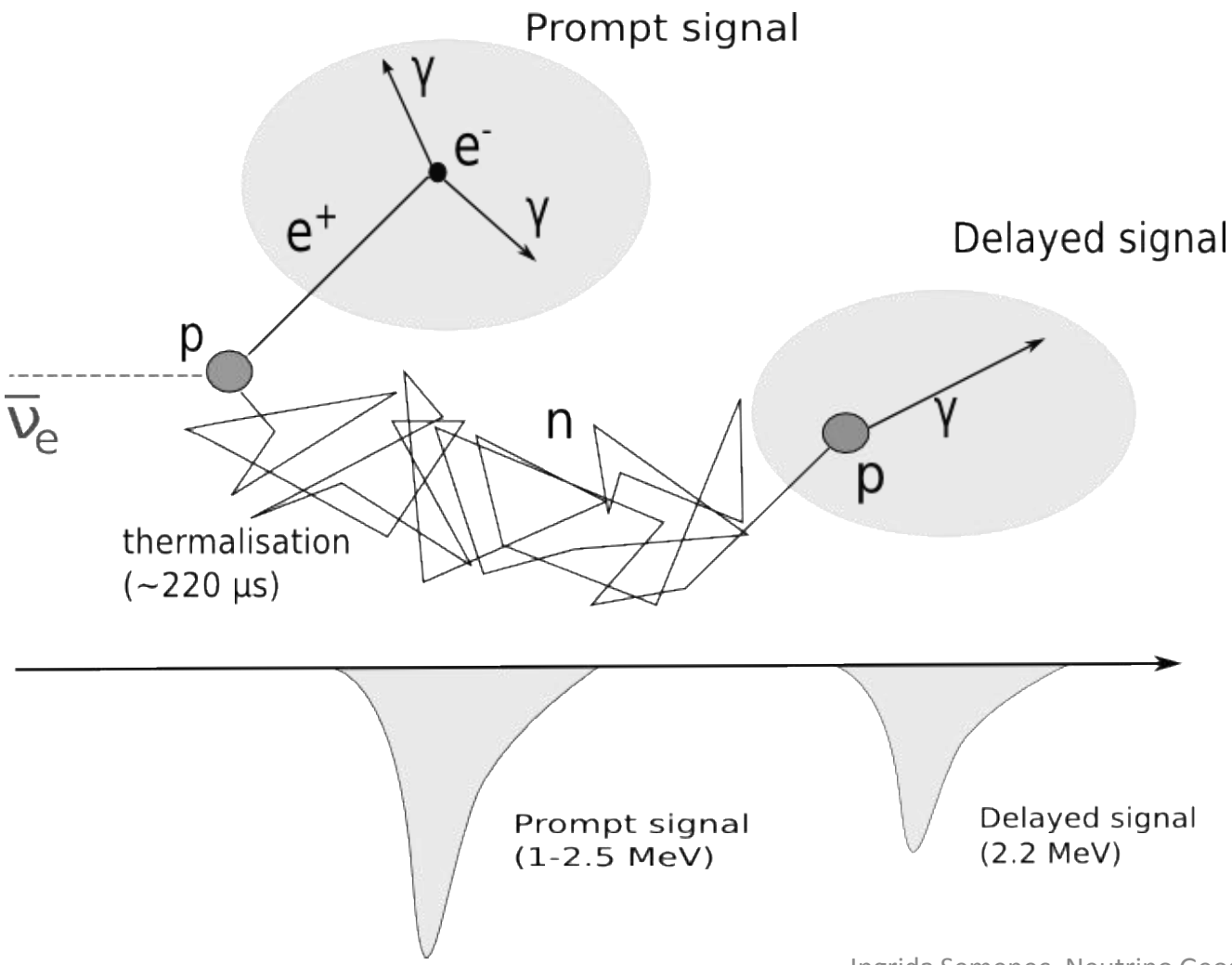


Geo-neutrinos

During scintillator phase of SNO+



Inverse beta decay

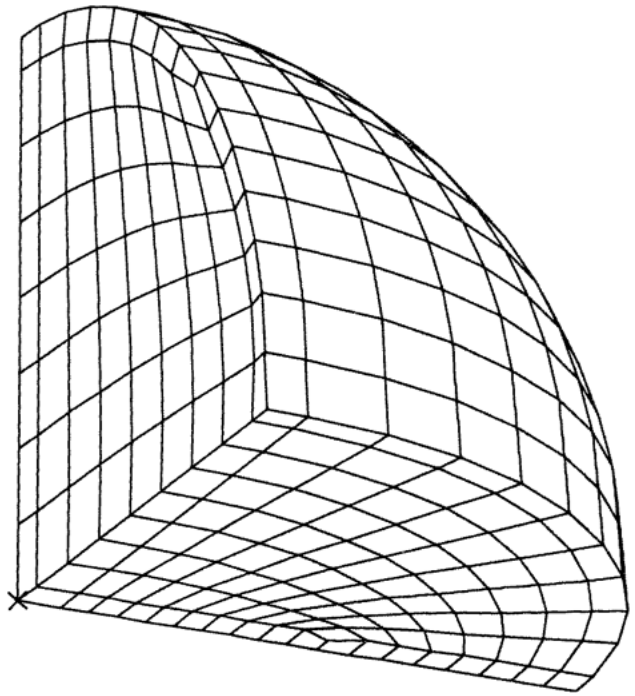


- Antineutrinos are detected in SNO+ via charged current interactions with protons in SNO+ liquid scintillator.
- $\bar{\nu}_e + p \rightarrow e^+ + n$
- **Prompt:** On ns timescales the created positron ionizes with the scintillator and quickly loses energy, before annihilating with an electron.
- **Delayed:** On μs timescales the neutron thermalizes and gets captured by Hydrogen, which then deexcites by releasing a 2.2 MeV gamma.
- The anti-neutrino energy:

$E_\nu = E_{prompt} + (M_n - M_p) - m_e = E_{prompt} + 0.8$ MeV

Geo-neutrino flux

$$\phi(\vec{r}) = \frac{X\lambda N_A}{\mu} n_\nu \langle P_{ee} \rangle \iiint \frac{A(\vec{r}\,')\rho(\vec{r}\,')}{4\pi\,|\vec{r} - \vec{r}\,'|^2} d\vec{r}\,'$$



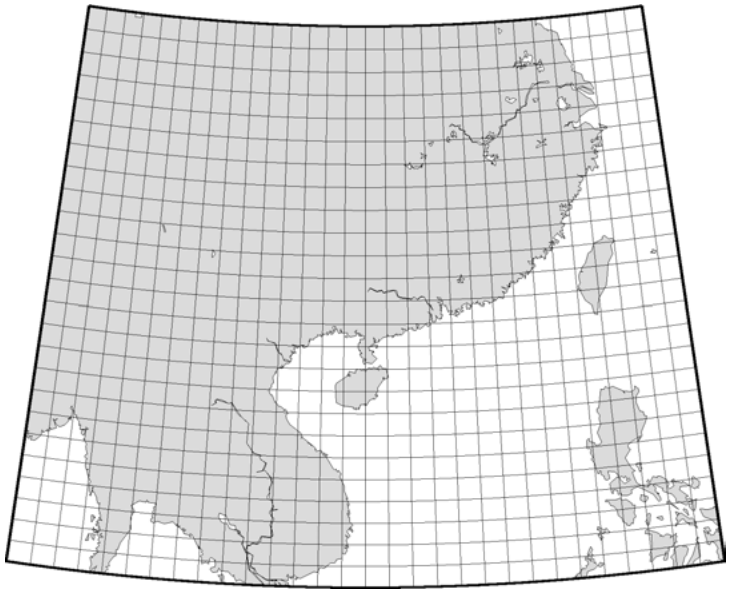
ϕ - Antineutrino flux
X -Natural isotopic mole fraction
λ – Decay constant
N_A - Avogadro's number
μ - Standard atomic mass
n_ν - Number of antineutrinos per decay
⟨Pee⟩ - Average survival probability
A - Elemental abundance
ρ - Mass density
r - position

	Crust event rate (TNU)	**Mantle event rate (TNU)**		
	Crust	Low Q (10TW)	Mid Q (20TW)	High Q (30TW)
U+Th	35.28±5.10	2.64±1.59	8.36±2.77	17.77±2.62

Geo-neutrino predicted rates courtesy of O.Šrámek

Crustal and mantle models

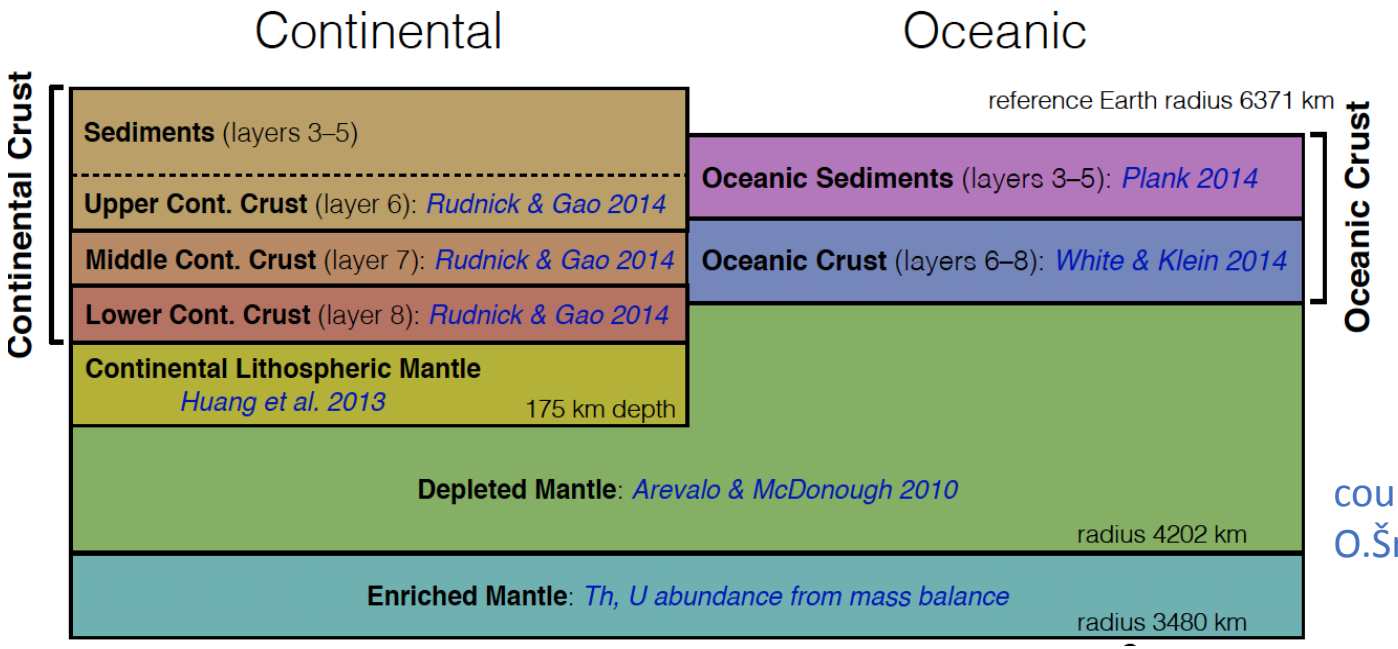
Crust 1.0



1º lat : 1º lon crustal tiles

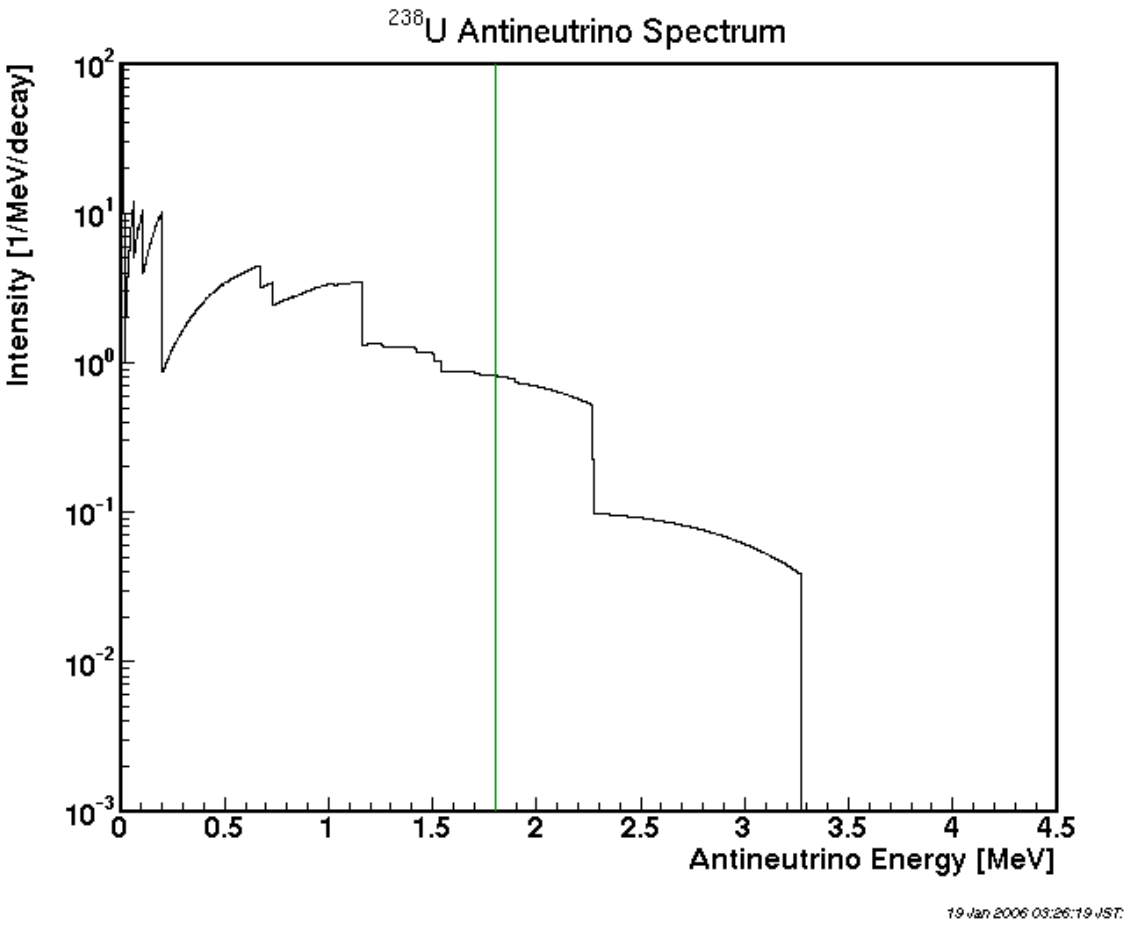
- Model of crustal geometry and material density from CRUST1.0 model (Laske et al.)
- Material density in the mantle from PREM model (Dziewonski & Anderson 1981)
- Assume negligible Th, U in the core

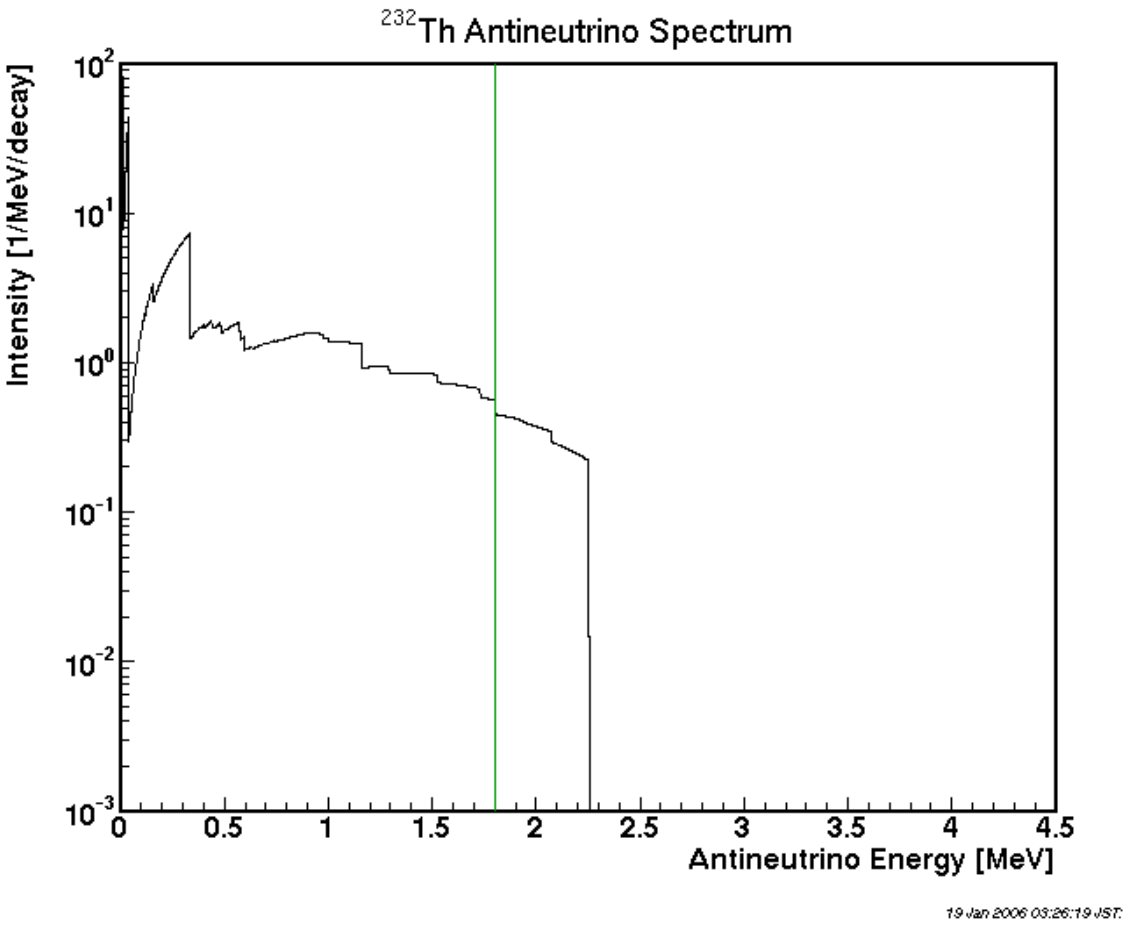
No uncertainty in structure here



courtesy of O.Šrámek

Geoneutrino spectrum





By Enomoto Sanshiro

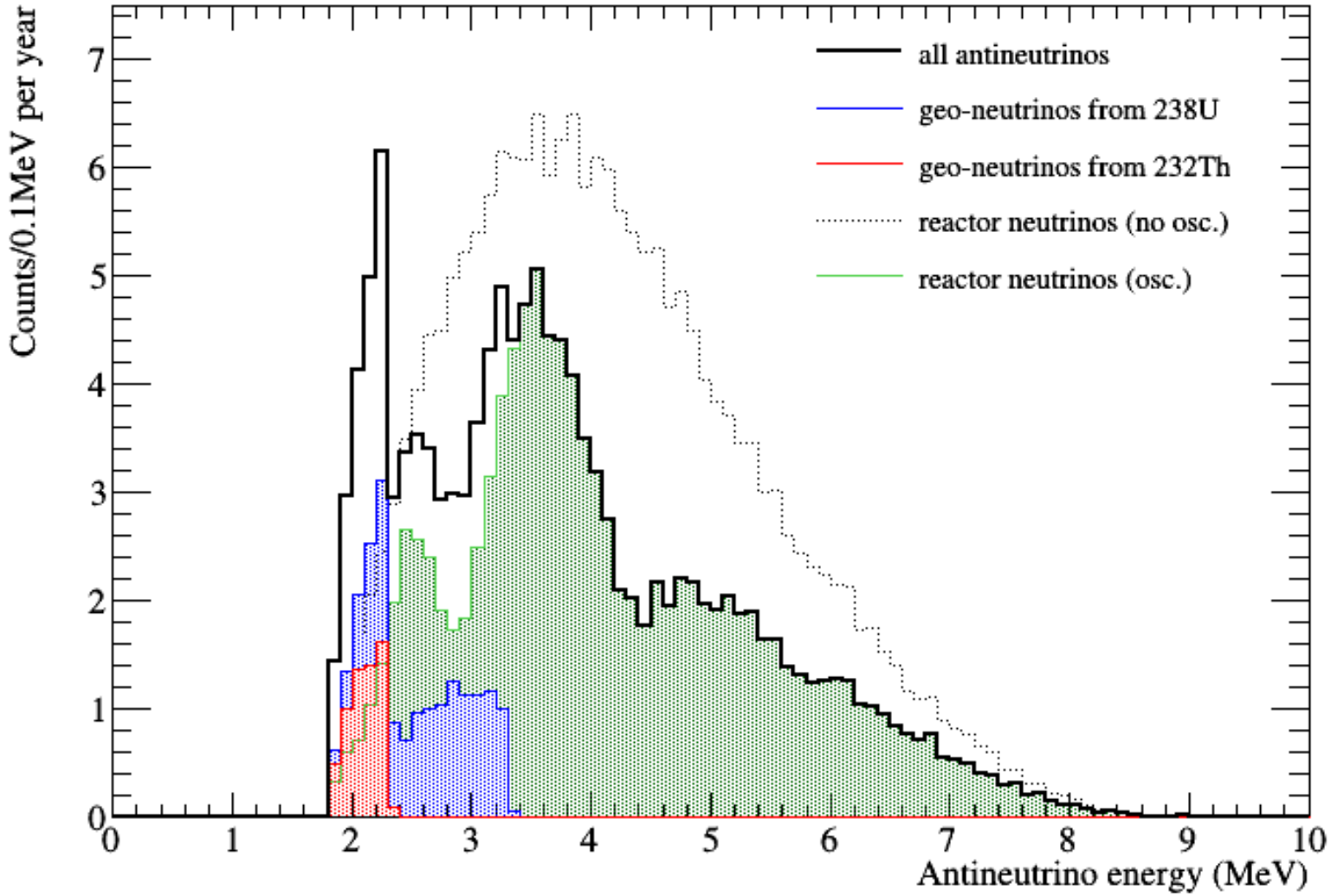
Expected geoneutrino event rates at SNO+

- TNU is defined as one interaction over a year-long fully efficient exposure of 10^{32} free protons.
- Event rate depends on detector size and efficiency of detection.
- Therefore rates in TNU must be converted to the expected rate at SNO+
- The conversion factor for TNU to evs/year scintillator is 0.57719 (100% eff.).

rates in MC geoneutrino generator

Mid Q 20TW	TNU	TNU*0.57719 =evs/year	Hz
U	34.12	19.69	6.2437e-7
Th	9.53	5.5	1.74e-7
Low Q 10TW			
U	29.73	17.16	5.4414e-7
Th	8.21	4.74	1.503e-7
High Q 30TW			
U	41.54	23.98	7.604e-7
Th	11.4	7.604	2.087e-7

Antineutrino Spectrum



Expected $\bar{\nu}_e$ energy spectrum in SNO+ (solid). Geo-neutrinos from ^{238}U (blue) and ^{232}Th (red) decays in the Earth. Contribution from nuclear reactors is in green.

SNO+ site

Local geology around SNO+ site is well studied. Would be a first geo-neutrino measurement in North America.

Northern 60%: ancient Neoarchean to Mesoproterozoic crust; Superior Province (west) & Grenville Province (east)

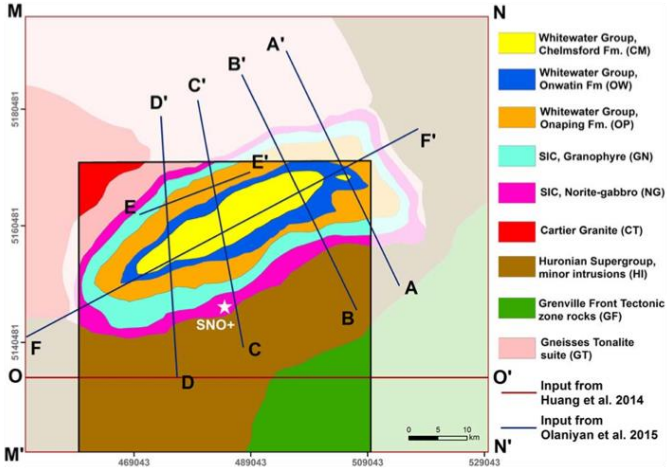
Southern 40%: Paleozoic Sedimentary rocks

Courtesy of Shirey; base map: Reed et al 2005

Virginia Strati and Scott Wipperfurth visiting SNOLAB

Perceiving the Crust in 3-D: 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], and Fabio Mantovani[2,4]



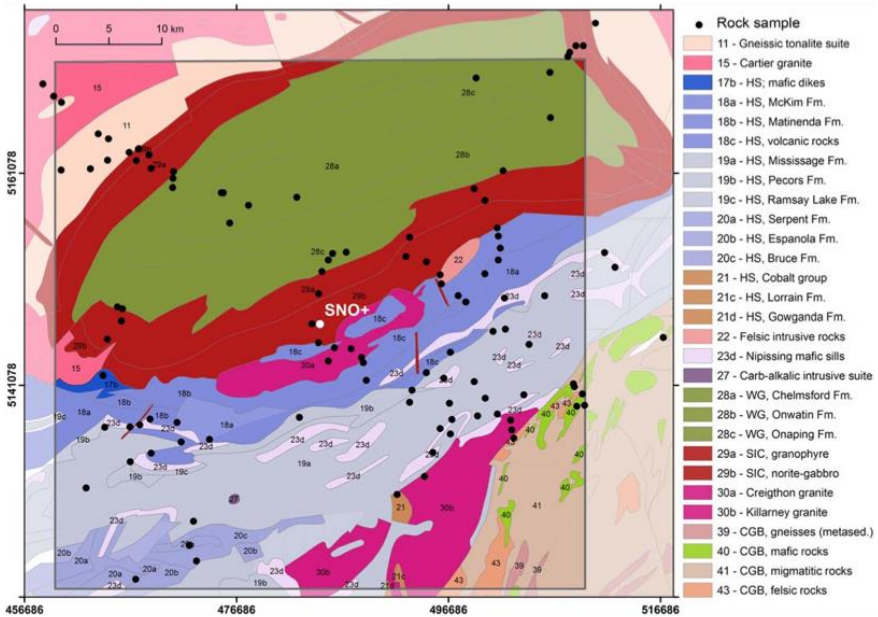
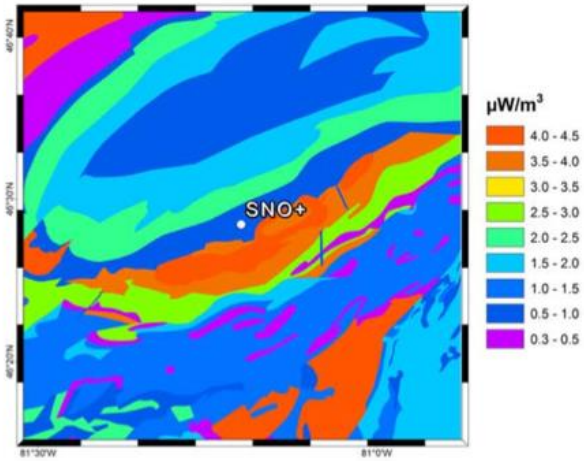


Figure 4. Geophysical inputs used for the construction of the 3-D model. The six cross sections derived from Olaniyan et al. (2015) (AA', BB', CC', DD', EE', FF') and the five cross sections extracted from the H14 model (MM', M'N', NN', MN, OO') are projected on the simplified geological map. The inner box represents the CUC. (Cartographic reference system NAD1927 UTM Zone 17N).



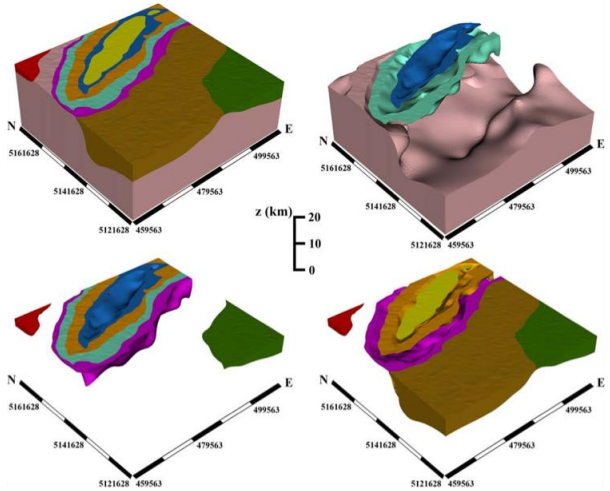
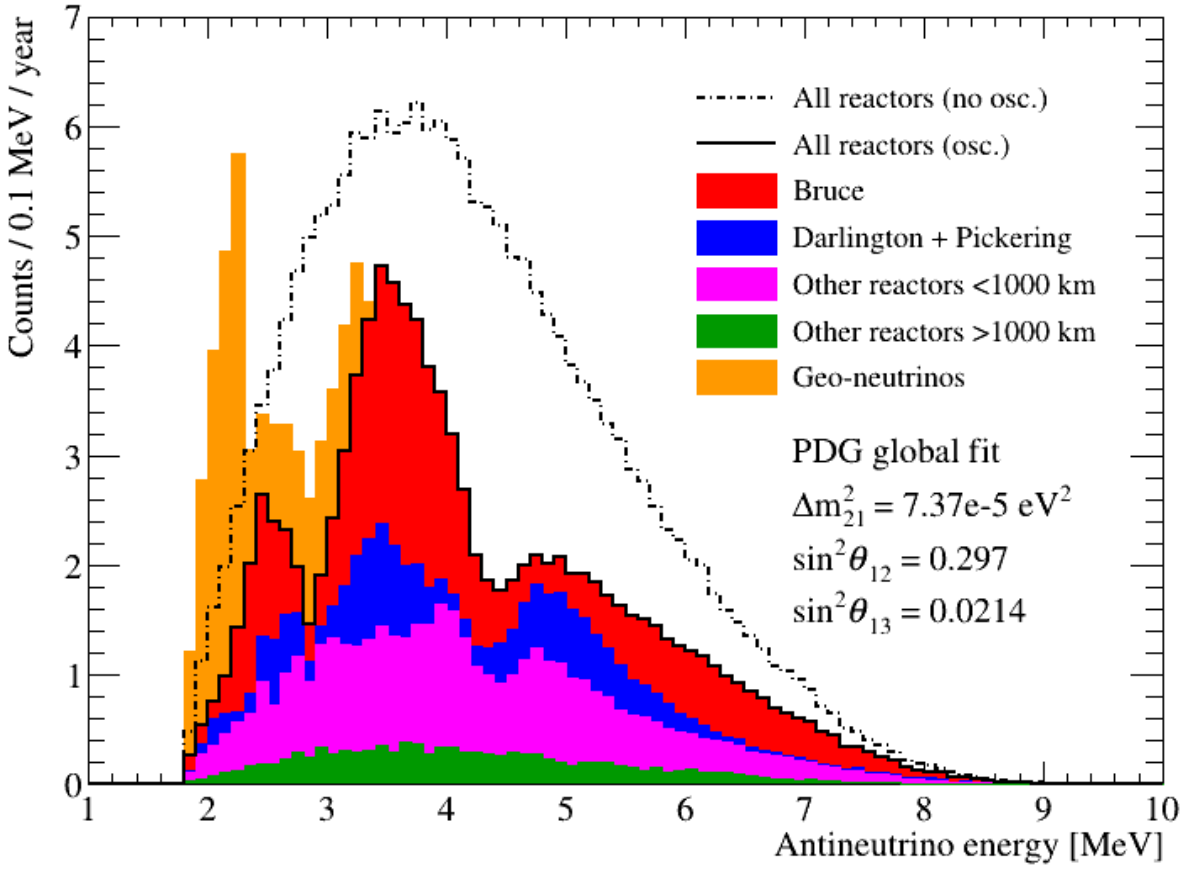


Figure 3. Rock sample of lapilli tuff (Geocode 28c, Onaping Fm.). (a) Each sample was collected from fresh outcrop and (b) then crushed and sealed in polycarbonate box of 180 cm^3 of volume.

Reactor antineutrinos



Plot by Stefan Nae, SNO+ collaboration

Originates from the burning of nuclear fuel. Main fraction of the anti-neutrinos that will be observed in SNO+ come from 3 power plants in Canada:

- Bruce at 240km
- Pickering and Darlington at 350km
- The rest with longer baselines

Dashed line shows the reactor antineutrino spectrum without applied neutrino oscillation effects. SNO+ will measure Δm^2_{12} neutrino oscillation parameter.

Some other backgrounds

AlphaN

- **$^{13}C(\alpha, n)^{16}O$:** true coincidence background created by alpha particles coming from ^{210}Po contamination within scintillator. This background is being measured during scintillator fill.

- The initial estimation is happening now during the partial fill of scintillator.

Random Coincidences

- **Accidental coincidences:** Pairs of uncorrelated signals close to each other in space and time. These can come from neutrons from external background sources or other random radioactive decays inside the detector. Cuts will be applied to supress this background.

Conclusions

- SNO+ is a multipurpose liquid scintillator detector.
- Geo-neutrino flux can be detected by SNO+ during pure scintillator and Te-loaded phases.
- Geo-neutrino flux predictions at SNO+ site keep being improved.
- Backgrounds are being estimated and compared to MC simulations of geo-neutrino signal.

Thank you!
Děkuju!