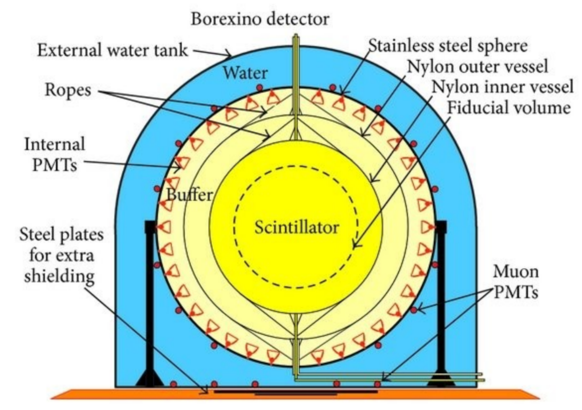
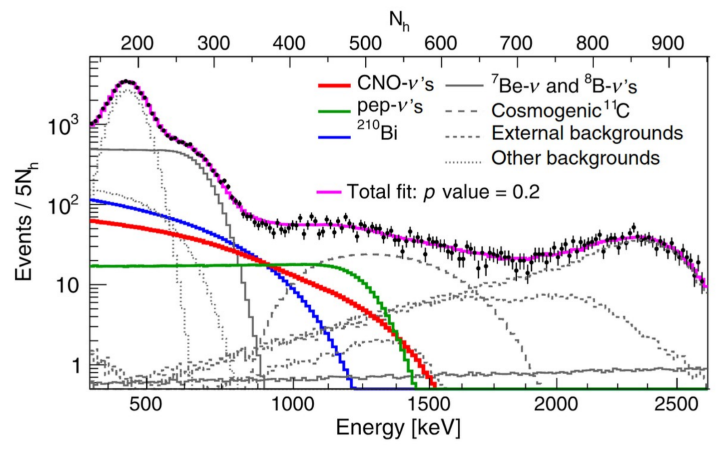
Potassium influence on Earth's mantle convection and Borexino data.



- Overburden 4200 m.w.e.
- Liquid scintillator volume 315 m3 placed in thin (125 um) nylon film.
- Single events from neutrinos and antineutrinos are detected. Mainly from the Sun
- Due to radioactive containment of the film sensitive volume was decreased down to 73 t.

The 5th International Symposium on Cosmic Rays and Astrophysics (ISCRA-2025)

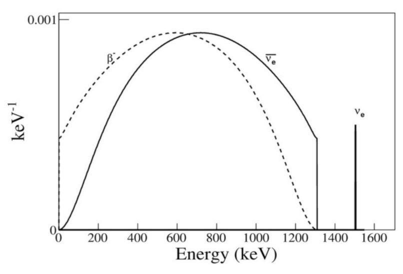
Ivan Karpikov
Institute for Nuclear Research RAS



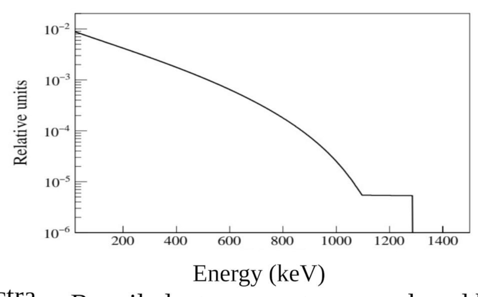
Borexino measurement result in 2022.

R_{CNO} = 6.7 events per d/100 tons

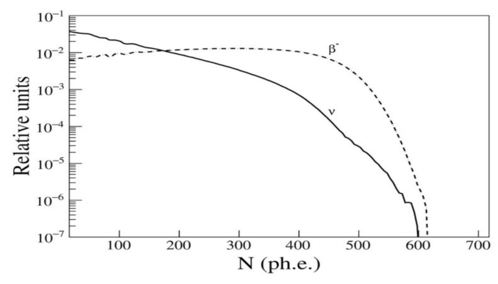
Motivation
What proportion of potassium in the Earth does Borexino allow?



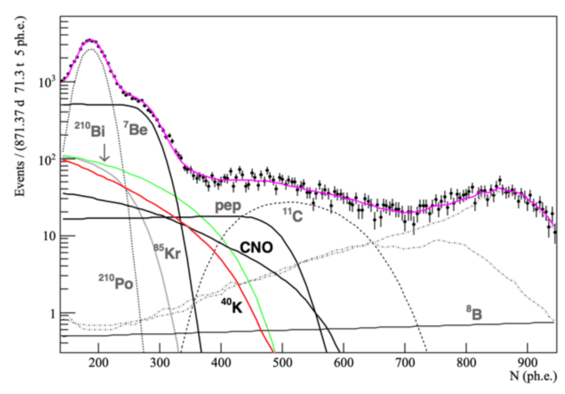
Antineutrino, beta and neutrino ^{40}K spectra.



Recoil electron spectrum produced by antineutrinos and neutrinos from ^{40}K.



PDF for beta and neutrino ^{40}K.



INR analysis with ^{40}K account.
Red line – ^{40}K spectrum.

R(CNO) = 3.9±1.6 cpd/100t (low metal model)
R(^{40}K) = 11 ± 2 cpd/100t

χ^2 = 175

Estimation of heat flow from ^{40}K

Potassium makes up about 2.6% of the weight of the Earth's crust.

High neutrino count rate from ^{40}K in data Borexino indicates its high abundance throughout the Earth.

Taking into account its isotopic abundance 0.0117%, the total amount of potassium in the all Earth is 3.2%.

m(^{40}K) = 2.1 · 10^{22} g

H = (m(^{40}K) · N_a · $E_{release}$ · α) / (A · τ) ,

where N_a - Avogadro number, A - atomic number, $E_{release}$ = 0.6 MeV - average energy release in ^{40}K decay, τ = $t_{1/2}$ / ln2 - mean lifetime of isotope, α - the conversion factor 1 MeV = 1.6 · 10^{-13} J

This amount of ^{40}K results in a total heat flow of about **600 TW**!

While the entire heat flow of the Earth is **47 TW**

The question arises:
how does the increased content of radioactive potassium affect the Earth's thermal balance?

Boussinesq approximation
Thermal convection nondimensionalized equations

We solved the following nondimensionalized equations of mass, momentum, energy, and conservation in 2-D spherical annulus geometry for incompressible mantle flow

$$-\nabla P + \nabla \cdot [\eta(\nabla \mathbf{V} + (\nabla \mathbf{V})^T)] = Ra T \mathbf{e}_r$$

$$\nabla \cdot \mathbf{V} = 0$$

$$\frac{\partial T}{\partial t} + (\mathbf{V} \cdot \nabla) T = \nabla \cdot (\kappa \nabla T) + H(t)$$

Here $\mathbf{V}$ is the velocity vector, P is the pressure, T is the temperature, t is the time, η is the coefficient of dynamic viscosity, κ is the coefficient of thermal diffusivity, $H(t)$ is the heat source. Ra is the Rayleigh number, defined as

$$Ra = \frac{\alpha \cdot \rho_0 \cdot g \cdot \delta T \cdot D^3}{\eta_0 \cdot \kappa_0}$$

with α the surface thermal expansivity; g the gravitational acceleration; ΔT the temperature drop across the mantle; ρ the reference density; η_0 the reference viscosity; D the thickness of the mantle

Initial and boundary conditions
Simulation parameters

- $\alpha_0 = 2 \times 10^{-5}$ K^{-1}
- $\rho = 4.5 \times 10^3$ kg/m^3
- $D = 2900$ km
- $\Delta T = 3700$K
- $\eta_0 = 5 \times 10^{21}$Pa·s
- $\kappa = 10^{-5}$ m^2/s
- $c_p = 1.25 \times 10^3$ J/(kg K)
- $Ra = 10^5$ and $Ra = 10^6$

Heat sources from ^{40}K inside the mantle

$$H(t) = H_0 \cdot exp(-t/t_{40K})$$

, where $H_0 = H_{now} \cdot exp(t_{max}/t_{40K})$

- Low ^{40}K concentration $H_{now} = 5 \times 10^{-12}$ W/kg   20 TW
- High ^{40}K concentration $H_{now} = 15 \times 10^{-12}$ W/kg   60 TW

No leakage condition
V $|_{r=0}$ = **V** $|_{r=D}$ = 0

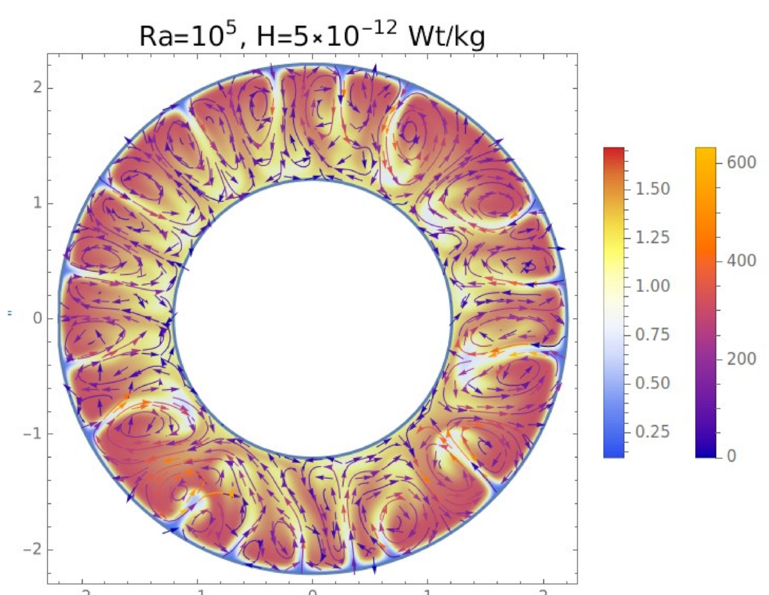
Temperature at the mantle-crust boundary
T$|_{r=0}$ = 0.12 ΔT = 420 K^0

Temperature at the mantle-core boundary
T$|_{r=D}$ = 1.12 ΔT = 3920 K^0

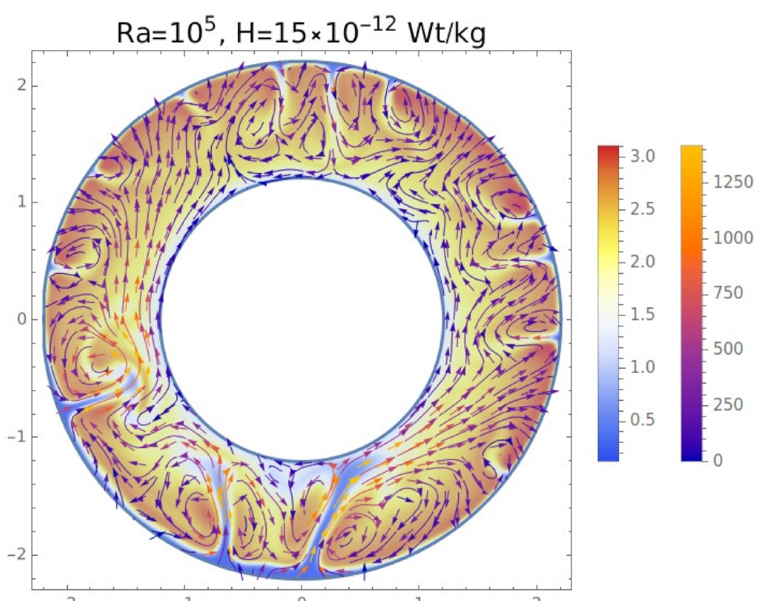
Initial conditions
V = 0
T = ΔT = 3500 K^0

t_{max} = 4500 Myr

Results of mantle convection modeling for Ra = 10^5

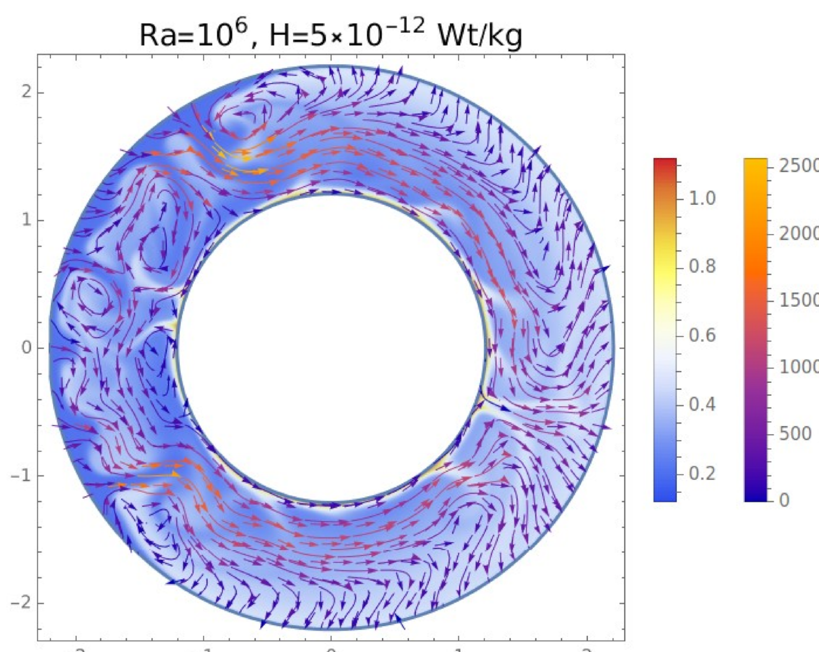


Low ^{40}K

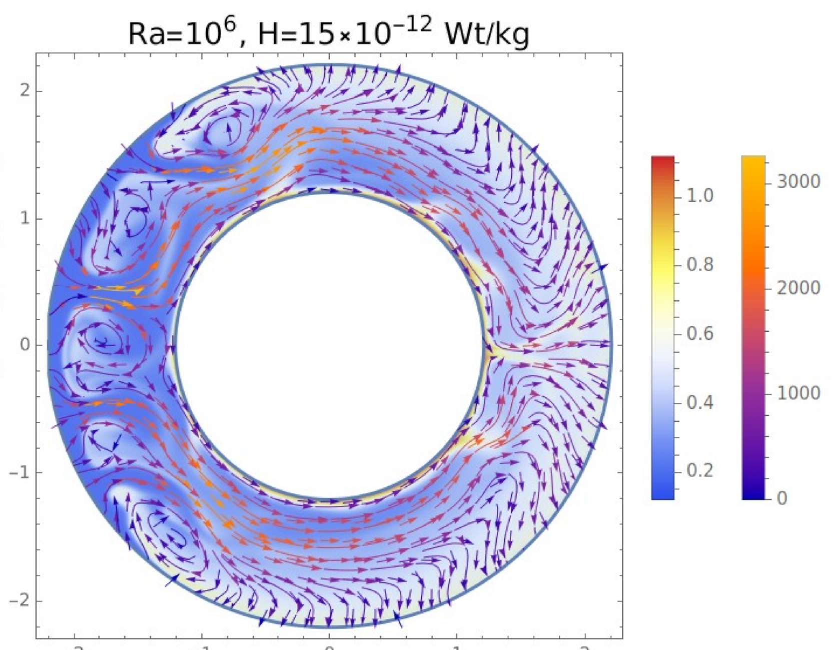


High ^{40}K

Results of mantle convection modeling for Ra = 10^6

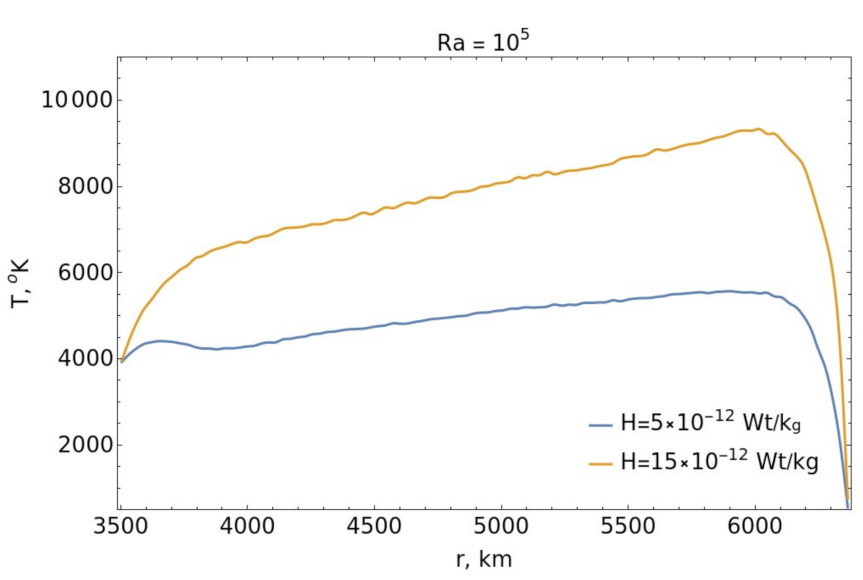


Low ^{40}K

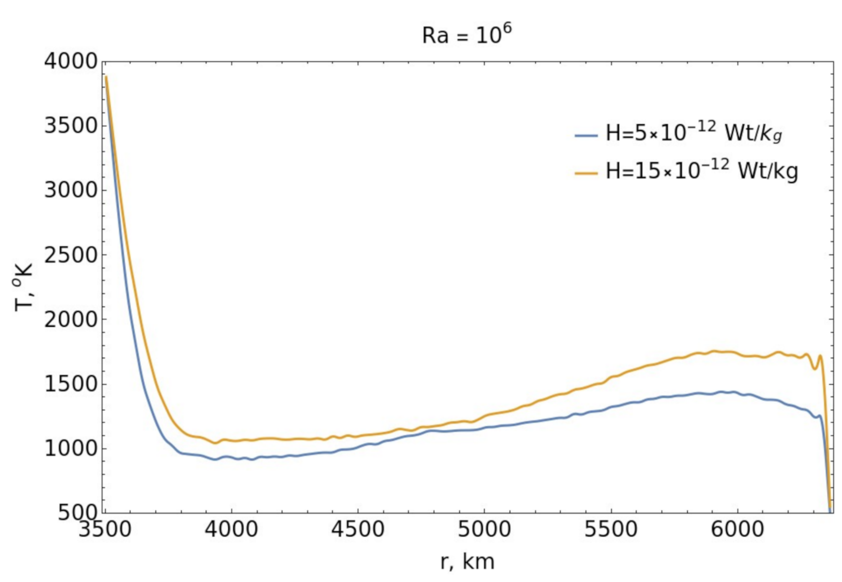


High ^{40}K

Dependence of temperature T on depth r for different amounts of 40 K concentration



Ra = 10^5

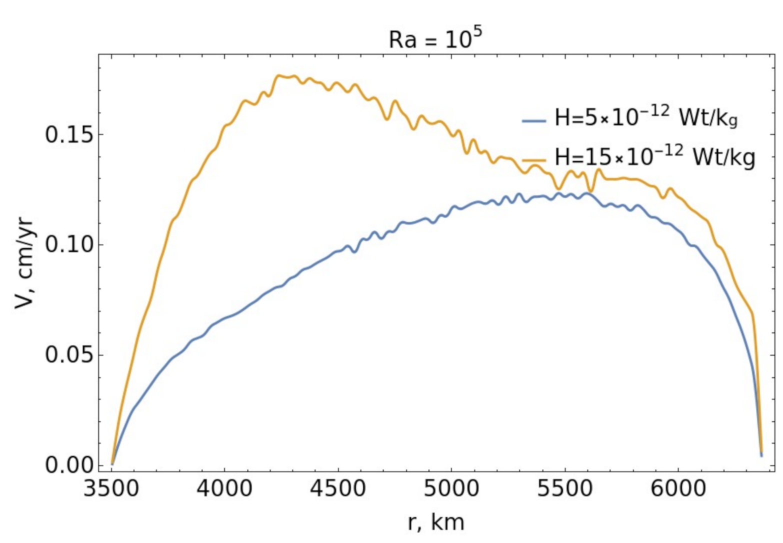


Ra = 10^6

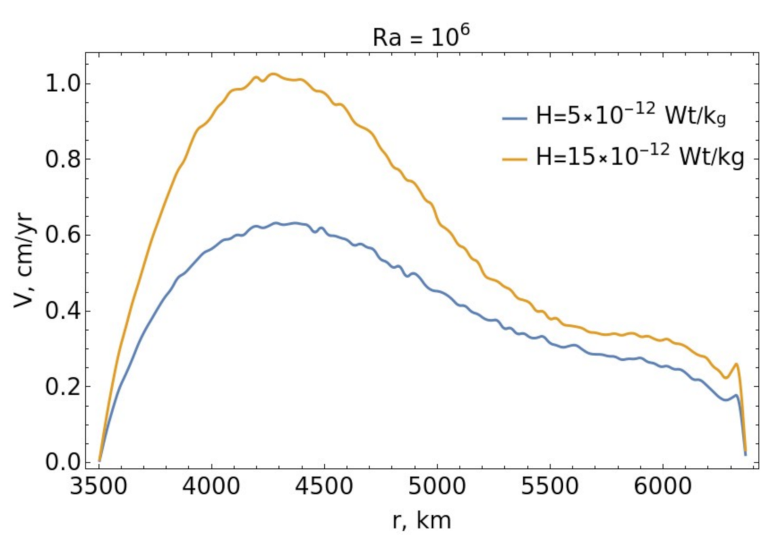
Discussion and conclusion

- We provide the indication of high flux of 40 K geo-antineutrino and geo-neutrino (40 K-geo-(ν̄ + ν)) with Borexino Phase III data
- Large geoneutrino flux from 40 K indicates low metallicity of the Sun
- The abundance of potassium in the range 2 - 4% from the Earth mass can give such flux.
- We modeled the heat distribution in the Earth taking into account the heat from the high 40 K concentration.
- At sufficiently large Rayleigh numbers, excess heat from 40 K is transferred to mantle convection.

Dependence of mean convection velocity V cm/yr on depth r for different amounts of 40 K concentration



Ra = 10^5



Ra = 10^6