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A worldwide map of reactor antineutrino signals

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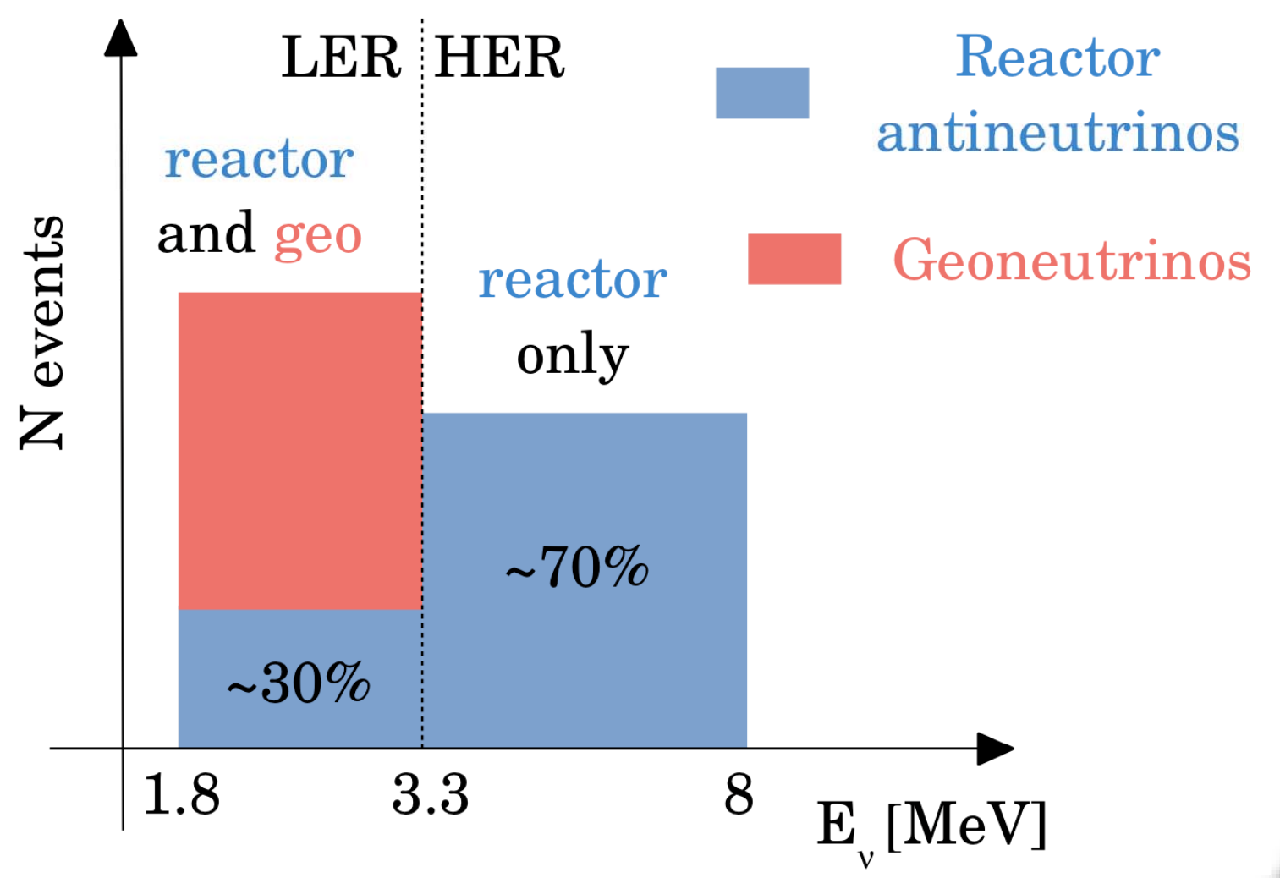
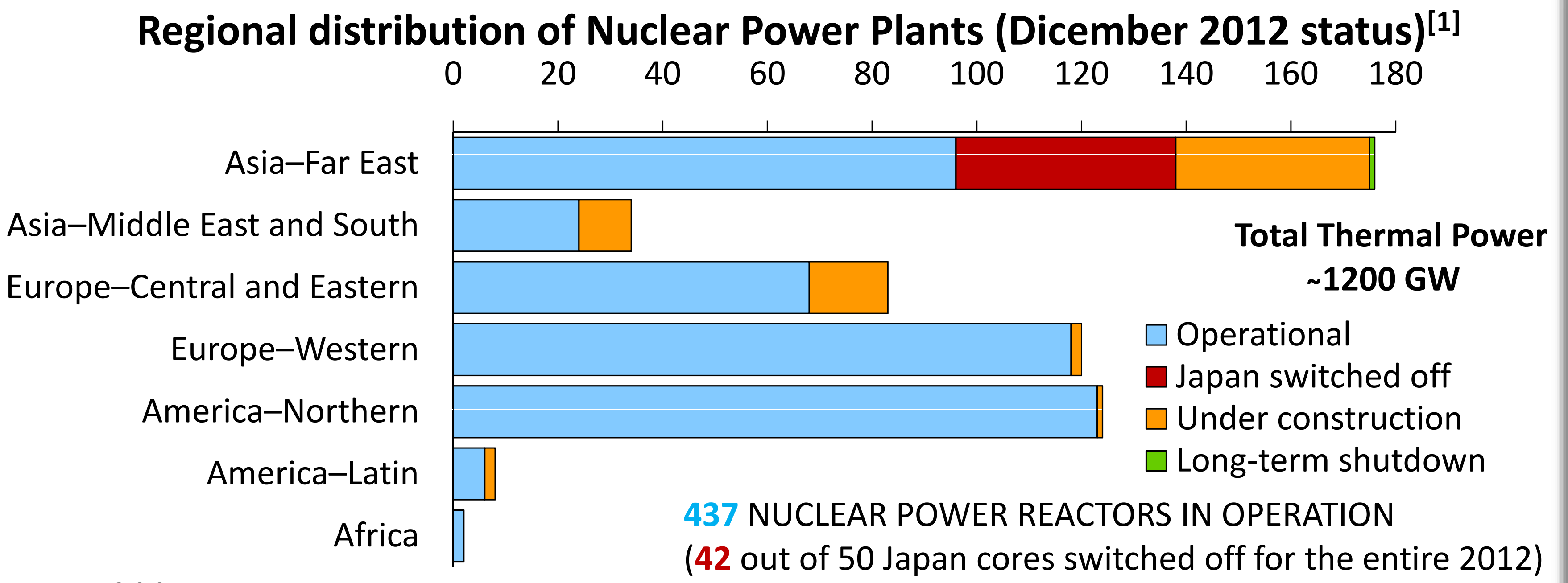
Scientific motivations

- The detection of **geoneutrinos**, i.e. electron antineutrinos generated in ^{238}U and ^{232}Th decay chains, is a major goal of ongoing (**KamLAND** and **Borexino**), future (**SNO+**) and proposed (**LENA**, **HanoHano**, **JUNO** and **RENO-50**) neutrino experiments, as it allows for assessing the radioactive content of our planet
- The main background in geoneutrino measurements is due to **reactor antineutrinos** produced in beta decays of fission products, whose energy spectrum extends beyond the end point of the geoneutrino one
- Predictions on the number of events in the **High Energy Region (HER)** are crucial for modeling the expected reactor antineutrino signal in the **Low Energy Region (LER)** and therefore for extracting information on the geoneutrino component

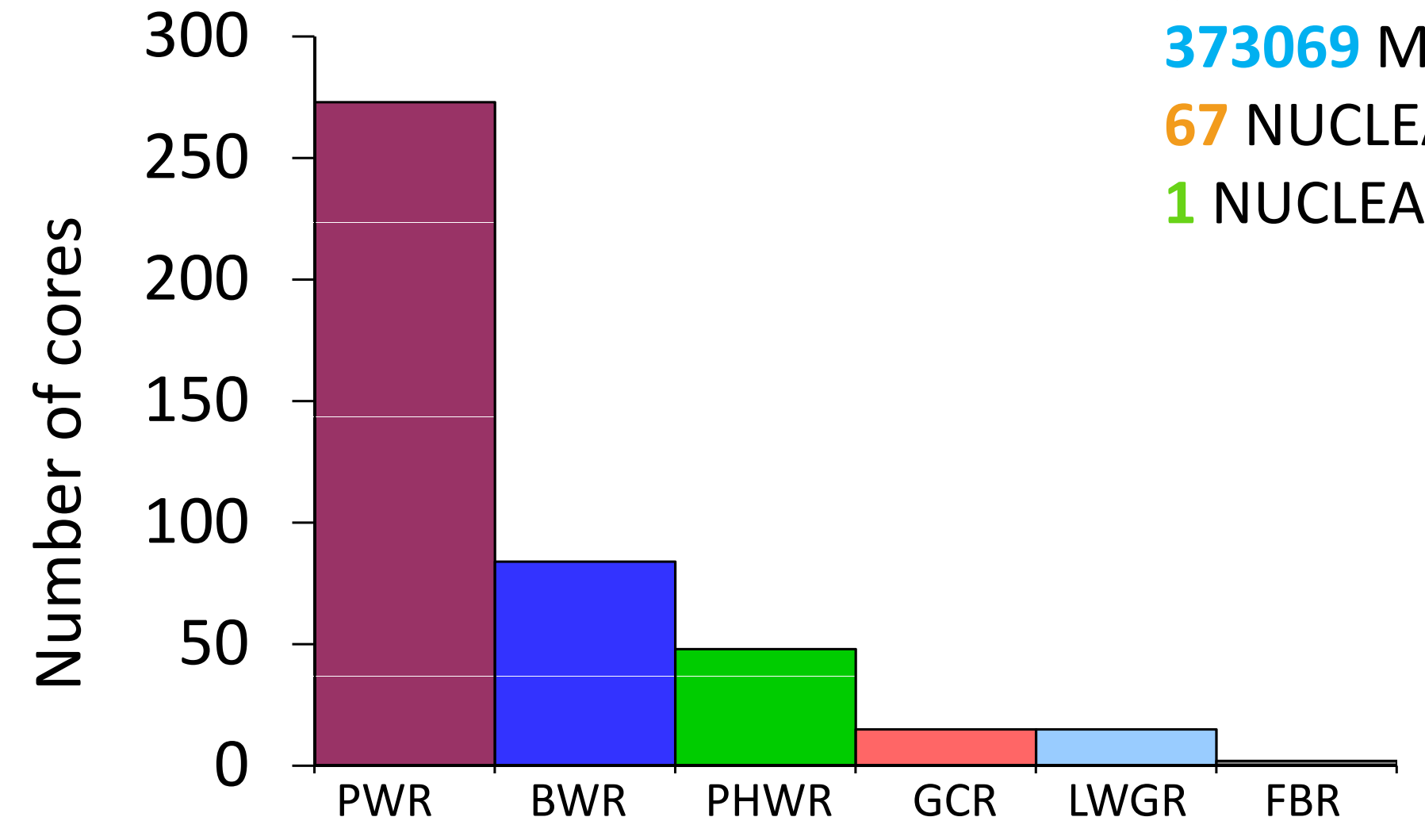


Nuclear power plants in the world

Regional distribution of Nuclear Power Plants (December 2012 status)[1]



437 NUCLEAR POWER REACTORS IN OPERATION
(42 out of 50 Japan cores switched off for the entire 2012)
373069 MWe TOTAL NET INSTALLED CAPACITY
67 NUCLEAR POWER REACTORS UNDER CONSTRUCTION
1 NUCLEAR POWER REACTOR IN LONG-TERM SHUTDOWN



PWR :	Pressurized Water Reactor
BWR :	Boiling Water Reactor
PHWR	Pressurized Heavy Water Reactor
GCR :	Gas Cooled Reactor
LWGR :	Light Water Graphite Reactor
FBR :	Fast Breeder Reactor

Reactor antineutrino signal calculation

- The reactor antineutrino signal evaluation requires several ingredients for modeling the three antineutrino life stages: **production**, **propagation** and **detection**

DETECTOR

- ε = 100% efficiency
- τ = 1 year
- $N_p = 10^{32}$ target protons (~ 1kton liquid scintillator mass)

ν PHYSICS

- P_{ee} = ν_e oscillation survival probability [2]
- $\sigma_{IBD}(E)$ = IBD cross section [3]

$\bar{\nu}_e + p \rightarrow e^+ + n$ (E_{th} = 1.806 MeV)

$$N_{TOT} = \varepsilon N_p \tau \sum_{i=1}^{N_{reactor}} \frac{P_i}{4\pi d_i^2} \langle LF_i \rangle \int dE_\nu \sum_{k=1}^{4} \frac{p_k}{Q_k} \lambda_k(E_\nu) P_{ee}(E_\nu, d_i) \sigma_{IBD}(E_\nu)$$

$k = {}^{235}U, {}^{238}U, {}^{239}Pu, {}^{241}Pu$

REACTOR

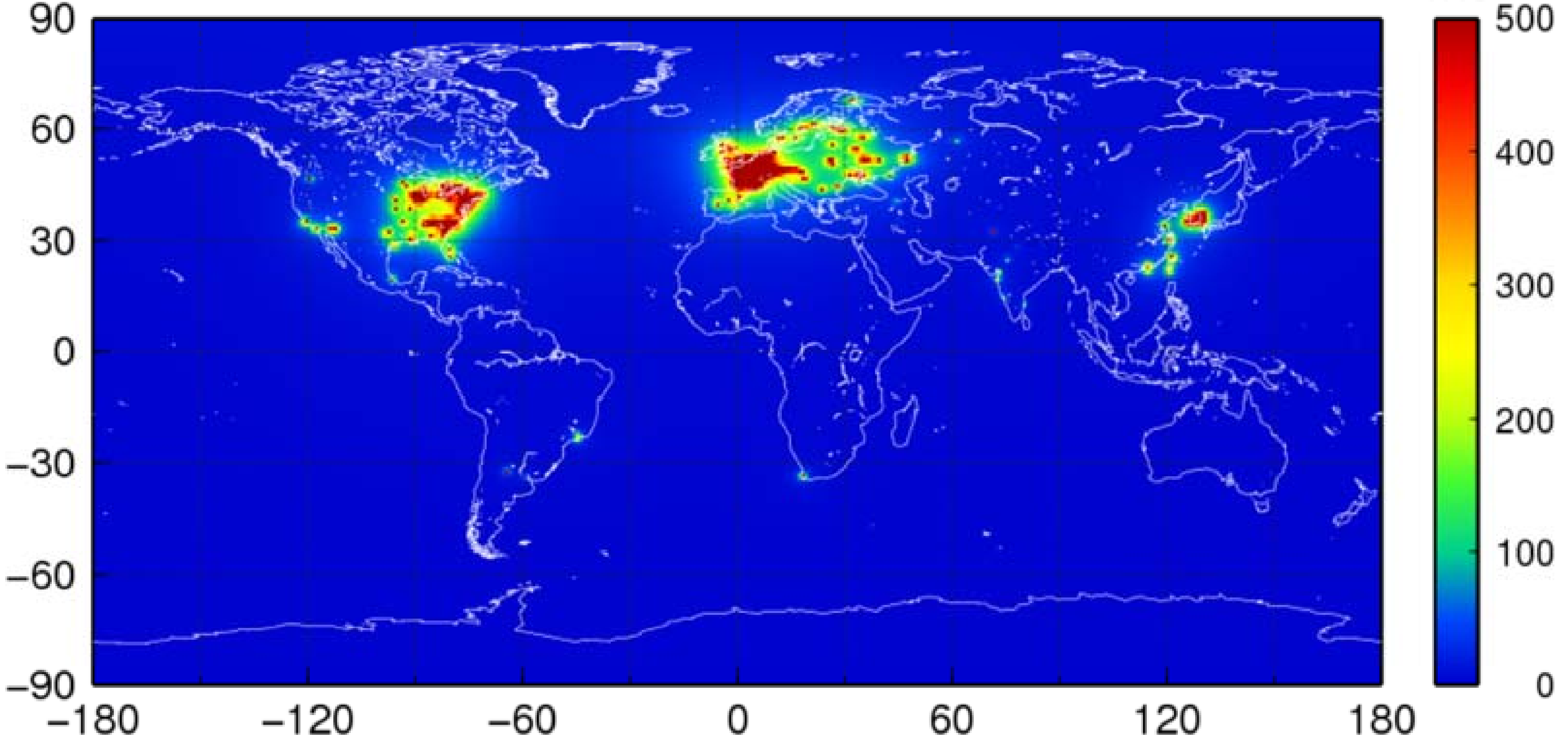
- d_i = reactor distance
- P_i = thermal power
- LF = Load Factor [1]
- p_k = power fraction

NUCLEAR

- Q_k = energy released per fission [4]
- λ_k = reactor antineutrino spectrum [5]

The 2012 world map of reactor antineutrino signal

[1 TNU = 1 event / 10^{32} target protons /year]



- The total uncertainty on the predicted signal is about **5%**: the main contributions arise from **antineutrinos oscillation and spectra** and from **reactors fuel composition** and **thermal power**

Reactor anti-ν and geo-ν at different sites

R = total reactor anti-ν_e signal
R_G = reactor anti-ν_e signal in the geo-ν energy window (LER)
G = geo-ν signal

	R [TNU]	R_G [TNU]	G [TNU][6]	R_G/G
LNGS	85.8 ± 4.6	22.8 ± 1.1	$40.3^{+7.3}_{-5.8}$	0.6
KAMIOKA	70.1 ± 3.7	18.7 ± 1.1	$31.5^{+4.9}_{-4.1}$	0.6
SUDBURY	174.6 ± 9.0	43.1 ± 2.1	$45.4^{+7.5}_{-6.3}$	0.9
PHYASALMI	69.2 ± 3.7	17.5 ± 0.8	$45.3^{+7.0}_{-5.9}$	0.4
FREJUS	587.9 ± 31.0	134.0 ± 7.1	$42.4^{+7.6}_{-6.2}$	3.2
HOMESTAKE	27.7 ± 1.5	7.3 ± 0.3	$48.7^{+8.4}_{-6.9}$	0.1
HAWAII	3.4 ± 0.2	0.9 ± 0.04	$12.0^{+0.7}_{-0.6}$	0.1
CURACAO	9.5 ± 0.5	2.5 ± 0.1	$29.3^{+4.2}_{-3.3}$	0.1
JUNO	99.0 ± 5.1	27.4 ± 1.4	$39.7^{+6.5}_{-5.1}$	0.7

- Frejus requires a detailed knowledge of close-by reactors
- In 2012 Kamioka was an excellent location for geo-ν measurements[7]
- Hawaii and Curacao are ideal candidate sites for geo-ν experiments

Conclusions and perspectives

- We produced a **worldwide map** of the **reactor antineutrino signal** by using **2012** operational information on nuclear power plants and the most updated data on reactor antineutrino spectrum and neutrino oscillation mechanism
- Ratios between the expected reactor antineutrino signals in the LER and the geoneutrino signals **R_G/G** were **estimated at several sites**, providing a hint on geoneutrino measurements potential
- Signal calculation with **2013 data on nuclear power plants** is ongoing: a prediction of the expected reactor signal with all the reactors under construction switched on is also possible
- A refined analysis of the **uncertainties propagation** based on Monte Carlo methods is on schedule

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[7] Gando, A., et al., *Reactor on-off antineutrino measurement with KamLAND*, Physical Review D 88.3 (2013): 033001.