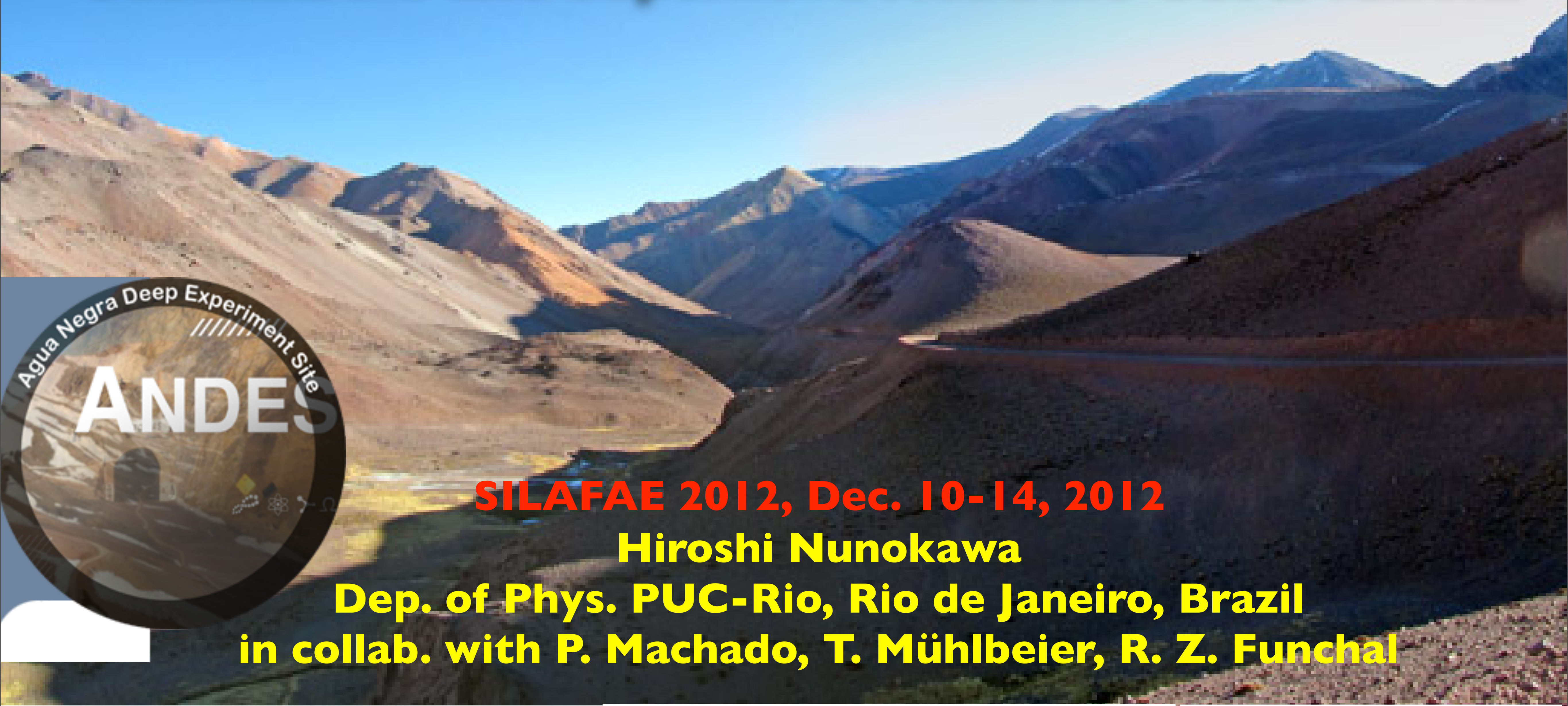
Potential of a Neutrino Detector in the ANDES Underground Laboratory for Geoneutrino and Supernova Neutrino Observations



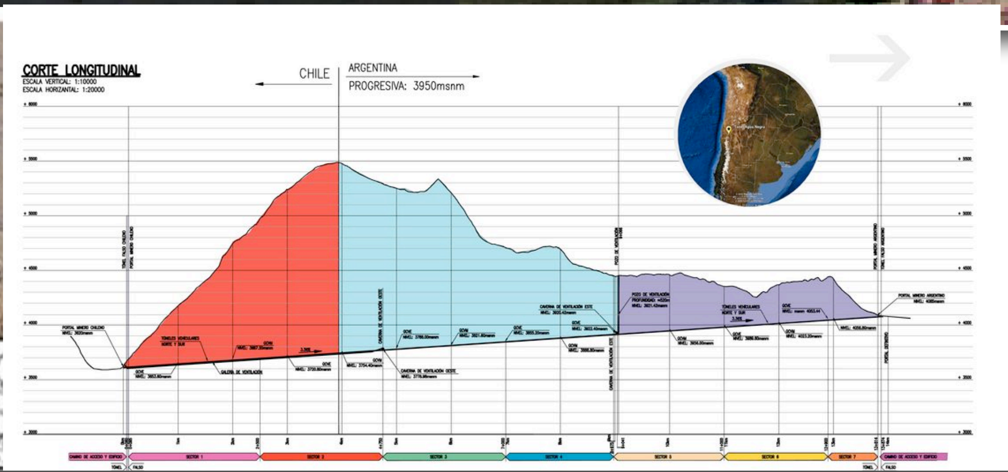
Agua Negra Deep Experiment Site
ANDES

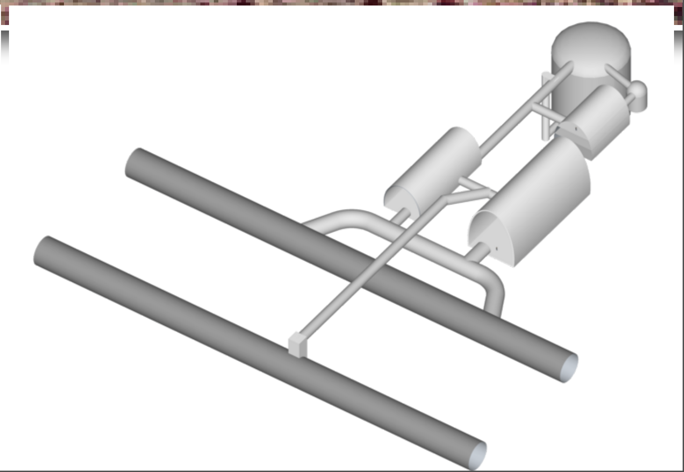
SILAFAE 2012, Dec. 10-14, 2012

Hiroshi Nunokawa

Dep. of Phys. PUC-Rio, Rio de Janeiro, Brazil

in collab. with P. Machado, T. Mühlbeier, R. Z. Funchal





Plan of the talk

Introduction to the ANDES Underground Laboratory

(see talk by Claudio Dib)

Possible neutrino detector at ANDES for

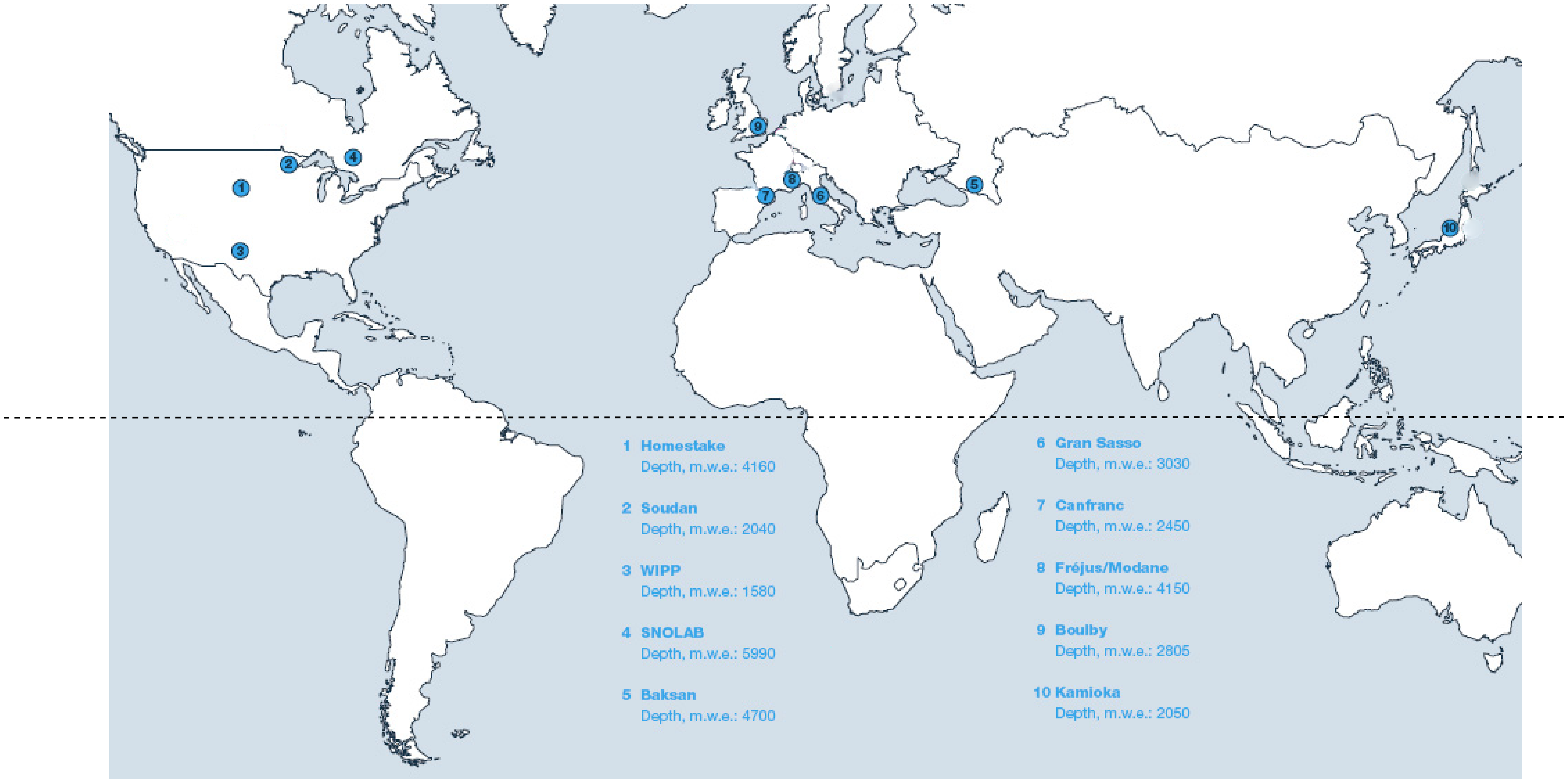
- **Geoneutrino observation**
- **Supernova neutrino observation**

Summary

Based on PRD86, 125001 (2012) [arXiv:1207.5454[hep-ph]]

in collab. with P. Machado, T. Mühlbeier, R. Z. Funchal

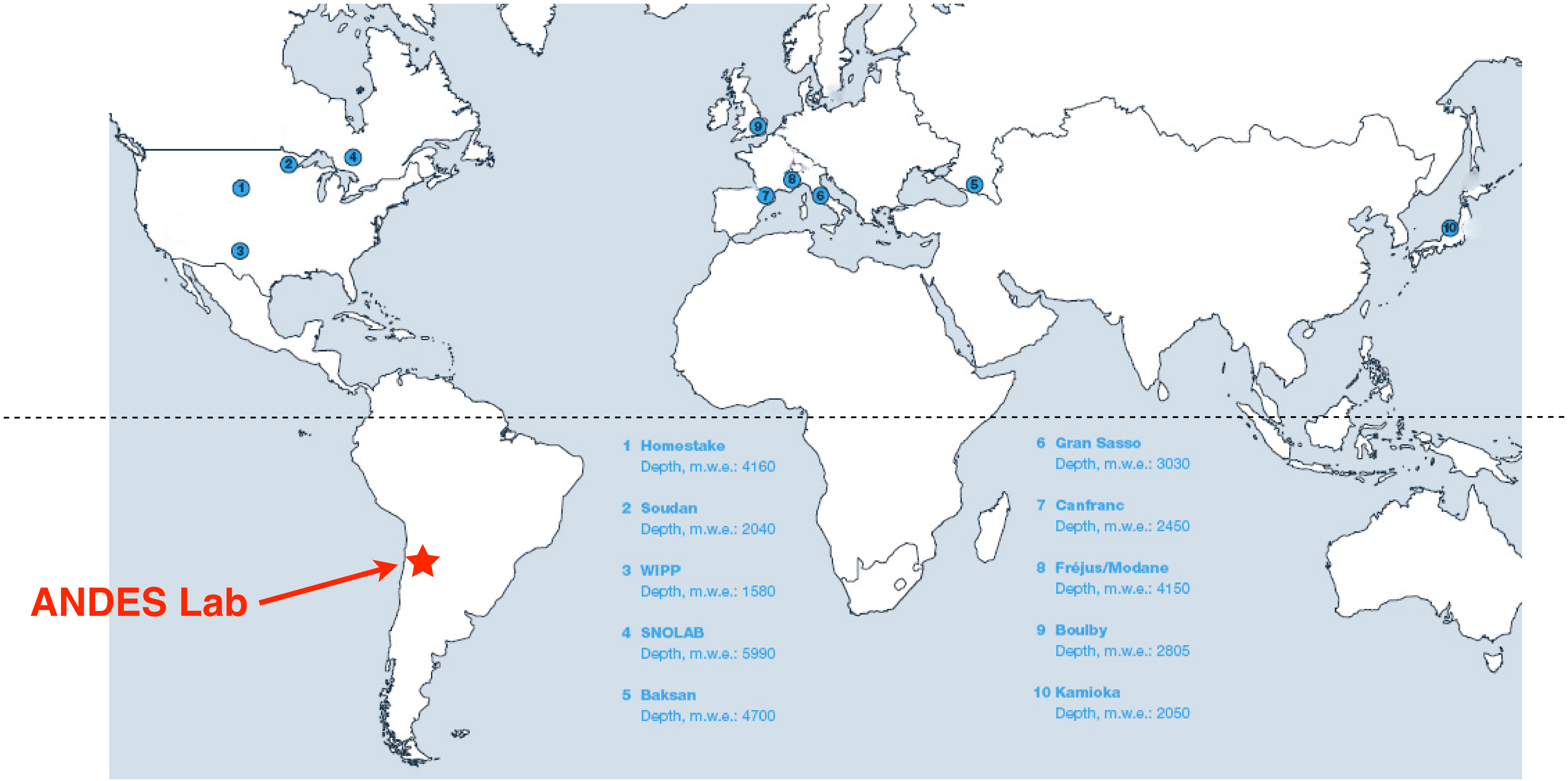
Deep Underground Laboratories in the World



+ China, Korea, India
- None in the southern hemisphere

- Plan to build the first deep underground laboratory in the southern hemisphere

Deep Underground Laboratories in the World



+ China, Korea, India
- None in the southern hemisphere

- Plan to build the first deep underground laboratory in the southern hemisphere

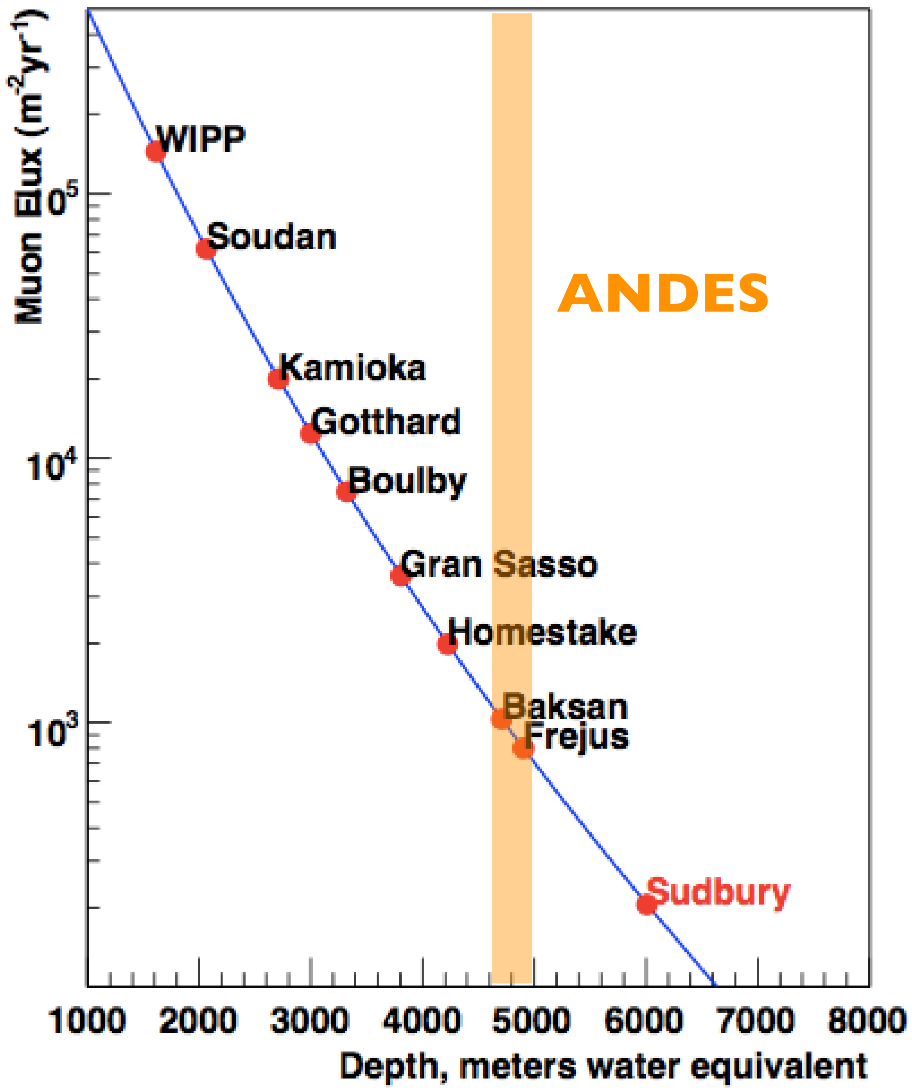
Agua **N**egra **D**eep **E**xperiment **S**ite
ANDES

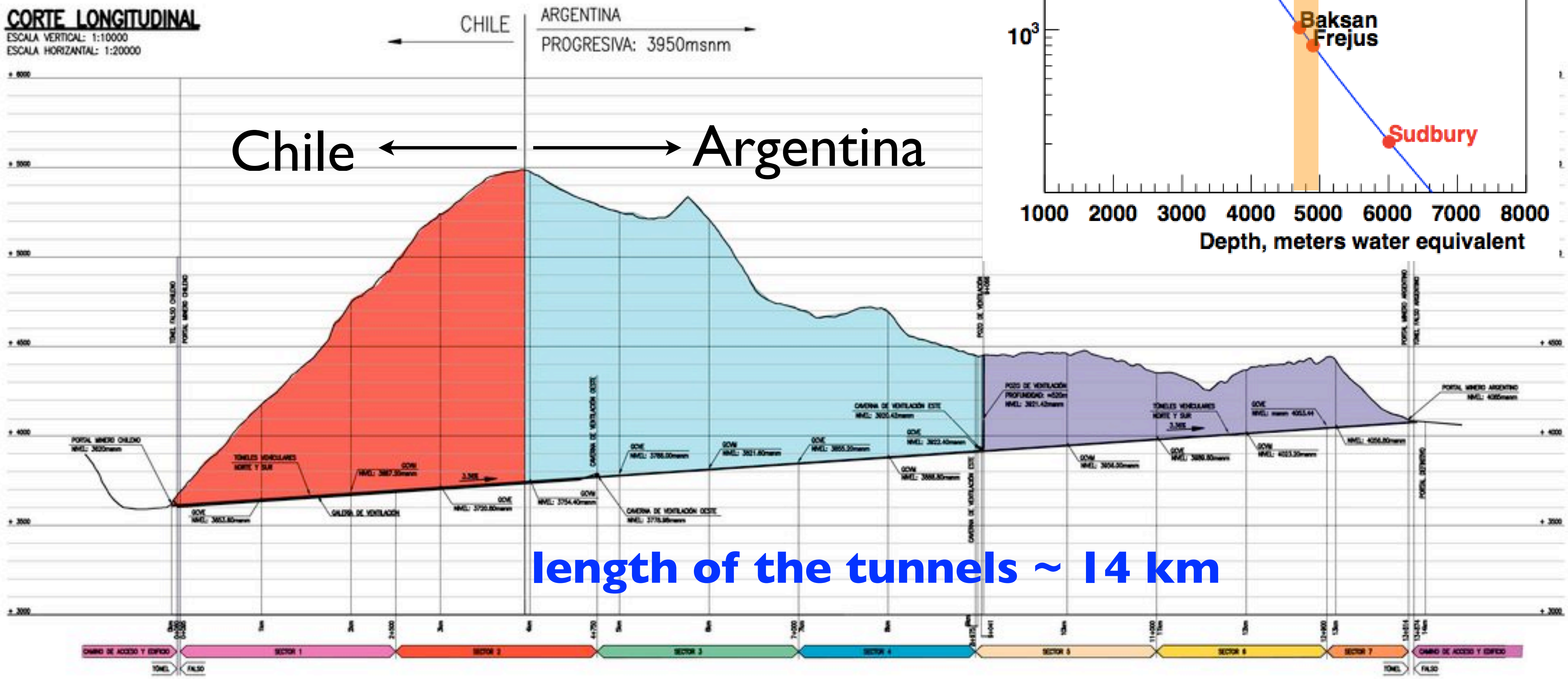
-First Underground Laboratory in the Southern Hemisphere-

Agua Negra Tunnels

there will be 2 tunnels

~4600-5000 mwe





Chile ⟵ ⟶ Argentina

length of the tunnels ~ 14 km

maximum overburden ~ 1.7 km

Possible Scientific Programs for ANDES Lab

Neutrinos

neutrino detector of ~ a few kton
scintilator like KamLAND/Borexino/SNO

observation of Solar/Geo/Supernova Neutrinos

neutrinoless double beta decay

Dark Matter

seasonal variation?
new technology ?

Geophysics -seismology network between Chile and Argentina

Biology - effect of the low radiation for the evolution of life

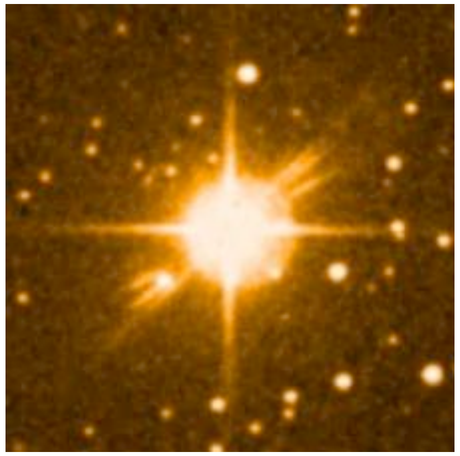
Experiments with underground accelerator

nuclear astrophysics
small accelerator (cyclotron) as neutrino source

In this talk we consider two ν soruces

Earth

Supernovae



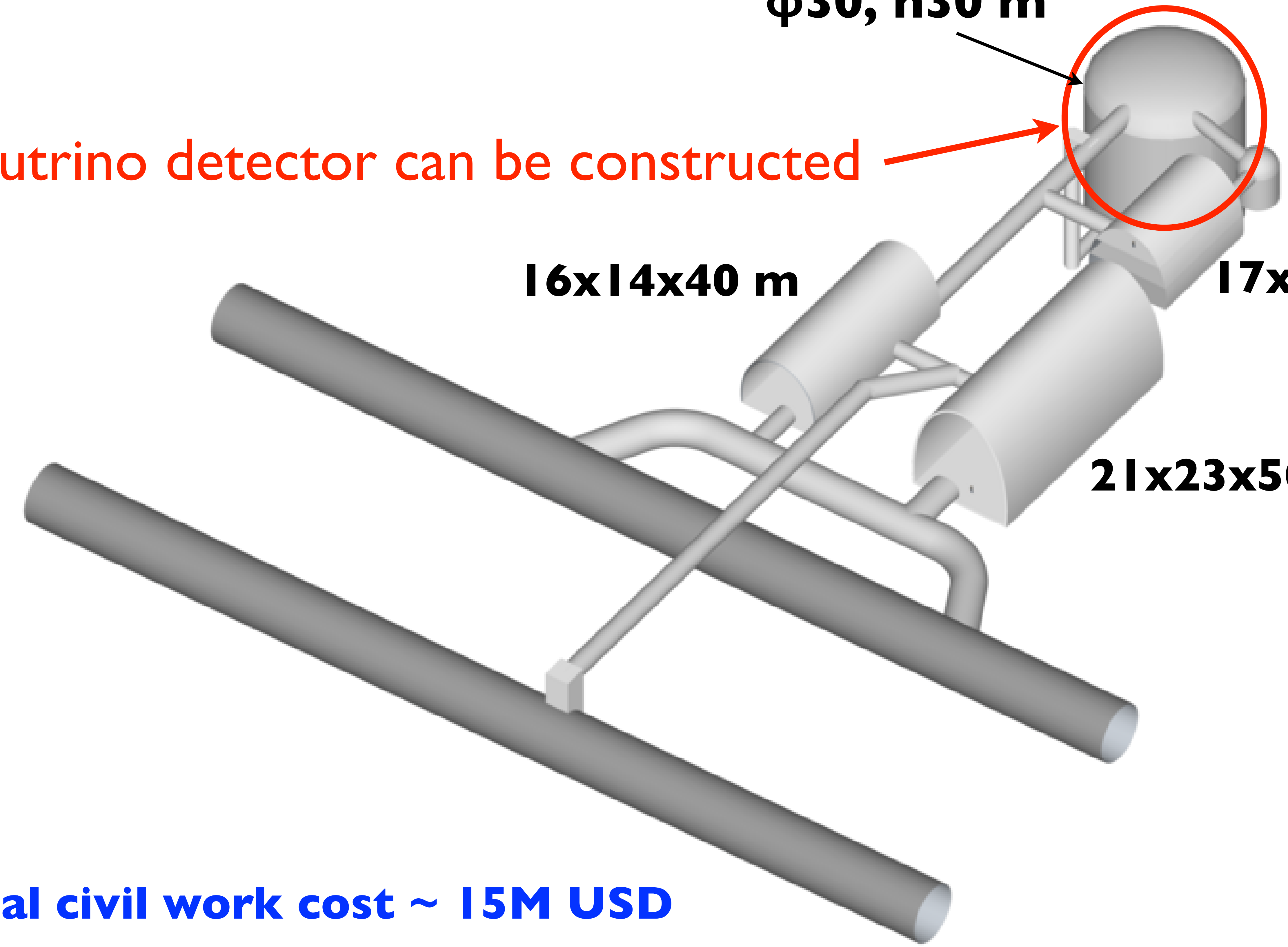
Two different approaches possible

1. Use ν as a tool to study properties (physics) of these sources

2. Use these sources to study ν properties

ANDES Laboratory concept

current design

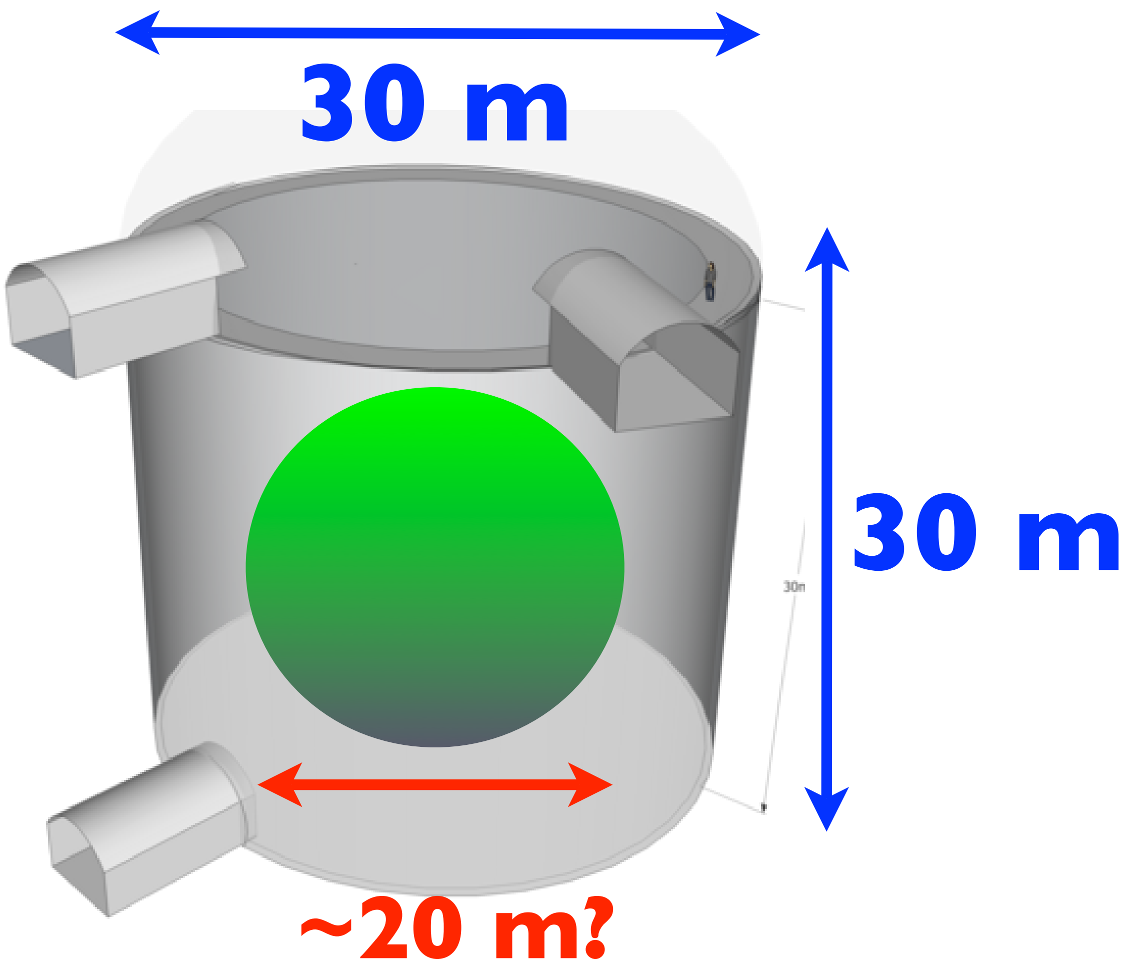


neutrino detector can be constructed

total civil work cost ~ 15M USD

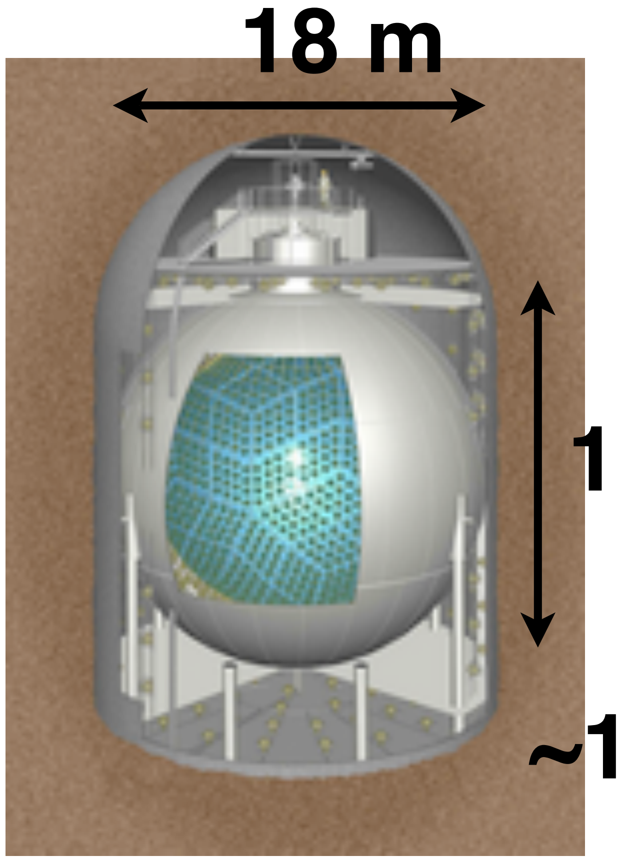
X. Bertou, 3rd ANDES workshop, Valparaiso, January 2012

Possible Neutrino Detector at ANDES



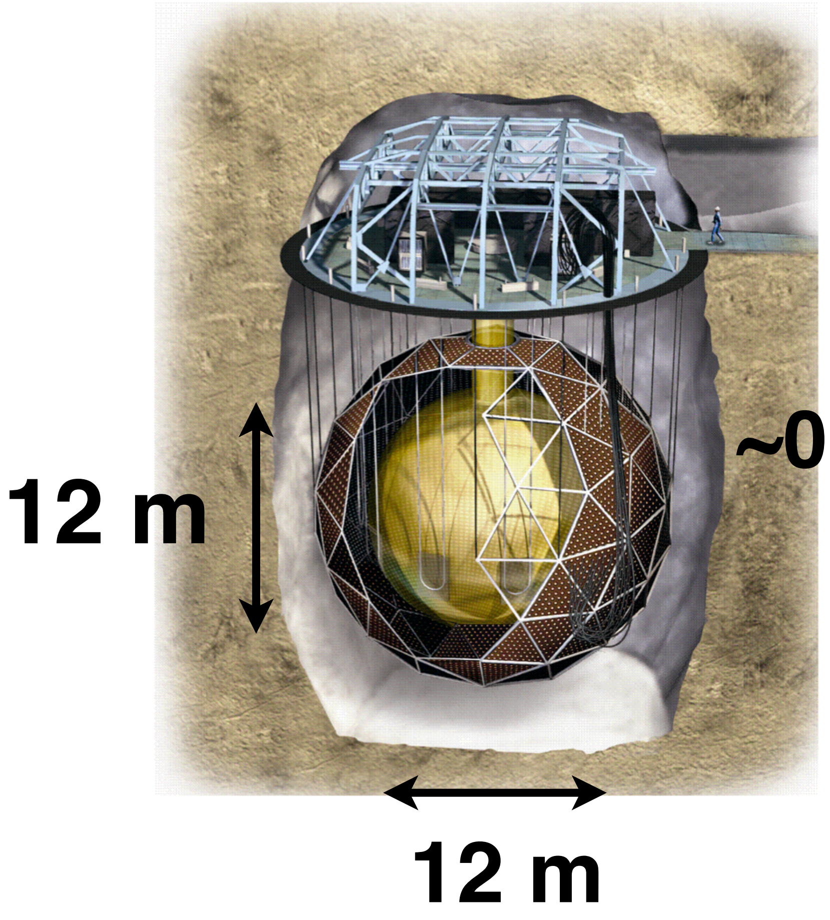
We assume that KamLAND/SNO+ like detector with a few kt can be constructed

For definetness,
let us assume 3kt L.S. of
$C_6H_5C_{12}H_{25}$ (alkyl Benzene)



KamLAND

~1kt scintilator

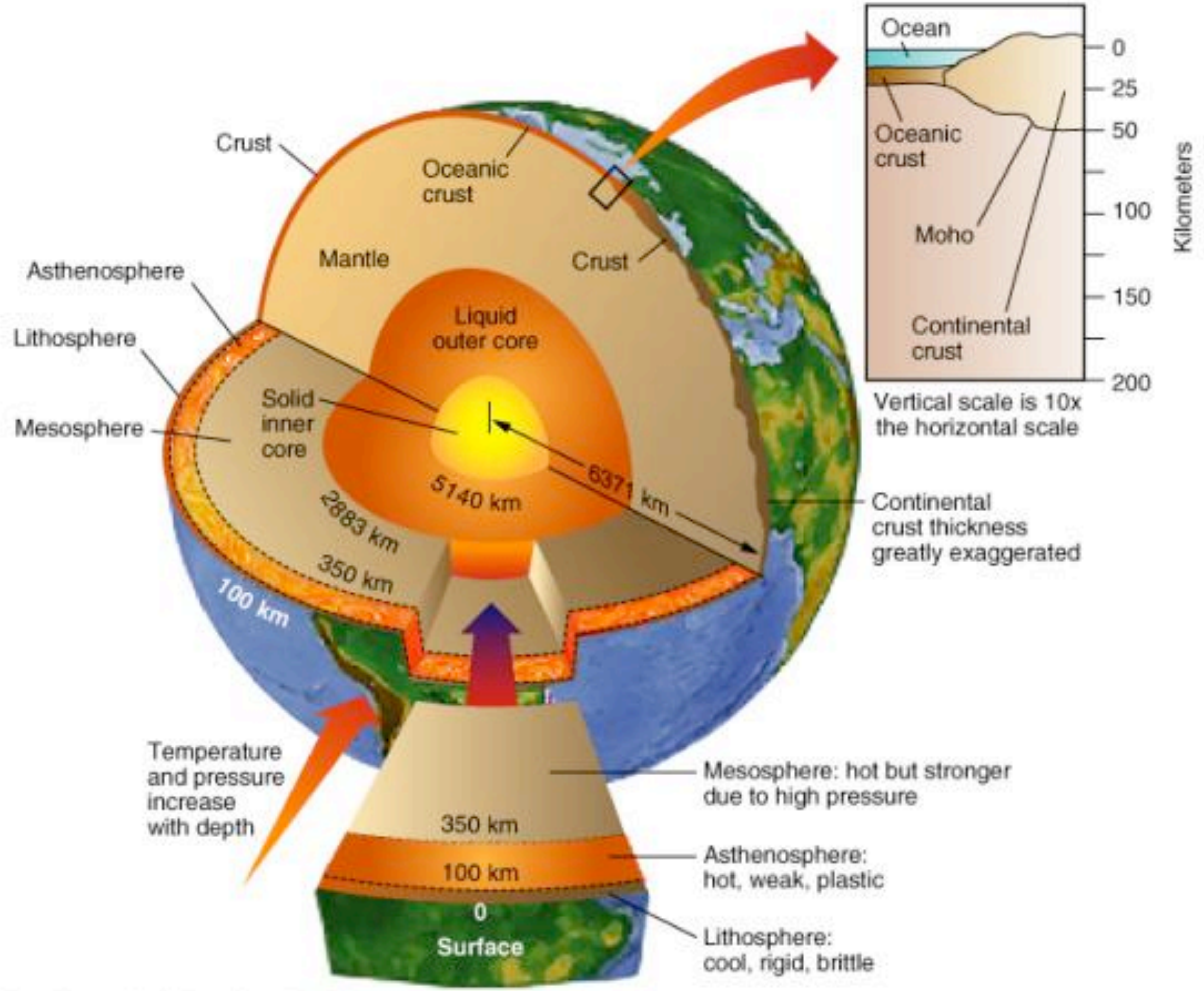


~0.8 kt scintilator

SNO+

Observation of Geoneutrinos at ANDES

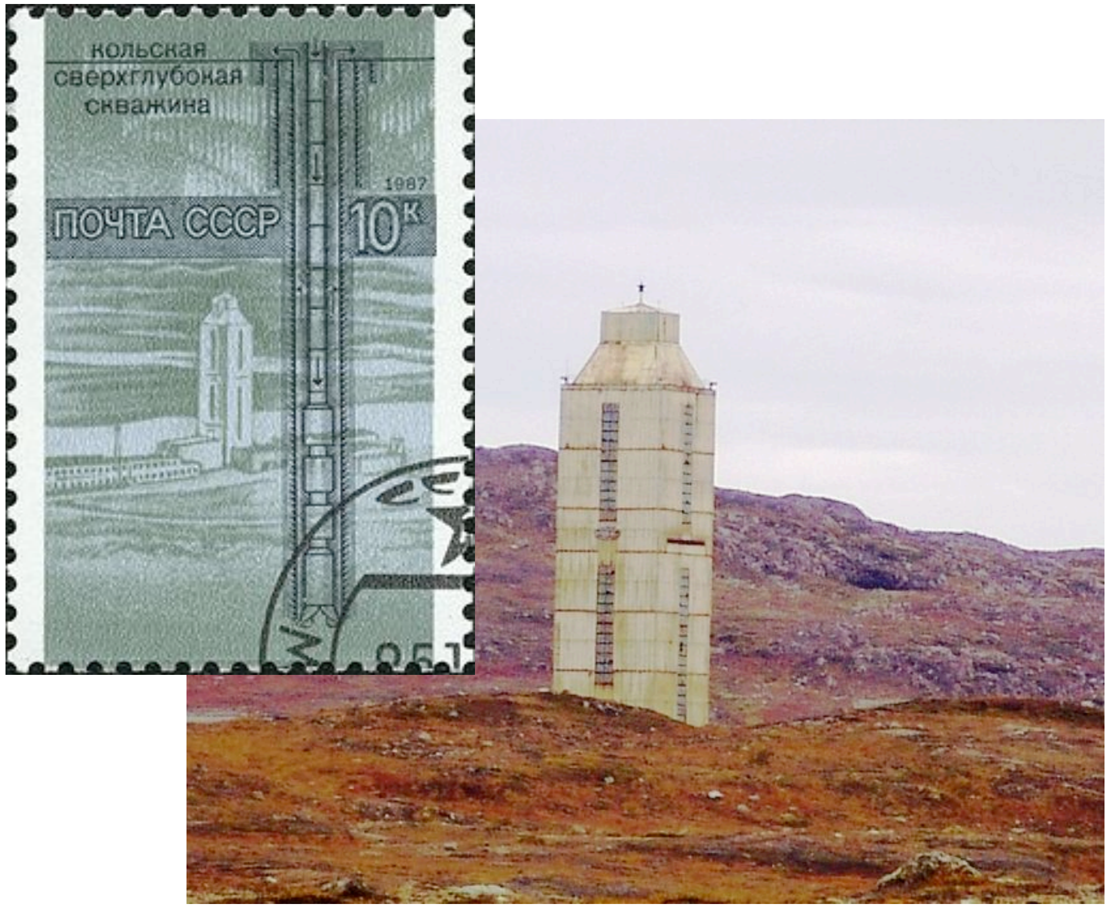
We know that Earth Interior should be something like below ...



but not so easy to probe directly ...

deepest hole in the Earth ~ 12 km depth

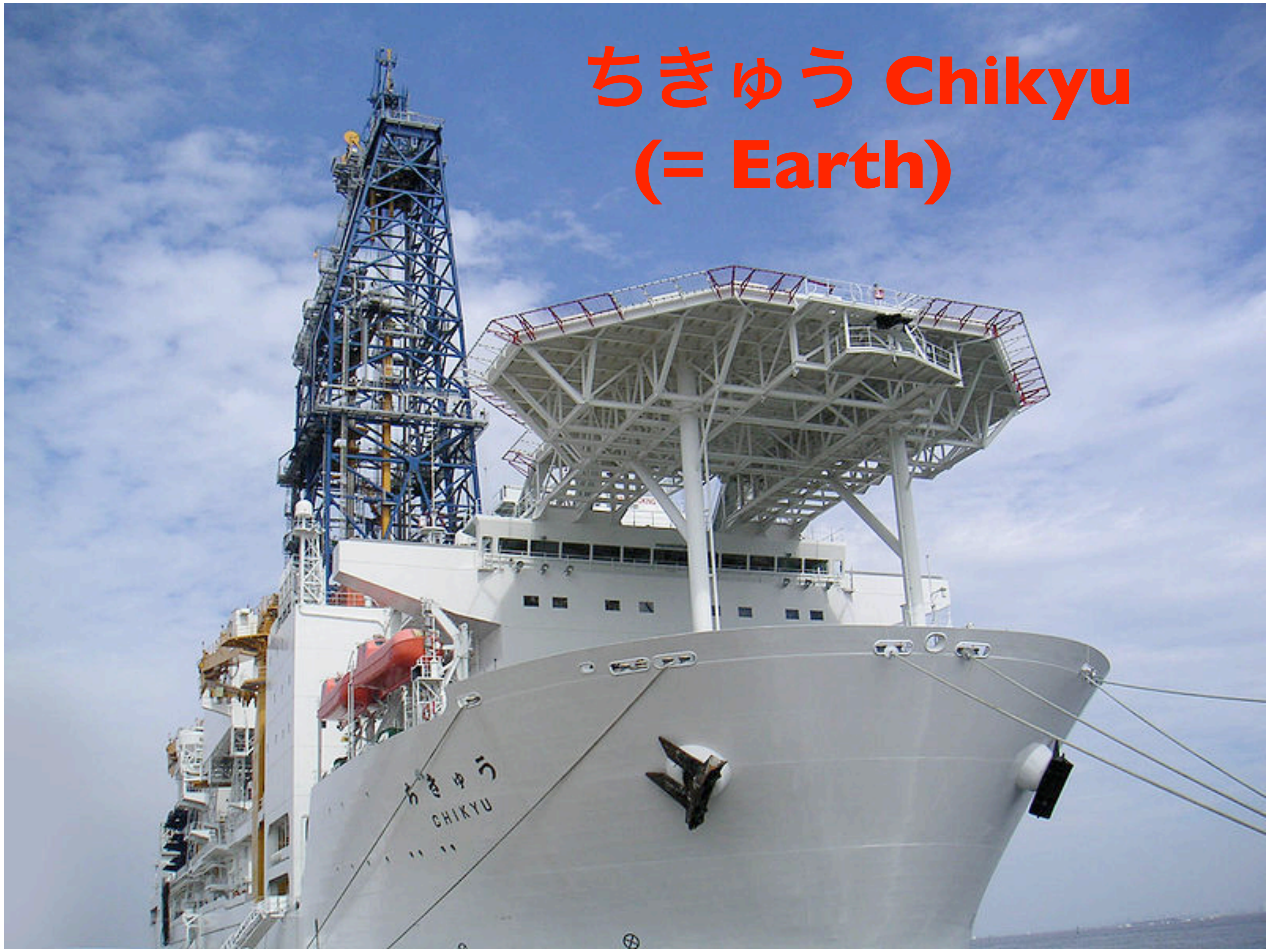
only ~ 0.2 % of the Earth Radius,
only upper part of the Earth crust !

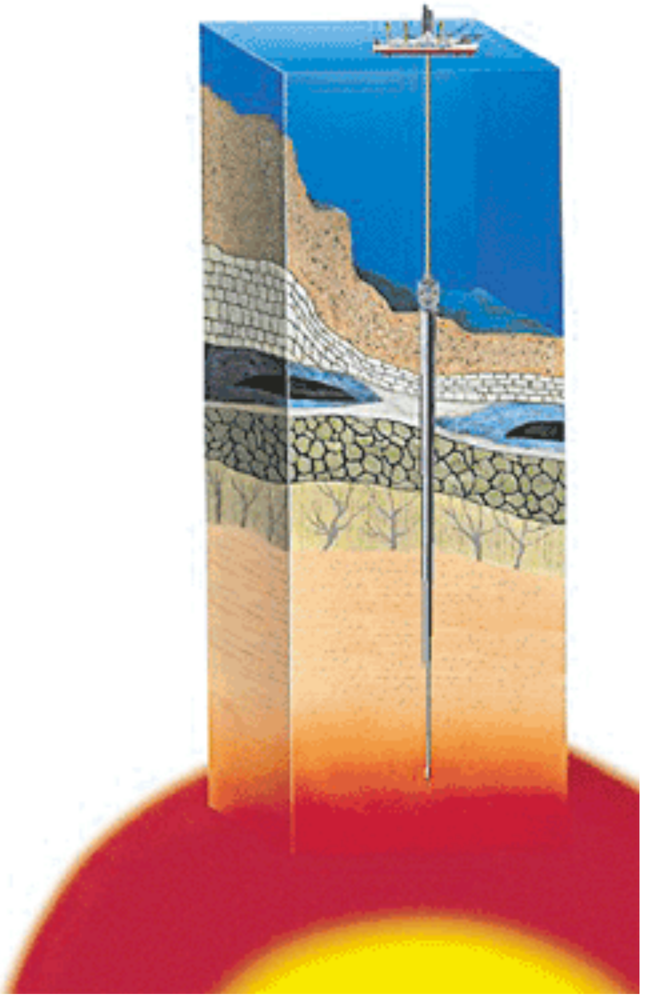


deepest hole of 12.262 m depth 1989

Kola Superdeep Barehole (Soviet Union)

Integrated Ocean Driling Program (IODP)





capable to dig more than 7 km from the seabed

one of the purposes: direct access to the Earth Mantle

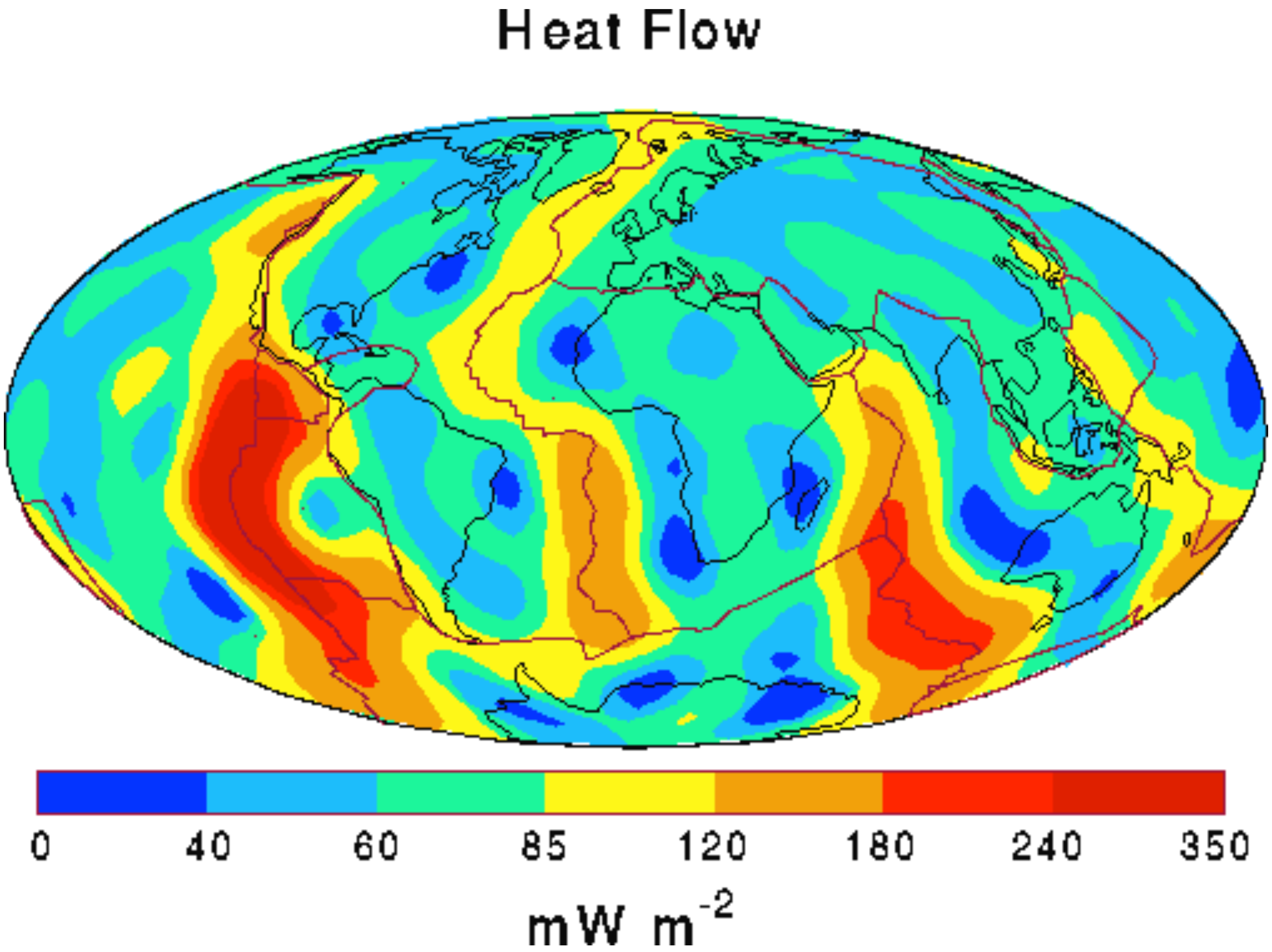
Methods to study Earth Interior

geochemistry: analysis of samples from the crust and upper mantle (deepest hole ~ 12 km, deepst rock samples from ~ 200 km)

seismology: it is possible to reconstruct the density profile of the Earth (and ditinguish solid from liquid) but not the compositions

geoneutrinos: new probe to study Earth Interior

Origin of the Earth Heat?

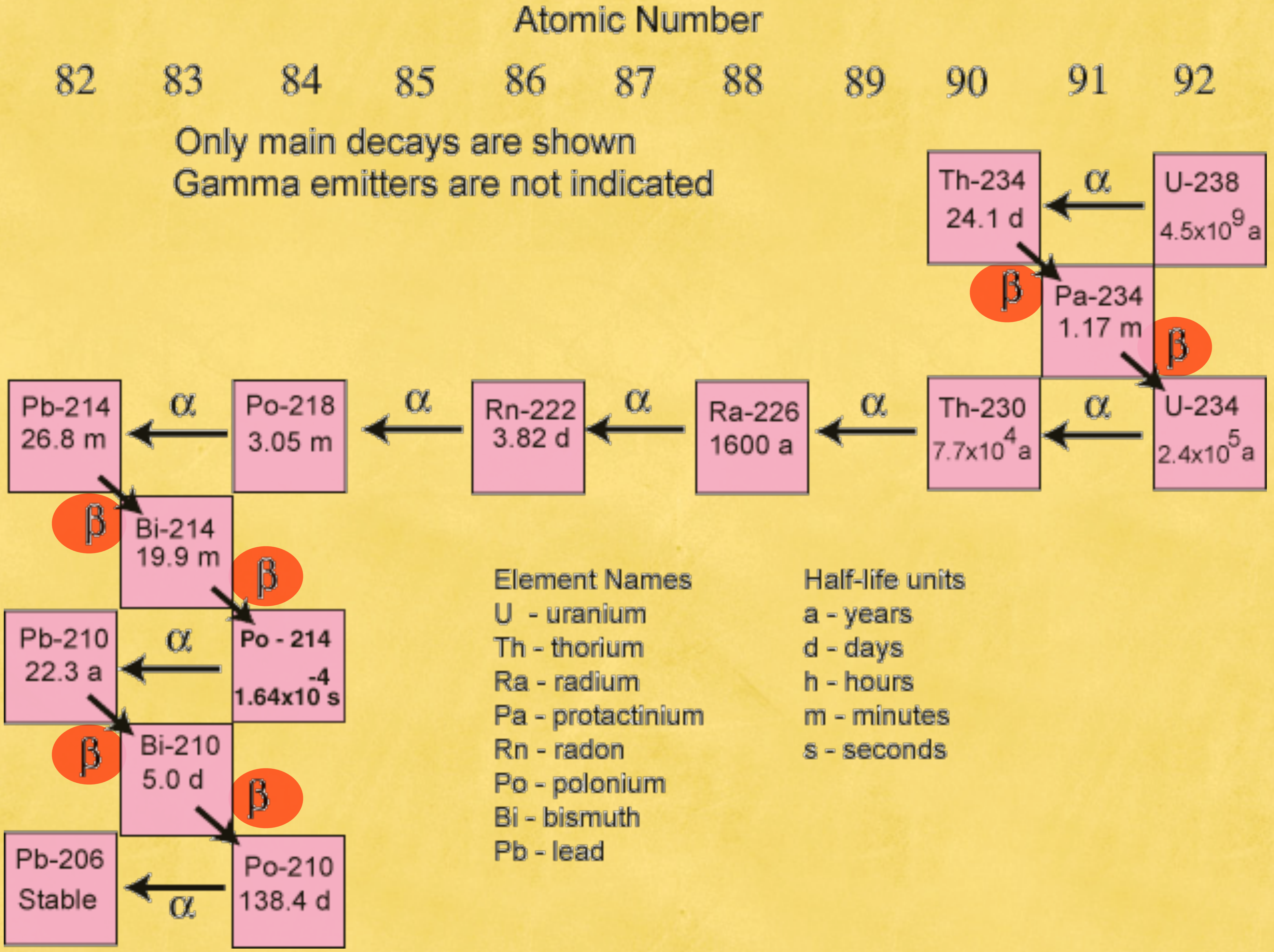


Observed (estimated): ~ 44 ± 1 TW

Theoretical Predictions: ~ 20 - 45 TW

large uncertainty

The Uranium-238 Decay Chain



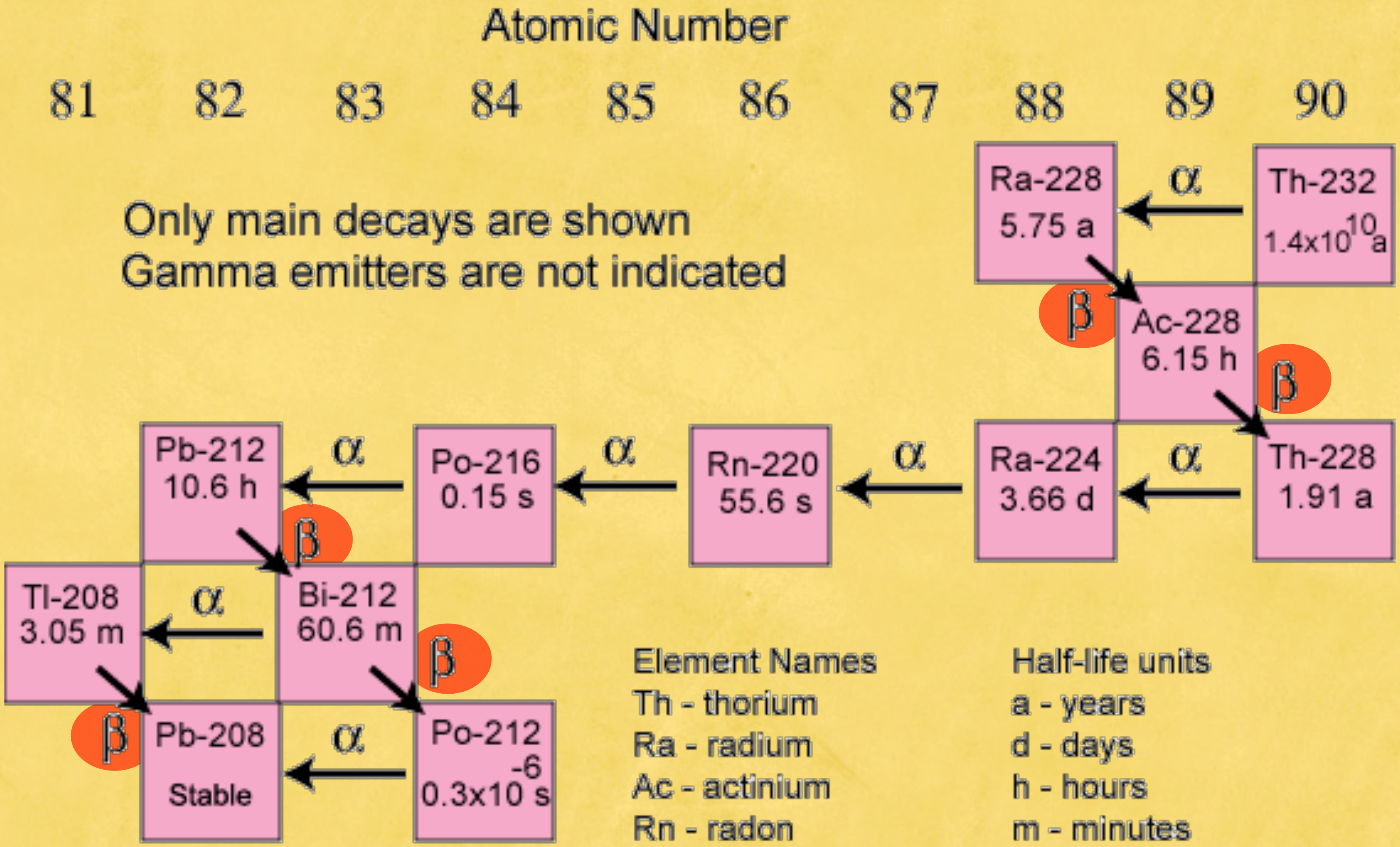
Only main decays are shown
Gamma emitters are not indicated

Element Names
U - uranium
Th - thorium
Ra - radium
Pa - protactinium
Rn - radon
Po - polonium
Bi - bismuth
Pb - lead

Half-life units
a - years
d - days
h - hours
m - minutes
s - seconds

$$^{238}\mathrm{U} \;\rightarrow\; {}^{206}\mathrm{Pb} + 8\;{}^{4}\mathrm{He} + 6\,\mathrm{e}^{-} + 6\,\bar{\nu}_{\mathrm{e}} + 51.7\ [\mathrm{MeV}]$$

The Thorium-232 Decay Chain



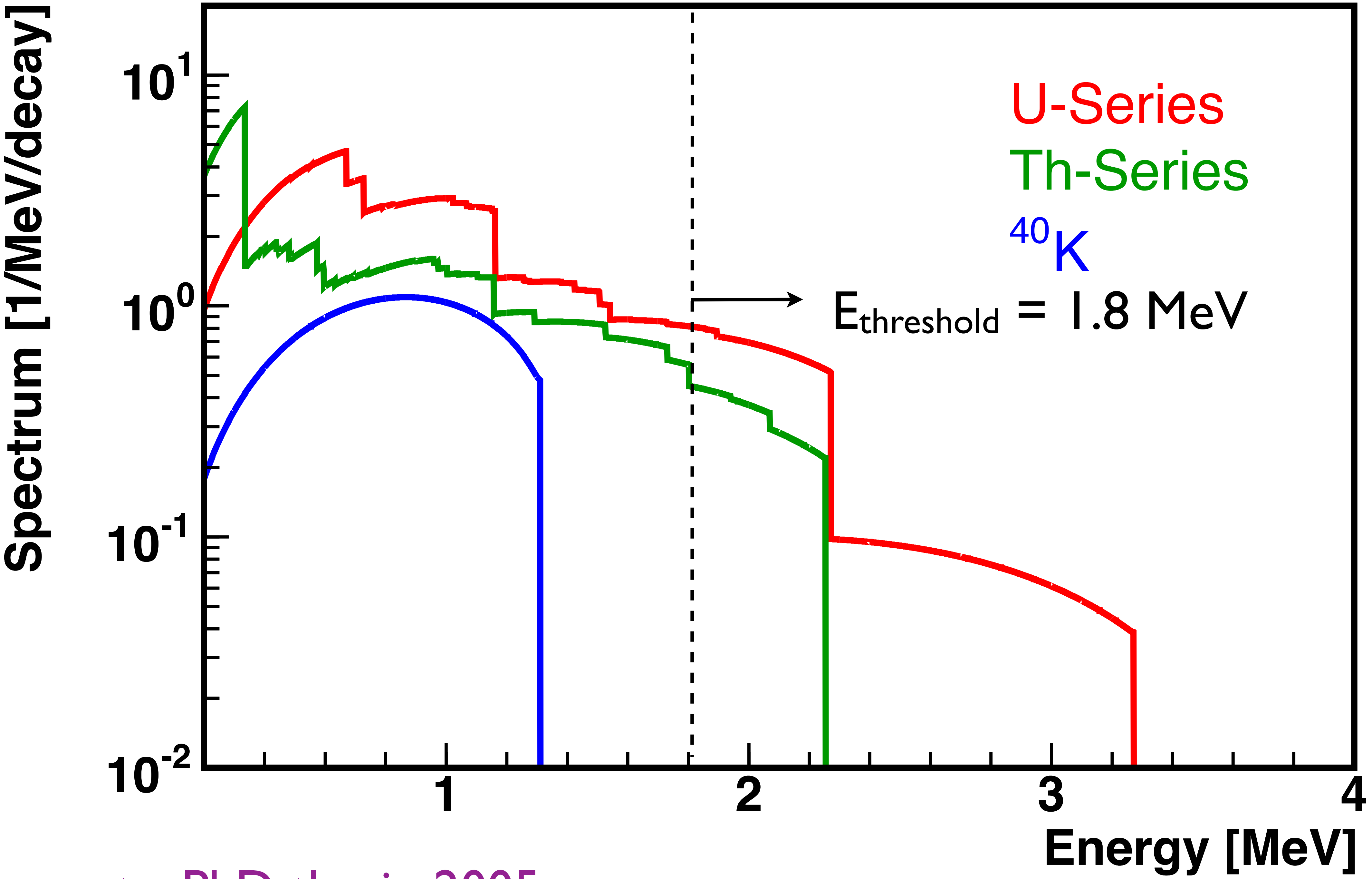
Only main decays are shown
Gamma emitters are not indicated

Element Names
Th - thorium
Ra - radium
Ac - actinium
Rn - radon
Po - polonium
Bi - bismuth
Pb - lead
Tl - thallium

Half-life units
a - years
d - days
h - hours
m - minutes
s - seconds

$$^{232}\mathrm{Th} \rightarrow {}^{206}\mathrm{Pb} + 6\,{}^{4}\mathrm{He} + 4\,\mathrm{e}^{-} + 4\,\bar{\nu}_{\mathrm{e}} + 42.7\ [\mathrm{MeV}]$$

Expected Geoneutrino Spectra



Enomoto, PhD thesis, 2005

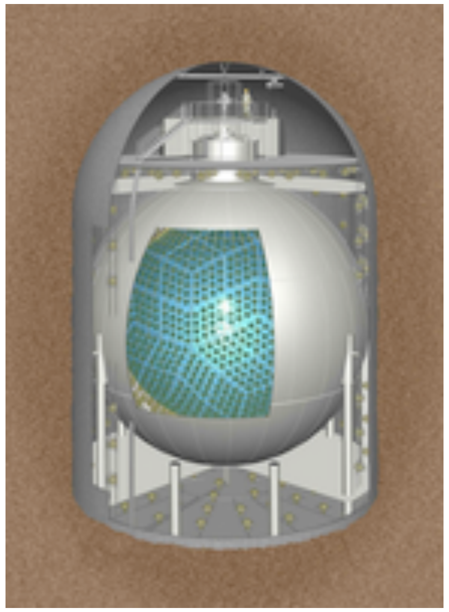
Can be detected by the inverse beta decay reaction

$$\bar{\nu}_e + p \rightarrow n + e^{+}$$

$E_{threshold}$ = 1.8 MeV

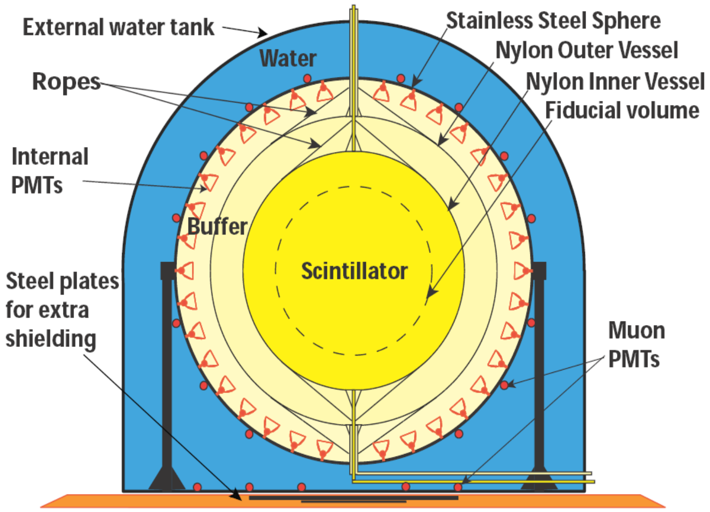
KamLAND

Nature Geocience 4, 647 (2011)

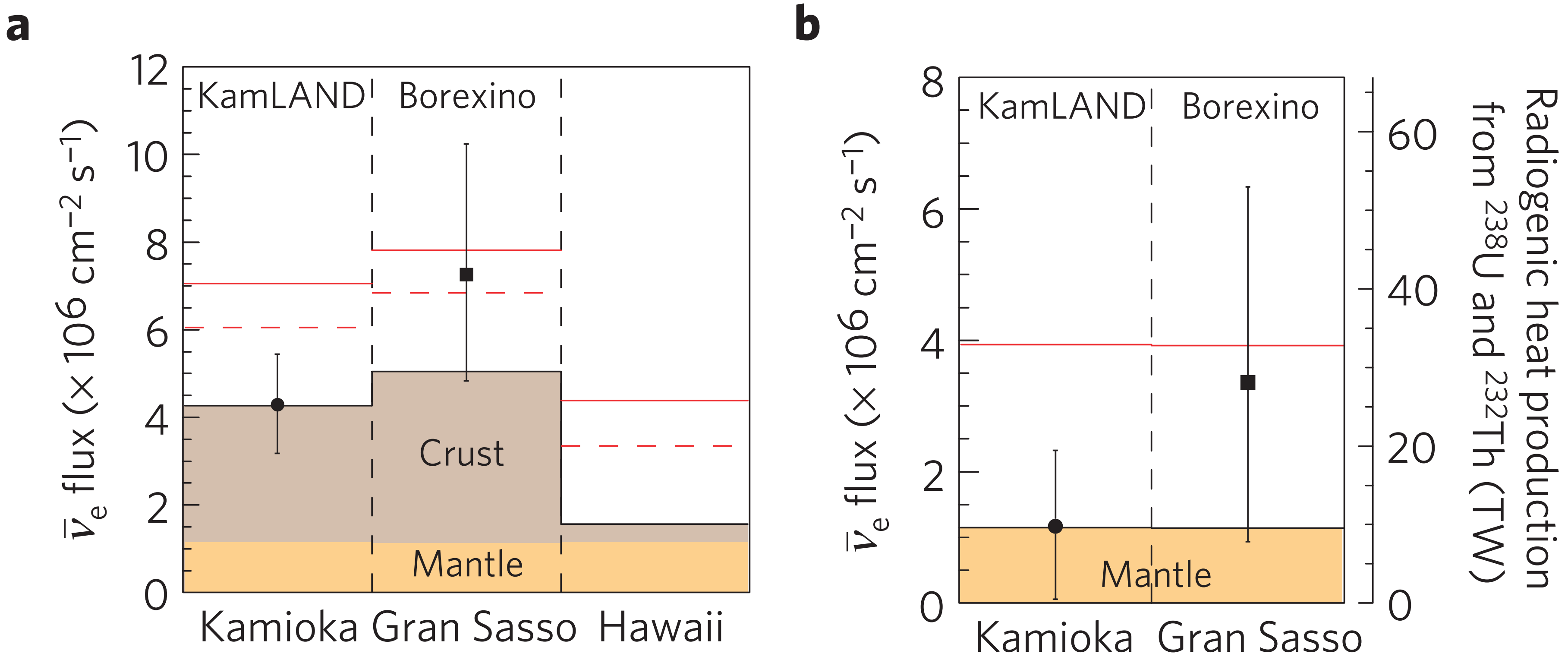


Borexino

Phys. Lett. B687, 299 (2010)



Active Target: 278 Tons of Liquid Scintillator
in Nylon Vessel of 4.25 m radius



KamLAND + Borexino ⟶ 20.0+8.8-8.6 TW

Fully radiogenic model is disfavored at 97.2 % CL.

Only ~ half of the observaed heat flow ~ 44 TW.

Observation of Geoneutrinos at ANDES

Why at ANDES?

Interesting Location (Higher Geo-nu flux)

Interesting to confirm site dependence

Very low reactor neutrino background

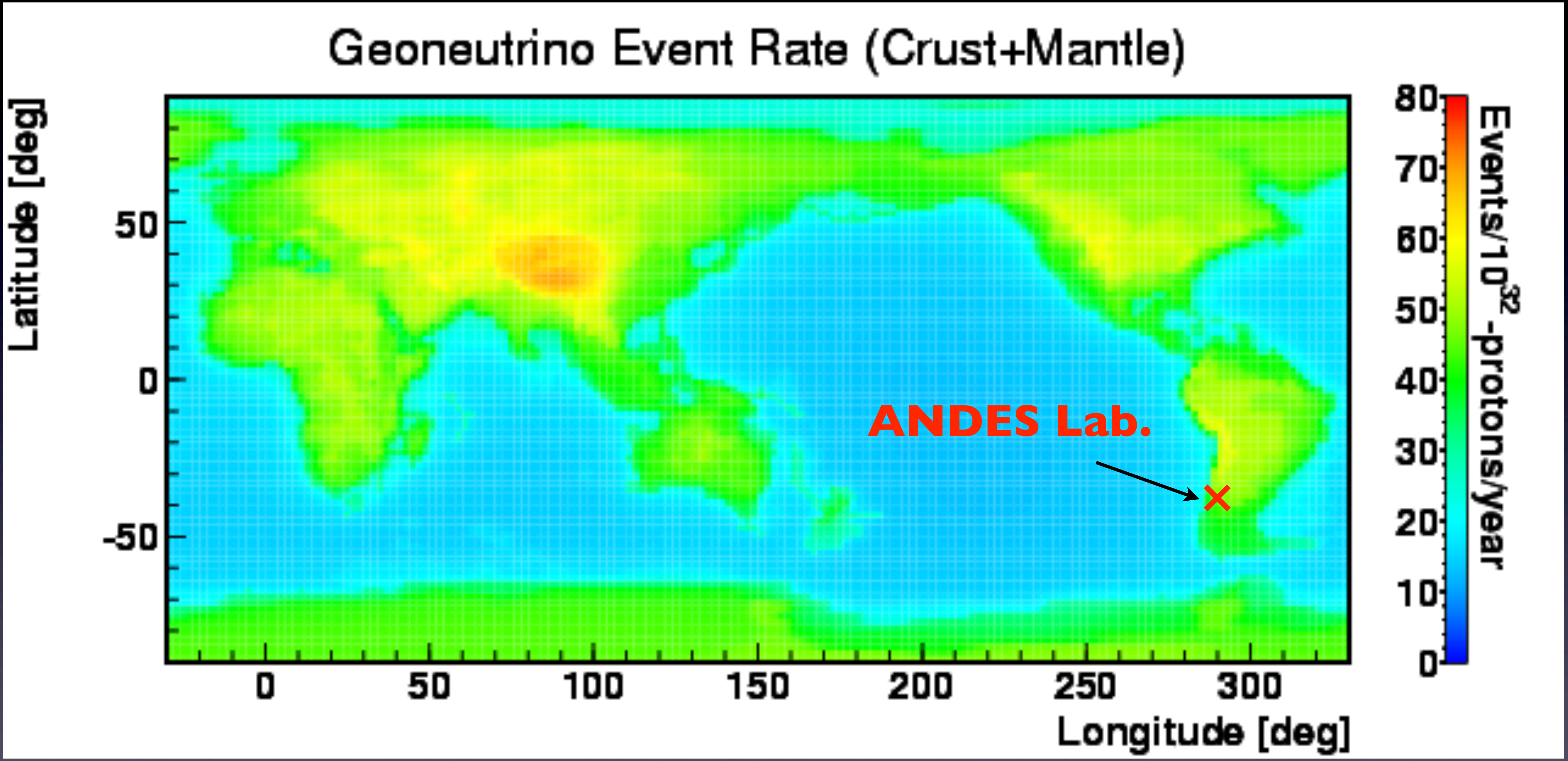
Concentrations of U and Th assumed in this work

Layer	c_{U} (μ g/g)	c_{Th} (μ g/g)
Oceanic Sediment	1.68	6.91
Oceanic Crust	0.1	0.22
Continental Sediment	2.8	10.7
Upper Continental Crust	2.8	10.7
Middle Continental Crust	1.6	6.1
Lower Continental Crust	0.2	1.2
Upper Mantle	0.012	0.048
Lower Mantle	0.012	0.048

Typically, Th/U ~ 4

Larger U and Th concentration in the continental crust

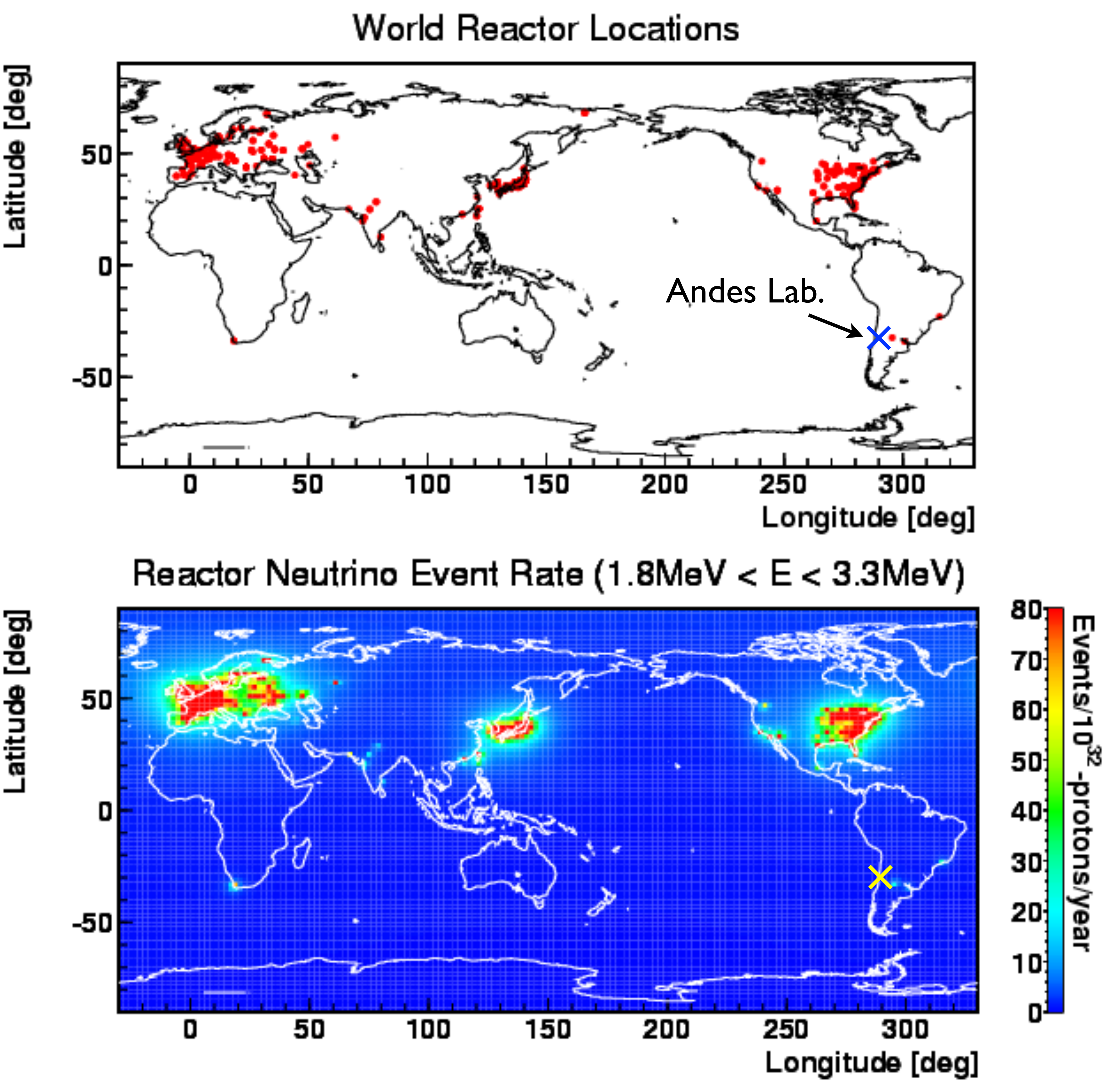
Interesting place because of larger flux of Geo-neutrinos (to confirm site dependence)



Enomoto, Neutrino Sciences 2007

U and Th are more concentrated in the continental crust

Another Advantage: Very few reactors



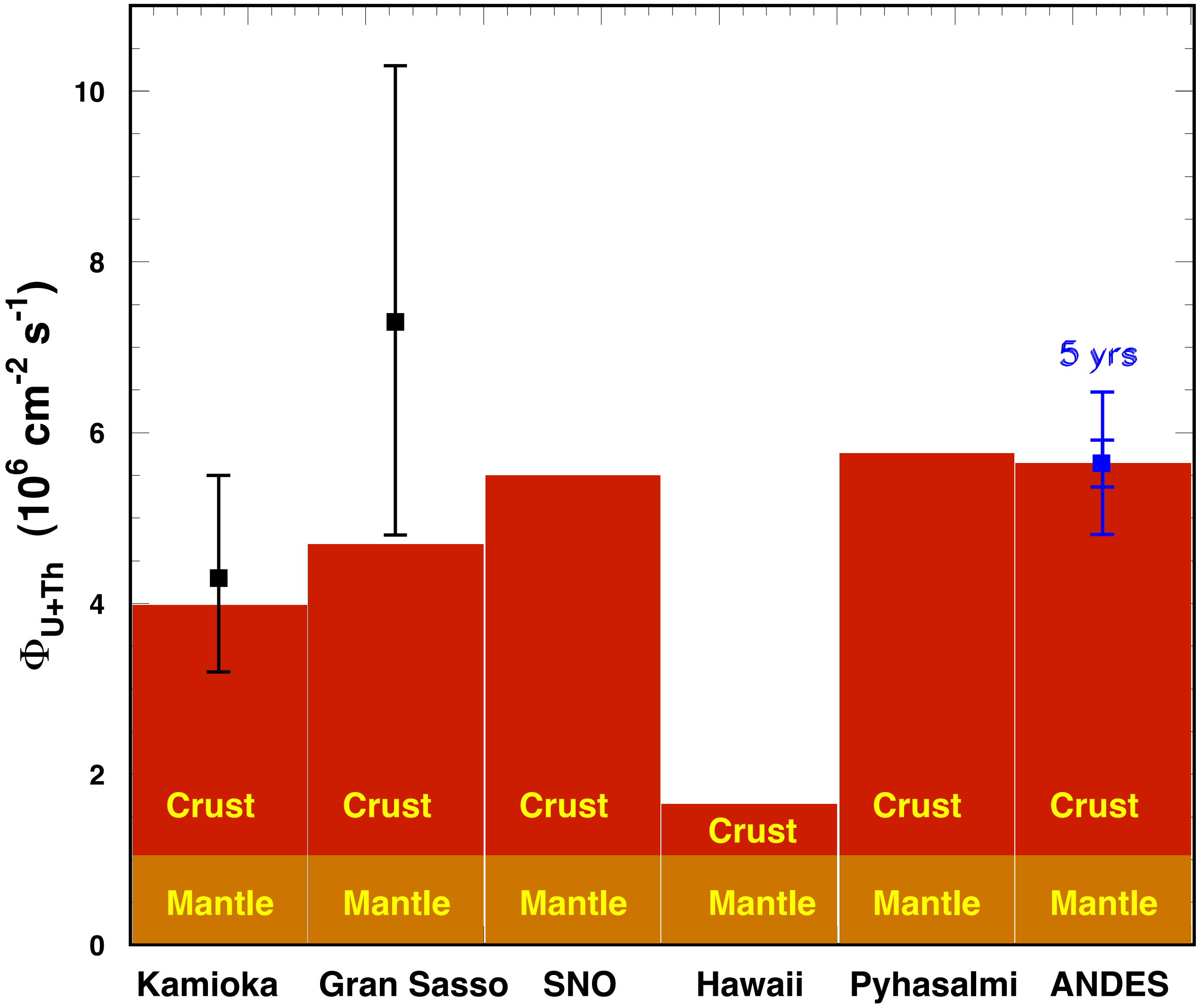
distance to nearest reactor ~ 600 km

$N_{\text{reac BG}}$ ~ 2 event for 3 kt/yr at Andes Laboratory

Enomoto, Neutrino Sciences 2007

Expected Geoneutrino flux and events at ANDES

comparison with other sites



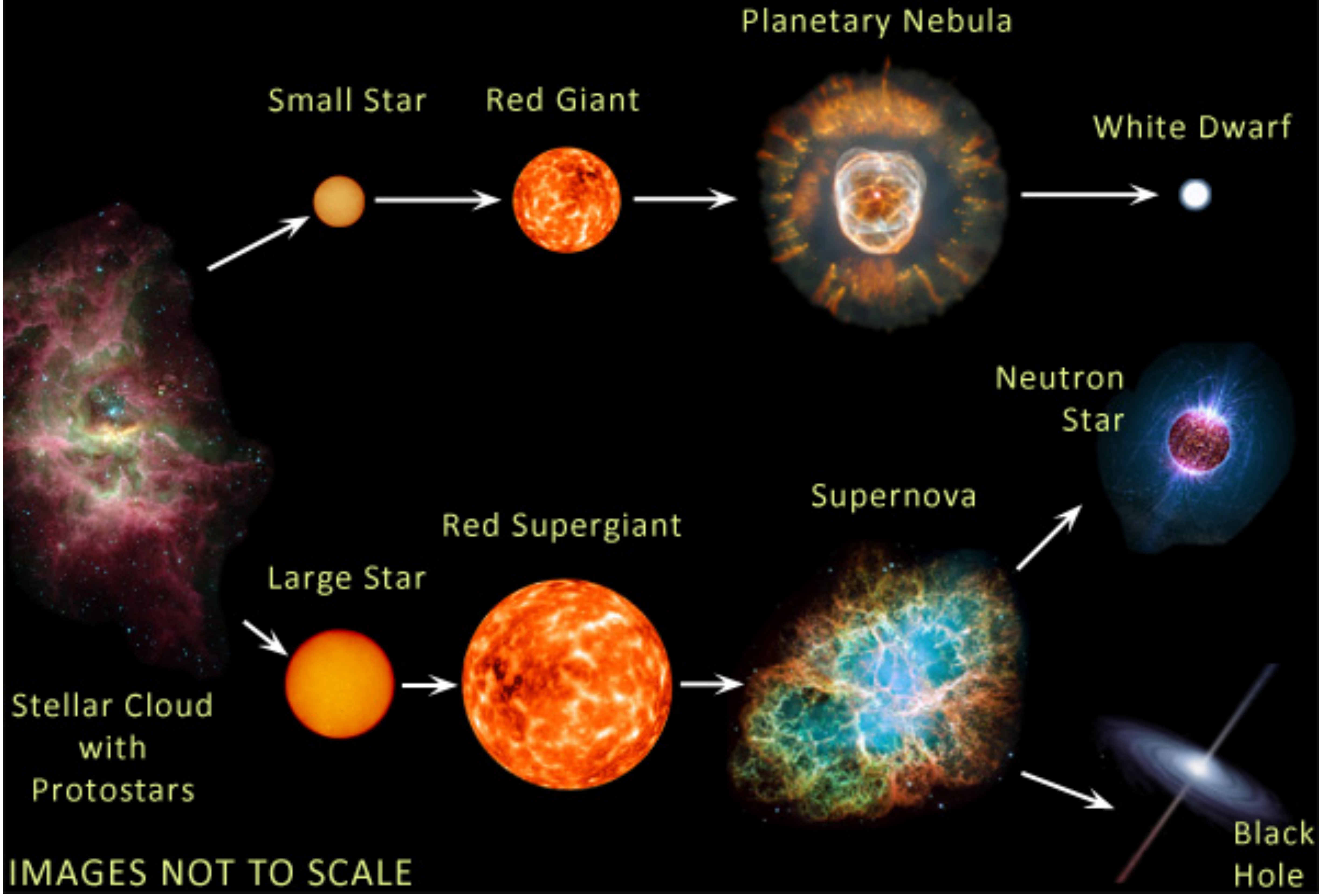
LENA?

of event /3 kt/yr

Location	Number from U	Number from Th	Total
Gran Sasso	53.8	14.7	68.5
Kamioka	45.7	12.4	58.1
Hawaii	27.3	7.4	34.7
Sudbury	63.2	17.2	80.4
Pyhäsalmi	66.1	18.0	84.1
ANDES	64.8	17.6	82.4

Observation of Supernova (SN) Neutrinos at ANDES

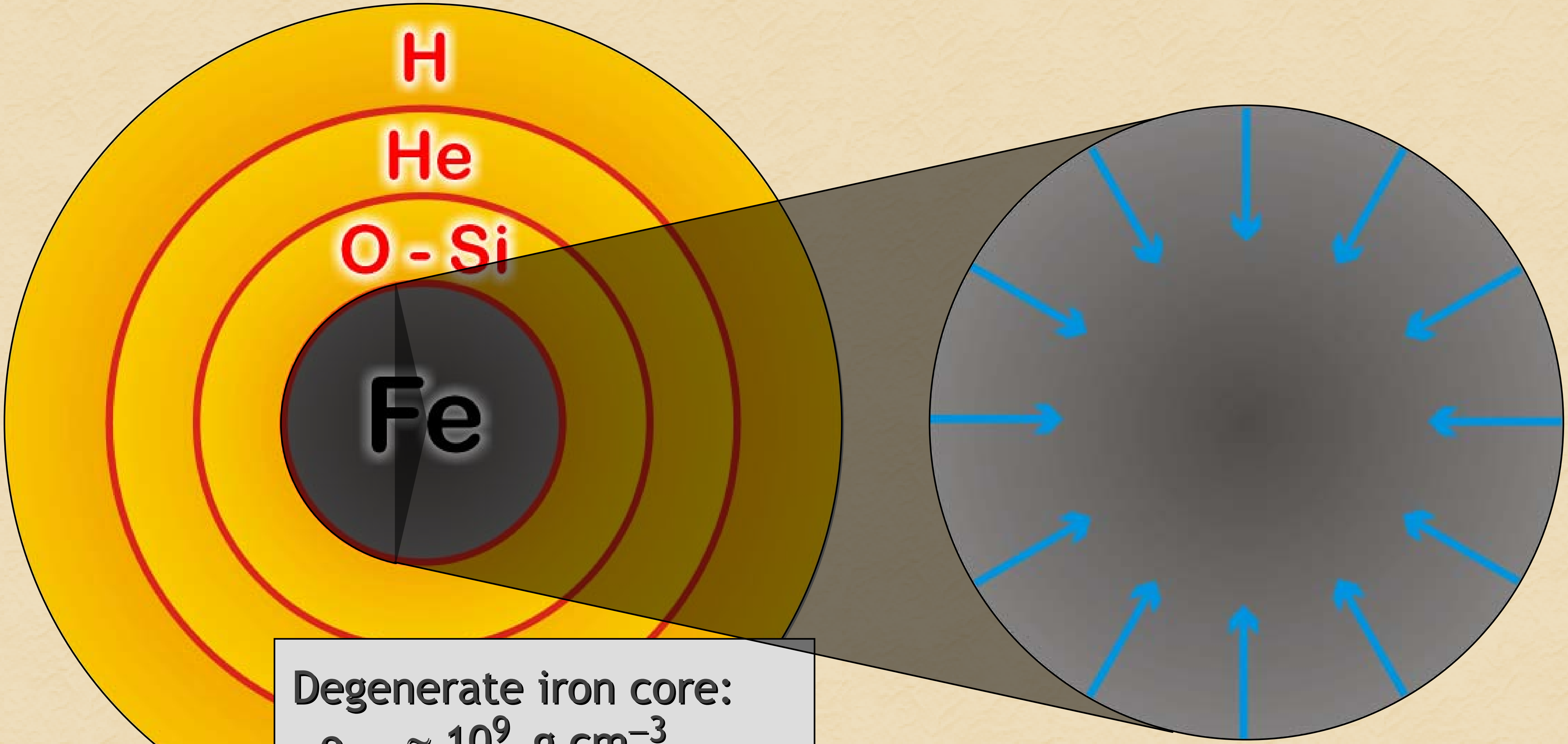
Stellar Evolution



Stellar Collapse and Supernova Explosion

Onion structure

Collapse (implosion)



Degenerate iron core:

$\rho \approx 10^9$ g cm^{-3}

$T \approx 10^{10}$ K

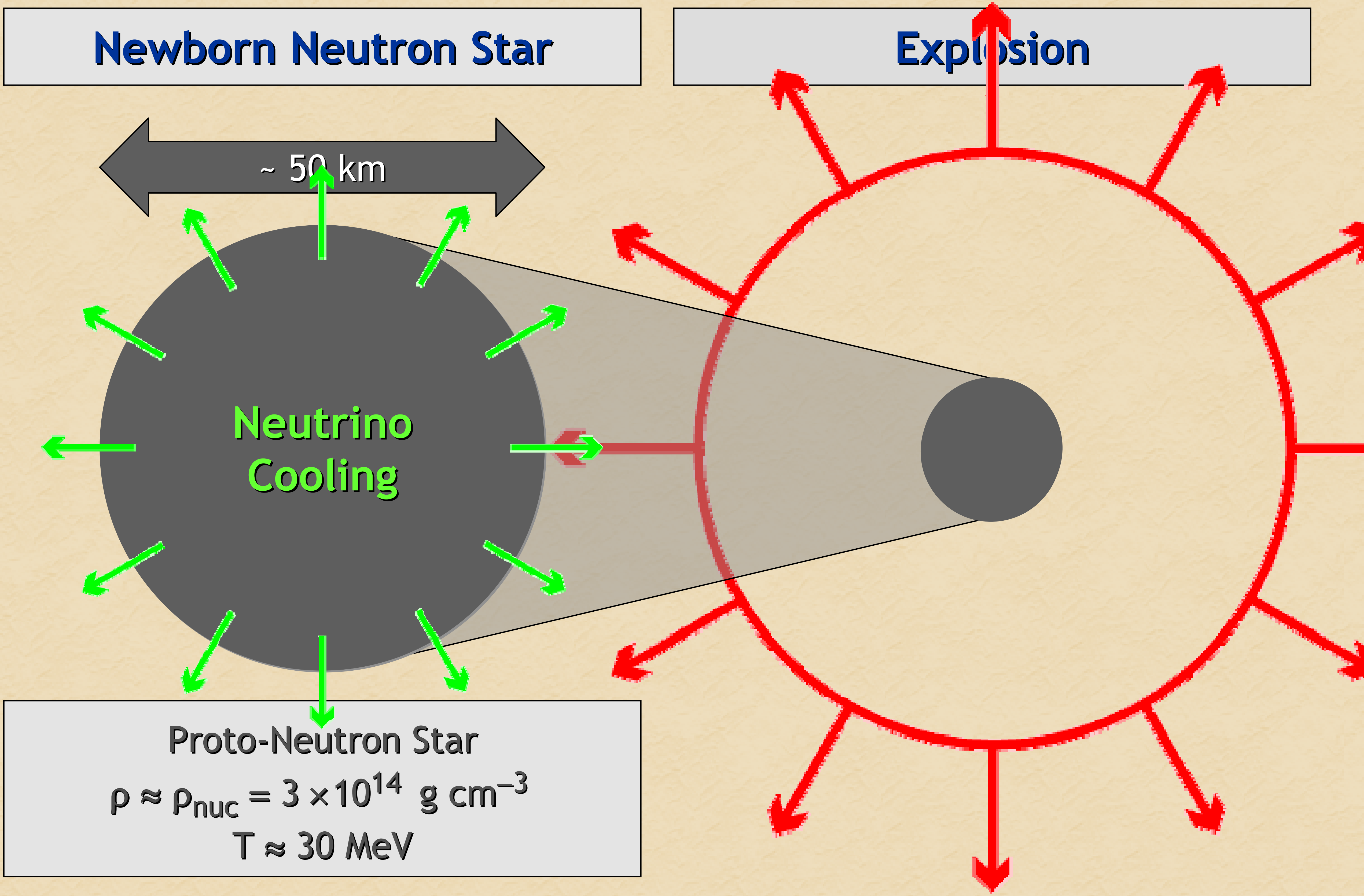
$M_{Fe} \approx 1.5\ M_{sun}$

$R_{Fe} \approx 8000$ km

G. Raffelt @ISAPP2008

Stellar Collapse and Supernova Explosion

G. Raffelt @ISAPP2008



Newborn Neutron Star

Explosion

Proto-Neutron Star

$\rho \approx \rho_{\rm nuc} = 3\times10^{14}\ {\rm g\ cm^{-3}}$

$T \approx 30\ {\rm MeV}$

Sanduleak –69 202

Tarantula Nebula

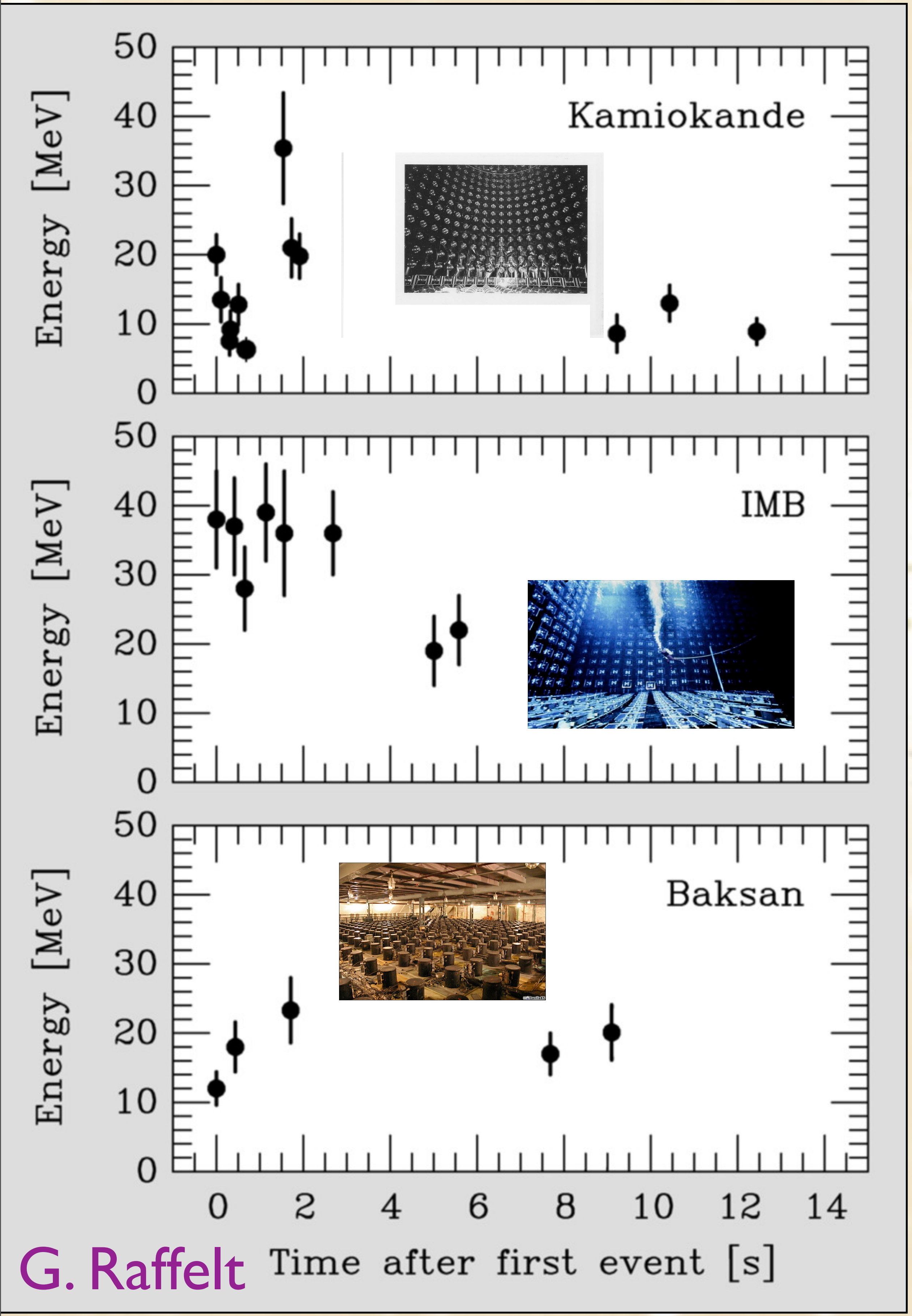
Large Magellanic Cloud
Distance 50 kpc
(160.000 light years)

Sanduleak –69 202

Supernova 1987A

23 February 1987

Neutrino Signal of Supernova 1987A



Kamiokande-II (Japan)
Water Cherenkov detector
2140 tons
Clock uncertainty ±1 min

Irvine-Michigan-Brookhaven (US)
Water Cherenkov detector
6800 tons
Clock uncertainty ±50 ms

Baksan Scintillator Telescope
(Soviet Union), 200 tons
Random event cluster ~ 0.7/day
Clock uncertainty +2/-54 s

Within clock uncertainties,
signals are contemporaneous

Observation of Supernova (SN) Neutrinos at ANDES

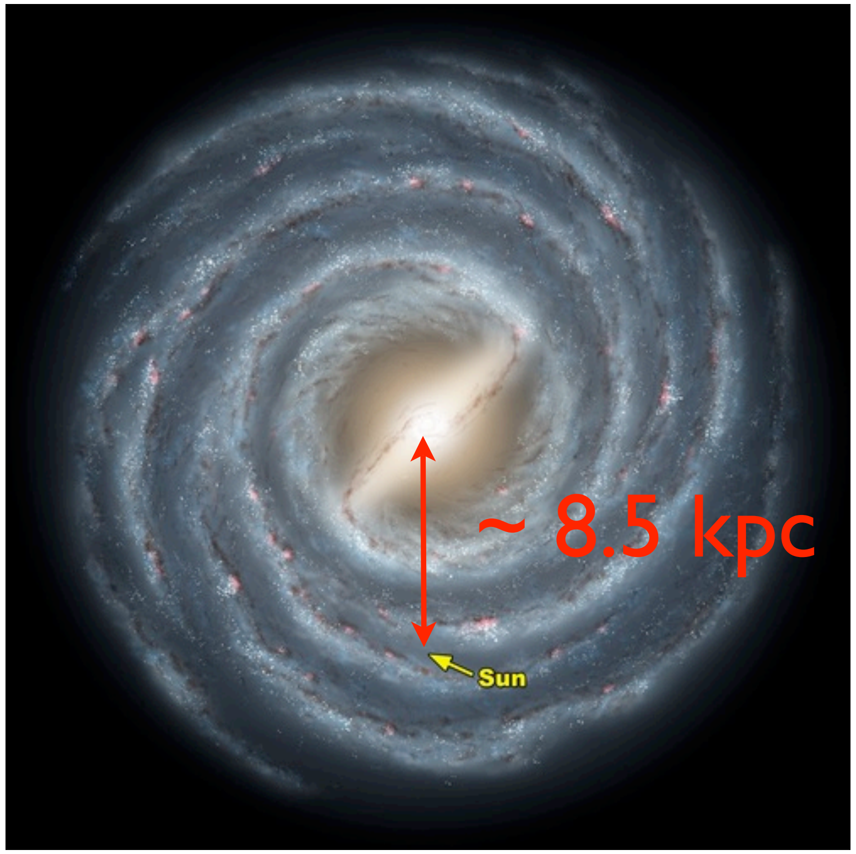
Relevance of the ANDES detector

Galactic SN is so rare that it is highly welcome to have as many detector runnig as possible

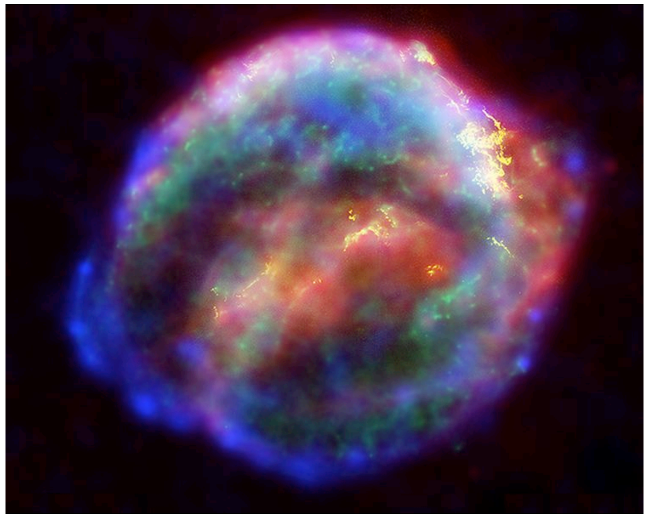
~ 10 Galactic SN in last ~ 2000 yrs

Complementary to the detectors in the Northern Hemisphere, increase the chance to see Earth matter effect

Observation of ν coming from next galactic supernova

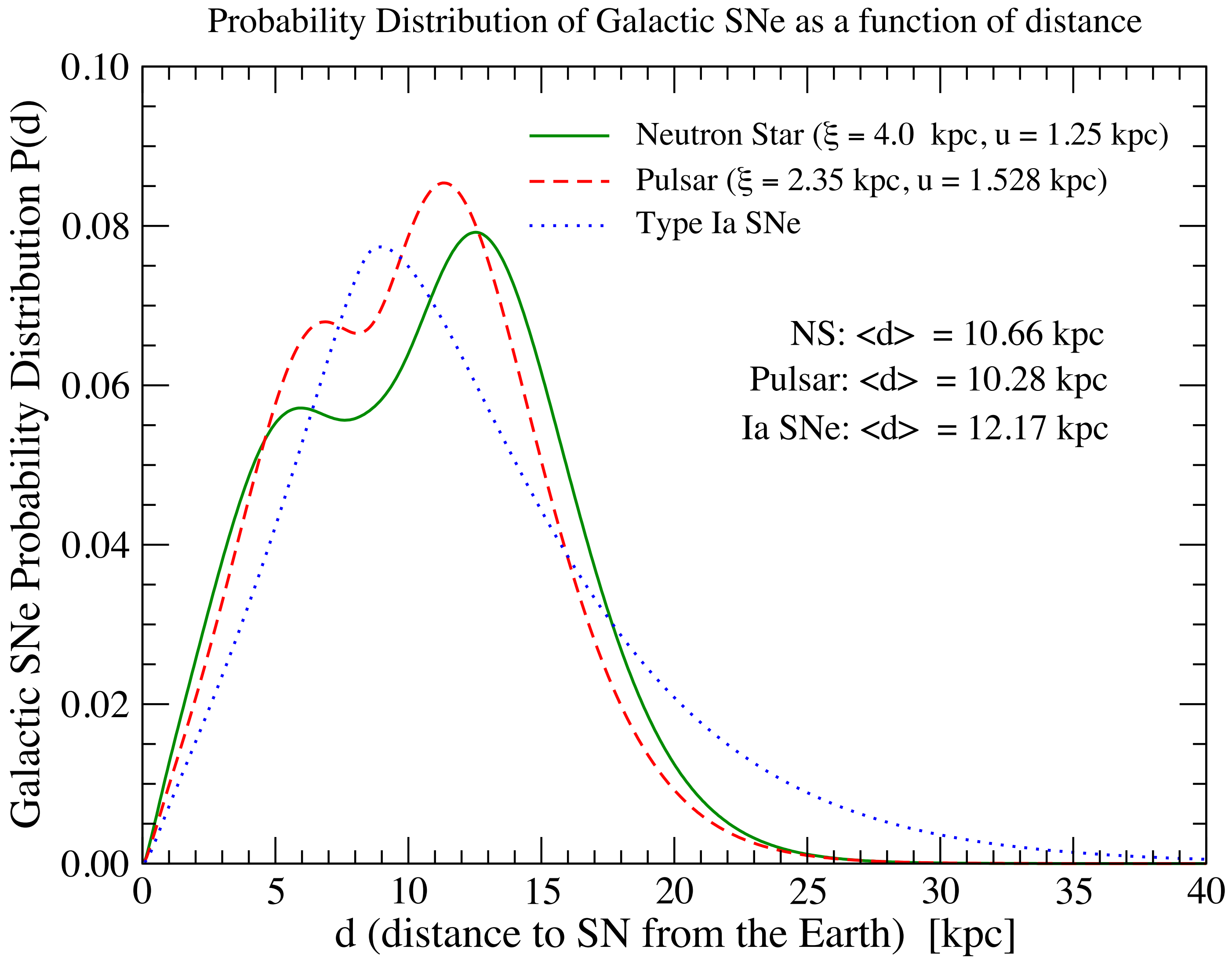


last Galactic SN was observed in1604



Distance ~ 6 kpc

theoretical prediction
rate of galactic SN
~ a few SN per century



Distributions taken from Mirizzi et al, JCAP05, 012 (2006)

For simplicity, we consider only the following 2 channels of CC and NC reactions

(1) CC: Inverse Beta Decay

$$\bar{\nu}_{\mathrm{e}} + \mathrm{p} \rightarrow \mathrm{n} + \mathrm{e}^{+}$$

depends on neutrino oscillation

(2) NC: Neutrino-Proton elastic scattering

$$\nu + \mathrm{p} \rightarrow \nu + \mathrm{p}$$

does not depend on oscillation

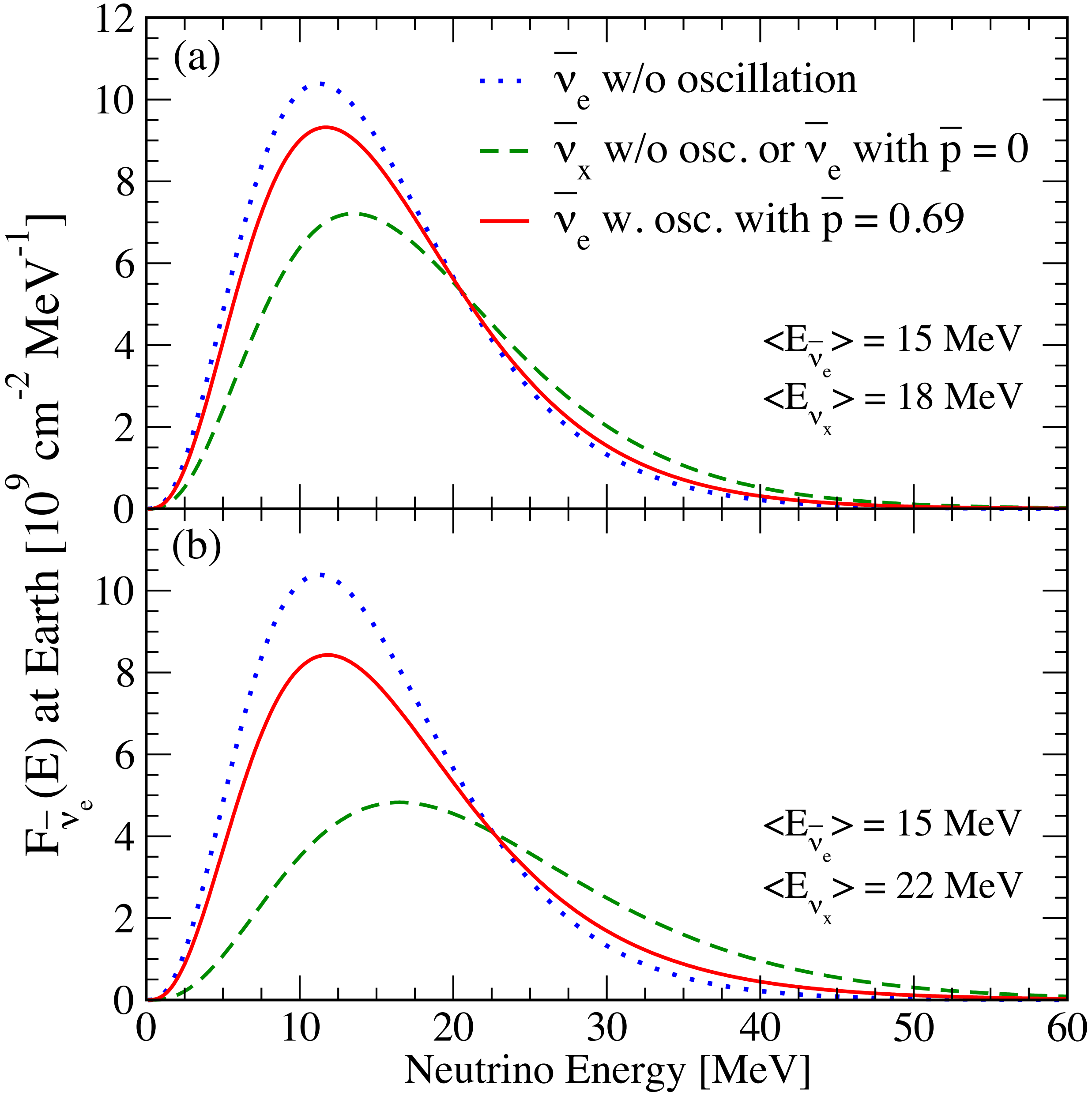
Beacom, Farr & Vogel, PRD66, 033001 (2002)

Dasgupta & Beacom, PRD83, 113006 (2011)

Expected SN neutrino spectra at Earth

$$F_{\bar{\nu}_e}(E) = \bar{p}(E)\, F^0_{\bar{\nu}_e}(E) + [1-\bar{p}(E)] F^0_{\bar{\nu}_x}(E)\,,$$

$$F^0_{\nu_\alpha}(E) = \frac{1}{4\pi D^2}\,\frac{\Phi_{\nu_\alpha}}{\langle E_{\nu_\alpha}\rangle}\,\frac{\beta_\alpha^{\beta_\alpha}}{\Gamma(\beta_\alpha)}\left[\frac{E}{\langle E_{\nu_\alpha}\rangle}\right]^{\beta_\alpha-1} \exp\left[-\beta_\alpha\frac{E}{\langle E_{\nu_\alpha}\rangle}\right]$$



reference SN parameters

$\langle E_{\nu_e}\rangle = 12$ MeV

$\langle E_{\bar{\nu}_e}\rangle = 15$ MeV $\quad D = 10$ kpc

$\langle E_{\nu_x}\rangle = 18$ MeV

$\nu_x = \nu_\mu, \nu_\tau, \bar{\nu}_\mu, \bar{\nu}_\tau$

$\langle E_{\nu_\alpha}\rangle \Phi_{\nu_\alpha} = 5\times 10^{52}$ erg for any flavor

$\beta = 4$

reference Osc. parameters

$\bar{p}(E) \sim \cos^2\theta_{12} = 0.69$

for normal mass hierarchy

$\bar{p}(E) \sim 0$

for inverted mass hierarchy

However, collective effects, shock wave, etc, can change the value of $\bar{p}$(E)

Expected # of events for galactic SN

Prediction for ANDES D = 10kpc

3kt liquid scintilator

type KamLAND BOREXINO SNO

	Chemical Composition of the Scintillator			
Reaction	(a) $C_{12}H_{26}$ + C_9H_{12} (80% + 20%)	(b) C_9H_{12} pseudocumene	(c) $C_6H_5C_{12}H_{25}$ alkyl benzene	Assumptions
$\bar{\nu}_e + p \to n + e^+$	873	630	762	No Oscillation
$\bar{\nu}_e + p \to n + e^+$	924	669	804	$\bar{p} = c_{12}^2 = 0.69$ (NH), $\langle E_{\nu_x} \rangle = 18$ MeV
$\bar{\nu}_e + p \to n + e^+$	1038	750	903	$\bar{p} = 0.0$ (IH), $\langle E_{\nu_x} \rangle = 18$ MeV
$\bar{\nu}_e + p \to n + e^+$	957	690	834	$\bar{p} = c_{12}^2 = 0.69$ (NH), $\langle E_{\nu_x} \rangle = 20$ MeV
$\bar{\nu}_e + p \to n + e^+$	1140	825	993	$\bar{p} = 0.0$ (IH), $\langle E_{\nu_x} \rangle = 20$ MeV
$\bar{\nu}_e + p \to n + e^+$	987	714	858	$\bar{p} = c_{12}^2 = 0.69$ (NH), $\langle E_{\nu_x} \rangle = 22$ MeV
$\bar{\nu}_e + p \to n + e^+$	1239	894	1080	$\bar{p} = 0.0$ (IH), $\langle E_{\nu_x} \rangle = 22$ MeV
$\nu + p \to \nu + p$	294	318	453	all flavors $T' > 0.2$ MeV, $\langle E_{\nu_x} \rangle = 18$ MeV
$\nu + p \to \nu + p$	399	405	561	all flavors $T' > 0.2$ MeV, $\langle E_{\nu_x} \rangle = 20$ MeV
$\nu + p \to \nu + p$	510	492	663	all flavors $T' > 0.2$ MeV, $\langle E_{\nu_x} \rangle = 22$ MeV

# of event for $\bar{\nu}_\mathrm{e} + \mathrm{p} \to \mathrm{n} + \mathrm{e}^+$ ~ 800-1000 for 3 kt

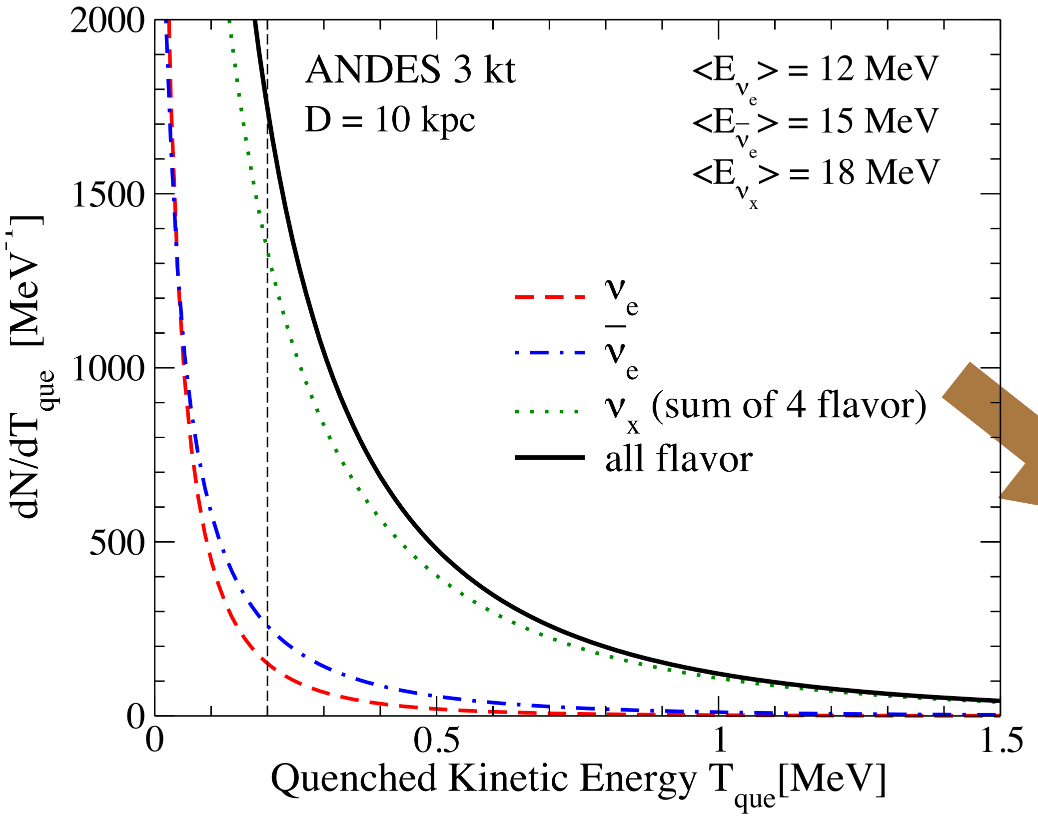
 # event for $\nu + \mathrm{p} \to \nu + \mathrm{p}$ ~ 350-650 for 3 kt

Reconstruction of the Original SN ν flux

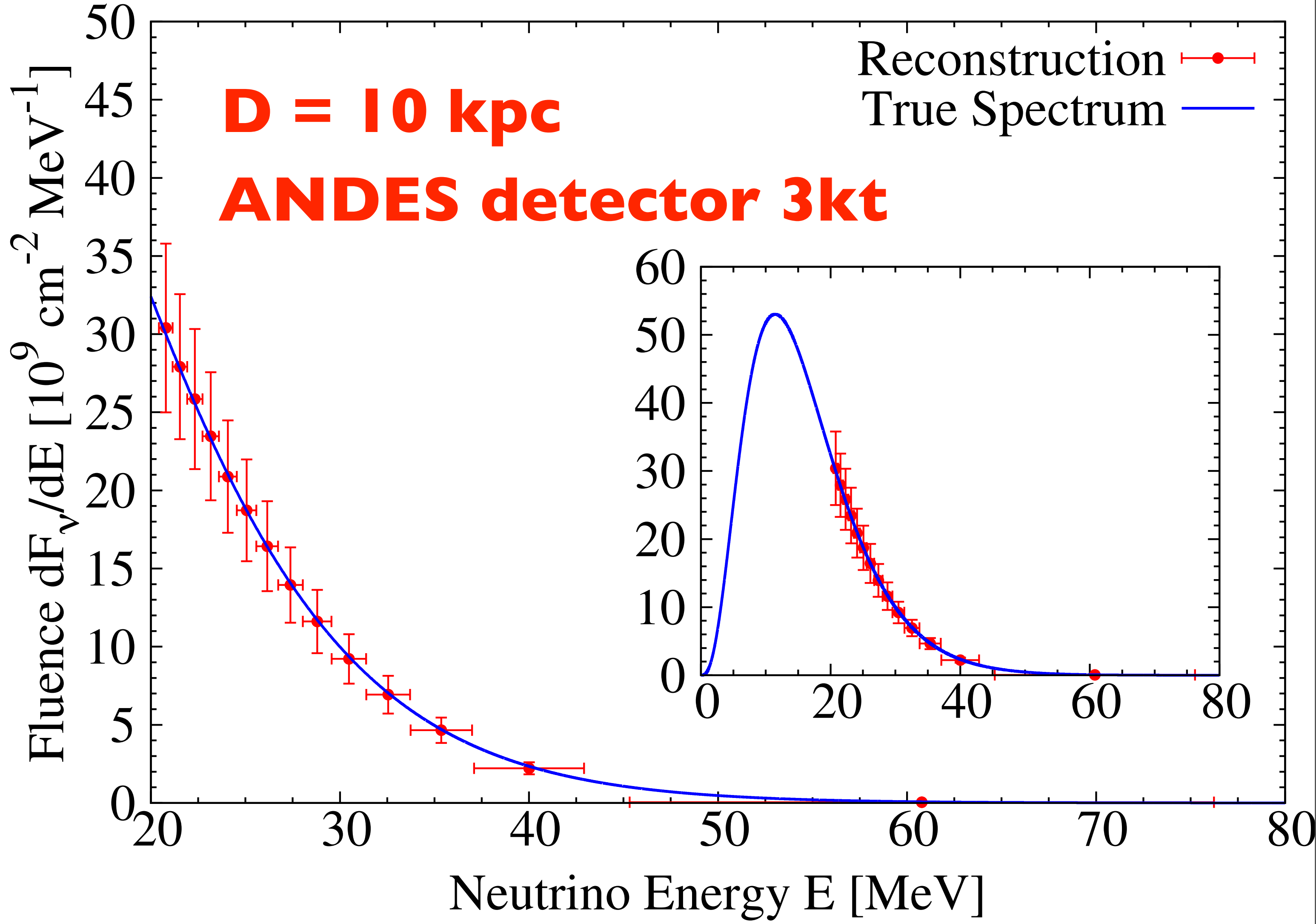
Beacom, Farr & Vogel, PRD66, 033001 (2002)
Dasgupta & Beacom, PRD83, 113006 (2011)

$\nu + \mathrm{p} \rightarrow \nu + \mathrm{p}$ **: Neutral Current (common for all types of neutrinos)**

recoil proton energy dist.



results do not depend on oscillation!

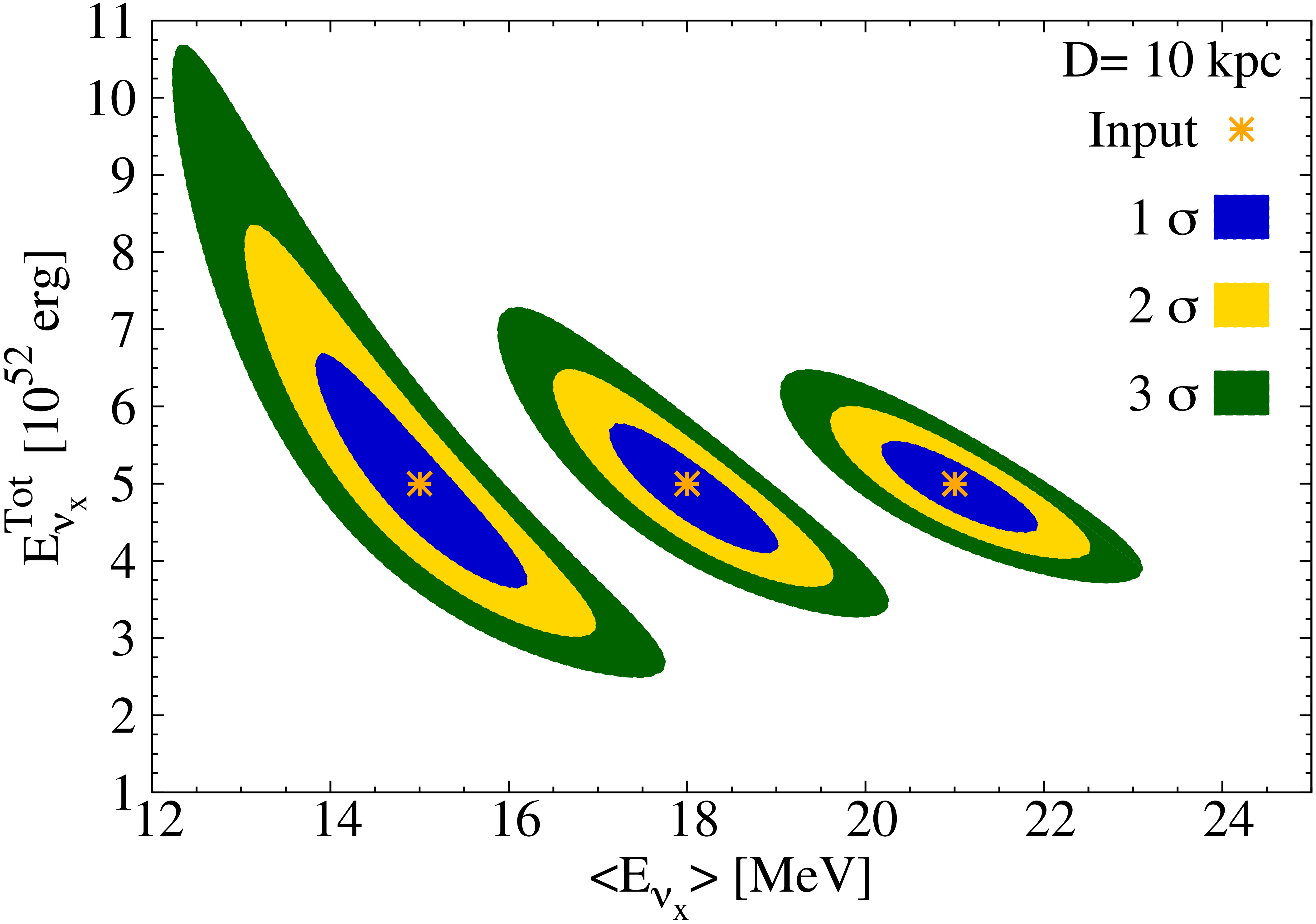


if $\langle E_{\nu_x} \rangle > \langle E_{\bar{\nu}_e} \rangle$, we can reconstruct spectra of ν_x

Determination of SN paramters for ν_μ, ν_τ

Beacom, Farr & Vogel, PRD66, 033001 (2002)

Dasgupta & Beacom, PRD83, 113006 (2011)



$\nu + \mathbf{p} \rightarrow \nu + \mathbf{p}$

No Uncertainty by Neutrino Oscillations!

Earth Matter Effect ?

Necessary Conditions

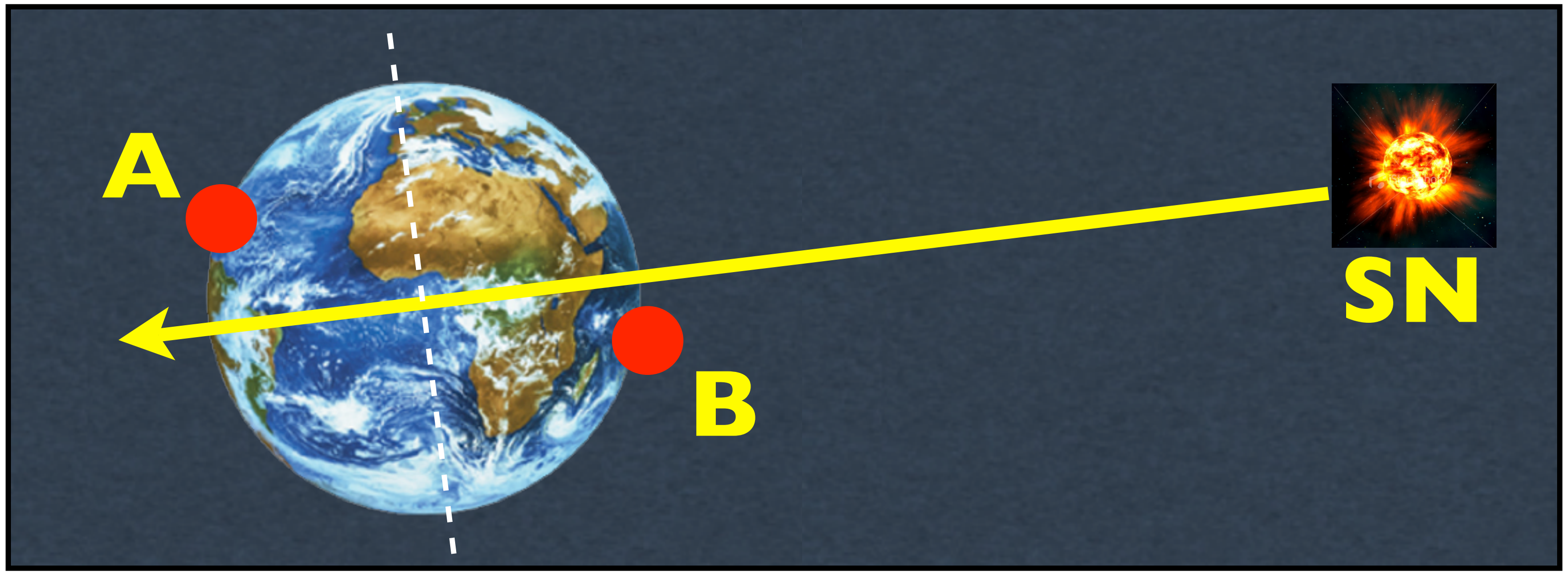
Dighe & Smirnov, PRD62, 033007 (2000)

(1) Mass Hierarchy must be Normal

(2) Original Spectra of ν_e, $\bar{\nu}_e$ and ν_μ, ν_τ, $\bar{\nu}_\mu$, $\bar{\nu}_\tau$ must be significantly different

Earth Matter Effect: Shadowing probabilities

Mirizzi, Raffelt and Serpico, JCAP05, 012 (2006)



SN is

shadowed for A

non-shadowed for B

Site	Latitude	Longitude	Shadowing Probability Mantle (Core)
Kamioka, Japan	36.42^{o}N	137.3^o E	0.559 (0.103)
South Pole	90^{o}N	-	0.413 (0.065)
ANDES	30.25^{o}S	68.88^{o}W	0.449 (0.067)
SNO, Canada	46.476^{o}N	81.20^{o}E	0.571 (0.110)

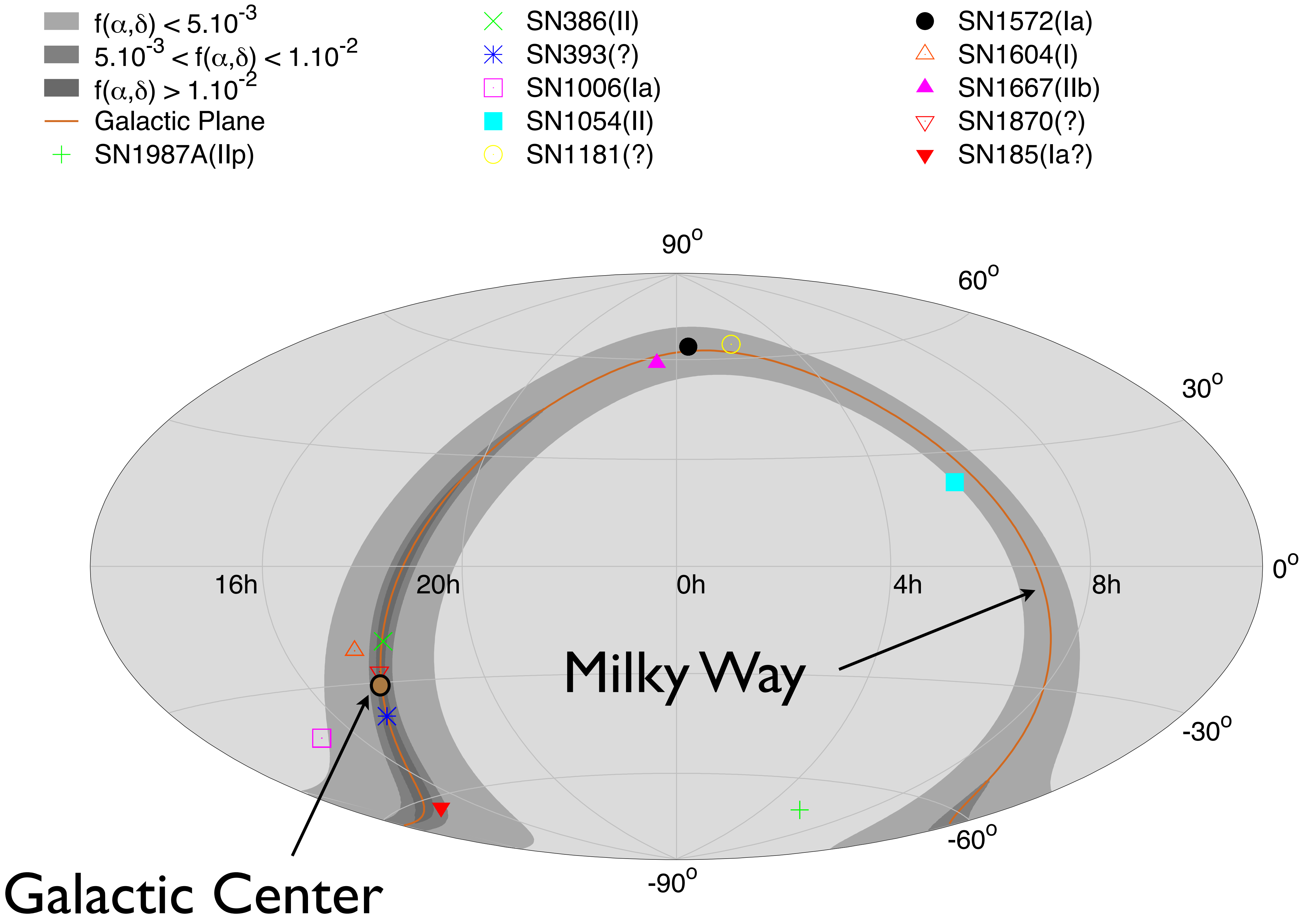
← shadowing prob. for one detector only

	Earth Matter Effect		
Case	Kamioka	South Pole	Shadowing Probability Mantle (Core)
(1)	No	No	0.152 (0.832)
(2)	Yes	No	0.435 (0.104)
(3)	No	Yes	0.288 (0.065)
(4)	Yes	Yes	0.125 (0.000)

← shadowing prob. for two detectors

prob. that at least one detector is showed is **0.848**

Historical Galactic SN distribution



prepared by T. Mühlbeier

Earth Matter Effect: Shadowing probabilities

	Earth Matter Effect			
Case	Kamioka	South Pole	ANDES	Shadowing Probability Mantle (Core)
(1)	No	No	No	0.024 (0.767)
(2)	Yes	No	No	0.388 (0.105)
(3)	No	Yes	No	0.034 (0.061)
(4)	No	No	Yes	0.128 (0.063)
(5)	Yes	Yes	No	0.106 (0.000)
(6)	No	Yes	Yes	0.254 (0.003)
(7)	Yes	No	Yes	0.047 (0.000)
(8)	Yes	Yes	Yes	0.020 (0.000)

shadowing prob. for three detectors

prob. that at least one detector is showed is **0.976**

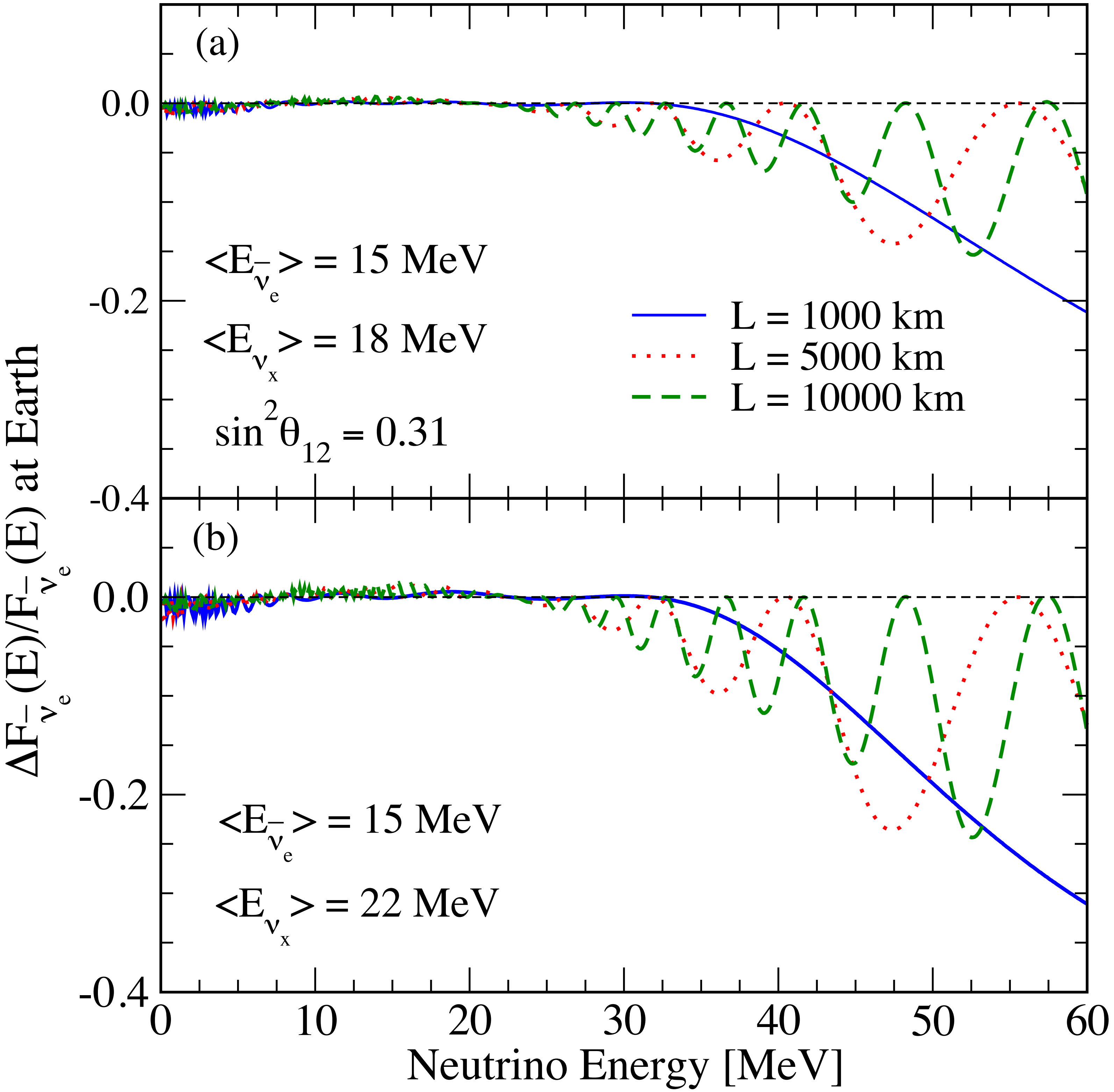
	Earth Matter Effect				
Case	Kamioka	South Pole	ANDES	SNO	Shadowing Probability Mantle (Core)
(1)	No	No	No	No	0.008 (0.657)
(2)	Yes	No	No	No	0.206 (0.105)
(3)	No	Yes	No	No	0.034 (0.061)
(4)	No	No	Yes	No	0.001 (0.063)
(5)	No	No	No	Yes	0.016 (0.111)
(6)	Yes	Yes	No	No	0.205 (0.000)
(7)	Yes	No	Yes	No	0.000 (0.000)
(8)	Yes	No	No	Yes	0.282 (0.000)
(9)	No	Yes	Yes	No	0.163 (0.003)
(10)	No	Yes	No	Yes	0.000 (0.000)
(11)	No	No	Yes	Yes	0.127 (0.000)
(12)	No	Yes	Yes	Yes	0.091 (0.000)
(13)	Yes	No	Yes	Yes	0.047 (0.000)
(14)	Yes	Yes	No	Yes	0.011 (0.000)
(15)	Yes	Yes	Yes	No	0.012 (0.000)
(16)	Yes	Yes	Yes	Yes	0.008 (0.000)

shadowing prob. for four detectors

prob. that at least one detector is showed is **0.992**

Earth Matter Effect

$$\Delta F_{\bar{\nu}_e}/F_{\bar{\nu}_e} \equiv [F^{\oplus}_{\bar{\nu}_e}(E) - F_{\bar{\nu}_e}(E)]/F_{\bar{\nu}_e}$$



Idenfitying the Earth Matter Effect by comparing SK and ANDES (for SN@5kpc)

	$E < 30$ MeV	$30 < E/\text{MeV} < 40$	$40 < E/\text{MeV} < 50$	$E > 50$ MeV	Case	Incompatibility
Vacuum (observed)	18159 ± 135	4973 ± 71	2032 ± 45	889 ± 30	$\langle E_{\nu_x} \rangle = 22$ MeV	3.1σ
1000 km (prediction)	18132 ± 374	5065 ± 198	1908 ± 121	700 ± 74	$\beta_x = \beta_e = 4$	
Vacuum (observed)	17395 ± 132	5785 ± 76	2583 ± 51	1147 ± 34	$\langle E_{\nu_x} \rangle = 22$ MeV	2.2σ
1000 km (prediction)	17370 ± 367	5858 ± 213	2483 ± 139	988 ± 87	$\beta_x = 4$ $\beta_e = 3$	
Vacuum (observed)	16031 ± 127	6674 ± 82	3594 ± 60	1978 ± 45	$\langle E_{\nu_x} \rangle = 22$ MeV	0.7σ
1000 km (prediction)	16011 ± 352	6728 ± 228	3541 ± 166	1917 ± 122	$\beta_x = 4$ $\beta_e = 2$	
Vacuum (observed)	16863 ± 130	5722 ± 76	2864 ± 54	1604 ± 40	$\langle E_{\nu_x} \rangle = 22$ MeV	3.2σ
1000 km (prediction)	16837 ± 361	5787 ± 212	2731 ± 145	1321 ± 101	$\beta_x = \beta_e = 3$	
Vacuum (observed)	15499 ± 125	6611 ± 81	3875 ± 62	2434 ± 49	$\langle E_{\nu_x} \rangle = 22$ MeV	1.7σ
1000 km (prediction)	15479 ± 346	6657 ± 227	3789 ± 171	2250 ± 132	$\beta_x = 3$ $\beta_e = 2$	
Vacuum (observed)	14790 ± 122	6388 ± 80	4089 ± 64	3059 ± 55	$\langle E_{\nu_x} \rangle = 22$ MeV	2.8σ
1000 km (prediction)	14766 ± 338	6419 ± 223	3971 ± 175	2701 ± 145	$\beta_x = \beta_e = 2$	
Vacuum (observed)	17686 ± 133	5240 ± 72	2439 ± 49	1285 ± 36	$\langle E_{\nu_x} \rangle = 24$ MeV	4.3σ
1000 km (prediction)	17655 ± 370	5343 ± 203	2272 ± 133	990 ± 88	$\beta_x = \beta_e = 4$	
Vacuum (observed)	16922 ± 130	6052 ± 78	2990 ± 55	1543 ± 39	$\langle E_{\nu_x} \rangle = 24$ MeV	3.1σ
1000 km (prediction)	16892 ± 362	6136 ± 218	2847 ± 148	1278 ± 100	$\beta_x = 4$ $\beta_e = 3$	
Vacuum (observed)	15557 ± 125	6941 ± 83	4001 ± 63	2374 ± 49	$\langle E_{\nu_x} \rangle = 24$ MeV	1.7σ
1000 km (prediction)	15533 ± 347	7006 ± 233	3905 ± 174	2207 ± 131	$\beta_x = 4$ $\beta_e = 2$	
Vacuum (observed)	16441 ± 128	5858 ± 77	3174 ± 56	2022 ± 45	$\langle E_{\nu_x} \rangle = 24$ MeV	4.0σ
1000 km (prediction)	16409 ± 356	5928 ± 214	3007 ± 153	1625 ± 112	$\beta_x = \beta_e = 3$	
Vacuum (observed)	15077 ± 123	6746 ± 82	4185 ± 65	2853 ± 53	$\langle E_{\nu_x} \rangle = 24$ MeV	2.5σ
1000 km (prediction)	15051 ± 341	6797 ± 229	4065 ± 177	2554 ± 141	$\beta_x = 3$ $\beta_e = 2$	
Vacuum (observed)	14439 ± 120	6400 ± 80	4248 ± 65	3402 ± 58	$\langle E_{\nu_x} \rangle = 24$ MeV	3.3σ
1000 km (prediction)	14410 ± 334	6430 ± 223	4116 ± 179	2948 ± 151	$\beta_x = \beta_e = 2$	

If Spectra at SK and ANDES do not agree,

→ Earth Matter Effect

Summary

ANDES (Agua Negra Deep Experiment Site)

- First Underground Laboratory in the Southern Hemisphere -

can offer varios interesting scientific programs

neutrinos (solar, geo SN neutrinos, $0\nu\beta\beta$, etc), dark matter,

nuclear astrophysics (cross section measurements), biology, etc

See the talk by Claudio Dib

We propose to build a few kt liquid scintilation based neutrino detector for

Geoneutrino observation (this talk)

SN neutrino observation (this talk)

Solar neutrinos, artificial sources (to be studied)

Some interesting (complementary) contributions to the current detectors can be achieved

Summary (2)

Geoneutrino observation

Higher geoneutrino flux than at Kamioka and Gran Sasso, interesting to confirm

Very few nearby reactors is an advantage for ANDES

SN neutrino observation

NC reactions (such as p-ν elastic scattering) provides better understanding of SN physics (independent of oscillation)

Earth matter effect, if observed, provides information on neutrino mass hierachy

Thank you very much!

http://andeslab.org

Agua Negra Deep Experiment Site

ANDES

Backup Slides

Earth Matter Effect

$$F_{\bar{\nu}_e}^{\oplus}(E) = \bar{p}^{\oplus}(E) F_{\bar{\nu}_e}^{0}(E) + [1 - \bar{p}^{\oplus}(E)] F_{\bar{\nu}_x}^{0}(E),$$

$$\bar{p}^{\oplus}(E) = \frac{1}{|U_{e2}|^2 - |U_{e1}|^2} \left[\left\{ |U_{e2}|^2 - \bar{p}(E) \right\} \bar{p}_{1e}^{\oplus} + \left\{ \bar{p}(E) - |U_{e1}|^2 \right\} \bar{p}_{2e}^{\oplus} \right]$$

$\bar{p}_{1e}^{\oplus} = |U_{e1}|^2, \; \bar{p}_{2e}^{\oplus} = |U_{e2}|^2$ means no earth effect

$$\Delta F_{\bar{\nu}_e} \equiv F_{\bar{\nu}_e}^{\oplus}(E) - F_{\bar{\nu}_e}(E) \simeq (\bar{p}_{1e}^{\oplus} - c_{12}^2) \left\{ F_{\bar{\nu}_e}^{0}(E) - F_{\bar{\nu}_x}^{0}(E) \right\}$$

Normal Mass Hierarchy

Dighe-Smirnov, hep-ph/9907423

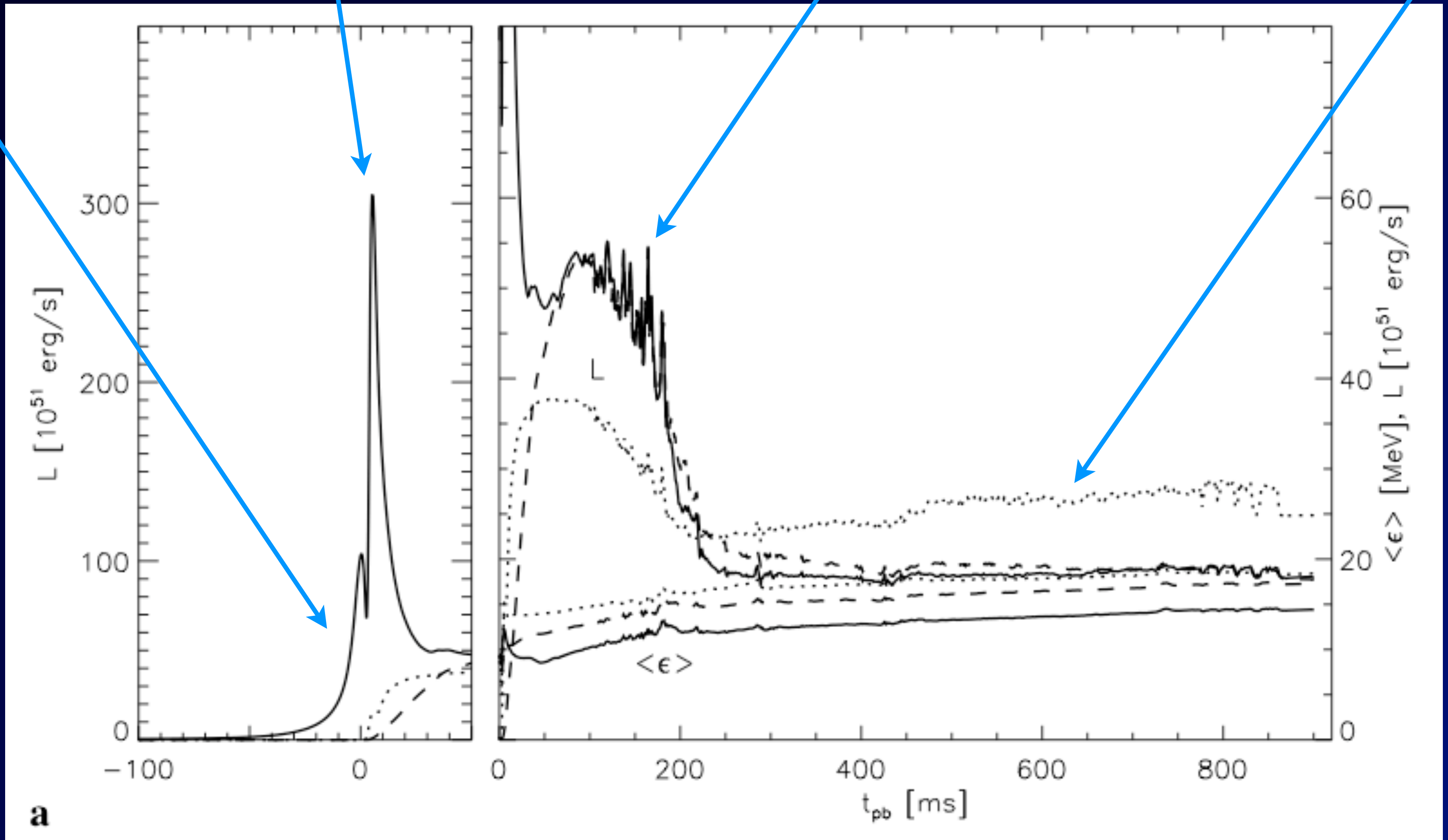
At least five phases of neutrino emission can be identified.

1. Infall

2. Shock breakout

3. Accretion

4. Kelvin-Helmholtz



Buras et al. (2005)

$e^- + \text{“}p\text{”} \rightarrow \text{“}n\text{”} + \nu_e$

$e^+ + \text{“}n\text{”} \rightarrow \text{“}p\text{”} + \overline{\nu}_e$

$e^+ + e^- \rightarrow \nu_{e,\mu,\tau} + \overline{\nu}_{e,\mu,\tau}$

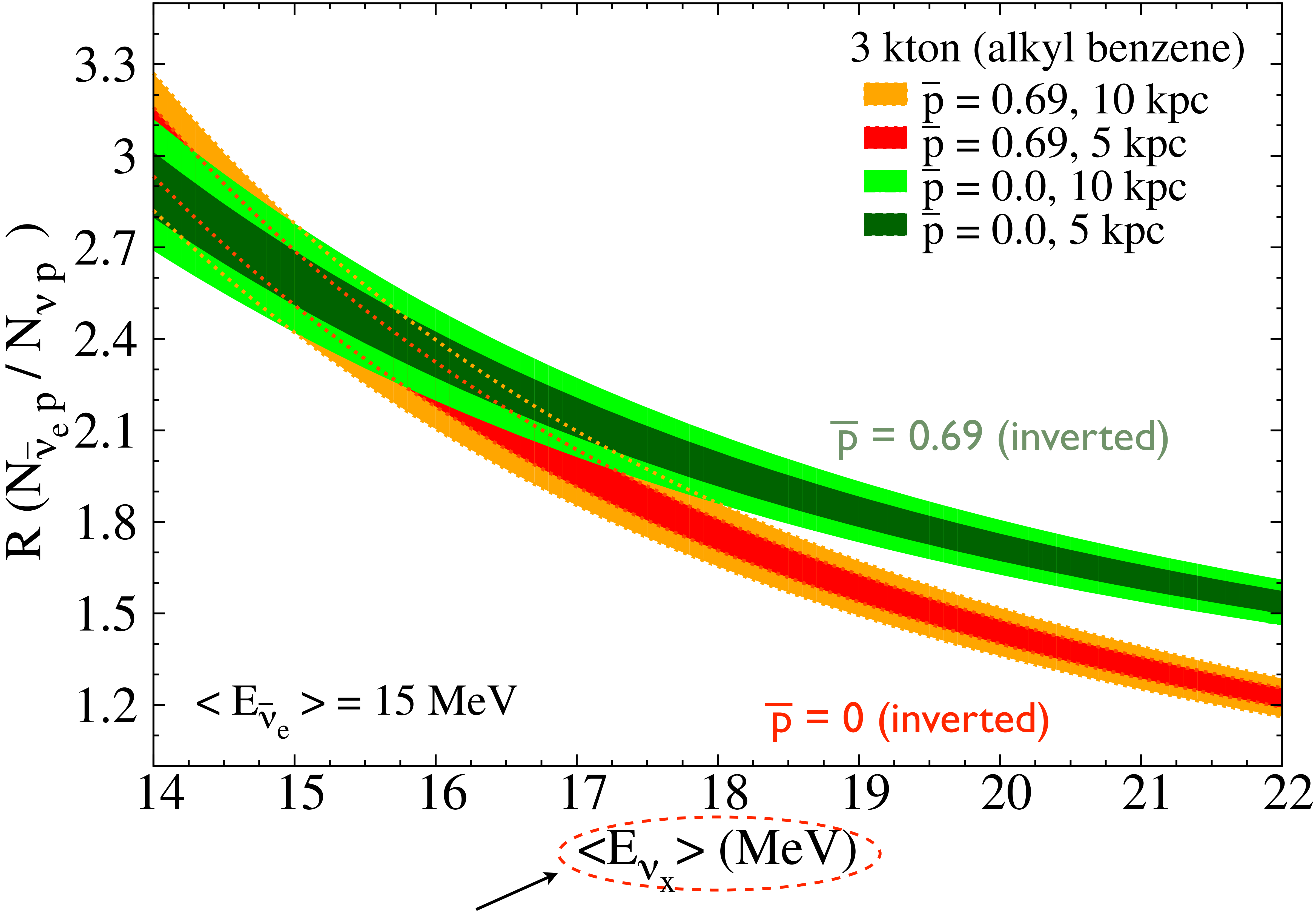
$N + N \rightarrow N + N + \nu_{e,\mu,\tau} + \overline{\nu}_{e,\mu,\tau}$

Scattering

To study the effect of oscillation and/or infer the original SN parameters in a less model dependent way, let us deifne,

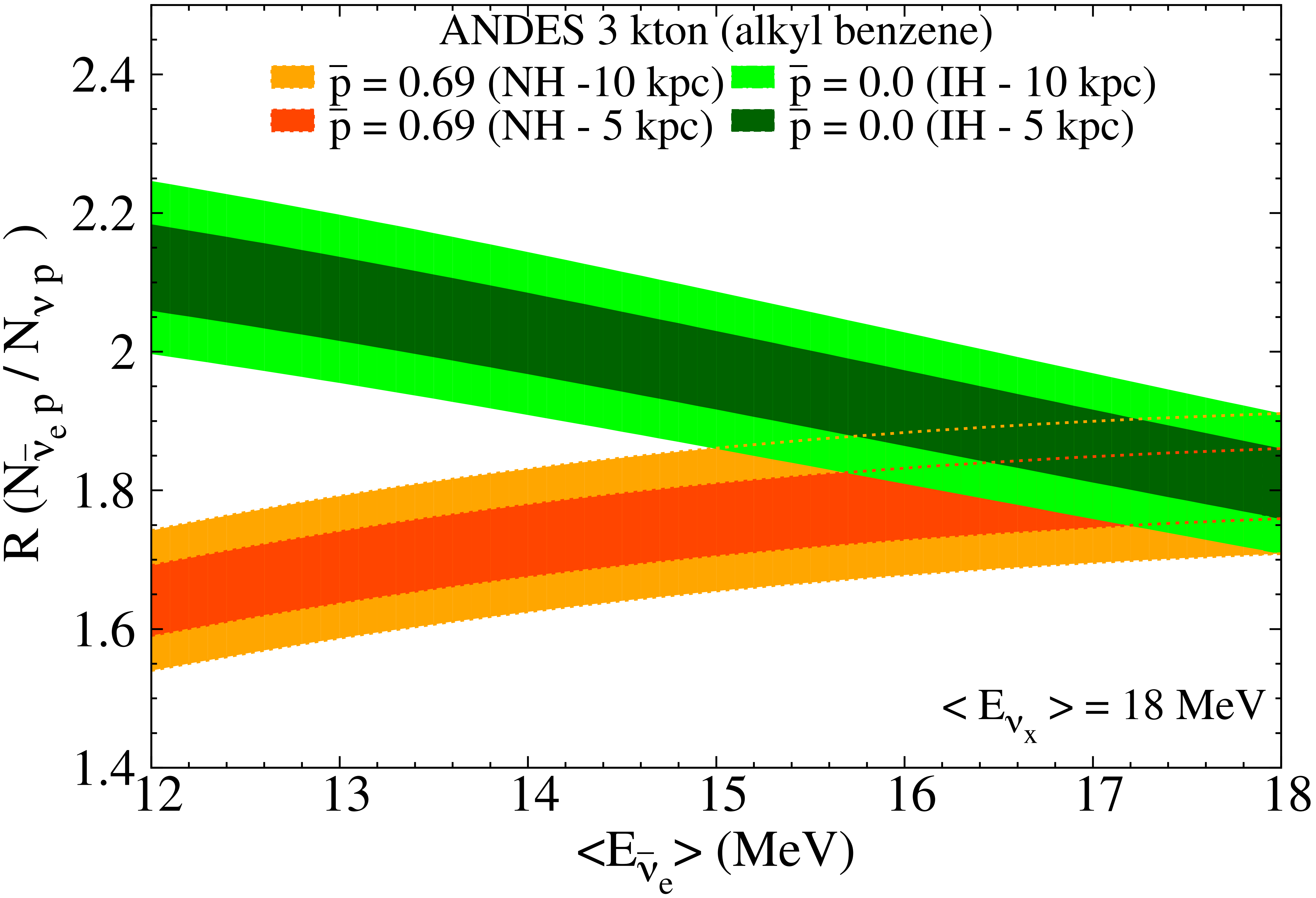
$$\boxed{R(N_{\bar{\nu}_e p}/N_{\nu p}) \equiv \left(\frac{\overset{\text{CC}}{N_{\bar{\nu}_e p}}}{\underset{\text{NC}}{N_{\nu p}}}\right)^{\text{obs}}}$$

CC/NC dependence on $\langle E_{\nu_x} \rangle$

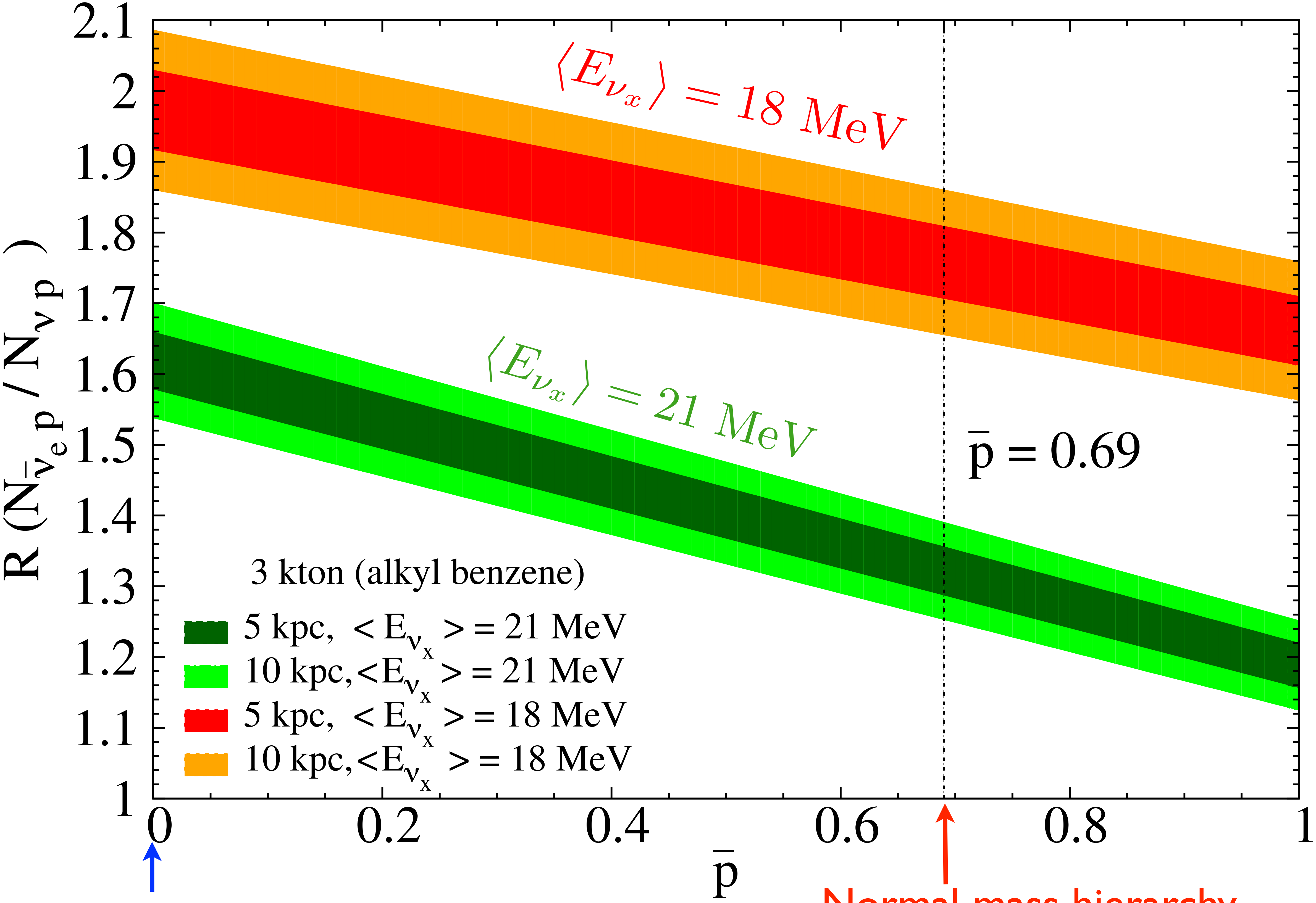


can be determined by ν-p reaction

CC/NC dependence on $\langle E_{\bar{\nu}_e} \rangle$



CC/NC dependence on $\bar{p}$

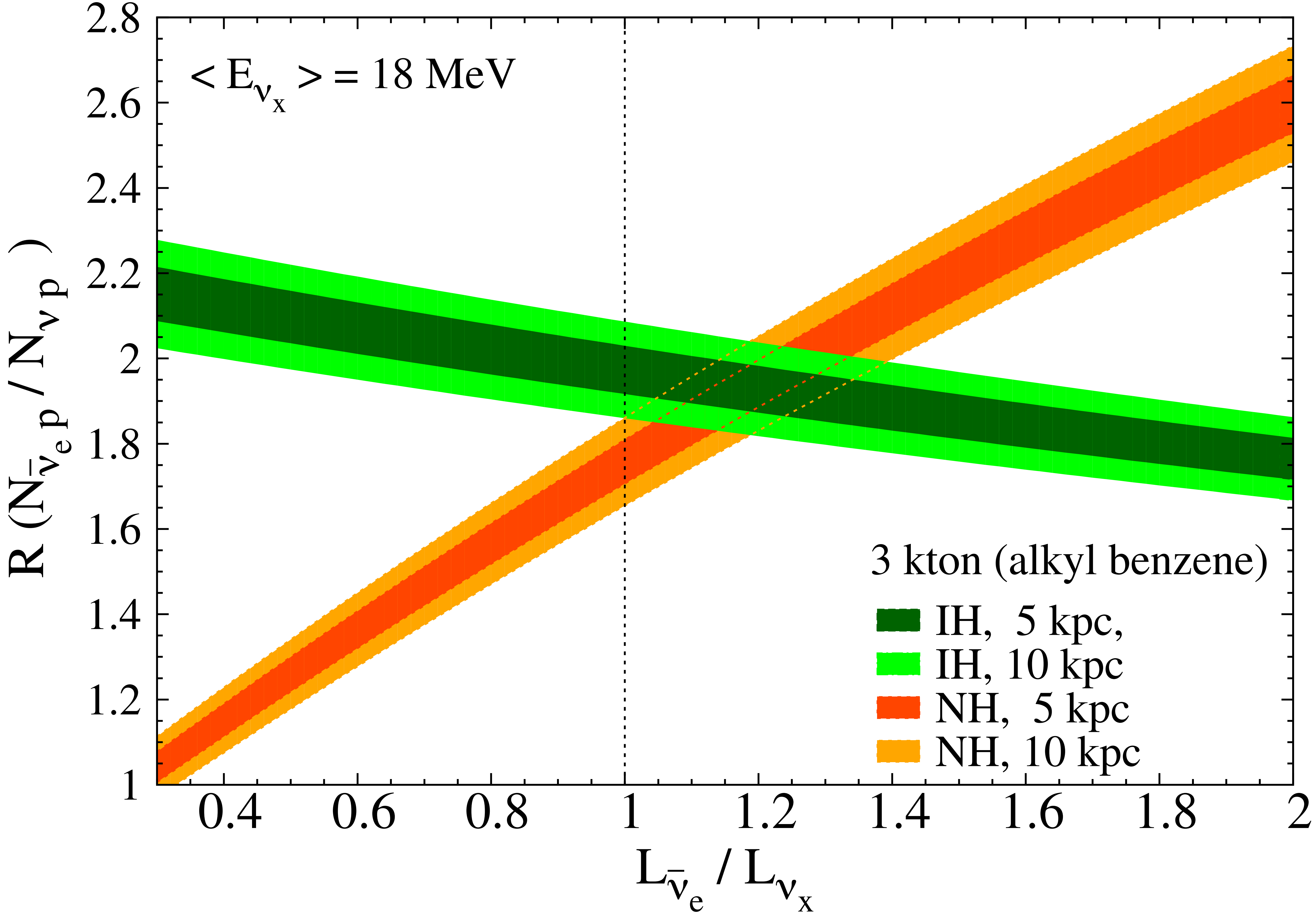


Inverted mass hierarchy

Normal mass hierarchy

usual MSW effect w/o collective effects

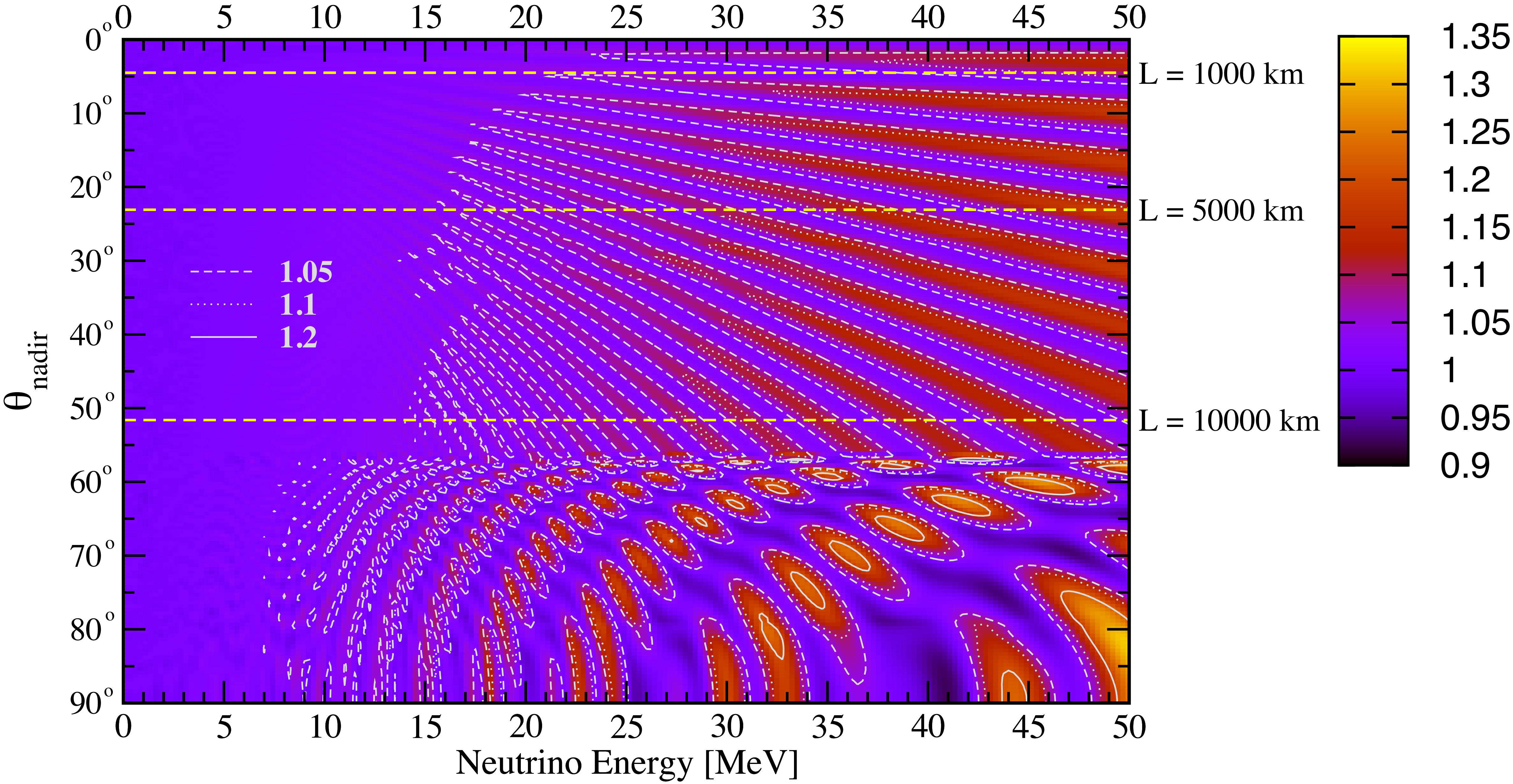
CC/NC dependence on luminosity



SN ν "Oscillogram"

Akhmedov, Maltoni & Smirnov, JHEP 05, 077 (2007), 06, 072 (2008)

Iso-contours of $P^{\oplus}(\bar{\nu}_1 \rightarrow \bar{\nu}_e)/\cos^2\theta_{12}$



We know that the concentration of U and Th is larger in the upper Earth Crust

Table 2.3: Uranium and Thorium Concentrations in Continental Crust

	Uranium Concentration [ppm]		
	Upper Crust	Middle Crust	Lower Crust
McLennan & Taylor (1999)	2.8	0.28	
	0.91		
Wedepohl (1995)	2.5	0.93	
	1.7		
Rudnick & Fountain (1995)	(2.8)	1.6	0.2
	1.42		
Condie (1993)	2.4 / 2.2	-	-

Enomoto, PhD thesis, 2005

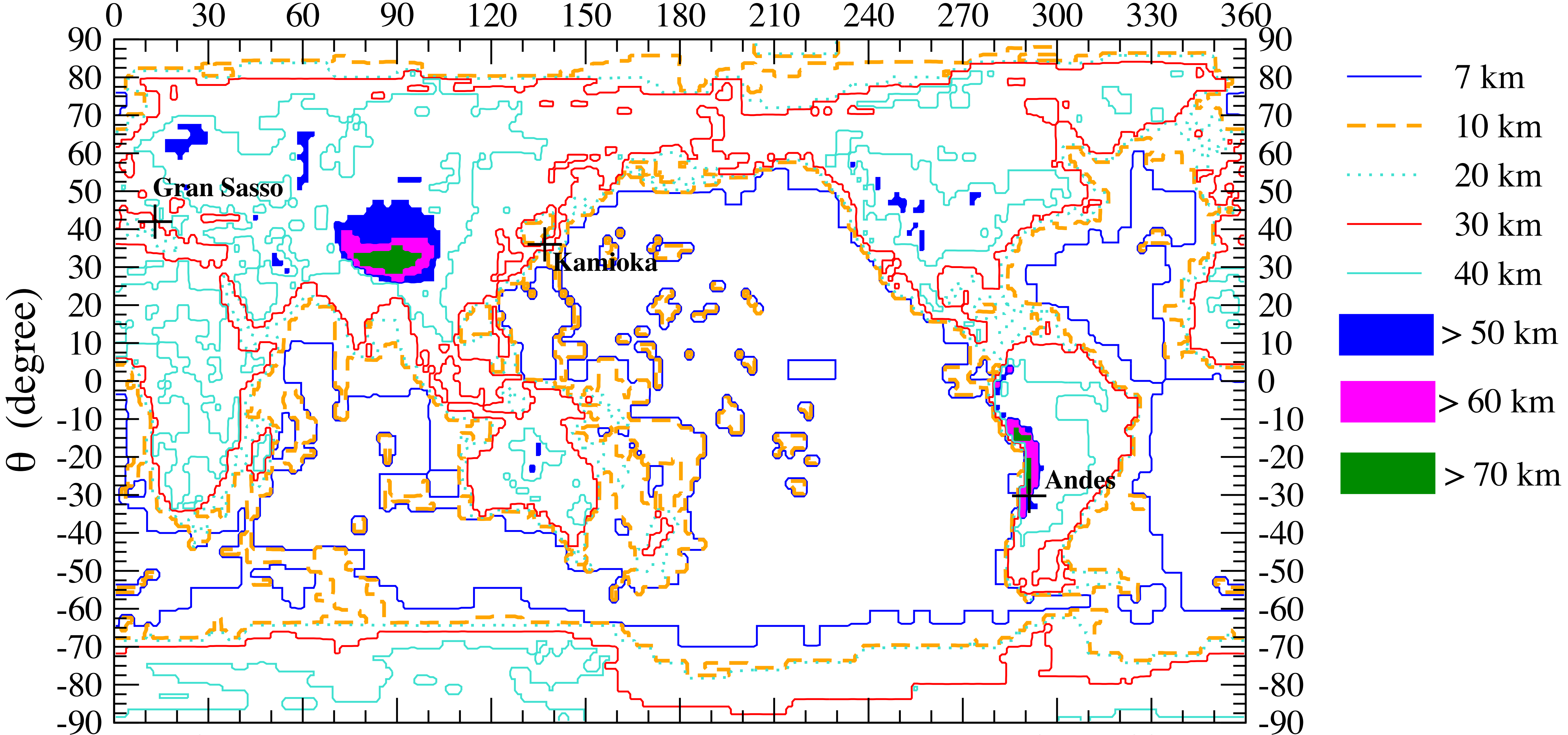
	Thorium Concentration [ppm]		
	Upper Crust	Middle Crust	Lower Crust
McLennan & Taylor (1999)	10.7	1.06	
	3.5		
Wedepohl (1995)	10.3	6.6	
	8.5		
Rudnick & Fountain (1995)	(10.7)	6.1	1.2
	5.6		
Condie (1993)	9.1 / 8.6	-	-

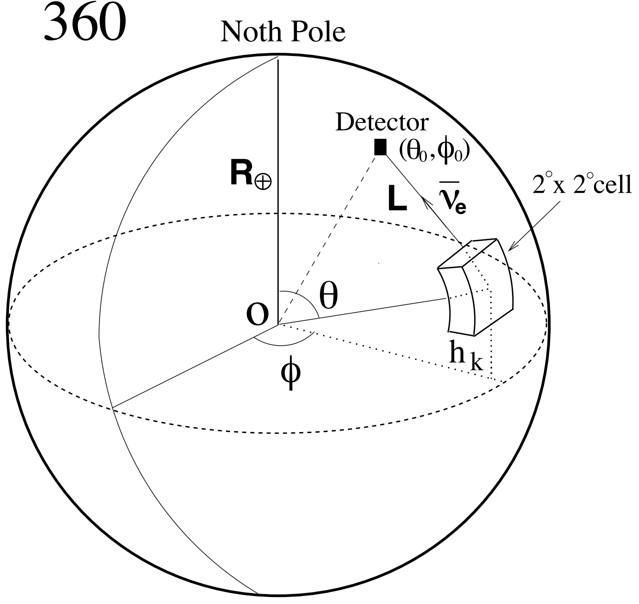
U: ~ 2,5 - 2,8 ppm Th: ~ 10,3 - 10,7 ppm Th/U ~ 4

But we do not know the concentration of U and Th in the deep Mantle (and core of Earth)

reference values for the Mantle : U ~ 0.012 pm, Th ~ 0.048 ppm

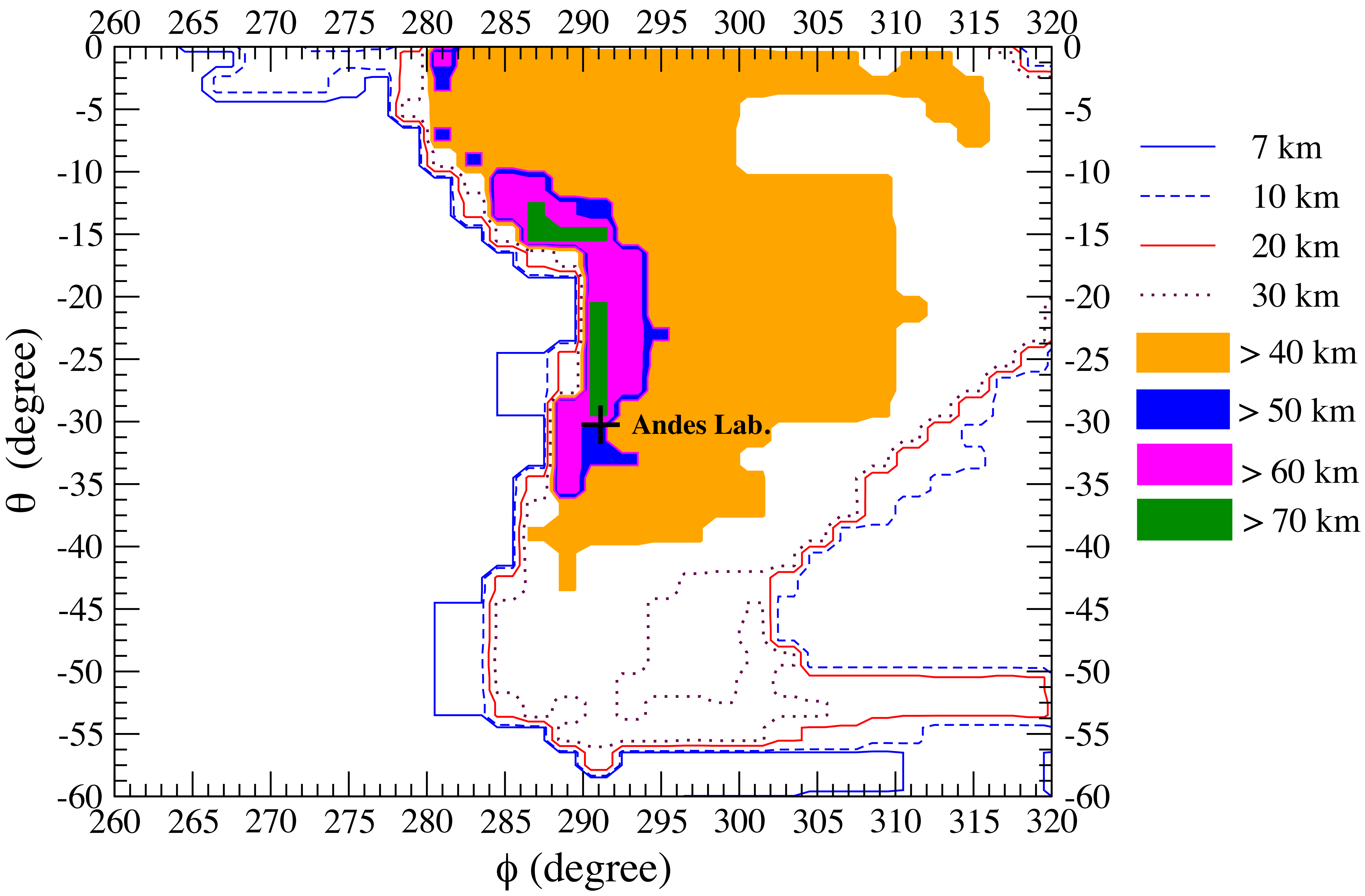
Earth Crust Thickness Map





crust was divided into16200 parts of 2 x 2 degrees

Earth Crust Thickness Map Around Andes Lab.

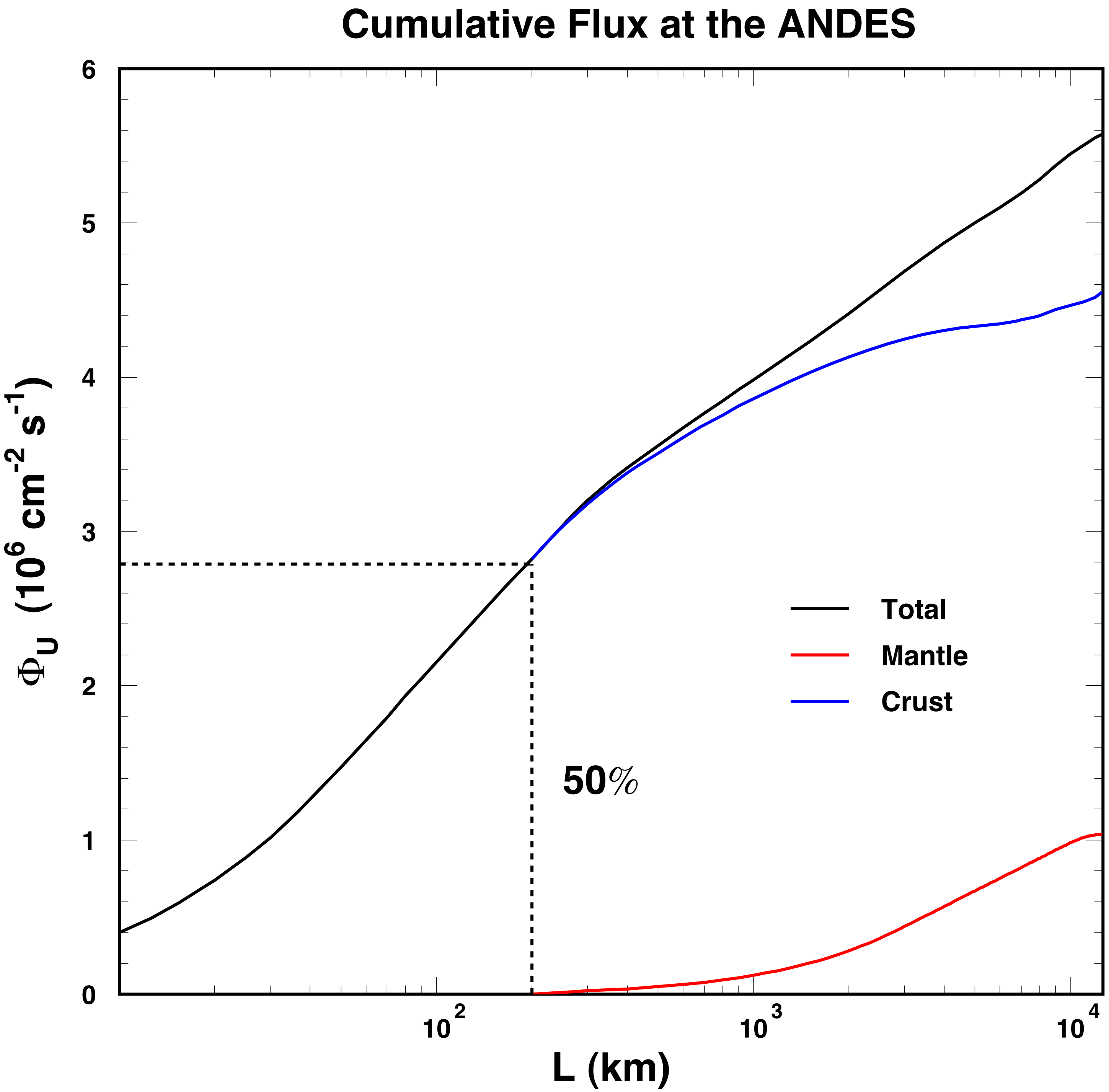


Expected Geoneutrino flux at ANDES

Flux of Geo-Neutrinos coming from U as a functio of the distance

http://maps.google.com/

ページ 1/1



P. Machado, T. Mühlbeier, H. Nunokawa, R. Z. Funchal, in preparation

Total energy released by SN

$$\Delta E = E_{\mathrm{inicial}} - E_{\mathrm{final}} \sim -G_N \frac{M}{R_{\mathrm{i}}} - \left(-G_N \frac{M}{R_{\mathrm{f}}} \right)$$

$$\sim G_N \frac{M}{R_{\mathrm{f}}} \sim 3 \times 10^{53} \mathrm{erg}$$

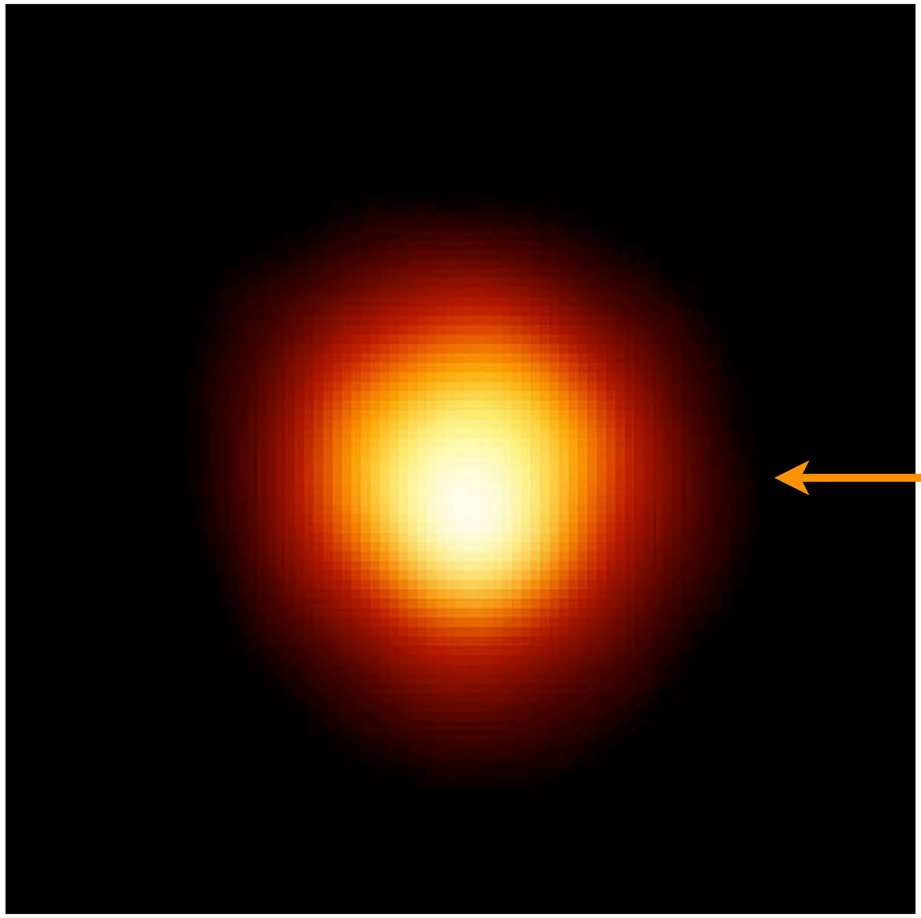
$$M \sim M_\odot, R_i \sim 1000 \text{ km}, R_f \sim 10 \text{ km}$$

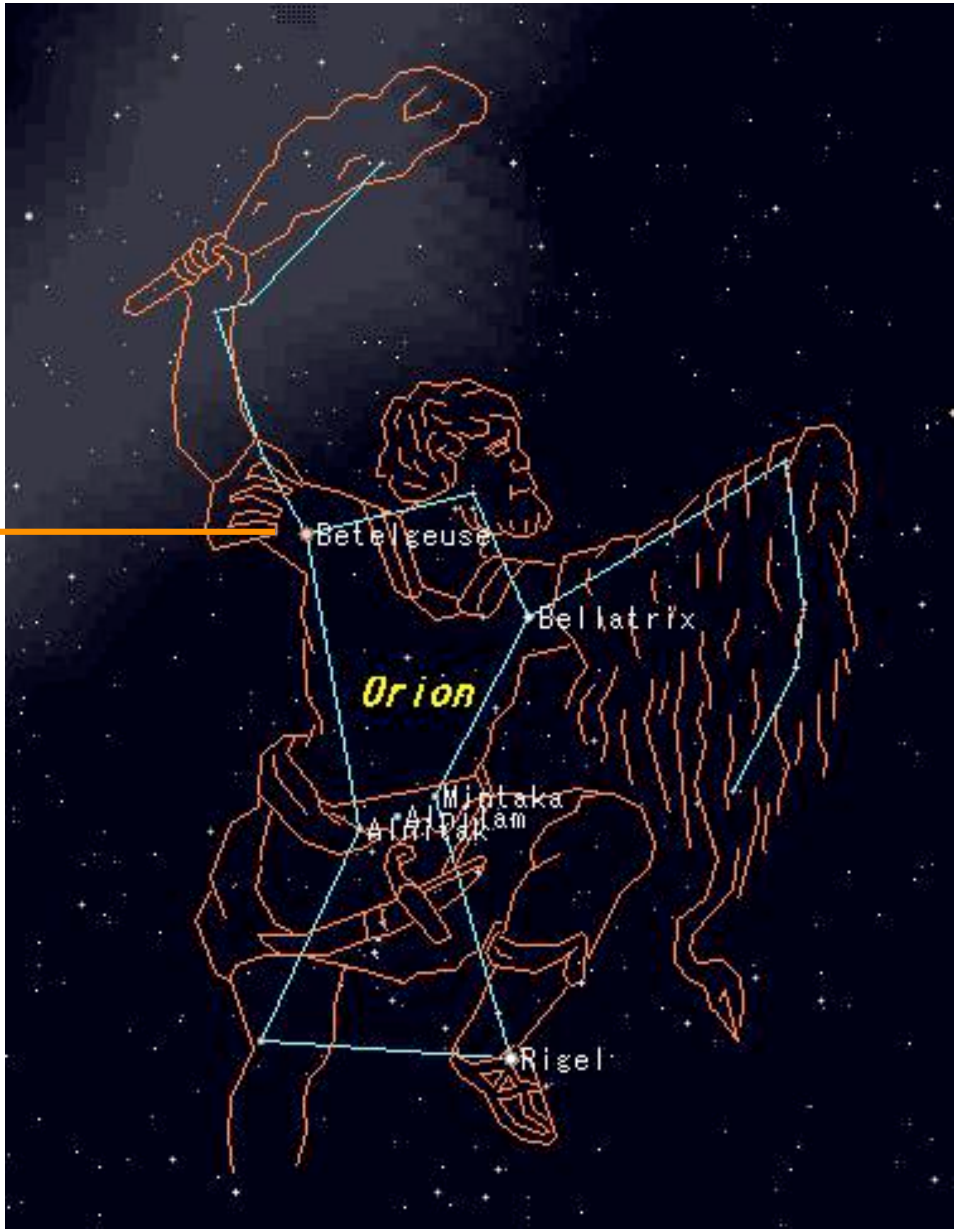
**observed energy of explostion (kinetic + radiation)
is only ~1 % de ΔE**

neutrinos carry ~ 99 % of energy of ΔE !

Candidate for the next galactic supernova

Betelgeuse !?





Distance ~ 640 light yrs

~ 20 solar mass

~ 1000 solar radius

red giant

Supernova Neutrino Early Warning System

Super-Kamiokande @Kamioka

LVD (Large Volume Detector)@Gran Sasso

Borexino@Gran Sasso

IceCube@South Pole

http://snews.bnl.gov/