

Alliance to Penetrate Mysteries of the Deep Earth

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International Workshop Muographers 2014, Tokyo



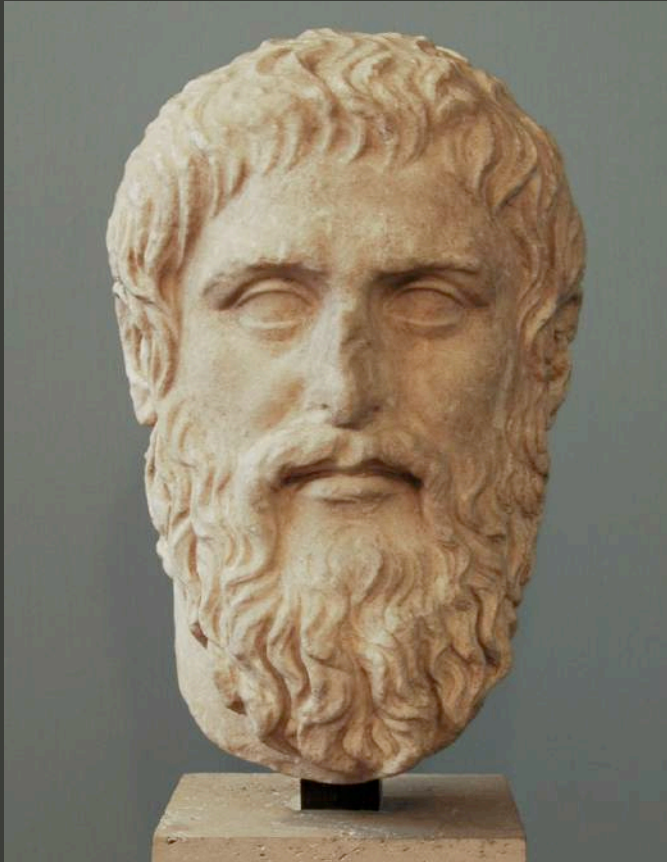
A successful growth

Ginkgo Biloba “Kitakanegasawa no-ichou”

[http://www.monumentaltrees.com/en/jpn/tohoku/aomori/3146_kitakanegasawa/]]

***Fundamental issues
have deep roots***

Mythology of ancient Greece: “*Pyriphlegethon*”, a “*fire-flaming*” river in deep Earth



Plato, portrait by Silanion (ca. 370 BC)

Roman copy, Musei Capitolini, Rome

[<http://ancientrome.ru/art/artwork/img.htm?id=4204>]

Plato (ca. 425-348 BC)

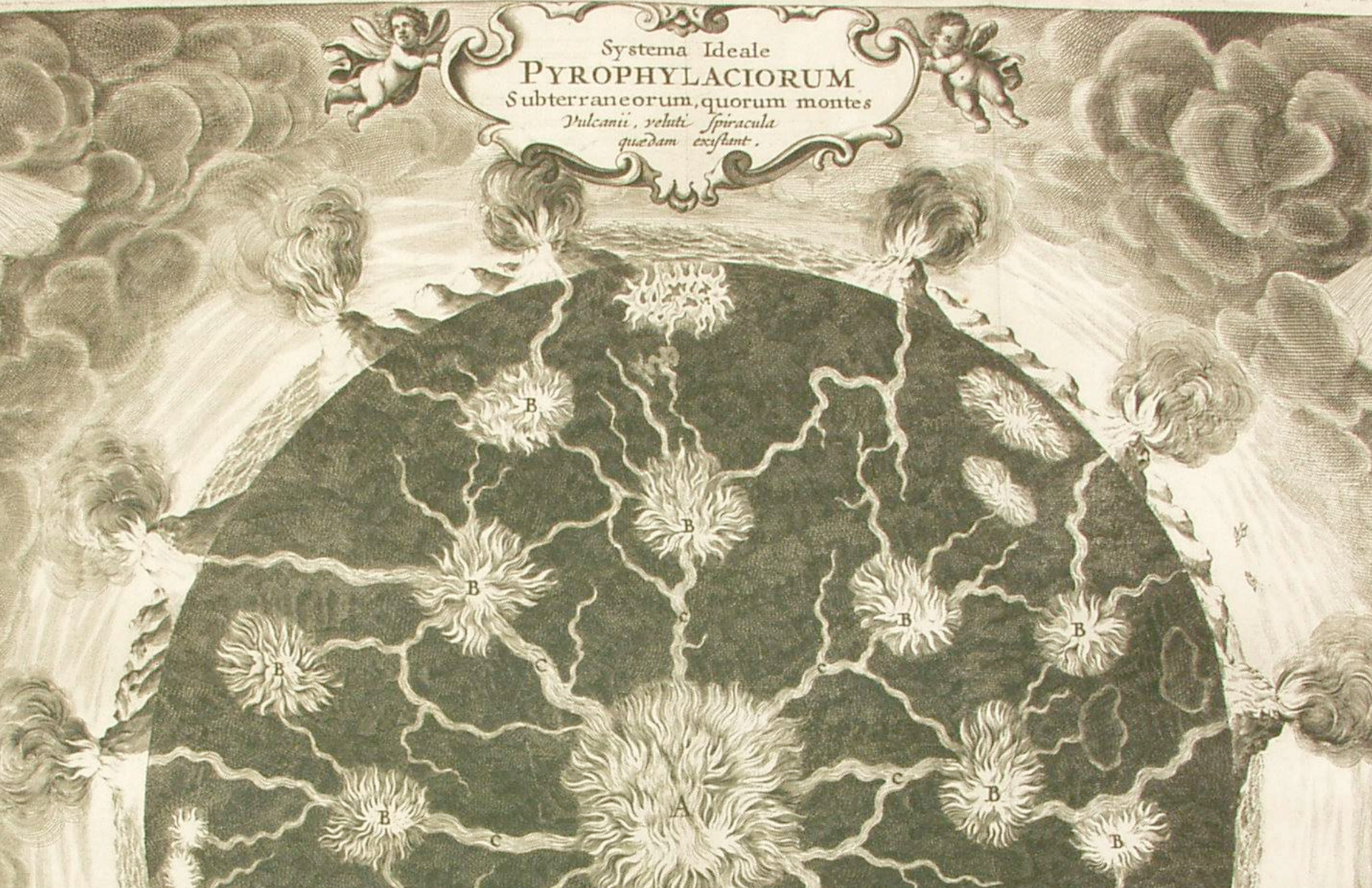
“A stream of fire, which coils round the Earth and flows into the depths of Tartarus” (*Phaedo*, 112b)

Hades: the underworld of the dead

Five rivers in the *Hades*: *Pyriphlegeton*, *Styx*, *Lethe*, *Cocytus* and *Acheron*

Tartarus: the underworld of dead banished by Deity Zeus (became the Christian *Hell*)

Homer (ca. 700 BC): *Tartarus* is “as far beneath Hades as Heaven is high above the Earth” (*Iliad*)



“The volcano mountains, such as vents of internal fire of the Earth”



Athanasius Kircher (1602-80)

Medicine and Biology

*Observation of microbes through a microscope
Prevention of infections by microorganisms
Hybridization of species: a “proto-evolutionist”?*

Theology: *Biblical studies*

Sinology: *History studies, Encyclopedia of China*

Geology and Paleontology

*Observations on Mt. Vesuvius
Volcanism (and tides) originate from an “Underground World”
Study on fossils as remnants of ancient animals*

Egyptology

Links between Copts and ancient Egyptians, hieroglyphs’ interpretation

Mathematics, Physics and Technology

*Combinatorial calculus
“Ars magna lucis and umbrae”: Art of light and shadow
Magnetic clock, automaton, the first megaphone*

Athanasius Kircher was a
“scientist”

The categorization of his work
in terms of today’s

“scientific disciplines”

is an exercise done
“a posteriori”

The expansion and deepening of “Science” implied focusing of interests to “disciplines”

*... sometimes with excessive
sacrifice of unitary vision*

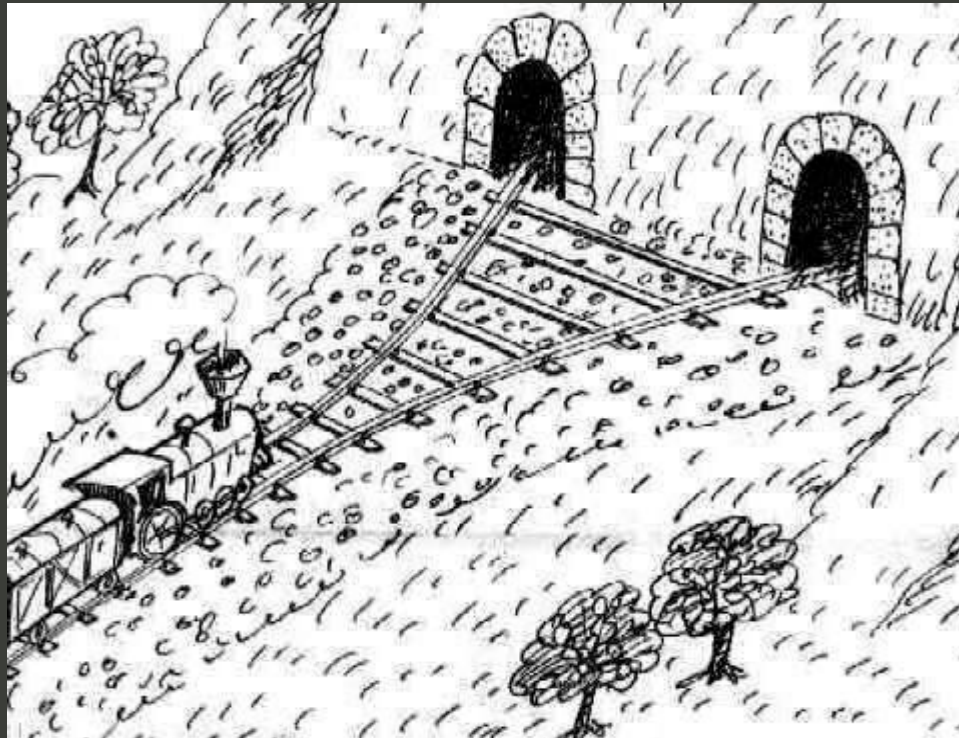


Image Mysearch [<http://www.mysearch.org.uk/website1/html/522.Duality.html>]

“Disciplines”: young compared to “Science”

Foundation of “discipline oriented” Societies
(for example Physics)

German Physical Society	1845
French Physical Society	1873
Physical Society of London → IoP	1874
Japan Physical Society	1877
Italian Physical Society	1897
American Physical Society	1899

And very successful

CONSEIL DE PHYSIQUE SOLVAY

BRUXELLES 1911



Photo Coupris, Bruxelles

GOLDSCHMIDT
NERNST

PLANCK
BRILLOUIN

KUBENS
SOLVAY

L'INDENMANN
SOMMERFELD
DE BROGLIE
LORENTE

HASDINSHEL
HOSTELET
KNUDSEN
WARBURG
PERRIN

HERZEN
WIEN
Madame CURIE

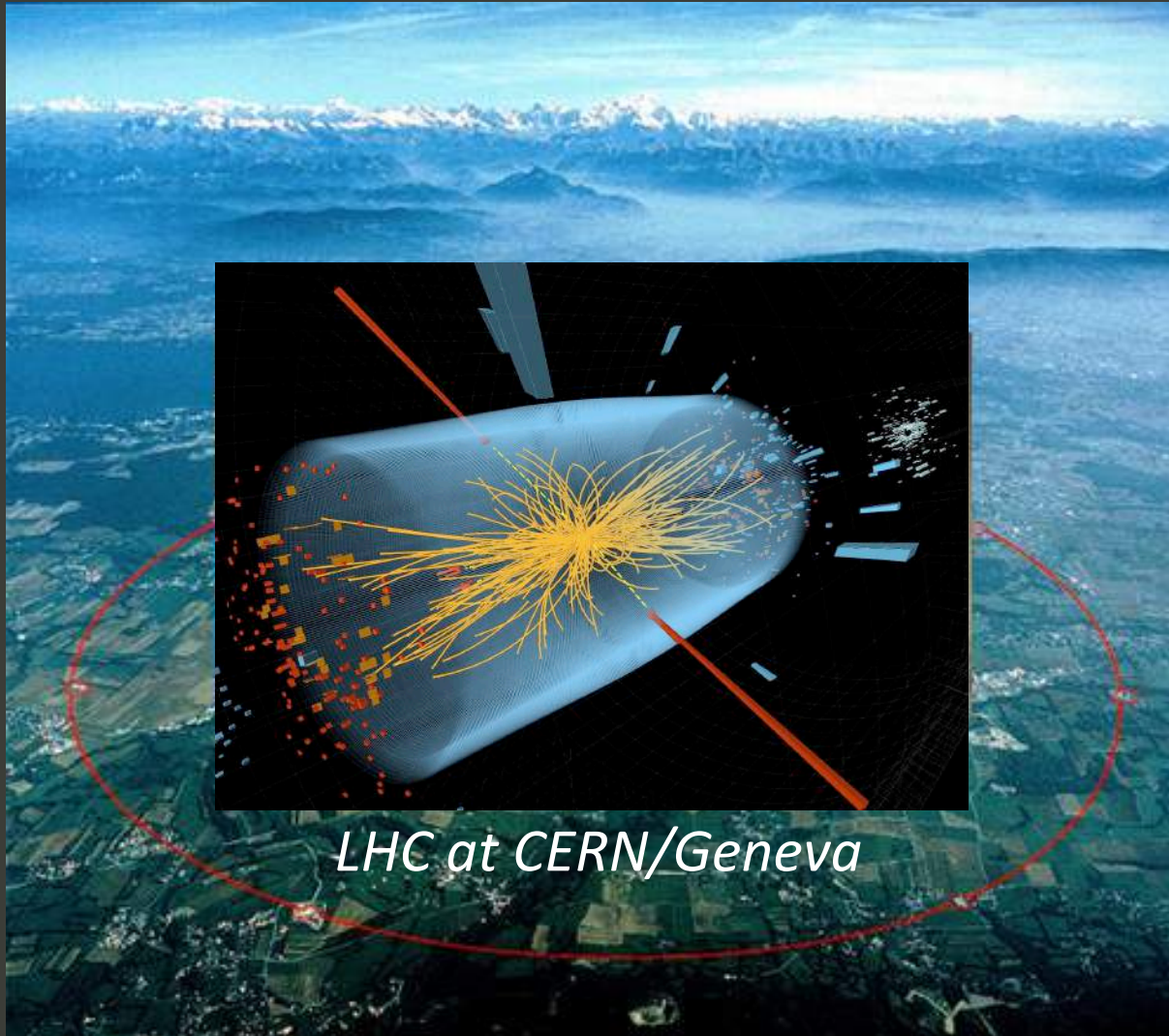
JEANS
RUTHERFORD
POINCARÉ

KAWERLINGH-ONNES

ENGSTEN

LANGEVIN

Disciplines: a necessity for researches requiring extreme specialization



LHC at CERN/Geneva

A unitary vision of Science became difficult

Cross-fertilization among “disciplines”

occurred in the form of:

Technological transfer “other” disciplines

Researches requiring expertise from “several” disciplines
(current multi-disciplinary researches)

What about “Earth Science”?



*Earth Science has traditionally offered a
field of research open
to multi-disciplinary contributions*

However ...

New challenges require new synergies



Earth rise on the Moon (NASA Apollo 11 mission, 1969)

New challenges in Earth Science connected to Particle Physics

μ



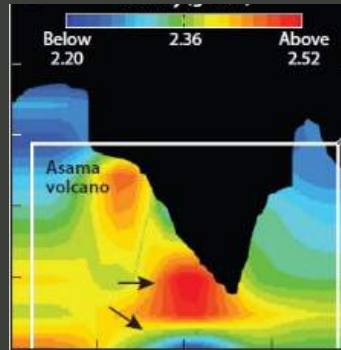
ν

New challenges in Earth Science

Muography

Volcanoes

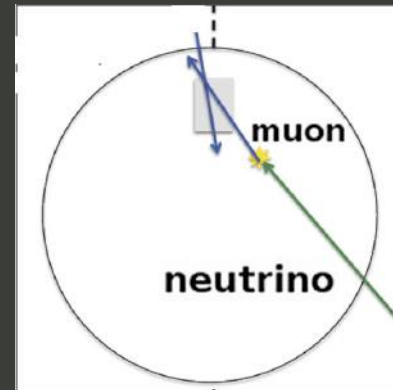
Nagamine, Tanaka et al. + ...



Neutrinoigraphy

Earth Core

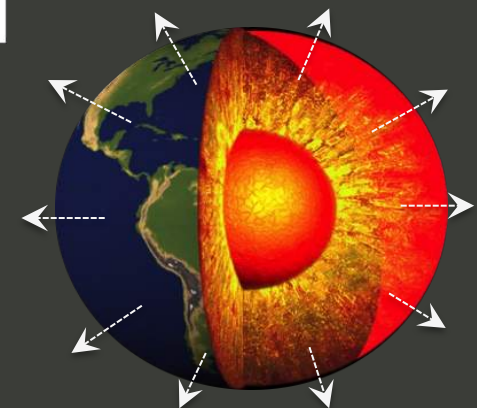
... IceCube, ... Km3Net



Geoneutrinos

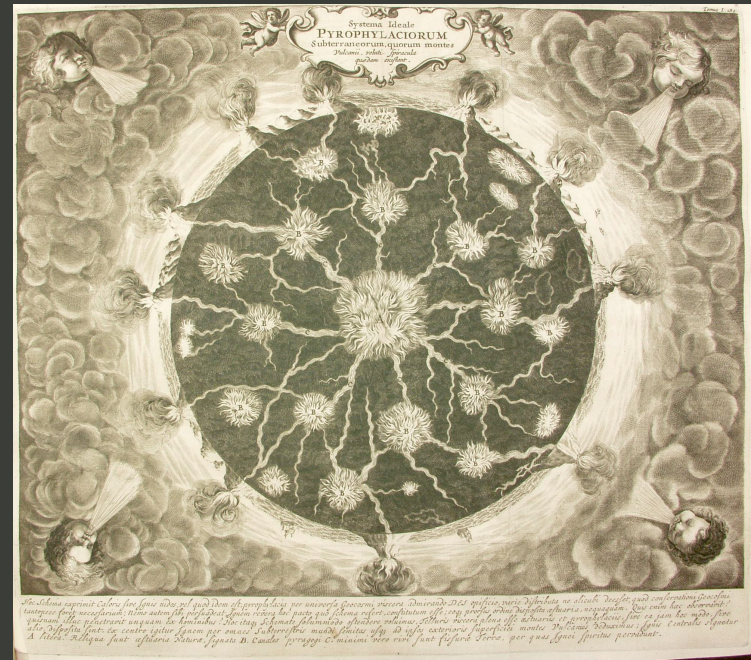
Earth Mantle

KamLAND, Borexino, ...



That's simply "Science"

*as at the times of
Athanasius Kircher*



Kitakanegasawa no-ichou

**"Alliance"
among disciplines
and Earth Science
to face
new challenges**

“Kitakanegasawa no-ichou” grew higher by an
“alliance of trunks”



Kitakanegasawa no-ichou in autumn splendor

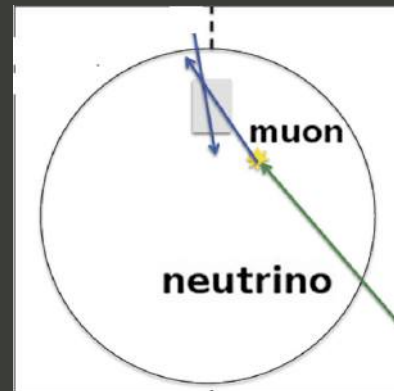
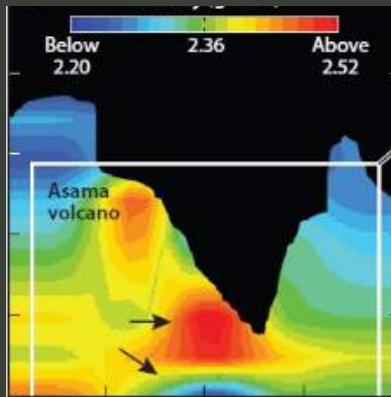


[http://huben.jp/desc/02_09.html]

New challenges

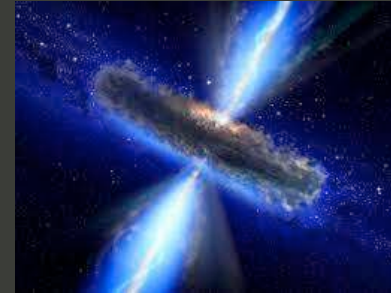
Muography

Neutrino-graphy

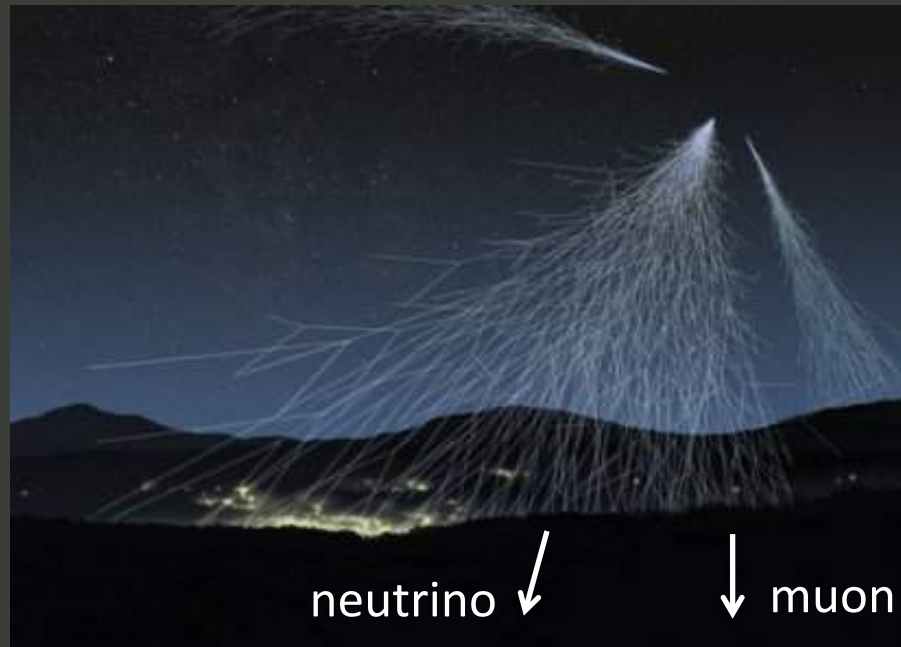


Nature provides muons and neutrinos

Very high energy particles from cosmic accelerators: “cosmic rays”



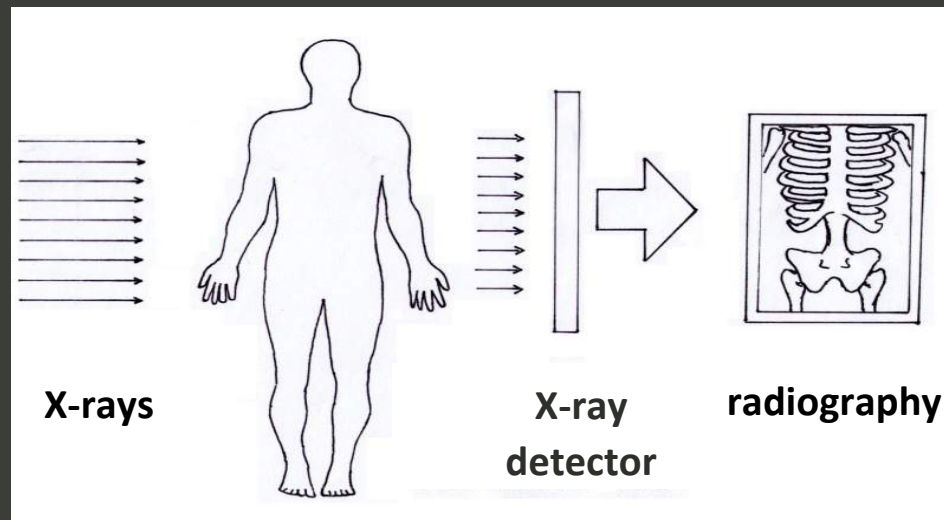
“Shower” of particles produced by cosmic rays hitting the atmosphere



Particles absorbed at the Earth’s surface

muons and neutrinos penetrate inside the Earth

Principle of internal imaging techniques



Source of penetrating particles

Absorption by higher densities

A detector sees internal structures as “shadows”

	Particle	Penetration	Source
Radiography	X –rays (radiations)	human body	artificial
Muography	Muons	(small) mountains	cosmic rays
Neutrinography	Neutrinos	the Earth	cosmic rays

Muography

*“See the hidden”
inside volcano edifices*



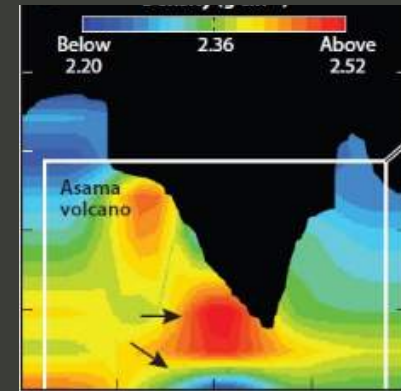
Antonio Corradini, *The Veiled Truth* (1752)
Sansevero Chapel, Napoli

[<http://www.italianways.com/la-pudicizia-scultura-e-segreti/>]

Volcano muography



cosmic ray
interactions
In atmosphere



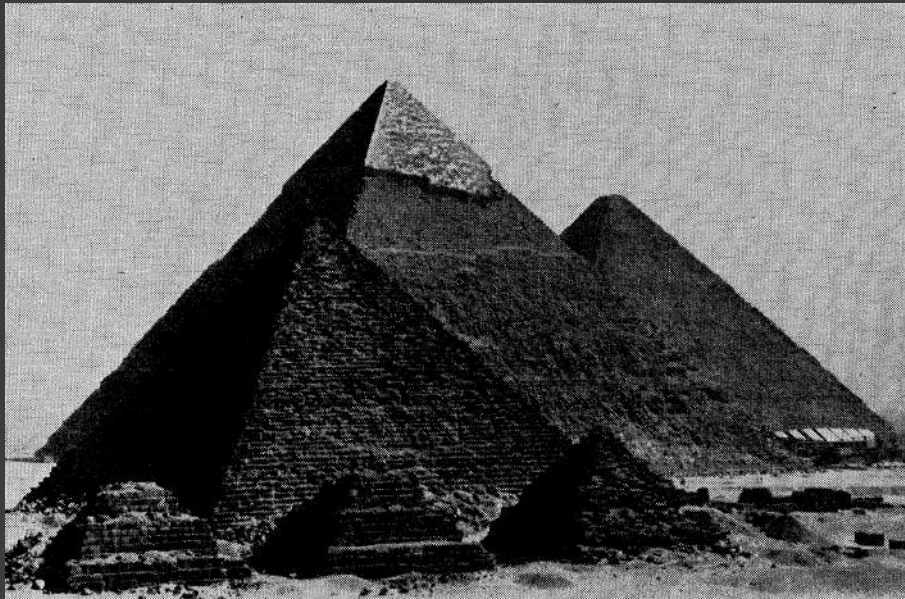
density map

Muon absorption creates a shadow and projects a “density map”

Combined analysis with resistivity and gravity data

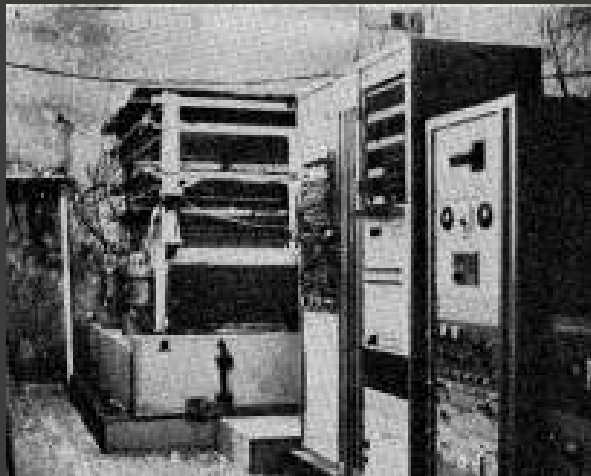
Muography applicable also to geological structures, Mining,
Archaeology, Civil Engineering, Security, ...

The first muography: Archaeology

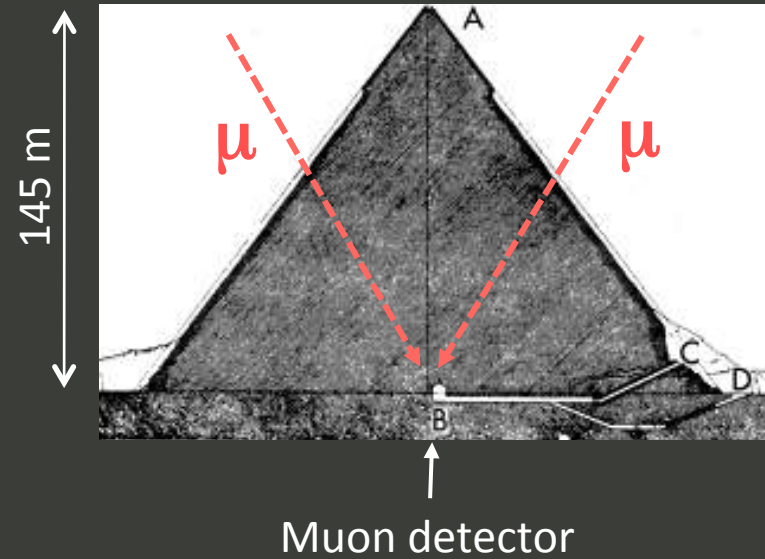


Search for a hidden chamber in the Chephren's Pyramid

(L.W. Alvarez et al., 1970)



Spark chamber muon detector

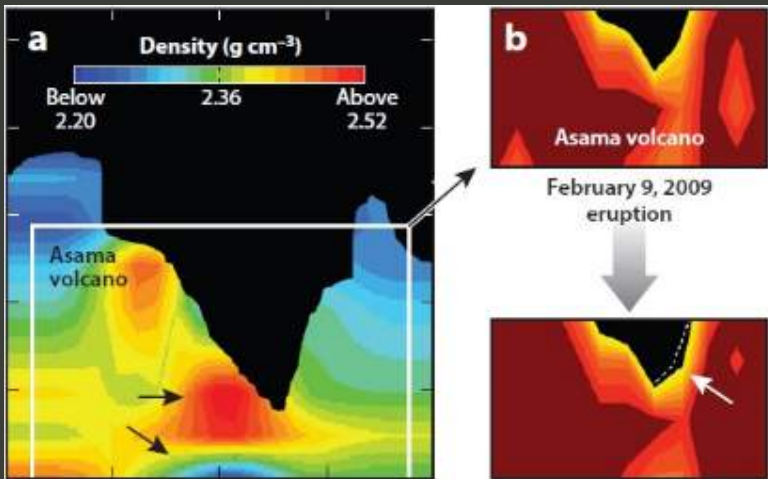


Volcano muography

Breakthrough

Summit of Mt. Asama
Rock density in colour scale
(Tanaka et al. 2007)

Muon detector
technique developed for
OPERA neutrino experiment



Until now

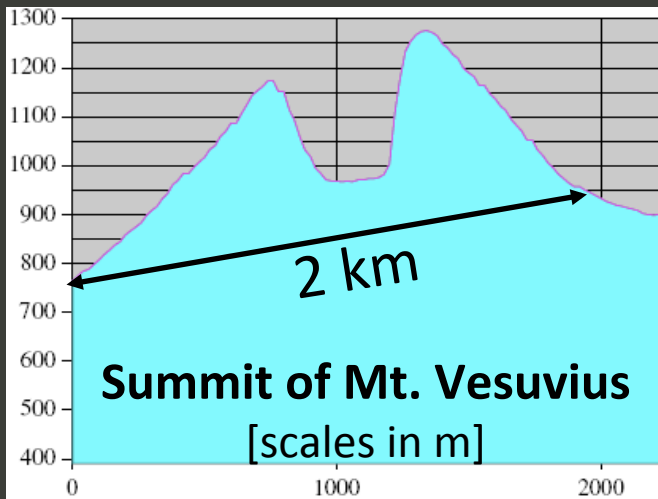
Observations and know-how in Japan, France and Italy
Impressive results, also combined with other techniques
Observation of time evolution

Towards a current “tool”

Rock thickness



“Rule of thumb”
2 km for 0.5-1 km height



The challenge

Sensitivity x 100

(Detector area x time) x 100

Very substantial background reduction

Angle resolution 10 mrad



Larger + better detectors, R&D

**Strong and effective
collaborations**

Also Science can do something for people



*Saint Gennaro
listened to people*



*... and stopped
the eruption*

*Napoli people invoke Saint Gennaro during
the last sub-plinian eruption of Mt. Vesuvius (1631)*

Micco Spadaro (1610-1675)

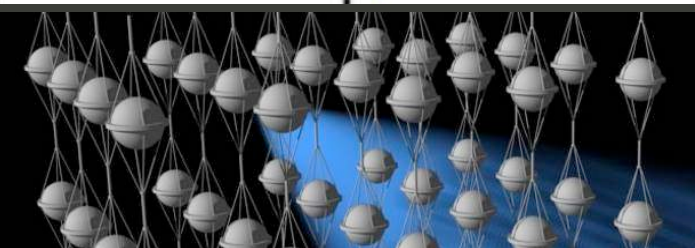
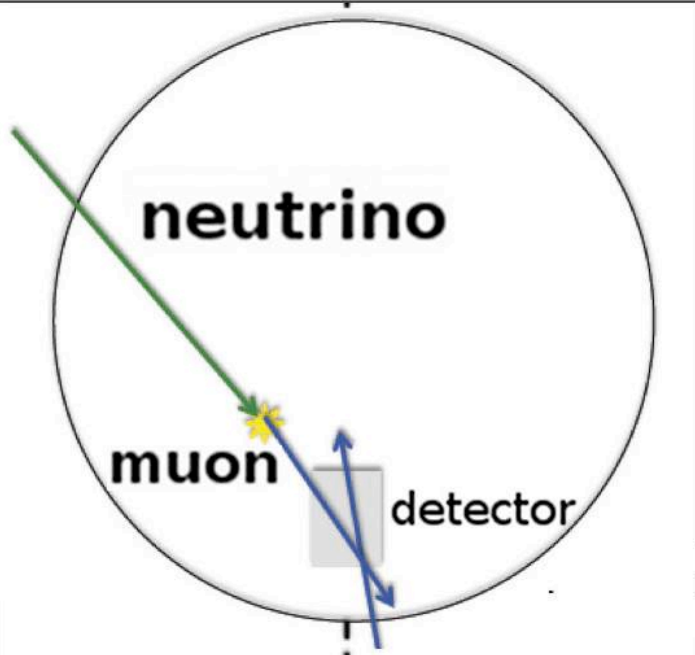
Neutrino-graphy

*Penetrating into
the Core of the Earth*



Concept of Earth's neutrino graphy

(density map given by neutrino absorption through Earth)



Neutrinos ν

Cosmic rays interacting in the atmosphere generate neutrinos



Earth: ν absorber and ν - μ converter

neutrinos interacting close to the detector generate observable muons μ

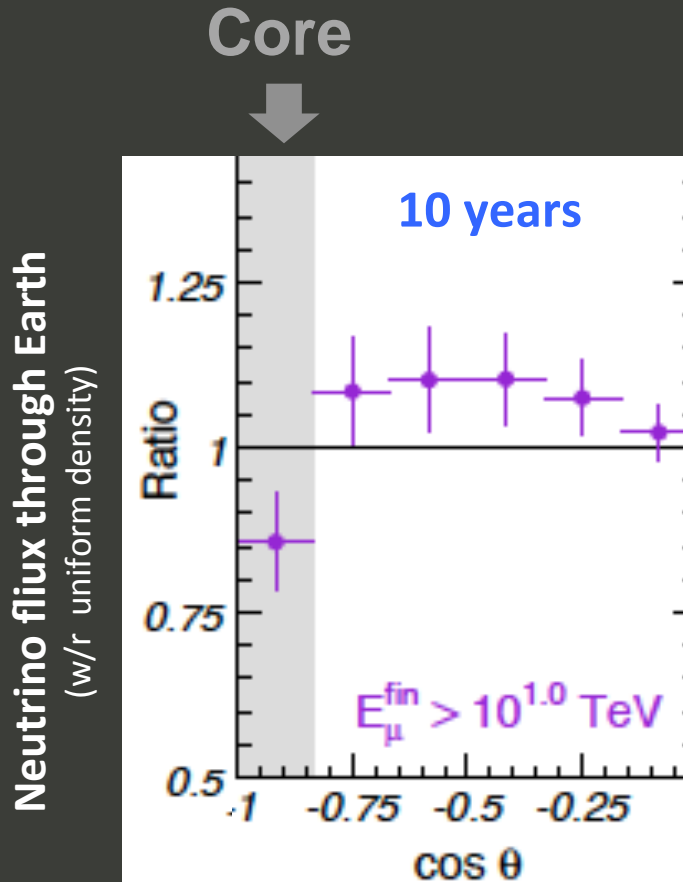


Muon detector

IceCube experiment under Antarctic ice sees Čerenkov light produced by muons
(as future Km3Net exp. in deep sea)

Computer simulation of an estimate of the Earth's Core density

(IceCube x 10 years)



Azimuthal angle



Neutrinos from antipodes

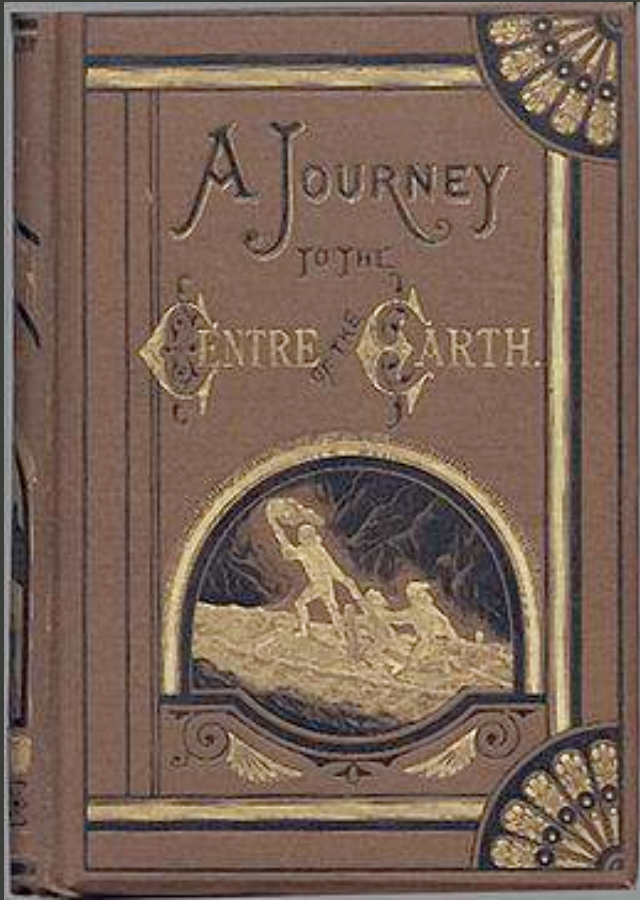
Current Earth's density model (PREM)

Select very high energy neutrinos
(higher interaction probability)

The lower neutrino flux through the Earth's Core indicates a higher absorption and gives an estimate of its density

Radiography of the Earth's core and mantle with atmospheric neutrinos
(Gonzalez-Garcia et al., 2008)

Neutrinos penetrate much deeper than imagined by Jules Verne, the precursor of Science Fiction

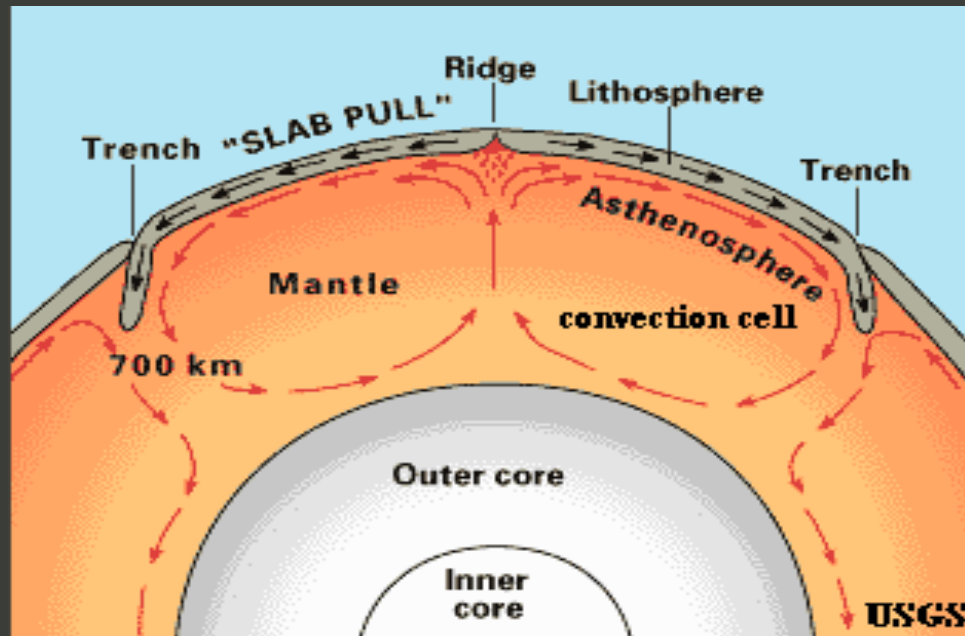


A Journey to the Centre of the Earth (1864)

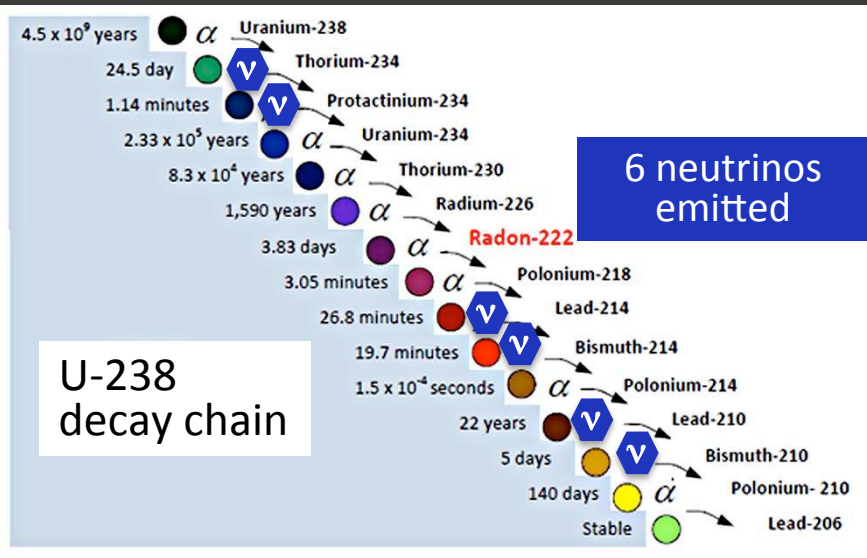
Jules Verne (1828-1905), Illustrations by Edouard Riou

Geo-neutrinos

Messengers from deep Earth



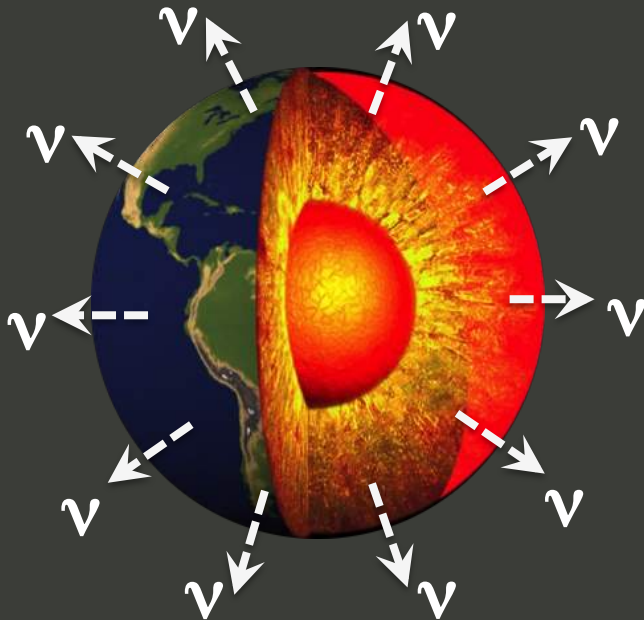
“Geoneutrinos”



Radioactive decay chains
of Uranium-238, Thorium-232
and Potassium-40



Emission of (anti-)neutrinos $\bar{\nu}$
+ Heat from energy
made available



Measure geoneutrino flux



estimate “radiogenic” heat

Our lives stand on the Earth's Mantle: geoneutrinos tell us about it's dynamics



Pop Art Murales in the Milwaukee's Metro

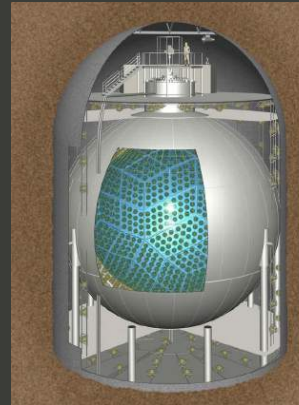
Keith Haring (1958-1990)

[<http://www.escopri.it/316512/keith-haring-il-murales-milwaukee-mostra-alla-reggia-caserta.html>]

“Geoneutrino” discovery by “neutrino” detectors in underground Physics/Astrophysics Laboratories

2005 **KamLAND**: first detection

2010 **Borexino**: detection with low
background from nuclear reactors



KamLAND (> 2002)
Liquid scintillator
1 kt, 1900 PMTs



Borexino (> 2007)
Liquid scintillator
0.3 kt, 2200 PMTs

2011 **Radiogenic contribution to Earth’s heat** (+ primordial source?)
Uranium and Thorium abundances

2013 **Radiogenic heat from Earth’s Mantle** from combined analysis

The first estimates

Coming soon: SNO+

KamLAND

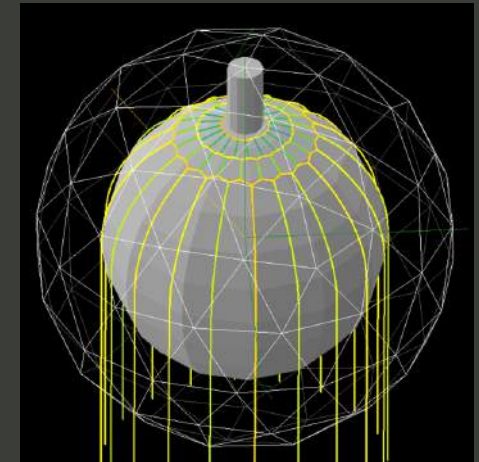
Liquid Scintillator
1 kt, 1900 PMTs
> 2002

Borexino

Liquid Scintillator
0.3 kt, 2200 PMTs
> 2007

SNO+

Liquid Scintillator
0.8 kt, 9000 PMTs
> 2014



Borexino .vs. both others

Lowest Liquid Scintillator mass
Lowest background

SNO+ .vs. KamLAND

Similar Liquid Scintillator mass
Background from nuclear reactors x 1/4

What can radiogenic heat from Earth's Mantle tell us?

Source of Earth's internal heat

Power supply for Mantle convection, plate tectonics, ...

A key to mysteries of deep-Earth phenomena affecting our lives



Future “geoneutrino detectors”



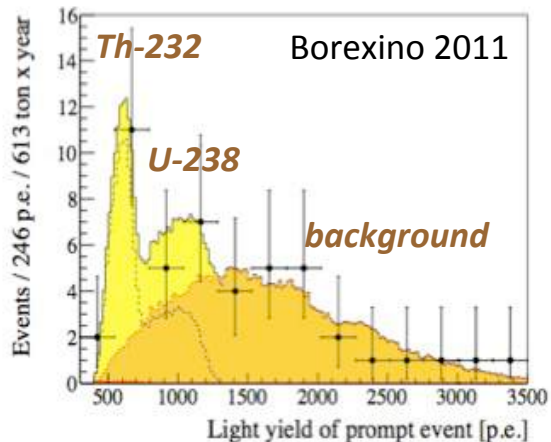
The “electronic eyes” inside Borexino

Breakthrough detectors *[see figures]*

Limited mass (< 1kt) and low statistics

Location for physics and astrophysics

“Blind counting” and looking for “peaks” in energy distribution



Thorium and Uranium peaks over background in the positron energy distribution (46 events)

New features

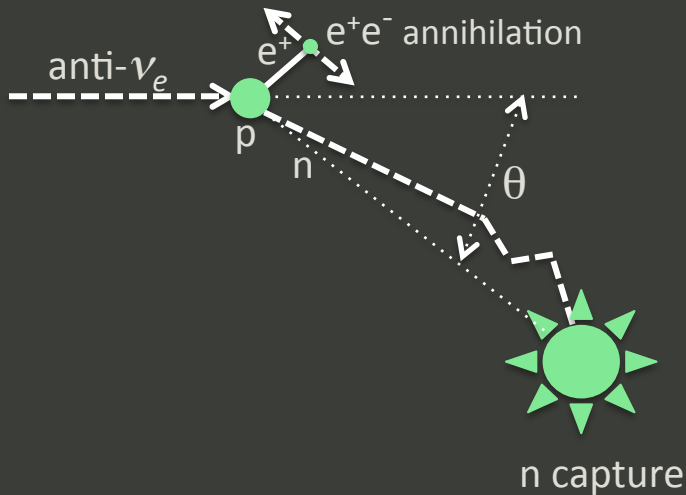
Mass x 10, hence larger statistics

Location for geoneutrinos:

Mantle and Crust signals, background from reactors

Tracing back geoneutrinos for source imaging

Tracing back geoneutrinos for source imaging




Liquid Scintillator: mostly Hydrogen (H)

The neutrino ($\bar{\nu}_e$) interacts on H nuclei (p) producing a positron e^+ and a neutron n

Interaction point seen through the prompt e^+ annihilation on e^-

The neutron recoil “remembers” the geoneutrino direction

Neutron diffusion at low energies before capture by a nucleus and measurement error on capture location: **memory lost**

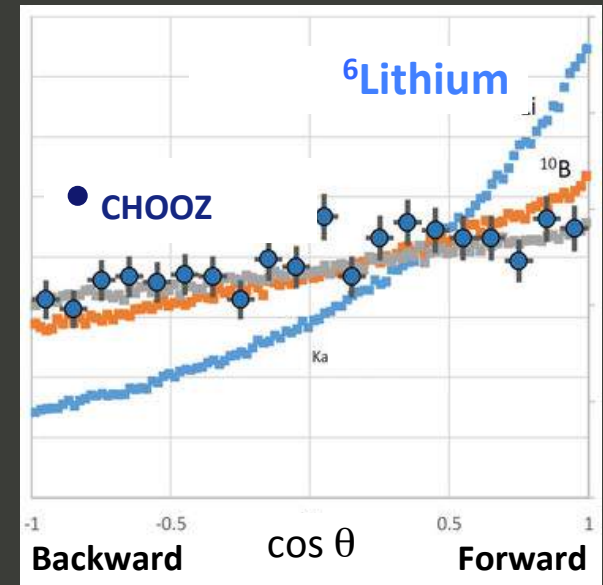
peak in correct neutrino direction 

With $^6\text{Lithium}$ -loaded Liquid Scintillator

Neutron soon captured, hence little diffusion
(also with Gadolinium loading)

Better location of the neutron capture
(not with Gadolinium loading)

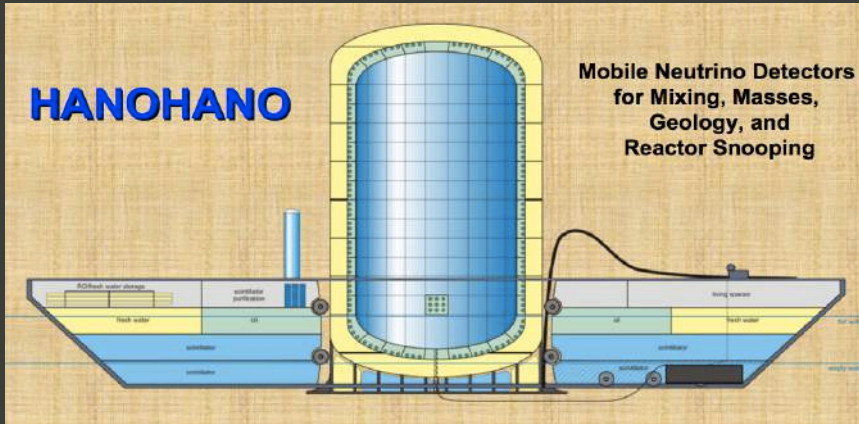
The neutron maintains memory of the neutrino direction



Apollonio et al. Phys. Rev D61 (2000): CHOOZ, with Gadolinium loading
Shimizu, Nucl. Phys. B 168 (2007)
Tanaka and Watanabe, Nature Scientific Reports 4 (2014)

Close to the source of Mantle geoneutrinos

J. Learned, S. Dye and S. Pakvasa
Neutrino Telescopes, 2007



Mobile detector (10 kt)
to be deployed and retrieved from a barge

On Continents:

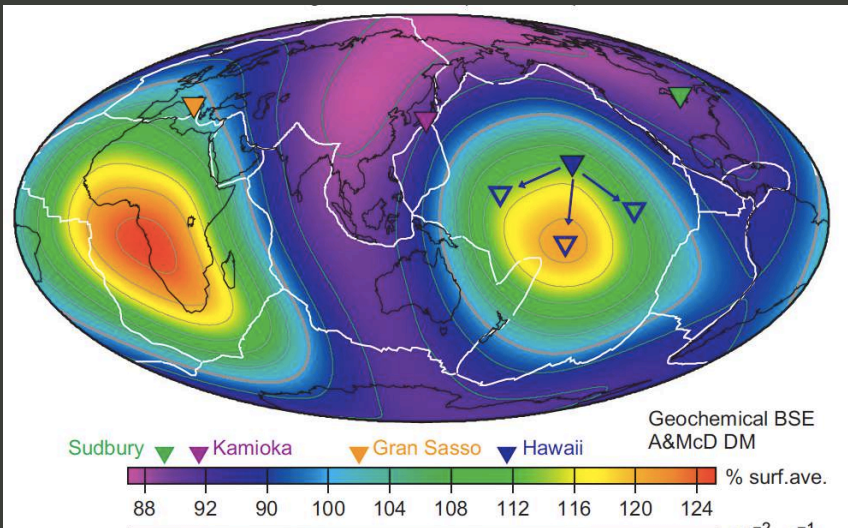
Crust geoneutrinos overwhelming
Location bound to caverns

In deep Ocean:

Clean Mantle signal

Mobile submarine detectors: Hanohano

Sramek et al.
Ea. Pl. Sci. Lett. 361, 2013



*The technique is suitable for monitoring the
existence of nuclear power reactors:
can this attract a special support by
governments?*

Mantle geoneutrino flux (%/average)
Proposed Hanohano sites in Pacific Ocean

For all the above
new challenges

*Alliance to penetrate
mysteries of the deep Earth*

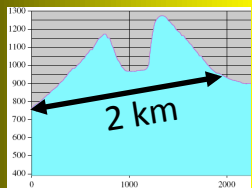
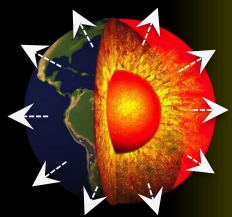


Listening to people

***A vision
on the road
towards the future***

1970 2005 2010 2015 2030 2050 2100

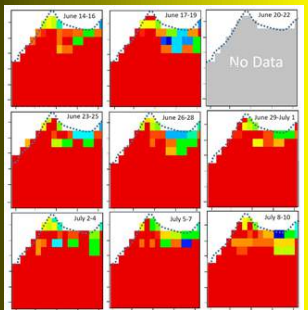
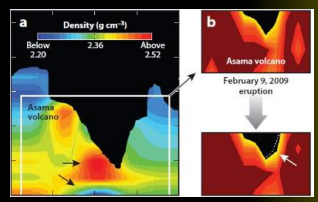
Earth Science



✘ Impossibile visualizzare l'immagine. La memoria del computer potrebbe essere insufficiente per aprire l'immagine oppure l'immagine potrebbe essere danneggiata. Riavviare il computer e aprire di nuovo il file. Se viene visualizzata di nuovo la x rossa, potrebbe essere necessario eliminare l'immagine e inserirla di nuovo.

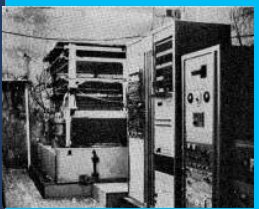
New challenges in Earth Science

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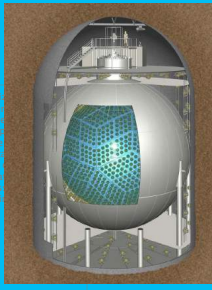


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Particle Physics



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***Alliance ERI-INFN-INGV:
engine for a boost forward***

... by a solid synergy of expertise

A photograph of a megalithic dolmen in Ballykeel, Ireland. The dolmen consists of three large, grey, rectangular stones. Two vertical stones support a thick, horizontal stone capstone. The structure is set in a grassy field with a fence and a house in the background under a blue sky. The text 'NEW CHALLENGES IN EARTH SCIENCE' is centered over the capstone. Below it, three columns of text are positioned: 'ERI Earth Science' on the left, 'INGV Earth Science' in the middle, and 'INFN muons neutrinos' on the right.

**NEW CHALLENGES
IN EARTH SCIENCE**

**ERI
Earth
Science**

**INGV
Earth
Science**

**INFN
muons
neutrinos**

A megalithic dolmen, Ballykeel, Ireland (4000-2500 BC)

In a tradition of collaboration between Italy-Japan

*K. Hokusai
(1760-1849)*

Great Wave



*P. Fabris
(1740-92)*

Mt. Vesuvius

From "Science and School" [<http://scienzaescuola.fisica.unina.it>]

**Similar concerns in Earth Science:
Earthquakes and volcanoes**

Different cultures create synergic waves