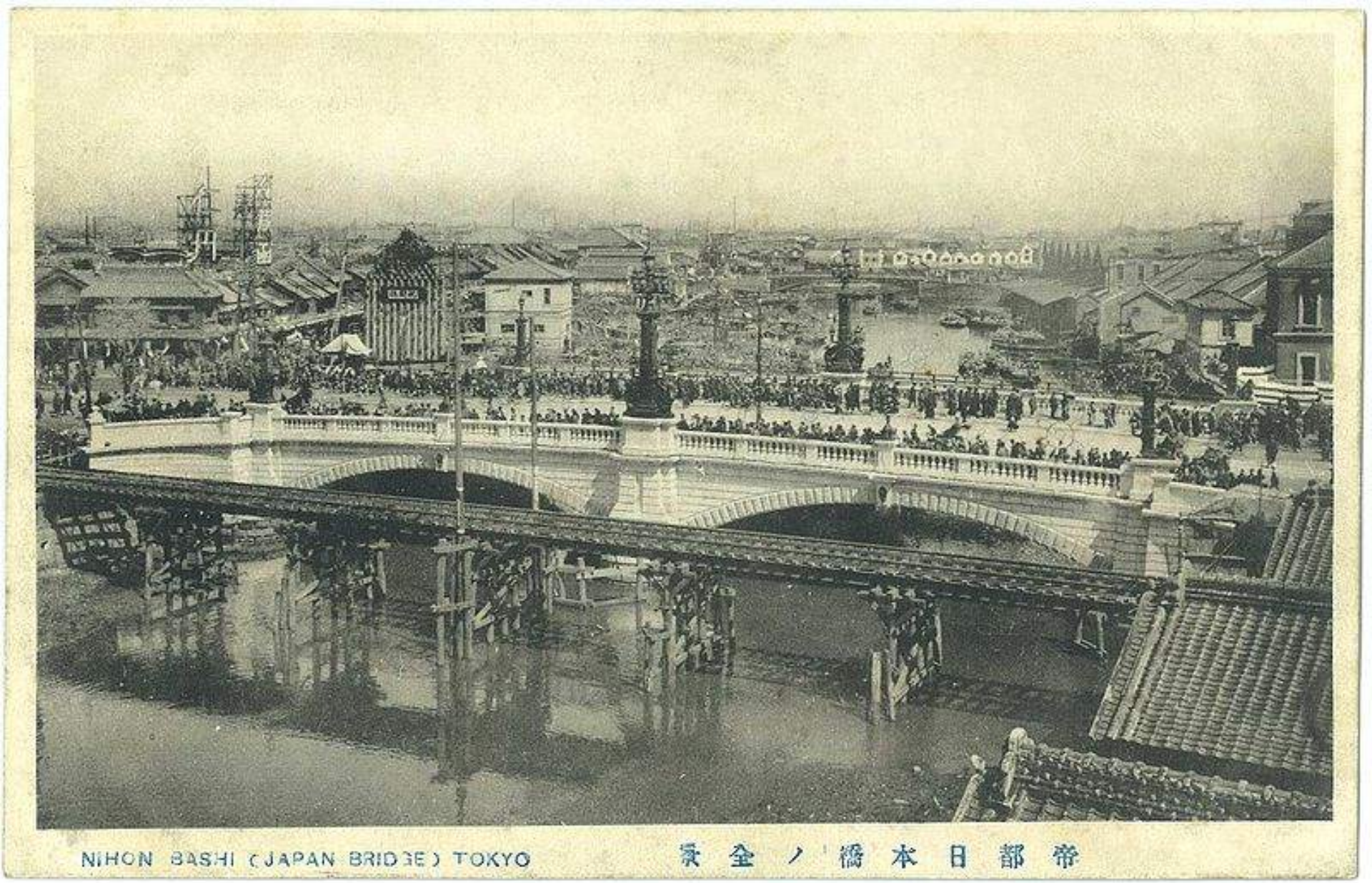
Muon and neutrinos for Earth studies

Paolo Strolin (Univ. Federico II and INFN, Napoli)

NIHONBASHI BRIDGE AT EDO TOWARD TOKKAIDO ROAD AND MT. FUJI (1863)

Utagawa Sadahide - Near end of Tokugawa period (1603-1868)

[http://www.myjapanesehanga.com/home/artists/utagawa-sadahide-1807-1873/view-of-a-daimyo-procession-at-nihonbashi]



THE NEWLY BUILT NIHONBASHI BRIDGE (1911)
An impressive change of townscape at the end of the Meji period (1868-1912)

[http://commons.wikimedia.org/wiki/File:NewlyBuilt_Nihonbashi_1911_Tokyo.jpg]

THE NIHONBASHI HISTORIC BRIDGE

A new change of townscape in recent years

[http://en.wikipedia.org/wiki/Nihonbashi]

The World is always changing

In an extension of the talk
I will come to this point regarding:

Why basic Science?

Science, Society and Education

An educational project

A growing tree:
muons and neutrinos for Earth studies

Dreams

Season of results

Breakthroughs

Deep roots in basic Science

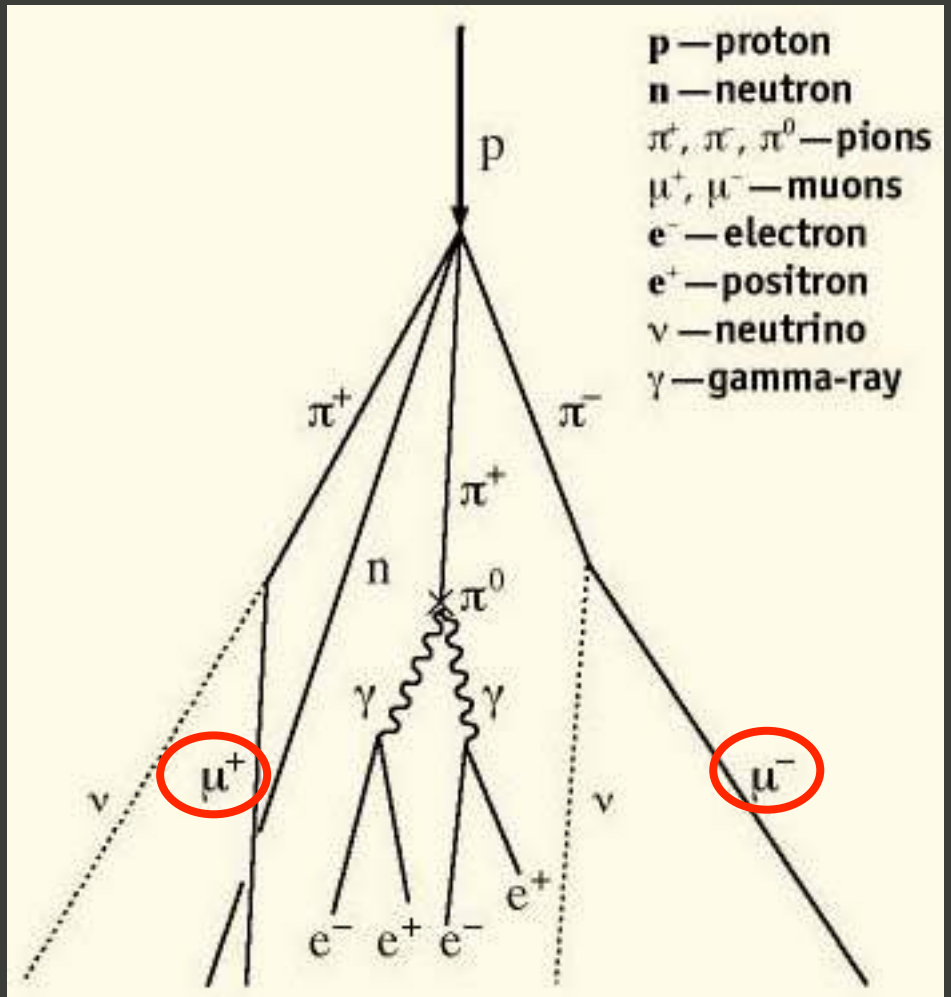
Muons

The discovery of cosmic rays: basic Science

Viktor F. Hess (centre)

with ionization measuring equipment on a hydrogen balloon at altitudes up to 5.3 km, at serious personal risk (1911-12)

From cosmic rays to Muon Radiography (Muography)



1935

Yukawa: "π meson" hypothesis

1937

Anderson-Neddermayer

".. particles less massive than protons but more penetrating than electrons"

produced by cosmic rays

Thought to be π

1947

Conversi-Pancini-Piccioni

No strong interactions: not π

"Muons" are born!

⬇

"Muography"

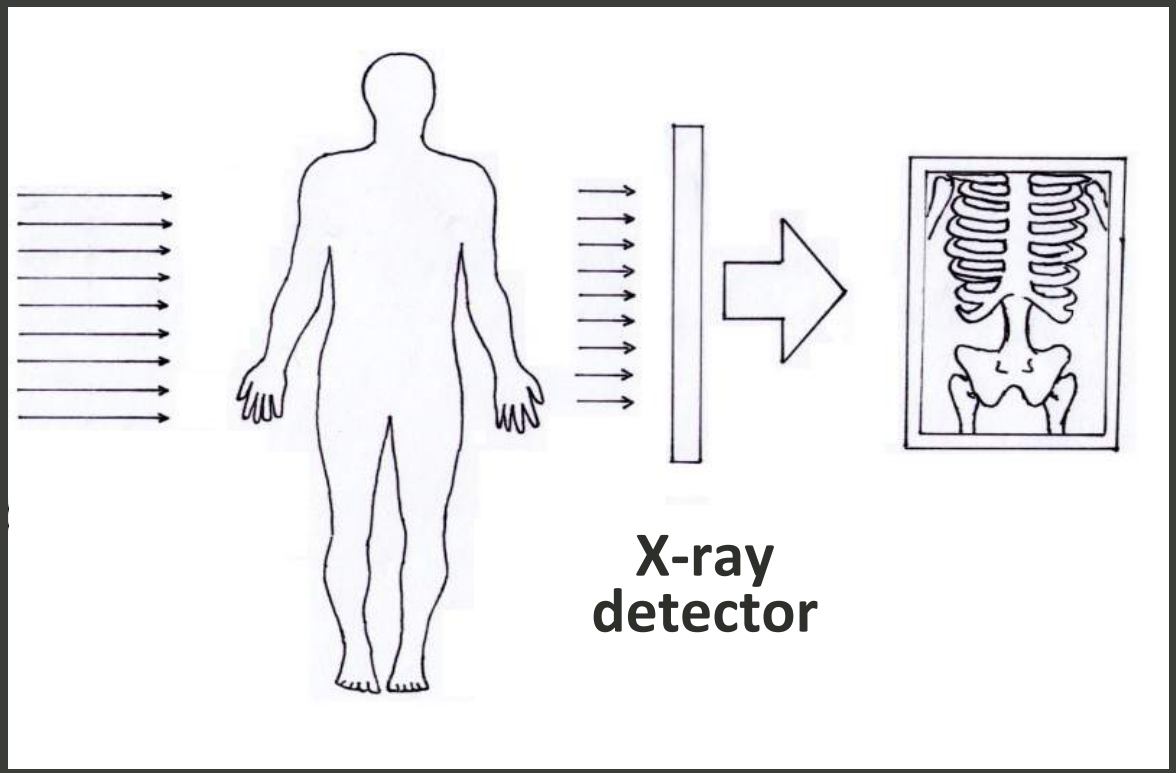
The principle of muon and neutrino radiography

“See the invisible” as a “shadow”

by observing absorption

depending on density of matter

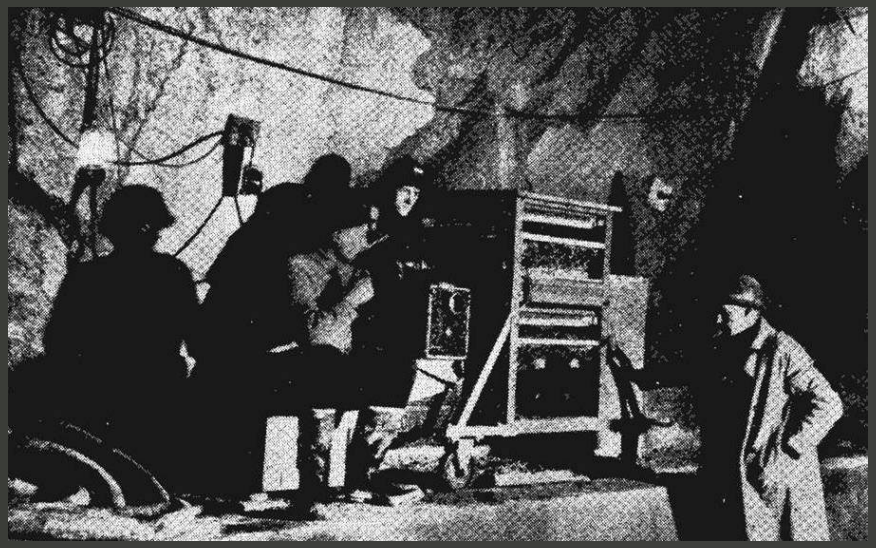
As with X-rays



The flavour of early times of muography

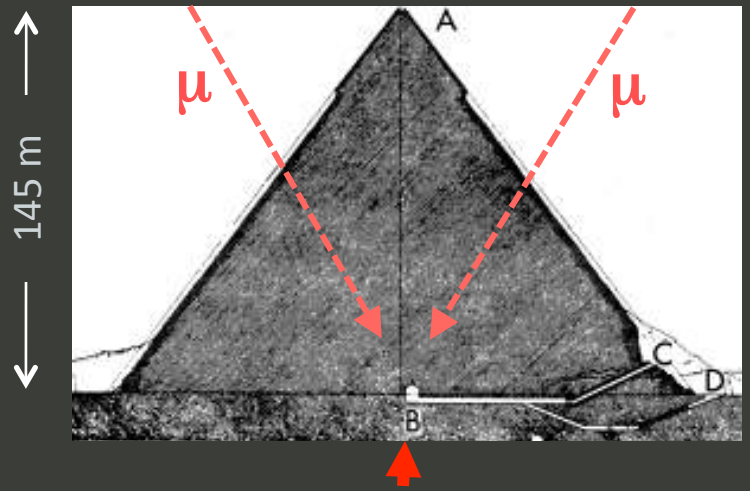
Cosmic Rays Measure Overburden of Tunnel

Fig. 1—Geiger counter "telescope" in operation in the Guthega-Munyang tunnel. From left are Dr. George and his assistants, Mr. Lehane and Mr. O'Neill.



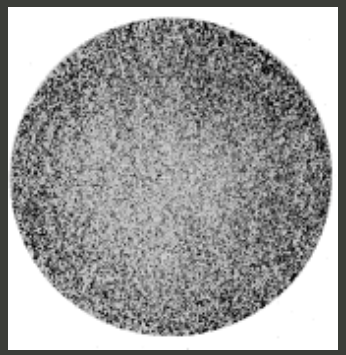
Rock thickness by muon absorption

E. P. George, Commonwealth Eng. (1955) 455

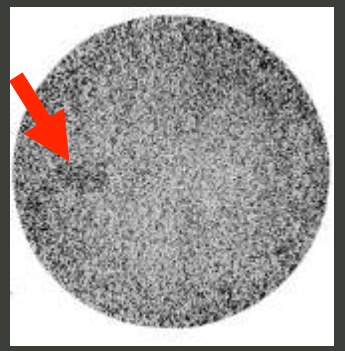


Spark Chamber muon telescope

Data: no chamber



Simulation: hidden chamber



Search for hidden chambers in the Chephren's Pyramid

L.W. Alvarez et al. Science 167 (1970) 832

The seminal work on volcano muography

Kanetada Nagamine

Geo-tomographic observation of inner structure of volcano with cosmic ray muons (in Japanese)

Journal of Geography 104 (1995) 998

Kanetada Nagamine, M. Iwasaki, K. Shimomura and K. Ishida

Methods of probing inner structure of geophysical substance with the horizontal cosmic-ray muons and possible application to volcanic eruption prediction

Nucl. Instr. and Meth. A356 (1995) 585

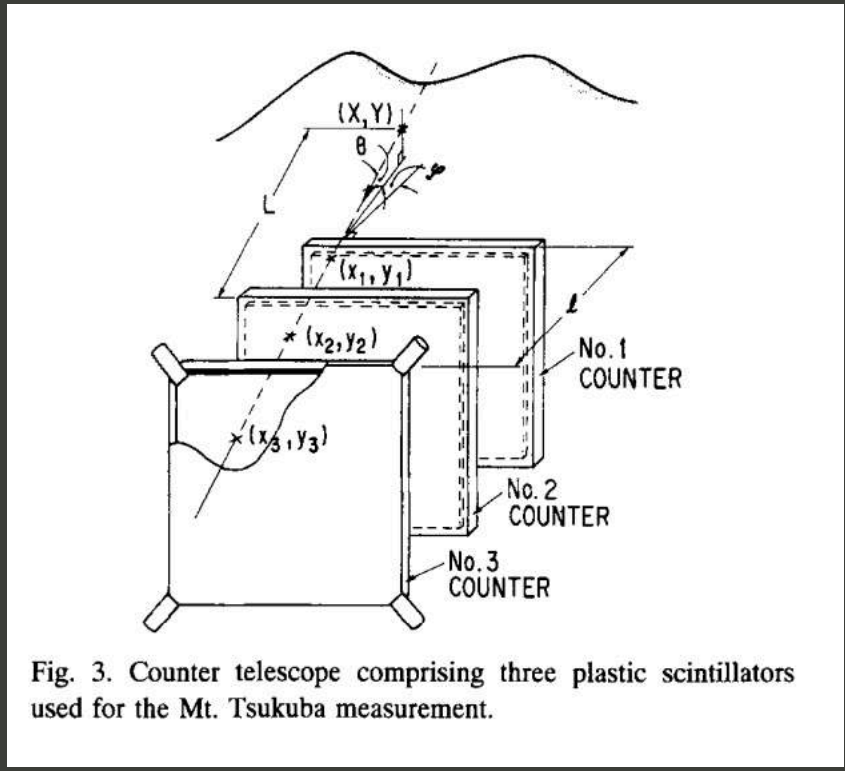
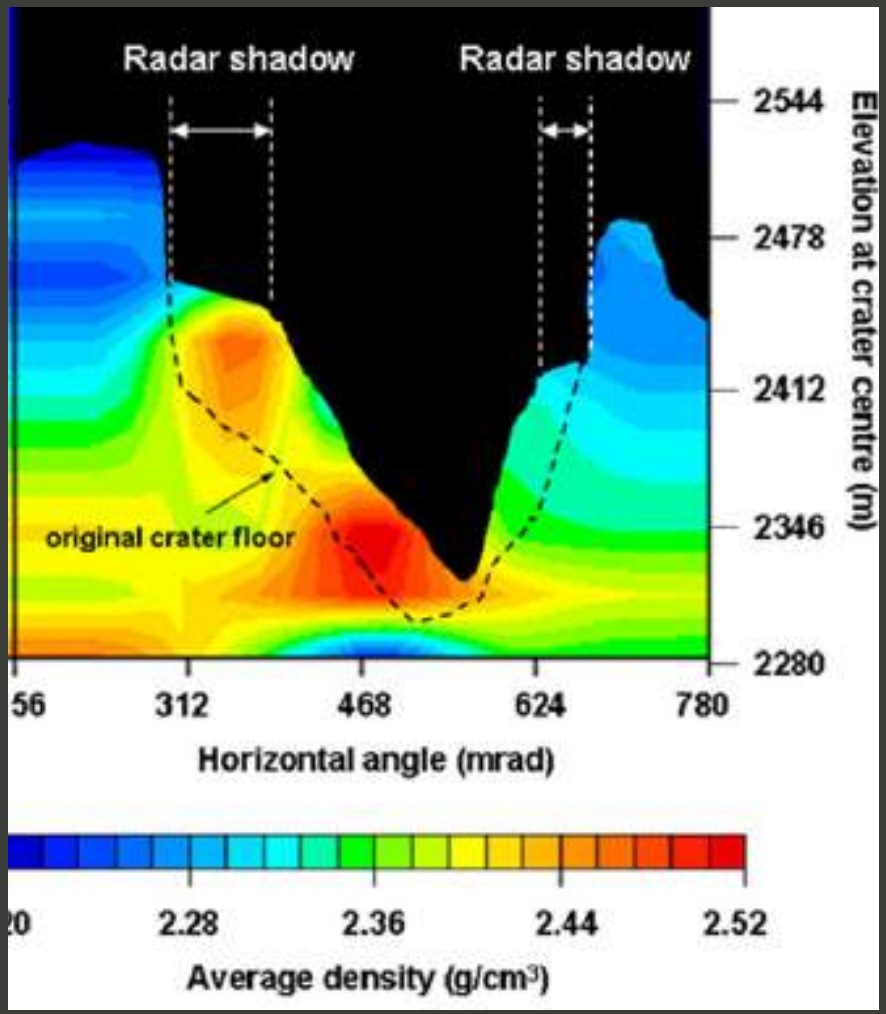


Fig. 3. Counter telescope comprising three plastic scintillators used for the Mt. Tsukuba measurement.

Test measurement

"it was made clear that nearly horizontal cosmic-ray muons can be used to explore the inner-structure of a gigantic geophysical substance, such as the top region of a volcano"

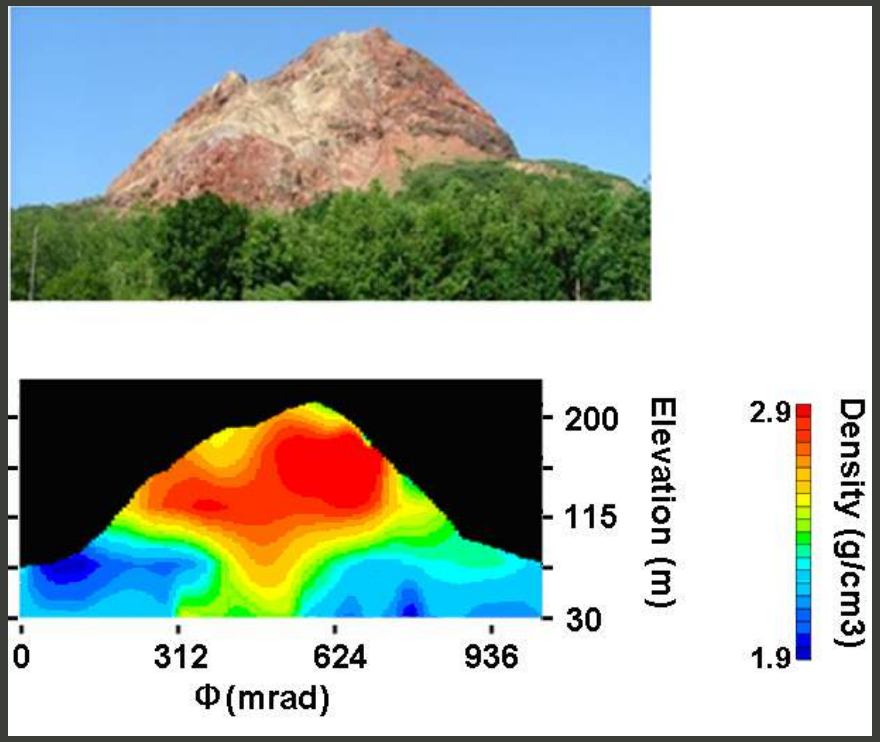
Breakthrough with volcanoes in Japan



Mt. Asama

H.K.M. Tanaka et al. (2007)

EPS Lett. 263 (2007)104

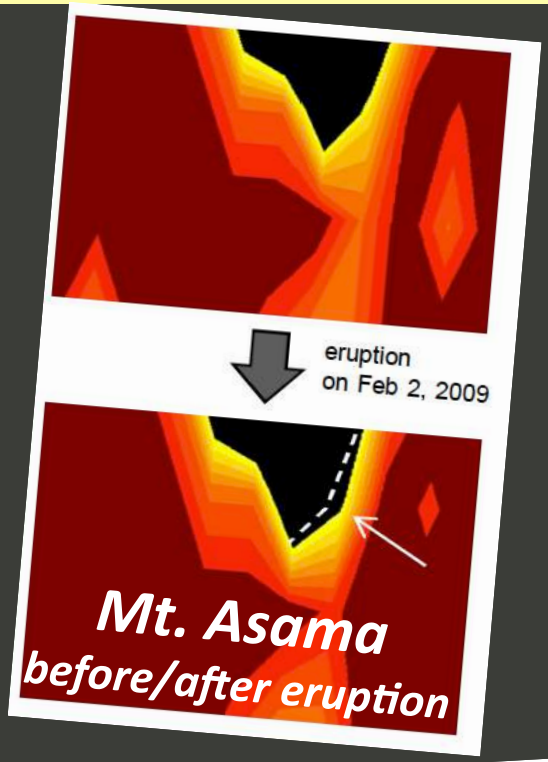


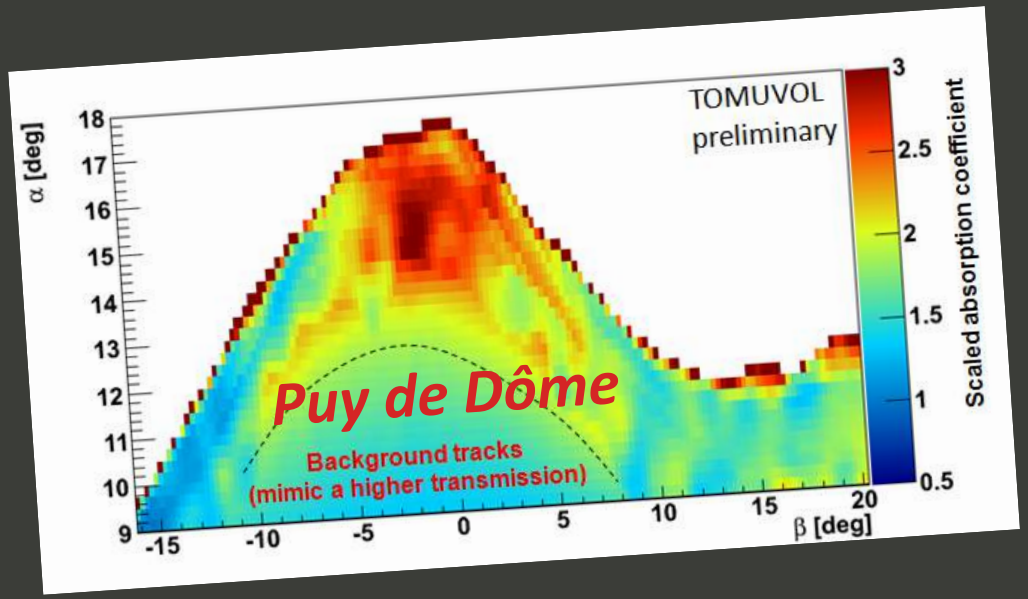
Showa-Shinzan lava dome at Usu volcano

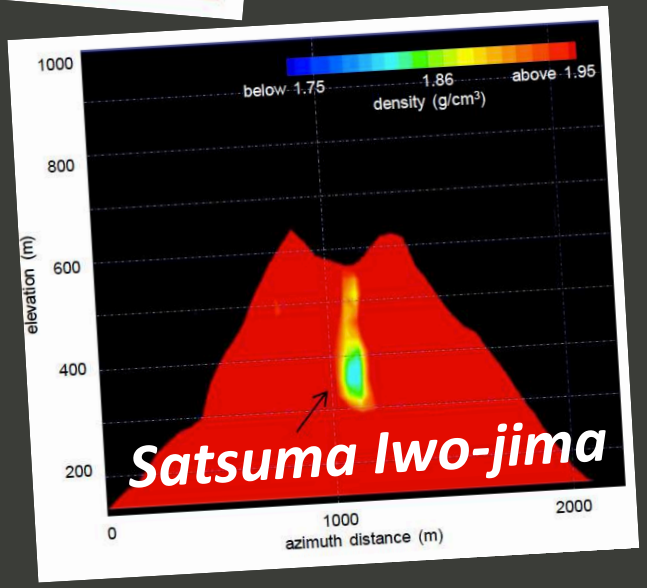
H.K.M. Tanaka and I. Yokoyama

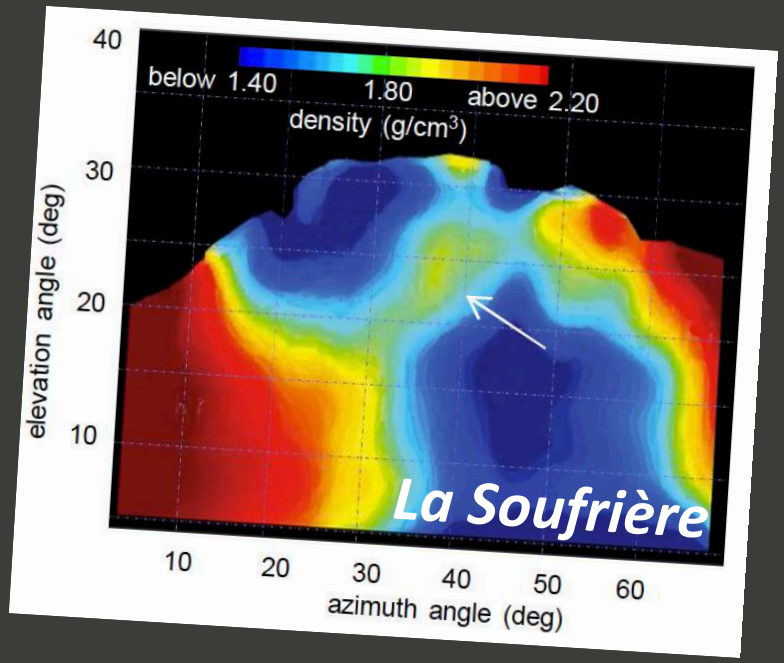
Proc. Jpn. Acad. B84 (2008) 107

Further results









Controlled Test of Geophysical Tomography

Douglas Bryman*
University of British Columbia

Collaboration
AAPS, Bern, Geological Survey of Canada, Nyrstar, UBC

- **A successful field trial has been performed with muon geotomography imaging a known massive sulfide deposit in a complex geological environment**
- **Inverted 3D density contrast images of the deposit are similar to a model derived from drill data**

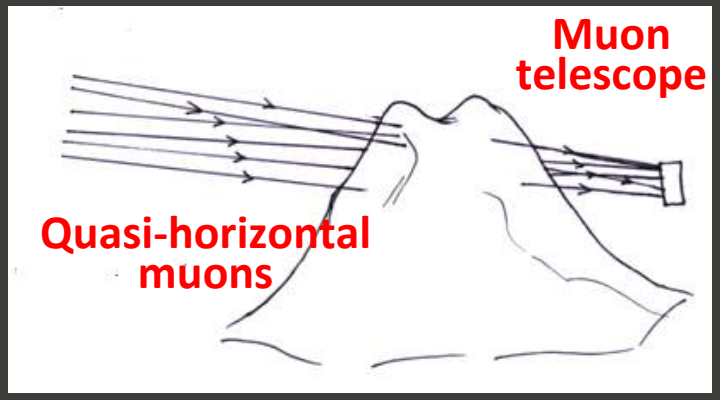
(total mass, mass distribution, and host rock densities were reproduced

- **Several exploration surveys are underway**

*doug@triumf.ca

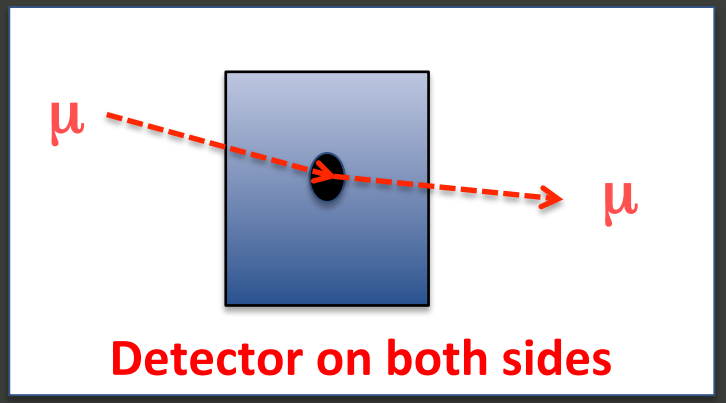
Methods and further applications

Absorption (density)



Multi-parameter combined analysis with resistivity and gravity data

Deflection (Z^2)



Suitable for high Z materials

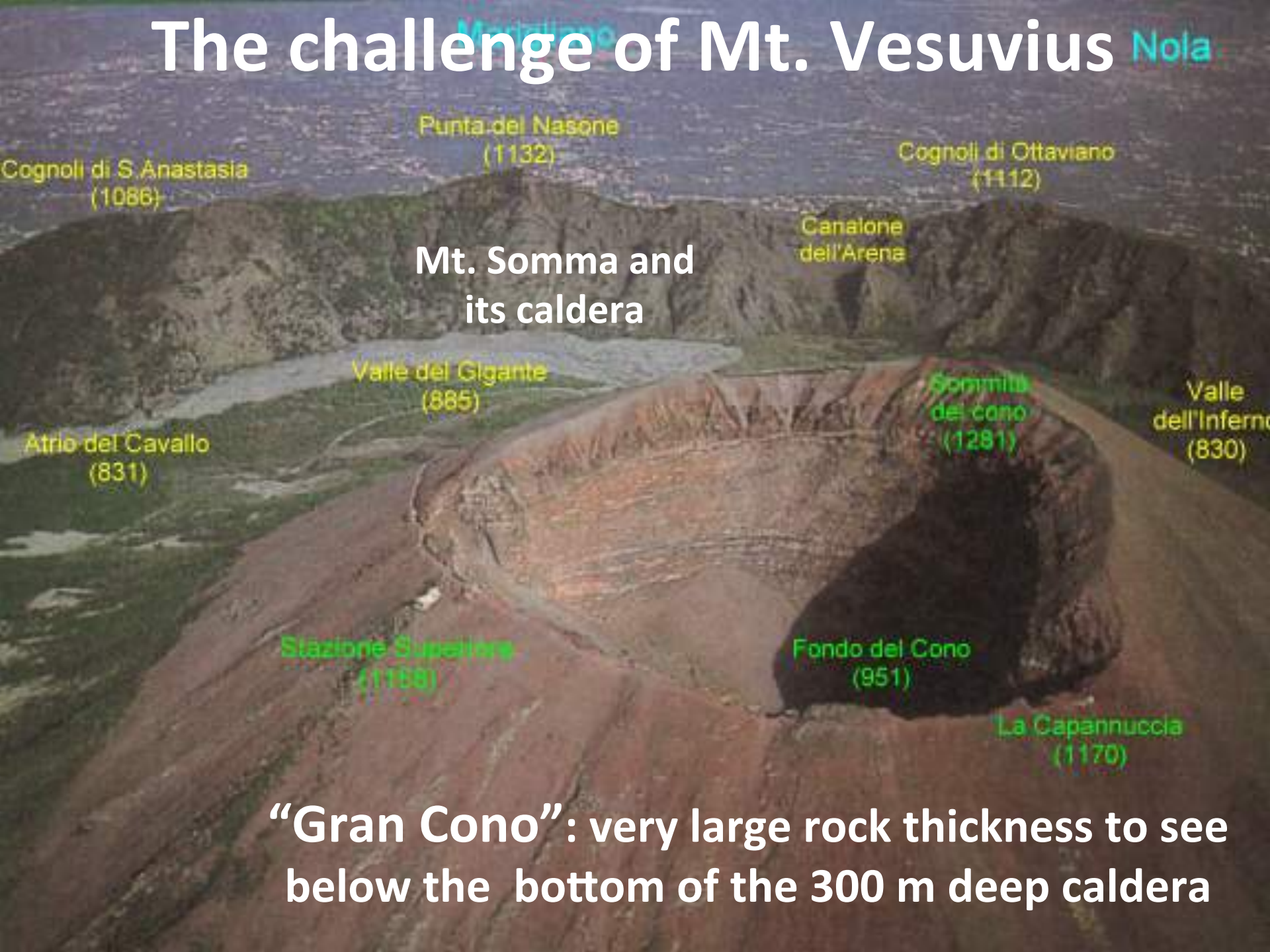
Archaeology
Civil Engineering
Security
Uranium in radioactive waste
Geological structures and mining
Volcanoes .....

The interior of volcanoes: a fascinating question

Athanasius Kircher, Mt. Vesuvius (1638)

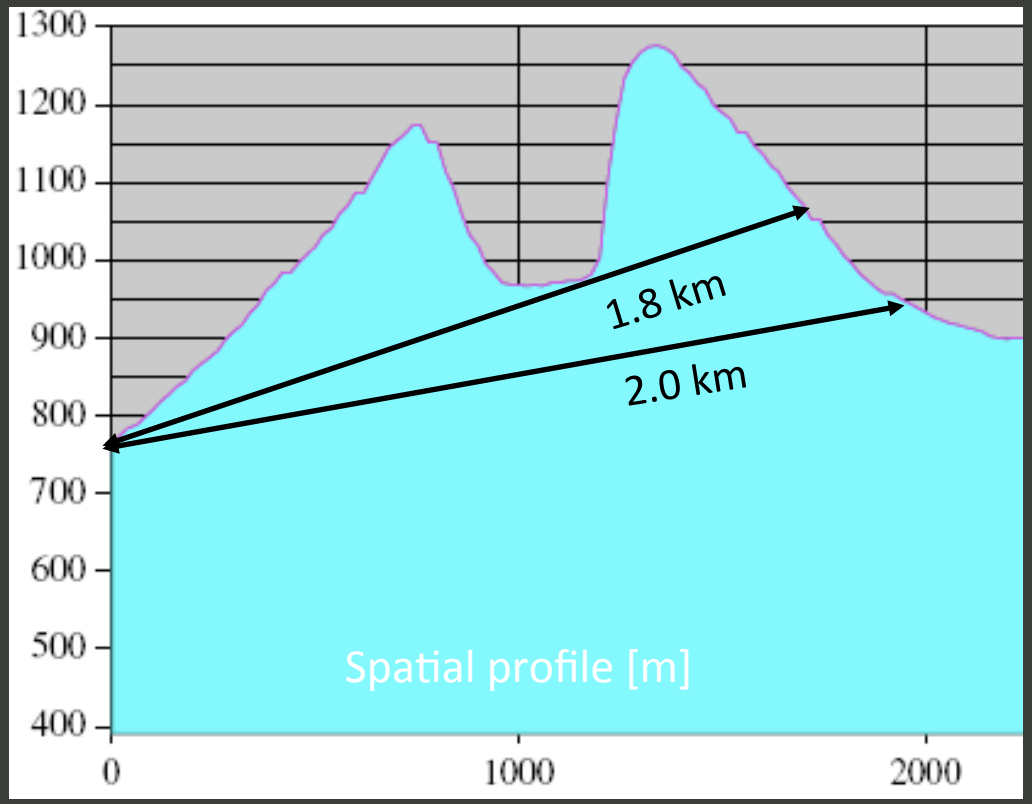
Hypothesis that volcanoes are connected to the interior of the Earth

The challenge of Mt. Vesuvius



"Gran Cono": very large rock thickness to see below the bottom of the 300 m deep caldera

Mt. Vesuvius



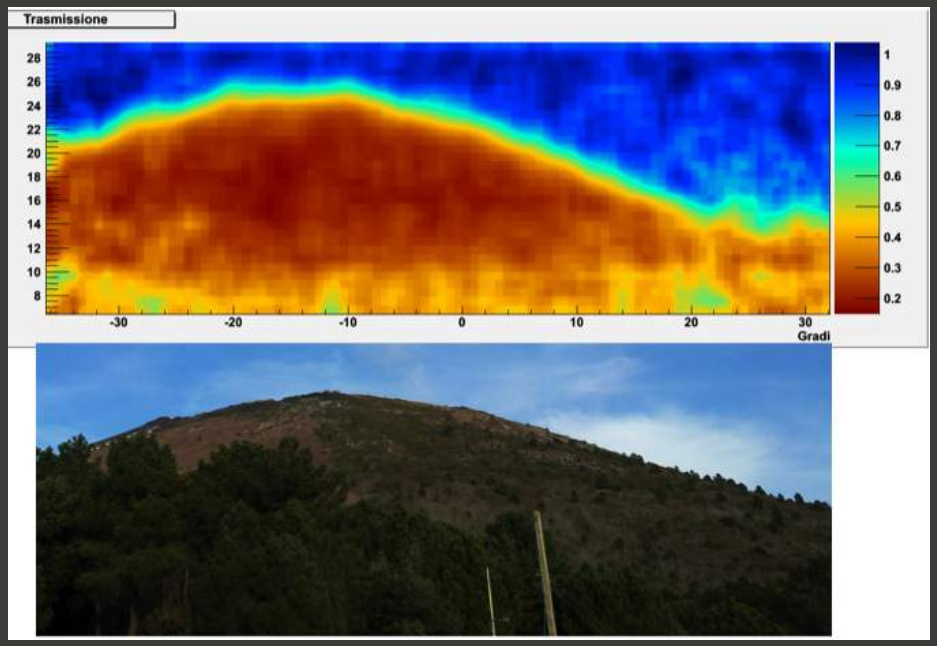
2 km rock thickness from a telescope at 750 m a.s.l.

↓

<u>Substantially improve the sensitivity (x 10^2)</u>

with respect to previous radiographies (< 1 km rock)

Mt. Vesuvius: MURAY Project

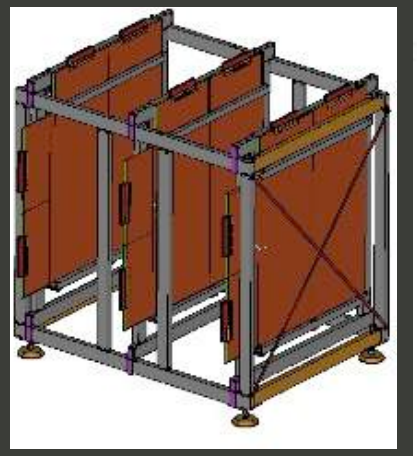


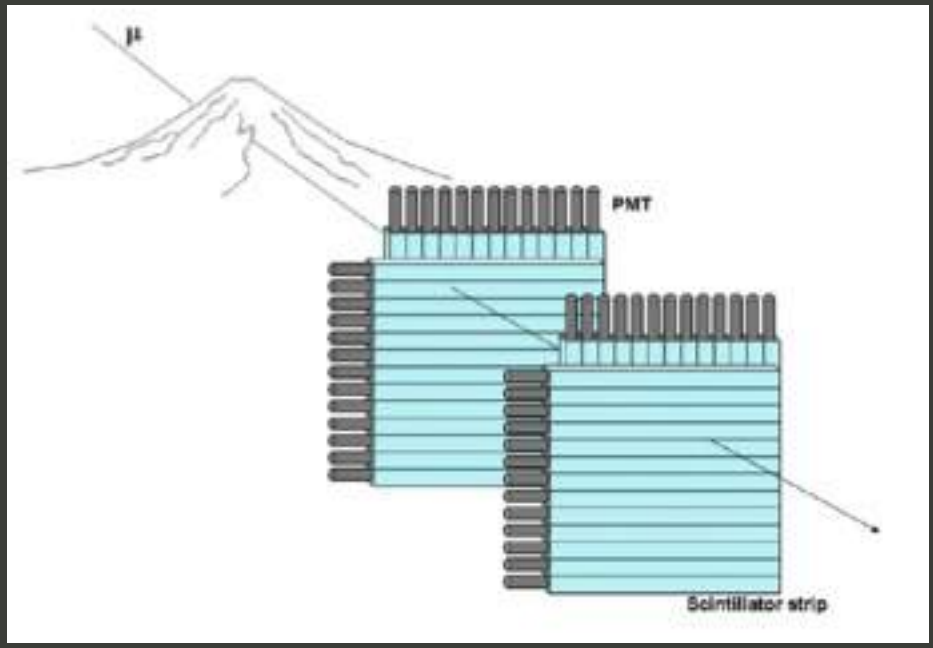
First results from a technical test of 1m2 prototype:
Vesuvius as seen by muons

For a muon radiography:
- 10 m2 or more telescope area
- years of data taking

Prototype 1 m2
“muon telescope”

Electronic detection technique:
highly segmented
“scintillation counters”

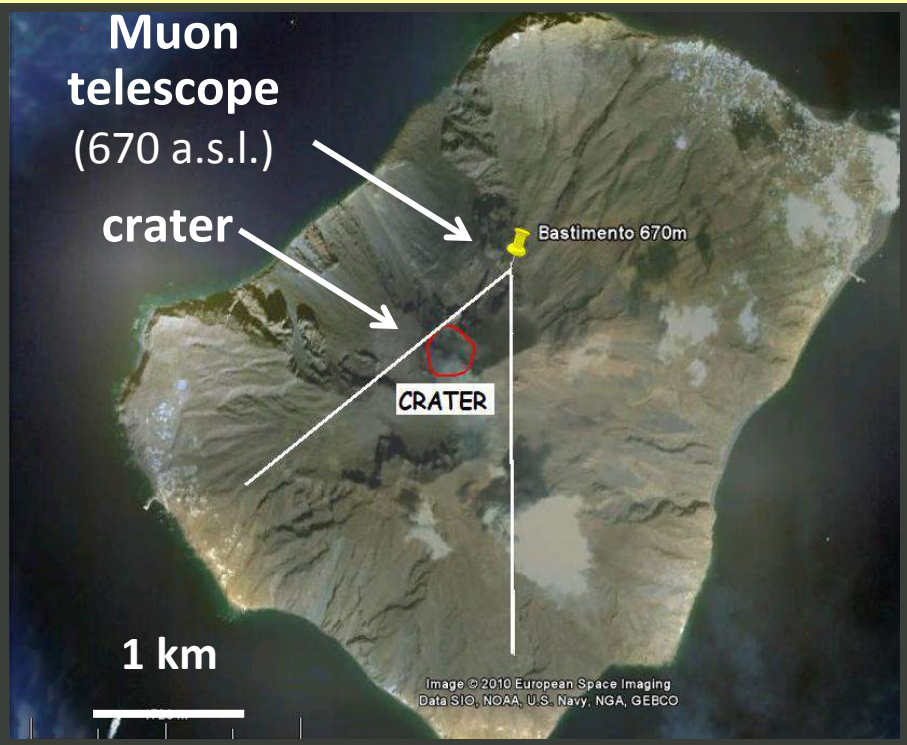




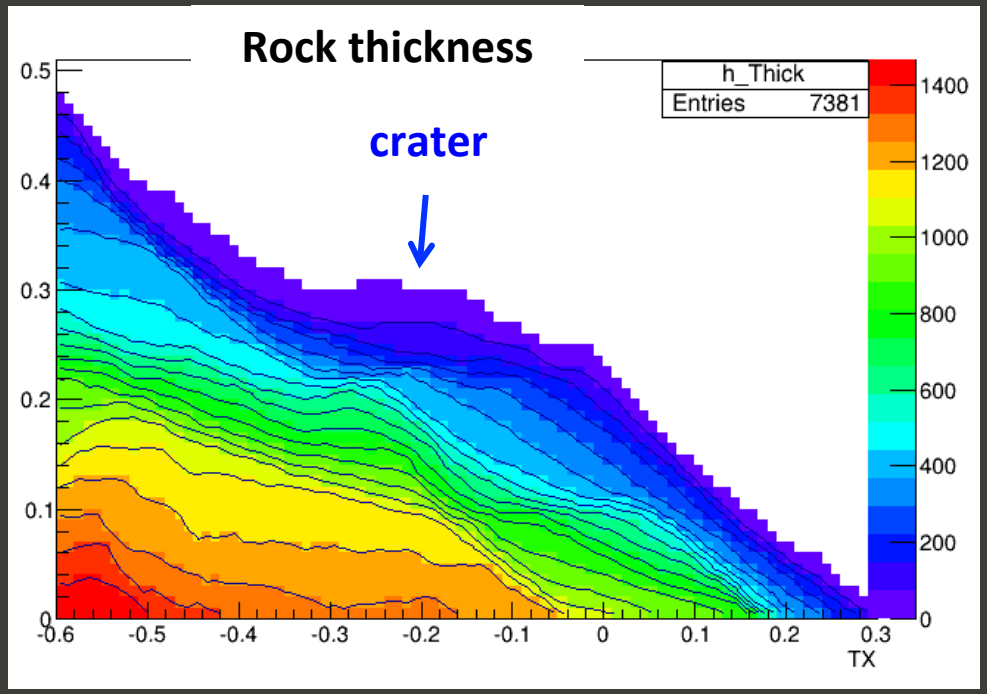
Stromboli

- **“Strombolian” activity**
  - essentially open conduit
  - intermittent eruptions due to build up of gas pressure
  - rare effusive activity
- **Summit at 926 m a.s.l.**
- **Crater at ~ 750 m a.s.l.**

The crater viewed from telescope location



A 1 m² muon telescope has taken data in winter 2011 (5 months)



The “naked” muon telescope

“Nuclear photographic emulsion” as muon detector

Protection from rain and moisture

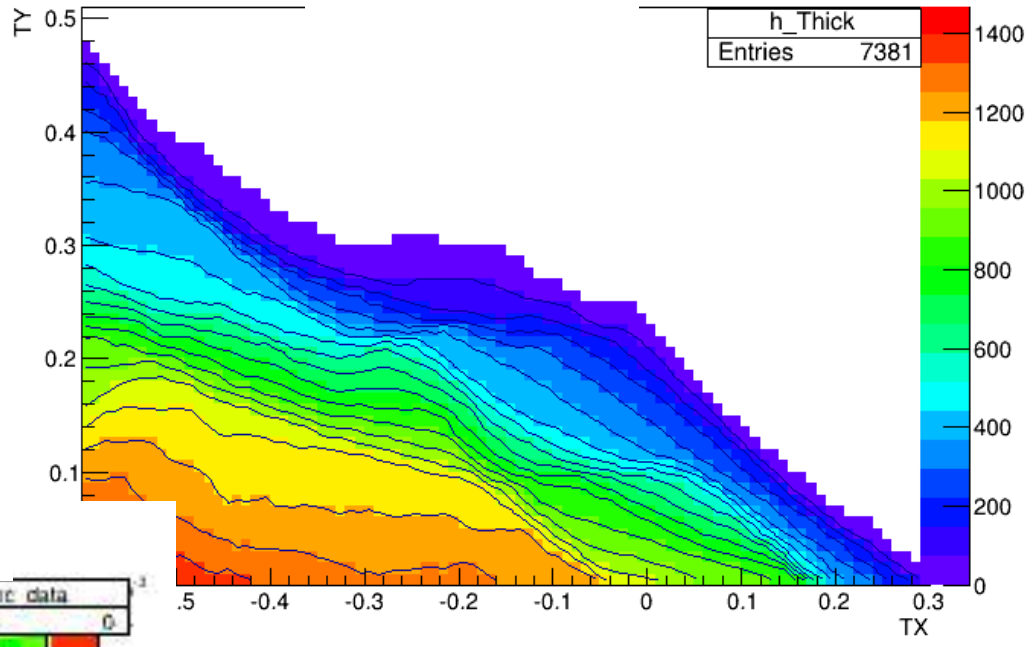
Temperature stabilization by rubber foam and expanded clay

A very first look inside the crater

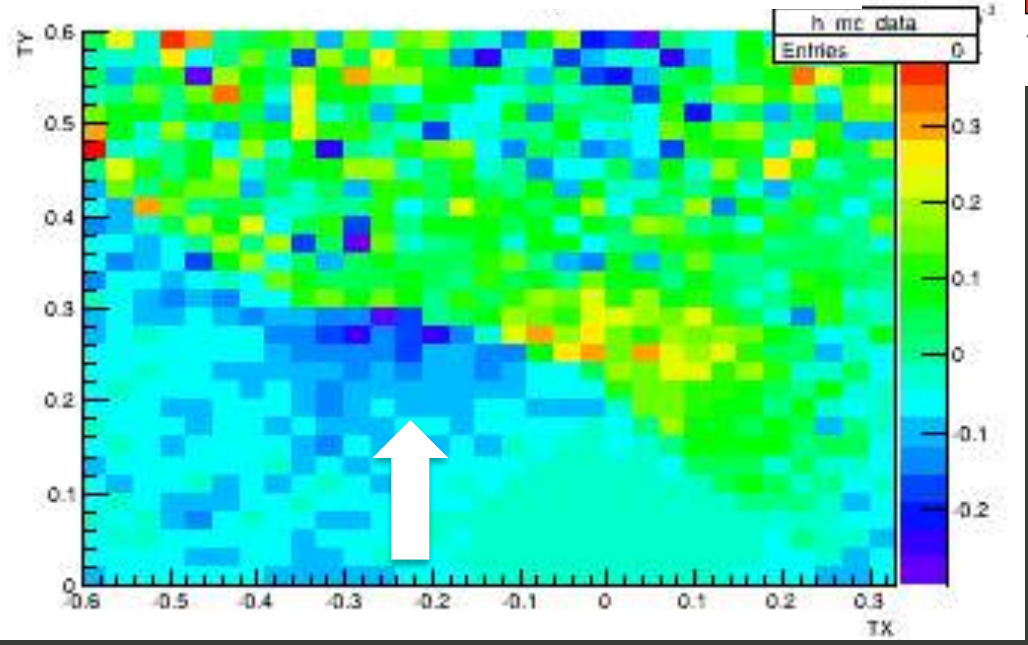
Comparison to simulation with constant rock density

(partial data)

Rock thickness



Data subtracted from simulation

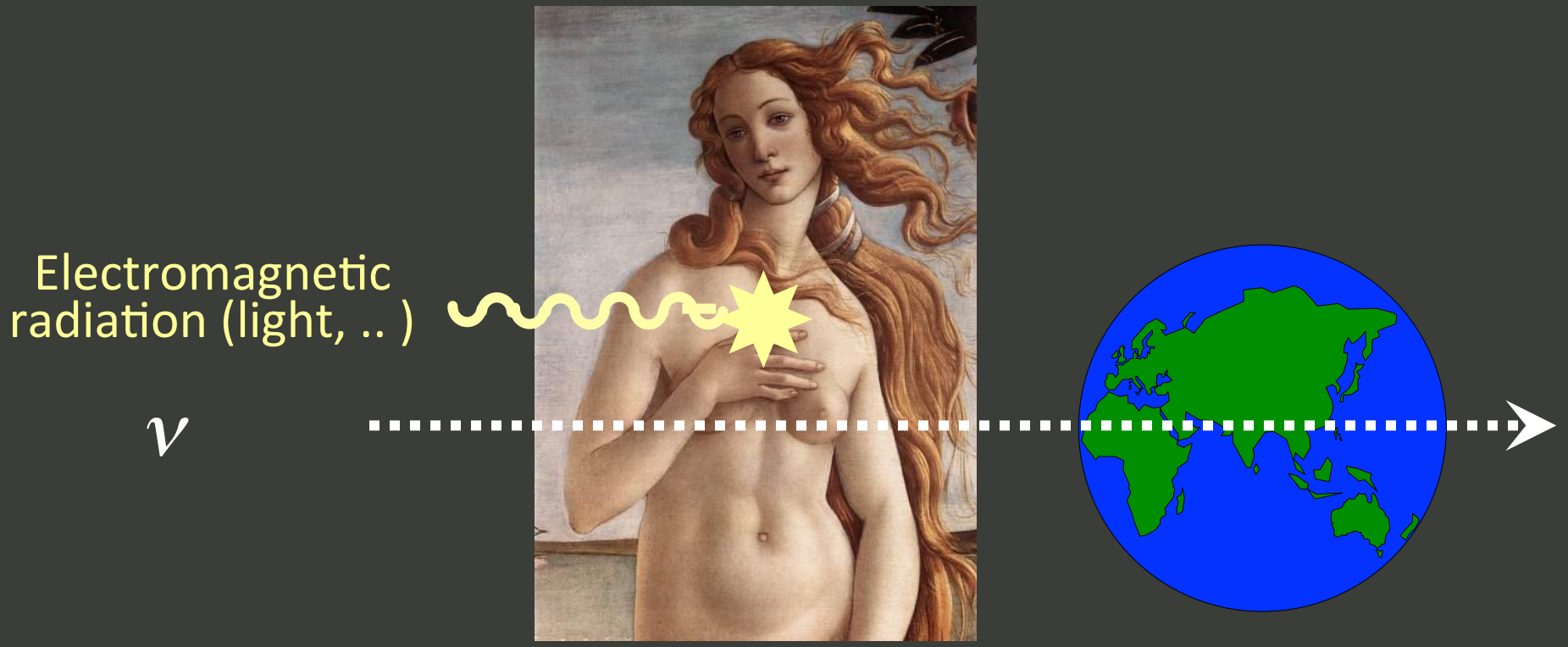


Some data excess in the crater region could be a sign of a structure with lower density

More work and full data needed

Neutrinos

Neutrinos (ν) are highly penetrating particles



Neutrinos: neutral, practically no interaction, no effect

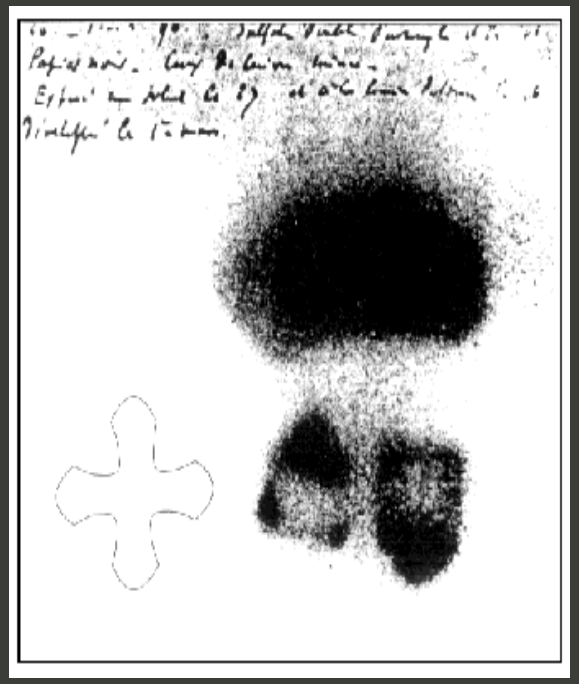
(traverse even Earth and Sun)

Messengers from inside the Sun and from far Cosmos

"Neutrino radiography" of the Earth

The neutrino adventure starts with basic Science

1896 Becquerel discovers natural "radioactivity"



An "accidental" discovery:
a photographic plate
placed in a dark drawer sees a mysterious
"radiation" emitted by Uranium salts

← *The "shadow" of a merit cross*

1930 Pauli's neutrino hypothesis as "desperate remedy" to save energy conservation in radioactive β-decay:

the electron is emitted together with an invisible (neutral) brother of zero mass

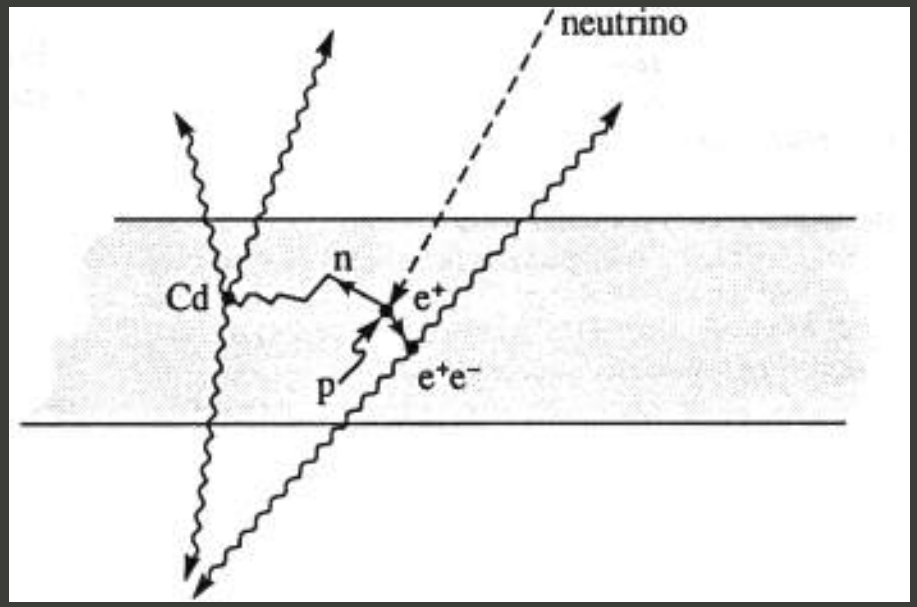
Neutrinos in Physics and Astrophysics

1933 Fermi: phenomenological theory of β-decay

1956 Reines and Cowan first observe neutrinos from nuclear reactor

Detection of inverse β-decay

Water + liquid scintillator (0.2 ton)

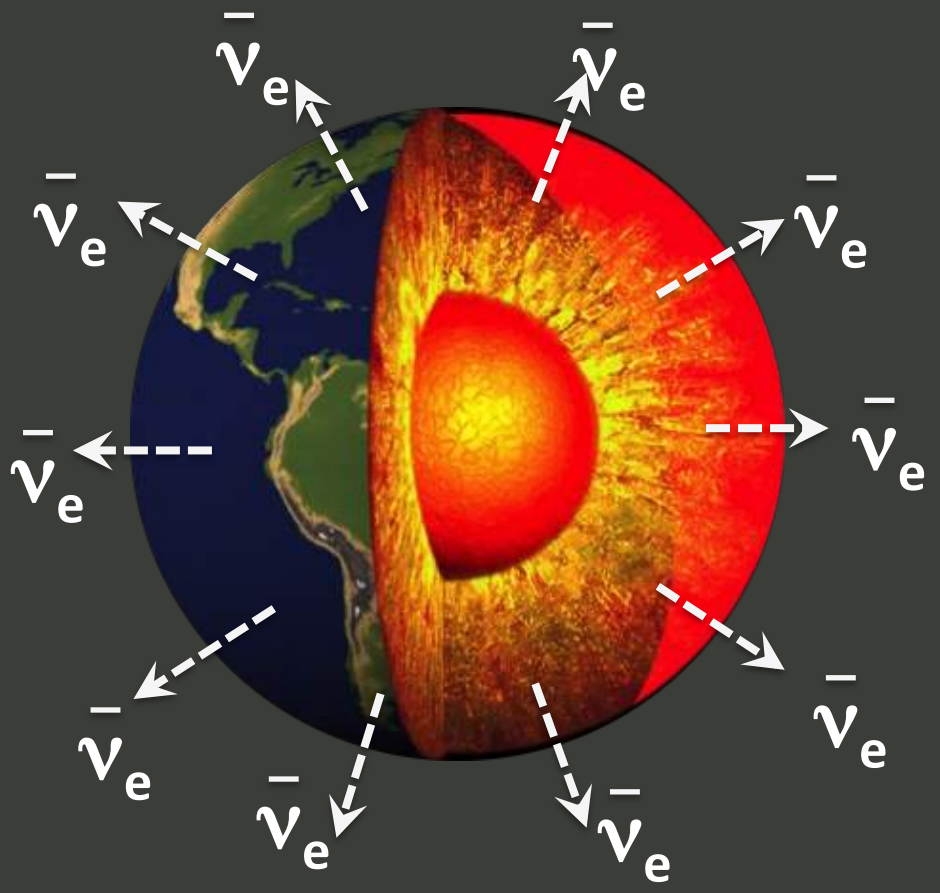


Prompt γs from e+ annihilation

Delayed coincidence with γs from n-capture in ^{108}Cd doping

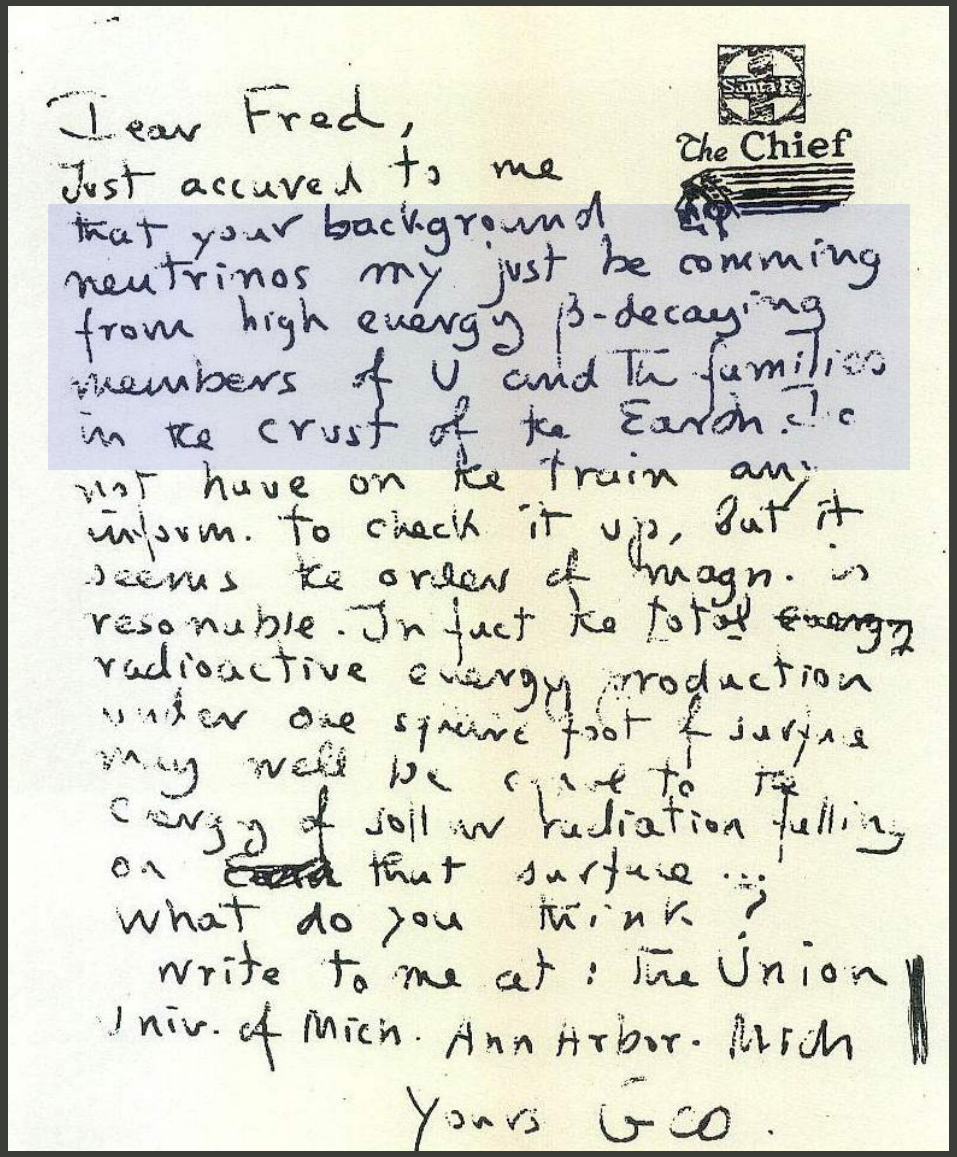
1968 Davis first observes neutrinos emitted in nuclear fusion reactions in the Sun (and stars)

Geo-neutrinos



Neutrinos and energy=heat from radioactive decays in the Earth ?

The first suggestion of geo-neutrinos:
a potential "background" in the discovery of neutrinos



Dear Fred,
Just occured to me
that your background
neutrinos my just be comming
from high energy β-decaying
members of U and Th families
in the crust of the Earth. I do
not have on the train any
inform. to check it up, but it
seems the order of magn. is
reasonable. In fact the total energy
radioactive energy production
under one square foot of surface
may well be equal to the
energy of soft UV radiation falling
on ~~Earth~~ that surface ...
What do you think?
write to me at: The Union
Univ. of Mich. Ann Arbor. Mich
Yours GCO.

G. Gamow (1904-1968)

George Gamow (Georgiy Gamov)
Letter to F. Reines (1953)

Dear Fred,
... your background neutrinos may just be coming from high energy β-decaying members of U and Th families in the crust of the Earth ...

Ideas

G. Marx (1927-2002)

G. Eder (1929-2000)

G. Marx and **N. Menyhard**
Über die Perspektiven der Neutrino-Astronomie
Mitteilungen der Sternwarte Budapest 48 (1960)

G. Eder: *Terrestrial neutrinos*, Nucl. Phys. 78 (1966)

Arguments are given for a remarkable abundance of radioactive elements within the Earth. Methods are discussed in order to measure this abundance by neutrino experiments.

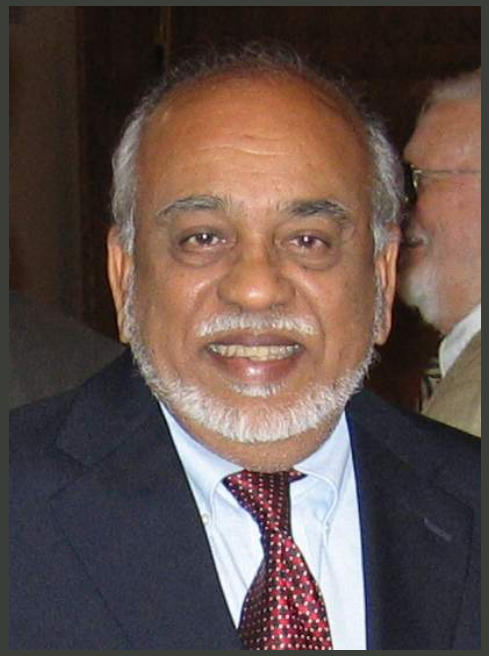
G. Marx: *Geophysics by neutrinos*
Czechoslovak Journal of Physics B 19 (1969)

… Searching the Sun with a neutrino telescope is well under way [Davies et al. 1968].

The present paper is concentrated on the second important task of neutrino physics: the Earth ….

……
……

Practical proposal



R. Raghavan(1937-2011)

R. Raghavan et al.

Measuring the global radioactivity in the earth by multi-detector antineutrino spectroscopy

Phys. Rev. Lett. 80 (1998)

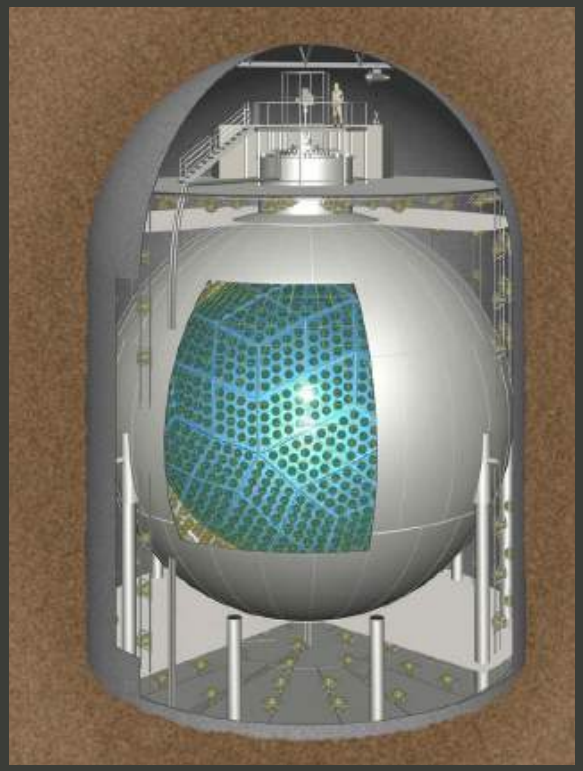
We show that electron antineutrino spectroscopy in upcoming detectors in Italy and Japan can be used to measure the separate global abundances of ^{238}U and ^{232}Th, thus ~ 90% of the radiogenic heat in the Earth.

Exploiting the unique advantage of their contrasting geological locations, they may also probe differences in U,Th areal densities in the continental and oceanic crusts and the mantle. ….

From Reines-Cowan's detector to present

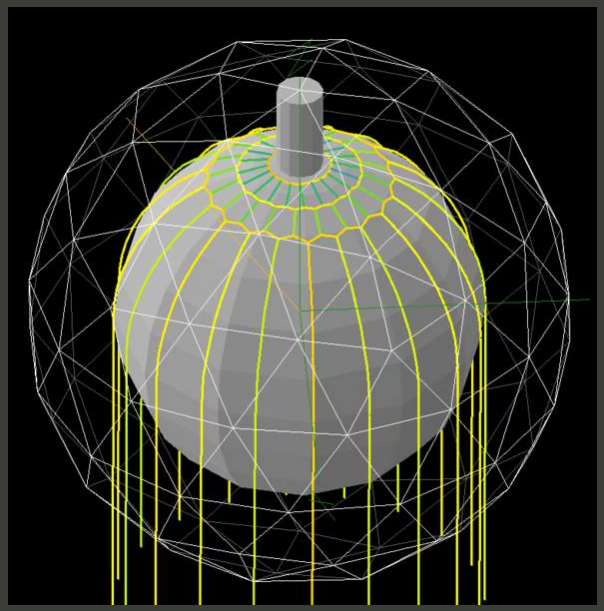
low threshold - low noise (radiopurity, underground) - high space resolution Liquid Scintillator neutrino detectors

KamLAND
1900 PMTs, 1 kt
> 2002

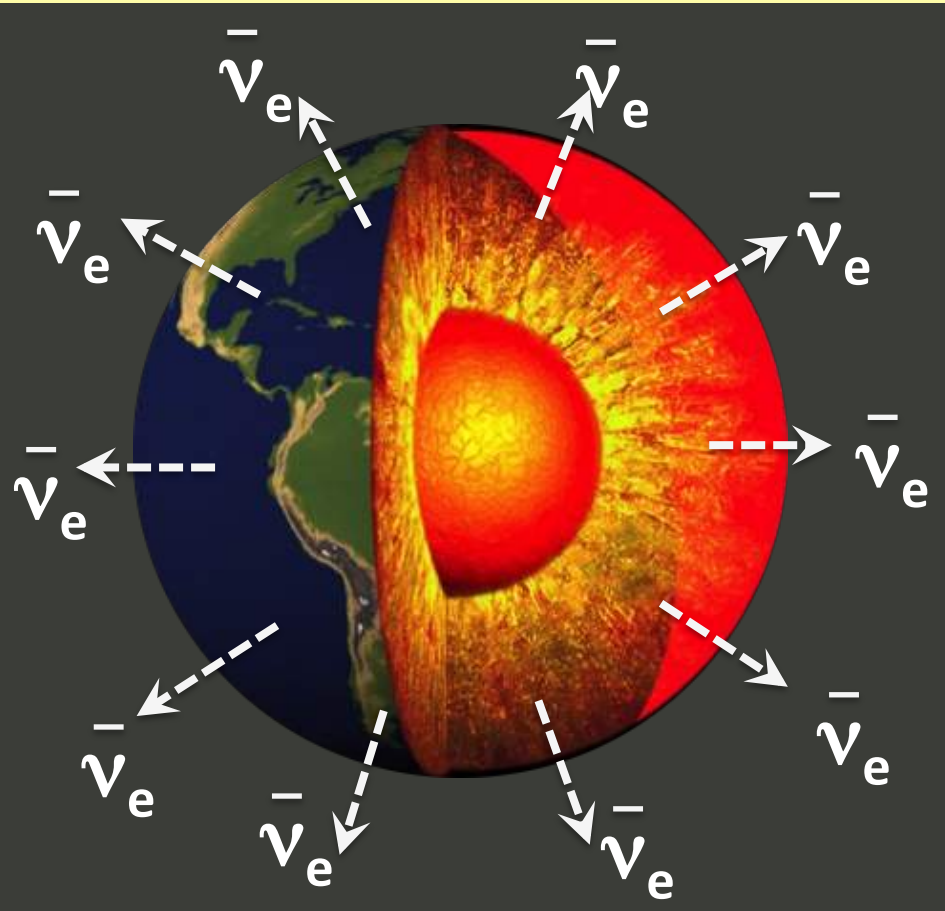


Borexino
2200 PMTs, 0.3 kt
> 2007

SNO+
10000 PMTs, 0.6 kt
> 2014



Geo-neutrinos detected!



2005 KamLAND: first geo-neutrinos

2010 Borexino: signal with low background from nuclear reactors

2011 Signal leaves room for primordial heat

2013 Combined analysis: Mantle signal

THE BACKGROUND
feared by Gamow for neutrino detection in Reines-Cowan experiment

THE SIGNAL
for Earth studies!

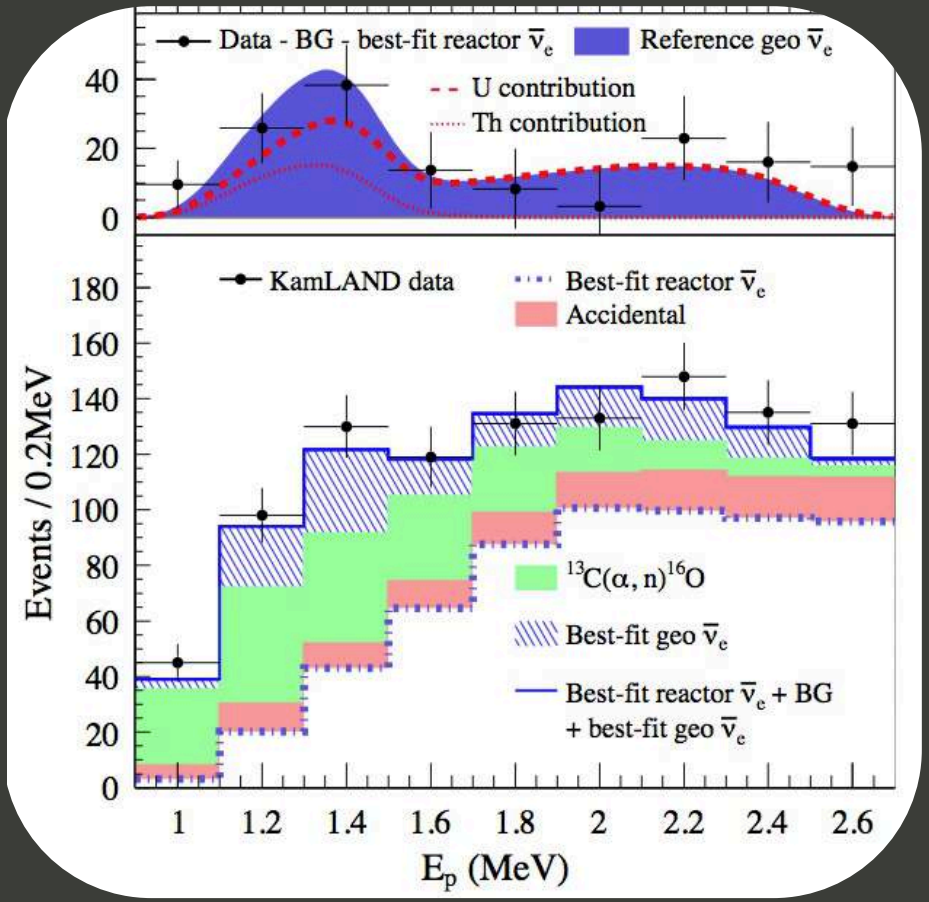
With view confined to basic physics the usual saying is

"The discovery of today is the background of tomorrow"

Geo-neutrinos 2013

KamLAND

Gando et al 2013

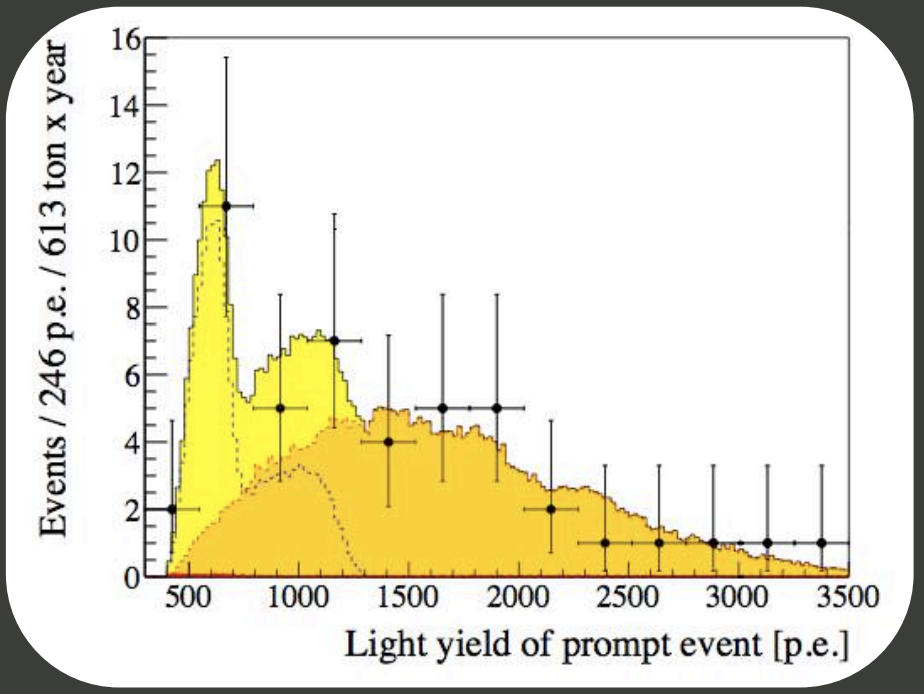


$N_{geo} = (116^{+28}_{-27})$

(large b.g. from reactors)

Borexino

Bellini et al 2013



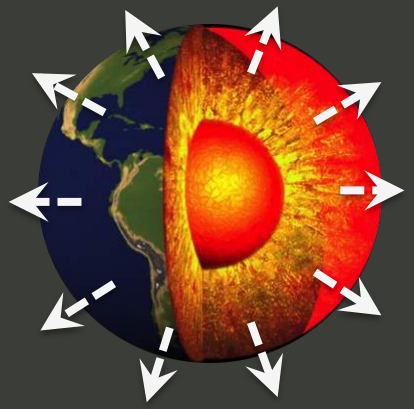
$N_{geo} = (14.3 \pm 4.4)$

$N_{rea} = (31.2\ ^{+7.0}_{-6.1})$

Geo-neutrinos from Earth Mantle
(combined analysis Borexino – KamLand)

$$\text{Signal}_{geo} = S(\text{Crust}) + S(\text{Mantle}) = 38.3\ ^{+10.3}_{-9.9}\ \text{TNU}$$

By subtracting estimated signal from Crust



Signal(Mantle) = (14.1 ± 8.1) TNU

1 Terrestrial Neutrino Unit (TNU) = number of events detected during one year with a target of 10^{32} protons (~ 1 kton of liquid scintillator)

Where the Earth's heat come from?

(even children can ask such a question)

J.-M. Folon (1934-2005)

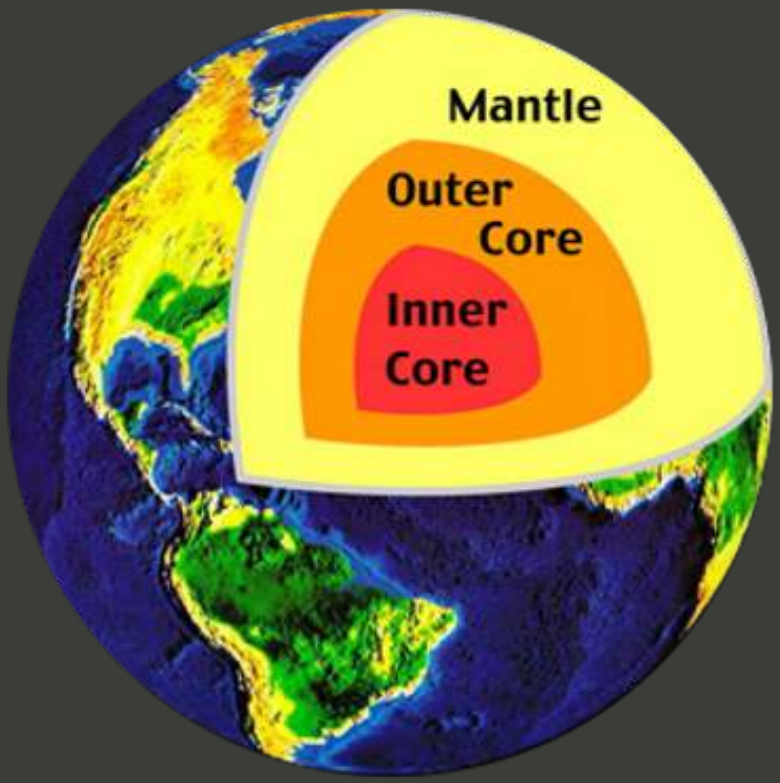
"Radiogenic" heat comes from the energy delivered in radioactive nuclear decays (mainly U and Th)

But insufficient to explain the total heat from Earth (volcanoes, …)

↓

Need of substantial but not dominant contribution from Earth's primordial heat supply or other source

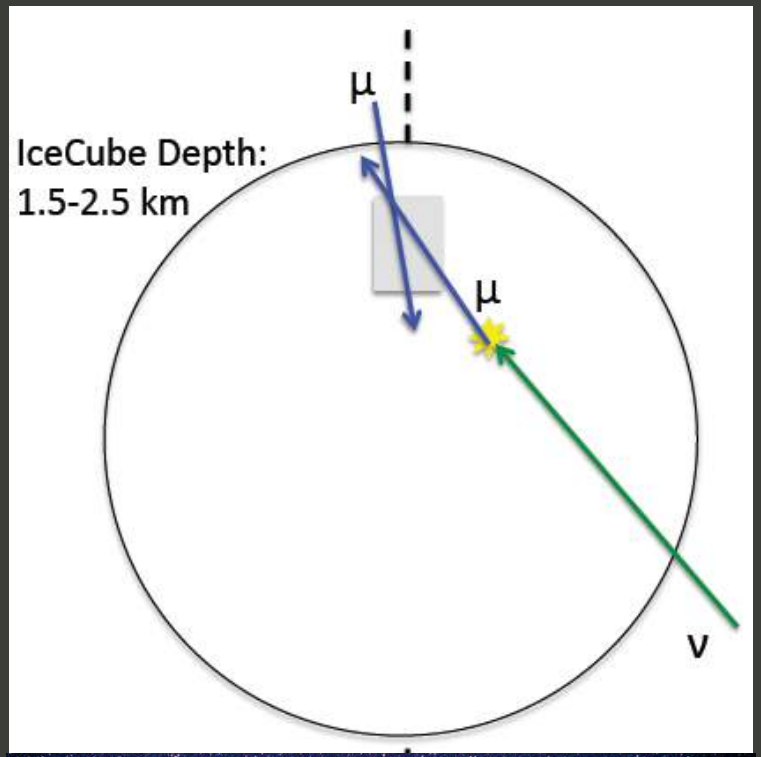
High energy neutrinos to explore the Earth's core



A mystery !

Basic Science: “Neutrino astronomy”

Other messengers (light, …) suffer absorption or deviation



“Neutrino telescope” sees Čerenkov light produced by muons in water or ice

↑

Neutrinos interacting close to surface generate muons reaching detector: Earth as converter

↑

Neutrinos from far Cosmos at Antipodes go through Earth

“Neutrino Telescope” in deep Anctartic ice

Photo-Multiplier tubes see the Čerenkov light

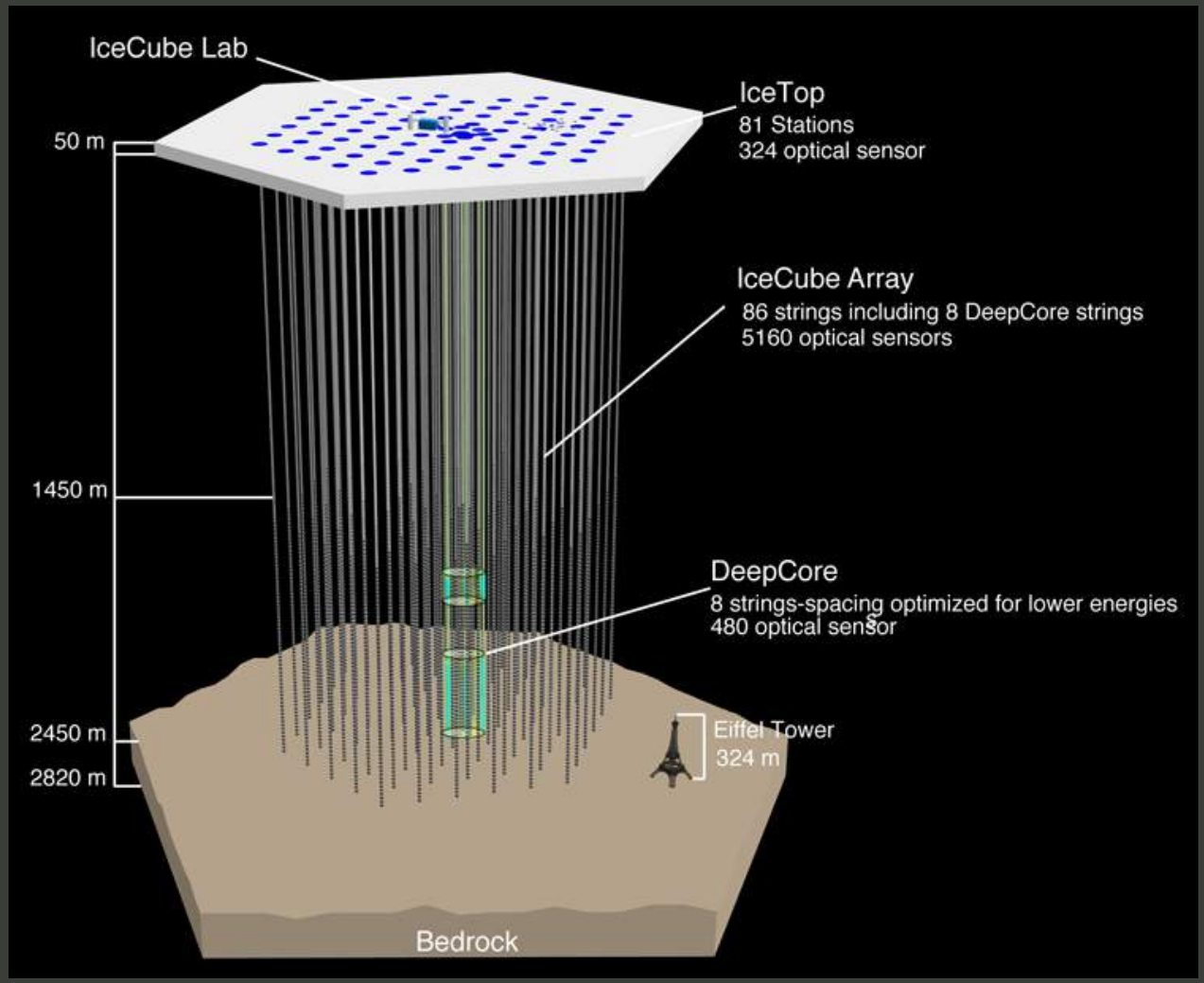
Strings of PM tubes

Array of PM Strings

5160 PM tubes

1450-2450 m depth

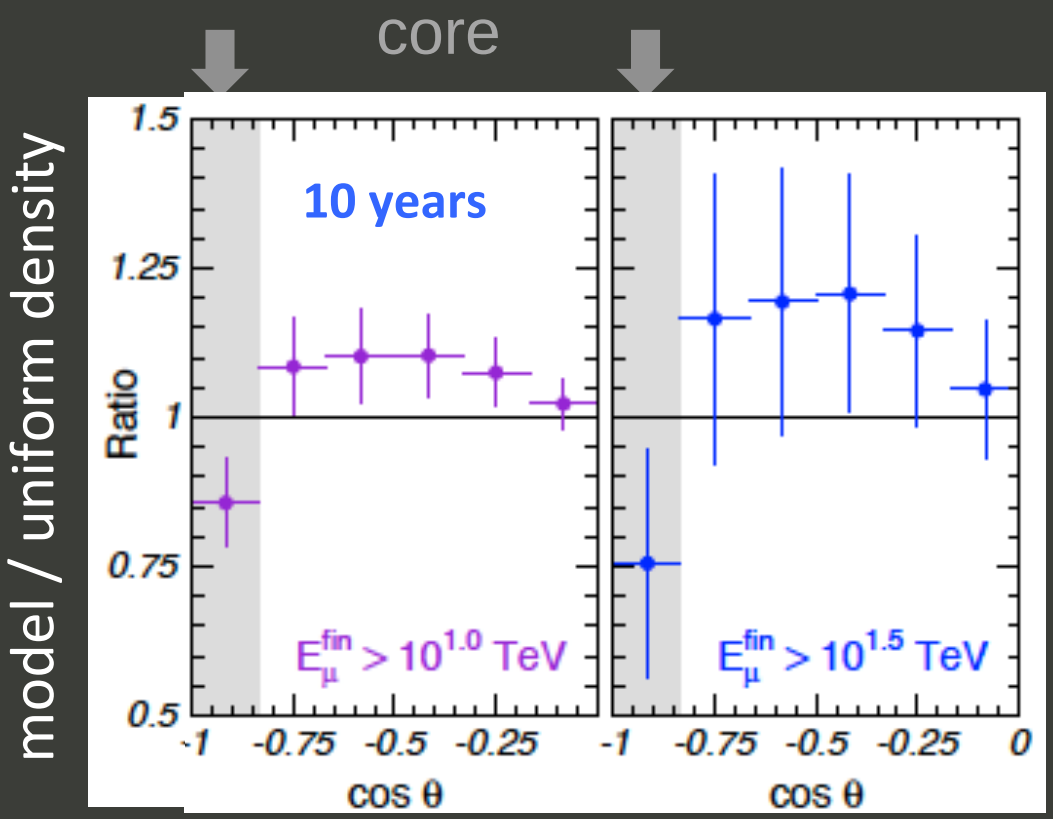
! Km2 area



*"**Background**" (for neutrino astronomy)*
neutrinos produced by cosmic rays in the Atmosphere at the Antipodes

"Signal"
for Neutrino Radiography of the Earth !

Direct measurement of Earth's core matter density from absorption of atmospheric neutrinos of very high energy (larger cross-section)



Calculations with current model (PREM) for IceCube, showing detectable deviation with respect to uniform density

Radiography of the Earth' core and mantle with Atmospheric neutrinos

(Gonzalez-Garcia et al., Phys. Rev. Lett. 2008)

A challenge/dream: Earth's core average chemical composition from neutrino oscillation?

An application of neutrino oscillations: Study of the Earth's core composition using atmospheric neutrinos
(A. Taketa, H.K.M. Tanaka and C. Rott, 3rd Hyper-Kamiokande Meeting, 21-22 June 2013)

Atoms have electrons and not muons
→ electron neutrinos have additional interactions in matter

Neutrino oscillation in matter depends of electron density

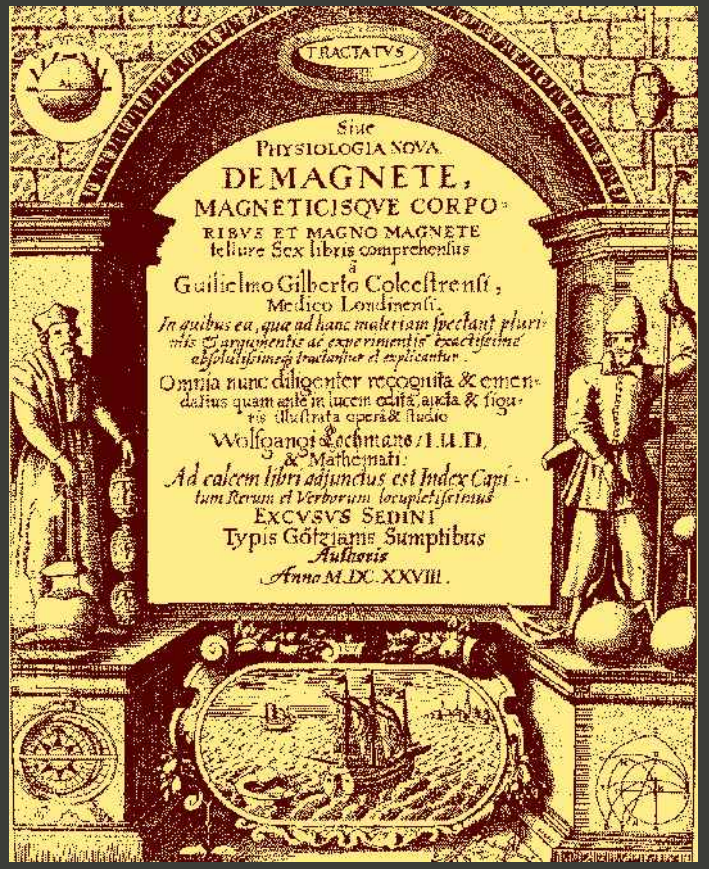
↓

Average chemical (Z/A) composition

by combining matter (conventlonal meas. and neutrinos) and electron density data

A great mystery of Earth's Science

Mostly Fe for generation of geomagnetic field?
(Gilbert 1600: permanent magnet; Elsasser 1946: dynamo)
…… ?



ABSTRACT OF THE TALK

Why basic Science?

The visible driving force is the desire for knowledge that characterizes the human species and has led to our way of living in this World

What muons and neutrinos can do for Earth studies provides a beautiful example of a much broader motivation and shows the richness of Science as a whole

The spirit of this talk as from its abstract is ….

Why basic Science?

An answer through “Muon and neutrinos for Earth studies”

NIHONBASHI BRIDGE AT EDO TOWARD TOKKAIDO ROAD AND MT. FUJI (1863)

Utagawa Sadahide - Near end of Tokugawa period (1603-1868)

Even more fundamental questions

Why Science specially now?
What can scientists do for Science Education?

A project: “Science and School”

The World scenario is changing

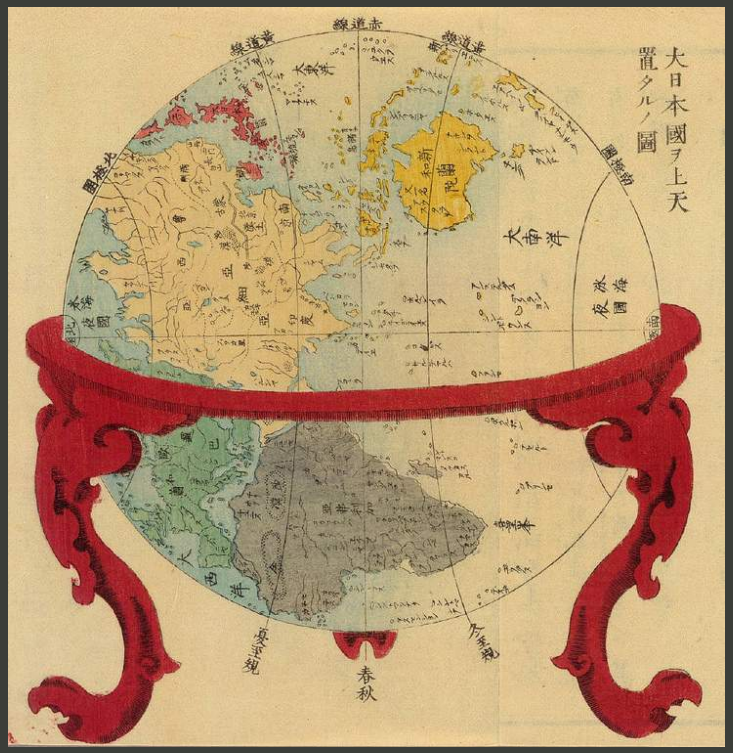
New countries strongly emerging

For a number of "old" countries:

Economic hence social difficulties

Expensive manpower

Emigration of industrial production



Hashimoto Gyokuran (between 1856 and 1868)

Western cartography in the traditional woodprint style: Image of a changing scenario

http://assemblyman-eph.blogspot.it/2009/07/japanese-historical-world-maps.html

To remain among leading countries in a changing World

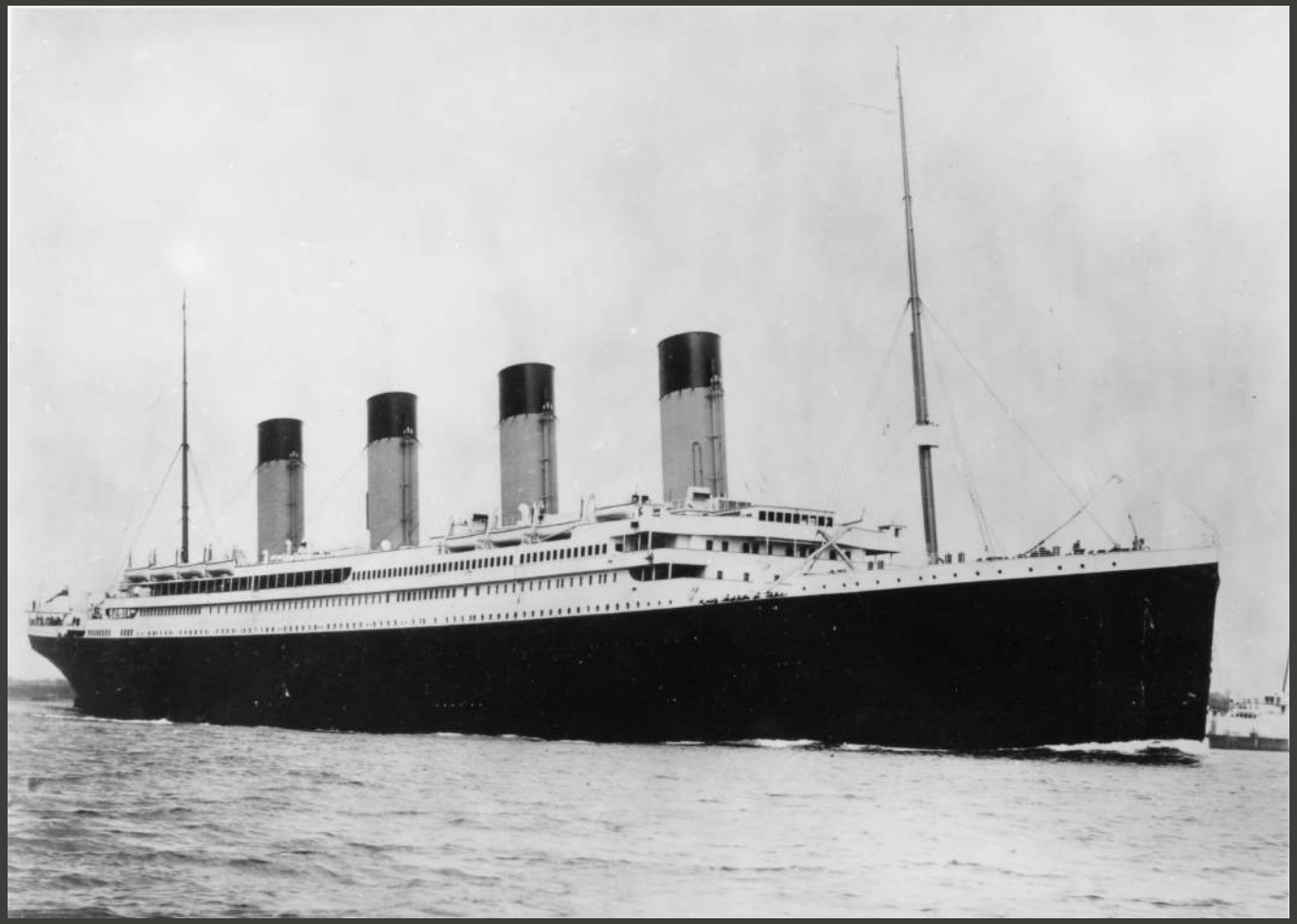
Science and Technology: THE resource of "old" countries

↓

Invest in Education

Which view of Education ?

Is the concept of separate educational compartments still appropriate?



Titanic (1912)

Designed to be unsinkable thanks to watertight compartments

The emerging vision of Education

- *The quality of the educational process comes from all stages:global care*
- *Inquiry Based Science Education (IBSE): "learning by doing" already at Primary School*
- *High School students must be trained in research*
- *Learn at School basics of modern Science: may need updating teachers' knowledge*
- *Train High School students to communication and international life*

No separate compartments

Needs for Education

- **Support by:**

  University/research scientists

  Public Institutions

"Science and School"

An educational project open to collaboration
Students, teacher and researchers on the same floor

Experiments at School

Experience in research Labs

Visit research Labs

Discussion Forum

Thematic essays

Training for Olympics

Ask an expert

Science and Humanities, Society, Sport, …

- Main Website: English + Italian
- Quasi-mirror Website: Japanese
- international experience:
  SKYSEF Forum @ Shizuoka Kita High School

SCIENCE and SCHOOL - SCIENZA e SCUOLA

科学と学校

A real and virtual Forum: together to advance

Un Forum reale e virtuale: insieme per crescere

Inviare gli articoli a scienzaescuola@gmail.com

La pagina Facebook è un'estensione del Sito web: raccomandiamo di visitarla e di condividerla

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Hanno parlato di noi
Comune di Napoli
INFN
Città della Scienza
Scienzapertutti
Youlaurea
Orizzontescuola

unisciti a noi

Mi piace 315

Siti amici (pagina con link)

SCUOLE SUPERIORI
Calamandrei (Napoli)
Cantone (Pomigliano d'Arco)
Comenio (Napoli)
Di Giacomo (S. Seb. Vesuvio)
Don Milani (Gragnano)
Imbriani (Pomigliano d'Arco)
Galilei (Napoli)
Gandhi (Napoli)
Gatto (Agropoli)
Mercalli (Napoli)
Salvemini (Sorrento)
Torricelli (Somma Vesuviana)
Vico (Napoli)
Vittorio Emanuele II (Napoli)

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Sciencestorming
Scienza under 18 Mantova
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SITEMAP

FORUM

ScienzaeScuola
Curated by ScienzaeScuola

Simmetrie: dai solidi platonici...

Scoop.it!

http://scienzaescuola.fisica.unina.it/

"The mind is not a vessel to be filled, but wood that needs igniting"

Plutarch (ca. 46-127 aC)

On listening to lectures