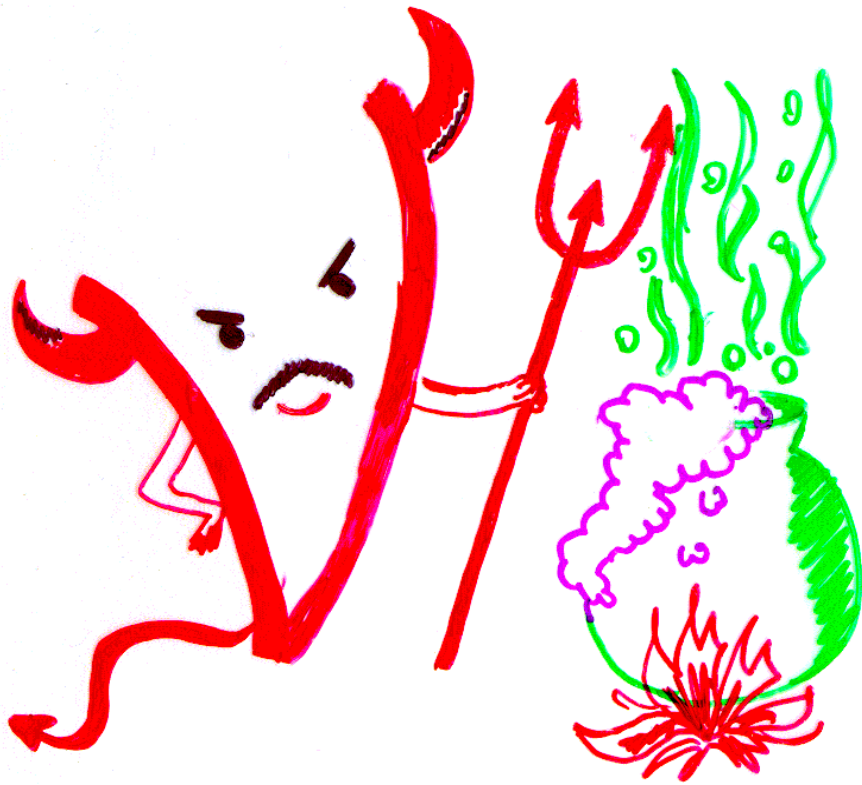


Why neutrinos ?



- *Prehistory*
- *History*
- *No neutrinos, no life*
- *Fascinating mysteries*
- *Earth and Cosmos*

Neutrino ✓

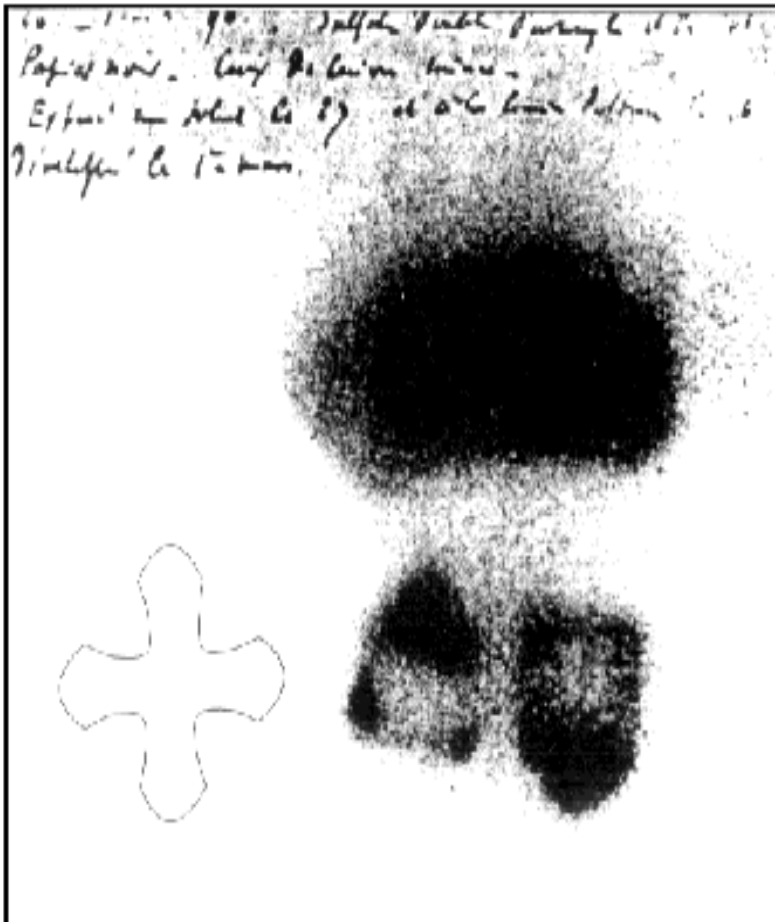
as seen by Laura Strolin

Paolo Strolin, March 2013

The primeval times

1896 Becquerel

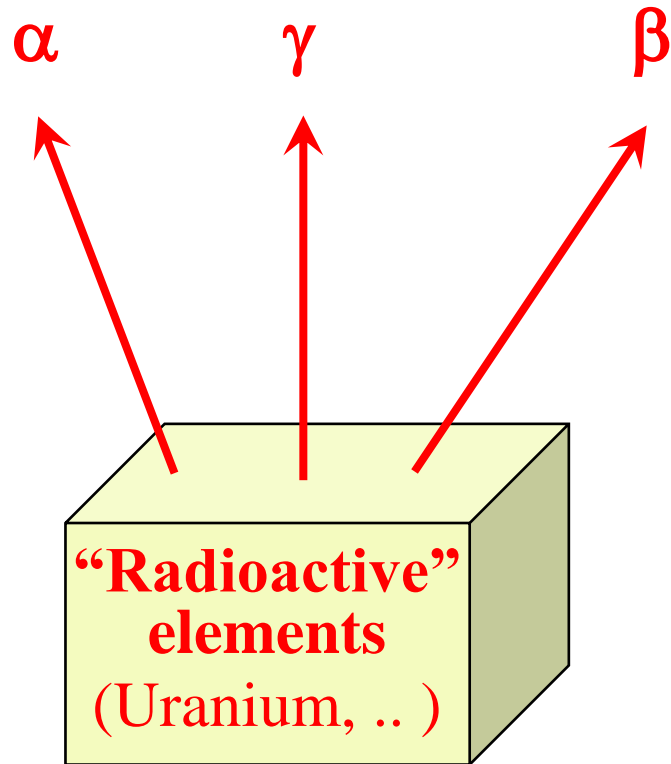
Discovery (accidental) of natural "radioactivity"



A photographic plate placed in a dark drawer sees a mysterious "radiation" emitted by Uranium salts

← *The "shadow" of a merit cross*

Beginning to understand



1899 Rutherford

Different rays α , β , γ

1903 Rutherford and Soddy

*“Magic” transmutation of
chemical elements by
“radioactive decay” of atomic
nuclei*

The transmutation of chemical elements becomes reality

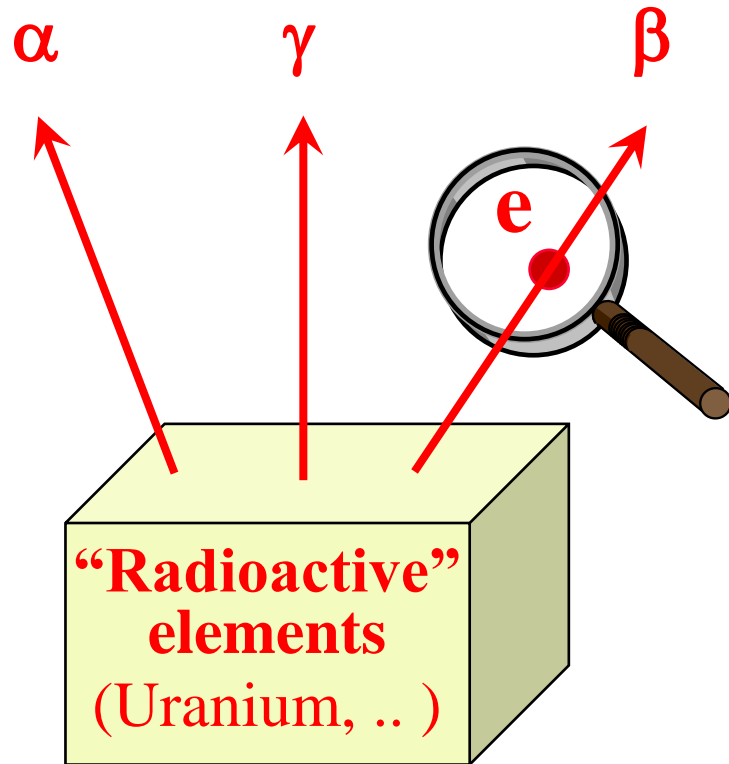
*The dream of alchemists:
transform Iron into Gold !*

*“The laboratory of the alchemist”
(detail)*

*Jan Van der Straet (1523-1605)
Palazzo Vecchio (Firenze)*



Electrons emitted in “ β decays”



1899 Rutherford

Different rays α , β , γ

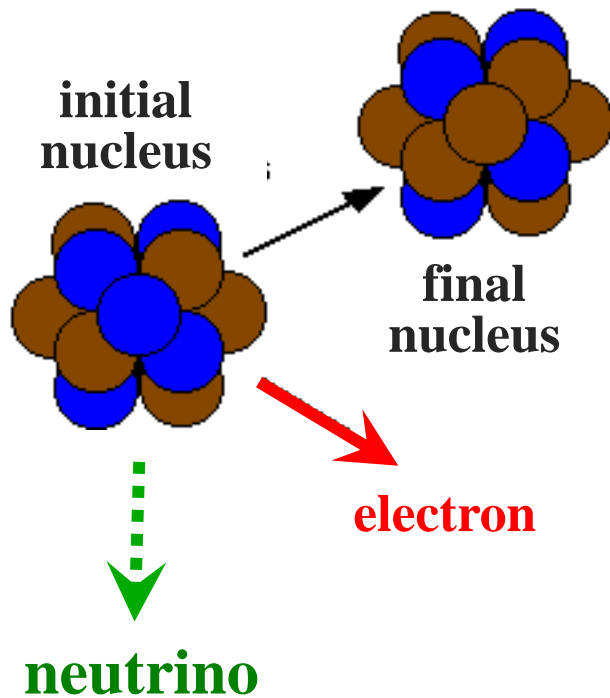
1903 Rutherford and Soddy

“Magic” transmutation of chemical elements by “radioactive decay” of atomic nuclei

1909 Bucherer

β rays are electrons

Mystery: missing energy in β decay ?



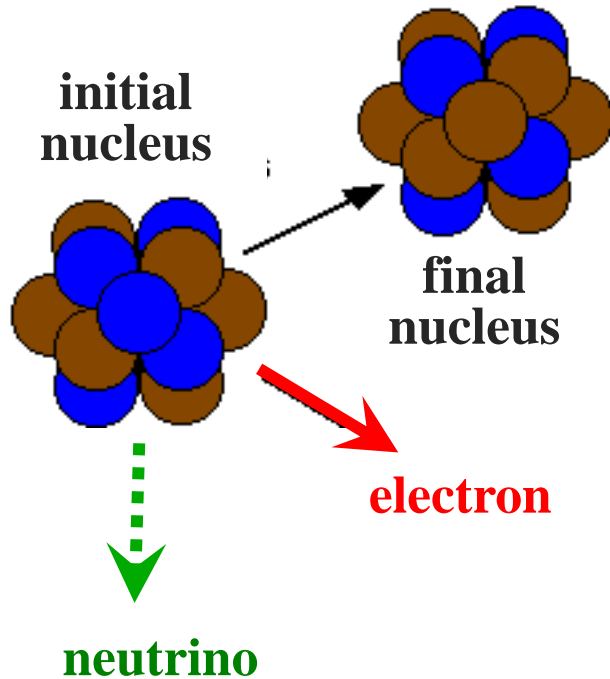
stolen energy ?

*electron energy less than
available energy = $(M_{initial} - M_{final}) c^2$*

1930 Pauli: neutrino hypothesis

A massless neutral (invisible) particle is also emitted

The “Weak Interaction”



The β decay
is a rare process:
very few nuclei decay
out of an enormous number
(Avogadro's number = 6×10^{23} nuclei/mole)



Induced by a new interaction called “Weak”

(“interactions” generate “forces” on each single body)

“Creation” of particles by radioactive decays: *violation of “nothing is created, nothing is destroyed” ?*

Einstein (1905)

A black and white photograph of the handwritten equation $E = mc^2$ on a piece of paper.

energy **matter**

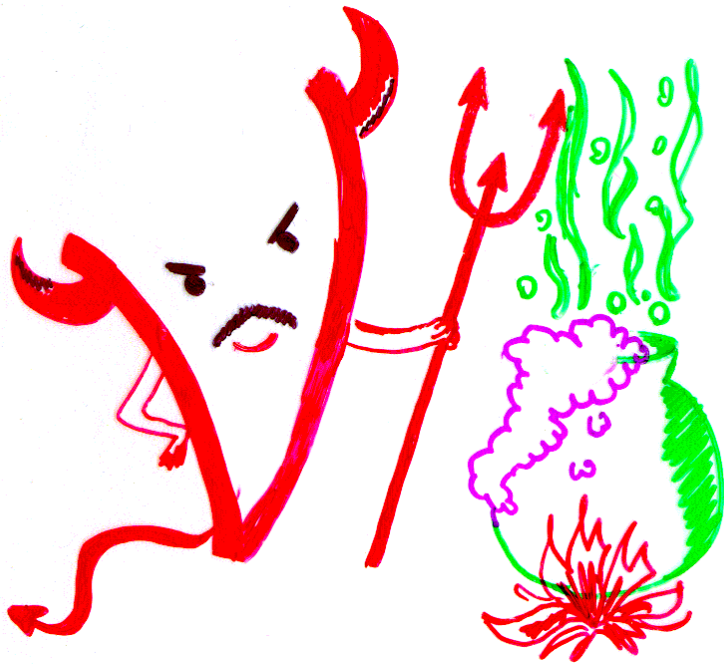
Discovery of anti-matter

Dirac Equation (1928); discovery of the positron (Anderson, 1932)



*Putting in balance energy and (anti)matter
"nothing is created, nothing is destroyed"*

The anti-neutrino comes on stage



Neutrino ν



anti-neutrino $\bar{\nu}$

A mystery: is it really a “different” particle ?

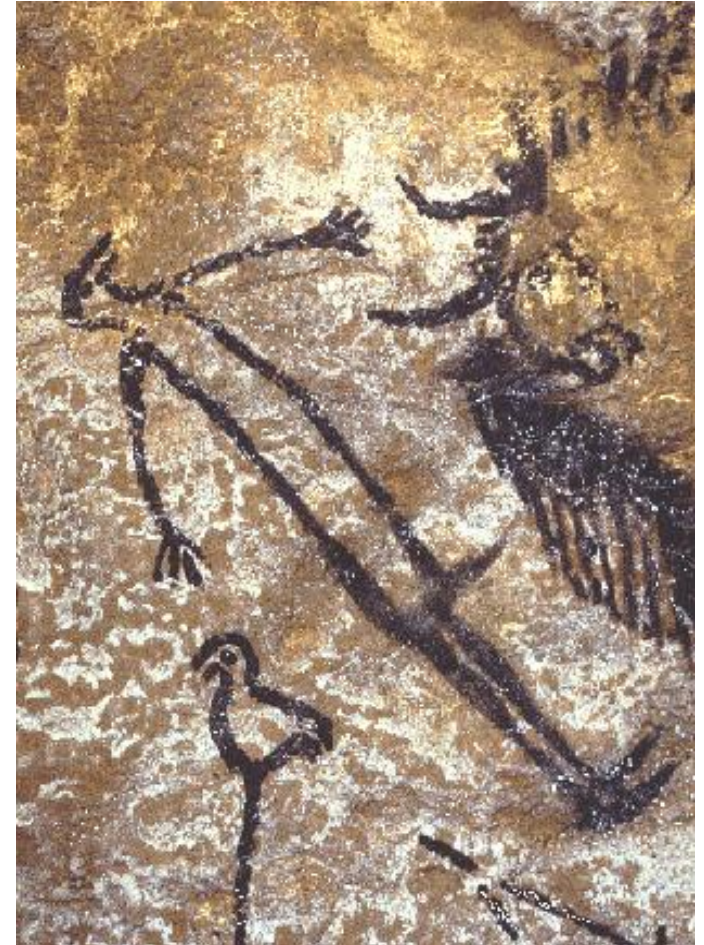
This was the "prehistory" of the neutrino

Information comes from images



Rouffignac (France)

Cave of a Hundred Mammoths
(geological epoch: Pleistocene)



Lascaux (France)

Man and "auroch" (ancestor of cattle)
(ca. 15,000 BC)

"History" begins with writing



*Sumerian cuneiform writing on tablet
(about 3 millennia BC)*

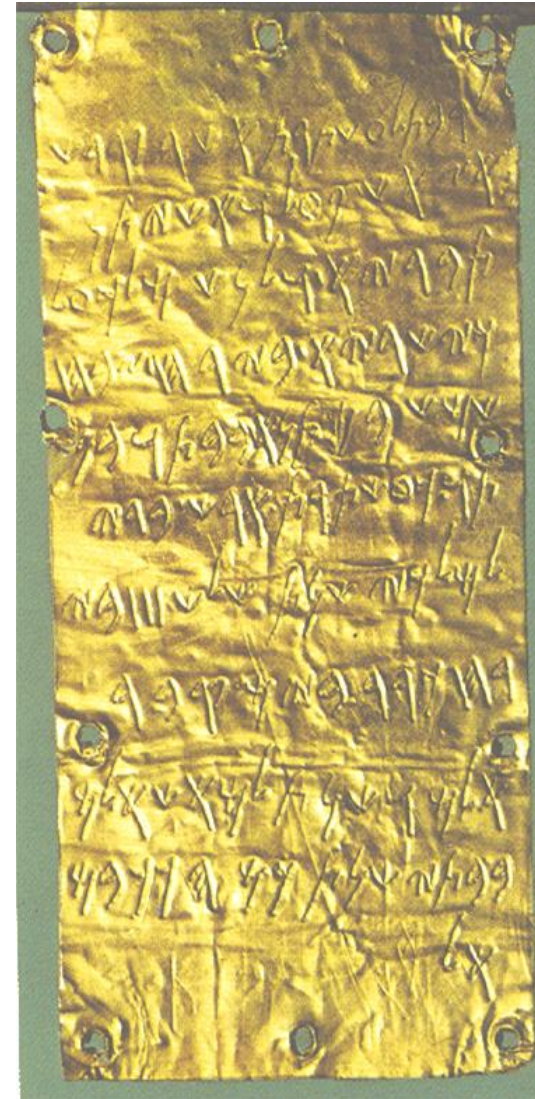
Use of abstract characters or
stylized symbols

Writing



*detailed and
quantitative
descriptions*

A great invention for practical
purposes: trade, treatises,
inventories ...

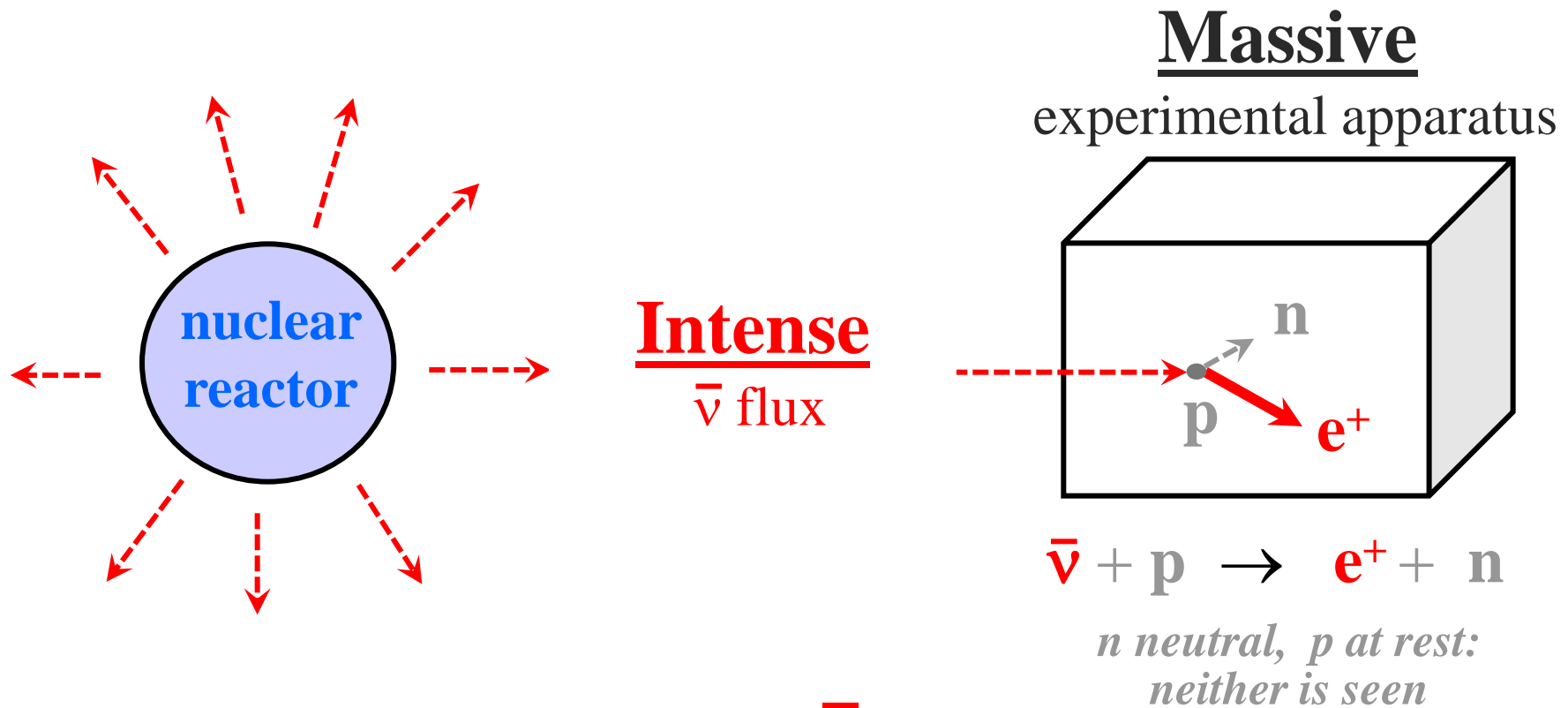


*Phoenician inscription on gold leaf
(Pyrgi-Italy, V-VI century BC)*

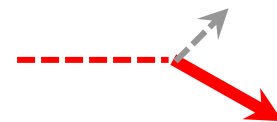
The neutrino starts writing in 1956:

“direct” observation through its “Weak Interactions”

Reines and Cowan (26 years after Pauli hypothesis), idea by Pontecorvo 1946



The "signature" of the neutrino
nothing visible enters, a positron exits



What for?

*Without
neutrinos, the
Sun would not
heat!*

No neutrinos
no life on
Earth

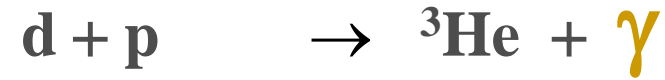
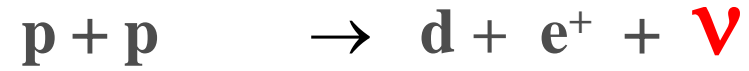


*Il Caravaggio (1573-1610)
Fruit basket (1590?), Galleria Ambrosiana (Milano)*

How the sun heats: nuclear reactions



● proton ● neutron



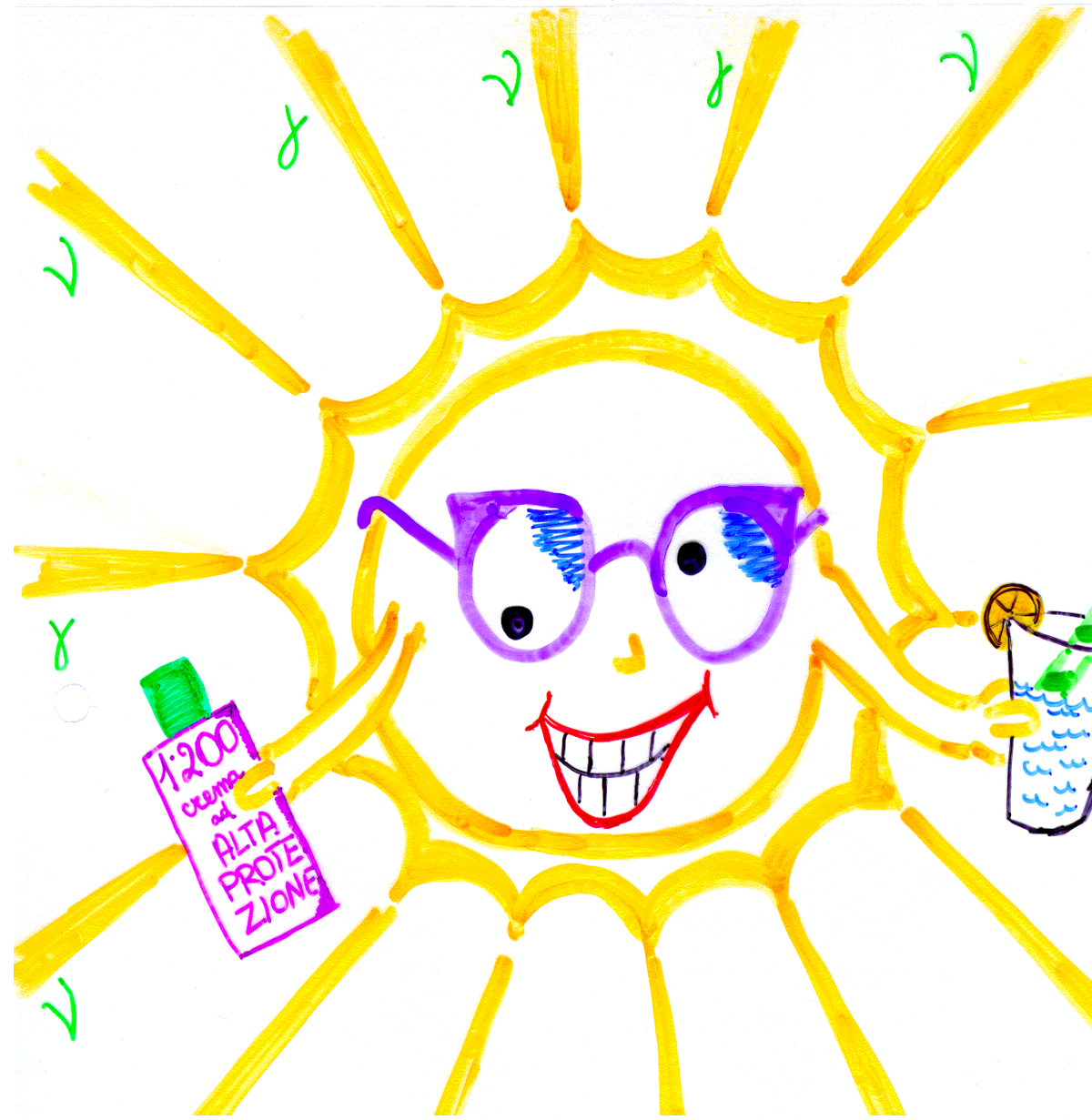
No neutrinos

No nuclear reactions

No light and heat, no life

light and heat

An incredible solar neutrino flux on Earth !

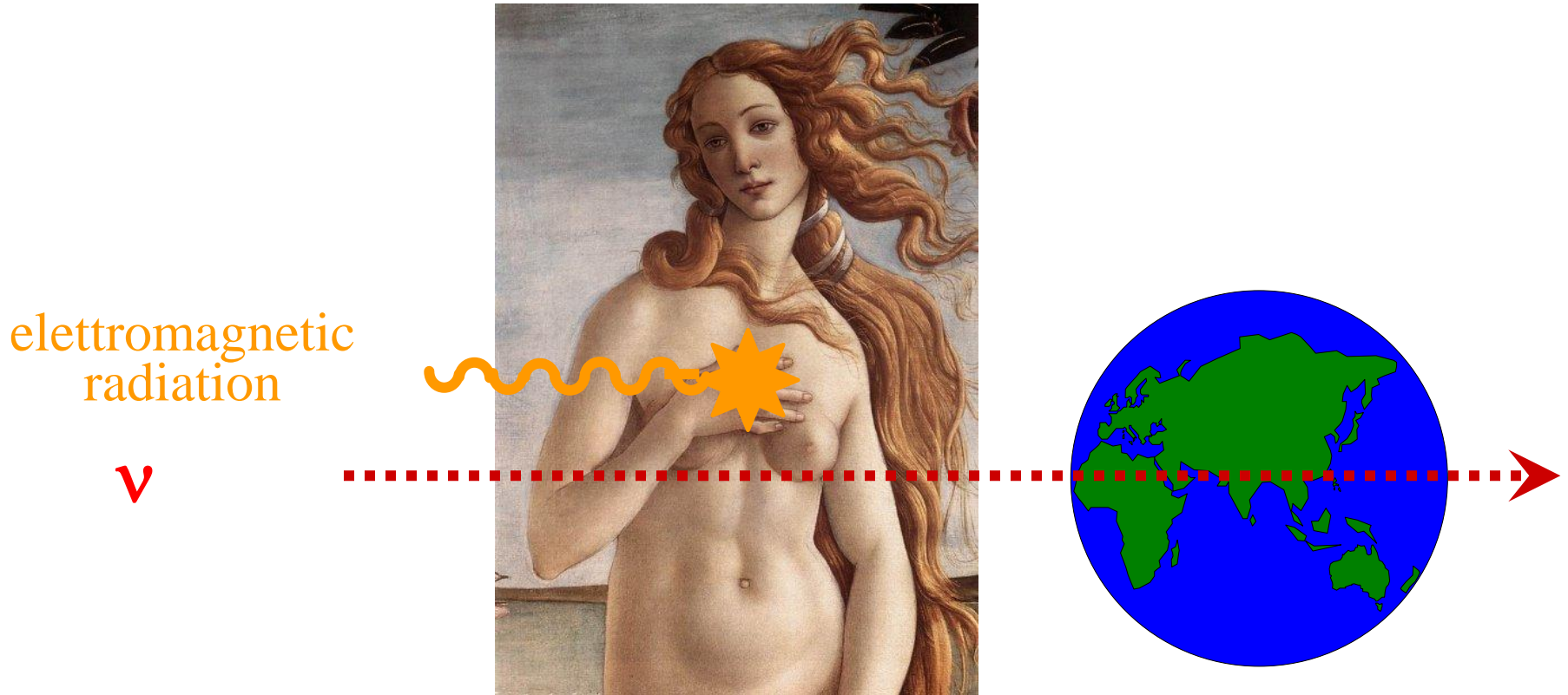


As intense as the
electro-magnetic
radiation (γ)
bringing light and
heat

*In a second
one hundred
billion neutrinos
through your nail*

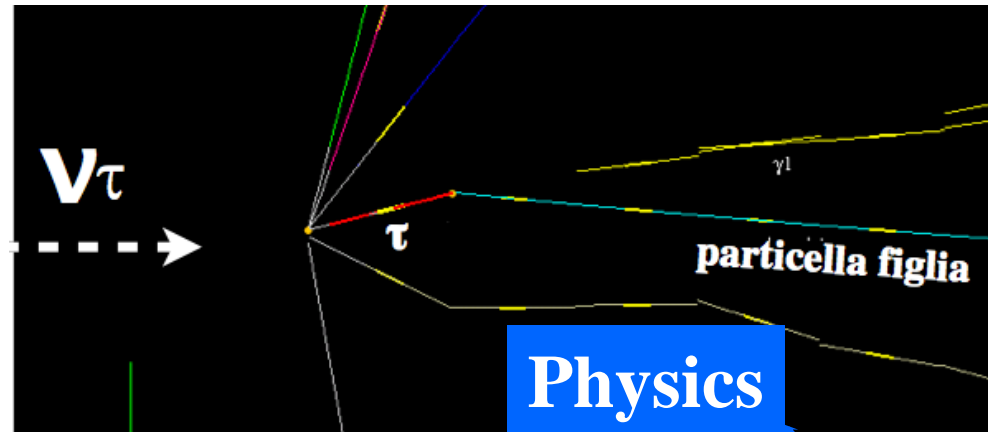
Why our body does not care about neutrinos ?

The electromagnetic radiation (IR, light, UV) interacts with our body and there deposits its energy (heat)

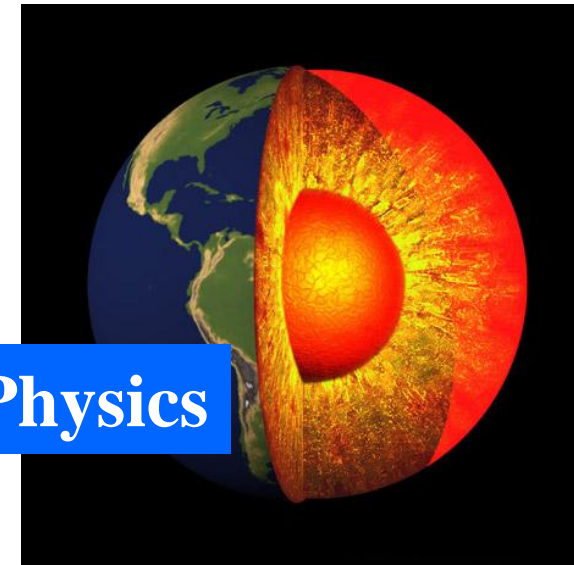


Neutrinos: no interaction, no effect
(pass even through the Earth!)

Neutrino. Earth and Cosmos



Physics



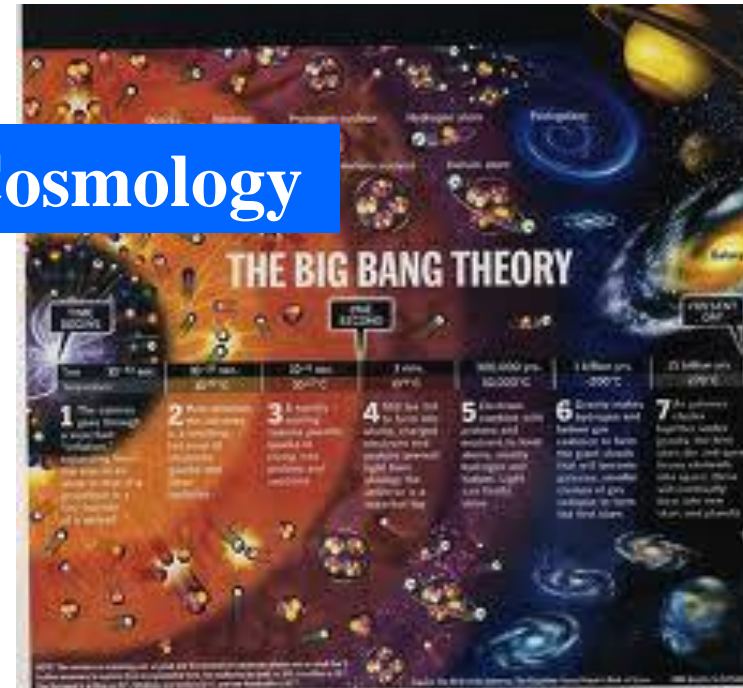
Earth Physics



Astrophysics

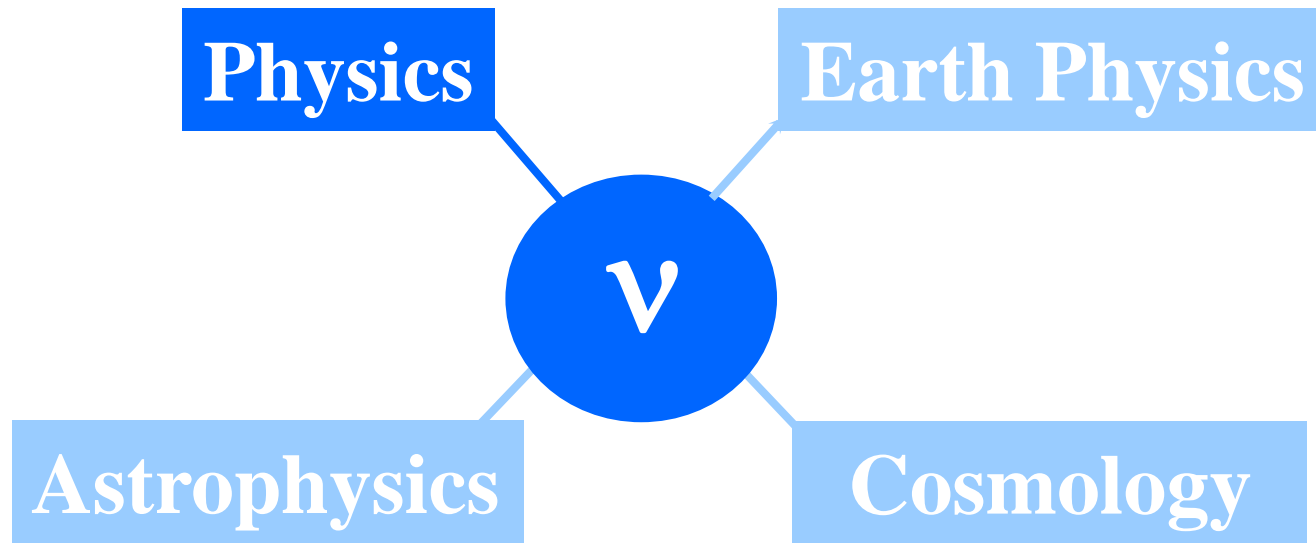


Cosmology

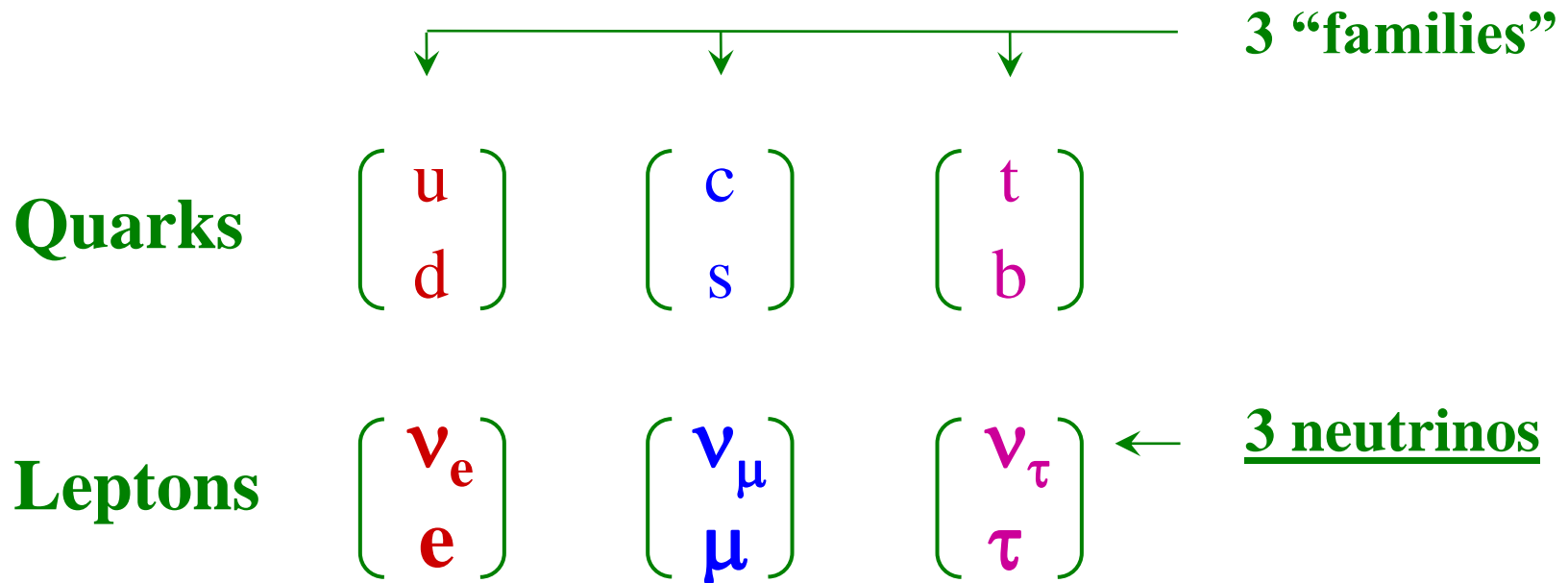


Some examples

Neutrinos and Physics



The “Elementary Particles”, today



The neutrino: a very special particle

Mass “assumed to be zero” until few years ago

Mysteries waiting for discovery

Very low probability of
interacting with matter



Very difficult experiments



Still fascinating
mysteries

Juan Miró (1893-1988)

*The beautiful bird revealing the
unknown to a pair of lovers*

Museum of Modern Art (New York)



Physical properties: many questions

electric charge

0

“spin” angular momentum

$1/2$

interaction with matter

“electro-weak”

mass

very small*: how much?

violation of “CP symmetry”

???

$\nu \neq \bar{\nu}$ (*Dirac*) or $\nu = \bar{\nu}$ (*Majorana*)

???

other properties

???

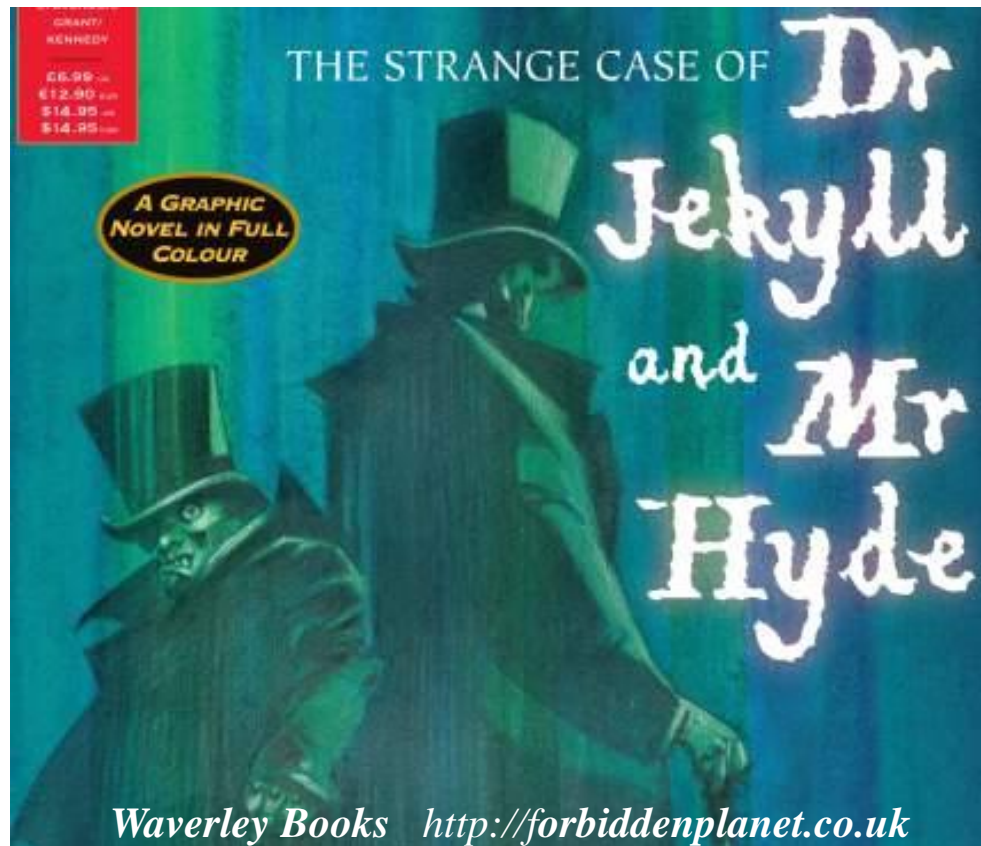
* *Recent discovery: neutrinos have non zero mass.
But in absolute scale, we only know that is less than
one billionth of that of the proton*

The key for the discovery of non-zero mass: see “neutrino oscillation”

Pontecorvo (1957); Maki, Nakagawa and Sakata (1962); Pontecorvo and Gribov (1969)

Requires: non-zero mass and two souls (called “eigenstates”)

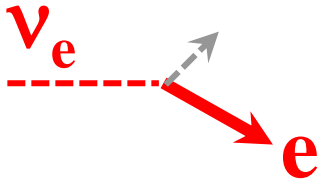
ν_1 ν_2 ν_3



ν_e ν_μ ν_τ

From the famous Stevenson's novel

Different souls (“eigenstates”) depending of circumstances (*Quantum Mechanics*)



Have birth and die as the usual $\nu_e \nu_\mu \nu_\tau$

- produced in association with $e \mu \tau$
- interacting with matter produce $e \mu \tau$

Mass does not need to be defined

ν_e electron neutrino

ν_μ muon neutrino

ν_τ tau neutrino



$\nu_1 \nu_2 \nu_3$
are mixtures of

$\nu_e \nu_\mu \nu_\tau$

Travel incognito with **definite mass** as $\nu_1 \nu_2 \nu_3$
required by the laws of motion



The magical neutrinos can change identity: “oscillate”!

(illustrated with reference of oscillation of muon to tau neutrino)

The accelerator
produces

ν_{μ}

a mixture of
 $\nu_1 \nu_2 \nu_3$

The wavelengths of

$\nu_1 \nu_2 \nu_3$

depend of their masses

If different, phase shifts arise:
the mixture changes!

long distance

At a far
experiment
sometimes
appears

ν_{τ}

a mixture different
than ν_{μ}

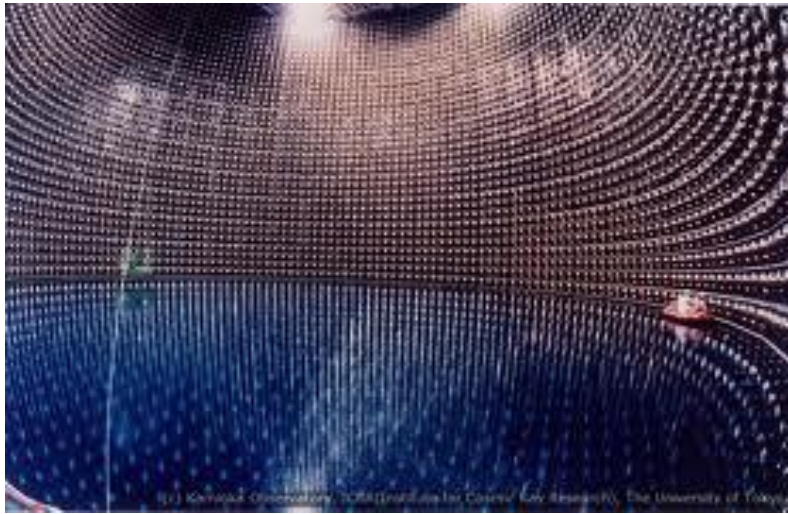


M.C. Escher, Metamorphose III (1967-68), part of a 0.2 m x 7 m xilography

Cosmic rays interact in the atmosphere producing neutrinos

ν_μ disappearance observed

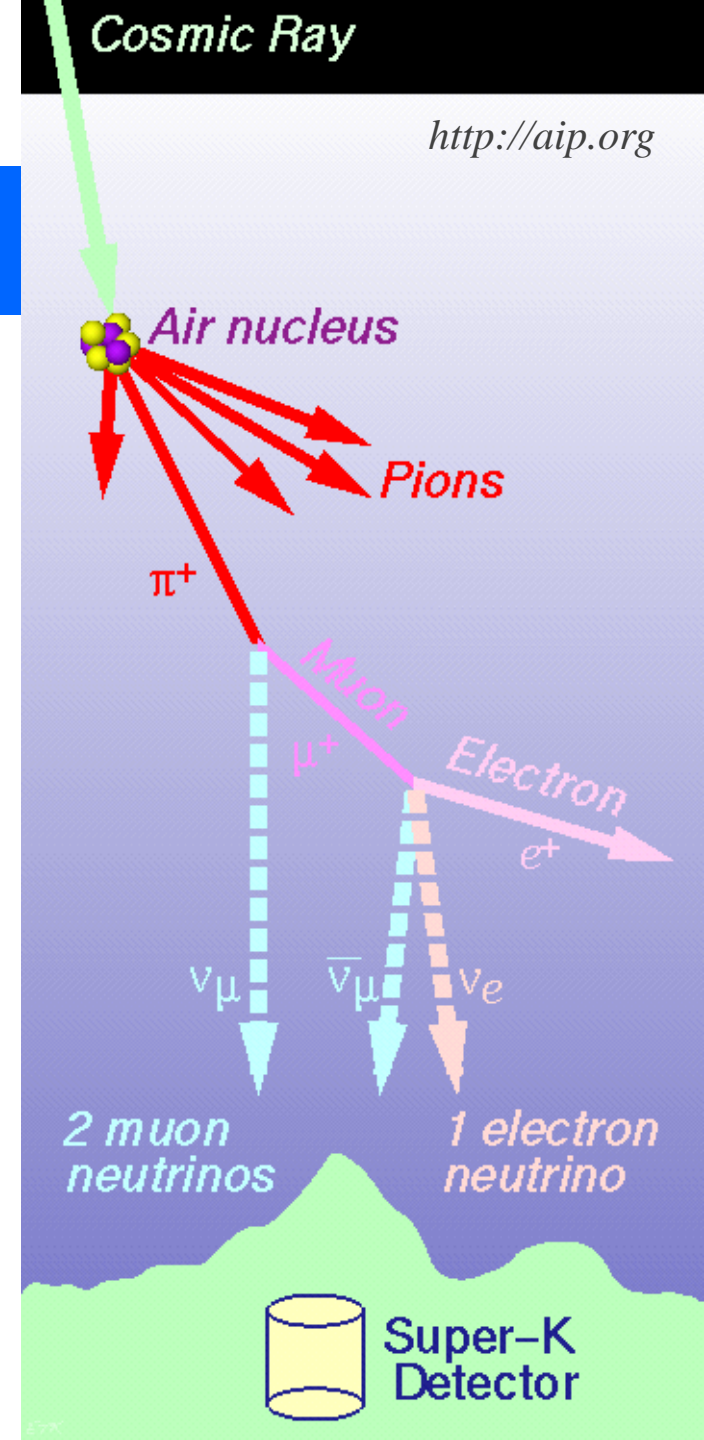
in 1998 by the underground experiment
Super-Kamiokande in Japan:
about 1/2 missing



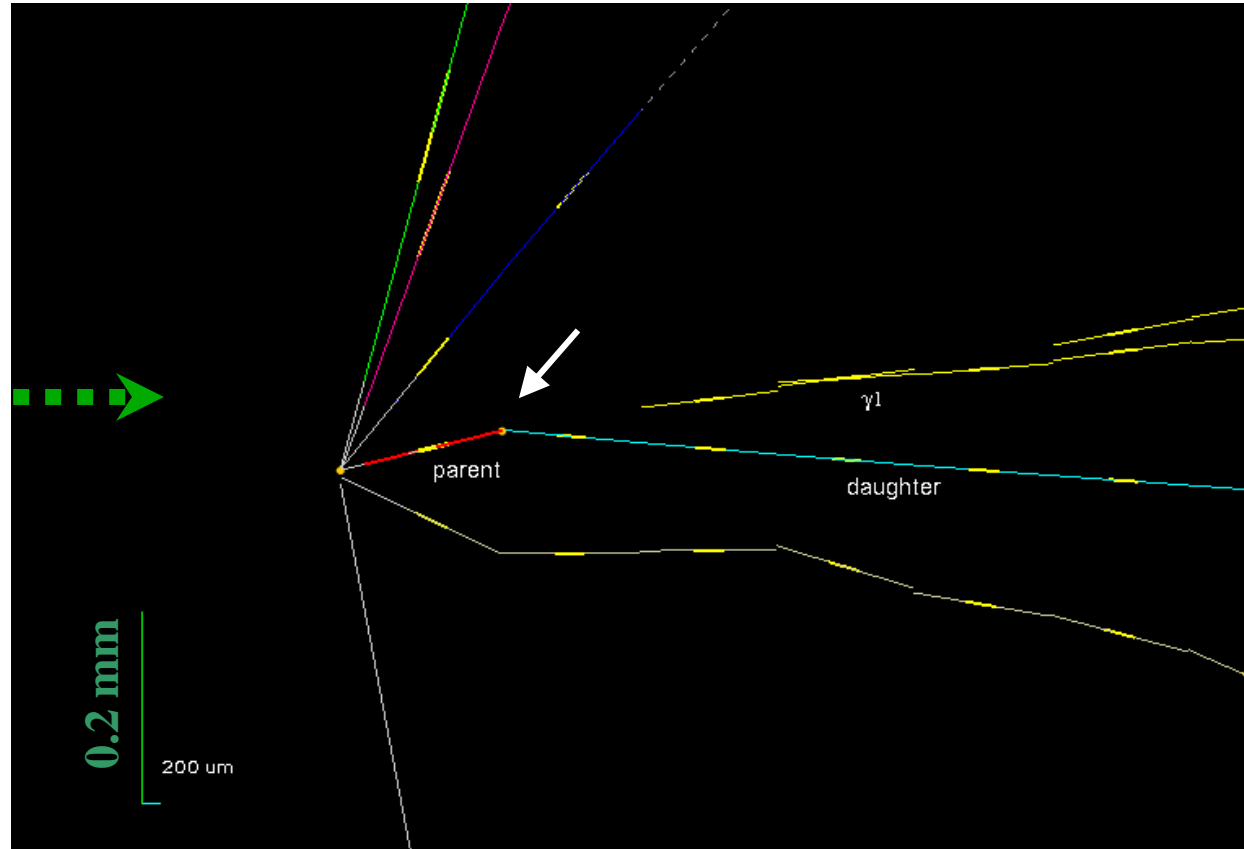
- consistent with $\nu_\mu \rightarrow \nu_\tau$ oscillation
- supports disappearance of solar ν_e by oscillation



Neutrinos have non-zero mass



OPERA at Gran Sasso sees ν_τ “appearance” (first event in 2010)



A ν_τ interaction at a sub-mm scale

The “smoking gun” proof of $\nu_\mu \rightarrow \nu_\tau$ oscillation

Neutrinos, anti(?) -neutrinos and kittens



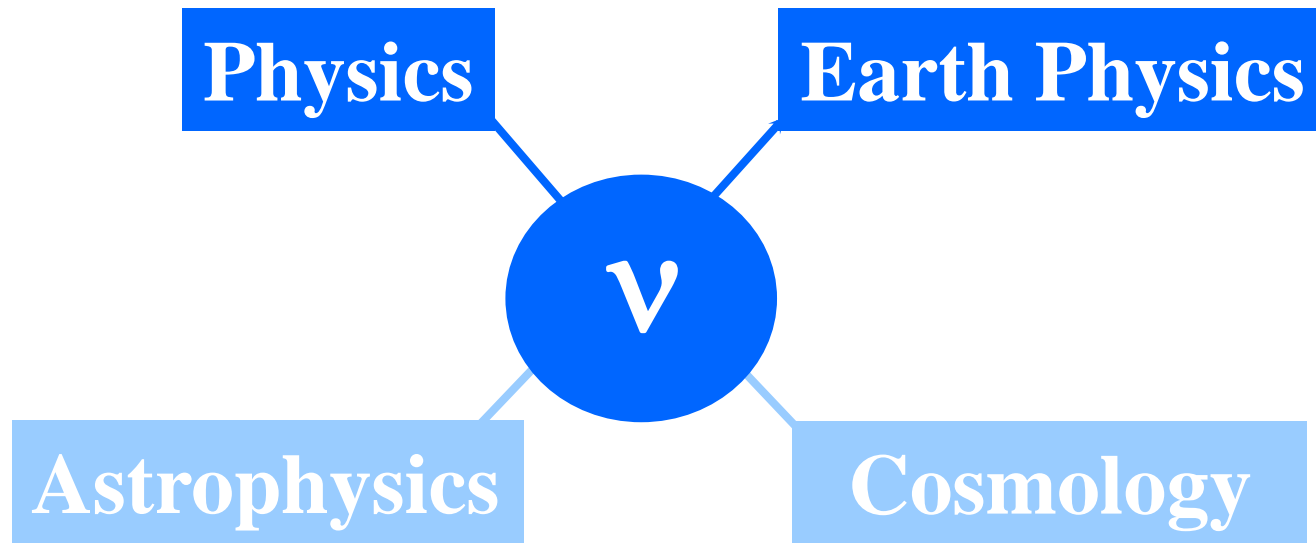
Do you want to know more?

Read “*Hic sunt neutrini*” on the Forum
of Science and School

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



Neutrinos: messengers from deep in the Earth

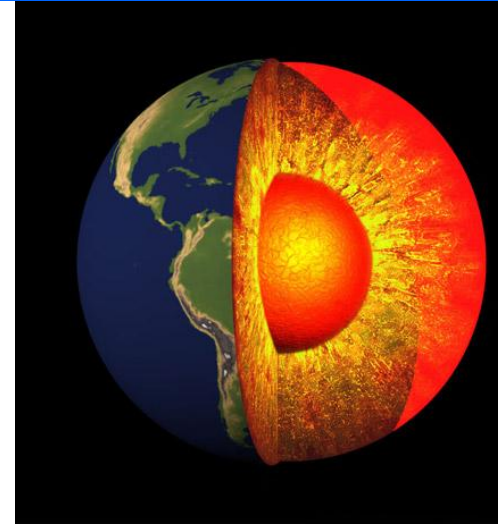


Why is the Earth warm?

An answer from “geo-neutrinos”

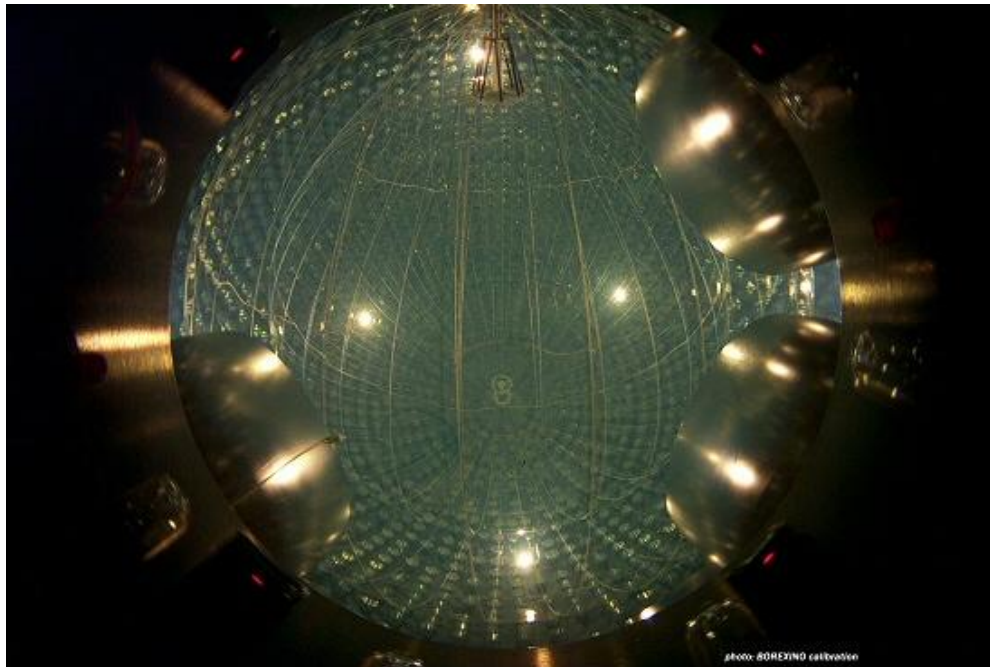
*electron anti-neutrinos from radioactive decays
in the Earth crust and mantle detected by
Borexino (Gran Sasso) and KamLAND (Kamioka)*

A new multi-disciplinary field of research



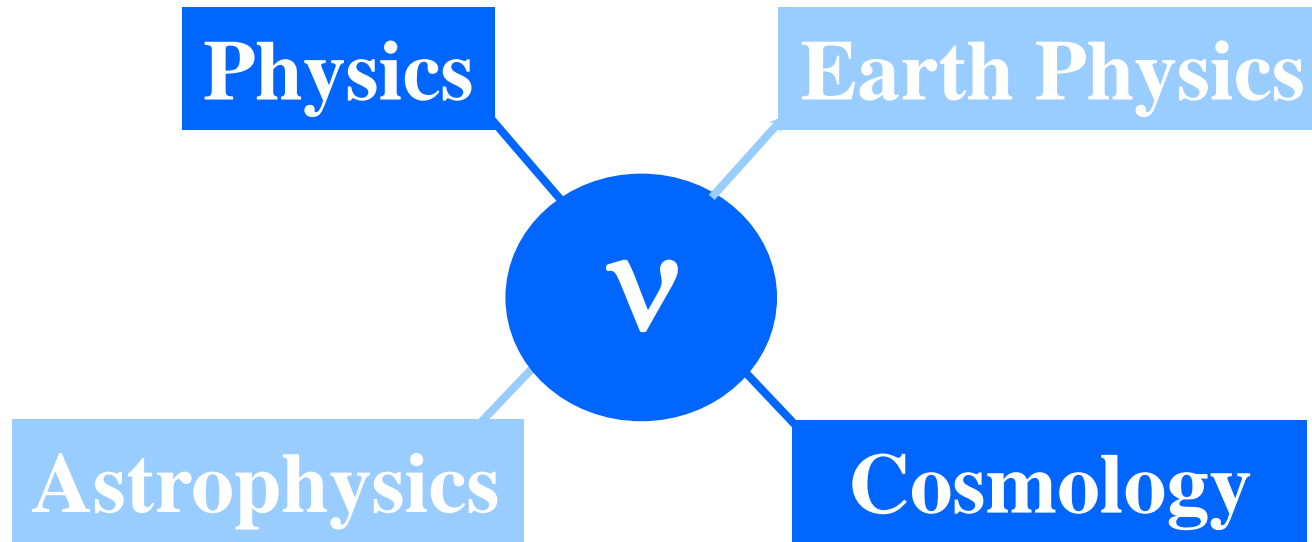
**Radioactivity is a major
source of energy**

Nuclei such as Thorium and Uranium are transmuted (decay) and produce massive amounts of heat

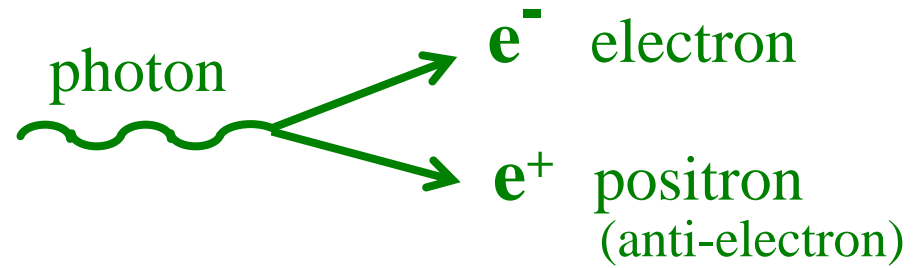


The core of the Borexino experiment at Gran Sasso

Why we live in an Universe of matter ? What happened to anti-matter ?



The elementary processes
following the Big Bang
created
matter and anti-matter



What if anti-matter would still be there ?

Annihilation !

matter



anti-matter

How did matter prevail over anti-matter?

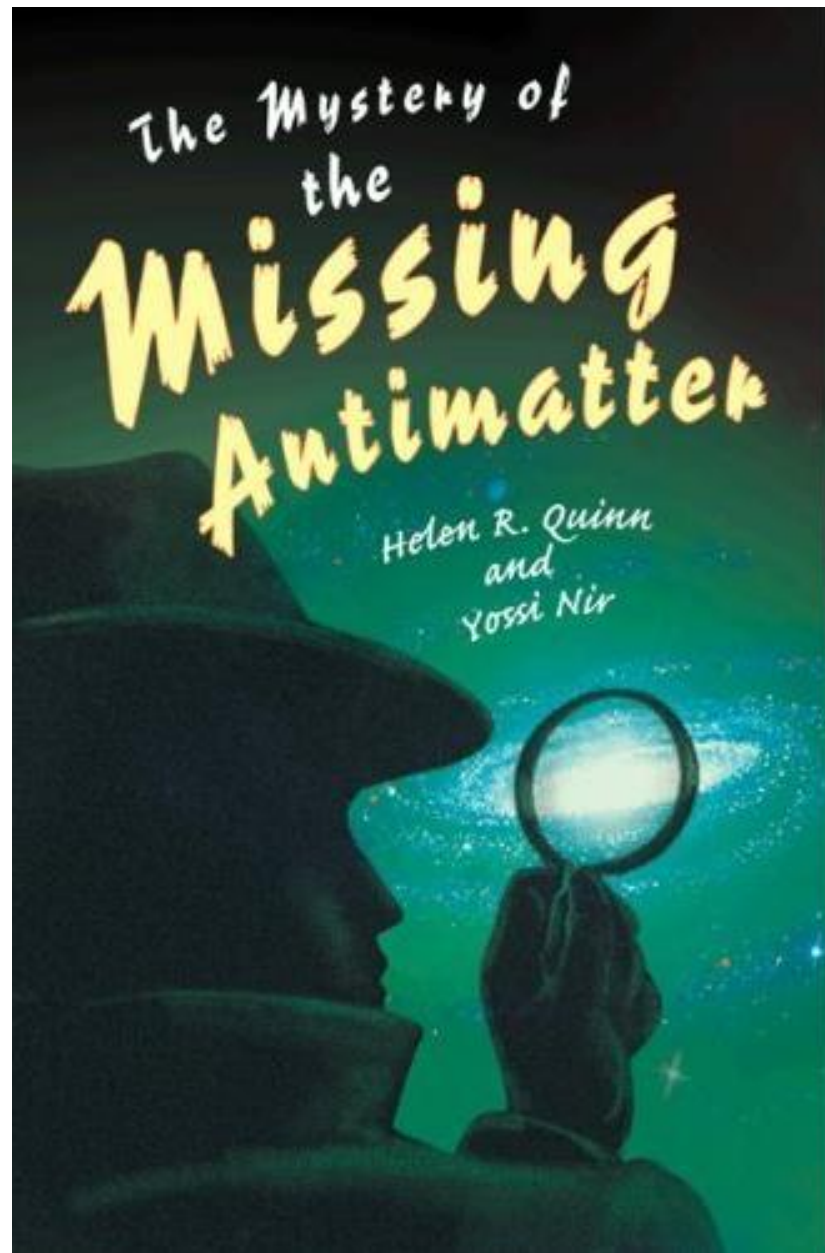
Bronzetto nuragico

*from Monte Arcosu
(Bronze Age, about 1500 BC)
Museo Nazionale di Cagliari
(Italy)*



*More than 10 billion years since the Big Bang:
a tiny asymmetry in their becoming is sufficient*

Did neutrinos save us ?



The Mystery of
the
**Missing
Antimatter**
Helen R. Quinn
and
Yossi Nir

The "CP asymmetry" in the becoming of quarks and anti-quarks is too small to explain the mystery

Is there a "CP asymmetry" for neutrinos ?

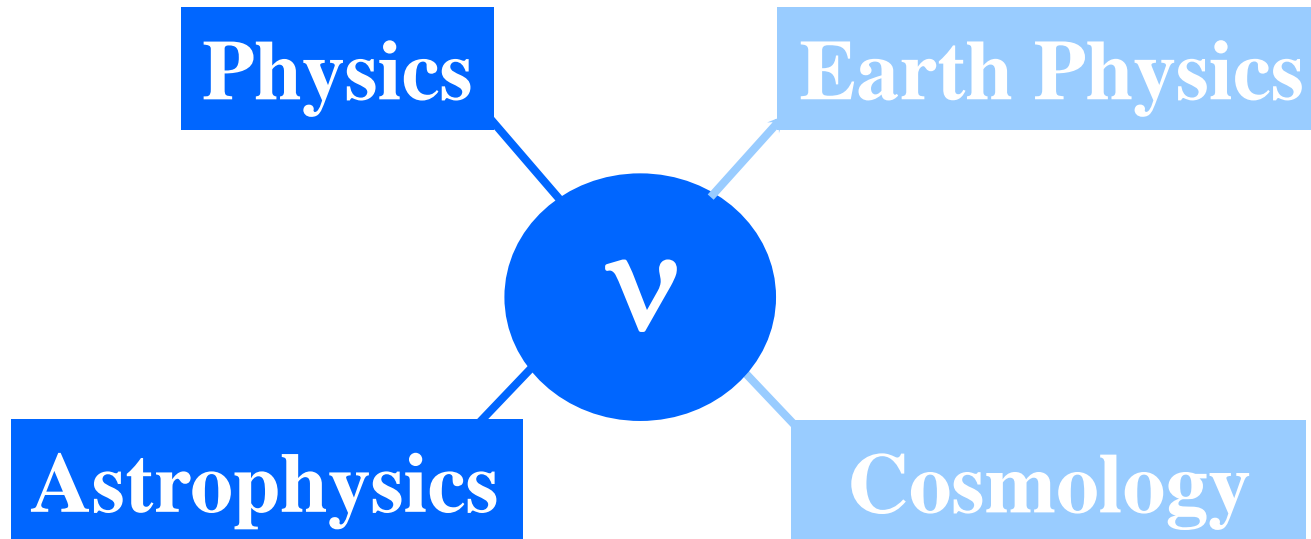
The ultimate aim in the line of research of the T2K experiment at Kamioka in Japan

*Neutrinos are highly penetrating particles
They can reach us from the core of the Sun and from the Cosmos:
exceptional "astrophysical messengers"*



“Neutrino Astrophysics”

Initiated by Davis and Koshiba: Nobel Prize 2002



The mystery of “missing solar neutrinos”

Neutrinos tell us about Nuclear Fusion reactions inside the Sun

Any other radiation (light, ...) does not emerge from its core

1920 Eddington: the solar energy cannot come from chemical burning

1938 Bethe: first calculation of the solar neutrino flux

1946 Pontecorvo: proposal of a solar neutrino detector

1962 Bahcall: beginnings of the “**Standard Solar Model (SMS)**”

1968 **Davis: observed $\frac{1}{3}$ of the solar neutrinos expected from SMS**

1988 **KamiokaNDE and later Gallex+SAGE confirm the “deficit”**



The solar neutrino puzzle

Sun and neutrinos: together to understand stars and particles

Two possibilities

1. SOLAR MODEL IS WRONG

2. A NEW PHENOMENON: “NEUTRINO OSCILLATION”

- *Solar neutrinos are “electron” neutrinos*
- *On the way to Earth are transformed by oscillation (Pontecorvo 1957) in neutrinos invisible by solar neutrino detectors*



M.C. Escher, Metamorphose III (1967-68)

1998 Super-KamiokaNDE: “muon” neutrinos from cosmic rays oscillate

2001 SNO and KamLAND assess solar “electron” neutrino oscillation

NEUTRINOS OSCILLATE - SOLAR MODEL IS RIGHT

2002 Nobel Prize to Davis and Koshiba for Neutrino Astrophysics

Scientists and (underground) experiments

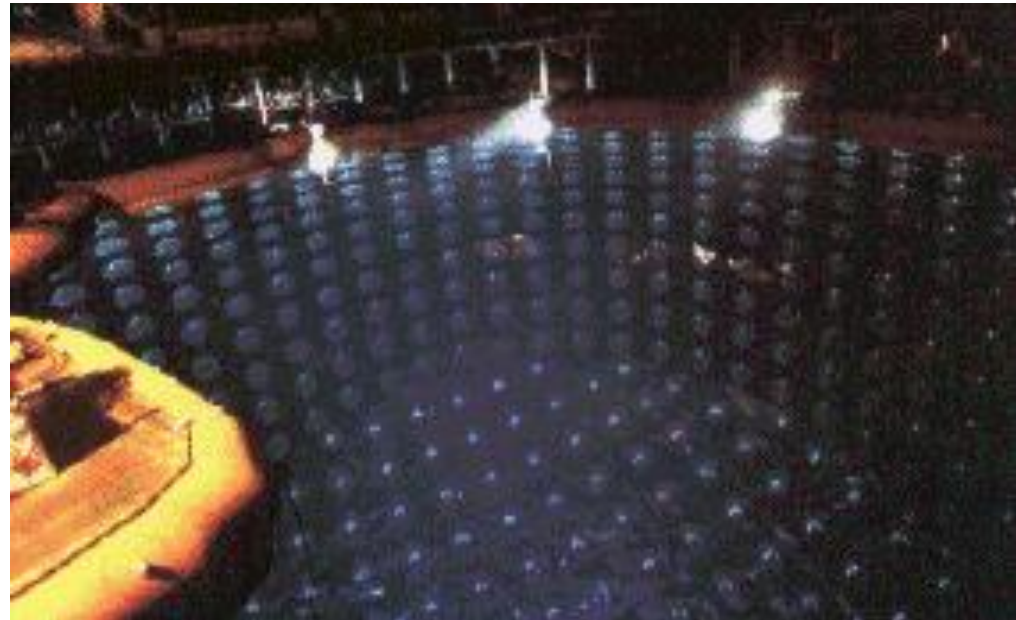


← Pontecorvo

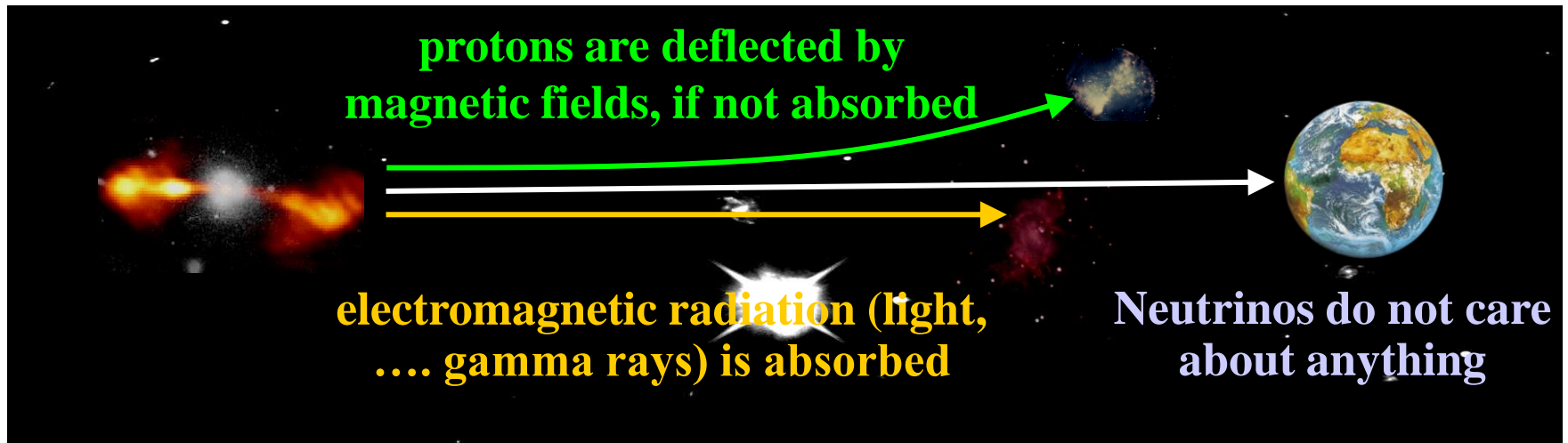
Koshihisa →

↙ Davis and Bahcall

KamiokaNDE ↘



Why from Optical to “Neutrino Astronomy”



Only neutrinos can show us the most remote Cosmos and tell us about its huge and unknown phenomena



“Neutrino Telescopes”

What do we learn from astrophysical neutrinos?

Big-Bang “Relics”

Solar

**From cosmic ray
interactions in the
atmosphere**

From Supernovae

From Cosmos

What happened at time 0?

Will they be observed?

How the stars work?

Neutrino mass

Successful experiments

Neutrino mass

Successful experiments

How a star collapses?

Observed only once (SN 1987A)

What is the origin of cosmic rays?

Neutrino Telescopes are starting

Neutrino energy

Why neutrinos ?

No neutrinos, no life

Fascinating for Physics

Help answering basic questions about Earth and Cosmos

Science expands the frontiers of knowledge

Some studies have immediate applications, others do not

Sciences have to be taken as a whole.