Why neutrino s?

as seen by Laura Strolin

Educational framework: Science and School

- *Prehistory and History*
- *Social role*
- *Role in Science*
- *Mysteries*

Paolo Strolin, Tokyo, March 17, 2013

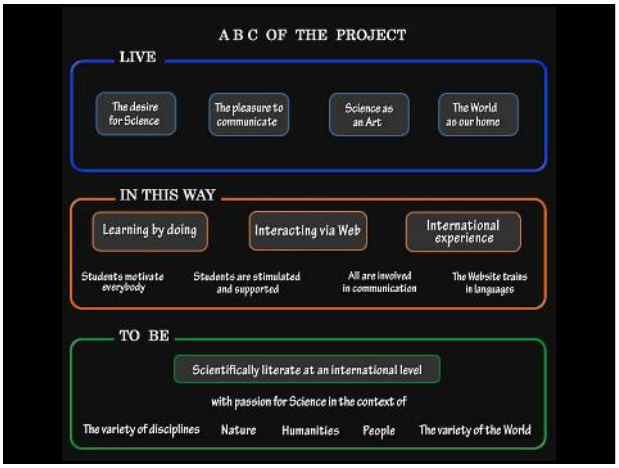
A new educational project: Science and School

Three pillars

Together to advance

"The mind is not a vessel to be filled, but a fire to be kindled"
Plutarch (ca. 46-127)

http://scienzaescuola.fisica.unina.it



How *(for more information visit the Website)*

Experiments at School and in research Labs

Visit research Labs

Discussion Forum

Training to Olympics

Ask an expert

- Multi-language Website: English + local
- Quasi-mirror Website: Japanese
- Gain international experience:
  SKYSEF Forum @ Shizuoka Kita High School
  .....

Italy - Japan

A long tradition of Collaboration in Science

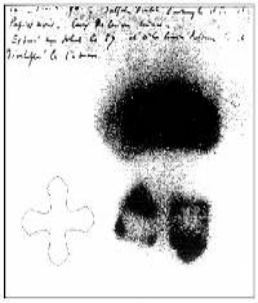
We wish a strong partnership with Japanese Universities, High Schools and Education/Communication Institutions

- *Prehistory*
- *History*
- *Social role*
- *Experiments*
- *Fascinating mysteries*

The primeval times

1896 Becquerel

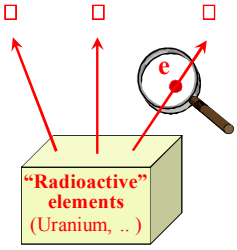
Discovery (accidental) of natural "radioactivity"



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 □,□, □

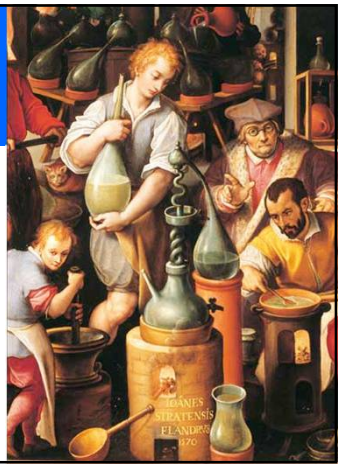
1903 Rutherford and Soddy

"Magic" transmutation of chemical elements by "radioactive decay" of atomic nuclei

1909 Bucherer

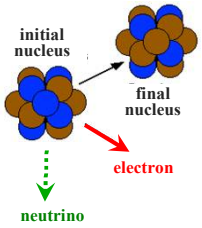
□ rays are electrons

Transmutation of chemical elements: *the dream of alchemists becomes reality*



"The laboratory of the alchemist"
(detail)
Jan Van der Straet (1523-1605)
Palazzo Vecchio (Firenze)

Mistery: missing energy in □ decay ?



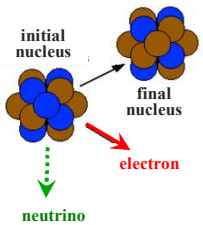
stolen energy ?

electron energy < available energy = $(M_{initial} - M_{final})\ c^2$

1930 Pauli: neutrino hypothesis

A massless neutral (invisible) particle is also emitted

The "Weak Interaction"



The □ 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)

energy **matter**

Discovery of anti-matter

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

e^- electron
e^+ positron (anti-electron)

energy ⇄ **particle + anti-particle**

e^- electron
□ anti-neutrino (bar above symbol)

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

The anti-neutrino comes on stage

A mystery: is it really a "different" particle ?

This was the "prehistory" of the neutrino

(in the absence of "writing", 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

Use of abstract characters or stylized symbols

Writing

detailed and quantitative descriptions

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

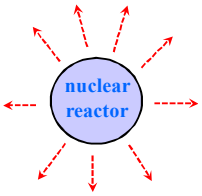
Sumerian cuneiform writing on tablet (about 3 millennia BC)

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

The neutrino starts writing:

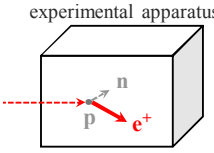
"direct" observation through its "weak" interactions

Reines and Cowan 1956 (26 years after Pauli hypothesis), idea by Pontecorvo 1946



Intense □ flux

Massive
experimental apparatus



□ □□p → e^+ □ n

n neutral, p at rest: neither is seen

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

Next: the "social role" of the neutrino

A. Lorenzetti, Detail from Effects of Good Government (1337-1340)
Palazzo Pubblico, Sienna (Italy)

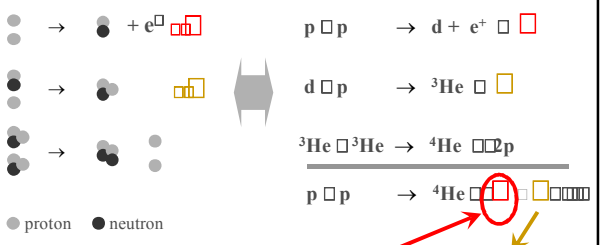
What for?

Without neutrinos, the Sun would not heat!

No life on Earth

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

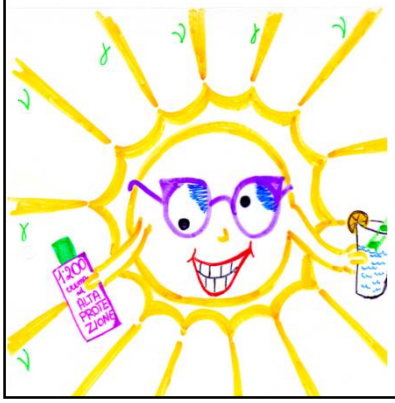
How the sun heats: nuclear reactions



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 ( ) bringing light and heat

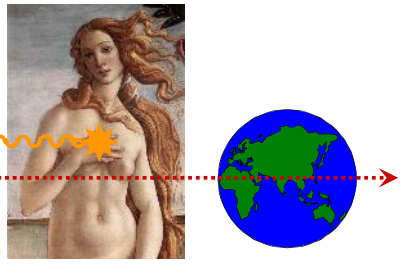
How many solar neutrinos on Earth ?

In a second
one hundred billion neutrinos through your nail

Why our body does not care about neutrinos ?

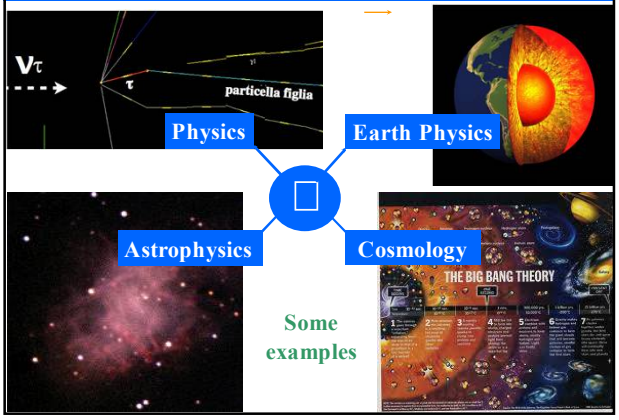
The electromagnetic radiation (IR, light, UV) interacts with our body and there deposits its energy (heat)

elettromagnetic radiation

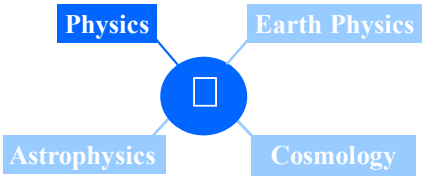


Neutrinos: no interaction, no effect
(pass even through the Earth!)

The neutrino: a "nodal point" in Science



Neutrinos and Physics



The "Elementary Particles", today

3 "families"

Quarks: (u d) (c s) (t b)

Leptons: (ν_e e) (ν_μ μ) (ν_τ τ) ← 3 neutrinos

The neutrino: a very special particle

Mass "assumed to be zero" until few years ago

Mysteries waiting for discovery

Physical properties: many questions

electric charge	0
"spin" angular momentum	½
interaction with matter	"electro-weak"
mass	very small*: how much?
violation of " CP symmetry"	???
$\nu \neq \bar{\nu}$ *(Dirac)* or $\nu \equiv \bar{\nu}$ *(Majorana)*	???
other properties	???

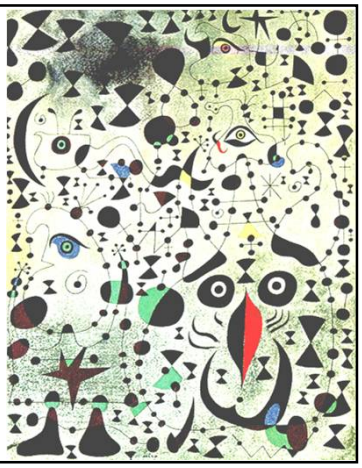
** Recent discovery: neutrinos have non zero mass.*
But in absolute scale, we only know that is less than one billionth of that of the proton

Why so many mysteries?

Very low probability of interacting with matter

↓

Very difficult experiments



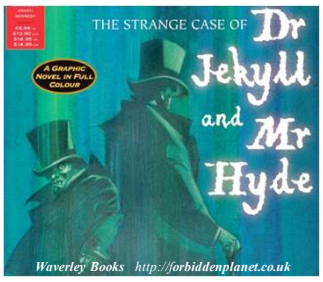
Juan Miró (1893-1988)
The beautiful bird revealing the unknown to a pair of lovers
Museum of Modern Art (New York)

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)*

ν_e → e

Have birth and die as the usual ν_e ν_μ ν_τ
- produced in association with e ν_μ ν_τ
- interacting with matter produce e ν_μ ν_τ

Mass does not need to be defined

ν_e electron neutrino
ν_μ muon neutrino
ν_τ tau neutrino

ν_1 ν_2 ν_3 are **mixtures** of ν_e ν_μ ν_τ

Travel incognito with **definite mass** as ν_1 ν_2 ν_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 ν_1 ν_2 ν_3

The wavelengths of ν_1 ν_2 ν_3 depend of their masses

If different, phase shifts arise: the mixture changes!

long distance

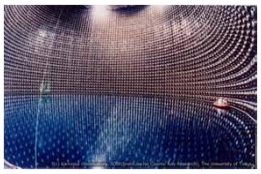
--→ At a far experiment sometimes appears ν_μ a mixture different than ν_μ

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

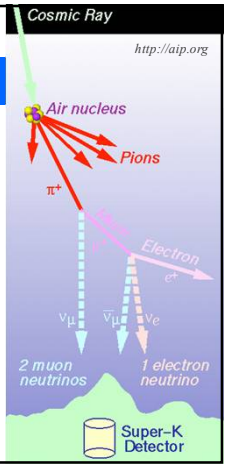
□μ disappearance observed

in 1998 by the underground experiment Super-Kamiokande in Japan: about ½ missing



- consistent with □μ→□τ oscillation
- supports disappearance of solar □e by oscillation

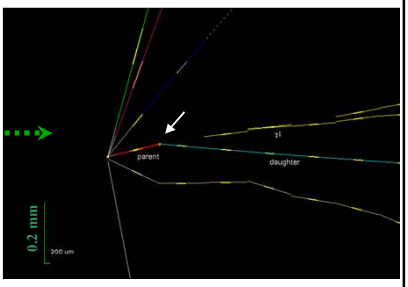
Neutrinos have non-zero mass



OPERA at Gran Sasso sees □τ "appearance"

(first event in 2010)

from CERN Geneva (730 km away)



A □τ interaction at a sub-mm scale

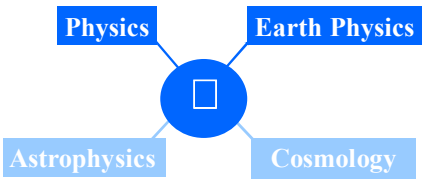
The "smoking gun" proof of □μ→□τ oscillation

Neutrinos, antineutrinos 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

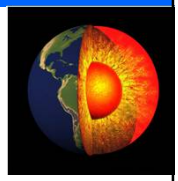


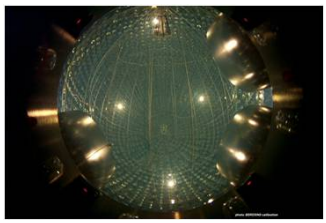
Why is the Earth so hot? Which energy sources?

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



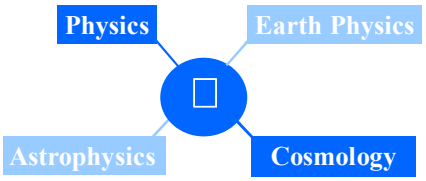


The core of the Borexino experiment at Gran Sasso

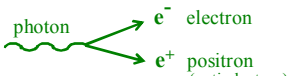
Radioactivity is a major source of energy.

Nuclei such as Thorium and Uranium are transmuted (decay) and produce massive amounts of heat, that dissolves rocks into magma.

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 !

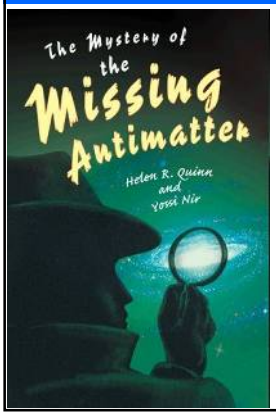
matter  anti-matter

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

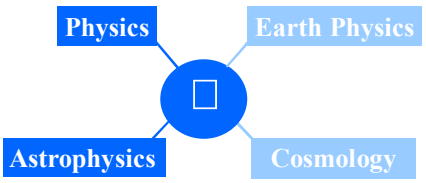
Is there a "CP asymmetry" for neutrinos ?

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 ⅓ of the solar neutrinos expected from SMS

1988 KamiokaNDE and later Gallex+SAGE confirm the "deficit"

http://www.nobelprize.org/nobel_prizes/physics/articles/bahcall/

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

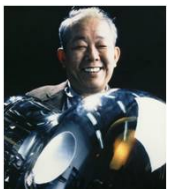
NEUTRINOS OSCILLATE - SOLAR MODEL IS RIGHT

2002 Nobel Prize to Davis and Koshiba for Neutrino Astrophysics

Scientists and (underground) experiments

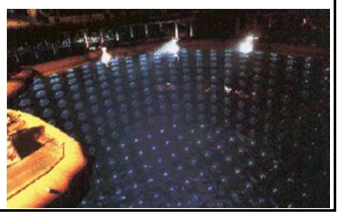
← Pontecorvo

Koshiba →

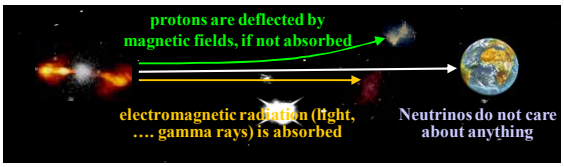


↙ Davis and Bahcall

KamiokaNDE ↘



Why from Optical to "Neutrino Astronomy"

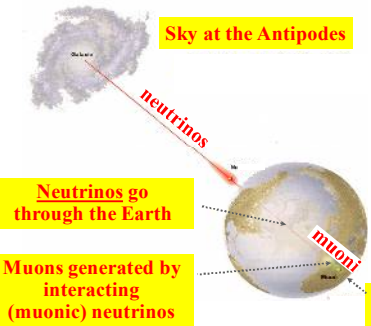


Only neutrinos can show us the most remote Cosmos and tell us about its huge and unknown phenomena

↓

"Neutrino Telescopes"

The Earth as a first "free of charge" passive component of a Neutrino Telescope



Neutrinos go through the Earth

Muons generated by interacting (muonic) neutrinos

Experimental apparatus for observing muons

"Free of charge" passive component to detect muons from cosmic neutrinos

Faint signals

↓

Huge experimental apparatus

↓

Technique using "free of charge" passive component

↓

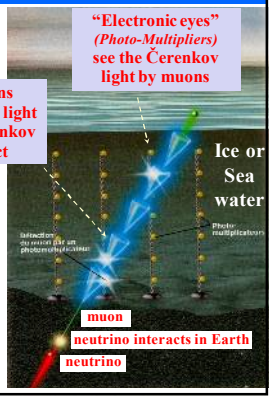
Čerenkov Light in:

Antarctic Ice
(Icecube, taking data)

or Sea Water
(European projects)

"Electronic eyes" *(Photo-Multipliers)* see the Čerenkov light by muons

Muons produce light by Čerenkov effect



What do we learn from astrophysical neutrinos?

Neutrino energy ↓

Big-Bang "Relics"	What happened at time 0? *Will they be observed?*
Solar	How the stars work? Neutrino mass *Successful experiments*
From cosmic ray interactions in the atmosphere	Neutrino mass *Successful experiments*
From Supernovae	How a star collapses? *Observed only once (SN 1987A)*
From Cosmos	What is the origin of cosmic rays? *Neutrino Telescopes are starting*

Final remark

You might ask, what is the practical use?

Science, or more appropriately Sciences, expand the frontiers of knowledge. It is an intellectual requirement of the "human species" that since prehistoric times, and dramatically in recent centuries, has led to such a strong differentiation and to live better.

There are studies that lead to immediate applications, others do not. Sciences have to be taken as a whole.

From "*Hic sunt neutrini*" on the Forum of Science and School
http://scienzaescuola.fisica.unina.it