Neutrinos and their flavor

The most elusive and mysterious particles

Instituto de Física Teórica UAM-CSIC

UAM CSIC Consejo Superior de Investigaciones Científicas

The Starndard Model of Particle Physics

What are we made of?

Everything around us is made up of elementary particles, for instance the quarks within protons and neutrons in atomic nuclei, like the leptons, like the electrons which orbit around nuclei. Together they form the atoms which are constituents of matter. Leptons also include antoher kind of particle: **neutrinos**. There are 3 families of quarks and leptons, with identical properties, except for their masses.

What holds particles together?

Elementary particles are subject to forces associated to four fundamental interactions: electromagnetism, the strong force, the weak interaction, and gravity.
Each one of these interactions is associated with one or several force particles, the gauge bosons: the photon, the Z y W bosons, the gluons and the (still hypothetical) graviton.

FERMIONS: Building blocks of the Universe

Leptons spin =1/2

Name	Mass (GeV)	Electric charge
ν_L lightest neutrino*	$<10^{-9}$	0
e electron	0.0005	–1
ν_M middle neutrino*	$<10^{-9}$	0
μ muon	0.1	–1
ν_H heaviest neutrino*	$<10^{-9}$	0
τ tau	1.8	–1

Quarks spin =1/2

Name	Approx. Mass (GeV)	Electric charge
u up	0.002	2/3
d down	0.005	–1/3
c charm	1.3	2/3
s strange	0.1	–1/3
t top	173	2/3
b bottom	4.2	–1/3

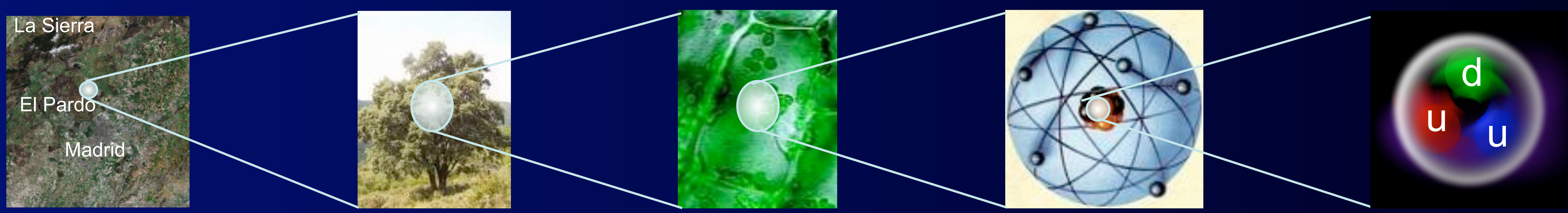
Bosons: The glue of the Universe

Unified Electroweak spin = 1

Name	Mass GeV/c^2	Electric charge
γ photon	0	0
W^- (W bosons)	80.39	–1
W^+ (W bosons)	80.39	+1
Z^0 Z boson	91.188	0

Strong (color) spin =1

Name	Mass GeV/c^2	Electric charge
g gluon	0	0



10^5 m = 100 Km
Satellite image of the Madrid area, centered on the El Pardo forest

1m
A holm oak tree in the El Pardo forest

10^{-5} m = 10 μm
Plant cell

10^{-10} m = 0.1nm
Carbon atom

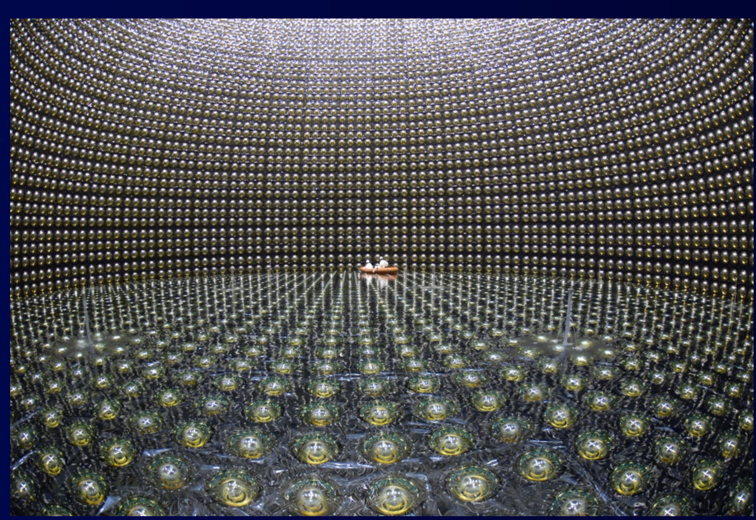
10^{-15} m
Internal structure of the proton

Neutrinos are elementary particles with neither electric charge nor color, they only feel the weak inteaction. Their mass is extremely small, millions of times smaller than that of electrons.

Neutrinos are very abundant particles in the universe. For each electron, proton or neutron, there are 10 000 000 000 neutrinos. **Neutrinos have very feeble interaction with any form of matter**, which makes them extremely difficult to detect. Neutrinos can travel huge amounts of matter without interacting, your body is at this very instant being crossed by millions of millions of neutrinos.

Nevertheless, it is possible to detect neutrinos by using underground experiments, like **SuperKamiokande** in Japan, an enormous tank filled with 50.000 tons or very pure water, covered with 11.000 Cherenkov radiation detectors, and located some 1000 meters underground.

These experiments allow to study neutrino properties, specially **neutrino oscillations and their relation with neutrino masses**.

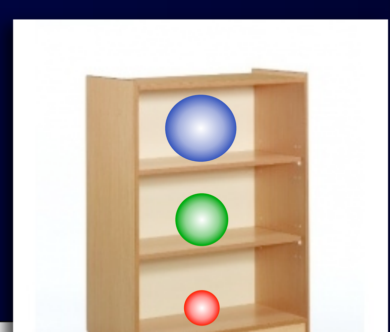


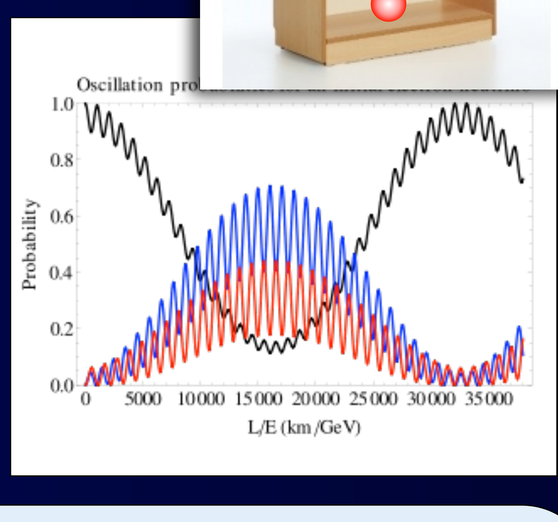
Neutrinos come in 3 varieties or "flavors", depending on their interaction with electrons, muons or tau leptons. These flavors can mix at the quantum level, leading to the phenomeno of **neutrino oscillations**.

Matter particles (quarks and leptons) are classifed in 3 families, with identical properties excepto for their mass. **There are 3 kinds or "flavors" of neutrinos**, known as **electronic, muonic and tauonic**, depending on the kind of charged lepton (electron, muon or tau) to which they connect via the weak interaction.

These 3 flavors mix among themselves in the propagation of neutrinos. In Quantum Mechanics, physical neutrinos are described as waves formed by the interference of waves associated to the 3 basic flavours. **Neutrino oscillation (in flavor)** corresponds to the changing of the interference pattern during neutrino flight. Hence, a neutrino botn as electronic at the core of the Sun may be detected as a muon neutrino upon arrival to Earch (see "the solar neutrino problem").

The oscillations among the 3 neutrino flavors has been studied in diverse experiments, with different parameters for the distance between the neutrino source and the detector, and the nature of neutrino source. There are **solar neutrinos** (from the Sun), **atmospheric neutrinos** (from cosmic ray collisions in upper layers of the atmosphere) and **reactor neutrinos** (from nuclear plants or particle accelerators).

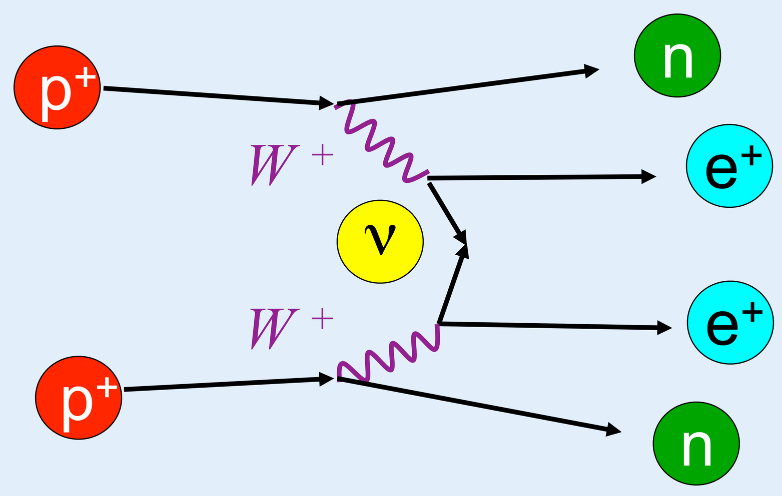




¿Neutrino=Antineutrino?

Each particle has its antiparticle, with equal mass but opposite charges. Neutrinos have neither electric charge nor color, hence **neutrinos could be their own antiparticles** (in jargon, they could correspond to Majorana spinors rather than Diract spinors).

This may be established experimentally by the detection of **"neutrinoless doucle beta decay"**, a process possible only if neutrinos are of Majorana type. There are several ongoing experiments attempting the detection of this process, including those in the Underground Laboratory in Canfranc (Huesca, Spain).



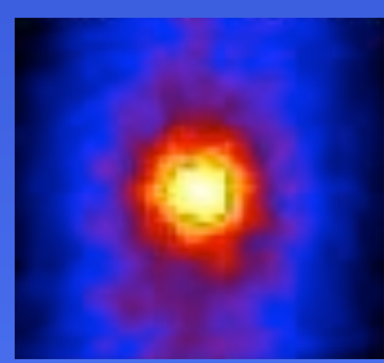
Why do stars shine?

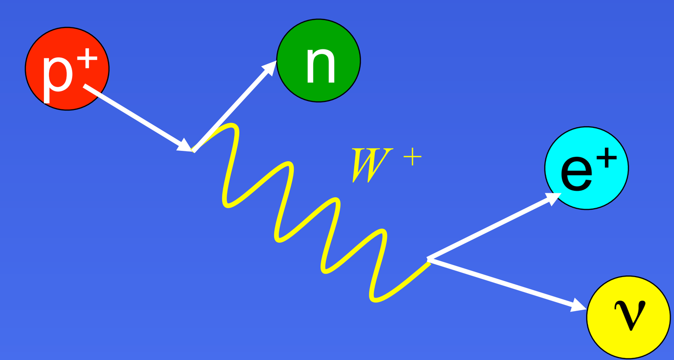
The weak force and neutrinos

Thanks to their subtle properties, **neutrinos are key players in the shining of stars.**

Stars produce energy by fusion processes in which 4 hydrogen nuclei (protons) combine into Helium-4 nuclei (2 protons and 2 neutrons). This requires an interaction able to transform the particles: the weak interaction, mediated by the W and Z. At the core of stars, protons turn into neutrons by emitting positrons (the antiparticle of the electron) and neutrinos ν.

Thus, besided light, the Sun emits neutrinos, as can be seen from this neutrino image of the Sun.



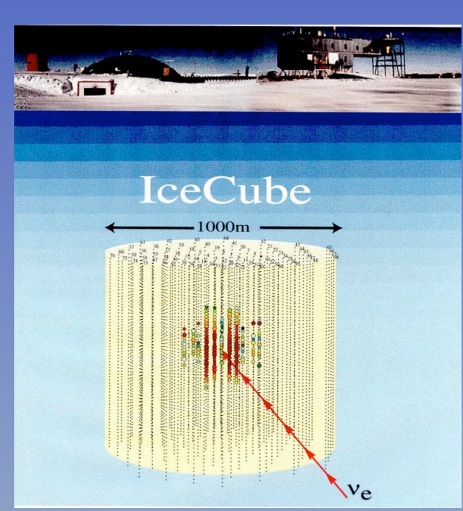


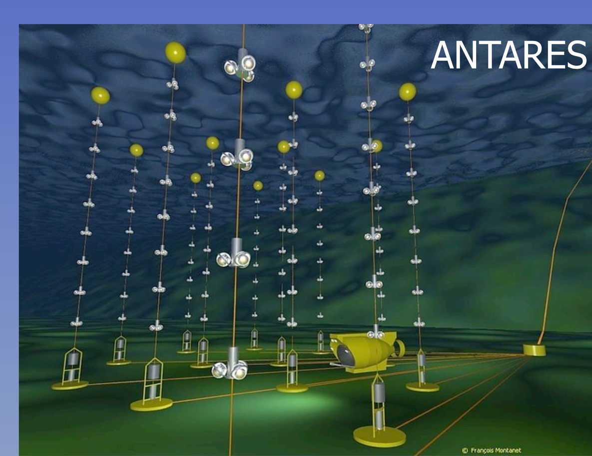
The solar neutrino problem

For a long time, scientists could not explain why the solar neutrino flux in Earth seemed lower than what the astrophysical solar model predicted. We now know that the **apparently missing electronic neutrinos from the Sun have oscillated into muon neutrinos during their travel to the Earth. la Tierra. Experiments able to detect all neutrino flavour measure no discrepancy.**

Neutrino Astronomy

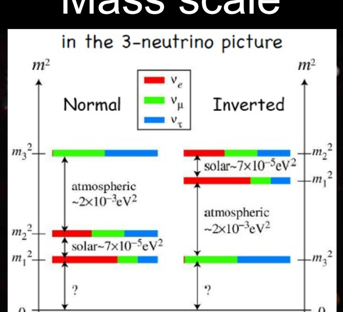
Detection of neutrinos from astrophysical sources (for instance IceCube in the South Pole or ANTARES in the Mediterraneus) is paving the way for the field of Neutrino Astronomy, which provides new methods to observe violent astrophysical processes, for instance supernova explosions, active galactic nuclei, or gamma ray bursts.





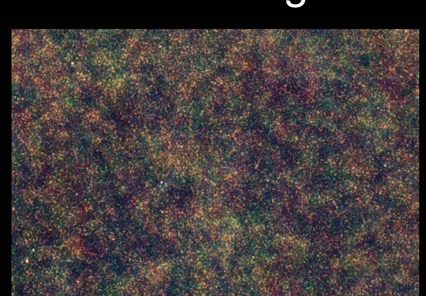
Open puzzles

Mass scale



Neutrino oscillation data are sentitive to the mass differences and mixings among the 3 neutrino species. Thus, we still have very scarce information about the absolute value of their mass scale.

Cosmic background

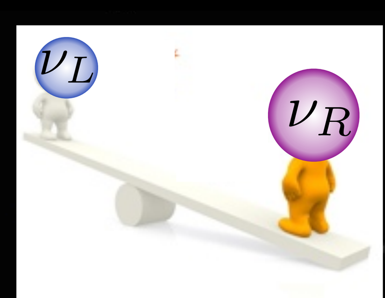


Similar to the Cosmic Microwave Background for photons, the universe is filled with a cosmic background of neutrinos, (still not detected), which would originate at the time of neutrino decoupling, some 2 seconds after the Big Bang.

Leptogenesis

The matter-antimatter asymmetry in the universe could be explained if neutrinos are their own antiparticles: in the early universe, an excess for leptons would eventually turn into an excess of baryons over antibaryons.

More neutrinos?



Neutrino masses are exceedingly small, but non-zero. To complete the Standard Model to include them, and to explain their tiny mass, the so-called see-saw mechanism proposes still unobserved new kinds of neutrinos with enormous masses.

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