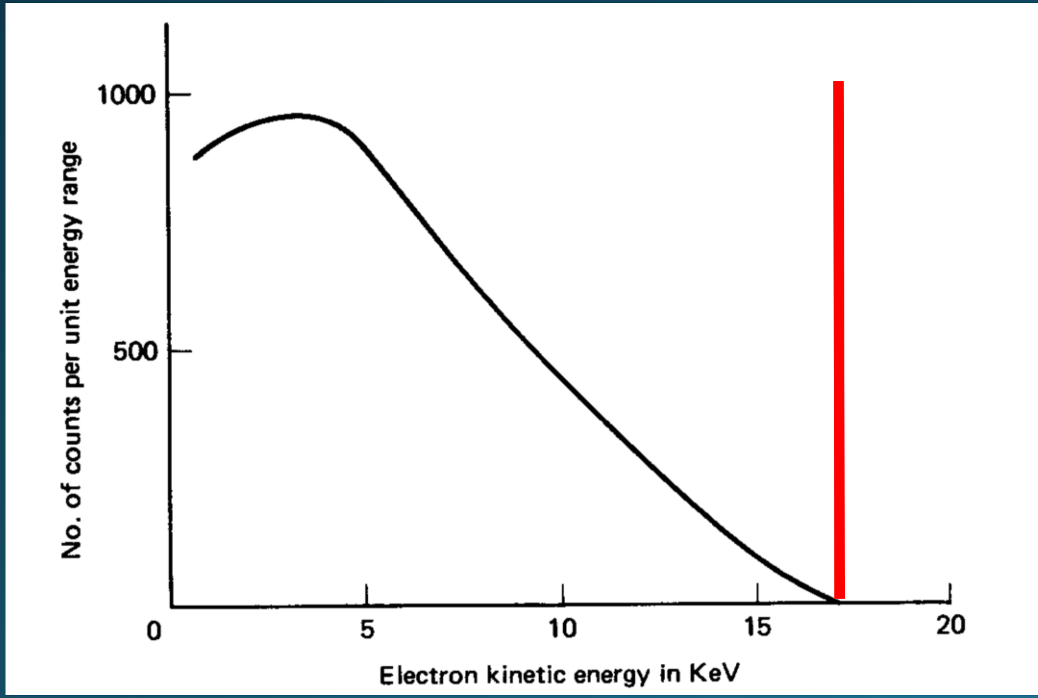
Ohana Rodrigues - Syracuse University, 10/24

Neutrinos and Astronomy

The beta decay problem

(1914) - Sir J. Chadwick

$$n \rightarrow p + e^{-}$$



Is energy not conserved in this decay?

Pauli’s solution for the beta decay problem

(1930) - W. Pauli

Original - Photocopie of PLC 0393

Abschrift/15.12.56 FN

Offener Brief an die Grunpe der Radioaktiven bei der Gauvereins-Tagung zu Tübingen.

Abschrift

Physikalisches Institut
der Eidg. Technischen Hochschule
Zürich

Zürich, 4. Des. 1930
Gloriastrasse

Liebe Radioaktive Damen und Herren,

Wie der Ueberbringer dieser Zeilen, den ich huldvollst anzuhören bitte, Ihnen des näheren auseinandersetzen wird, bin ich angesichts der "falschen" Statistik der N- und Li-6 Kerne, sowie des kontinuierlichen beta-Spektrums auf einen verzweifelten Ausweg verfallen um den "Wechselsatz" (1) der Statistik und den Energiesatz zu retten. Nämlich die Möglichkeit, es könnten elektrisch neutrale Teilchen, die ich Neutronen nennen will, in den Kernen existieren, welche den Spin 1/2 haben und das Ausschliessungsprinzip befolgen und sich von Lichtquanten ausserdem noch dadurch unterscheiden, dass sie nicht mit Lichtgeschwindigkeit laufen. Die Masse der Neutronen müsste von derselben Grossenordnung wie die Elektronenmasse sein und jedenfalls nicht grösser als 0,01 Protonenmasse.- Das kontinuierliche beta- Spektrum wäre dann verständlich unter der Annahme, dass beim beta-Zerfall mit dem Elektron jeweils noch ein Neutron emittiert wird, derart, dass die Summe der Energien von Neutron und Elektron konstant ist.

$$n \rightarrow p + e^- + \overline{\nu_e}$$

The ”missing” energy is acctually going to this other particle called neutrino!

The first neutrino measurement

1956 - Cowan-Reines
1995 Nobel prize

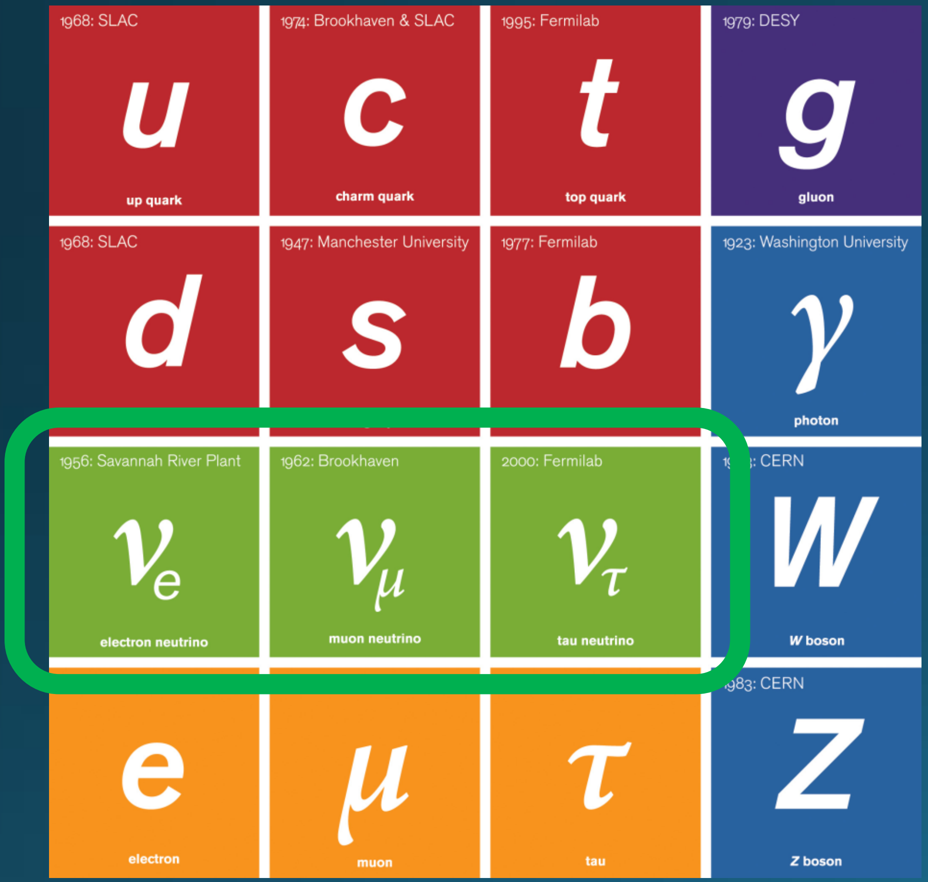
Savannah River Plant provided neutrinos ($10^{13}\ /cm^2/s$)

Tank of water + Cadmium Chloride

$$\overline{\nu} + p \rightarrow n + e^{+}$$

$$n \ + \ {}^{108}\mathrm{Cd} \ \rightarrow \ {}^{109}\mathrm{Cd} \ + \ \gamma$$

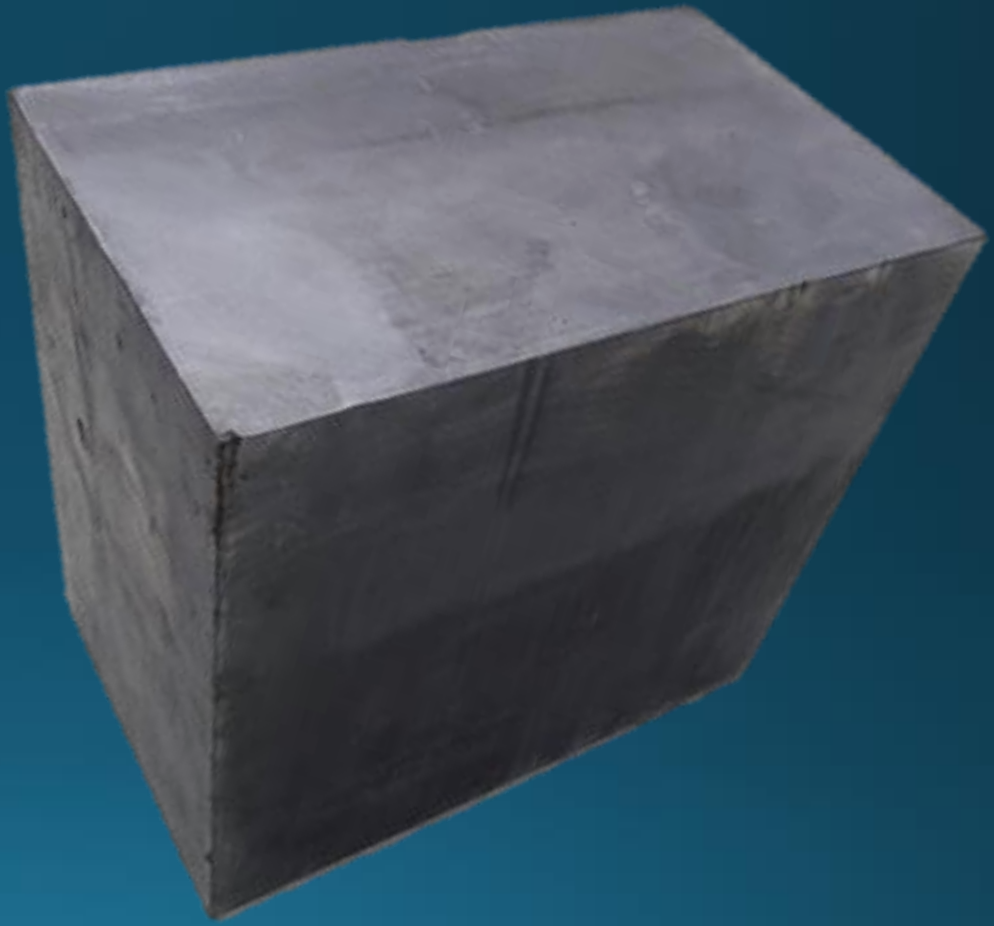
What are neutrinos?



- Strong: quarks
- Electromagnetic: quarks and charged leptons
- Weak: all fermions
- Gravity: anything

How difficult is for a neutrino to interact?

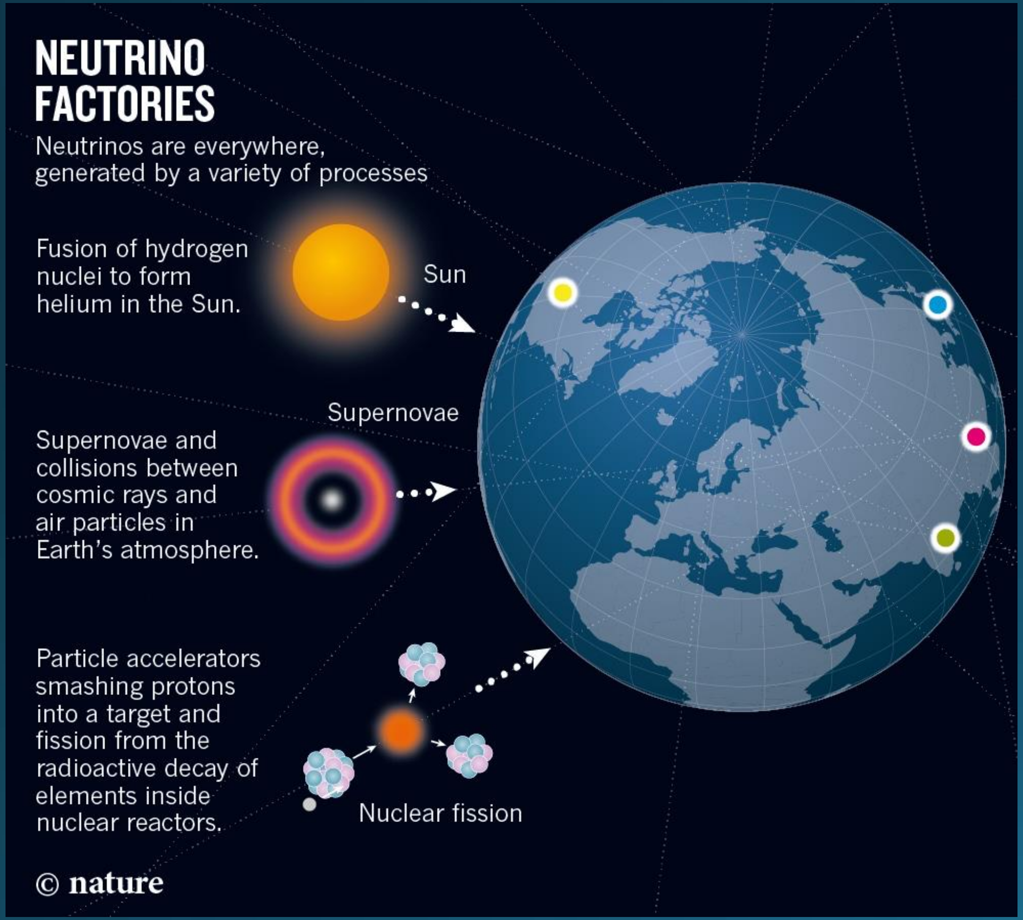
If we throw a neutrino in a lead block…



It will take 140 light-years for it to interact!!

In fact…~100 trillion neutrinos pass through your body each second

Neutrino sources



Nuclear fusion

CNO cyle
(dominant in biggers tars)

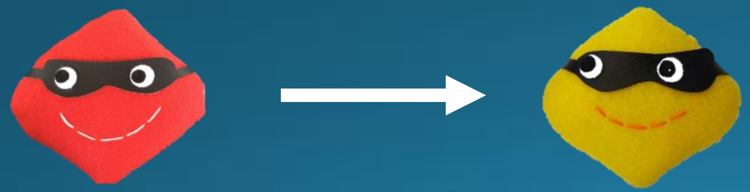
PP cycle
(dominant in smaller stars)

$2\ x$ 

Solar neutrinos

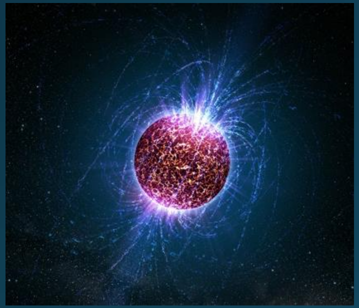
- First solar neutrino measurement
  - Ray Davis
  - Homestake gold mine in South Dakota
  - 615 tons of a fluid rich in chlorine
  - $\nu_e + Cl^{37} \rightarrow e^- + Ar^{37}$
  - 1 neutrino / 3 days
  - 2/3 smaller than the one theoretically predicted by John Bahcall

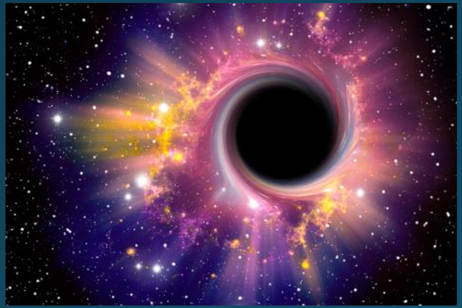
  - Why? Neutrino oscillation!



Supernova neutrinos

When massive stars exhaust their nuclear fuel…





They explode and become a neutron star or a black hole

This process emits a huge amount of neutrinos (and photons)

Supernova neutrinos

- Neutrinos interact less than photons
- Neutrinos escape before photons from the nucleus of the star
- 19 neutrinos were observed from the 1987A core-collapse supernova by Kamiokande-II and Irvine-Michigan- Brookhaven experiments
- Since then, we keep track of neutrinos events so astronomers know where to point their telescopes in case a supernova happens

LIGO measurement (should we see neutrinos from it?)

- LIGO measured the gravitational wave of 2 neutron stars merging
  - Supposing that…
    - The mass of the two neutron stars were totally neutrons
    - All the neutrons become protons
    - The flux of neutrinos would decrease with $\sim \frac{1}{r^2}$

    - We would still have 1 million less neutrinos coming from that event than we have coming from the sun per second

Low mass binary neutron star mergers: Gravitational waves and neutrino emission

Francois Foucart, Roland Haas, Matthew D. Duez, Evan O'Connor, Christian D. Ott, Luke Roberts, Lawrence E. Kidder, Jonas Lippuner, Harald P. Pfeiffer, and Mark A. Scheel

Phys. Rev. D **93**, 044019 – Published 8 February 2016

Did we find neutrinos from the neutrons star merge?

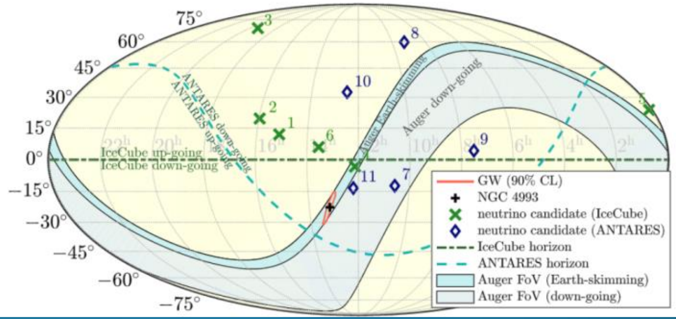
No

No neutrino emission from a binary neutron star merger

By Sílvia Bravo, 16 Oct 2017 09:00 AM

Today, the LIGO and Virgo collaborations have announced the detection of a new gravitational wave event, GW170817, which constitutes the first time that a binary neutron star merger has been detected with the LIGO observatory. This unique observation is even more compelling since the same collision was seen by the Fermi and INTEGRAL satellites as a result of a short gamma-ray burst (GRB) and, subsequently, across the electromagnetic spectrum, with radio, optical, and X-ray detections. These observations made it possible for the first time to pinpoint the source location of a gravitational wave event. The source was found to be in a galaxy 130 million light years away, known as NGC 4993.

In a joint effort by the ANTARES, IceCube, Pierre Auger, LIGO, and Virgo collaborations, scientists have searched for neutrino emission from this merger. The search looked for neutrinos in the GeV to EeV energy range and did not find any neutrino in directional coincidence with the host galaxy. The nondetection agrees well with our expectation from short GRB models of observations at a large off-axis angle, which is most likely the case for the GRB detected in conjunction with GW170817. These results have just been submitted to *The Astrophysical Journal*.

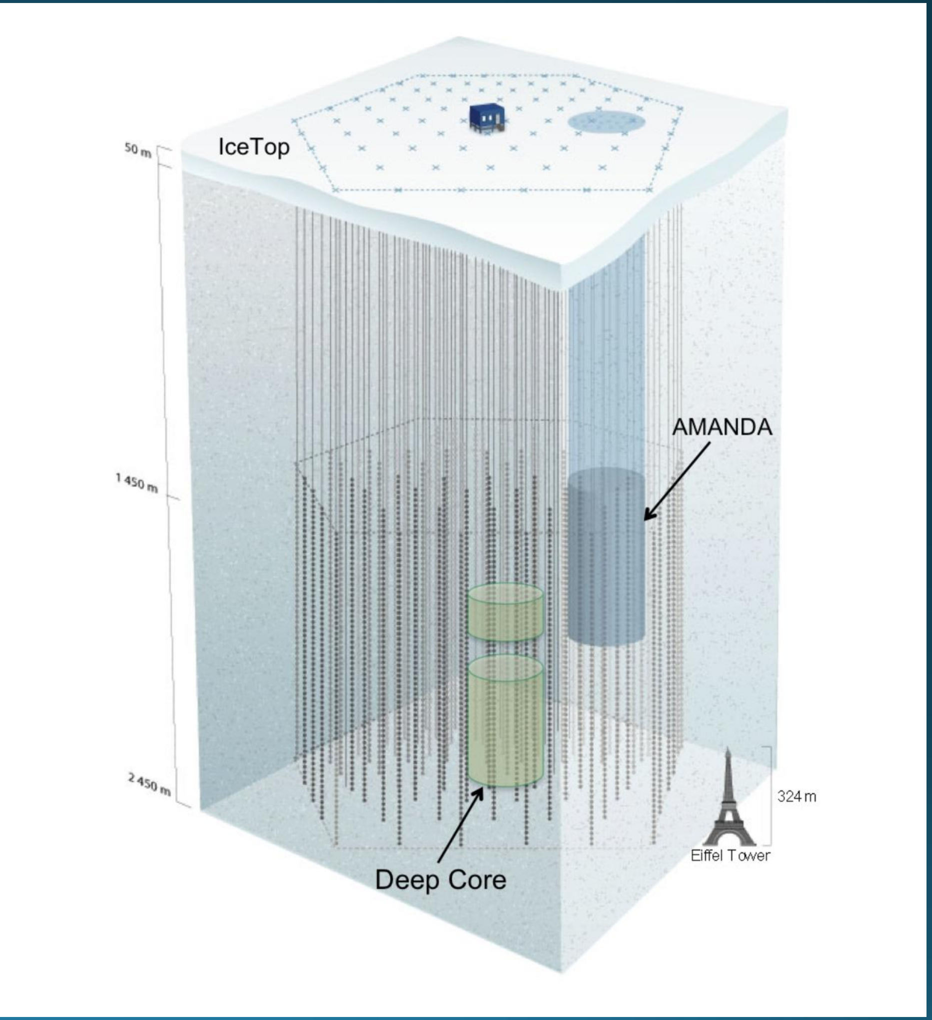


Icecube experiment

- South pole

- Looks for neutrinos from astrophysical sources:
    - exploding stars,
    - gamma-ray bursts,
    - black holes and
    - neutron stars

- one cubic kilometer of ice + 5160 in-ice sensitive light detectors



Neutrino oscillation physics

ν $= 20\% \, \nu_{sour} + 50\% \, \nu_{sweet} + 30\% \, \nu_{salt}$

ν $= 20\% \, \nu_{sour} + 60\% \, \nu_{sweet} + 20\% \, \nu_{salt}$

ν $= 30\% \, \nu_{sour} + 40\% \, \nu_{sweet} + 30\% \, \nu_{salt}$

Neutrino oscillation physics

ν $\rightarrow$ ν

$$\neq$$

$\overline{\nu}$ $\rightarrow$ $\overline{\nu}$

The particle zoo

https://www.particlezoo.net/

References

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