Neutrinos and the Case of the Missing Antimatter

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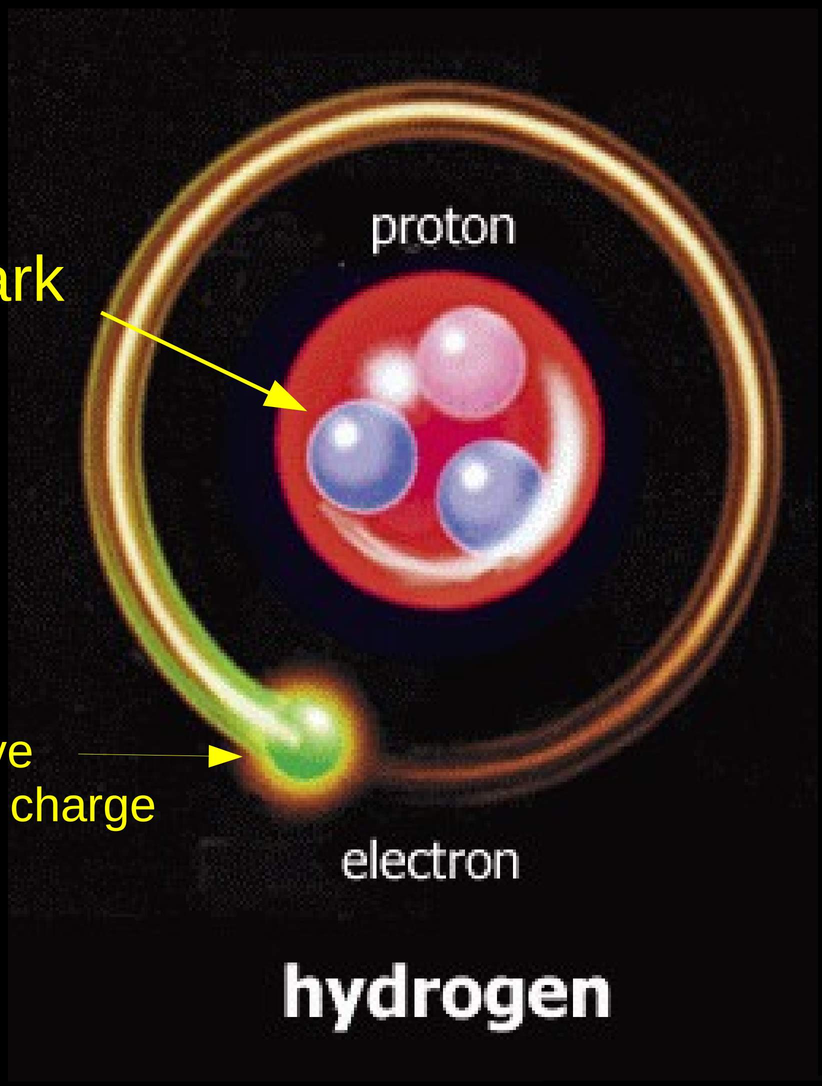
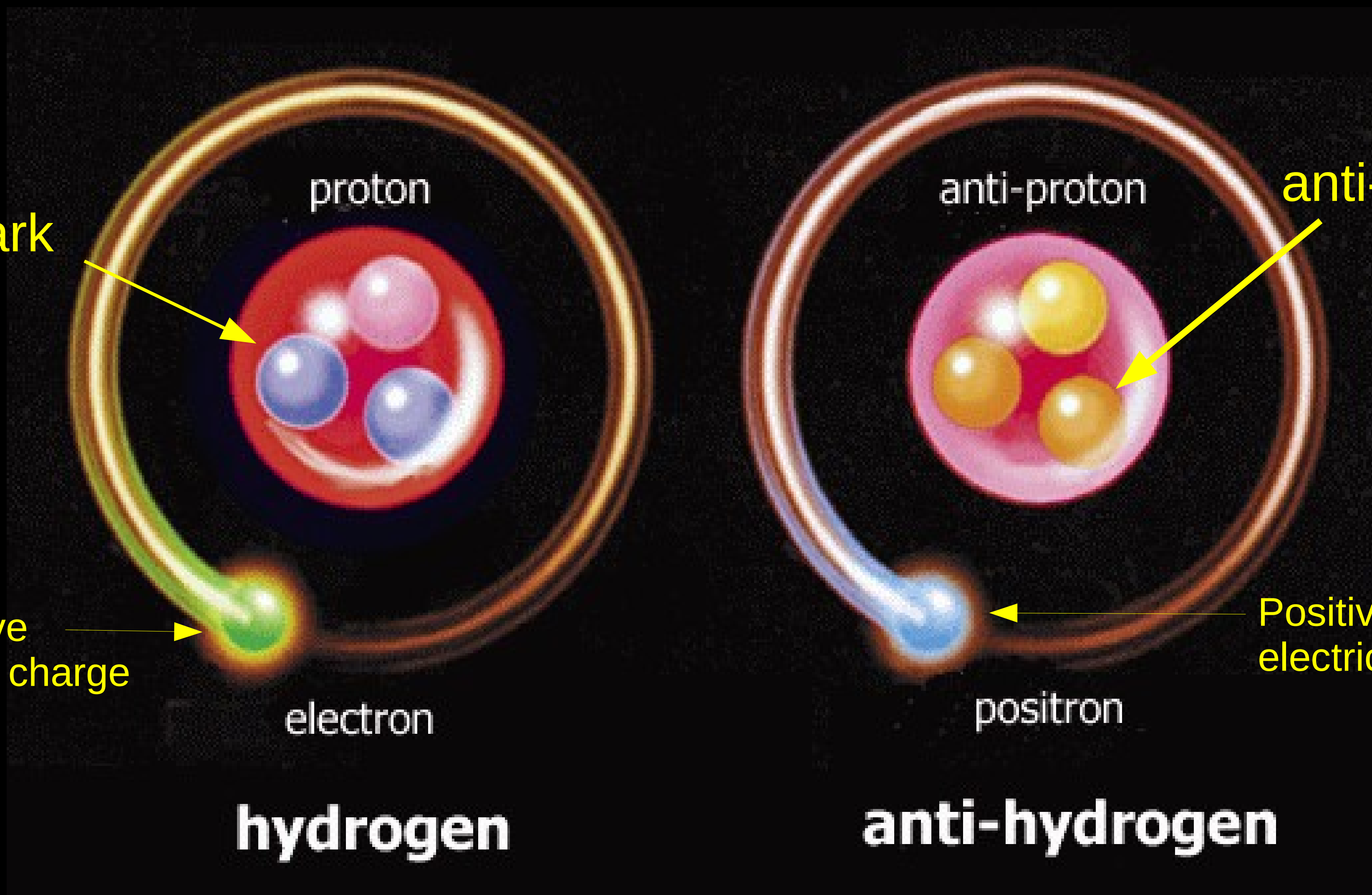
Where is all the antimatter?

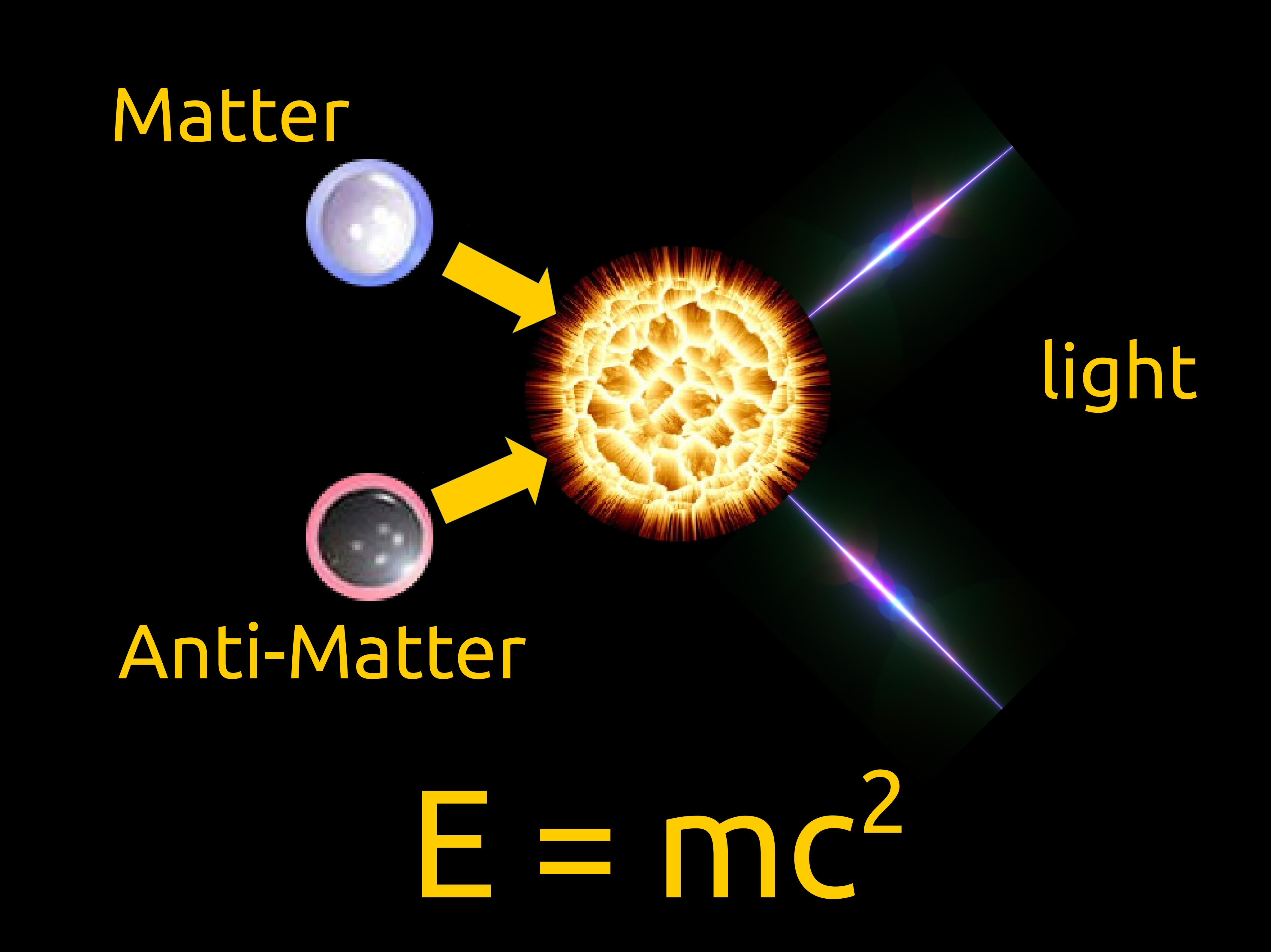
Matter

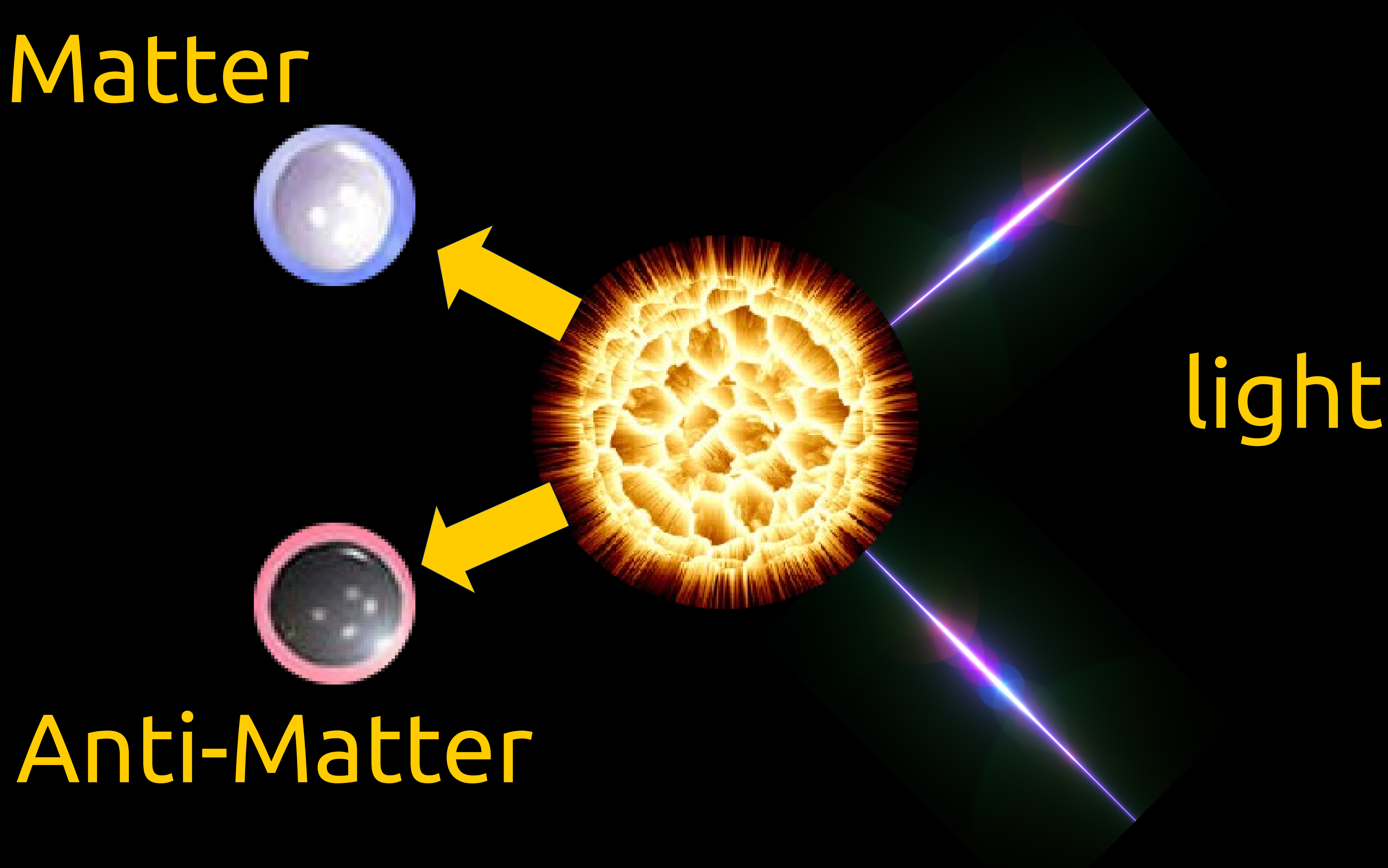


Matter Anti-Matter



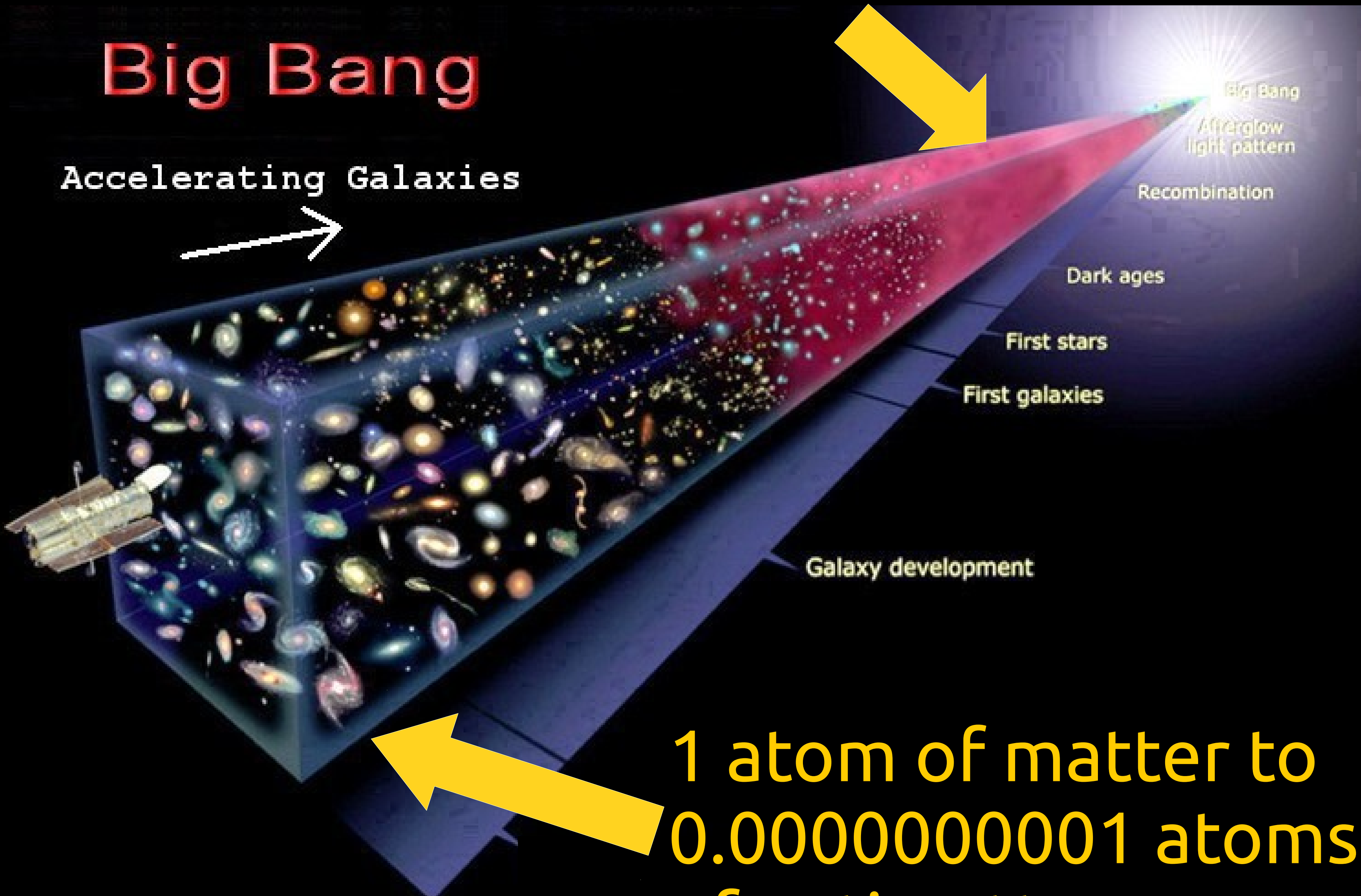
Predicted by Dirac in 1928
Discovered by Anderson in 1932


Matter
light
Anti-Matter
E = mc2



The reverse reaction should also happen with the same probability

Equal amounts of
matter and antimatter



1 atom of matter to
0.000000001 atoms
of antimatter

Neutrinos

The smallest, most insignificant (yet most common) particle in the cosmos may just hold the reason!

This particle is called the *neutrino*

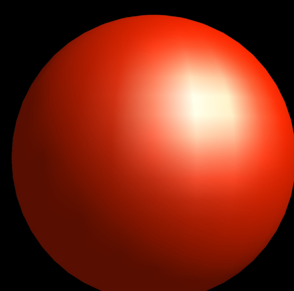
So what is a neutrino?

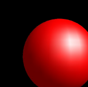
Neutrinos are the second most common particle in the universe. They are produced whenever something radioactively decays

Electron, e

Electron Neutrino, ν_e

Negative Charge

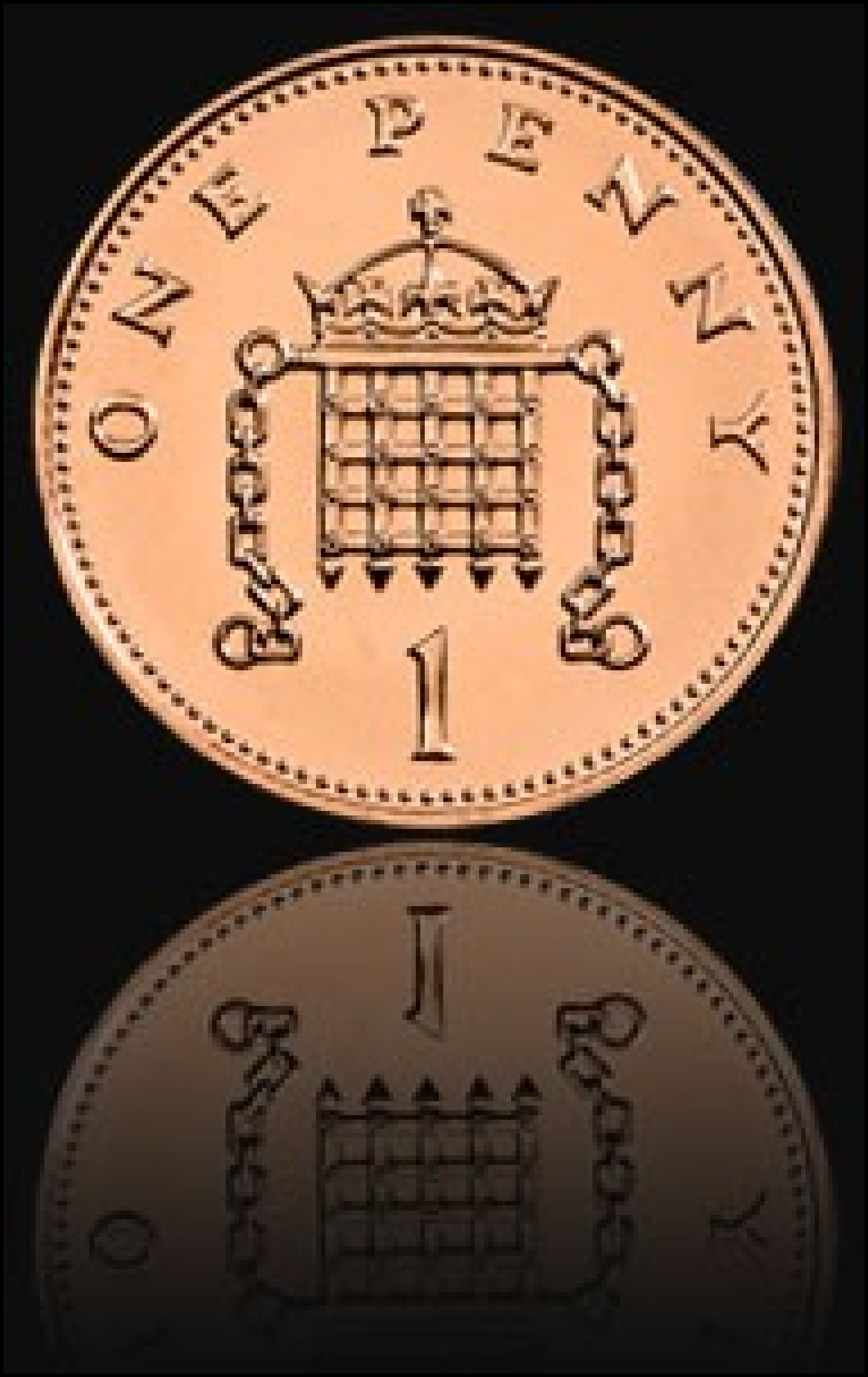


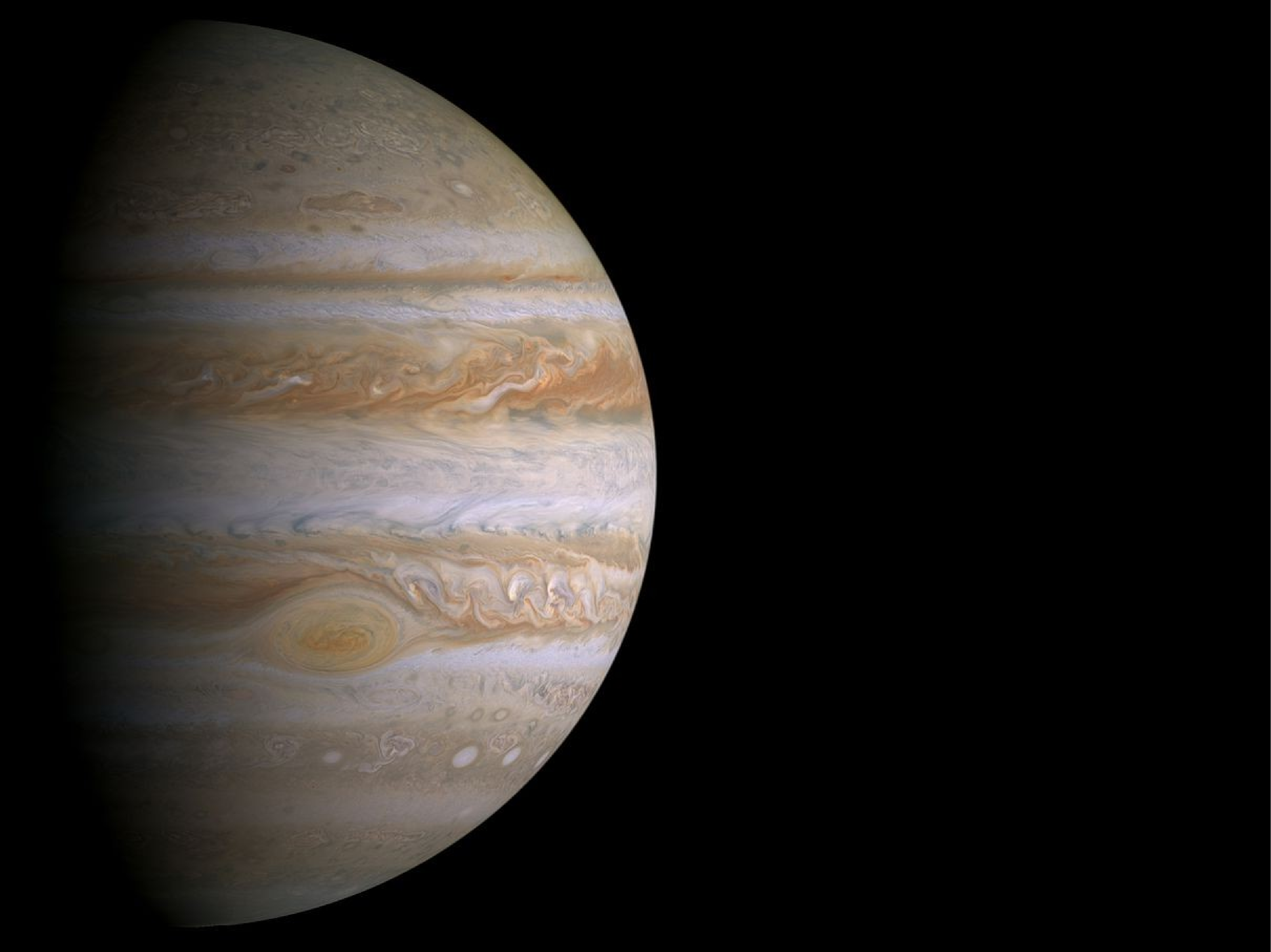


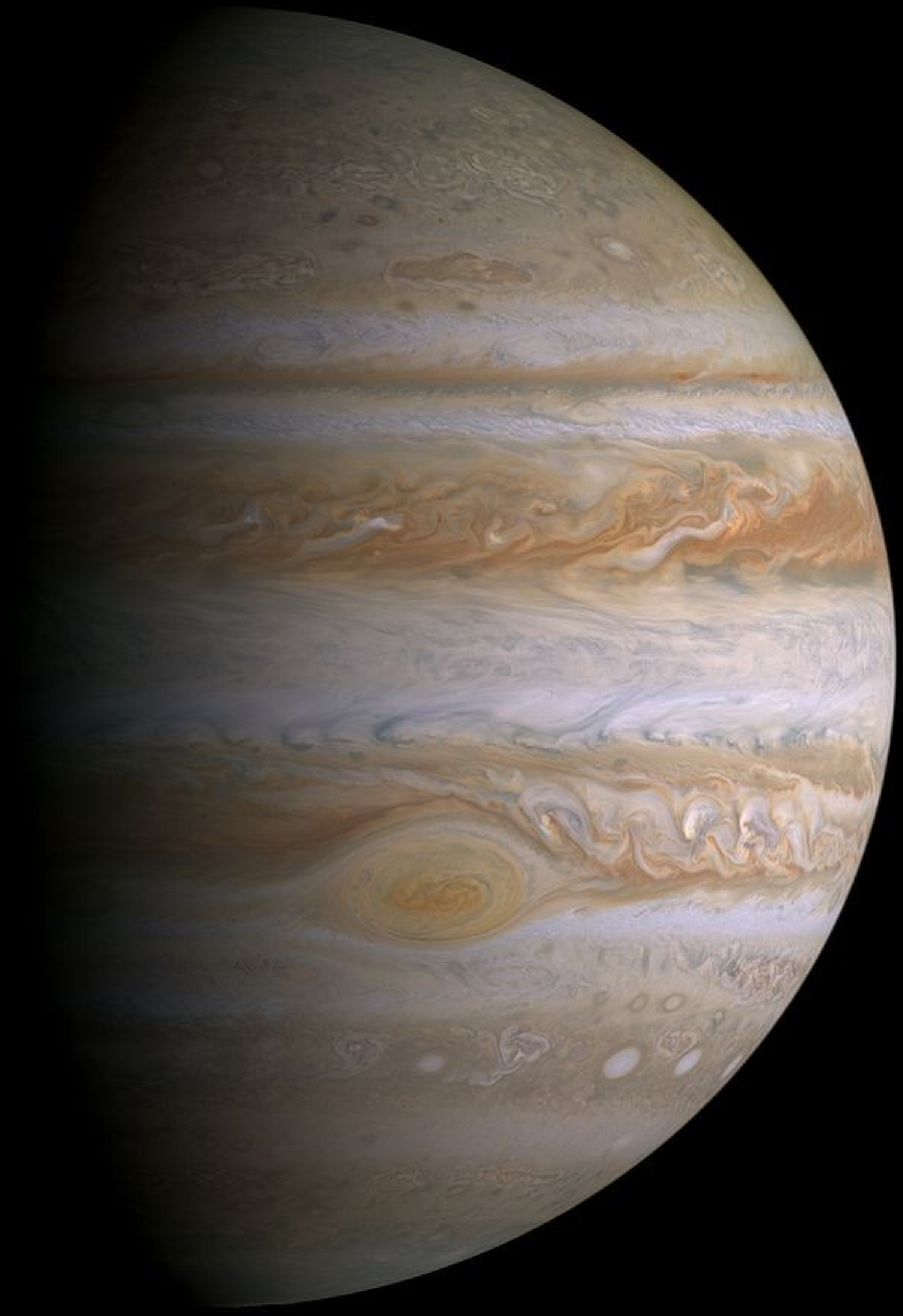
Neutral

Tiny mass (1)

Very tiny mass (<0.0000001)


ONE PENNY
1





x 150

Electron
Neutrino, ν_e

Electron
Antineutrino, $\bar{\nu}_e$

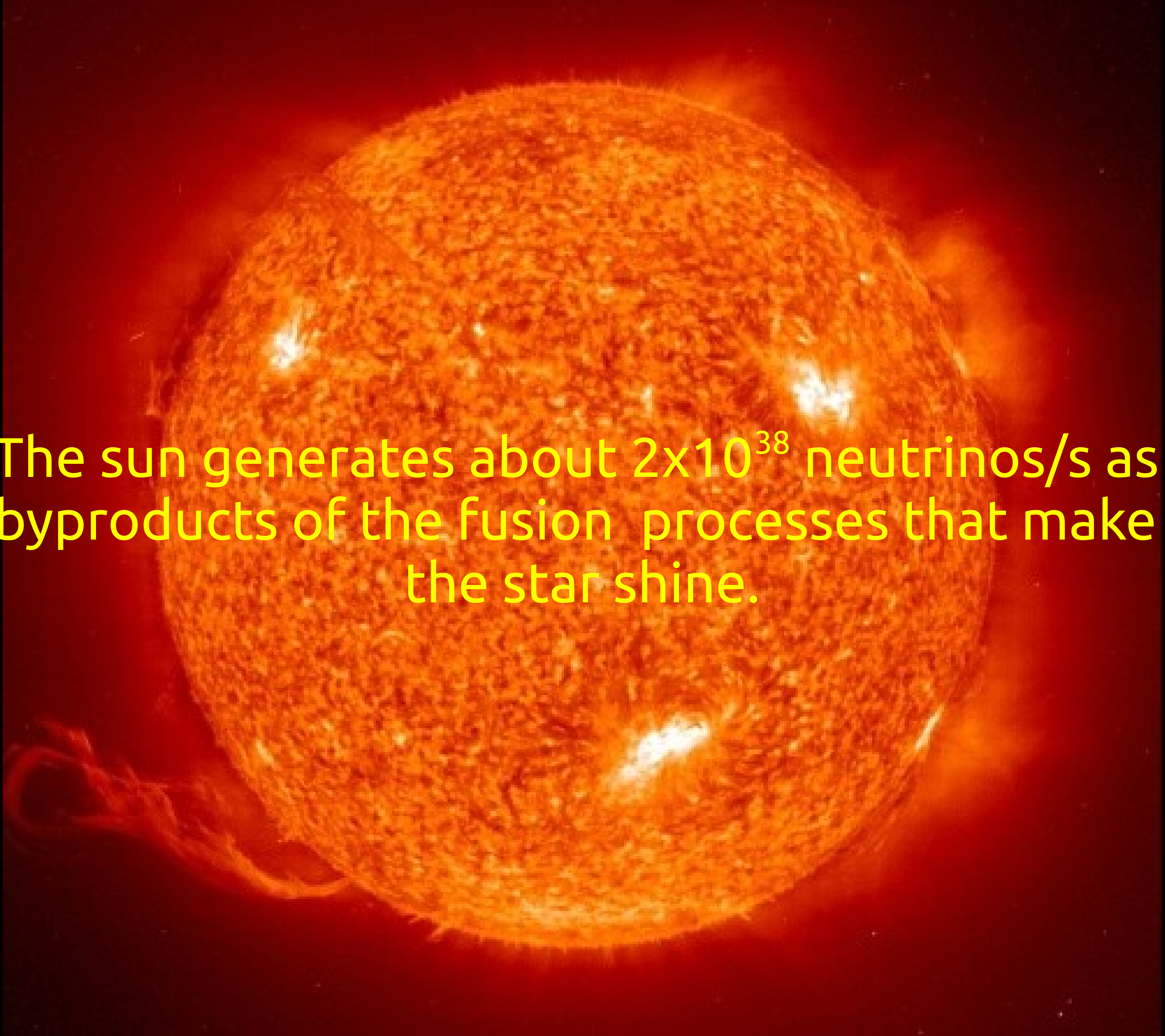
Muon
Neutrino, ν_{μ}

Muon
Antineutrino, $\bar{\nu}_{\mu}$

Tau
Neutrino, ν_{τ}

Tau
Antineutrino, $\bar{\nu}_{\mu}$

3 neutrino Flavours



The sun generates about 2×10^{38} neutrinos/s as byproducts of the fusion processes that make the star shine.

So why don't we notice?

ν are almost ghosts. They interact extremely weakly with matter.

To a neutrino a planet is mostly empty space.


500,000,000,000,000 neutrinos
from the sun just went through
each and every one of you

"The chances of a neutrino actually hitting something as it travels through all this howling emptiness are roughly comparable to that of dropping a ball bearing at random from a cruising 747 and hitting, say, an egg sandwich."

Douglas Adams - Mostly Harmless


Probability ≈ 1 x 10-13
BOEING
Egg Sandwich


ν_e

Probability $\approx 5 \times 10^{-13}$

How do we use neutrinos to study the matter/anti-matter asymmetry?

Electron Neutrino, ν_e

Electron Antineutrino, $\overline{\nu}_e$

Muon Neutrino, ν_μ

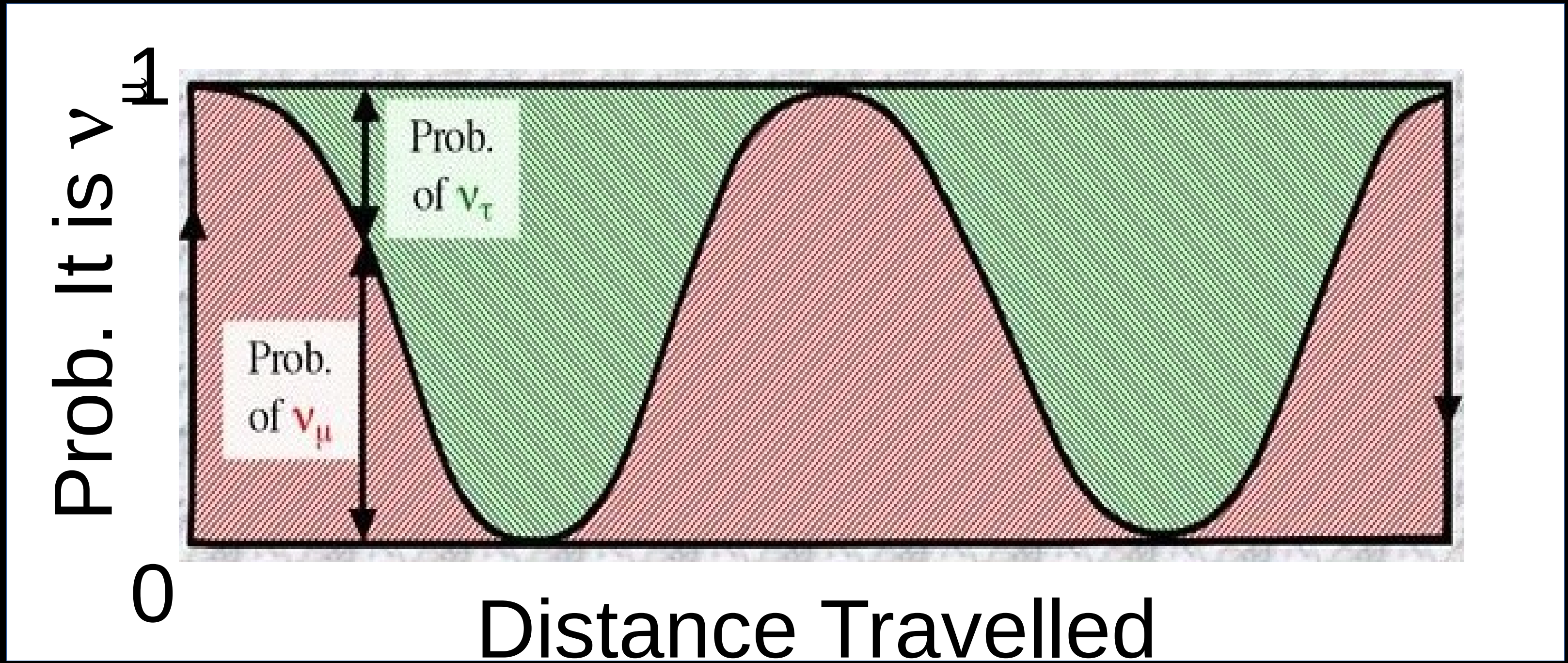
Muon Antineutrino, $\overline{\nu}_\mu$

Tau Neutrino, ν_τ

Tau Antineutrino, $\overline{\nu}_\mu$

3 neutrino <u>Flavours</u>

Neutrino Flavour Oscillations



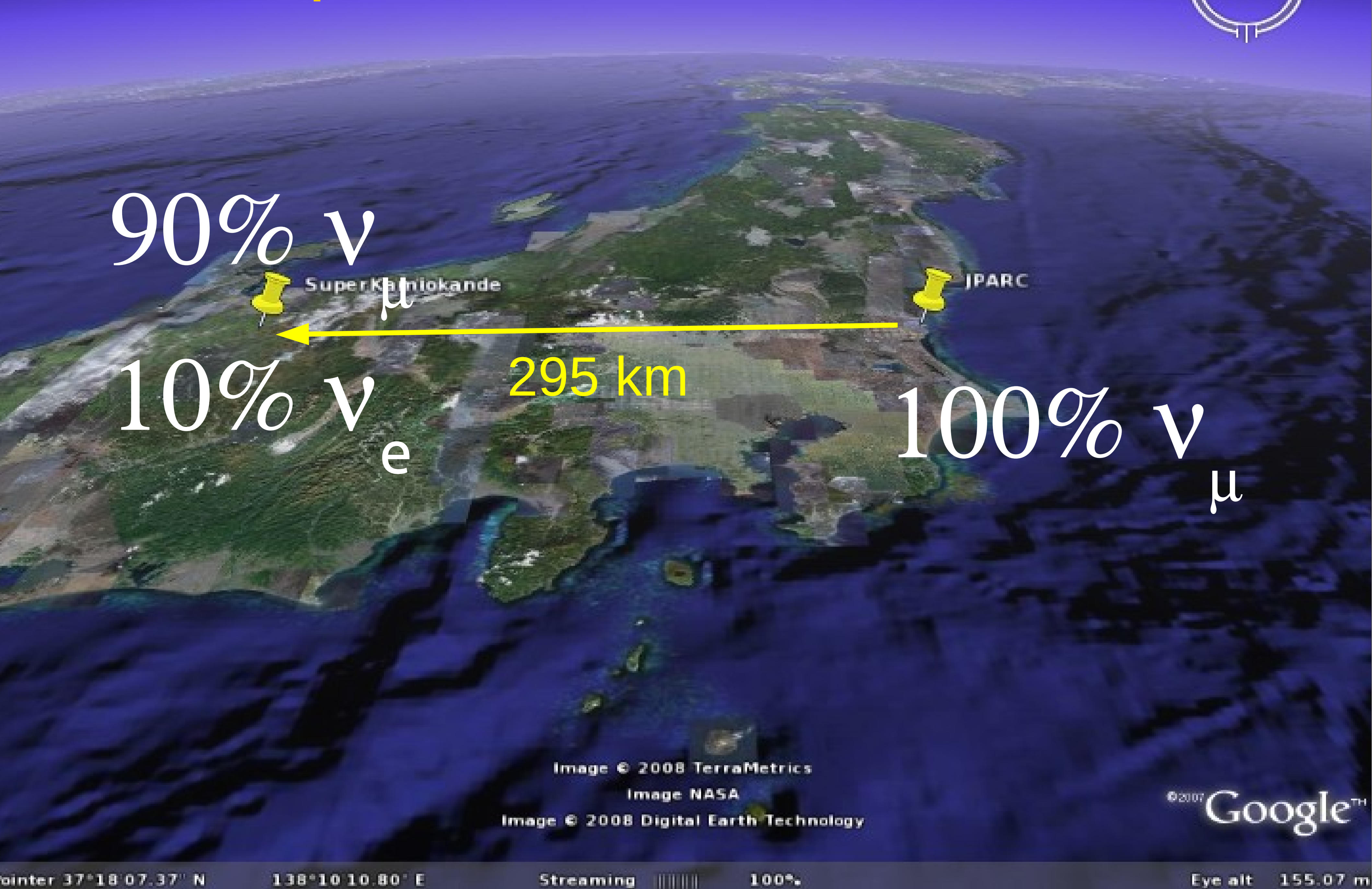
How do we use this?

$$Prob\left(\nu_{\mu} \rightarrow \nu_{e}\right) \neq Prob\left(\overline{\nu_{\mu}} \rightarrow \overline{\nu_{e}}\right)$$

Then neutrinos behave differently from anti-neutrinos

An idea floating around suggests that, if this happens, then the same thing will happen to matter and anti-matter

T2K Experiment



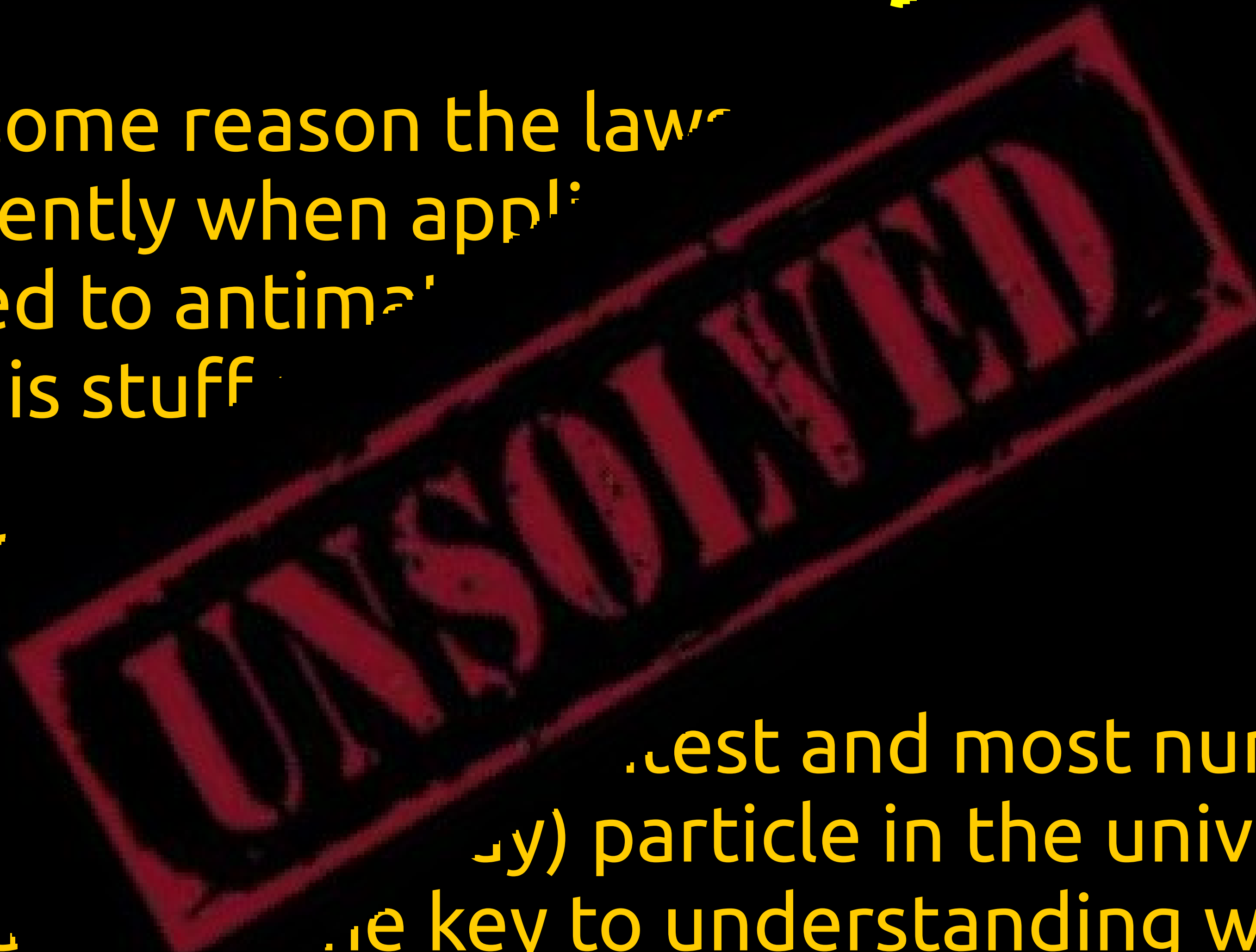
The case of the missing antimatter

- For some reason the laws of physics behave differently when applied to matter than when applied to antimatter. This is the reason why there is stuff around at all.

- We don't know why (yet)

- The neutrino – the lightest and most numerous (but hardest to study) particle in the universe may just hold the key to understanding why we are here at all.

The case of the missing a… atter



- For some reason the law… e differently when appl… n applied to antima… there is stuff …
- We …
- Th… …test and most numerous (but … …y) particle in the universe may ju… …e key to understanding why we are her… …all.

The case of the missing a atter

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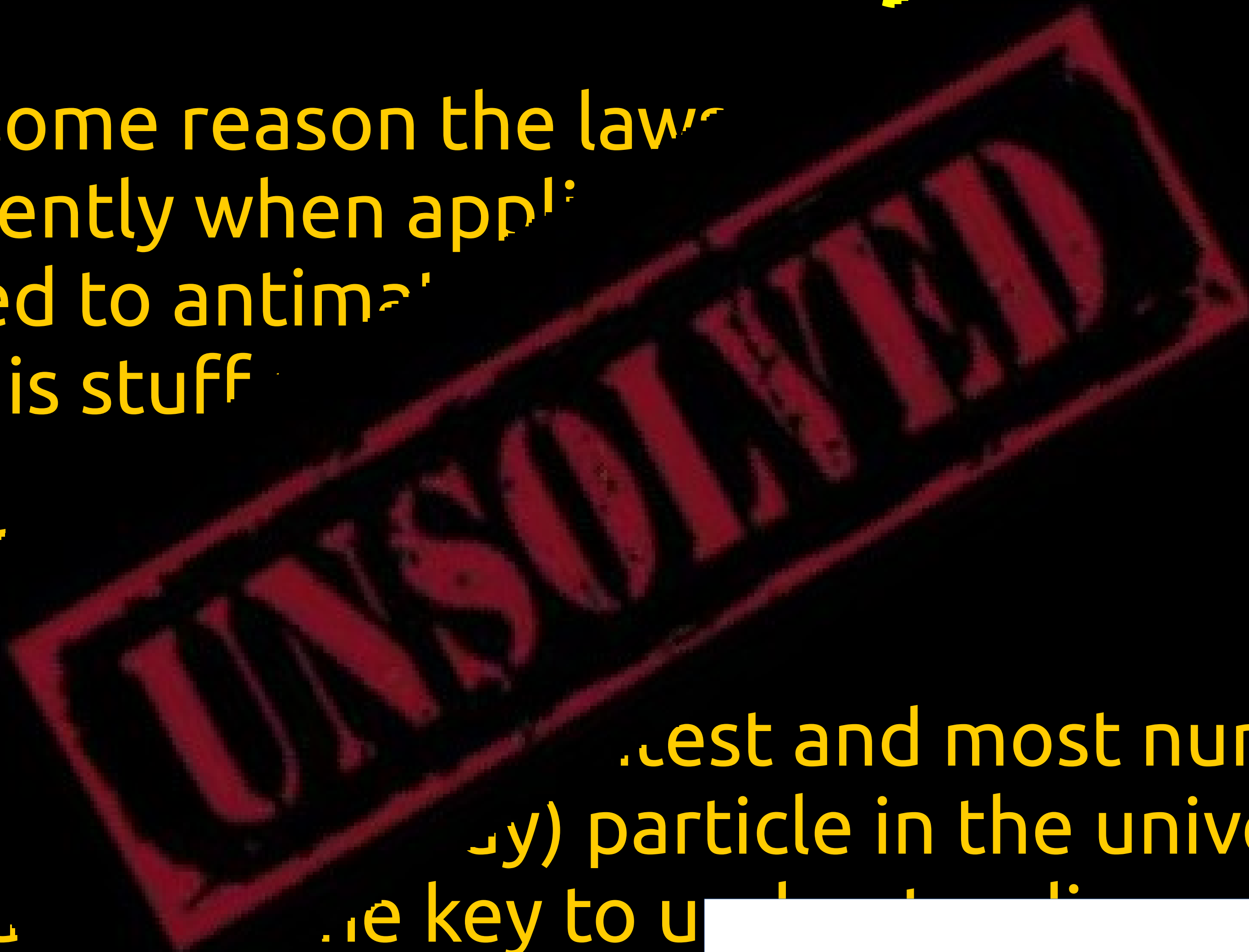


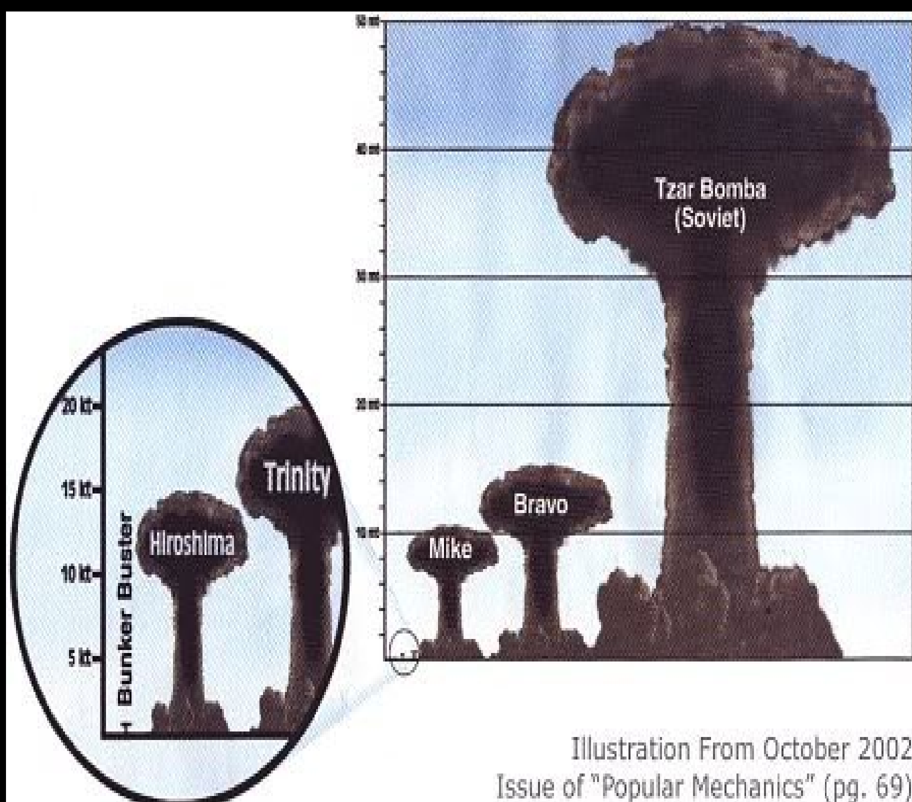
So far.........

There *is* a difference between the physics of matter and antimatter. It's name is *CP Violation*

LHCb

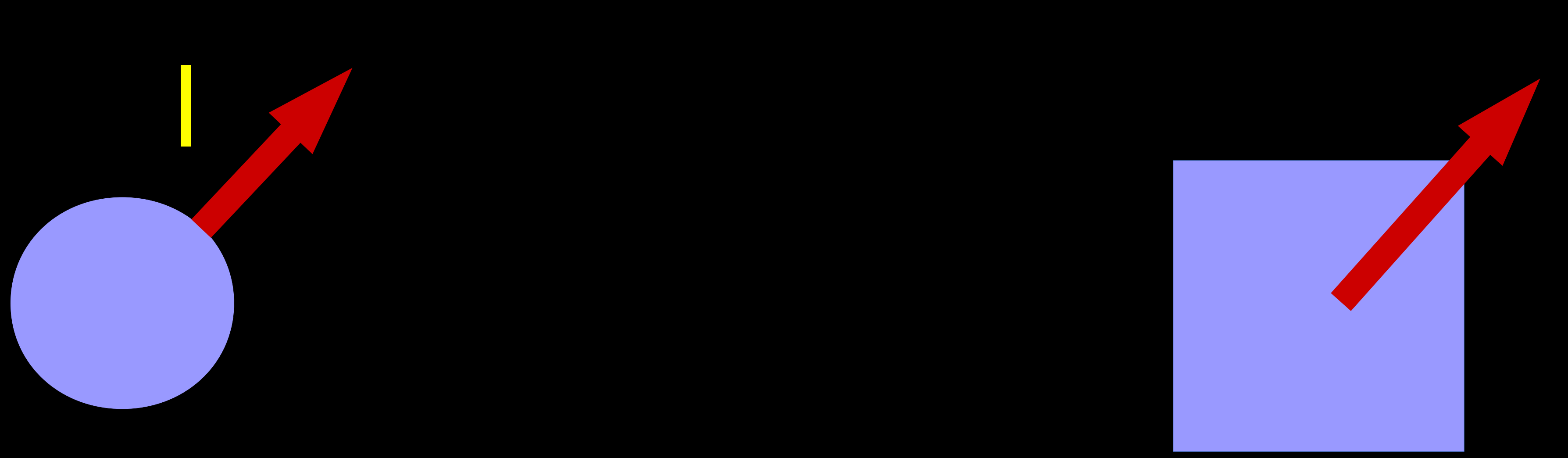
The LHC will study this by looking differences between particles called B^0 and $\bar{B}^0$ mesons

1 kilogram of matter
+
1 kilogram of antimatter



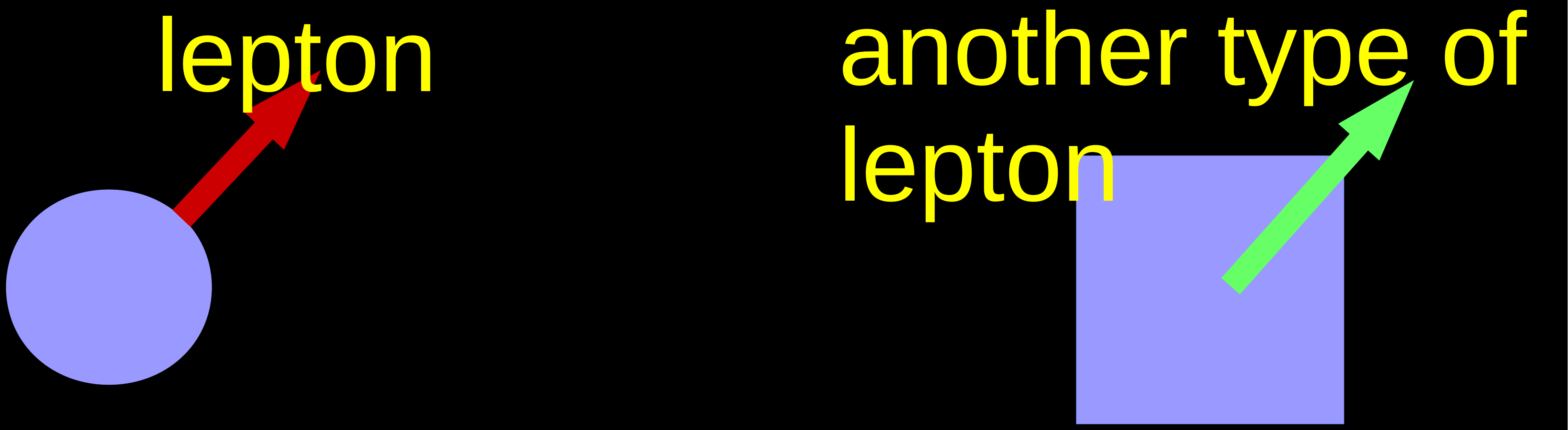
Neutrino Oscillations

THE most important discovery about neutrinos in the last 20 years

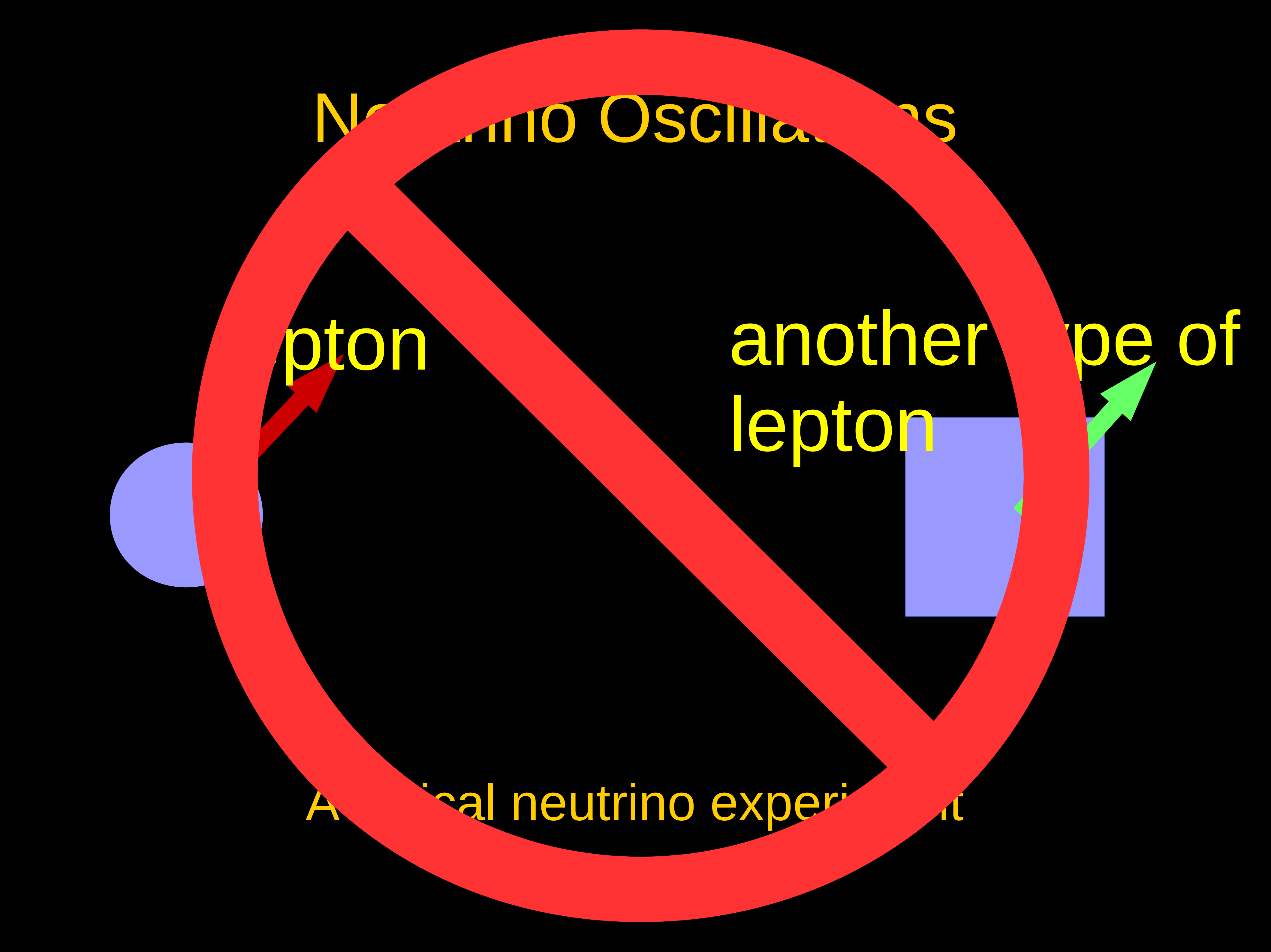


A typical neutrino experiment

Neutrino Oscillations



A typical neutrino experiment


another
of
lepton
neutrino

It's Quantum.....

$$|\nu_\alpha> = \sum_{i=1}^{3} U_{\alpha i} |\nu_i>$$ where $U_{\alpha i}$ is a unitary matrix

$$|\nu_k(t,x)> = e^{i(E_k t - p_k x)} |\nu_k(0,0)> \rightarrow P(\nu_\alpha(0,0) \rightarrow \nu_\beta(t,x)) = |<\nu_\beta(t,x)|\nu_\alpha(0,0)>|^2$$

$$|<\nu_\beta(t,x)|\nu_\alpha(0,0)>|^2 = \sum_k \sum_j U_{\alpha k} U^*_{\alpha j} U_{\beta k} U^*_{\beta j} e^{i((E_j - E_k)t - (p_j - p_k)x)}$$

$$(E_j - E_i)t - (p_j - p_i)x = (\sqrt{p_j^2 + m_j^2} - \sqrt{p_i^2 + m_i^2})x - (p_j - p_i)x =$$

$$(p_j(1 + \frac{1}{2}\frac{m_j^2}{p_j}) - p_i(1 + \frac{1}{2}\frac{m_i^2}{p_i})) \approx \frac{\Delta m_{ij}^2}{4E}$$

$$U = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix} \longrightarrow P(\nu_\alpha(0,0) \rightarrow \nu_\beta(t,x)) = \sin^2(2\theta)\sin^2(\frac{\Delta m_{12}^2 L}{4E})$$

Positron Emission Tomography (PET)