Matter-anti-matter asymmetry: is there a unified theory?

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1 Overview

- From atoms to elementary particles
- "Oscillation" between particle species
- A few large experiments - LHC, SuperK, SNO, Ice-Cube
- Dreams of an elegant description - unification, superstring theory ...

2 When are particles "elementary"?

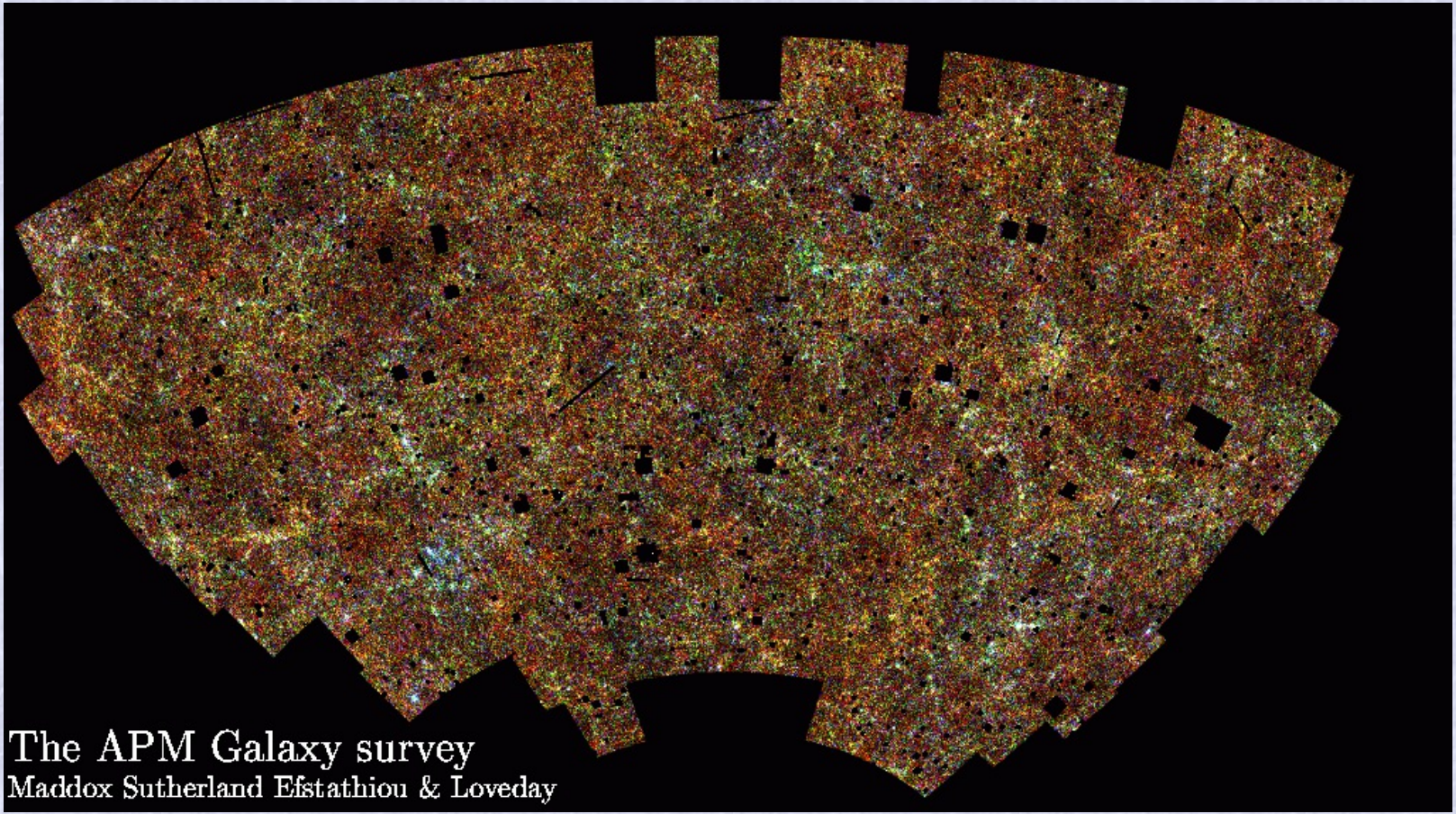
The progression - atoms in theory and atoms in pracitce

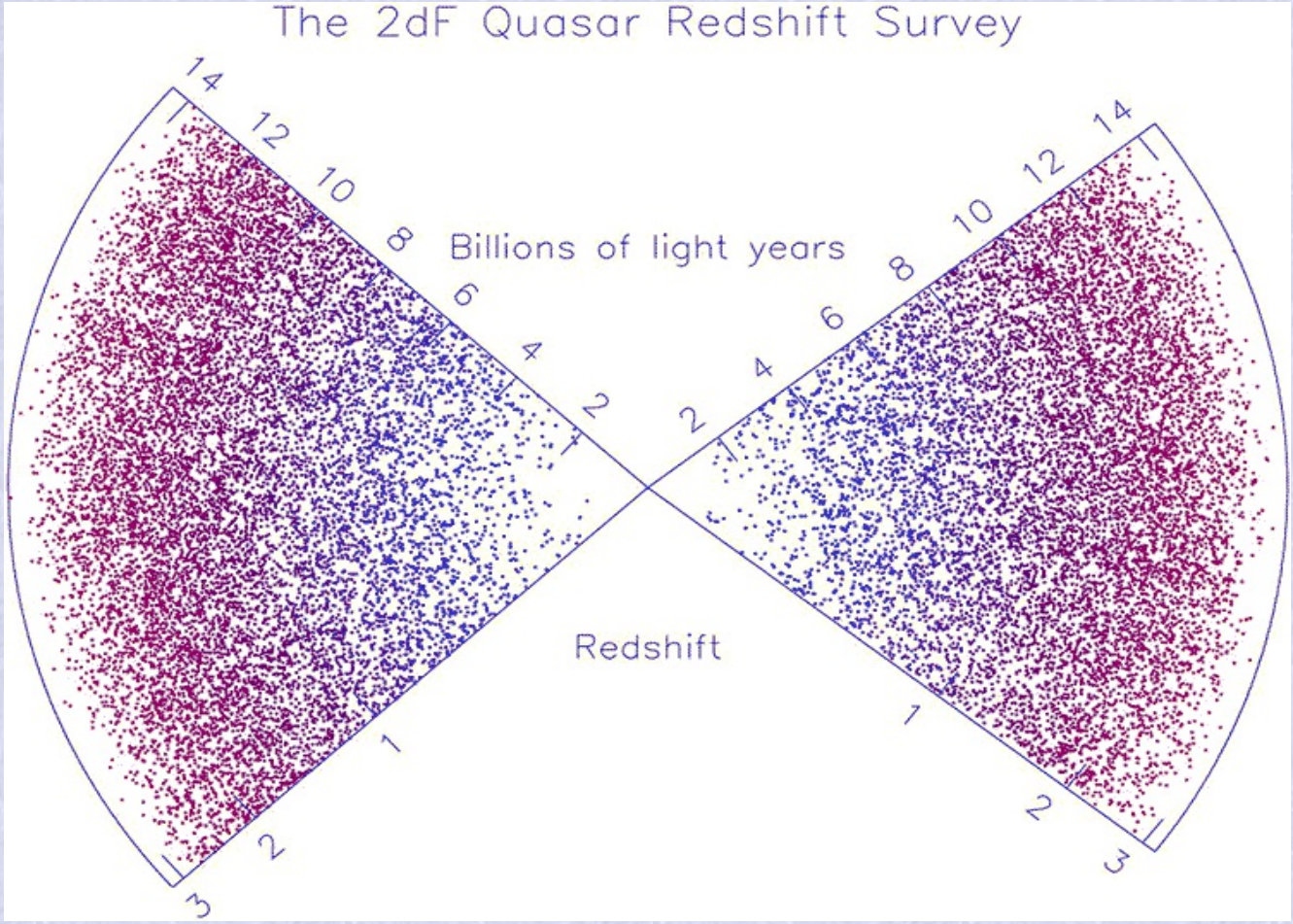
- Philosophy : Democritus "atom"; Kanada "kana"
- Evidence based science : Atoms and molecules Dalton, Avogadro, Canizzaro, Boltzmann 1810's ... to 1890's
- Becquerel discovers radioactivity 1890's
- Electron -> Thompson, Millikan ... 1890's ; 1910's

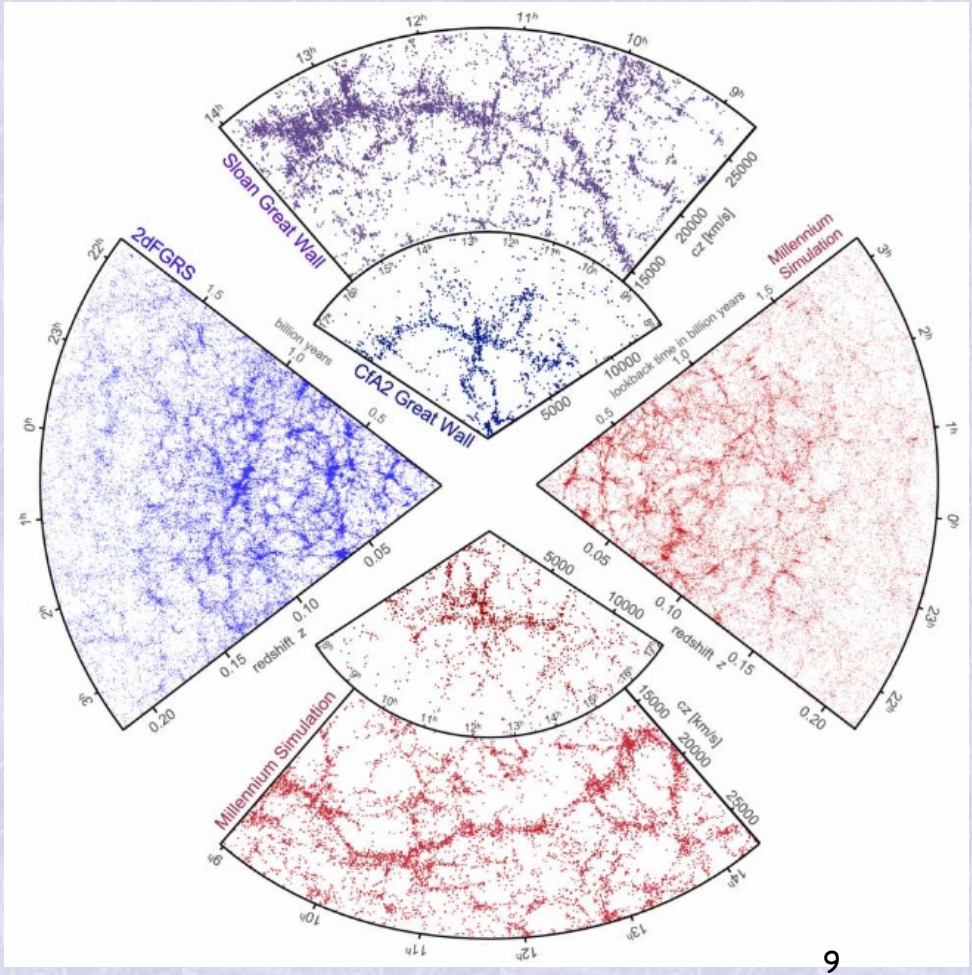
- Rutherford shoots through the atom 1908
- Positron is discovered in cosmic rays 1931
- Chandwick establises the neutron 1932

3 Matter anti-matter asymmetry

- No smoking gun signs of anti-matter
- Uniform distribution of galaxies - with irregularities within statistical tolerance
- *Where are all the anti-protons?* .... and positrons?
- "Baryon to photon ratio" : $\eta = \frac{n_B - n_{\bar{B}}}{s_\gamma} = 5 \times 10^{-10}$
  - From calculation using laboratory fusion rates
  - Observation of interstellar abundances


The APM Galaxy survey
Maddox Sutherland Efstathiou & Loveday

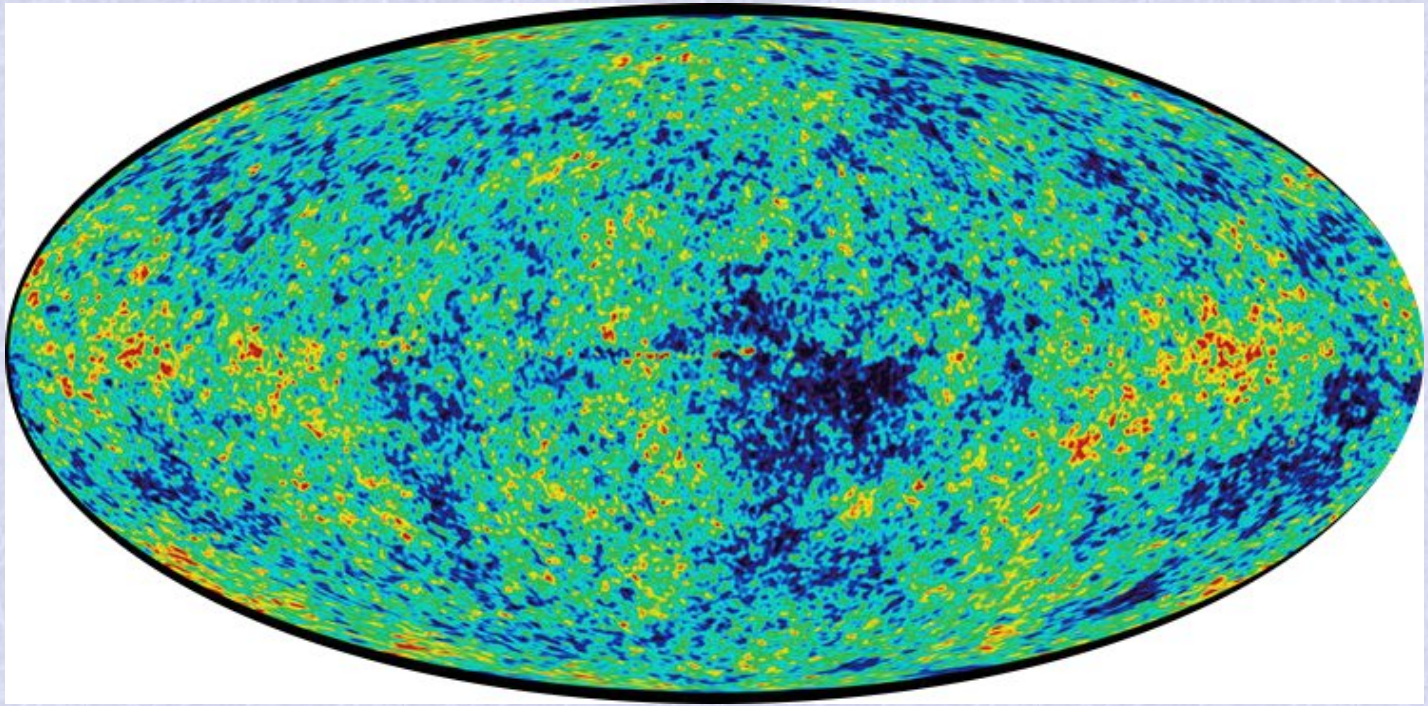

The 2dF Quasar Redshift Survey
Billions of light years
Redshift
14
12
10
8
6
4
2
1
2
3



Springel et al
Nature 2006

Surveys upper left
simulations lower right

3.1 Cosmic Microwave background Nobel 2006)



- The Universe as a whole a single glowing ball 13 billion years ago!!
- Its light today is "red shifted" into microwaves and is found to have almost exactly the same temperature 2.73 K in every direction in the sky.

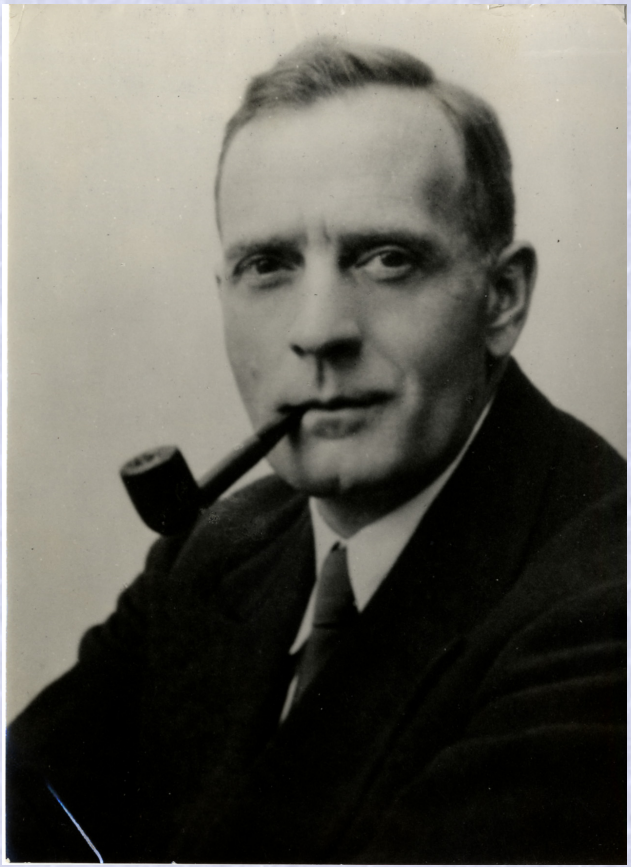
Declaration : Typeset using TEXMACS ...

3.2 Cosmology becomes science

The Universe is not willed as a simplistic design ...

.... its simplicity is the outcome elegant dynamics

- Einstein believed in static Newtonian universe
- Friedmann 1921 - 22 found dynamical solutions
- Edwin Hubble boldly drew the straight line 1929 ....
- LeMaitre grasped it all 1926 but shared cautiously



Edwin Hubble

Henrietta Leavitte

3.3 Particle cosmology is born ...

- 1920's the decade of expanding Universe
  - Friedmann, Hubble, LeMaitre ...
- 1948-49 Nucleosynthesis and CMB in "Big Bang" universe
  - Alpher "Bethe" and Gamow; Alpher and Herman
- 1964-65 : the classic year
  - Accidental discovery of cosmic microwave background

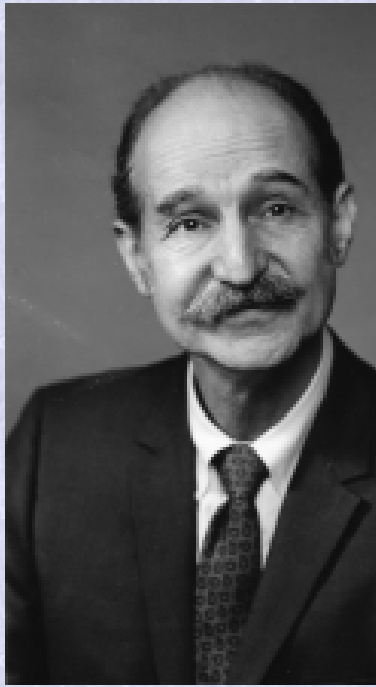
- Discovery of *CP* violation in *K*-meson decays

3.4 The cosmology – nuclear physics connection

- Alpher, "Bethe" and Gamow paper estiamtes He to H ratio 1948
- Alpher and Herman estimate 5K as the temperature of residual photons 1949

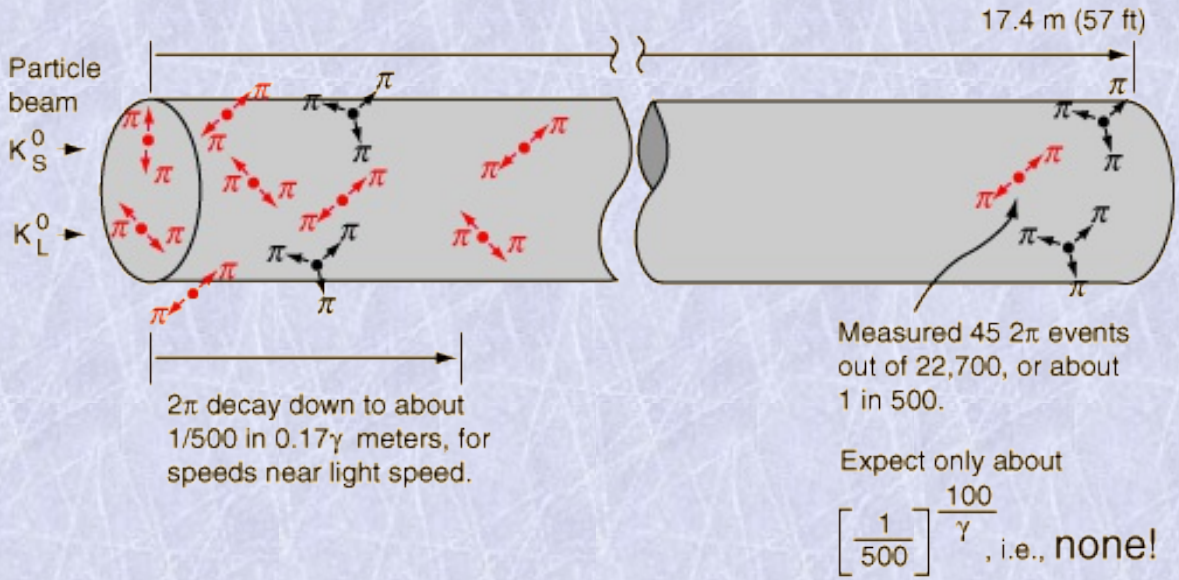
One concerns the MeV scale, the other concerns the eV scale!





Gamow; Alpher; Herman

Discovery of *CP* violation at Brookhaven National Lab 1964



(schematic courtsy hyperphysics website Georgia State U.)

Val Fitch and James Cronin Nobel 1980

Discovery of Cosmic Background

Microwave Receiver

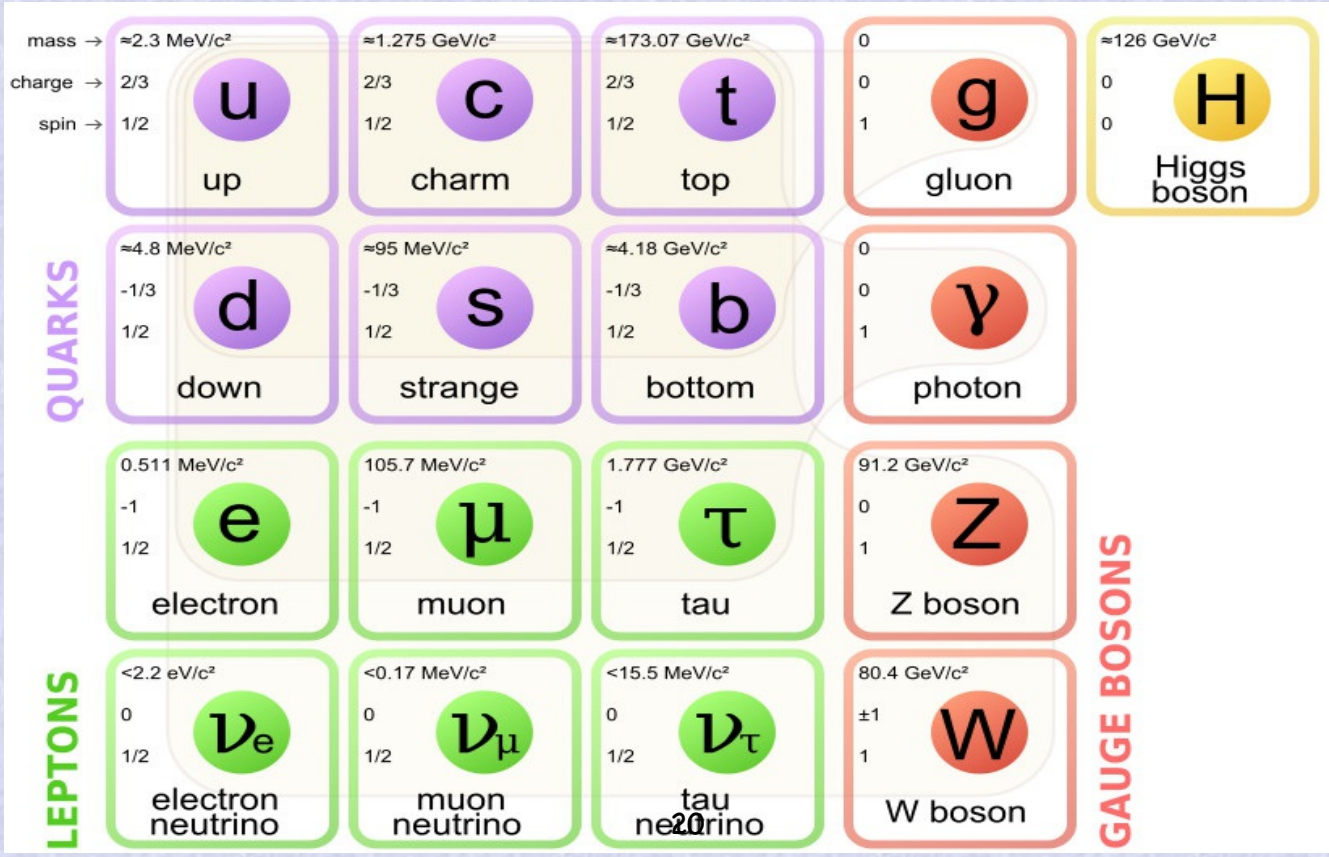
Arno Penzias

Robert Wilson

MAP990045

Nobel 1978

4 Particle "species"



4.1 What defines the species?

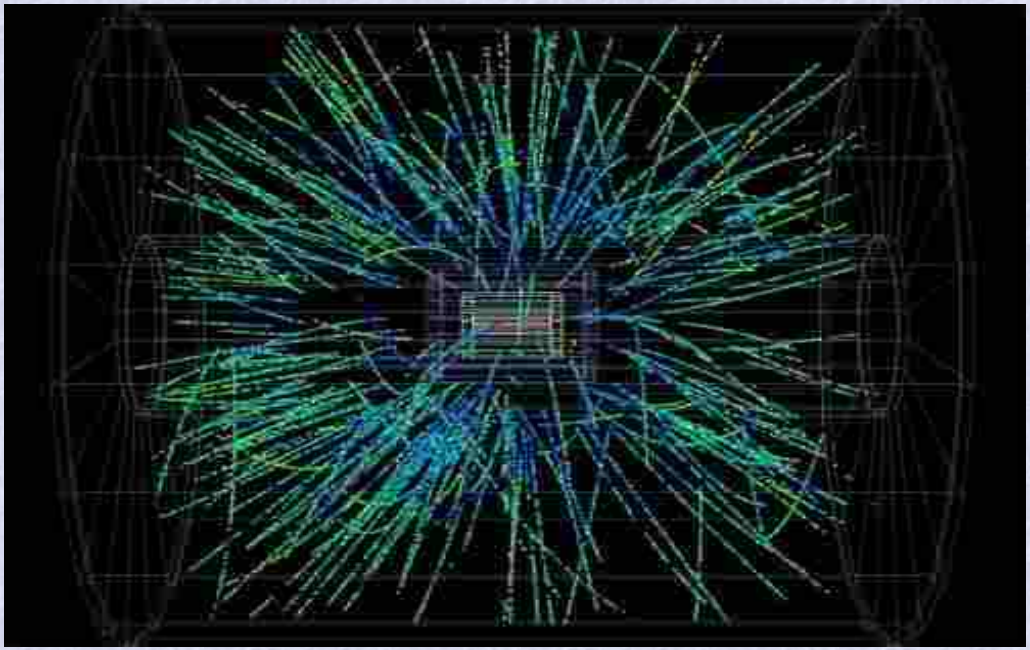
- Mass zero or non-zero
- Intrinsic spin integer or half integer in $\hbar$ units
  - Integer spin-1 Bosons are force carriers
  - Graviton is integer spin-2 boson (not in the table)
  - Half integer spin-1/2 fermions are "matter"
  - Higgs boson, the only particle with spin zero … assists the spin 1 force carriers

- Gauge charges
    i. Strong force charge "color"
    ii. Weak force charge "Weak isospin"
    iii. Electromagnetic charge
- Global "charge" (i) Baryon (ii) Lepton
    i. Flavour of B or L : All charges identical, only mass values differ. 3 families for baryons, 3 families for leptons, each family in both cases has 2 members, totally 6 generations

The main point of this talk :

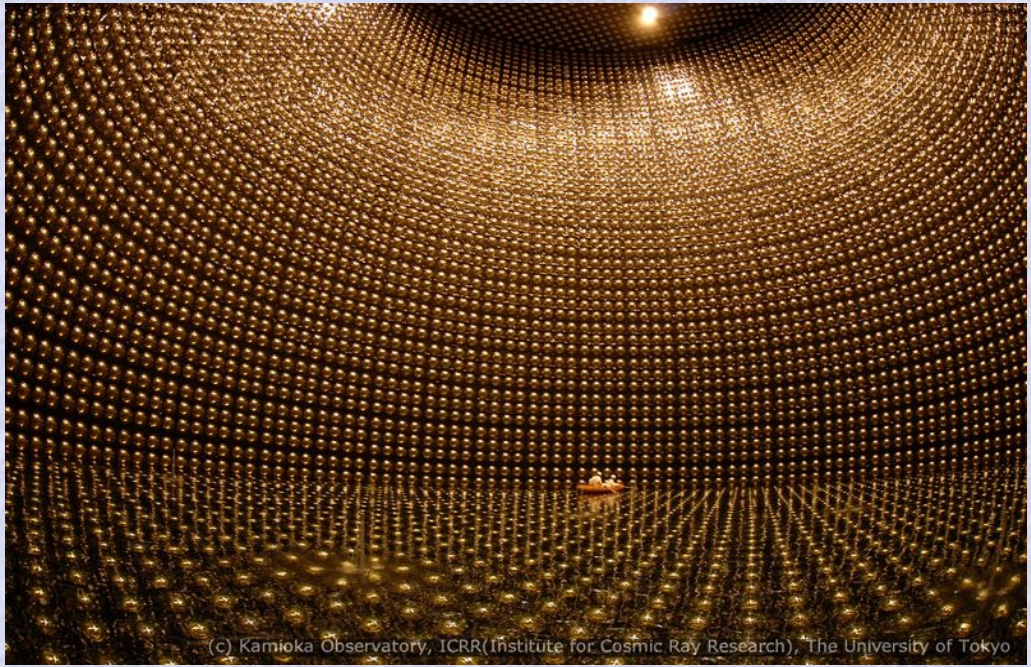
- If baryon or Lepton number can be violated (not really conserved)
- And if Time reversal symmetry also does not hold
- Then the Big Bang can generate the required matter anti-matter asymmetry of the Universe

4.2 The Large Hadronic Collider (LHC)

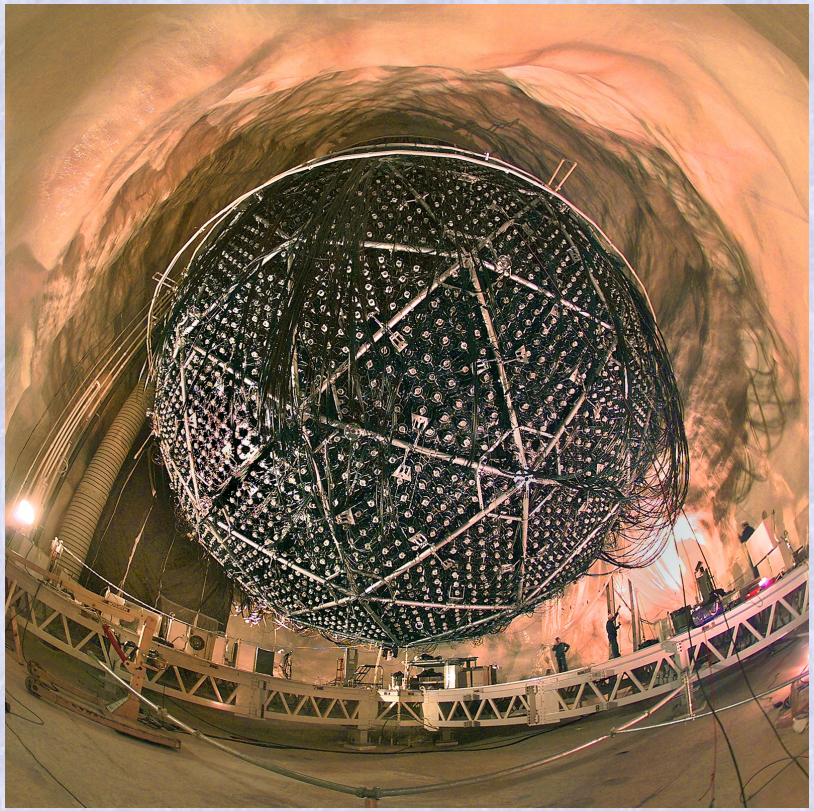


4.3 Hunting the elusive neutrinos

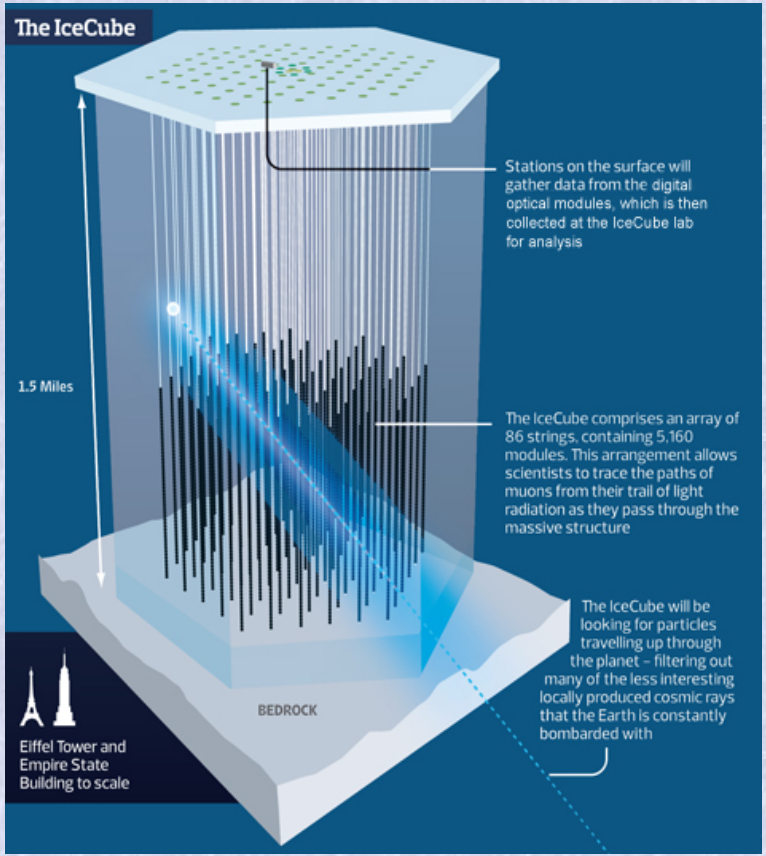
4.3.1 super-Kamiokande Japan



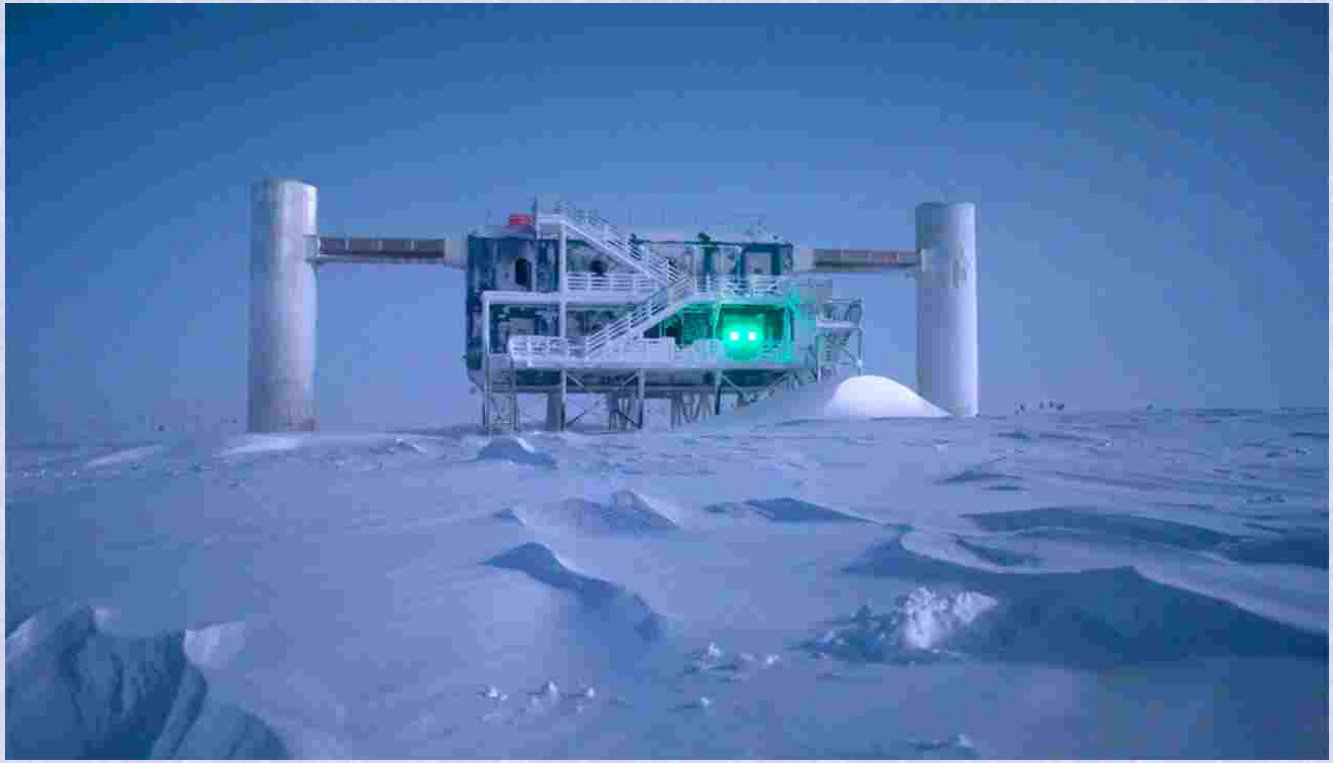
4.3.2 Sudbury Neutrino Observatory Canada



4.3.3 IceCube observatory – Antarctica



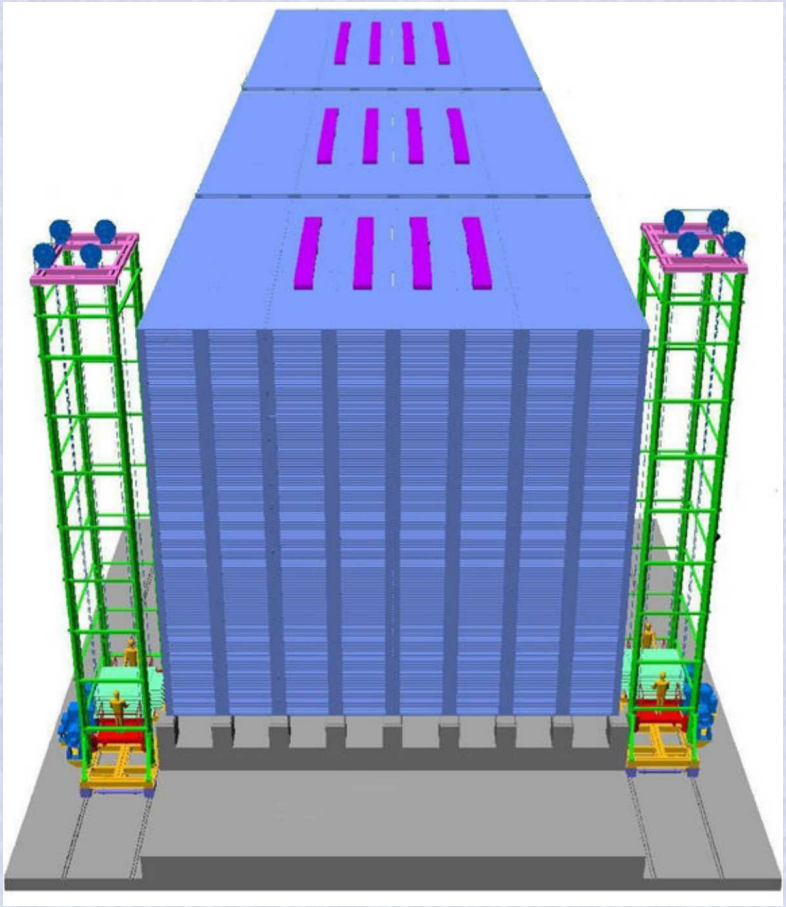
IceCube external view



4.3.4 The proposed India Based Neutrino Observatory (INO)

ICAL detector with 50 kTons iron to make the neutrino scatter

and create a μ lepton (muon) track in Resistive Plate Detectors (RPC's)



To be located under Nilgiri mountains at Theni, Madurai District, TN

5 Mathematics, Technology and Physics

- Why is there naturally occuring matter and no anti-matter (anti-Hydrogen)?
- Why are there three kinds of forces?
  - Grand Unified theory
- LHC, IceCube, SuperKamiokande, INO....
- Hubble Space Telescope, Astrosat I and II, ...

Hope you enjoyed it!

Thanks to TEXMACS