Le Laboratoire de l'Accélérateur Linéaire & ses thèmes de recherche

20 mai 2010

Nicolas Arnaud

- Le LAL : un grand laboratoire de recherche publique (CNRS-IN2P3)
- Une brève histoire des particules
- Un transparent sur l'histoire de l'Univers, du Big Bang à nos jours

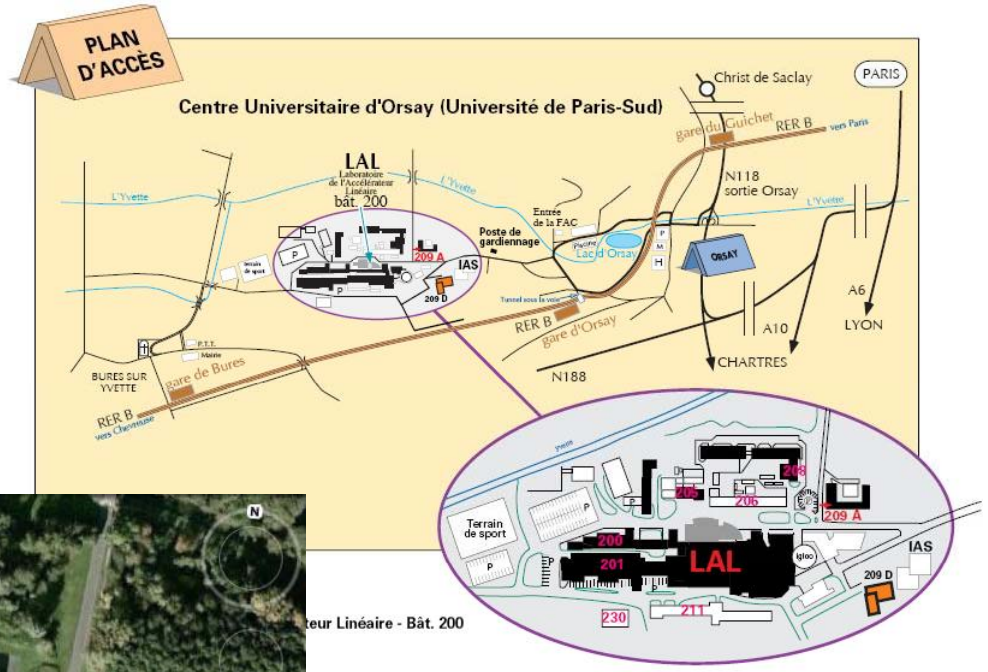
LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

Le LAL

Le Laboratoire de L'accélérateur Linéaire

- Le LAL est situé sur le campus de l'Université Paris Sud (Paris XI), entre Orsay et Bures sur Yvette

- Site web : http://www.lal.in2p3.fr/



- Laboratoire de l'Accélérateur Linéaire : LAL

- Nom historique : le grand accélérateur linéaire a cessé ses activités en 2004. Le LAL vient d'en construire un plus petit, PHIL, pour la R&D.

Présentation générale

- Le LAL est une unité mixte de l'IN2P3/CNRS et de l'Université Paris Sud

- CNRS : Centre National de la Recherche Scientifique
  → Un organisme public de recherche : 32 000 personnes, budget de 3,4 milliards d'€

- IN2P3 : Institut National de Physique Nucléaire et de Physique des Particules
  → Un des dix instituts [structures regroupant plusieurs disciplines proches] du CNRS
  → L'un des deux instituts nationaux ; créé en 1971

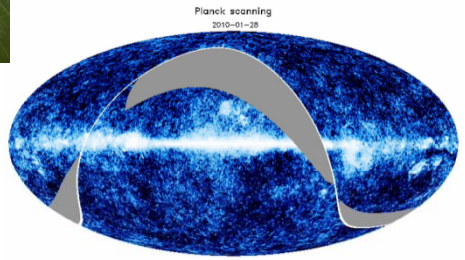
- Unité mixte : le LAL rassemble des chercheurs CNRS et des enseignants-chercheurs qui dépendent de l'Université Paris Sud et enseignent sur le campus

cnrs IN2P3
Institut national de physique nucléaire et de physique des particules

UNIVERSITÉ PARIS-SUD 11

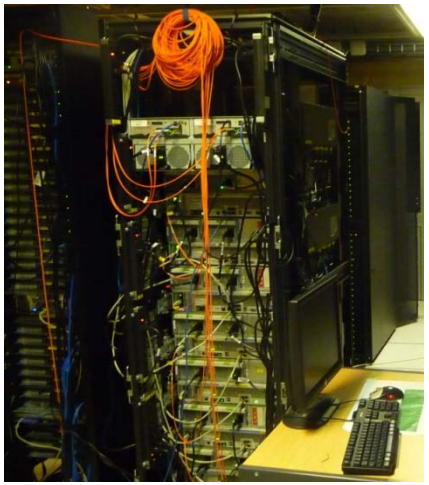
Les expériences au LAL

- Le plus grand laboratoire de l'IN2P3/CNRS consacré à la physique des particules et à la cosmologie :
  - ~120 chercheurs (70% / 30%) répartis en une douzaine de groupes
  - ~220 ingénieurs et techniciens
  - Budget annuel d'environ 20 millions d'€



- Implication dans des expériences sur plusieurs continents :
  Europe, Etats-Unis, Argentine, Japon et même… dans l'espace

- Six services techniques, beaucoup d'activités R&D sur accélérateurs



Le domaine de recherche du LAL

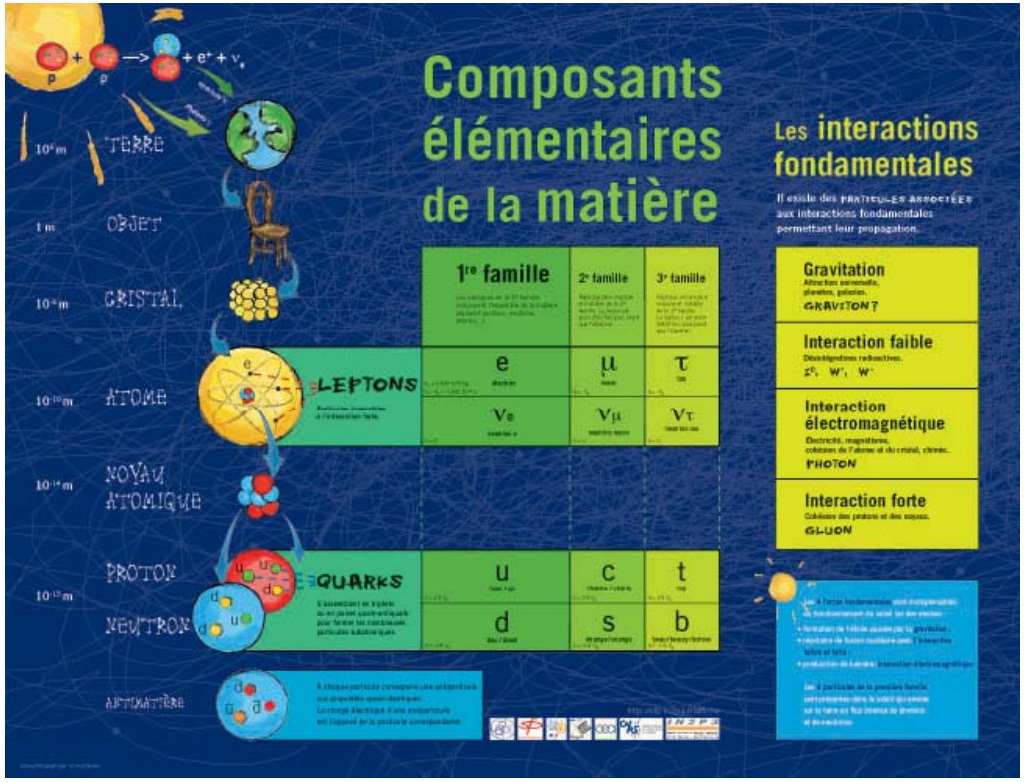
- Au LAL, on étudie les constituants de la matière : les particules élémentaires
  → Combien sont-elles ?
  → Quelles sont leurs propriétés ?
  → Quelles sont les forces qui les gouvernent ?

- Ce monde, « l'infiniment petit », a des liens étroits avec celui de « l'infiniment grand », c'est-à-dire l'étude de l'Univers.

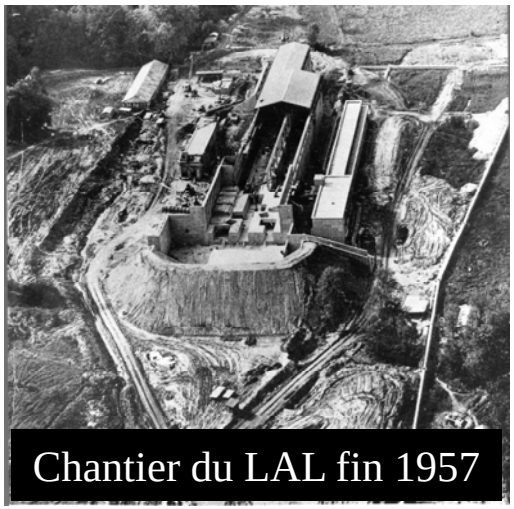
- Au LAL des groupes s'intéressent également à la composition de l'Univers et à son histoire, du Big-bang jusqu'à nos jours.

- On observe aussi des particules en provenance de l'espace !

- Ces études demandent d'importantes ressources techniques & informatiques.

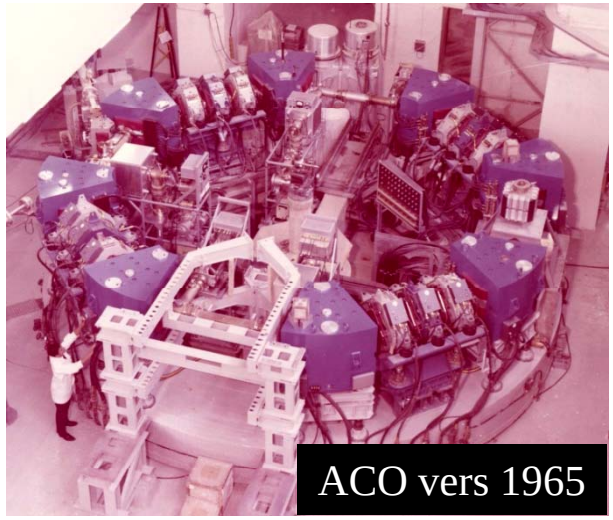


1956 – 2010 : survol de l'histoire du LAL



Chantier du LAL fin 1957

ADA au LAL en1962 : premier collisionneur e^+e^-



ACO vers 1965

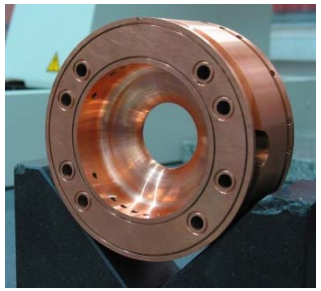
DCI (Dispositif de Collisions dans l'Igloo), années 1970

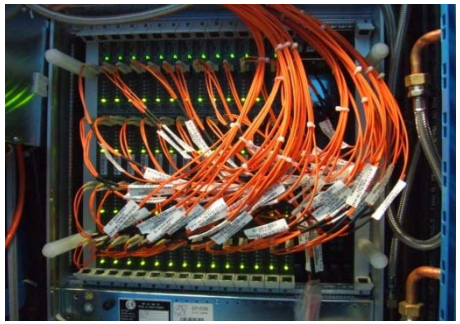
Le site du LAL en 1981

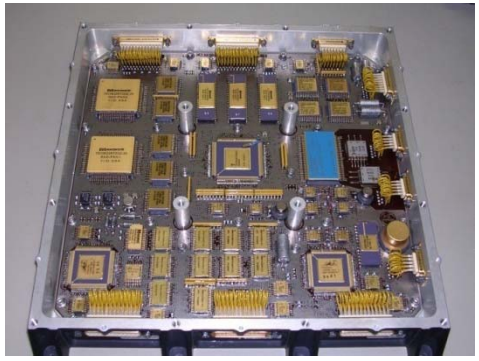
ACO aujourd'hui : un musée & un monument historique

Les services techniques & administratifs du LAL

- Services techniques : électronique, informatique, mécanique, accélérateurs, infrastructure, logistique et sécurité
- Des plateformes utilisées par d'autres laboratoires :
  → Pôle de micro-électronique, grille de calcul GRIF, magasin, etc.
- Services administratifs : accueil, financier, missions, personnel, information
- Quelques exemples de réalisations techniques :







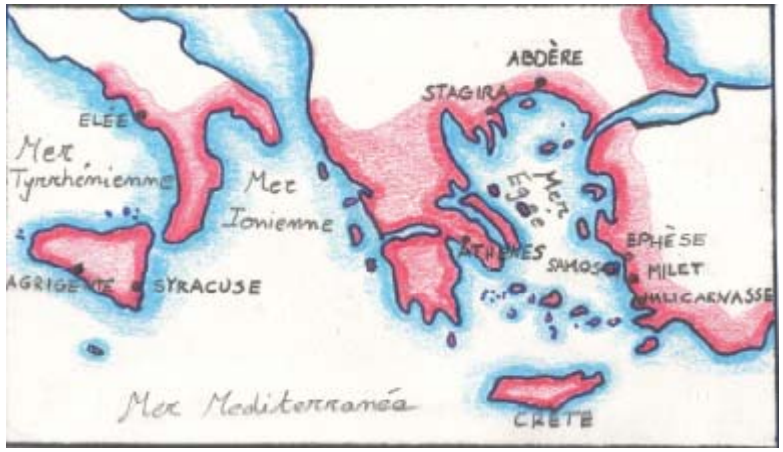

Une brève histoire des particules

Désolé pour les transparents en anglais… ☹

A taste of ancient Greek philosophy

- The atom : a 2,500 year-old concept

- A natural question :
  « what is the world made of? »



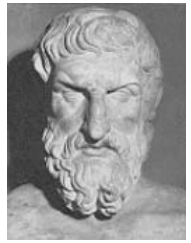
→ supernatural answers: extraordinary creatures (gods, titans, spirits…) give birth, shape and ordinate the whole world

- Everything changes from the VIth Century B.C.
  → philosophers try to understand and to explain the Nature (*Physis* in Greek)

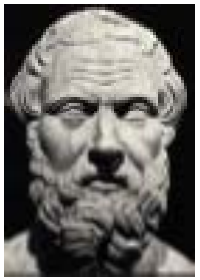
→ Thales of Miletus: « Water is the principle of all things »
→ Héraclitus of Ephesus: « All things are in motion and nothing remains still »
→ Empedocles: « The universe is a combination of four roots: Water, Earth, Fire and Air; they are ruled by two fundamental forces: Love and Strife ».

→ Anaxagoras: « there is something of each thing in all the things »
All the things are made of « indivisible seeds » infinitesimally small, endless in number, always inextricably combined and separated.
→ Atomism : Democritus, Epicurus and Lucretius

Atomism



- « Atoma » means « undividable » in Greek
  ⇒ Atoms are small, elementary and fraught.
  ⇒ Besides the atoms there is the void (infinite) in which atoms can move, pack or scatter.



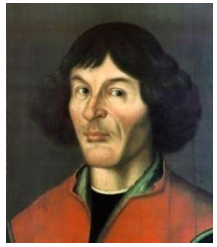
- The living beings and the things are created by assemblies of atoms
- There are several different types of atoms
- All feelings (hot, cold, bitter, sweet, salted…) can be explained by the different types of atoms and assemblies.
- The lightest atoms are the components of the souls

- Death ⇔ Atoms break up and are released in the void. As they are eternal, they can gather again later on to form new structures/universes

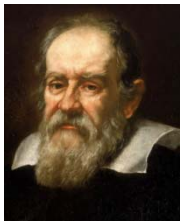
- After centuries of philosophical controversies (pro/against atoms), this conception of Nature falls into disfavour for a millenium when Christianism becomes the leading religion of the roman empire.

Gravity

- Ptolemy geocentric model of the solar system (IIth Century A.C.)
  → Earth in the center
  → All ‘wandering lights’ orbiting around it on complex sets of spheres



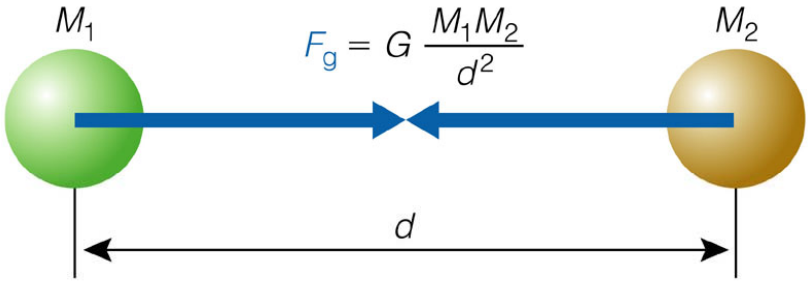
- First serious competitor: Copernicus heliocentric model (1543)
- Galileo: observations in contradiction with Ptolemy theory (1610)
  → Catholic church forces him to forswear Copernicus « mistake »
- Kepler (1609-1619): assumes heliocentric model & elliptical orbits
  → constructs 3 empirical laws and make successful predictions



Newton breakthrough

- Law of Universal Gravitation (1687):

« Every single point mass attracts every other point mass by a force heading along the line combining the two. The force is proportional to the product of the two masses and inversely proportional to the square of the distance between the point masses. »



- Simple and elegant
- Explains Kepler's laws
- Replaces the tons of spheres needed to make Ptolemy's model accurate

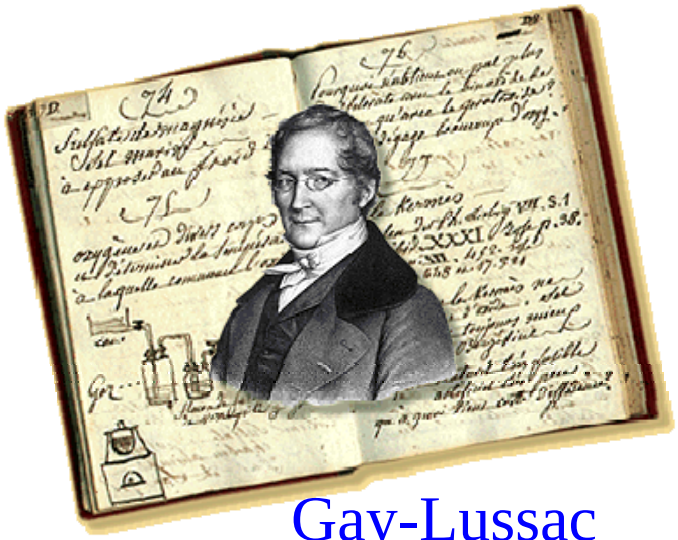
Rule cosmology for more than 2 centuries

Still widely used today!

The first chemists

Boyle

Lavoisier



Gay-Lussac

Cavendish

Dalton

- Boyle: A valid scientifical theory must lead on experiments.
- Lavoisier: « compounds » (molecules) are made of ≥1 element
- Gay-Lussac: Hydrogen and oxygen get combined in precise ratio
  to make water: $2\ H + O \rightarrow H_2O$
  $\Rightarrow$ chemical elements = basics components of matter
- Dalton: Each chemical element is made of a single type of atoms.
  About 20 such atoms are known at that time.

Electromagnetism

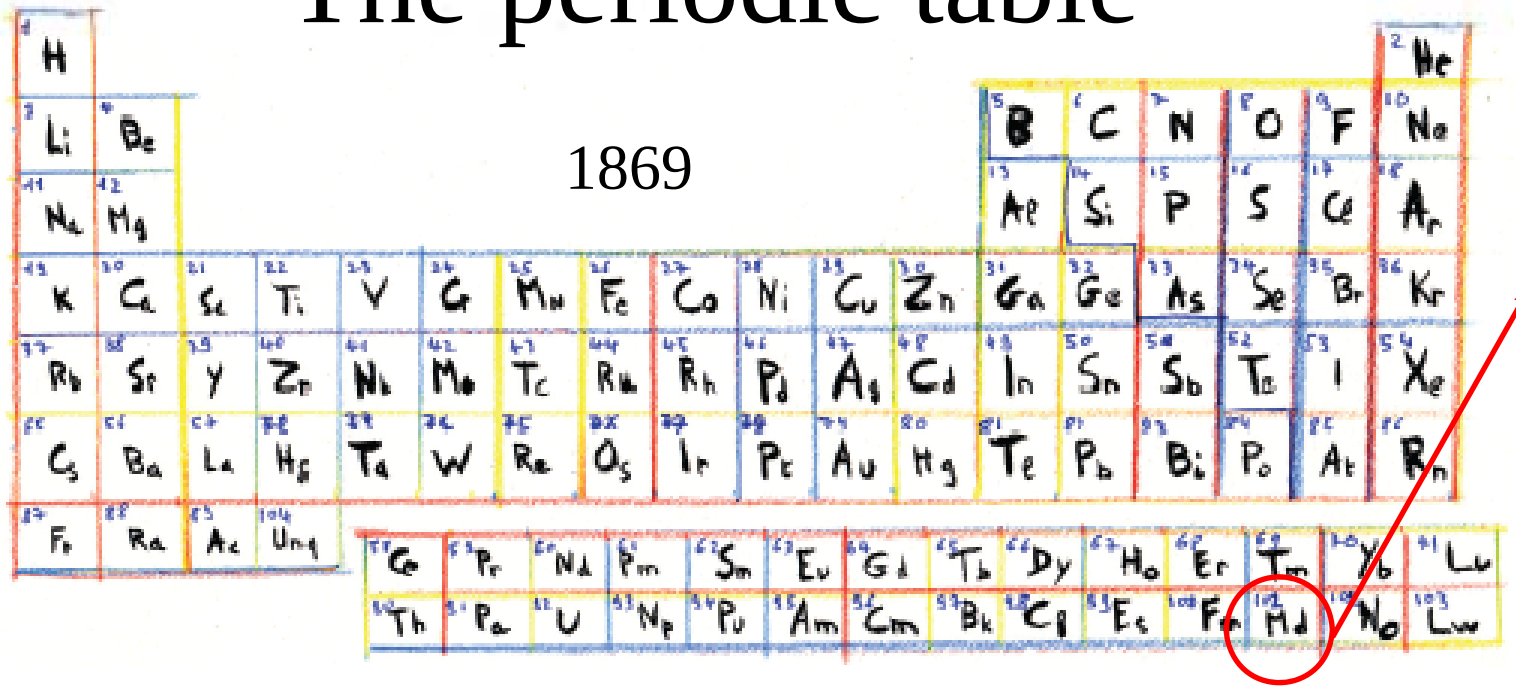
- James Clerk Maxwell (1864): « The agreement of the results seems to show that light and magnetism are affections of the same substance, and that light is an electromagnetic disturbance propagated through the field according to electromagnetic laws. »

→ Electricity and Magnetism are two sides of the same phenomenon
→ Fields travel through space, in the form of waves,
and at the constant speed of light.

- Foundations for modern physics, electrical engineering, astronomy, radio communication, television…

- Einstein about Maxwell's work: the « most profound and the most fruitful that physics has experienced since the time of Newton »

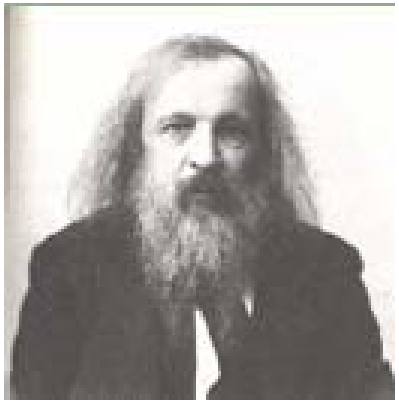
The periodic table



- Brilliant categorization :
  - ✓ intuitive, only based on experimental data
  - ✓ explained tens of years later once the electronic structure of the atoms got known.

- Mendeleïev left empty boxes for elements yet unknown but which *ought to* exist according to him
  → They got all discovered !

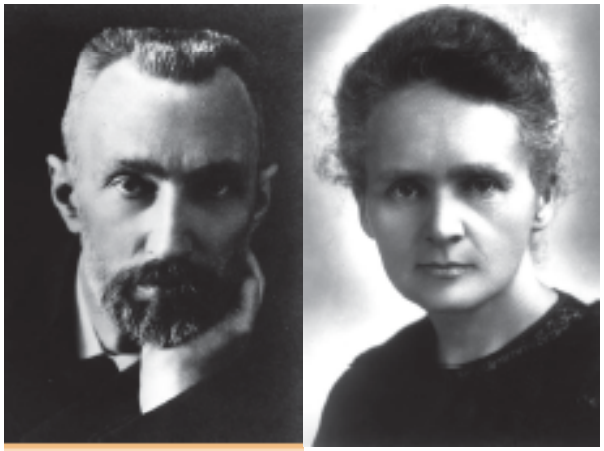
Mendeleïev



Discovery of the radioactivity

Röngten (1895)
X-ray discovery

Becquerel (1896)
Discovery of the
natural radioactivity

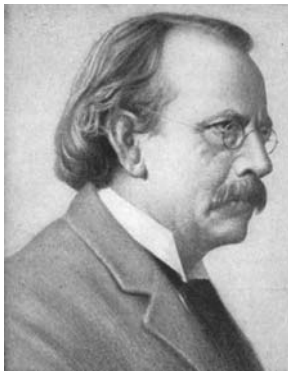


Pierre and Marie Curie
discover the polonium
and the radium (1898)

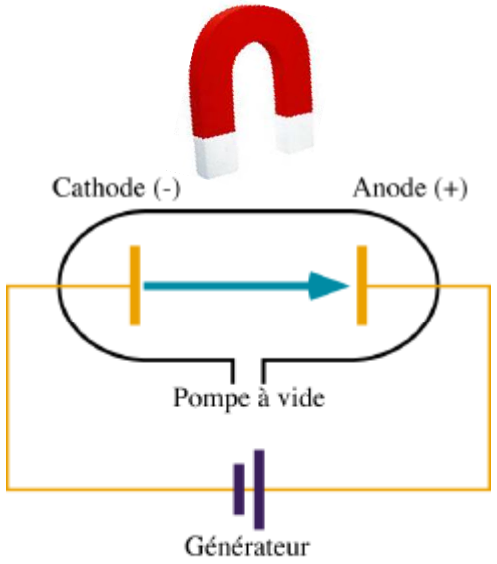
The radioactivity is the spontaneous emission of radiation (= of energy) by an object: carbon-14, uranium...

This discovery will drastically impact { the XXth Century science / the world

The discovery of the electron



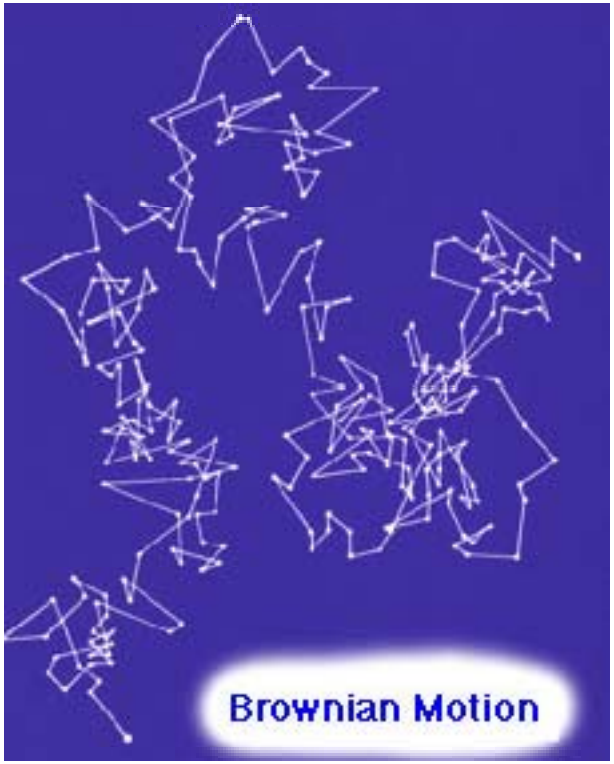
- Joseph John (« J.J ») Thomson (1897)
  → Study of cathode rays



- Rays are negatively charged
- Rays are sensitive to an electric field
  → characteristic of charged particles
- Charge to mass ratio ~ 1000 higher than for an hydrogen ion
  → new « corpuscles » are either highly charged or very small.
- Ratio independent of the material used in the experiment
  → they are universal among all materials

Do atoms really exist?

Robert Brown (1827)



Motion of an airborne pollen particle in the water

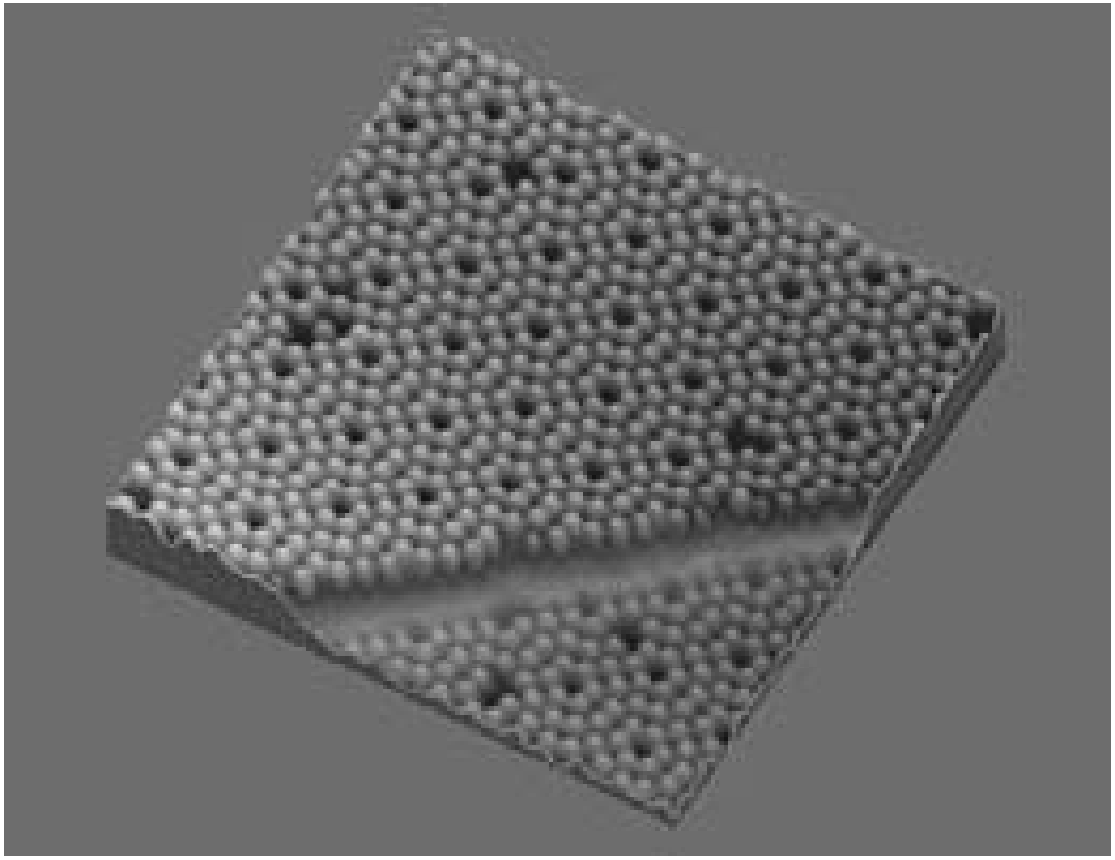
Where does it come from ?

1905 (« annus mirabilis »)

This motion is due to repeated random collisions between the pollen particle and the water molecules

Just over a century ago!

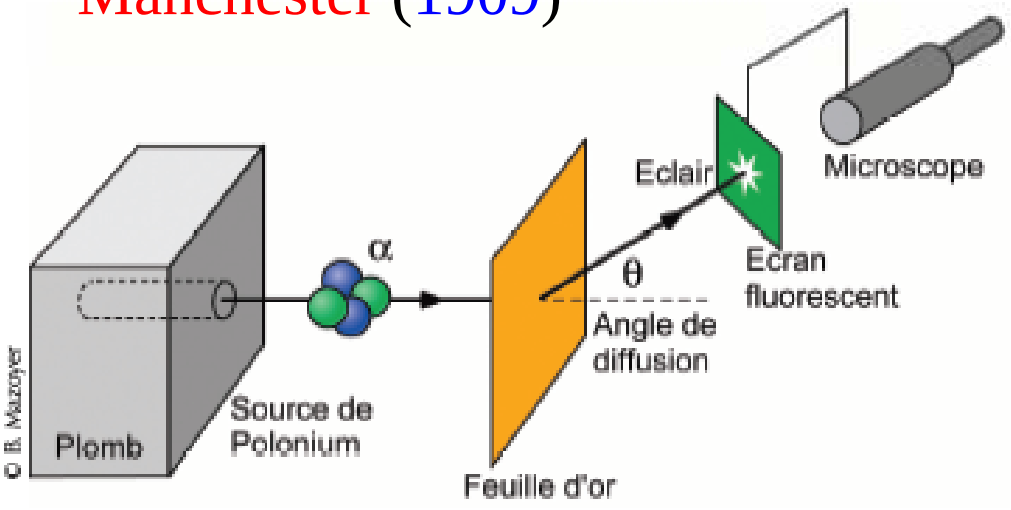
Yes, they do!

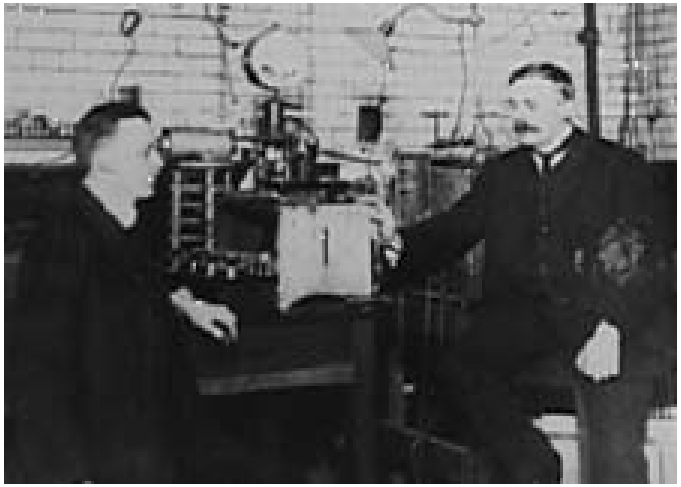


Silicium atoms seen through
a scanning tunneling microscope
Lund University (Sweden)

Atoms are almost void

Manchester (1909)

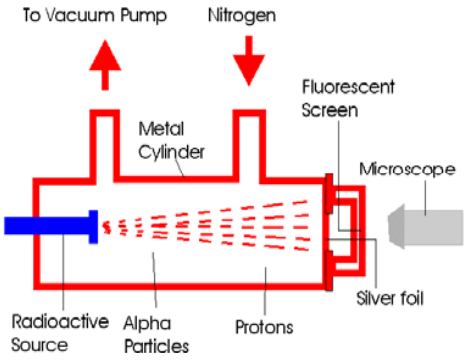




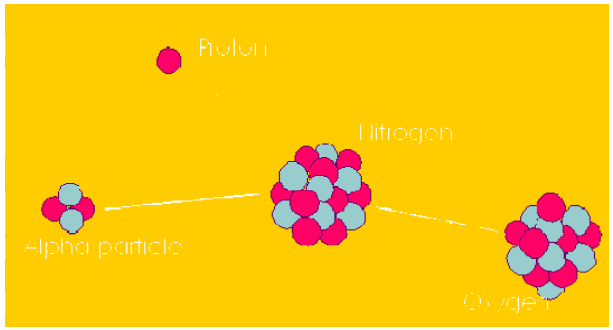
Geiger & Rutherford

- Helium α particles are thrown against a thin foil of gold
- Most nuclei are almost not deviated ⇒ they don't see « anything »!
- Some go « backward »
  ⇒ they hit something small and hard: the atomic nucleus
  10,000 times smaller than the atom!

Discovery of the proton



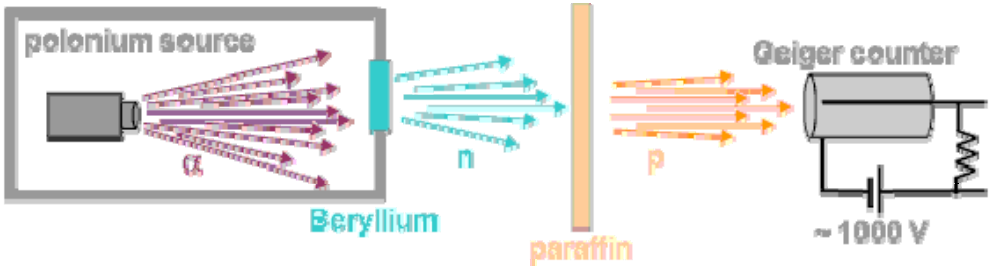
- Ernest Rutherford (1918)
- Another diffusion experience: α-particle shot on nitrogen gas
  → Found the signature of hydrogen nuclei in his detectors
  → Determined that hydrogen could only come from nitrogen
  → Nitrogen must contain the hydrogen nucleus!



- He suggested that the hydrogen nucleus was an elementary particle.
- Name « proton » given to pay tribute to William Prout who, in 1815 (!), hypothesized that the atomic weight of every element is an integer multiple of that of hydrogen, suggesting that the hydrogen atom is the only truly fundamental particle.

Discovery of the neutron

- « Neutrone » ⇔ « big neutral guy » in Italian
- Unknown radiation emitted by a berylium target hit by α particles (Helium nuclei)



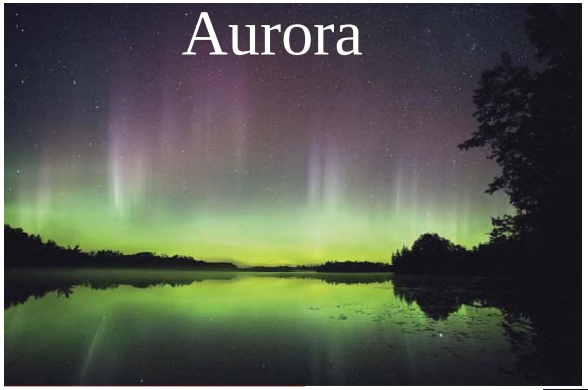
- First seen in France by Irene and Frederic Joliot-Curie
  → Wrong interpretation of the new phenomenon
- James Chadwick does a similar experiment and publishes the correct conclusion in January 1932
- The Joliot-Curie and Chadwick received Nobel prizes in 1935

  Artificial radioactivity — Neutron

Cosmics rays

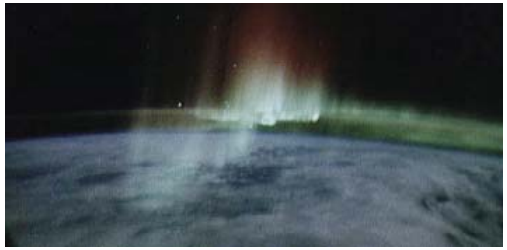
- Energetic particles originating from space:
  ~90% protons, ~9% helium nuclei, ~1% electrons…
- Sources: Sun, special stars, galactic or extra-galactic
- Can be as energetic as a tennis ball!

Victor Hess

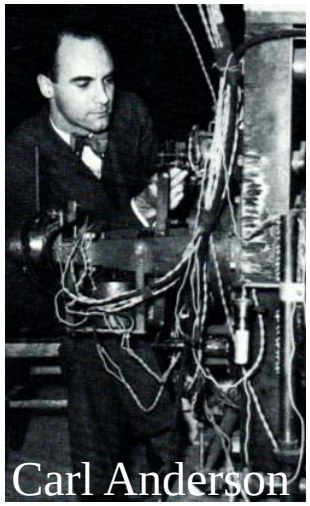


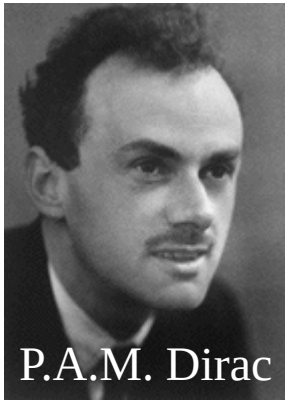
Free balloon flight

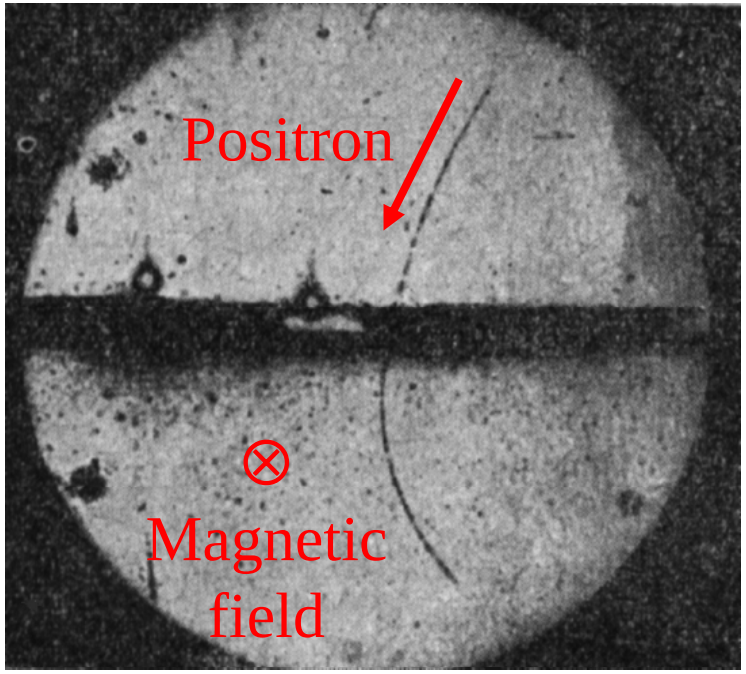
Seen from the
Space Shuttle



Discovery of the positron (1932)


Carl Anderson


P.A.M. Dirac



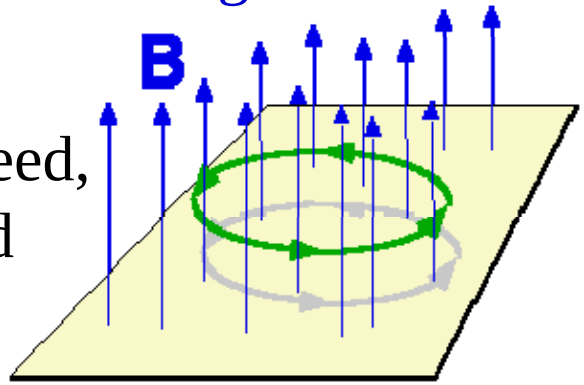
Lead plate

- Positive charge
- Much lighter than a proton

- First antimatter particle
- Predicted by theorist P.A.M. Dirac in 1928.

Particle motion in a magnetic field

The higher its speed, the less curved its trajectory.



Discovery of the muon

- Carl Anderson (1936)… again

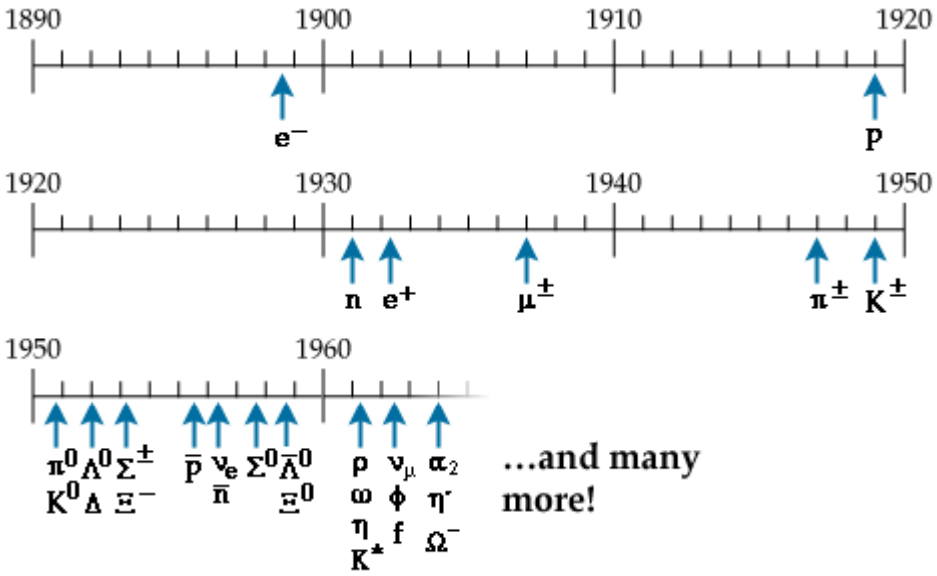
- The muon has the same charge as the electron
- Its mass is somewhere between electron and proton masses

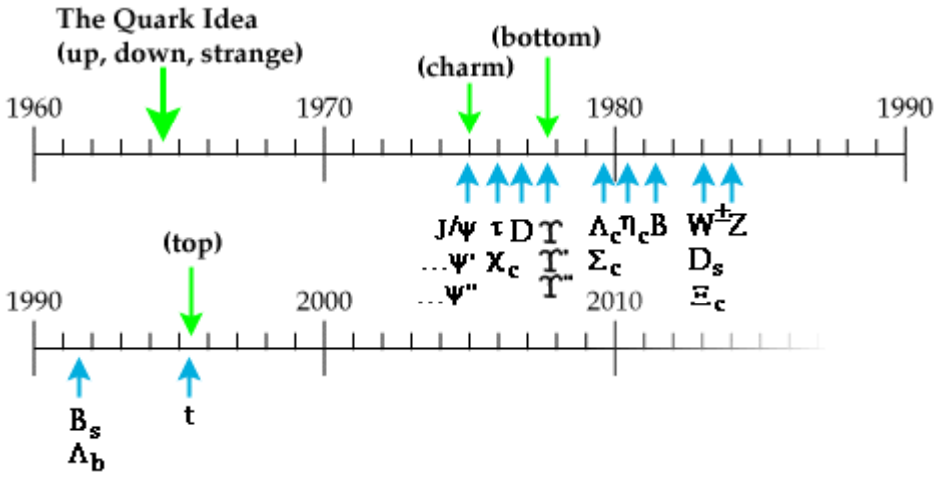
→ The new member of the particle's family wasn't expected!

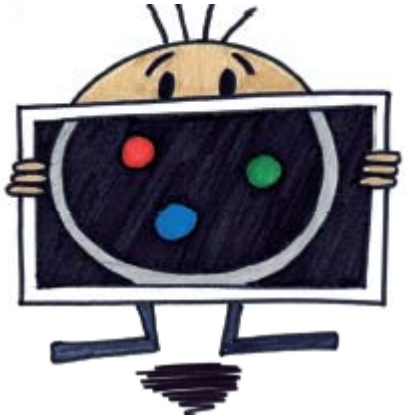
I. Rabi, 1944 Physics Nobel Prize

→ No theory available to explain the existence of this new particle

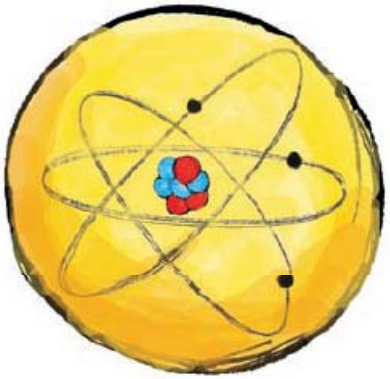
Particles « zoo »







Quarks

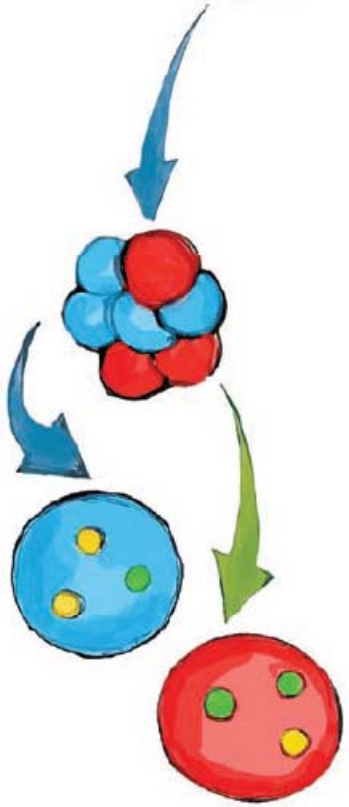


- 1930-1960: hundred of particles discovered!
  → where do they come from?

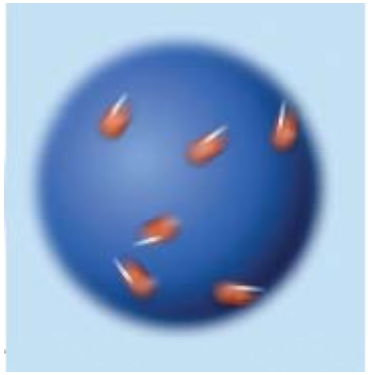
- New theory: most of these particles are made of quarks
  → e.g. protons and neutrons

- Strong force is holding them together in the particles

- Only 6 types of quarks
  → Things are ‘simple’ again!

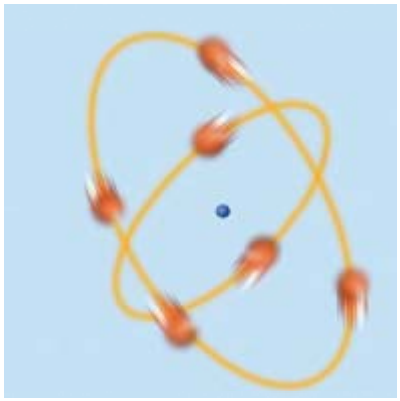


What does an atom look like?

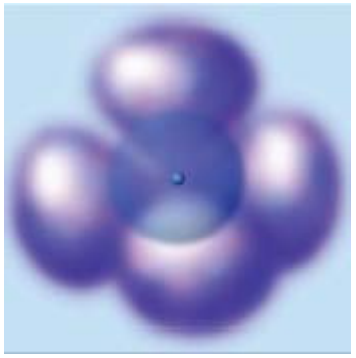


Thomson (1903)
« Plum-Pudding »

Rutherford (1909)



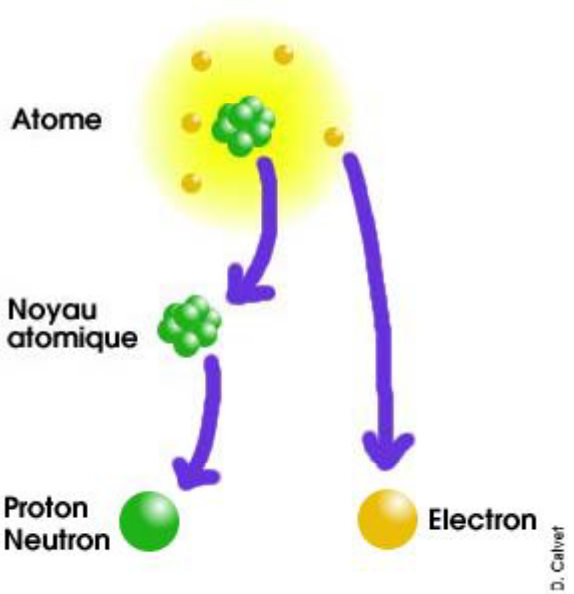
Bohr (1913)



« Modern » atom

- Electrons are living on different energy levels
- They are more like clouds than point particles
  → Probabilities

What is an atom made of?



- Nucleus:
  - ✓ proton, charge +1
  - ✓ neutron, charge 0
- Electronic cloud
  - → electron, charge -1
  - → atoms are neutral!
- A: mass number
- Z: charge number

$^{12}_{6}C$

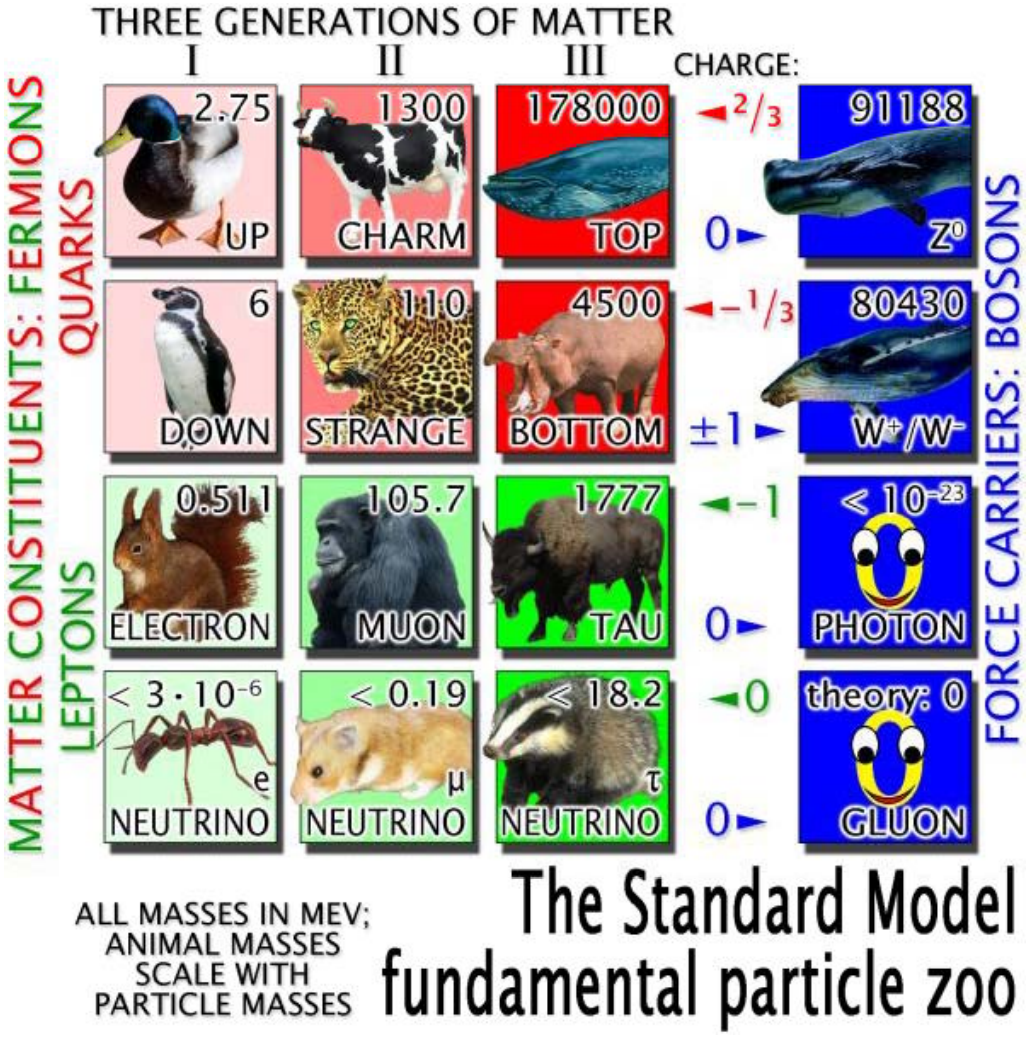
⇒ Atoms can be broken into pieces!

⇒ We also know how to break protons and neutrons

⇒ The electron doesn't seem to have an internal structure

Some remaining mysteries…

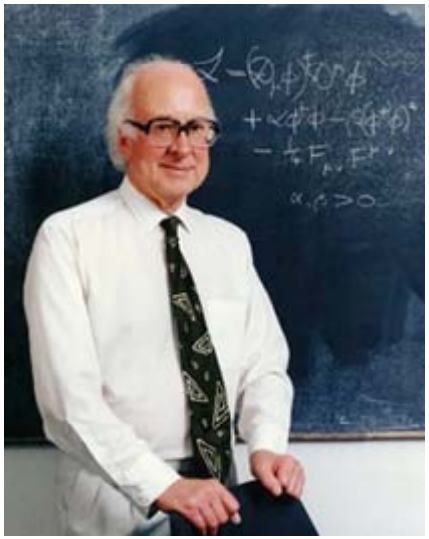
- Origin of the particle masses



Some remaining mysteries…

- Some particles are still ‘missing’
  → current theory (the Standard Model) explains very well all the experimental observations
  → its internal coherence requires additional particles…
  … which haven’t been discovered yet!

- Higgs boson, supersymmetric particles, etc.

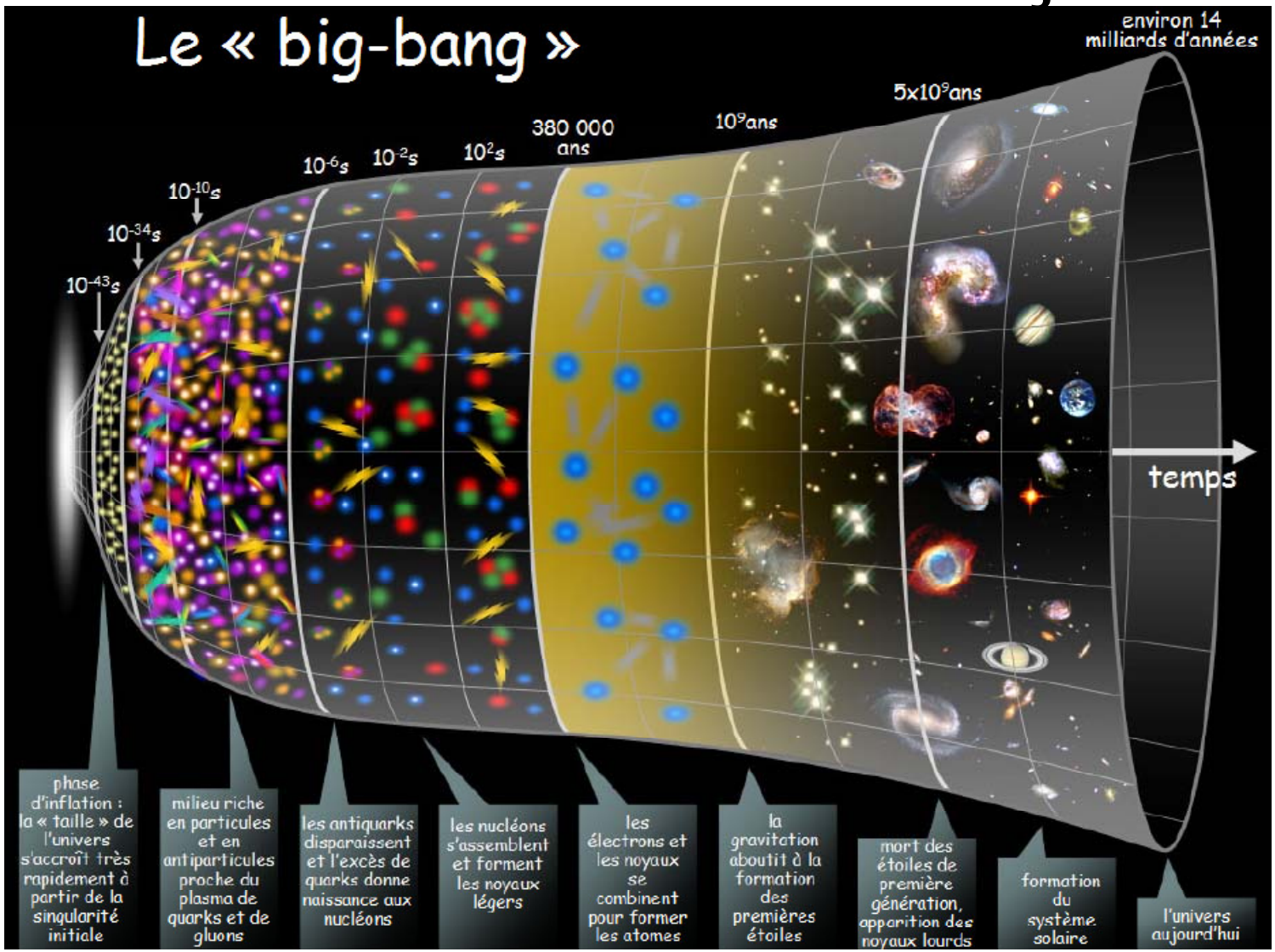


Peter Higgs

Fathers of the ‘Standard Model’

Sheldon Glashow, Abdus Salam, and Steven Weinberg sharing the Nobel Prize, 1979

Et l'Univers dans tout ça ?



La matière connue ne représente que 5% du contenu de l'Univers

Le reste, « matière noire » et « énergie noire », est mystérieux

Pour en savoir plus

- Les transparents présentés aujourd'hui sont disponibles sur la page web
  http://indico.lal.in2p3.fr/conferenceDisplay.py?confId=1120

- Des pages web de l'IN2P3-CNRS
  http://www.in2p3.fr/physique_pour_tous/informations/sites/sites.htm
  http://www.in2p3.fr/physique_pour_tous/questions/poser_une_question.htm
  http://www.in2p3.fr/physique_pour_tous/aulycee/tipe.htm

- L'affiche des composants élémentaires de la matière
  http://quarks.lal.in2p3.fr/afficheComposants/index.html

- La revue de vulgarisation « Élémentaire »
  http://elementaire.web.lal.in2p3.fr/

- Le « Passeport pour les 2 Infinis »
  http://www.passeport2i.fr/

- Le site LHC-France
  http://www.lhc-france.fr/