O Estranho Mundo das Partículas Elementares

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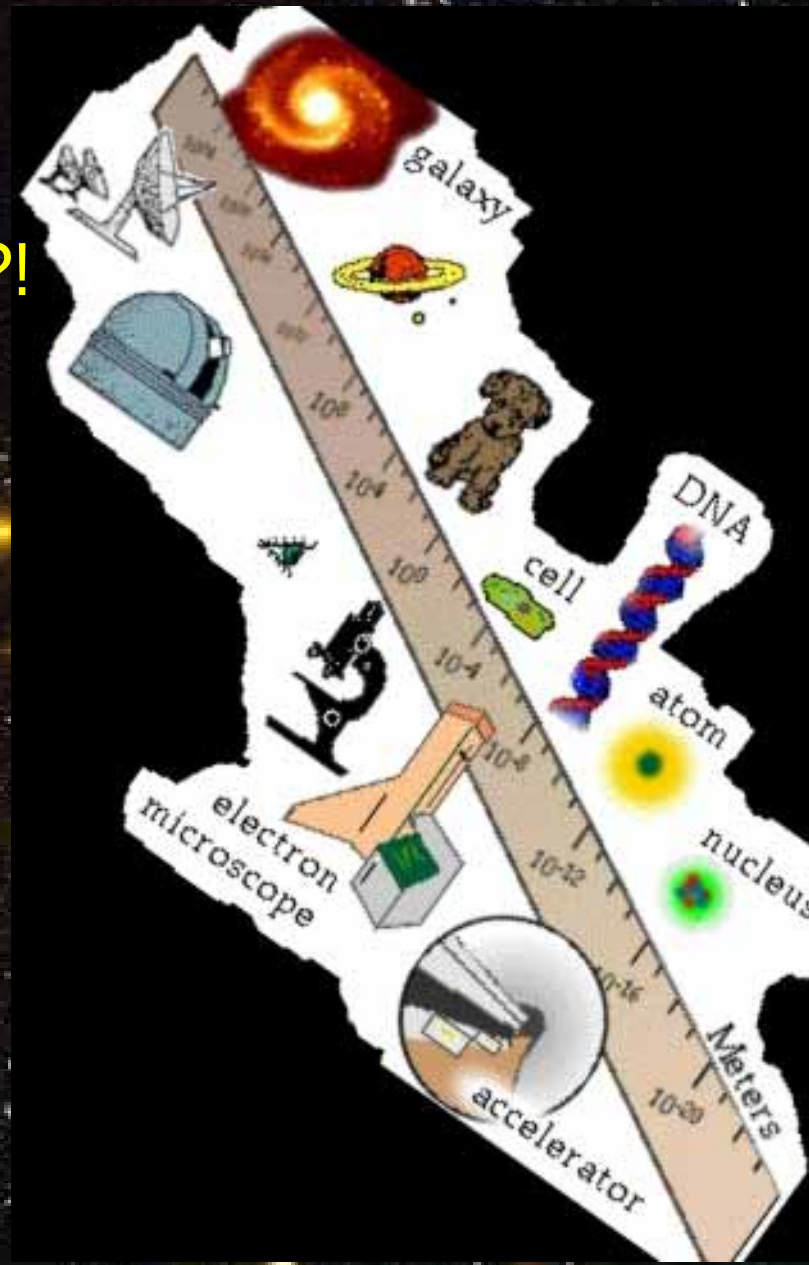
Masterclasses 2006

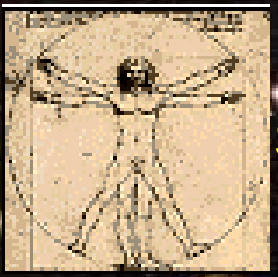
11 de Março, @ IST, LIP, Lisboa

Conteúdo

- De que é que somos feitos ?!
  - As peças de matéria
  - As regras do jogo
  - As partículas de interacção
- Mistérios em aberto!
  - Unificação das interacções ?
  - Sub-estrutura continua?
  - Matéria - Anti-Matéria ?
  - Partículas com massa ?
- E nós no meio!
  - ...potências de 10



A Estrutura da Matéria



Somos feitos de quê ?

Substâncias como água, proteínas, gorduras, açúcares, sais, ...

Constituídos por elementos como

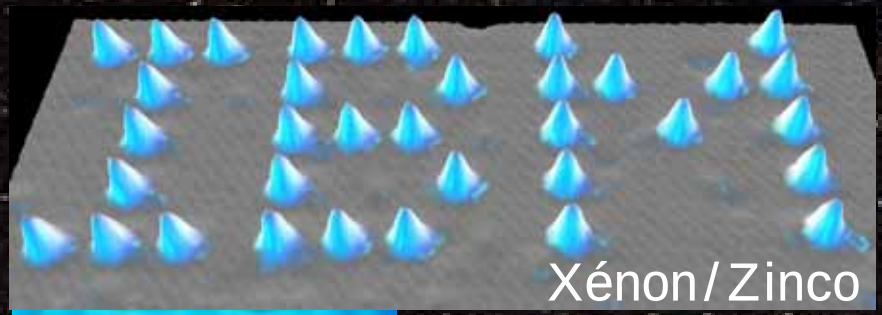
Hidrogénio
Cálcio,
Ferro
Carbono
Azoto
Oxigénio
Cloro
[Hélio],
e outros 100
elementos ..

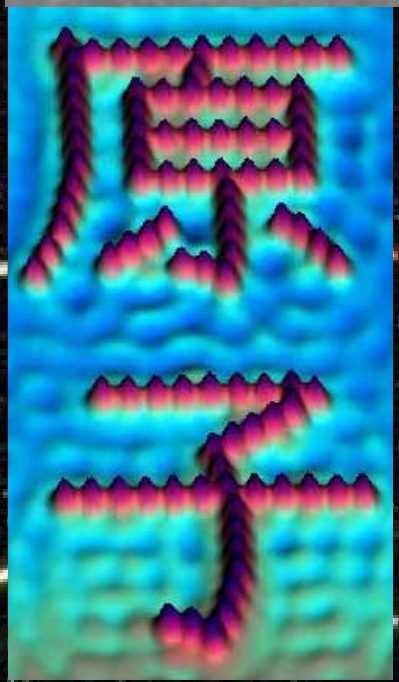
Reihen	Gruppe I. - R^2O	Gruppe II. - RO	Gruppe III. - R^2O^3	Gruppe IV. RH^4 RO^2	Gruppe V. RH^3 R^2O^5	Gruppe VI. RH^2 RO^3	Gruppe VII. RH R^2O^7	Gruppe VIII. - RO^4
1	H = 1							
2	Li = 7	Be = 9,4	B = 11	C = 12	N = 14	O = 16	F = 19	
3	Na = 23	Mg = 24	Al = 27,3	Si = 28	P = 31	S = 32	Cl = 35,5	
4	K = 39	Ca = 40	- = 44	Ti = 48	V = 51	Cr = 52	Mn = 55	Fe = 56, Co=59 Ni=59, Cu=63
5	(Cu = 63)	Zn = 65	- = 68	- = 72	As = 75	Se = 78	Br = 80	
6	Rb = 85	Sr = 87	?Yt = 88	Zr = 90	Nb = 94	Mo = 96	- = 100	Ru=104, Rh=104 Pd=106, Ag=108
7	Ag = 108	Cd = 112	In = 113	Sn = 118	Sb = 122	Te = 125	J = 127	
8	Cs = 133	Ba = 137	?Di = 138	?Ce = 140	-	-	-	- - - -
9	(-)	-	-	-	-	-	-	
10	-	-	?Er = 178	?La = 180	Ta = 182	W = 184	-	Os=195, Ir=197, Pt=198, Au=199
11	(Au = 199)	Hg = 200	Tl = 204	Pb = 207	Bi = 208	-	-	
12	-	-	-	Th = 231	-	U = 240	-	- - - -

Princ. Exclusão de Pauli => ESTRUTURA ELECTRÓNICA

E os Elementos ?!

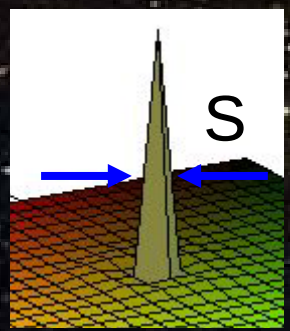
1ª Fotografia da estrutura atómica



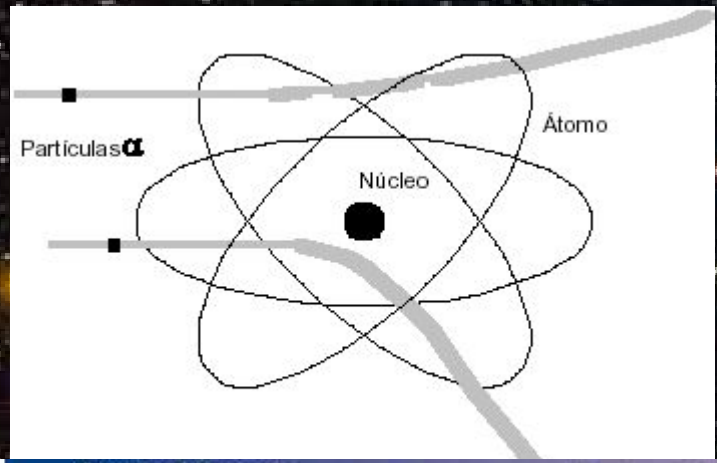


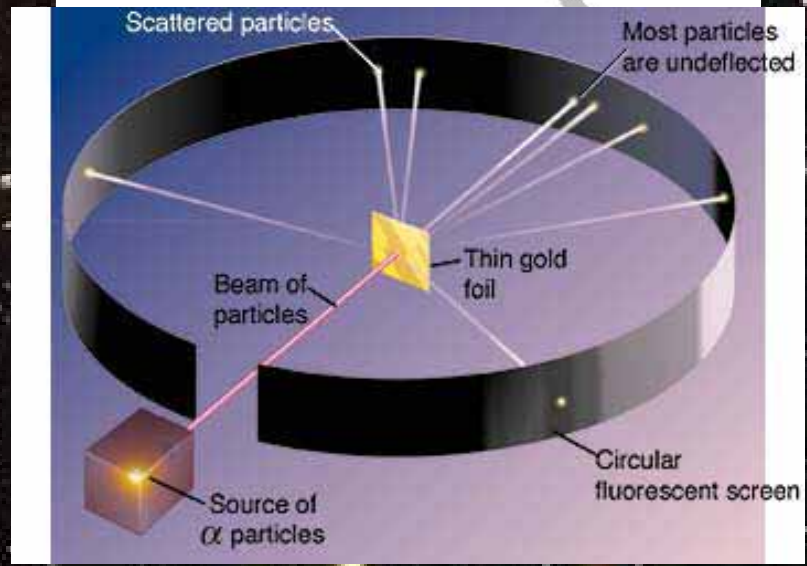
Átomo em chinês (Ferro/Cobre)

Prob.(r) – e^{-}



são átomos, mas não indivisíveis...





Experiência de Rutherford (Geiger)

A Tabela Periódica das Partículas

FERMIONS

matter constituents
spin = 1/2, 3/2, 5/2,...

Leptons spin = 1/2

Flavor	Mass GeV/c²	Electric charge
ν_e electron neutrino	$< 7\times10^{-9}$	0
e electron	0.000511	−1
ν_μ muon neutrino	< 0.0003	0
μ muon	0.106	−1
ν_τ tau neutrino	< 0.03	0
τ tau	1.7771	−1

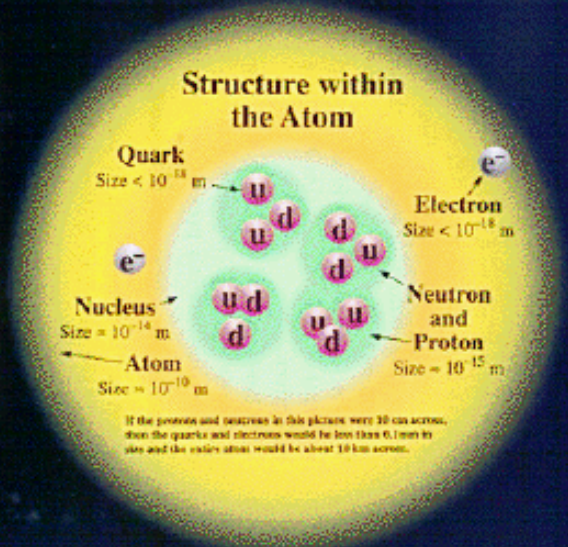
Quarks spin = 1/2

Flavor	Approx. Mass GeV/c²	Electric charge
u up	0.005	2/3
d down	0.01	−1/3
c charm	1.5	2/3
s strange	0.2	−1/3
t top (initial evidence)	170	2/3
b bottom	4.7	−1/3

Spin is the *intrinsic* angular momentum of particles. Spin is given in units of $\hbar$, which is the quantum unit of angular momentum, where $\hbar = h/2\pi = 6.58\times10^{-22}$ GeV s = 1.05×10^{-34} J s.

Electric charges are given in units of the proton's charge. In SI units the electric charge of the proton is 1.602×10^{-19} coulombs.

The **energy** unit of particle physics is the electron volt (eV), the energy gained by one electron in crossing a potential difference of one volt. Masses are given in GeV/c² (remember $E = mc^2$), where 1 GeV = 10^9 eV = 1.60×10^{-10} joule. The mass of the proton is 0.938 GeV/c² = 1.67×10^{-27} kg.



BOSONS

force carriers
spin = 0, 1, 2,...

Unified Electroweak spin = 1

	Mass GeV/c²	Electric charge
γ photon	0	0
W^-	80.22	−1
W^+	80.22	+1
Z^0	91.187	0

Strong or color spin = 1

	Mass GeV/c²	Electric charge
g gluon	0	0

Color Charge

Each quark carries one of three types of "strong charge," also called "color charge." These charges have nothing to do with the colors of visible light. There are eight possible types of color charge for gluons. Just as electrically charged particles interact by exchanging photons, in strong interactions color-charged particles exchange gluons. Leptons, photons, and W and Z bosons have no color charge and hence no strong interactions. One cannot isolate quarks and gluons; they are *confined* into color-neutral hadrons. This confinement (binding) results from multiple exchanges of gluons among the color-charged objects.

Confinement

As color-charged particles (quarks and gluons) are separated, the color force between them approaches a constant value and the energy in the color force field increases. This energy eventually is converted into additional quark-antiquark pairs (see the figures below). The objects that finally emerge are color-neutral combinations called **hadrons** (mesons and baryons).

Residual Strong Interactions

The strong binding of the color-neutral protons and neutrons to form nuclei is due to residual strong interactions between their color-charged constituents. It is similar to the residual electrical interaction which binds electrically neutral atoms to form molecules. It can be viewed as the exchange of mesons between the hadrons.

PROPERTIES OF THE INTERACTIONS

Property \ Interaction	Gravitational	Weak (Electroweak)	Electromagnetic (Electroweak)	Strong: Fundamental	Strong: Residual
Acts on:	Mass – Energy	Flavor	Electric Charge	Color charge	See Residual Strong Interaction Note
Particles experiencing:	All	Quarks, Leptons	Electrically charged	Quarks, Gluons	Hadrons
Particles mediating:	Graviton (not yet observed)	W^+ W^- Z^0	γ	Gluons	Mesons
Strength for two u quarks at: 10^{-18} m	10^{-41}	0.8	1	25	Not applicable to quarks
Strength for two u quarks at: 3×10^{-17} m (relative to electromagnetic)	10^{-41}	10^{-4}	1	60	
for two protons in nucleus	10^{-36}	10^{-7}	1	Not applicable to hadrons	20

Sample Fermionic Hadrons

Baryons qqq and Antibaryons $\bar{q}\bar{q}\bar{q}$

Symbol	Name	Quark content	Electric charge	Mass GeV/c²	Spin
p	proton	uud	1	0.938	1/2
$\bar{p}$	anti-proton	$\bar{u}\bar{u}\bar{d}$	−1	0.938	1/2
n	neutron	udd	0	0.940	1/2
Λ	lambda	uds	0	1.116	1/2
Ω^-	omega	sss	−1	1.672	3/2

Sample Bosonic Hadrons

Mesons $q\bar{q}$

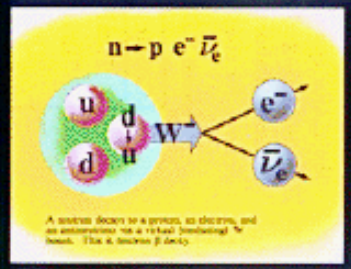
Symbol	Name	Quark content	Electric charge	Mass GeV/c²	Spin
π^+	pion	$u\bar{d}$	+1	0.140	0
K^-	kaon	$s\bar{u}$	−1	0.494	0
ρ^+	rho	$u\bar{d}$	+1	0.770	1
D^+	D^+	$c\bar{d}$	+1	1.869	0
η_c	eta-c	$c\bar{c}$	0	2.979	0

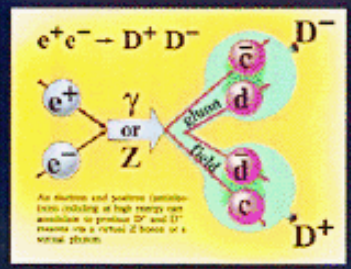
Matter and Antimatter

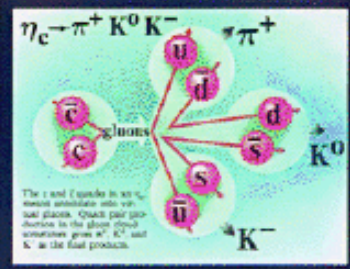
For every particle type there is a corresponding antiparticle type, denoted by a bar over the particle symbol. Particle and antiparticle have identical mass and spin but opposite charges. Some electrically neutral bosons (e.g., Z^0, γ, and η_c) are, but not K^0 and π^0) are their own antiparticles.

Figures

These diagrams are an artist's conception of physical processes. They are not exact and have no meaningful scale. Lines should never represent the exact path of a particle. Quarks and gluons are shown as particles with straight paths, and force fields are not shown.





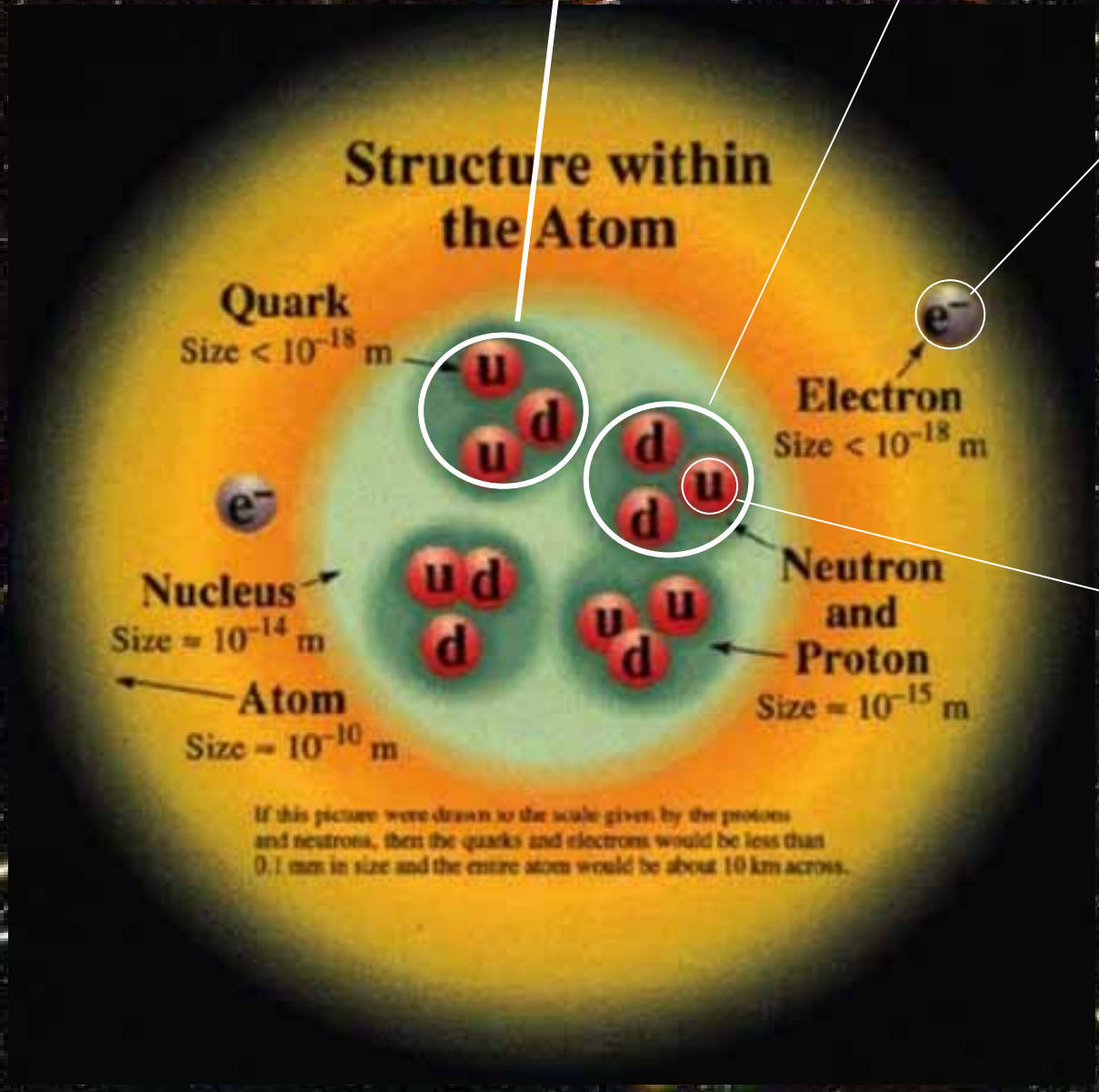


Contemporary Physics Education Project (CPEP)

CPEP is a non-profit organization of teachers, physicists, and educators. For information on the chart, software, books, packets of hands-on classroom activities, and web links, look on WWW at http://pdg.lbl.gov/cpep.html, send e-mail to pdg@LBL.gov, or write: CPEP, MS 50-308, Lawrence Berkeley Laboratory, Berkeley, CA 94720. Corporate and private donations, as well as material, loaning have been and remain critical to the success of this project.

U.S. Department of Energy
Lawrence Berkeley Laboratory
Stanford Linear Accelerator Center
American Assoc. of Physics Teachers
BURLE Electron Tubes

Átomos: Protões, Neutrões, Electrões

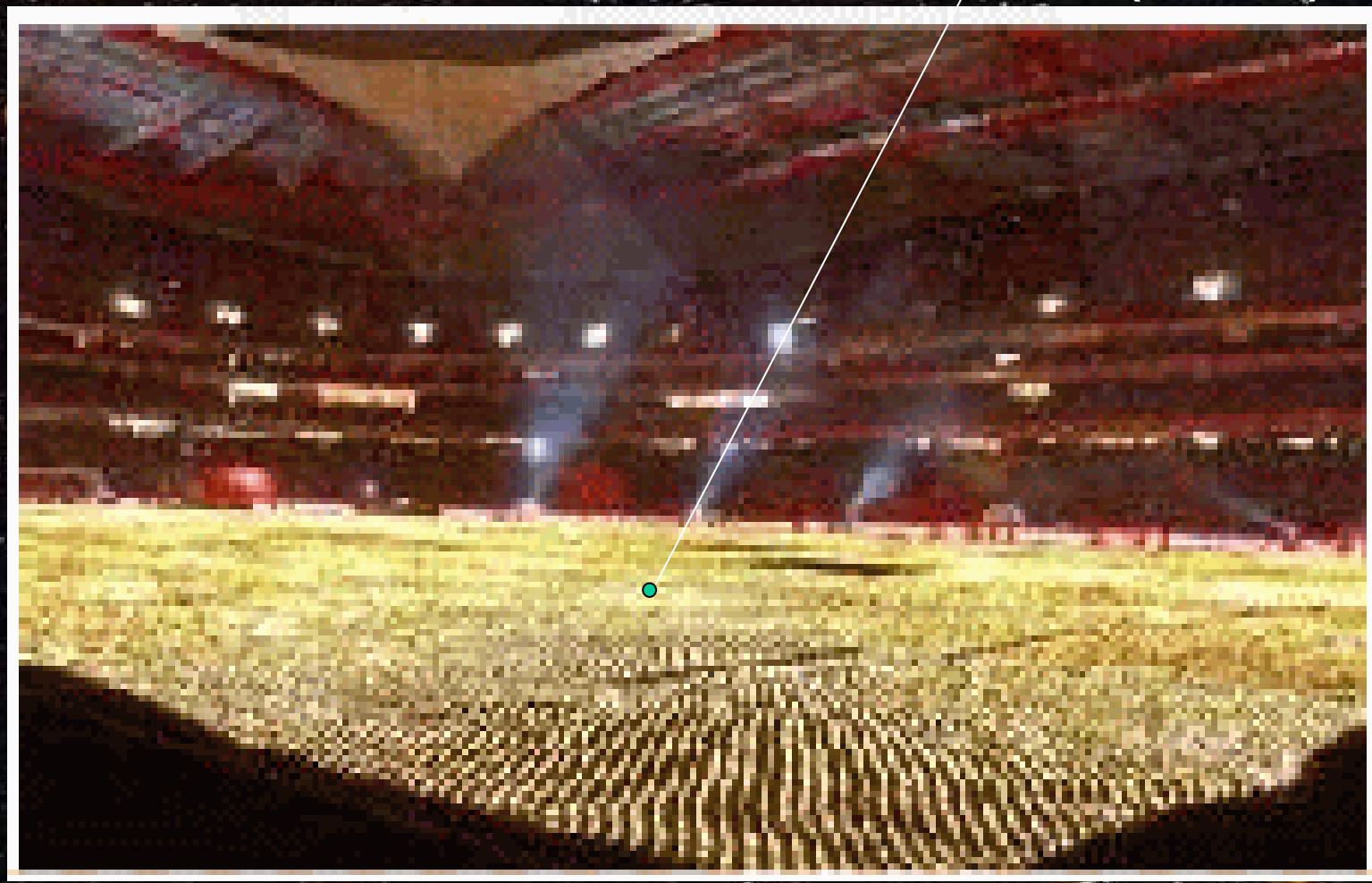


Protões (Neutrões)= Conjuntos de 3 quarks !

$d_{quark} < (d_P/1000)$

Escalas no átomo

Novo Estádio da Luz (átomo)



Fermiões

$1\ GeV/c^2 = 1.78 \times 10^{-27}\ Kg \approx m(protão)$

...obedecem ao Princípio de Exclusão de Pauli

Constituintes fundamentais da matéria

(ano)	Leptons spin = 1/2 Flavor	Mass GeV/c^2	Electric charge	Quarks spin = 1/2 Flavor	Approx. Mass GeV/c^2	Electric charge	(ano)
1956	ν_e electron neutrino	$<1\times10^{-8}$	0	u up	0.003	2/3	1964
1897	e electron	0.000511	−1	d down	0.006	−1/3	1964
1962	ν_μ muon neutrino	<0.0002	0	c charm	1.3	2/3	1974
1937	μ muon	0.106	−1	s strange	0.1	−1/3	1964
2001	ν_τ tau neutrino	<0.02	0	t top	175	2/3	1996
1975	τ tau	1.7771	−1	b bottom	4.3	−1/3	1977

Para quê ?!

mas os quarks não andam sozinhos!!!

Construções de quarks... (par)

Mesões

(todos instáveis)

constituídos por

QUARK

+

ANTI-QUARK

Mesons $q\bar{q}$

Mesons are bosonic hadrons.
There are about 140 types of mesons.

Symbol	Name	Quark content	Electric charge	Mass GeV/c^2	Spin
π^+	pion	$u\bar{d}$	+1	0.140	0
K^-	kaon	$s\bar{u}$	–1	0.494	0
ρ^+	rho	$u\bar{d}$	+1	0.770	1
B^0	B-zero	$d\bar{b}$	0	5.279	0
η_c	eta-c	$c\bar{c}$	0	2 .980	0

Construções de quarks... (tripleto)

Bariões

constituídos por

3 QUARKs

OU

3 ANTI-QUARKs

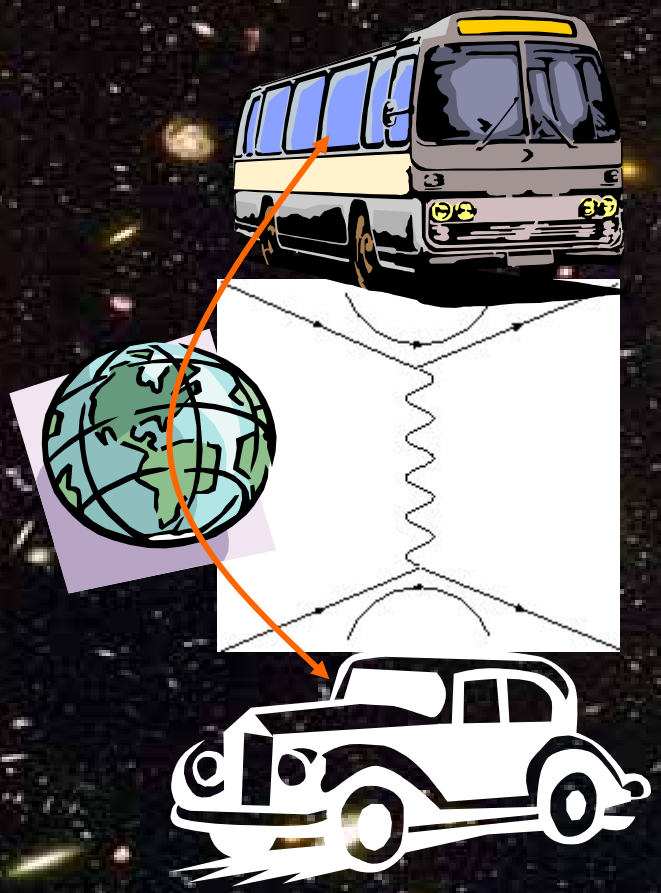
Baryons qqq and Antibaryons $\bar{q}\bar{q}\bar{q}$

Baryons are fermionic hadrons.
There are about 120 types of baryons.

Symbol	Name	Quark content	Electric charge	Mass GeV/c^2	Spin
p	proton	uud	1	0.938	1/2
$\bar{p}$	anti-proton	$\bar{u}\bar{u}\bar{d}$	–1	0.938	1/2
n	neutron	udd	0	0.940	1/2
Λ	lambda	uds	0	1.116	1/2
Ω^-	omega	sss	–1	1.672	3/2

(livres só o protão é estável; ligado, o neutrão tb. é estável)

Como é que interagem ?



Trocam Partículas de Interacção:

- de massa nula - alcance infinito
- de massa grande - alcance reduzido

Sim, também há partículas para as interacções!

PROPERTIES OF THE INTERACTIONS

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for two protons in nucleus	10^{-36}	10^{-7}	1	Not applicable to hadrons	20

Gravítica (Peso)

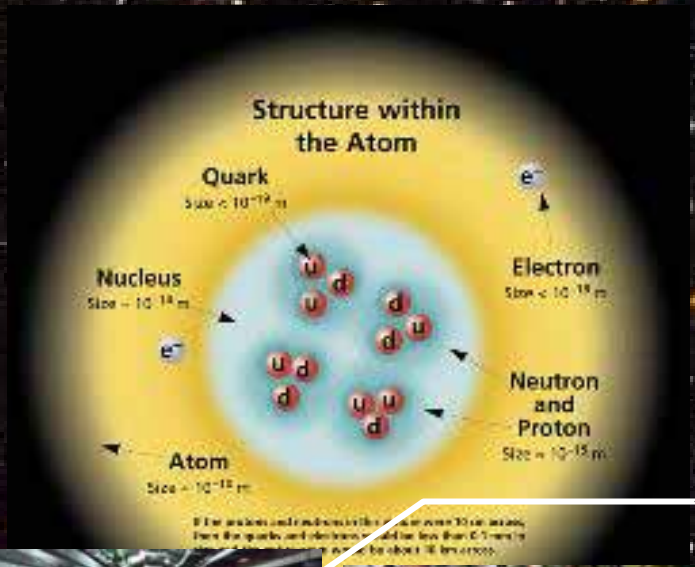
Força Fraca (Radioactividade)

Electromagnética (Corrente eléctrica, luz, ímans)

Força Forte (Coesão dos Núcleos Atómicos)

...e ainda outras interacções (Relações Humanas, etc.)

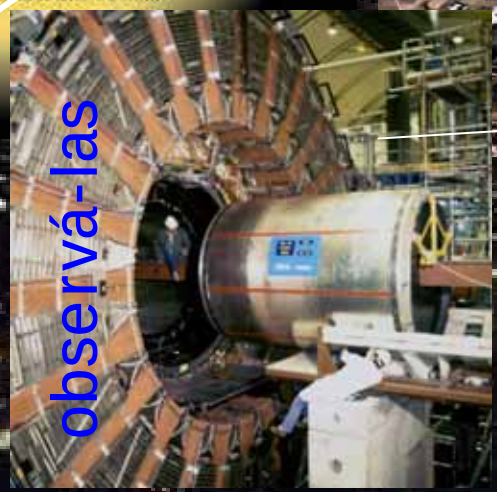
Estudamos o Quê, Onde e Como...



o Quê: de que é a matéria feita, na mais pequena escala possível

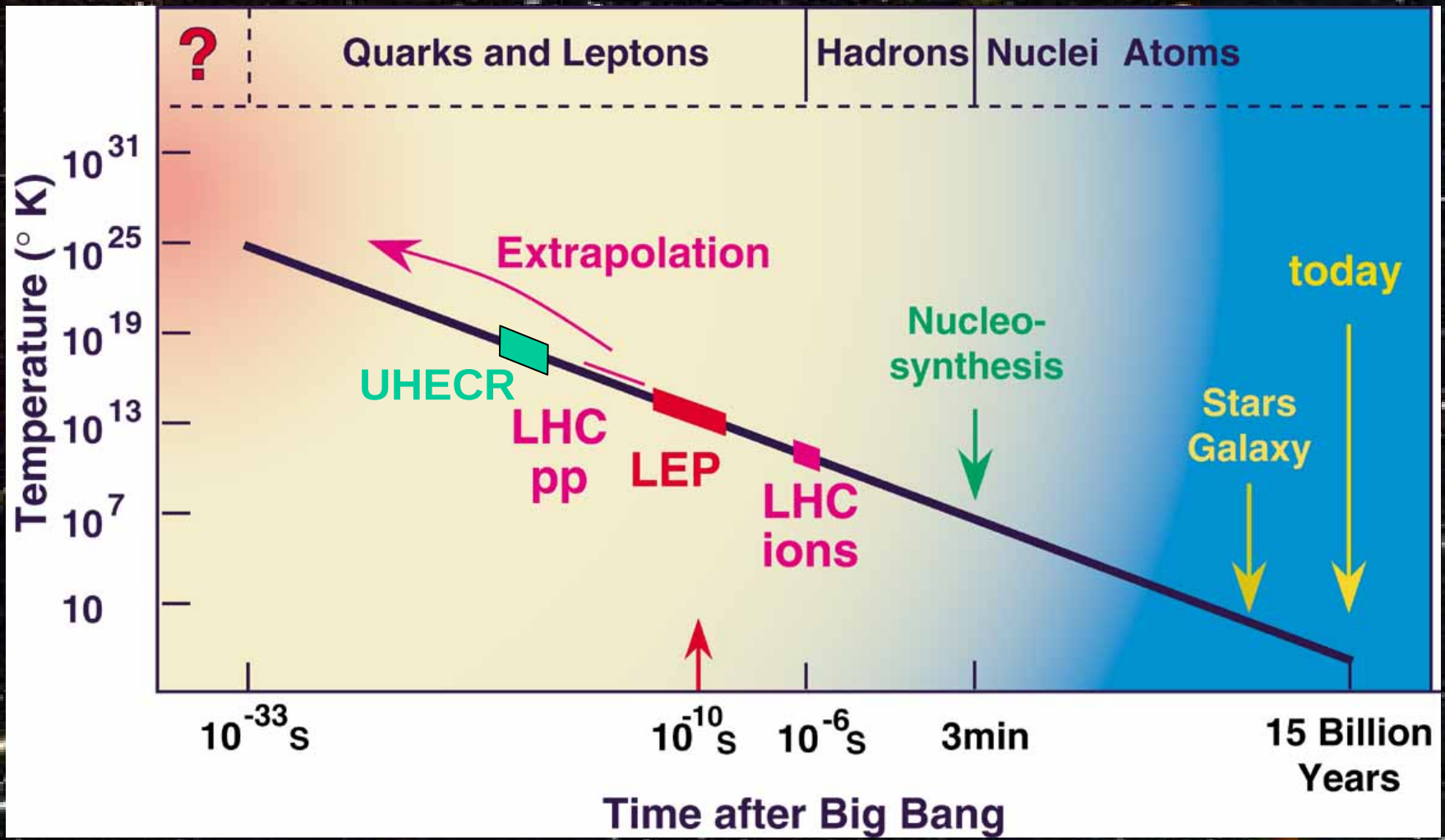
Onde: nos grandes laboratórios

Como



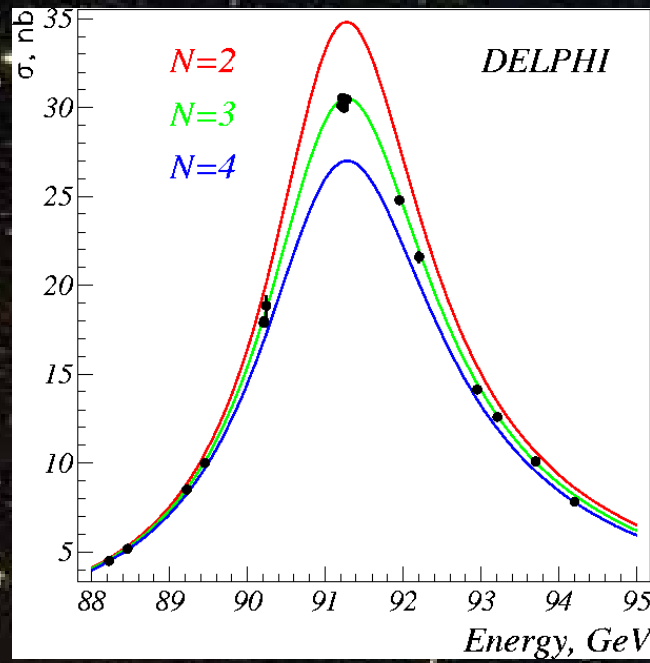
Colaborações Internacionais ~1000 Cientistas

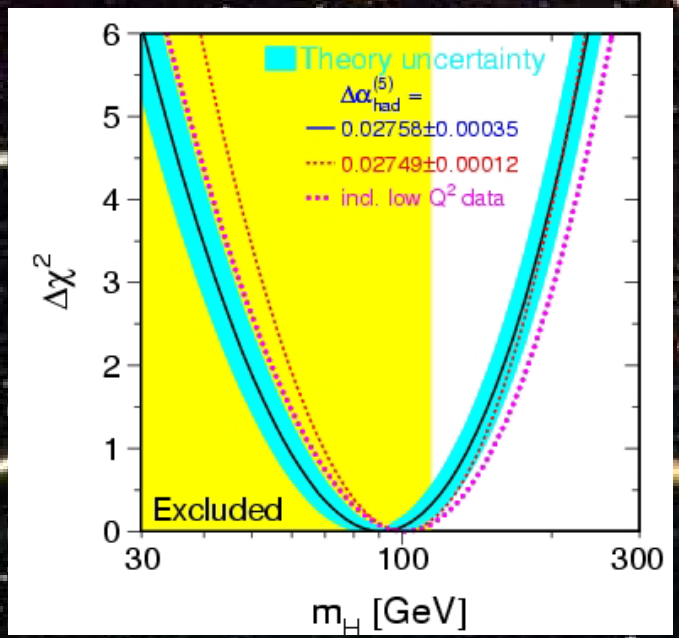
Para o início do Universo...



Mistérios por resolver

- **Porquê 3** famílias de neutrinos leves **?**
- A Origem da Massa das Partículas – à procura do **Bosão de Higgs**





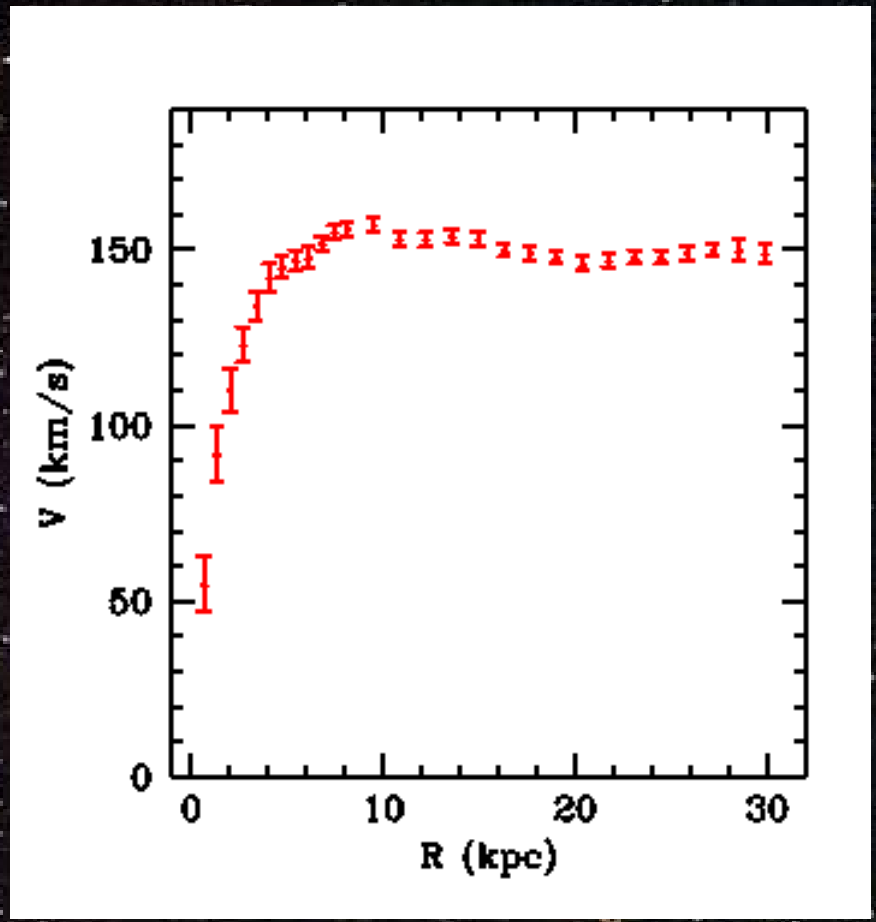
- Assimetria Matéria – Anti-Matéria

E na Astrofísica ?

- De que é feita afinal a maior parte do Universo ?!
  - Não é de matéria simples, normal, conhecida!!!

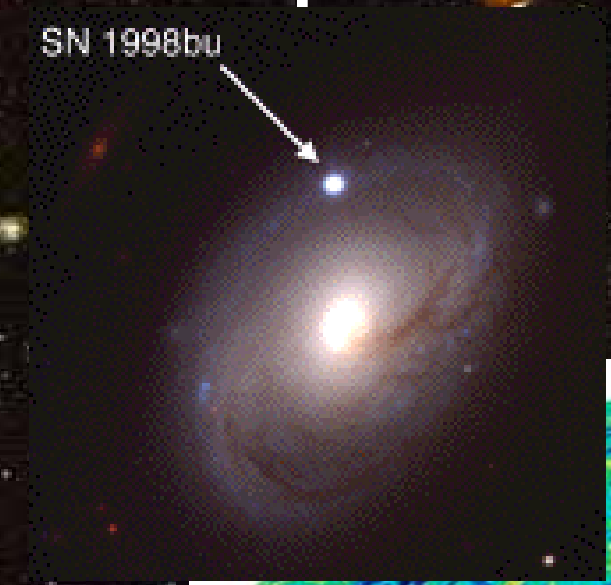
- O que pode acelerar partículas até $E>10^{21}$ eV ?!
  - Estas deveriam perder energia no caminho!!!

O problema da matéria escura

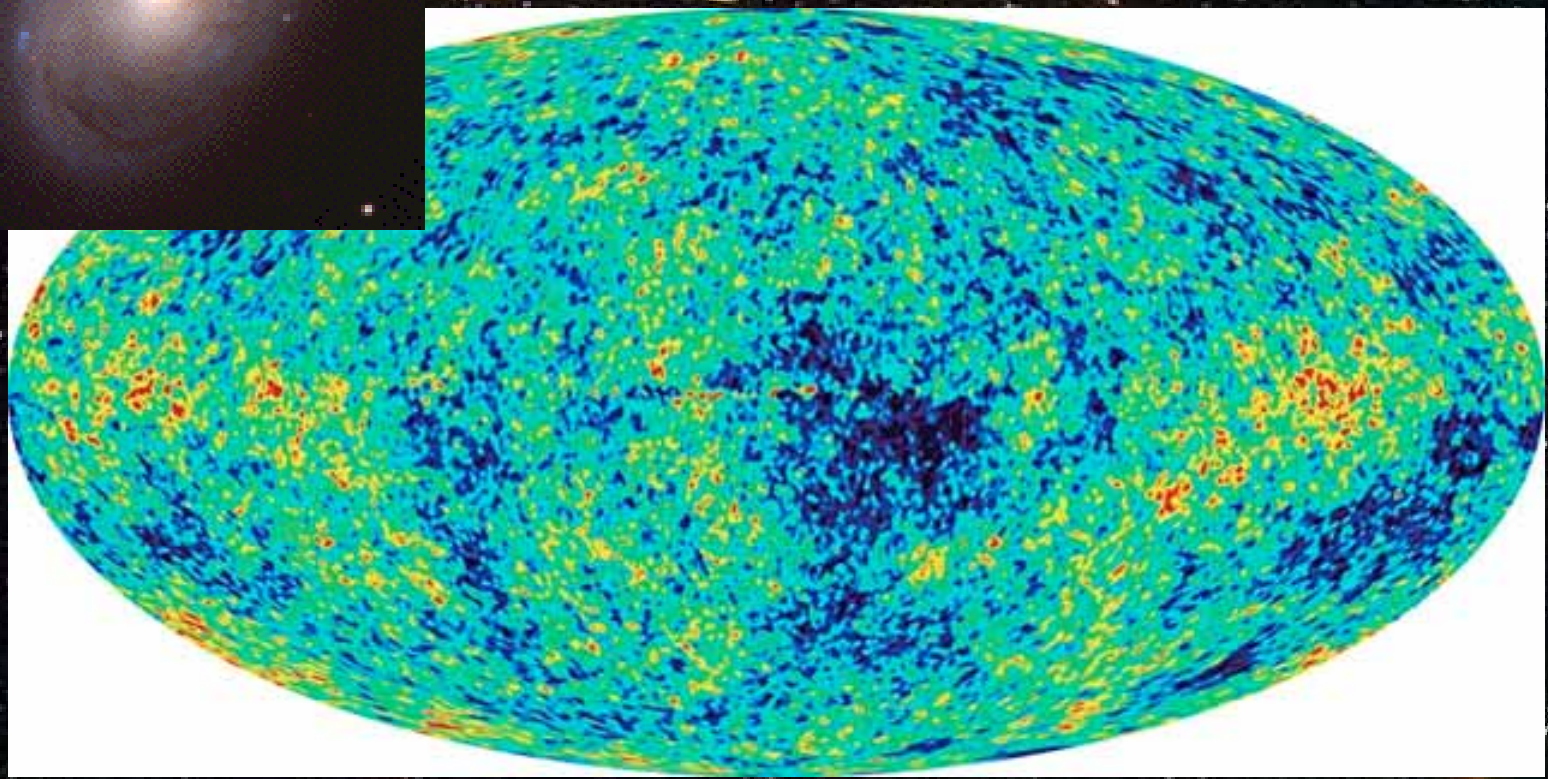


...que se agrava para escalas maiores!

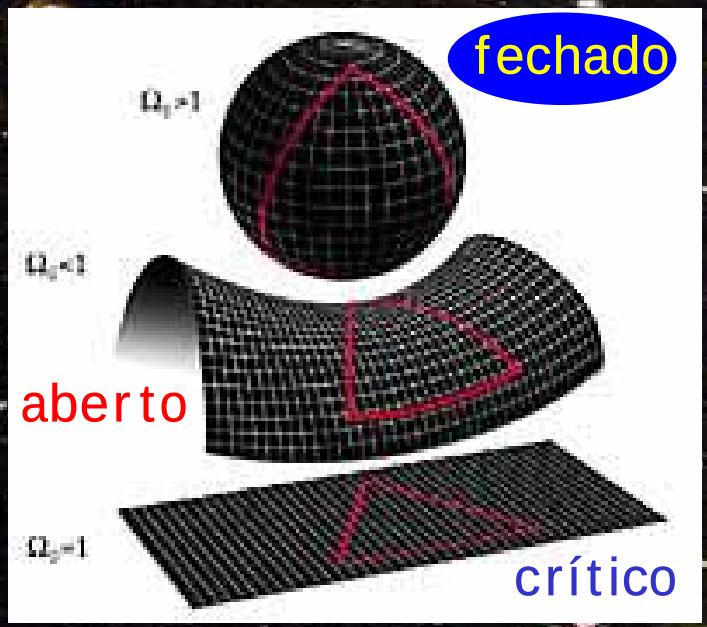
O problema da energia escura!

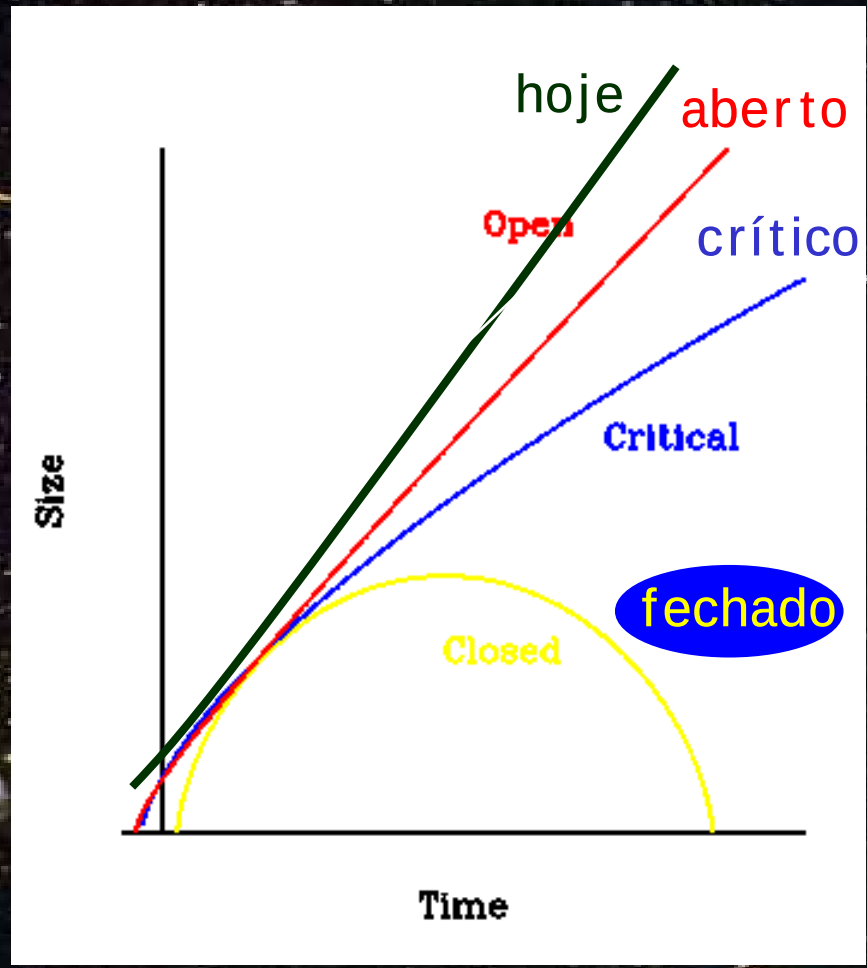


O Universo está em expansão ACELERADA!

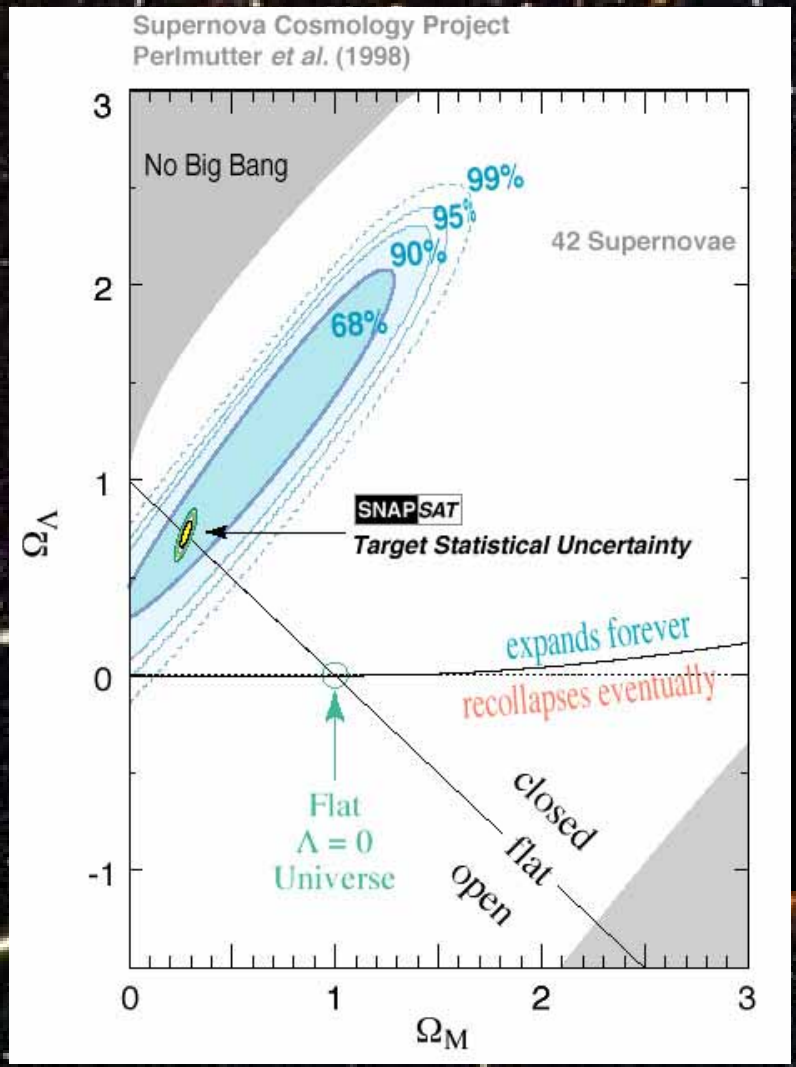


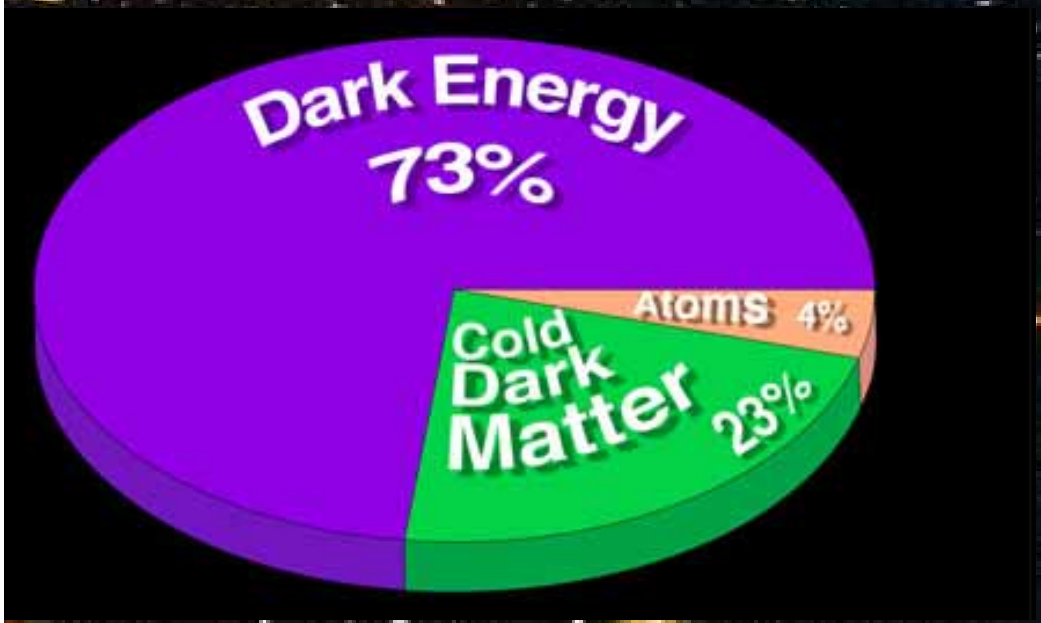
A curvatura do Universo





A composição do Universo(?!)





...e para concluir:

Uma viagem a várias escalas!

http://www.powersof10.com