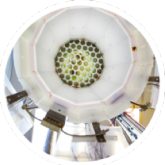
Bem vindos ao LIP !

Experimental particle and **astroparticle physics**



Development of **new instruments** and **methods**

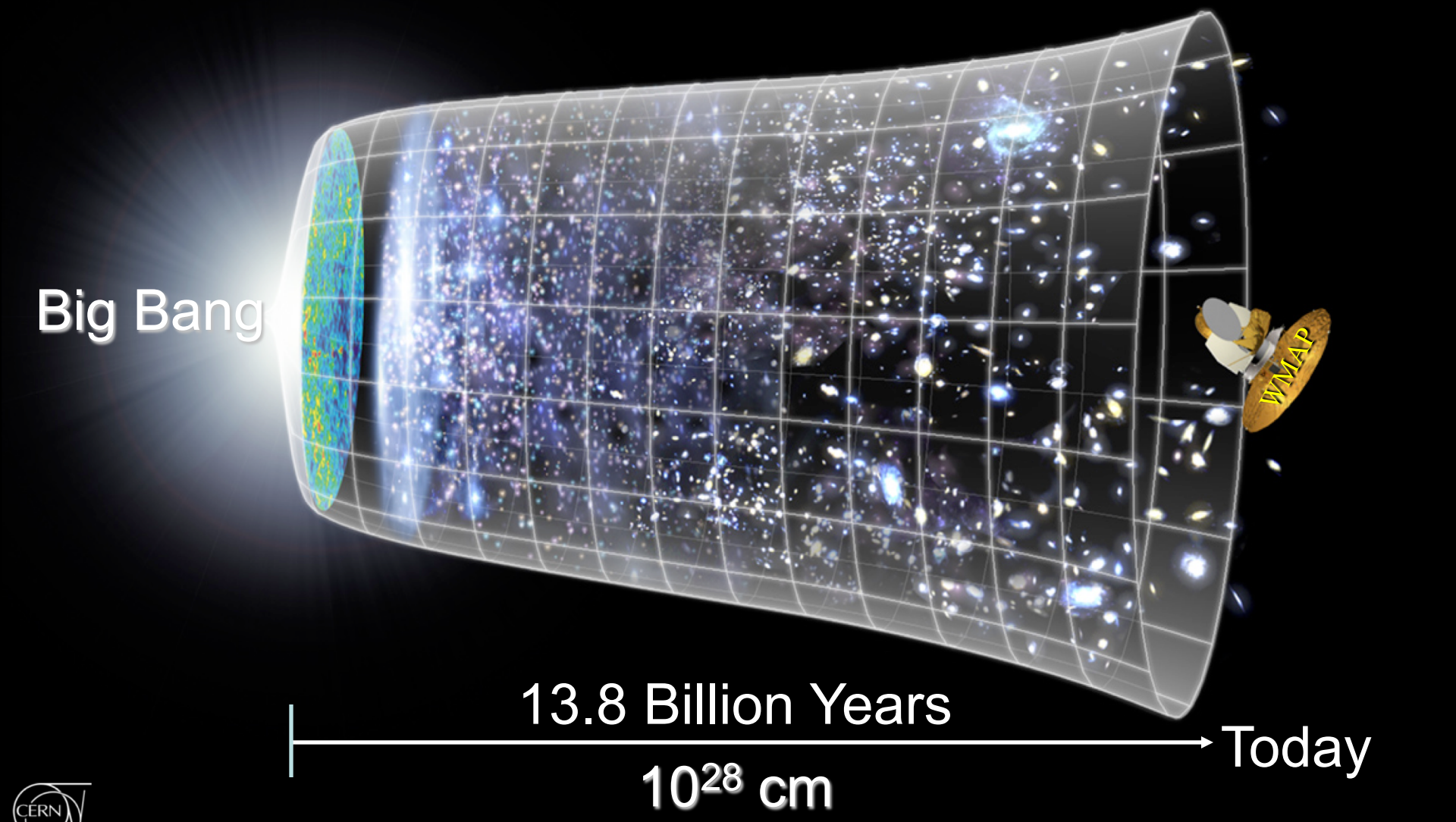
Scientific computing

Knowledge transfer, education and **outreach**

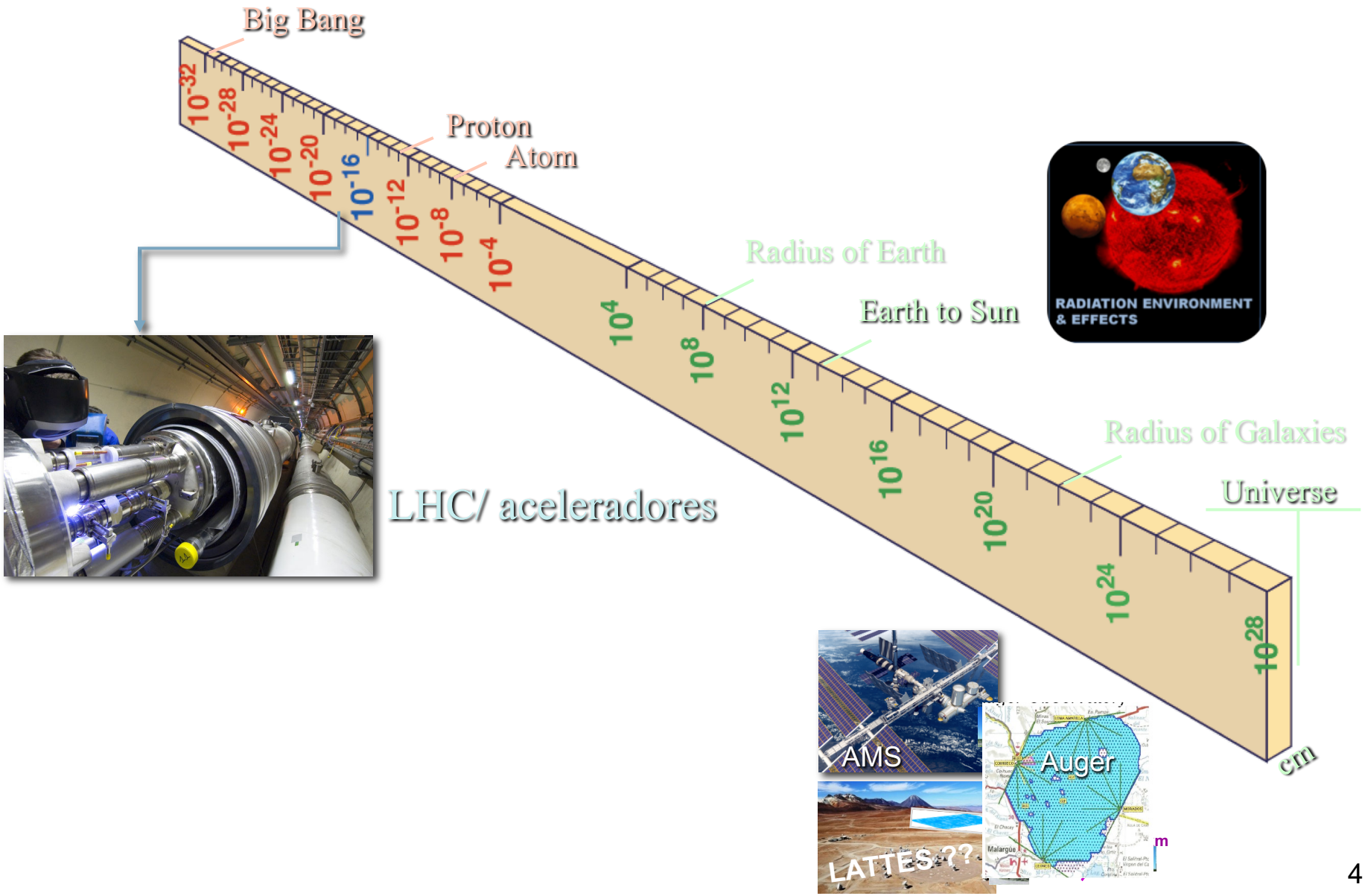
A aventura da Física de Partículas e Astropartículas

Mário Pimenta
Lisboa, Julho 2019

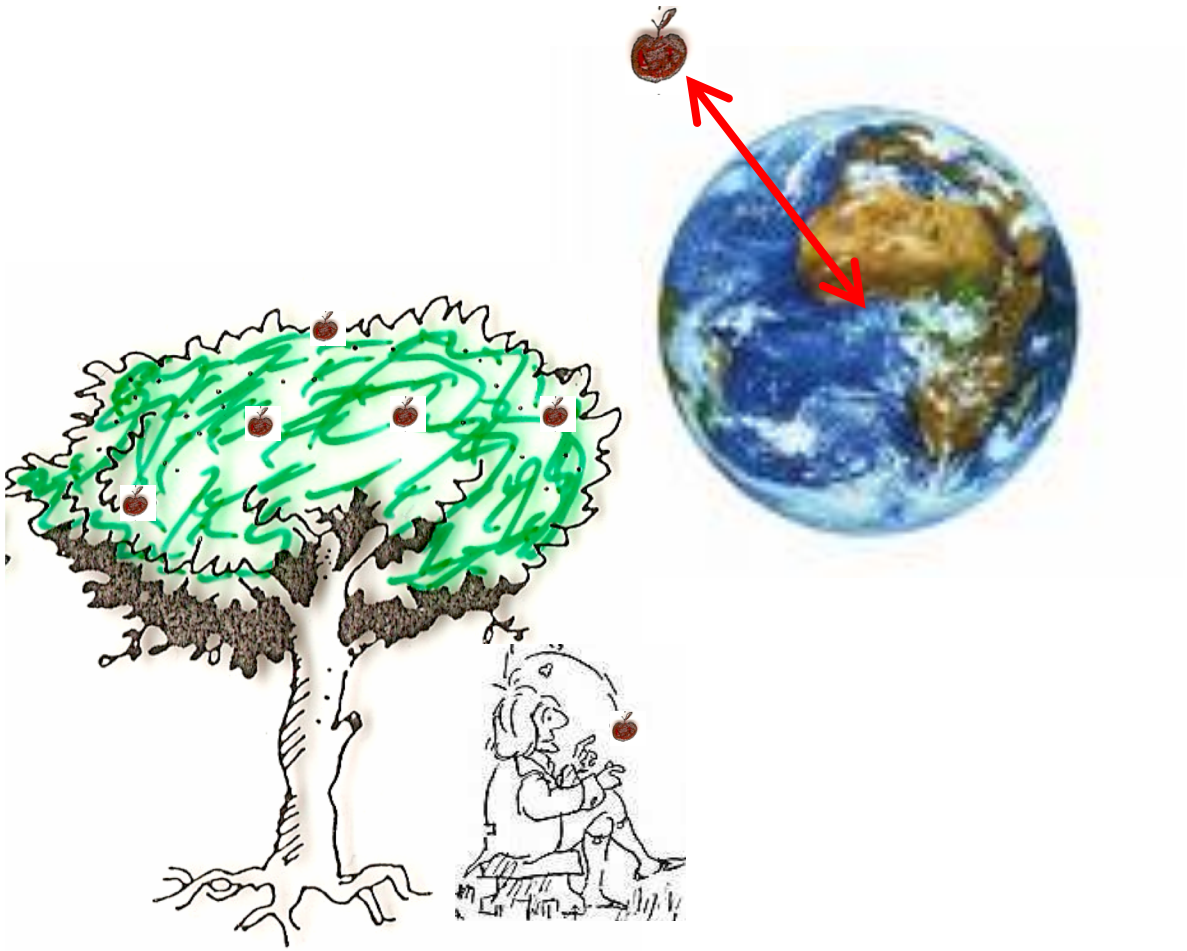
O Universo para compreender, ...



Escalas, ...

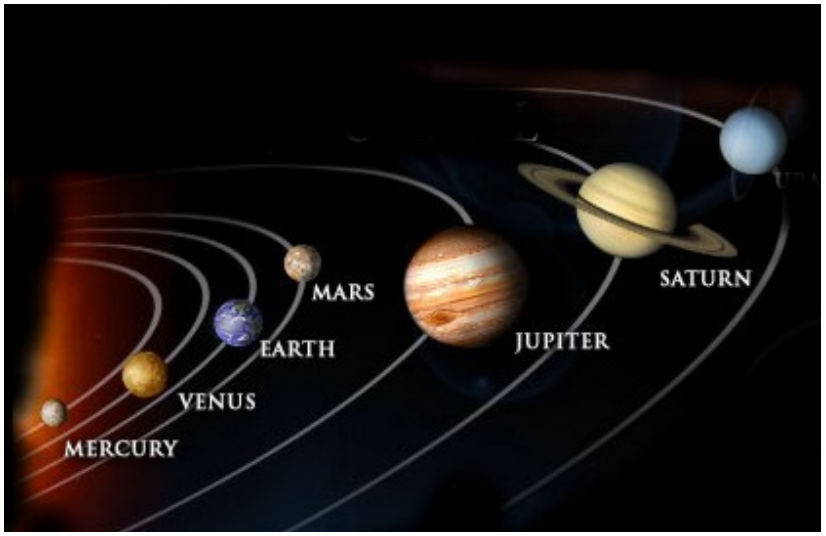

Big Bang
Proton
Atom
Radius of Earth
Earth to Sun
Radius of Galaxies
Universe
10^{-32}
10^{-28}
10^{-24}
10^{-20}
10^{-16}
10^{-12}
10^{-8}
10^{-4}
10^{4}
10^{8}
10^{12}
10^{16}
10^{20}
10^{24}
10^{28}
cm
RADIATION ENVIRONMENT & EFFECTS
LHC/ aceleradores
AMS
Auger
LATTES ??
Malargüe
m

Da maçã ao Universo



I. Newton

Da maçã ao Universo



I. Newton

Lei da atracção Universal:

$$F = G \frac{m_{1g}\, m_{2g}}{r_{12}^{2}}$$

A gravidade !

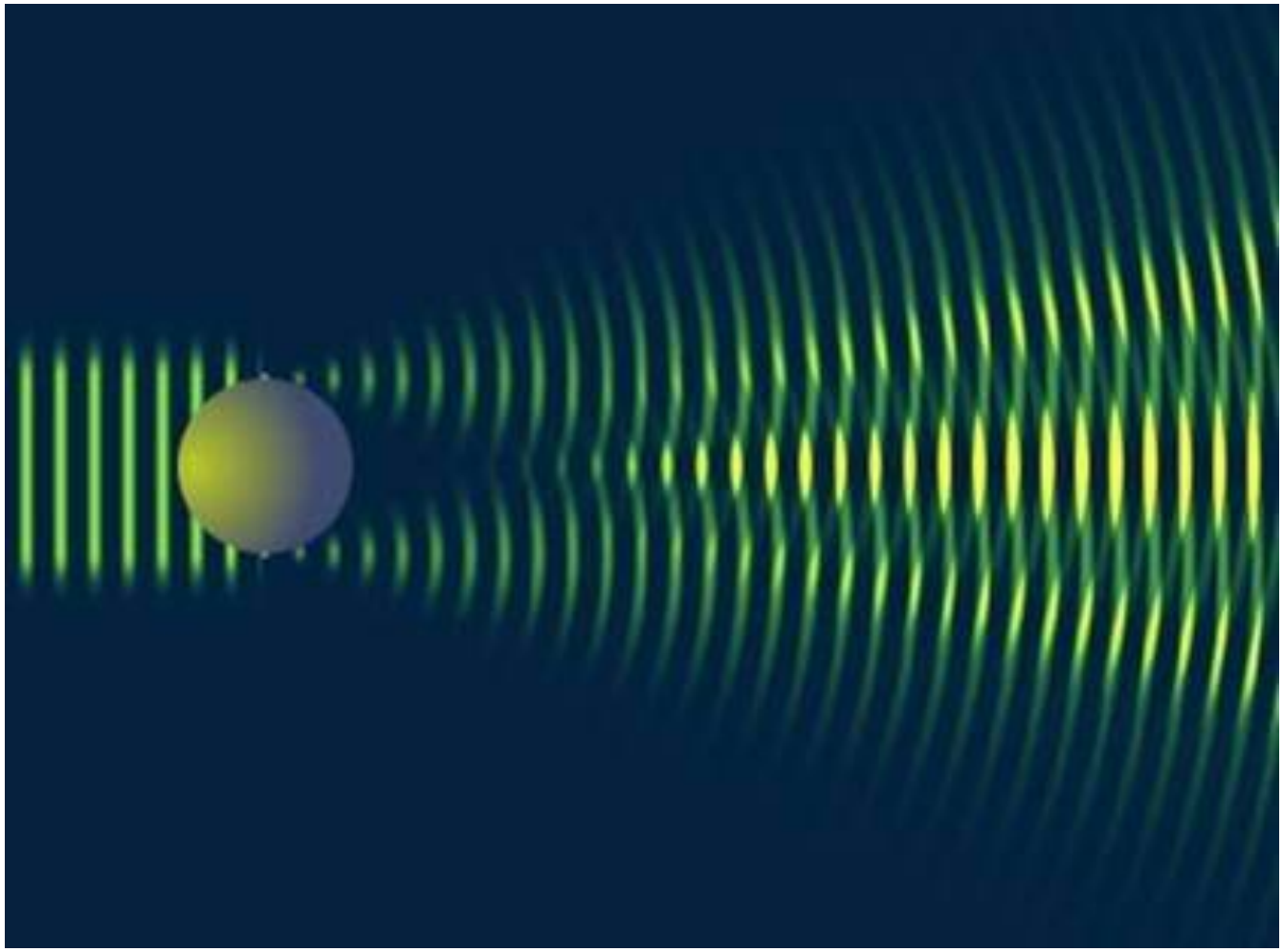
Será que a maçã é elementar?

Ver o interior da maçã ???

Mas a luz propaga-se como uma onda ...

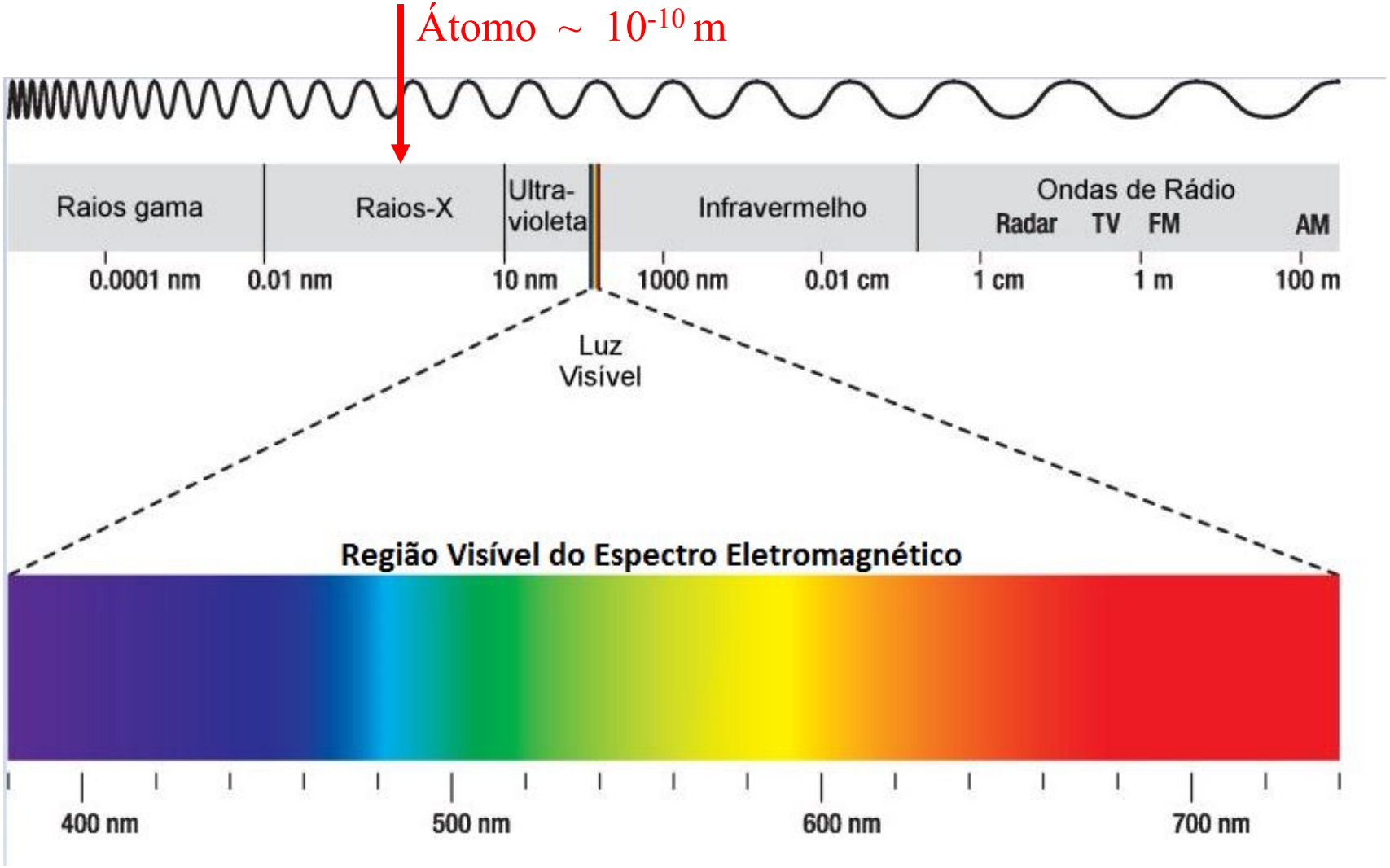
As ondas podem difractar-se ...

Se λ for da ordem do tamanho do objecto



Só se podem ver objectos com uma dimensão maior que λ !

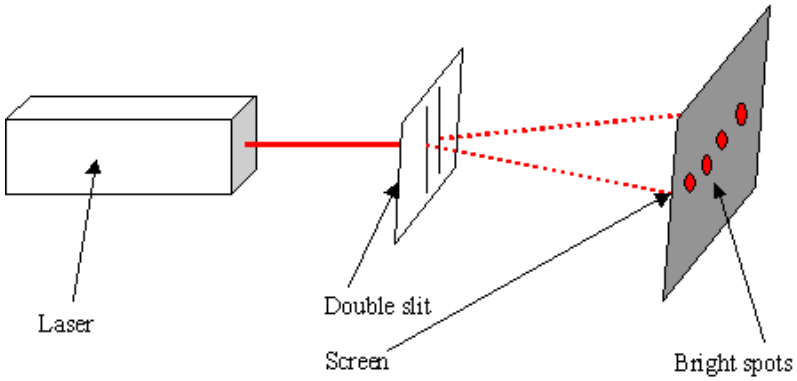
O comprimento de onda da luz



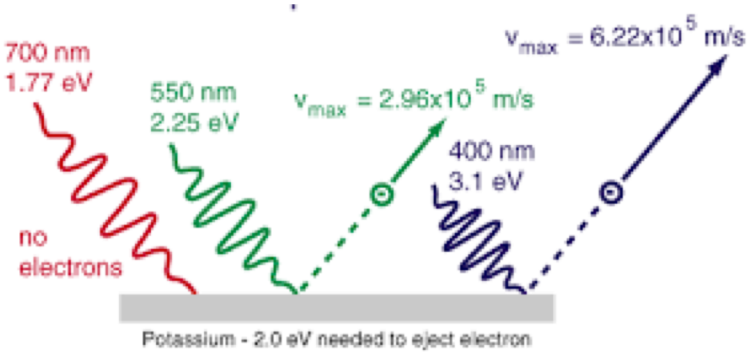
$\lambda_{\text{visível}} \approx 10^{-7}$ m

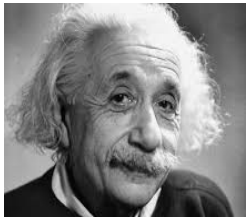
Ondas e partículas : a Luz

Propaga-se como uma onda



Interage como uma partícula



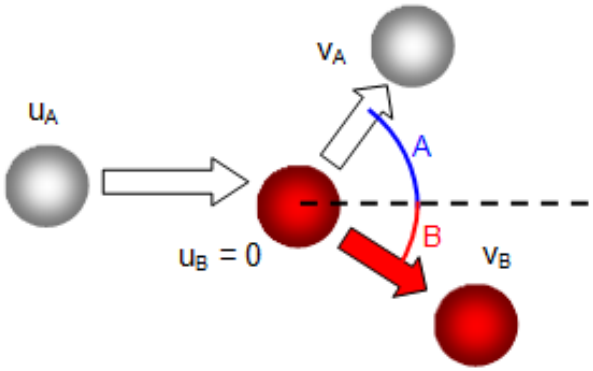


Einstein

O fotão !

Ondas e partículas : o electrão

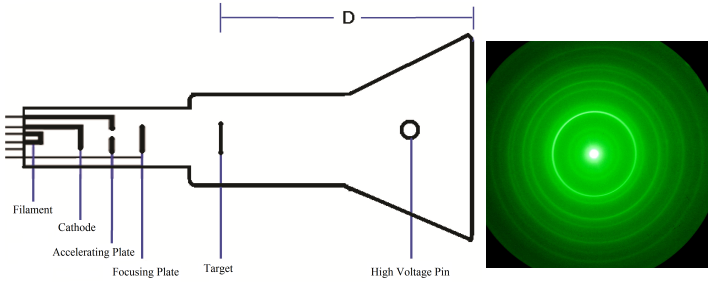
Interage como uma partícula



Propaga-se como uma onda

Louis de Broglie

$$\lambda = \frac{h}{p}$$

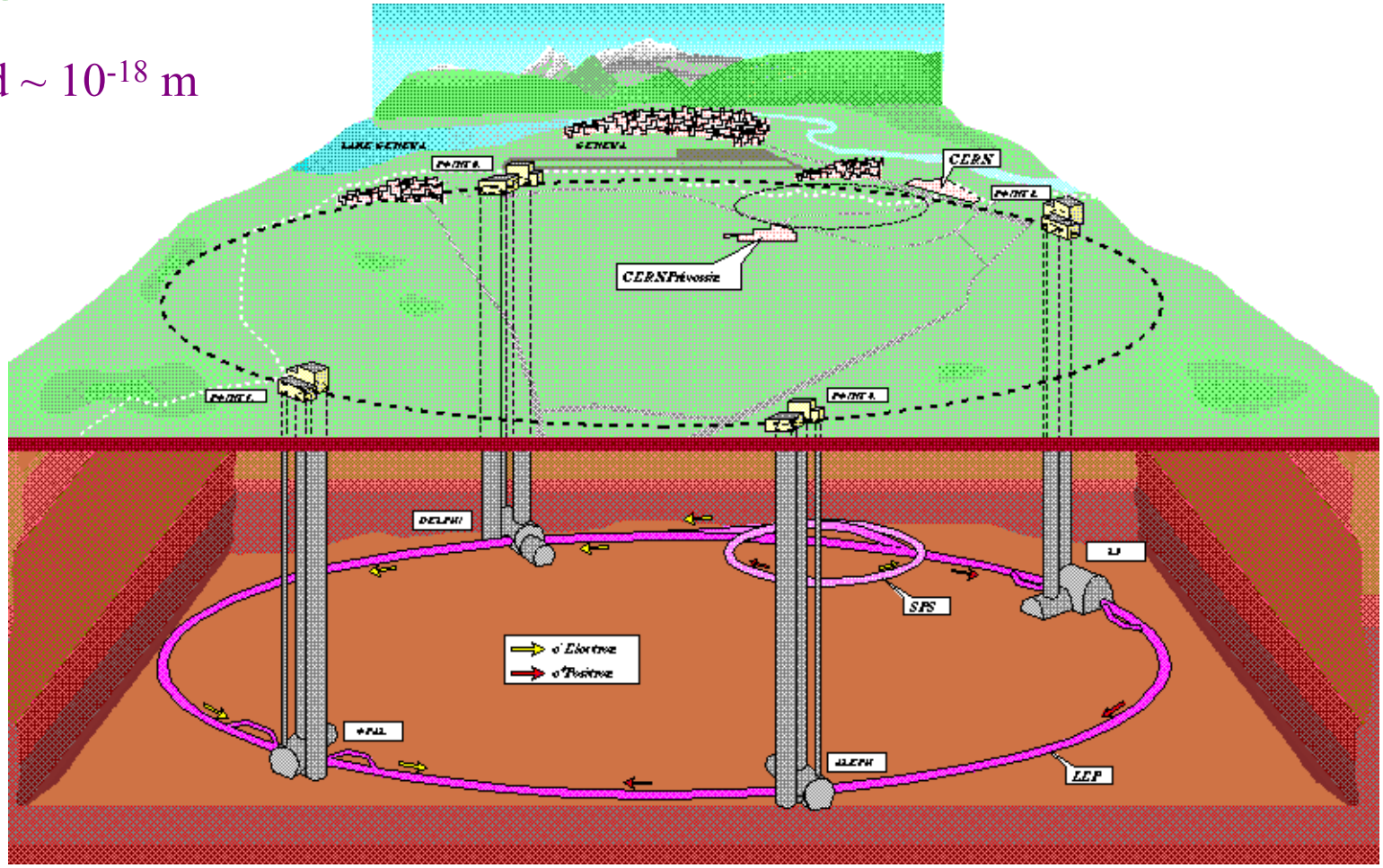


Ver com partículas

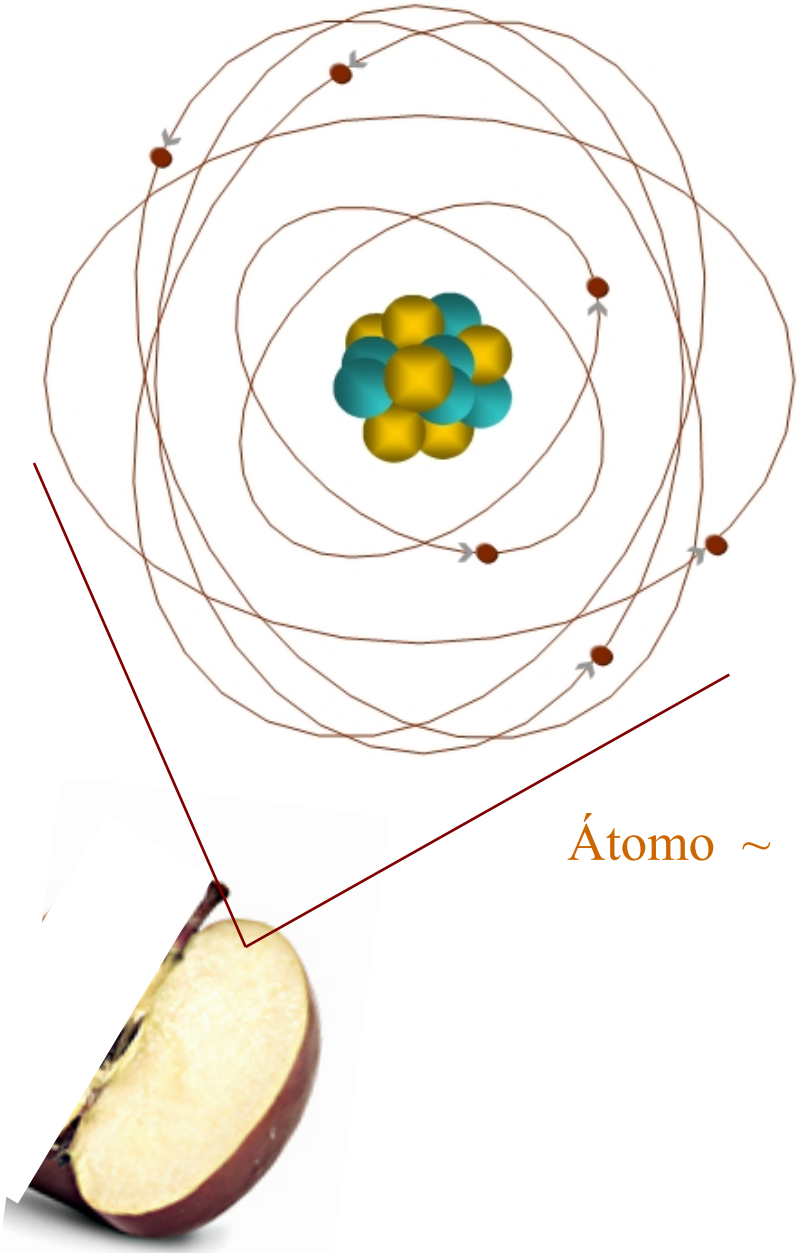
$$\lambda = \frac{h}{p}$$

CERN

d ~ 10^{-18} m



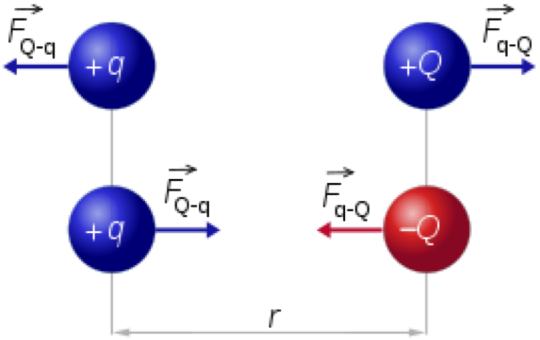
Será que a maçã é elementar?



A Força electromagnética

J. Maxwell

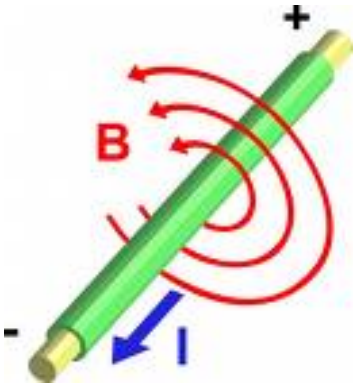
Atracção / Repulsão



$$F_C = K \frac{q_1 q_2}{r_{12}^2}$$

campo eléctrico

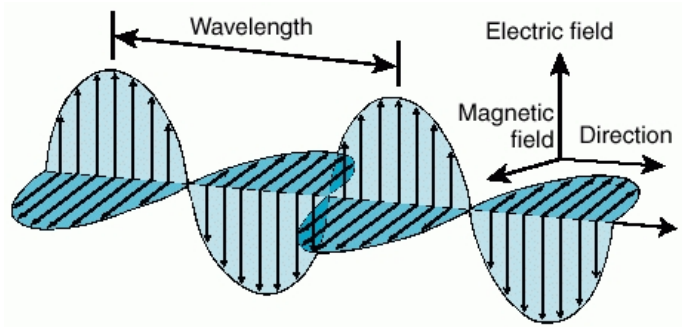
correntes



$$\vec{F}_L = q\,(\vec{E} + \vec{v} \otimes \vec{B})$$

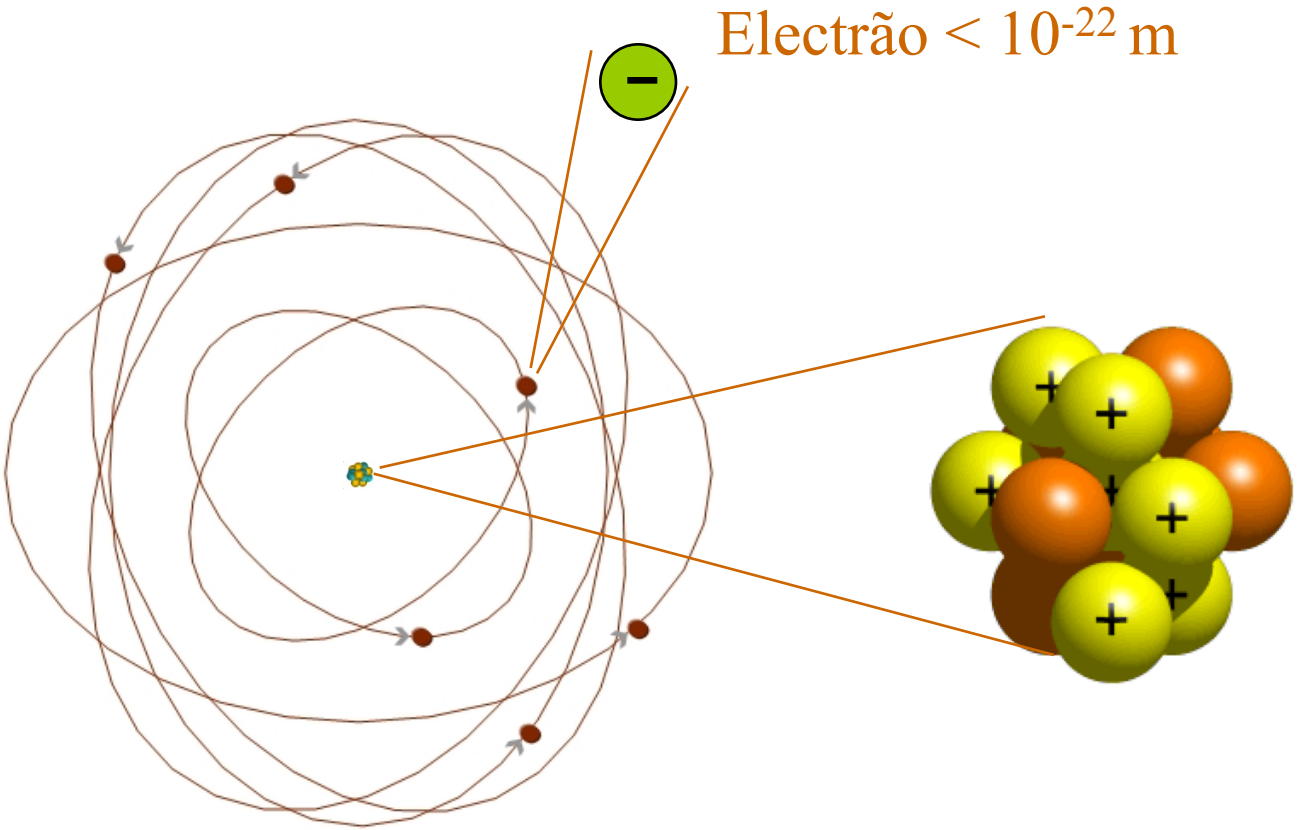
campo magnético

ondas



campo electromagnético

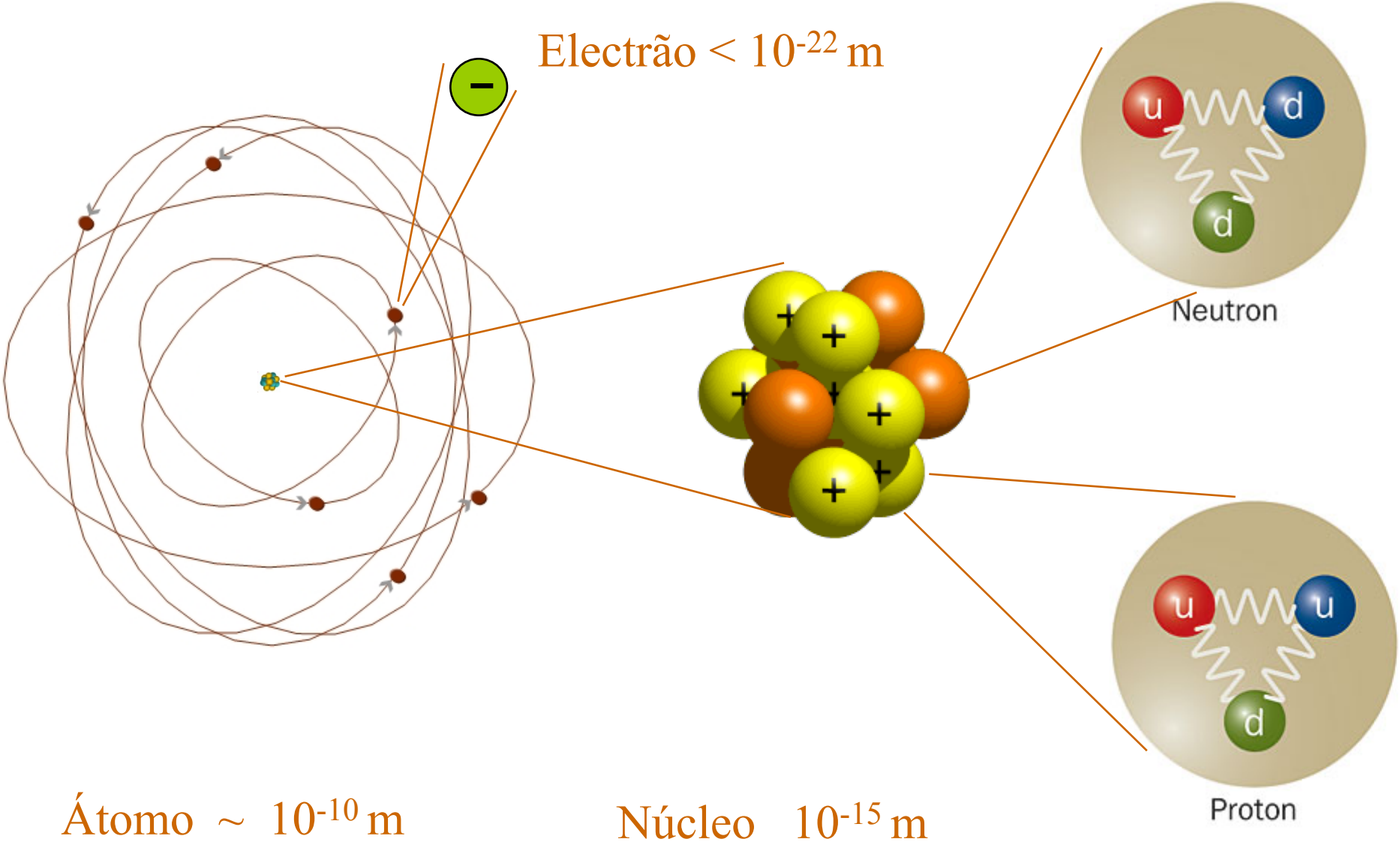
No interior dos átomos



Átomo ~ 10^{-10} m

Núcleo 10^{-15} m

No interior dos átomos



Vários quarks, muitas partículas !!!

Quarks:

$$\begin{pmatrix} u \\ d \end{pmatrix}$$

Q = + 2/3

Q = - 1/3

Vários quarks, muitas partículas !!!

Quarks:

$$\begin{pmatrix} u \\ d \end{pmatrix} \begin{pmatrix} c \\ s \end{pmatrix} \begin{pmatrix} t \\ b \end{pmatrix} \begin{pmatrix} ? \\ \end{pmatrix}$$

Q = + 2/3

Q = - 1/3

Vários quarks, muitas partículas !!!

Quarks:

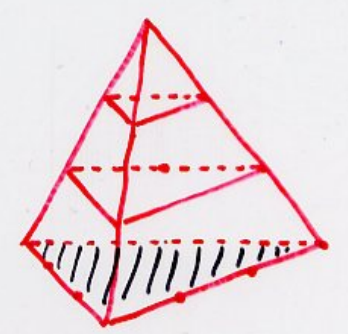
$$\begin{pmatrix} u \\ d \end{pmatrix} \begin{pmatrix} c \\ s \end{pmatrix} \begin{pmatrix} t \\ b \end{pmatrix} \begin{pmatrix} ? \end{pmatrix}$$

Q = + 2/3

Q = - 1/3

Combinar

$q_i q_j q_k$



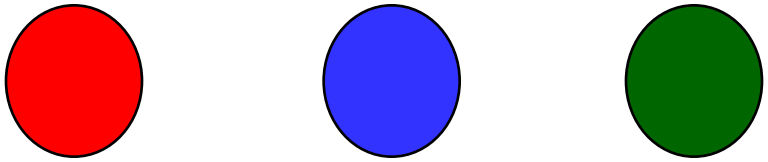
$q_i \vec{q}_i$

$p\ ,n\ ,\Sigma\ ,\lambda\ ,\Xi\ ,\Delta\ ,\ldots$

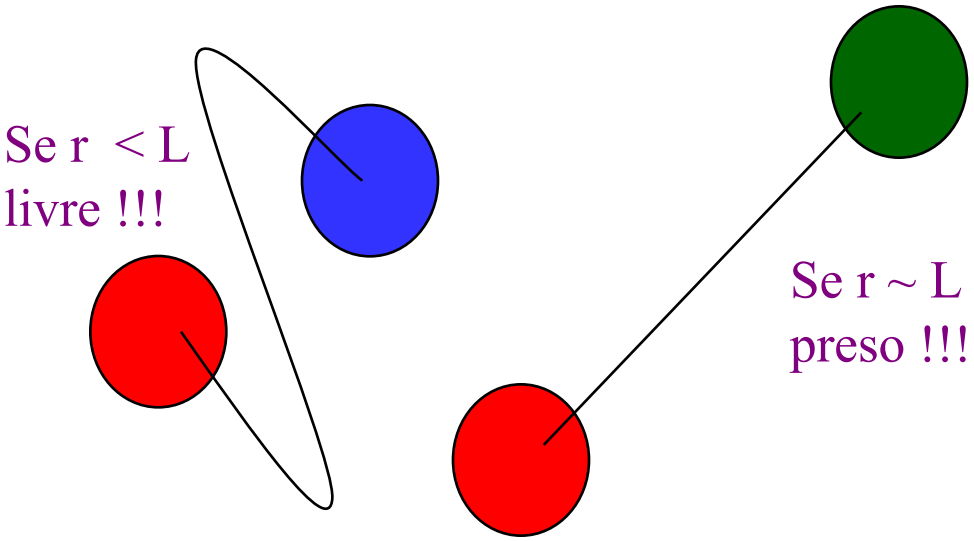
$\pi\ ,k\ ,\eta\ ,\rho\ ,\psi,\ldots$

A força forte

Quarks de três cores:

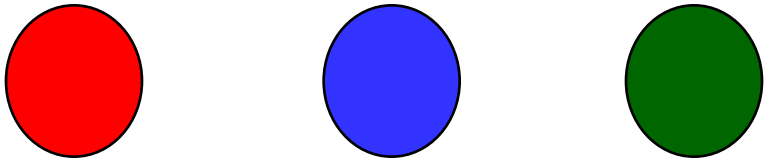


Ligados por “cordas”

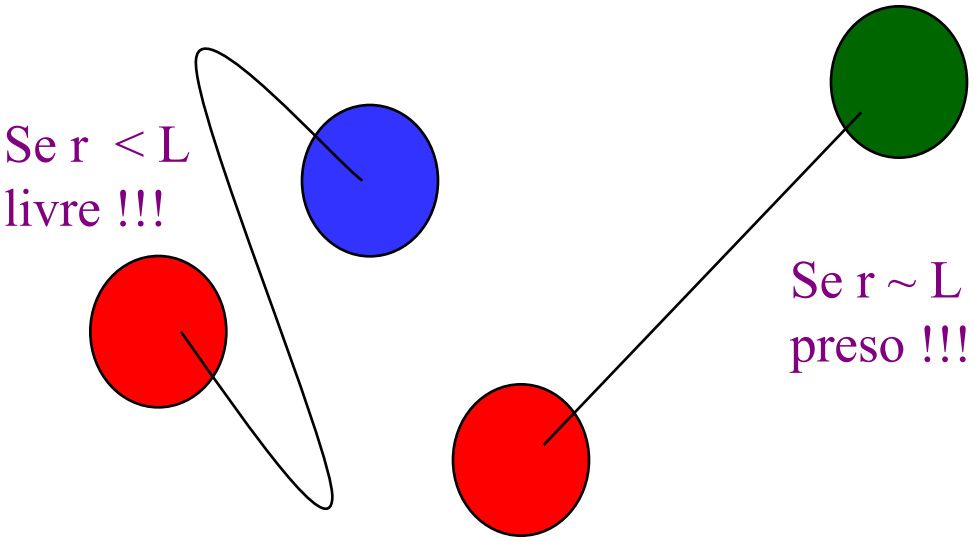


A força forte

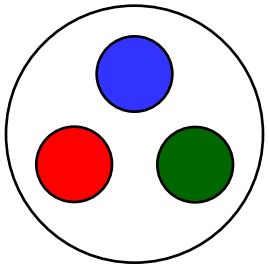
Quarks de três cores:



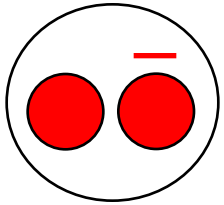
Ligados por “cordas”



Partículas “sem cor”

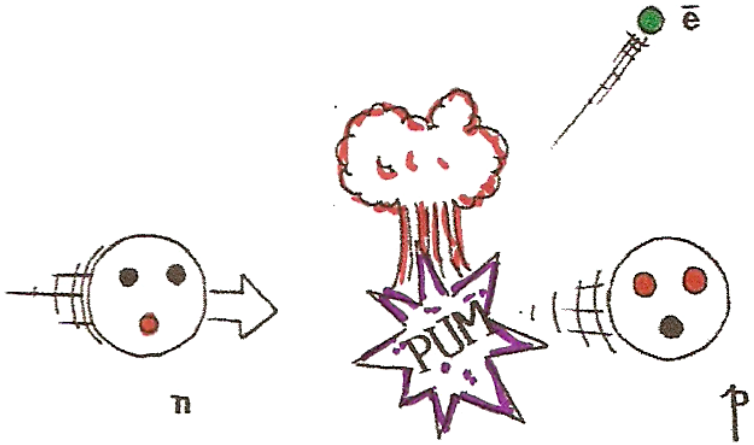


Bariões

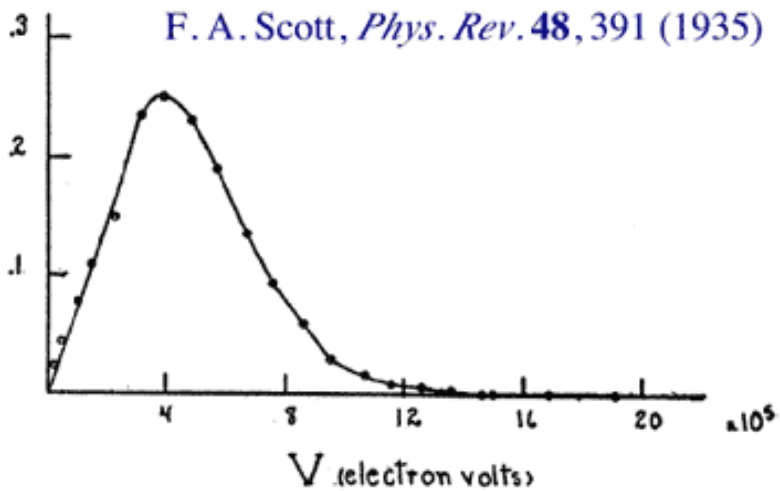


Mesões

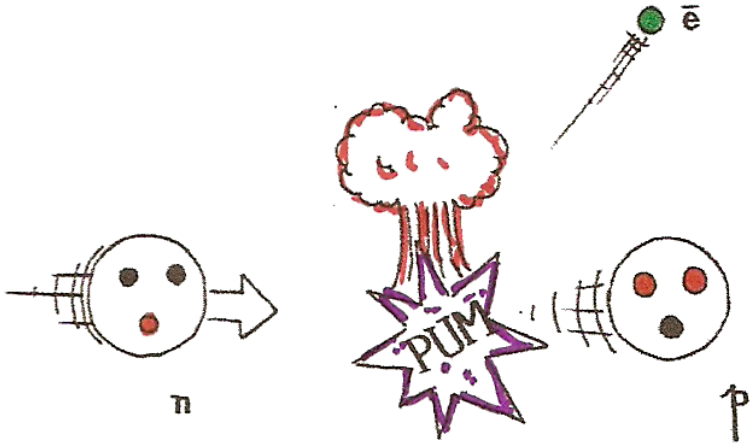
O neutrão decai…



conservação o E e $\vec{P}$???



O neutrão decai…



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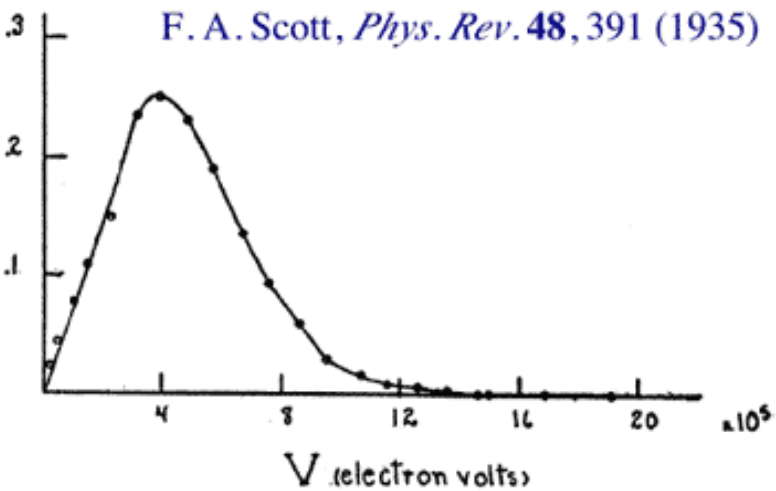
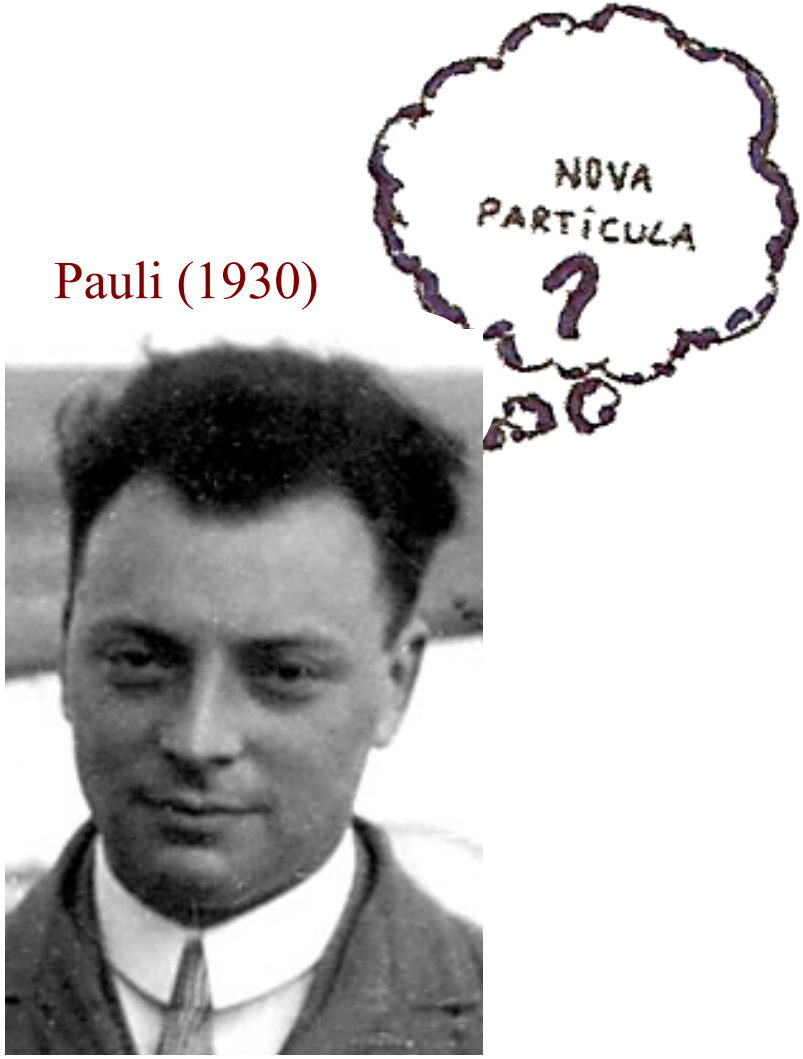


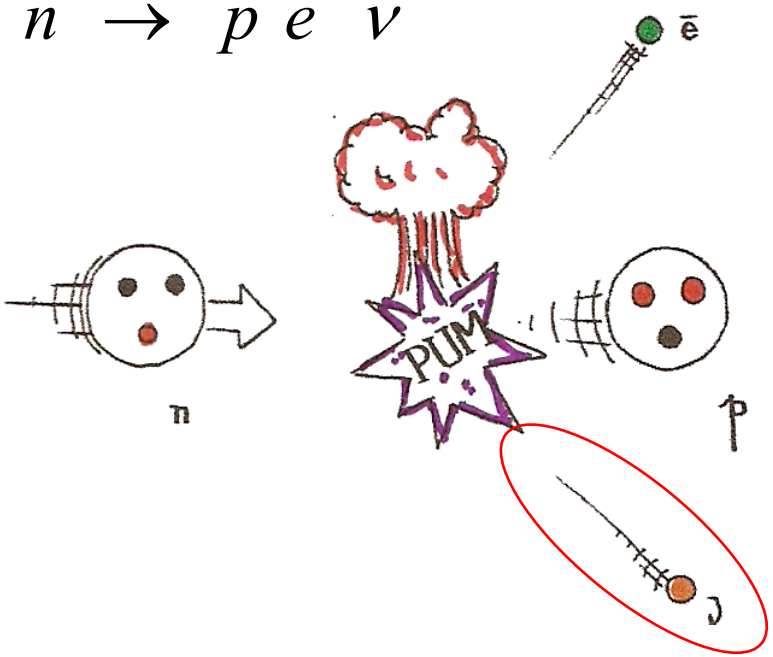
Pauli (1930)

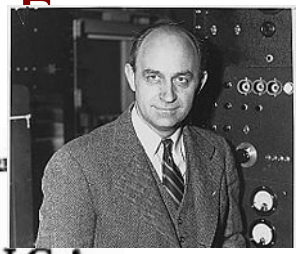


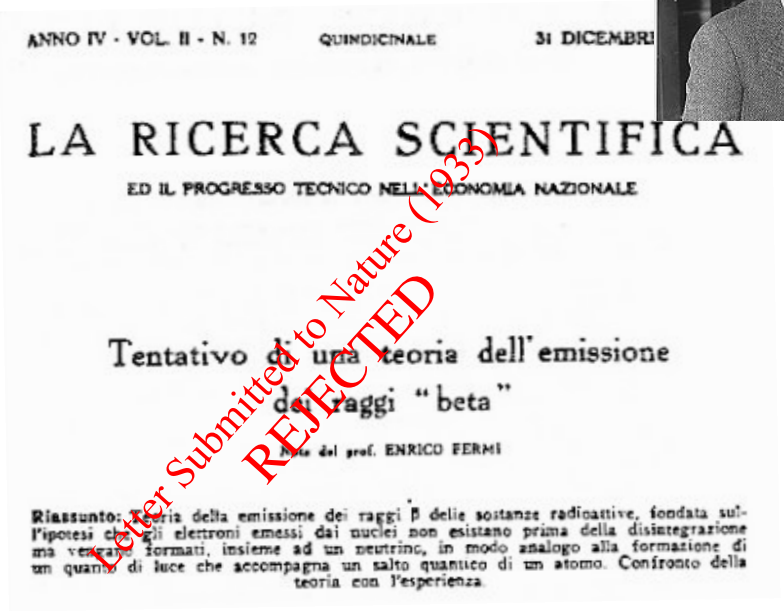
O neutrino !!!

A força fraca

$$n \rightarrow p\, e^{-}\, \bar{\nu}$$







ANNO IV - VOL. II - N. 12 QUINDICINALE 31 DICEMBRE

LA RICERCA SCIENTIFICA

ED IL PROGRESSO TECNICO NELL'ECONOMIA NAZIONALE

Tentativo di una teoria dell'emissione dei raggi "beta"

Nota del prof. ENRICO FERMI

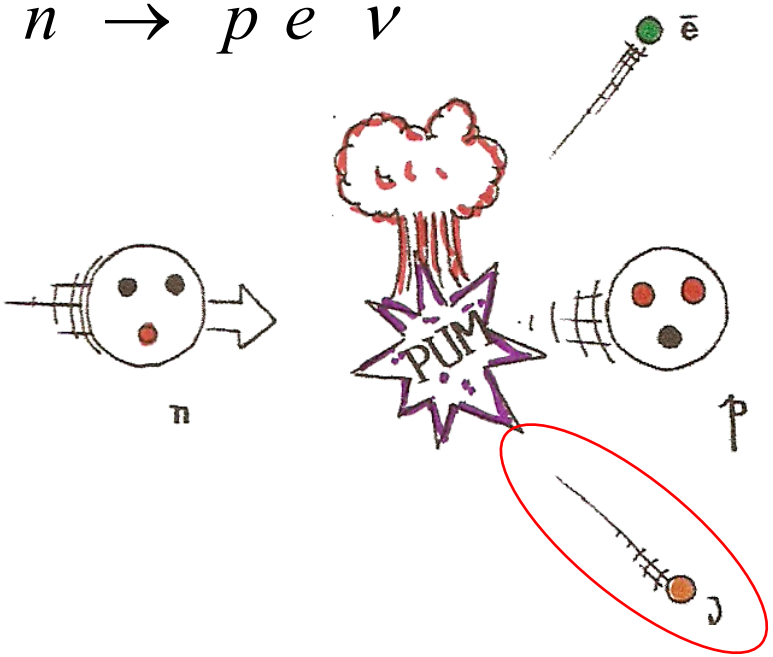
Riassunto: Teoria della emissione dei raggi β delle sostanze radioattive, fondata sull'ipotesi che gli elettroni emessi dai nuclei non esistano prima della disintegrazione ma vengano formati, insieme ad un neutrino, in modo analogo alla formazione di un quanto di luce che accompagna un salto quantico di un atomo. Confronto della teoria con l'esperienza.

Letter Submitted to Nature (1933)
REJECTED

Nuovo Cimento and Zeitschrift fur Physik

A força fraca

$$n \rightarrow p\, e^{-}\, \bar{\nu}$$



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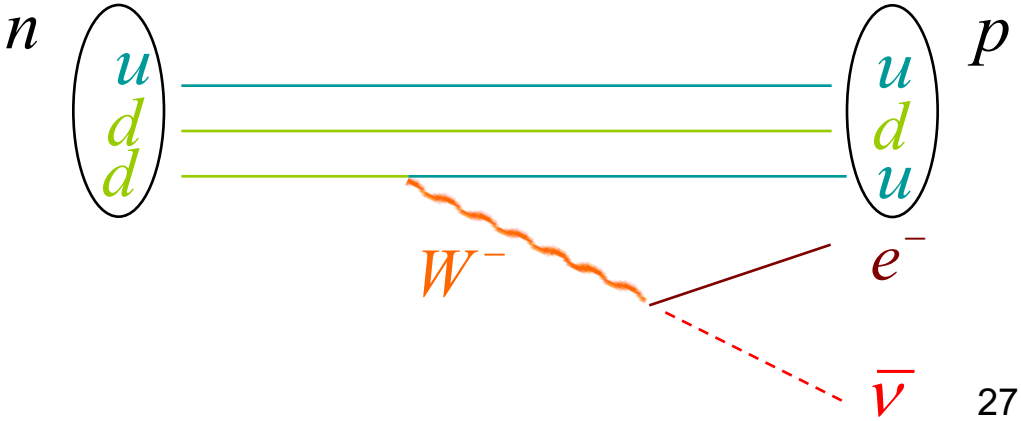
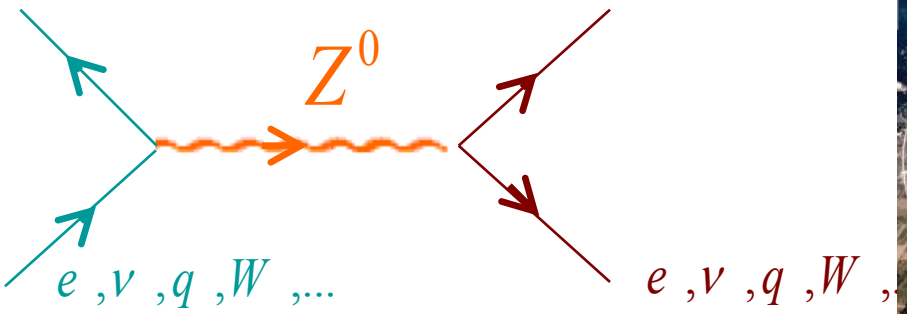
A visão moderna !

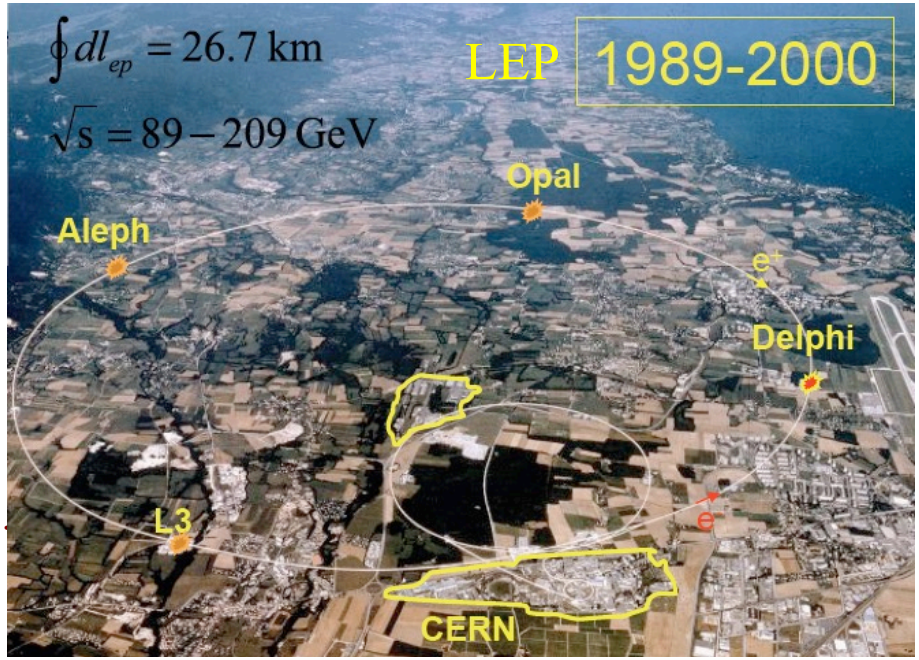
Um quark d transforma-se num quark u emitindo um bosão W que "decai" num par electrão, anti-neutrino



O Z^0

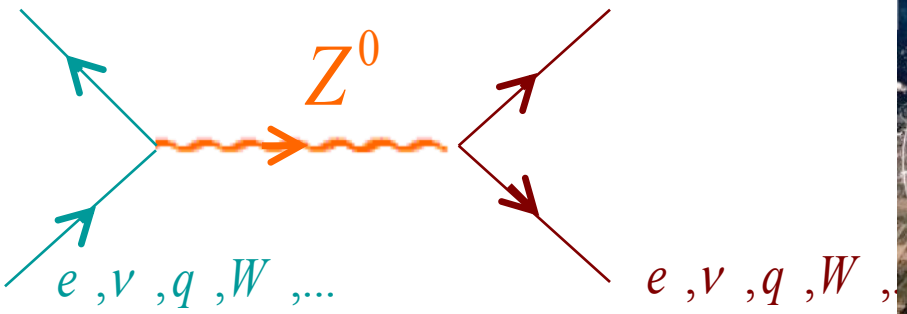
Parceiro neutro dos W´s

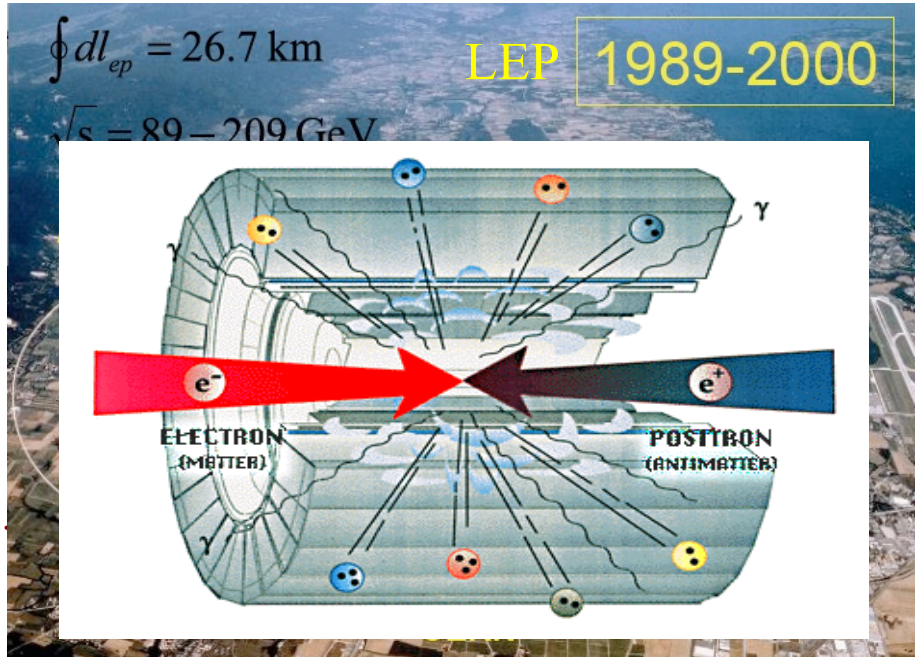




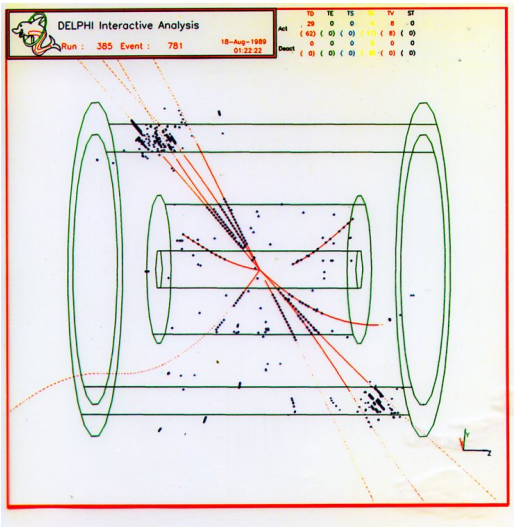
O Z^0

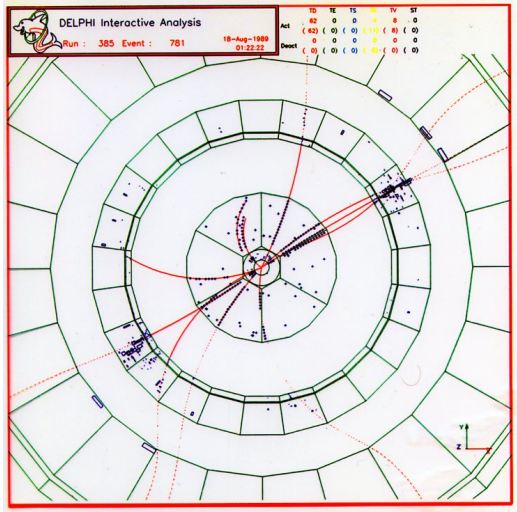
Parceiro neutro dos W´s

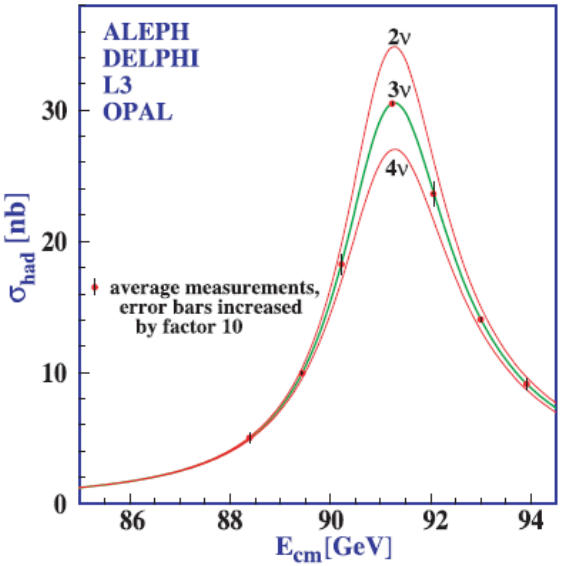




$e^+e^- \rightarrow q\bar{q}$



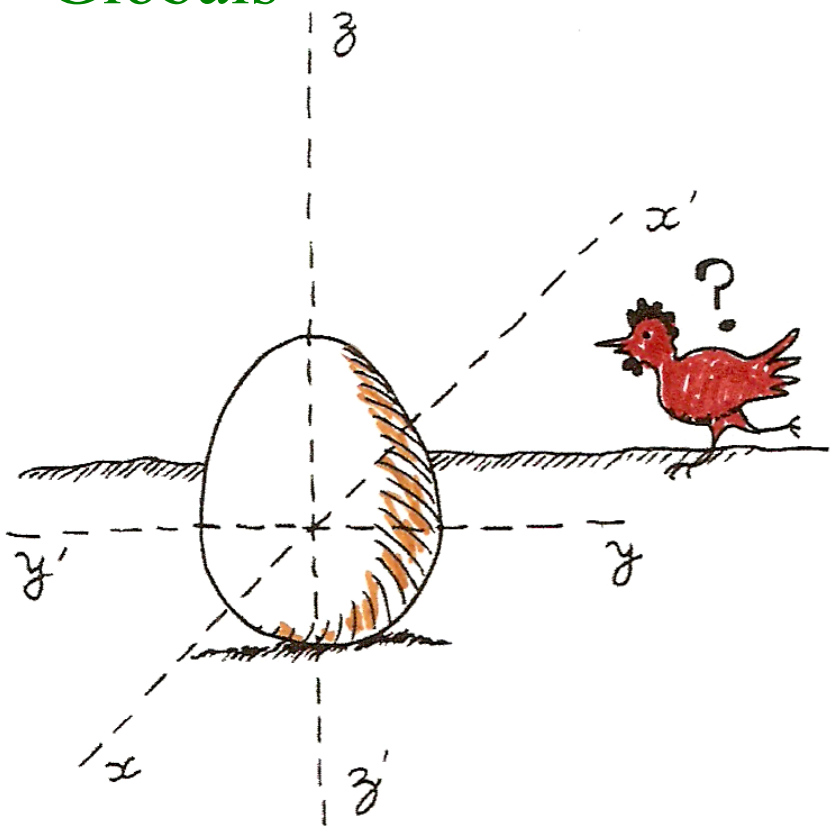




$M_z = 91.1875 \pm 0.0021$ GeV/c

Simetrias !!!

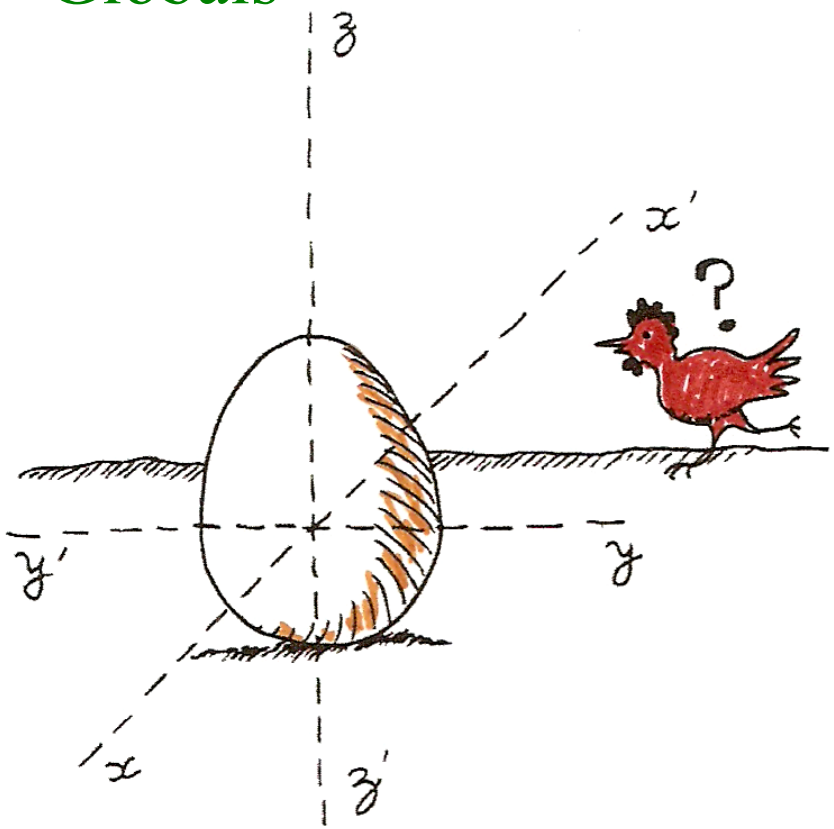
Globais



Leis de conservação:
Energia, Momento linear,
Momento Angular

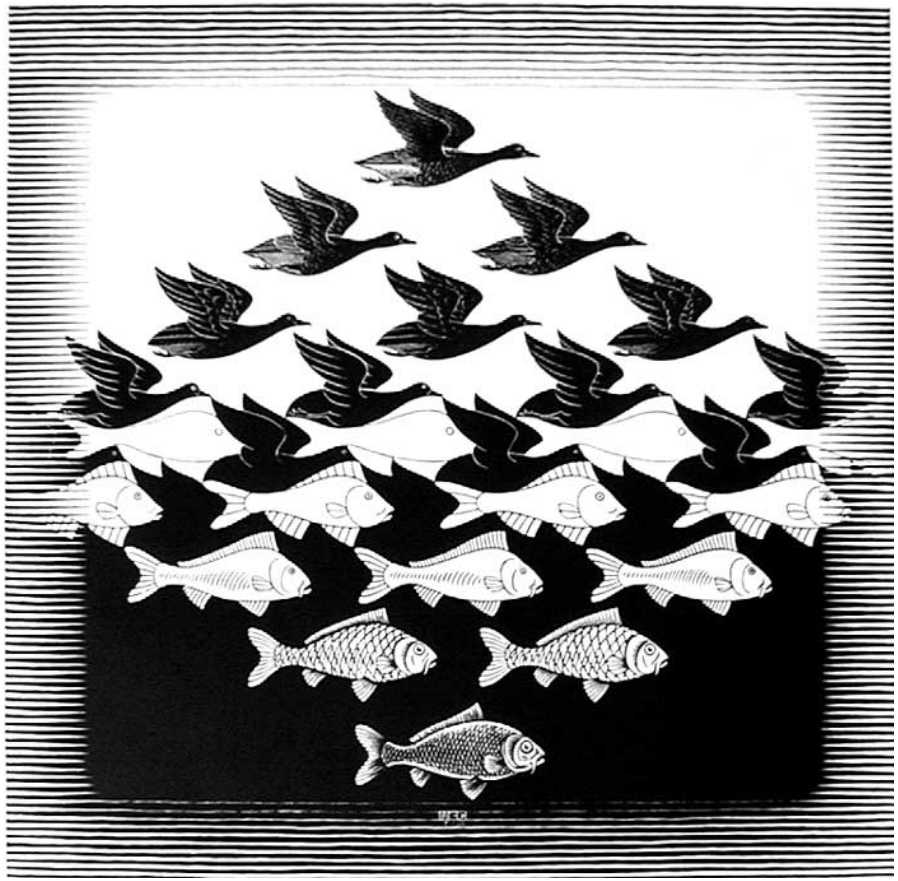
Simetrias !!!

Globais



Locais

M.C.Escher



Leis de conservação:
Energia, Momento linear,
Momento Angular

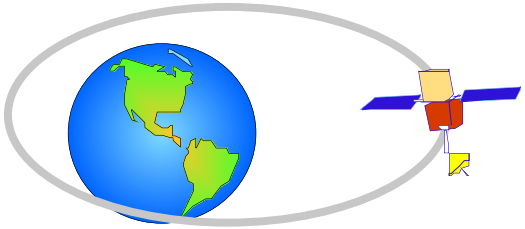
Campos de interacção:
Electromagnético,fraco,forte,
gravítico???,

As interações

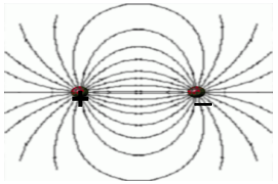
Unificação e Simetrias (locais)

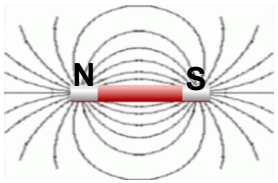
?

gravíticas

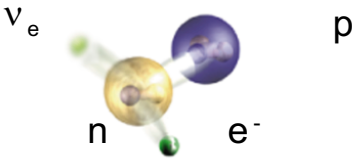


electromagneticas

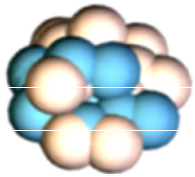




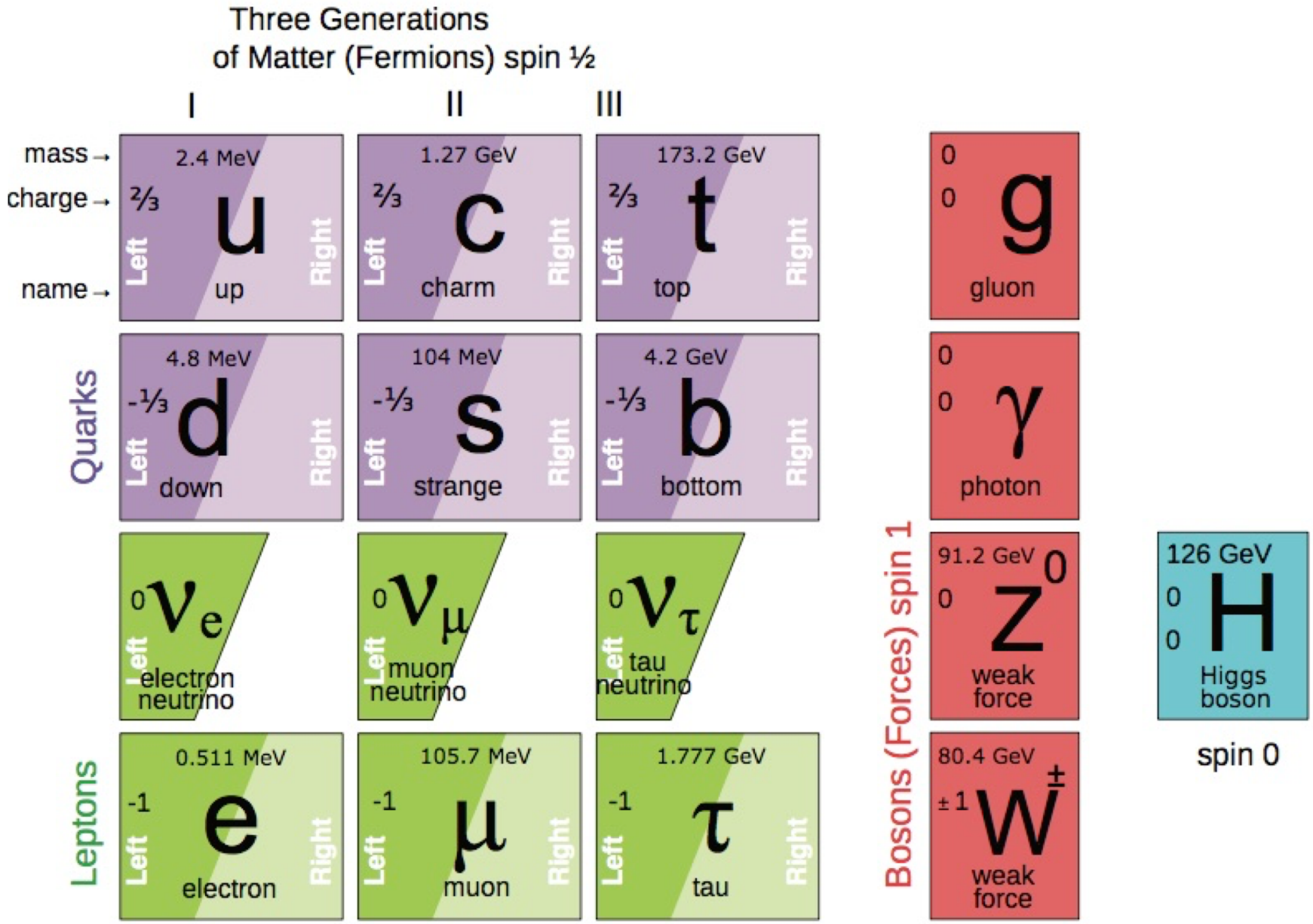
fracas



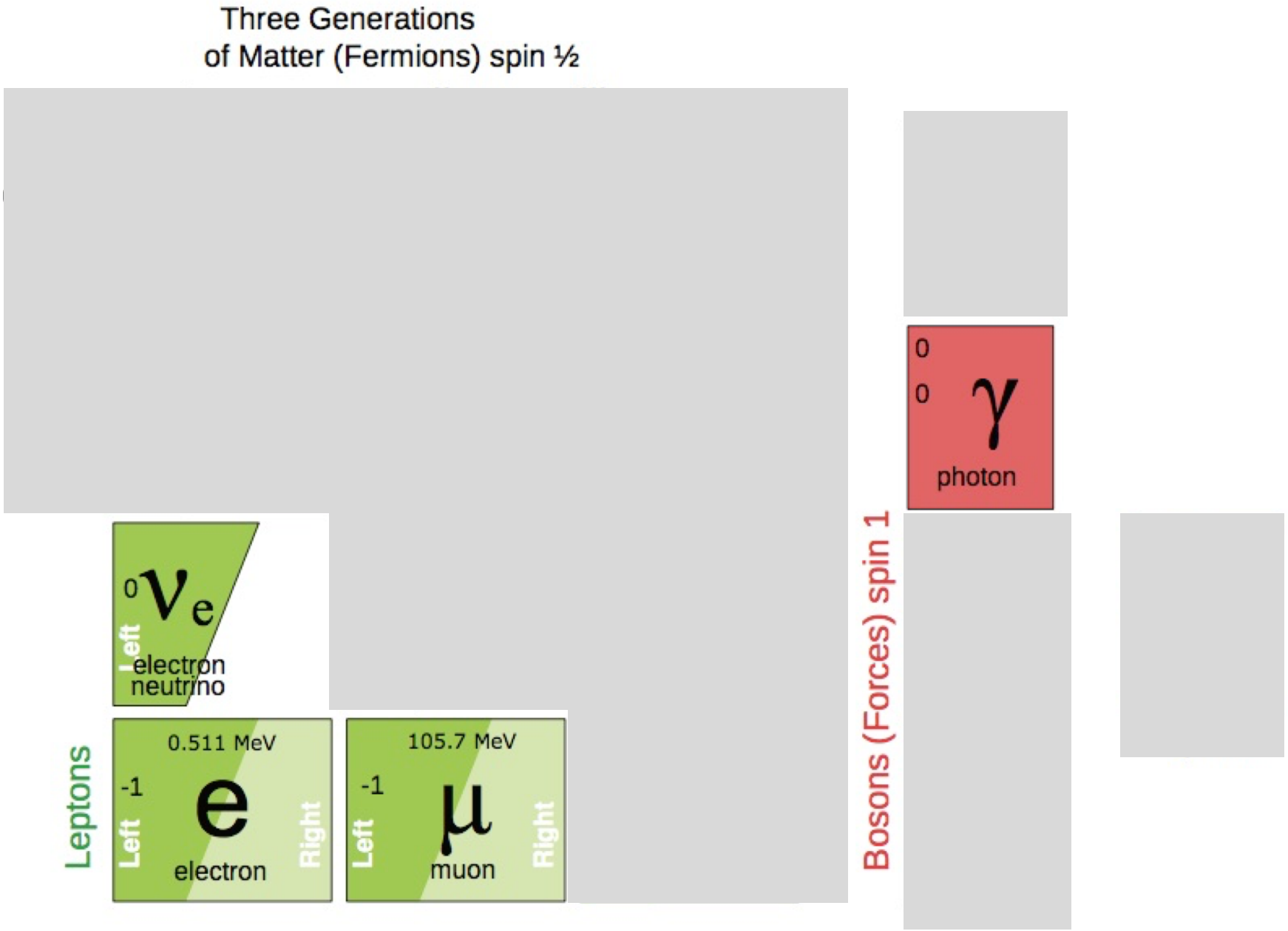
fortes



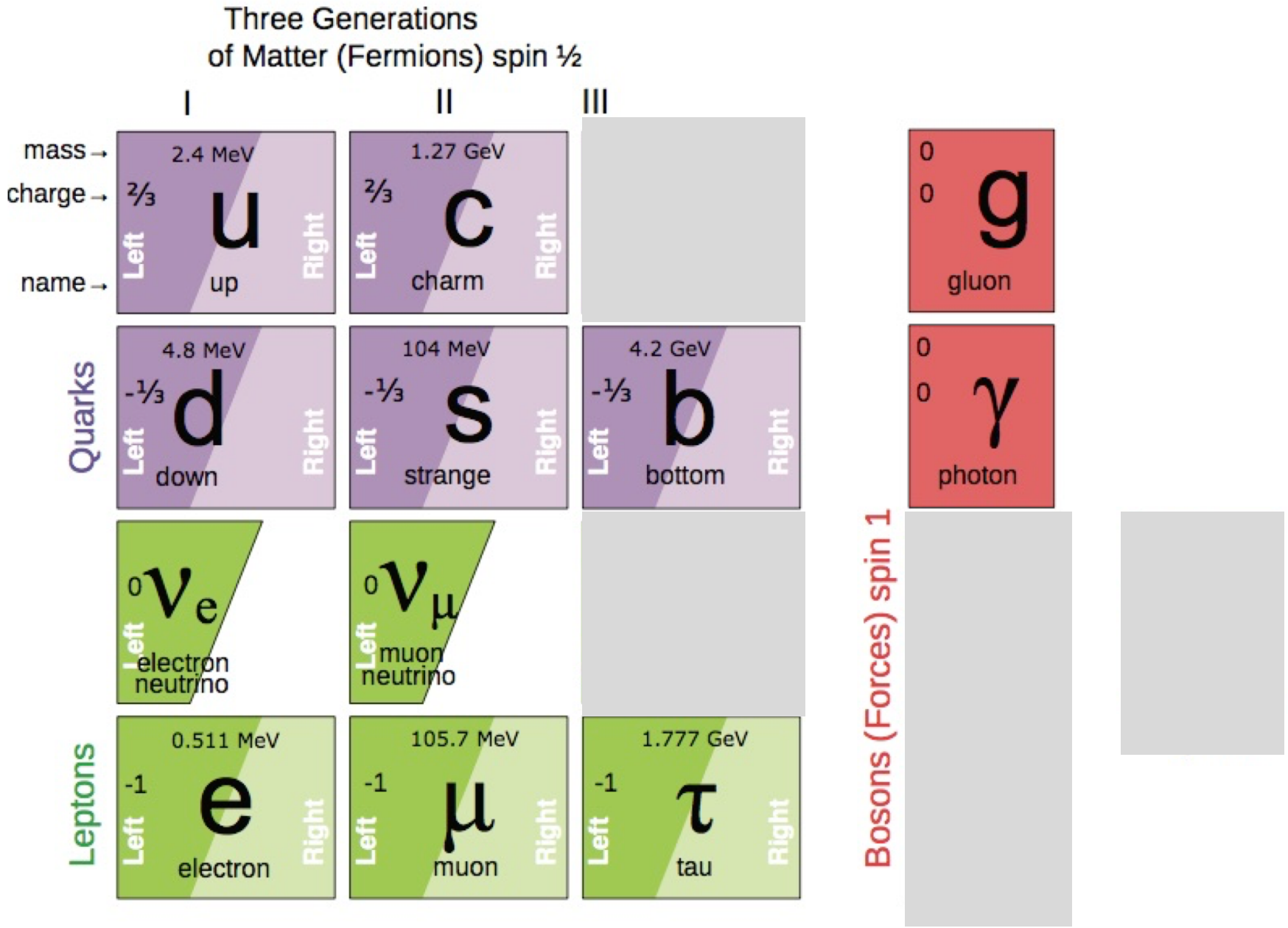
As partículas elementares hoje!



As partículas elementares em 1957



As partículas elementares em 1980



Mas as Partículas têm massa

em eV/c^2

$m_\nu \sim 10^{-1}$

$m_e \sim 500\ 10^{3}$

$m_u \sim 5\ 10^{6}$

$m_t \sim 174\ 10^{9}$

…

$m_\gamma = 0$

$m_W \sim 80\ 10^{9}$

$m_Z \sim 91\ 10^{9}$

$m_H \sim 125\ 10^{9}$

Como é que as massas são geradas ???

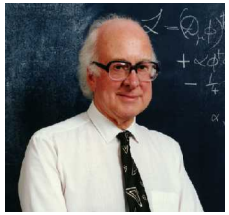
Por é que são tão diferentes ???

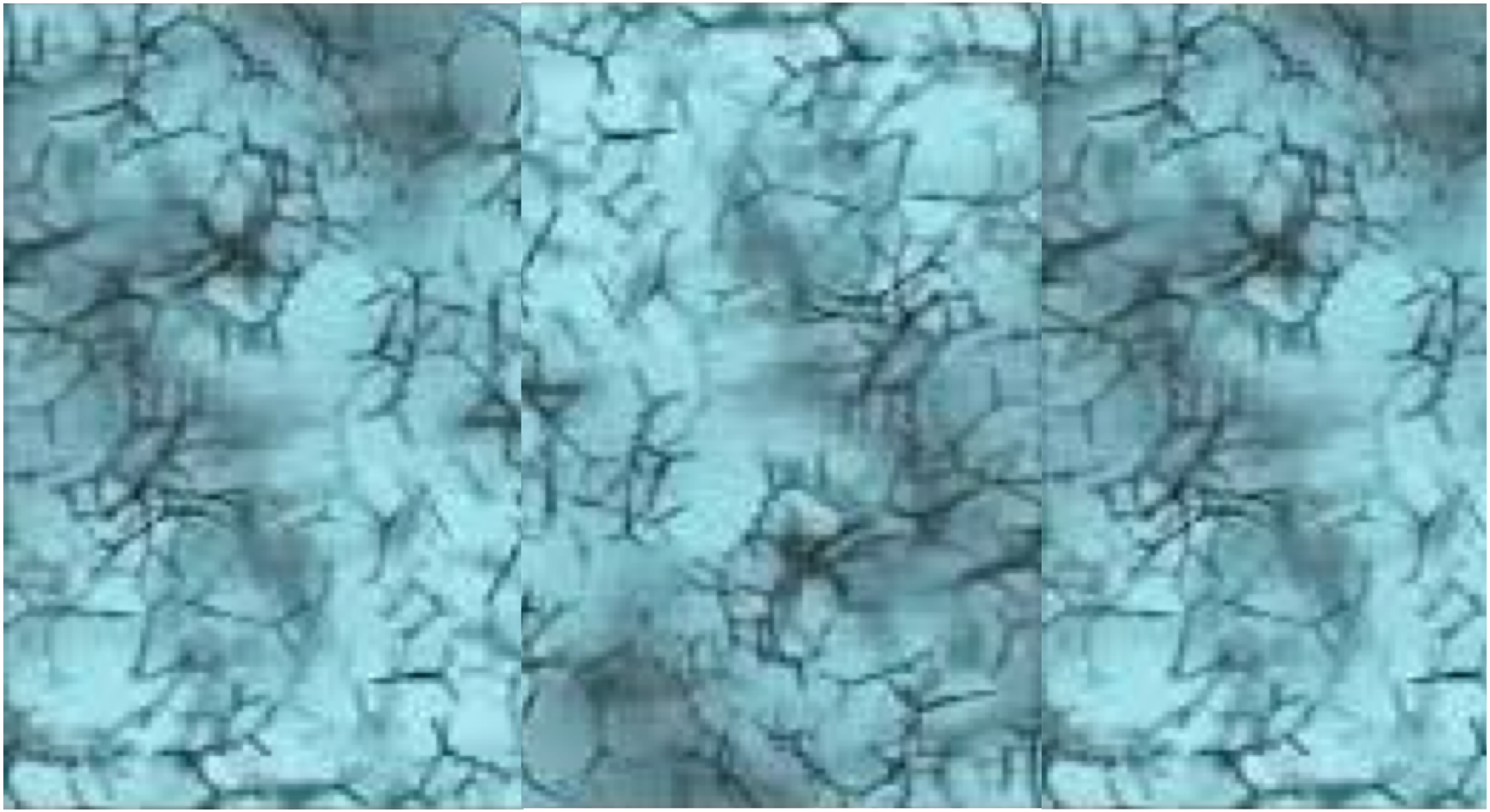
$1\ eV \sim 1.8\ 10^{-36} Kg$

O campo de Higgs

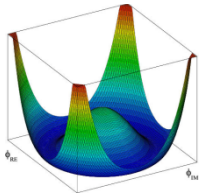
Higgs, Englert, Brout - 1964

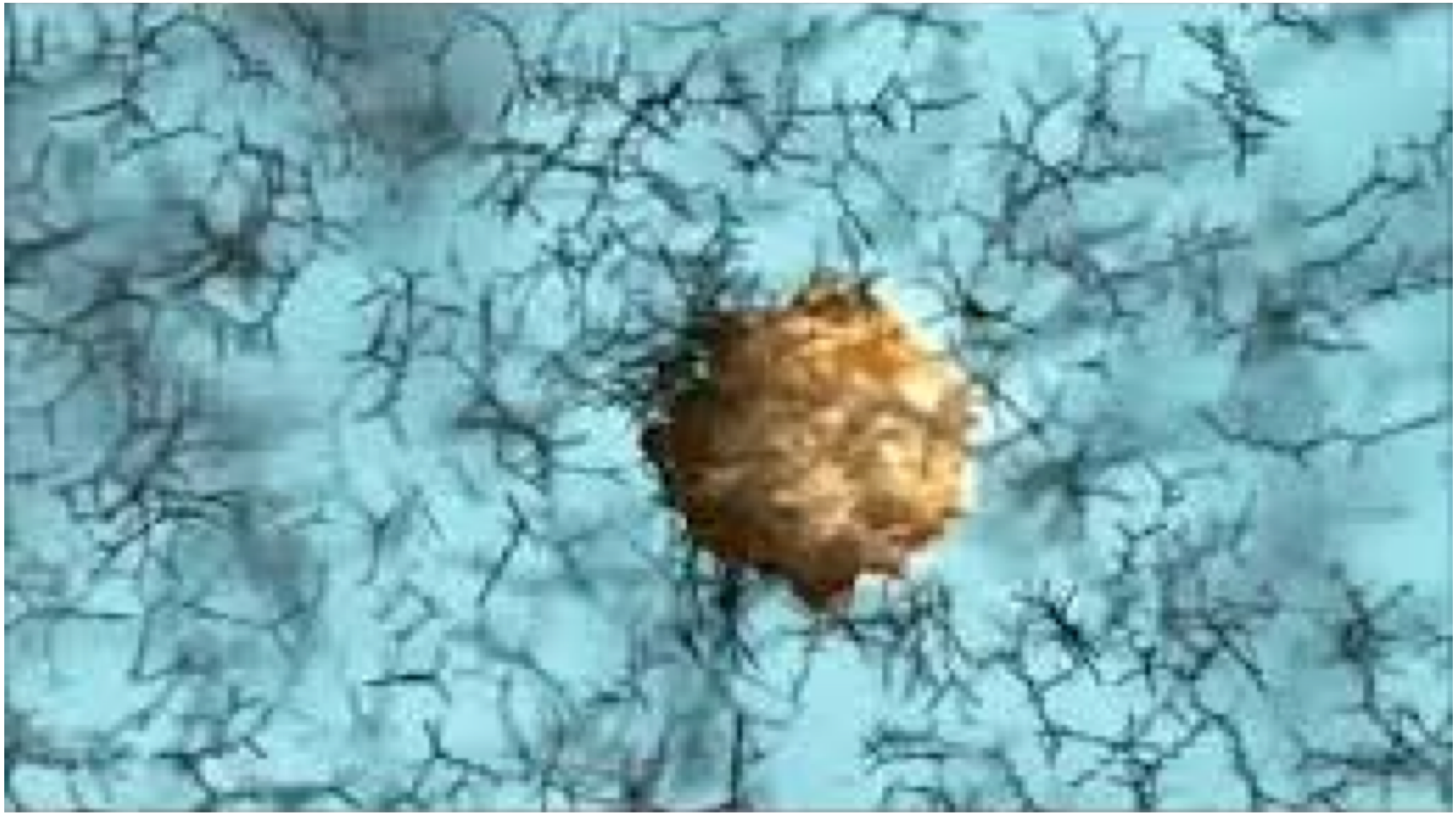
Peter Higgs





O mecanismo de Higgs





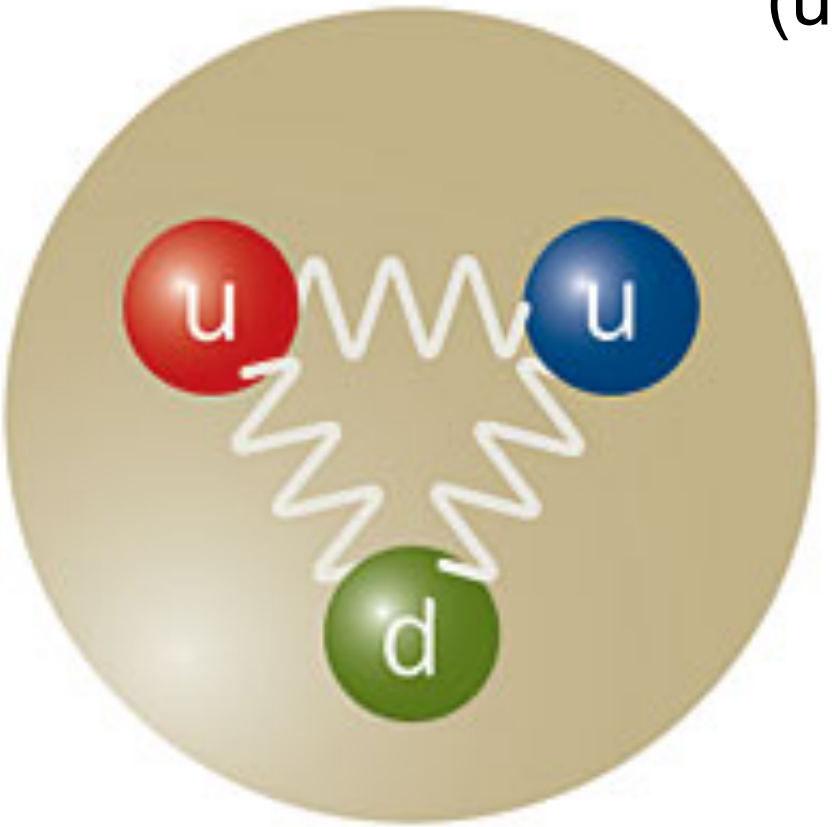
A massa é gerada na interacção com o campo

O bosão de Higgs

4 Julho 2012: CERN

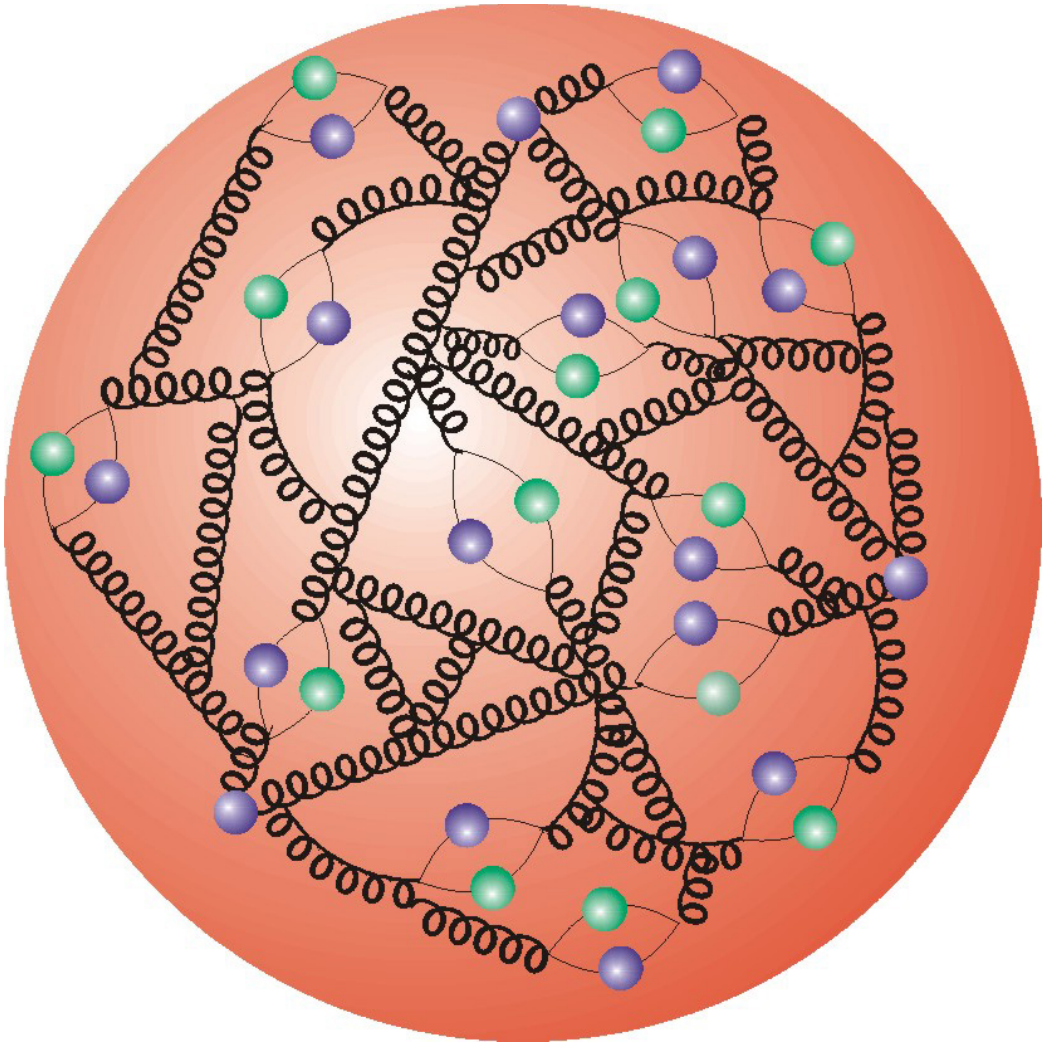
O Protão

(uud)



10^{-14} m

O Protão



A massa do Protão

$$M = \sum m_{quarks} + E_{campo}/c^2$$

A massa do Protão

$$M = \sum m_{quarks} + E_{campo}/c^2$$

$$938 \sim (\quad 15 \quad + \quad 925)\ MeV/c^2$$

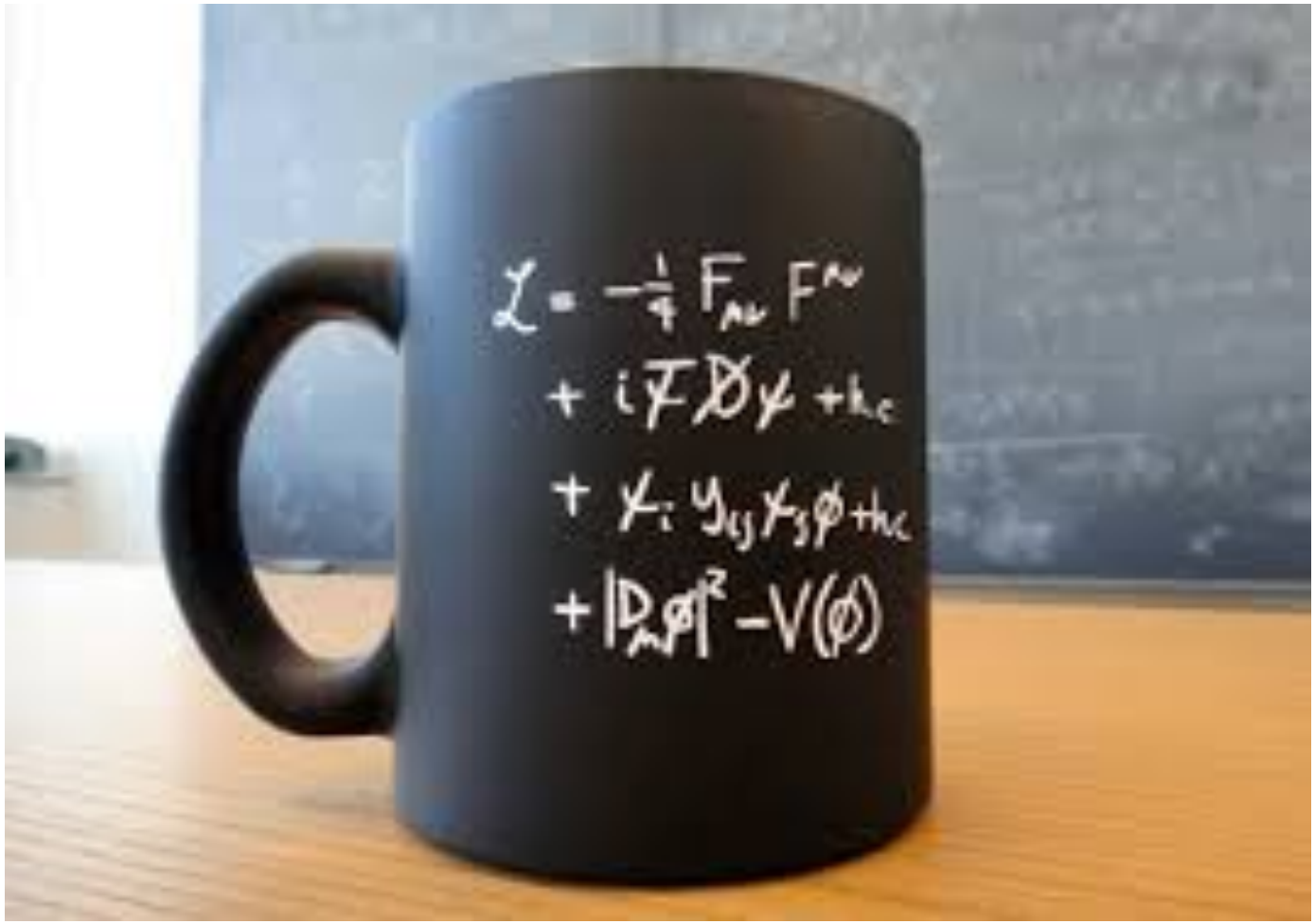
$$1\ MeV/c^2 \sim 1.8\ 10^{-30} Kg$$

O Modelo Padrão: $SU(2)_L \otimes U_1$

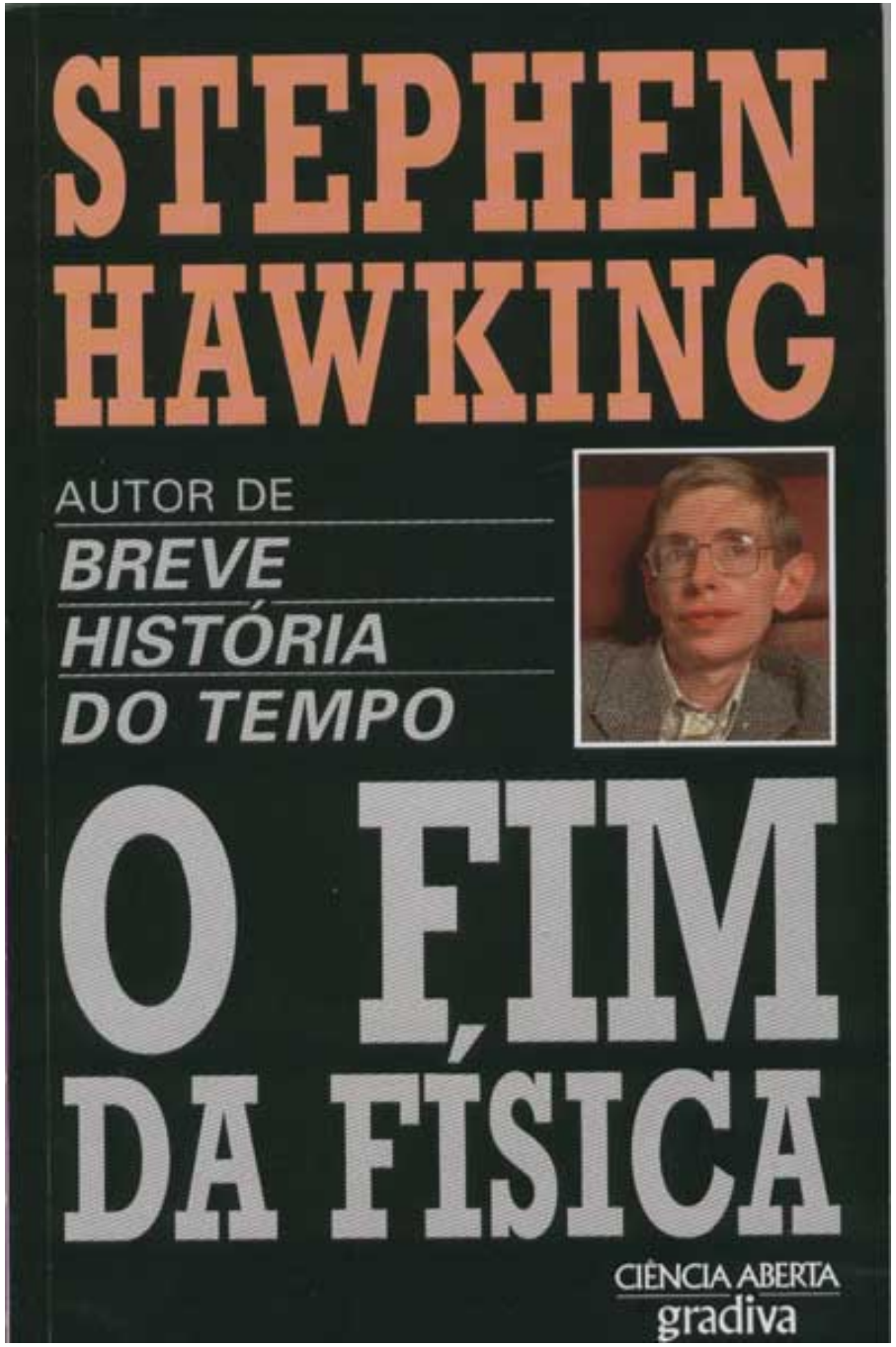
Glashow

Salam

Weinberg



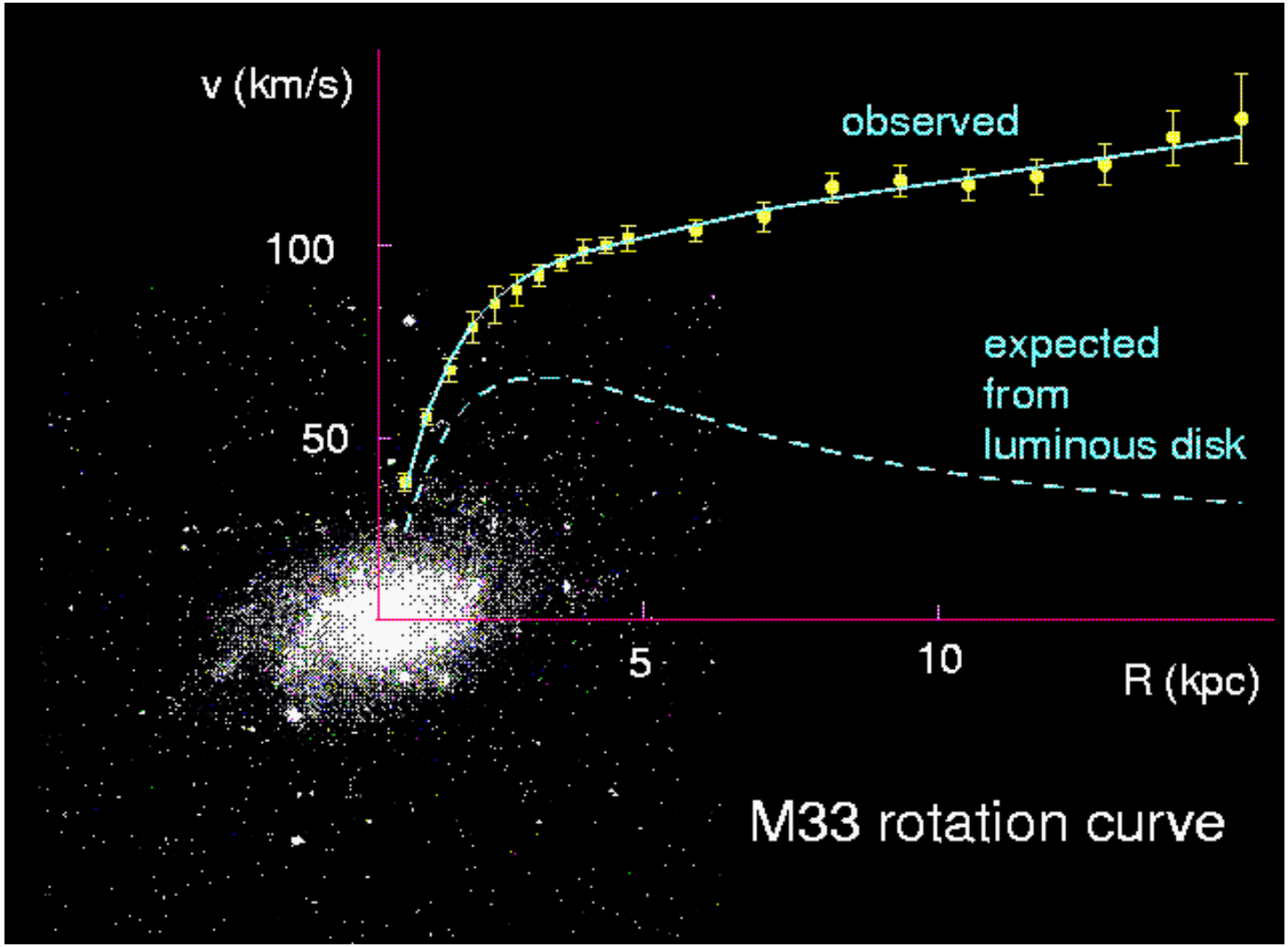
O fim da Física ?



A matéria luminosa

A velocidade de rotação das estrelas periféricas

Rodar em torno do centro da galáxia

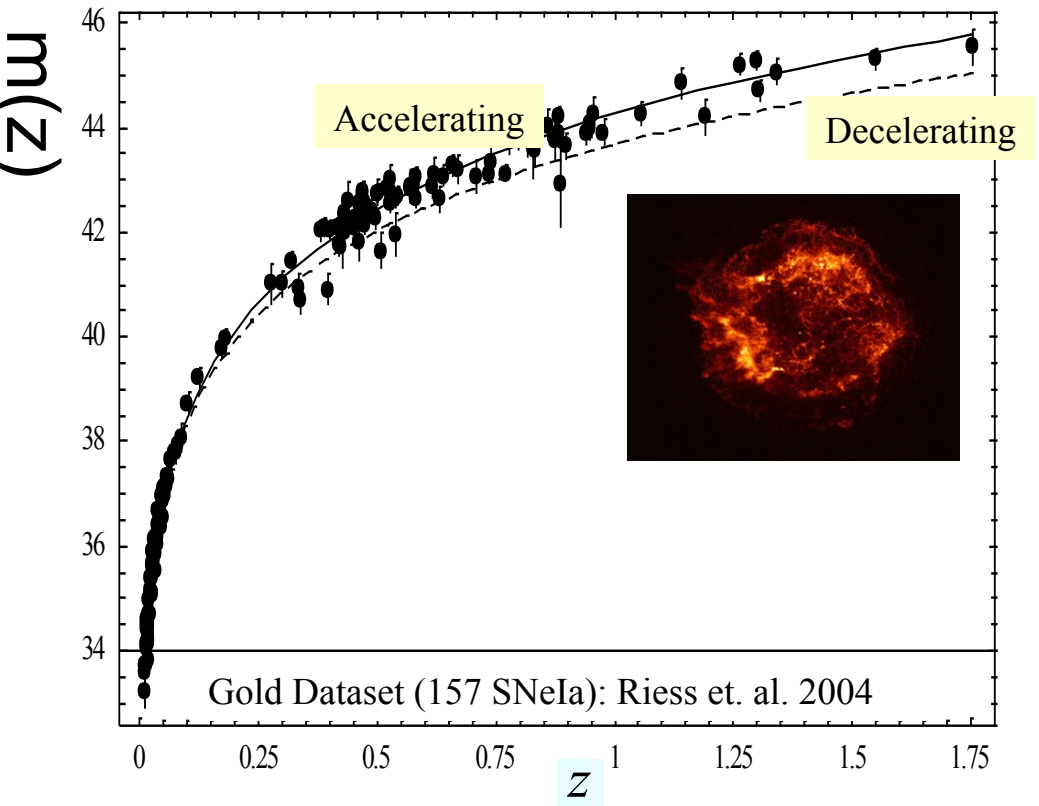


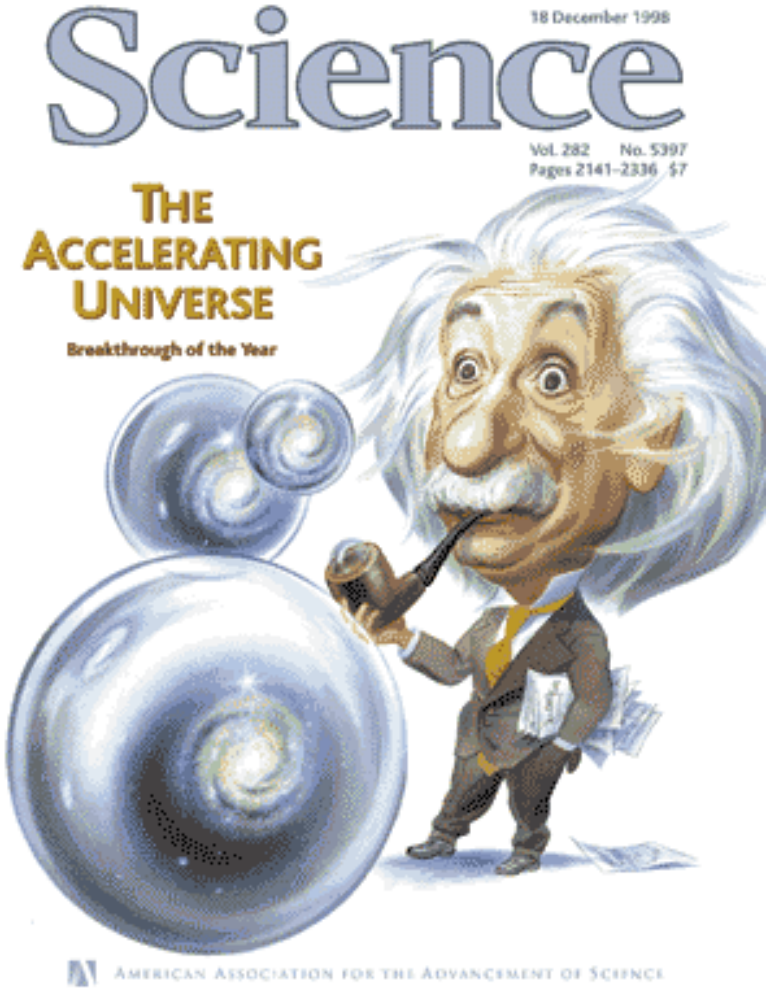
Um halo de matéria escura!

A matéria escura

A energia escura !

Diagrama de Huble

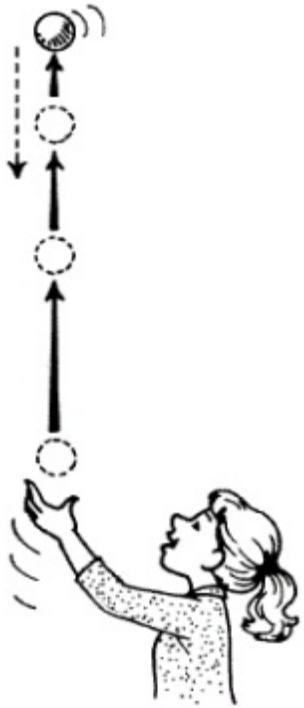




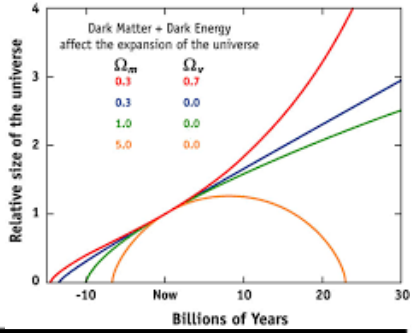
O Universo encontra-se numa expansão acelerada !!!

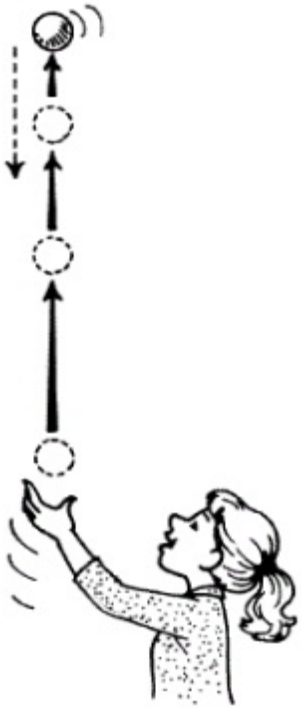
Energia escura – anti-gravítica

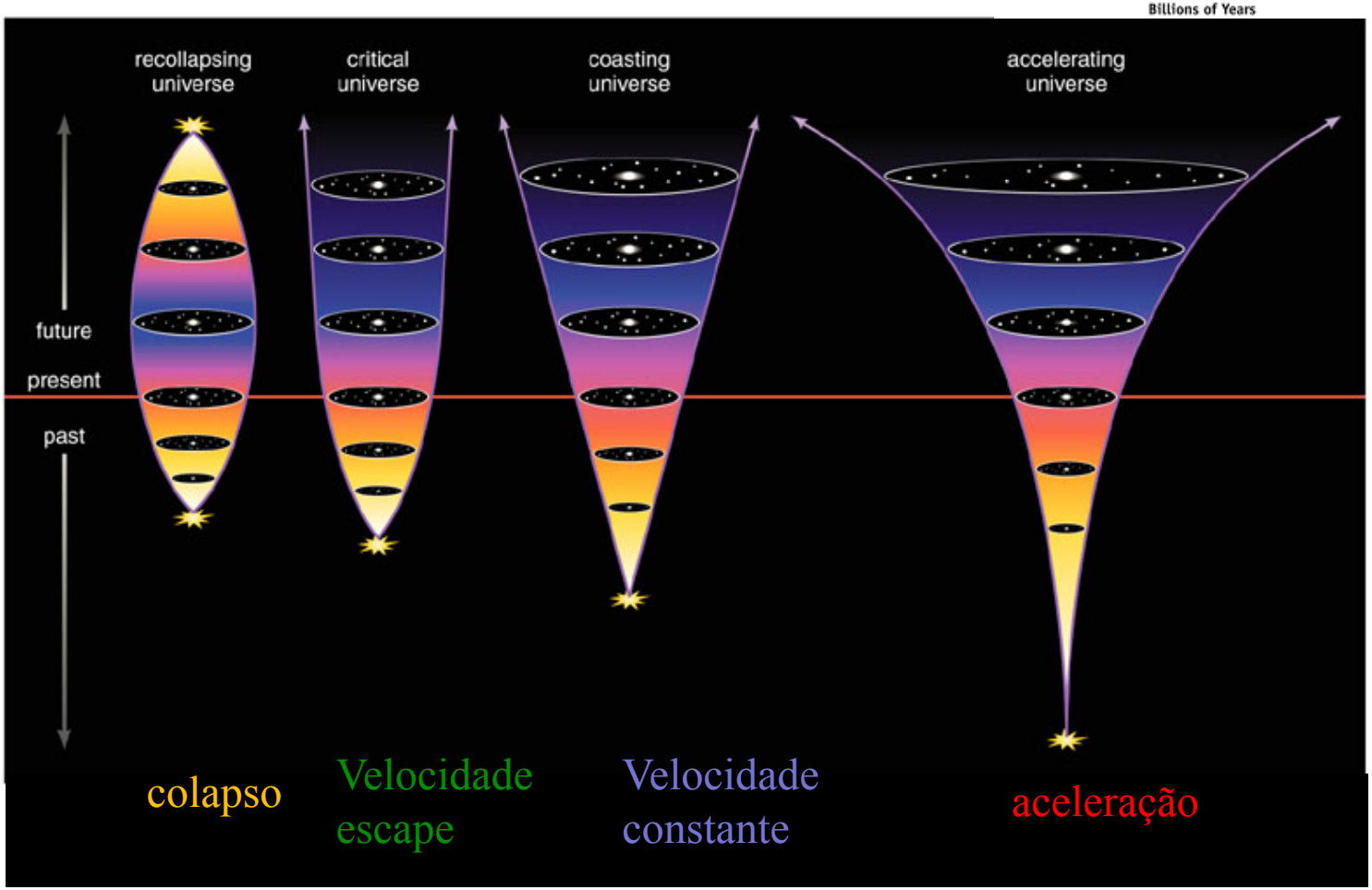
A expansão do Unverso



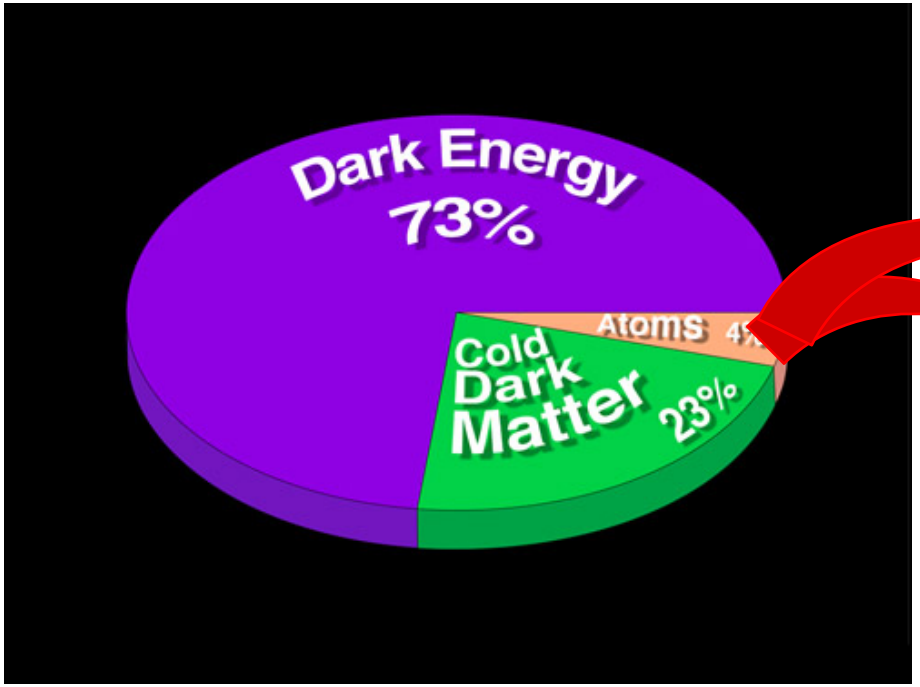
A expansão do Unverso







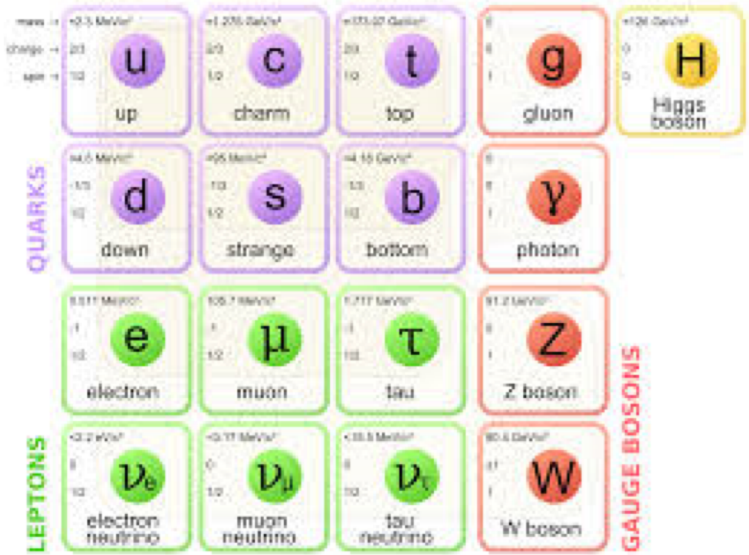
Fronteiras do nosso (des)conhecimento

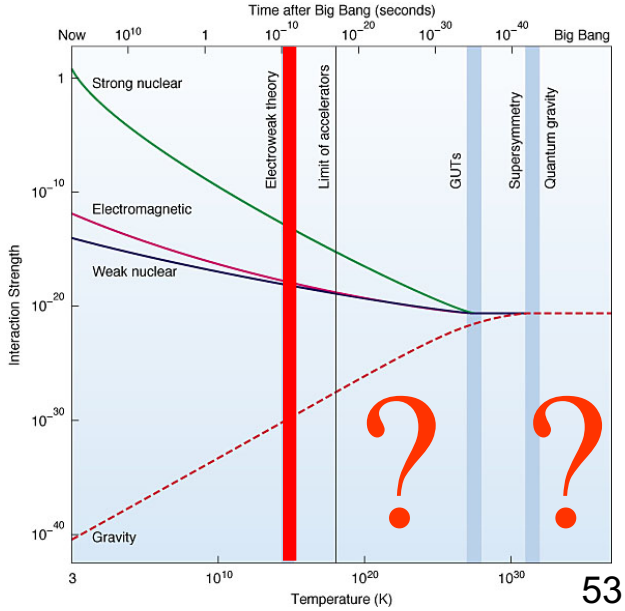


O modelo padrão

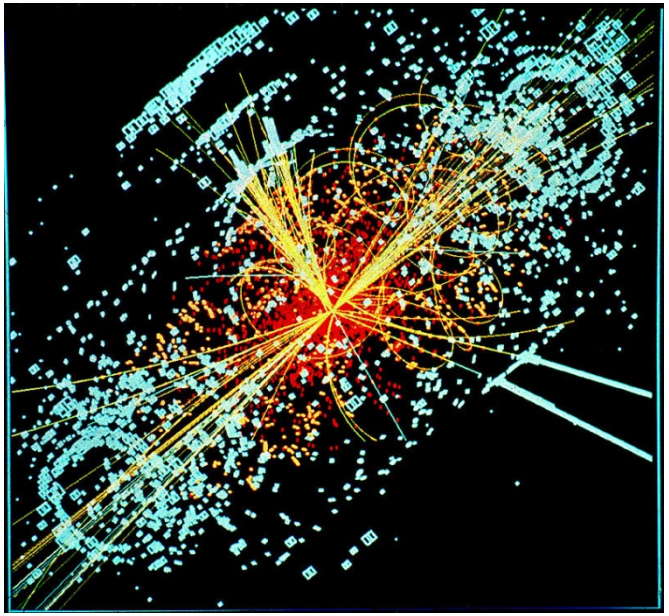
$E_{CM} \sim 1$ TeV

$R \sim 10^{-18}$ m



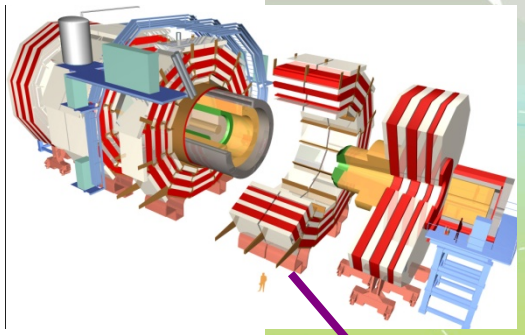


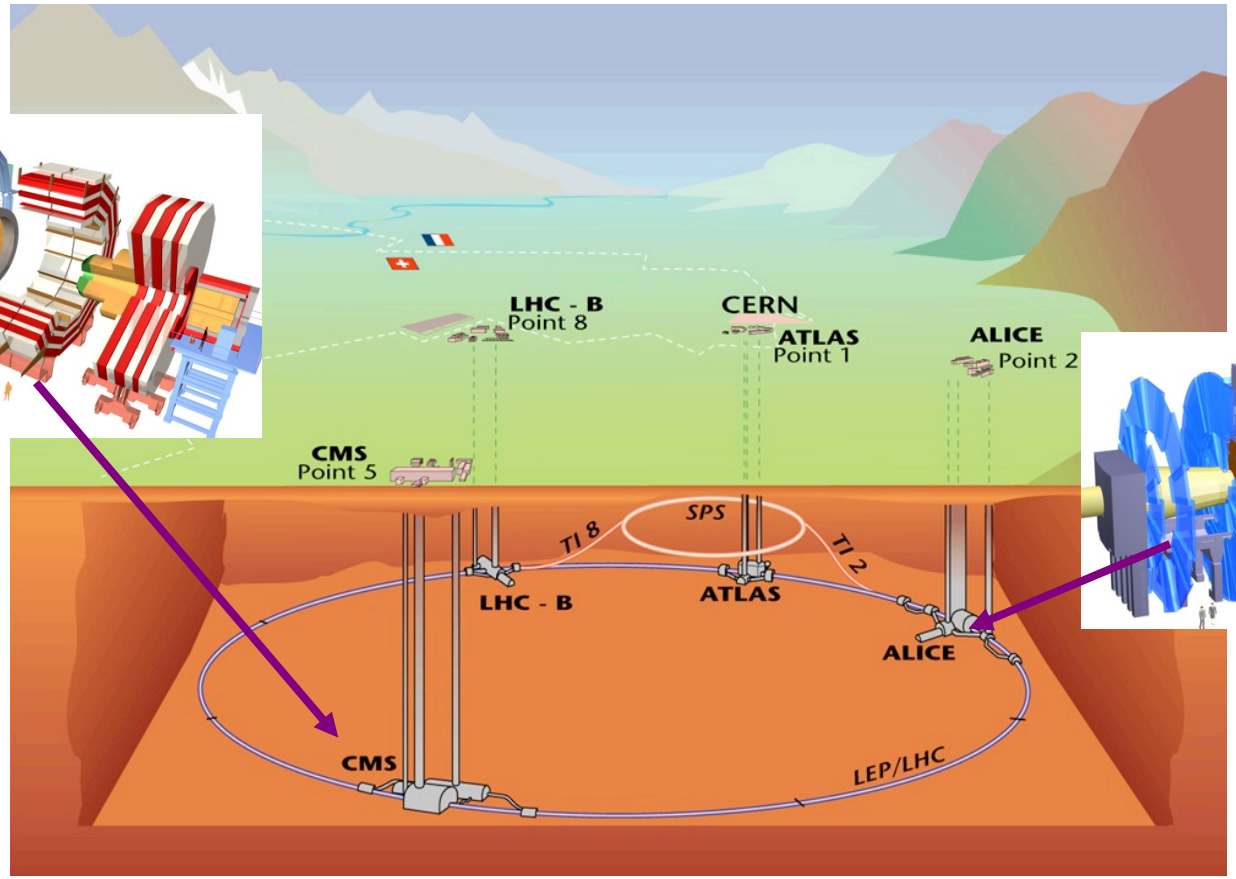
Olhar o Universo no sec. XXI



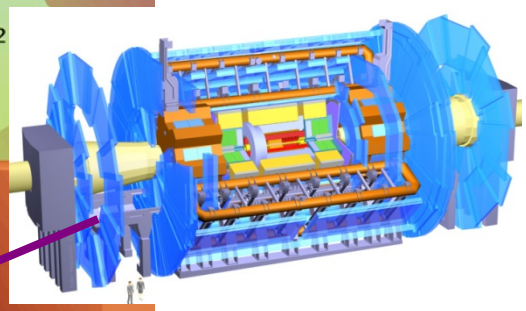
O LHC no CERN

CMS

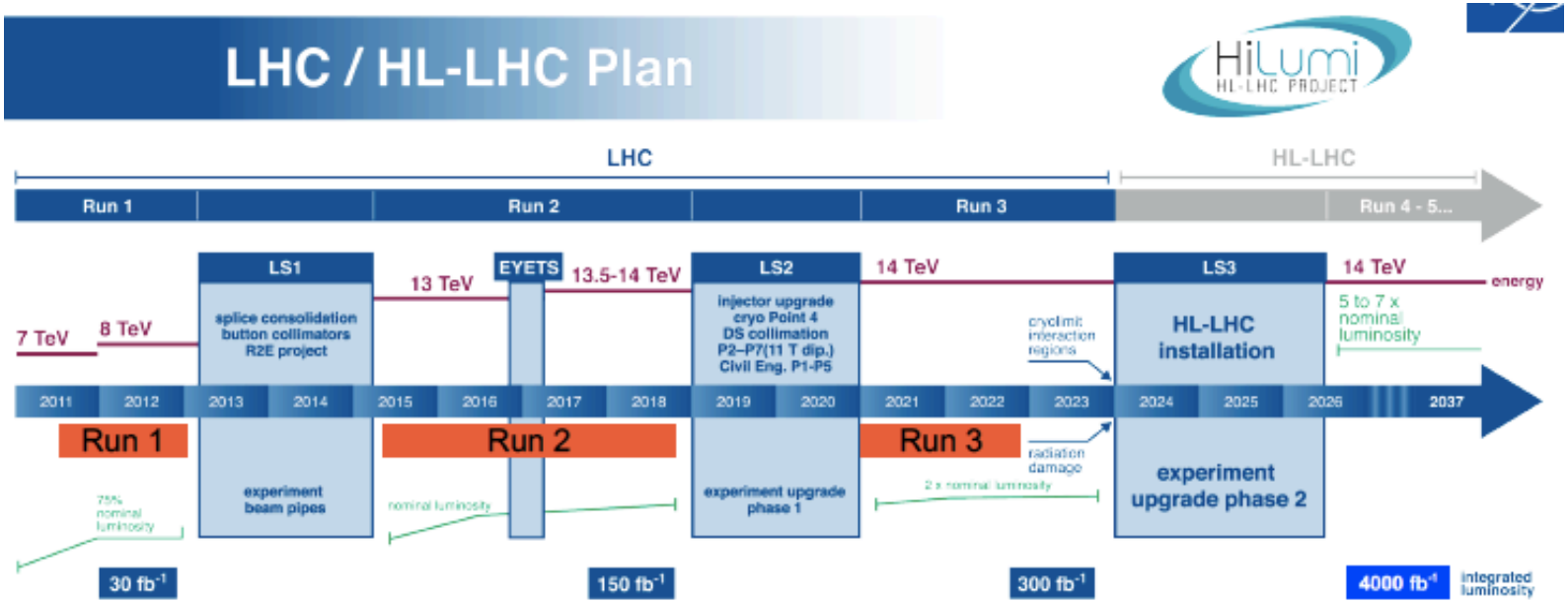


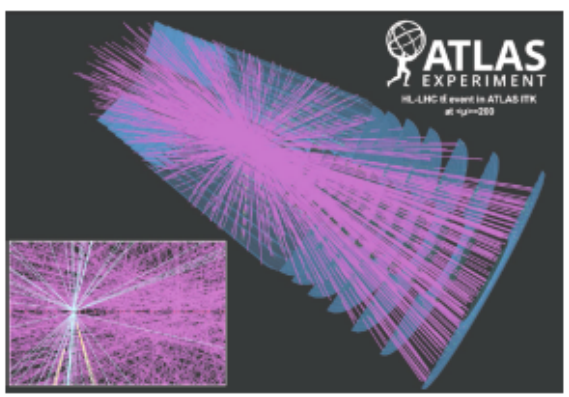


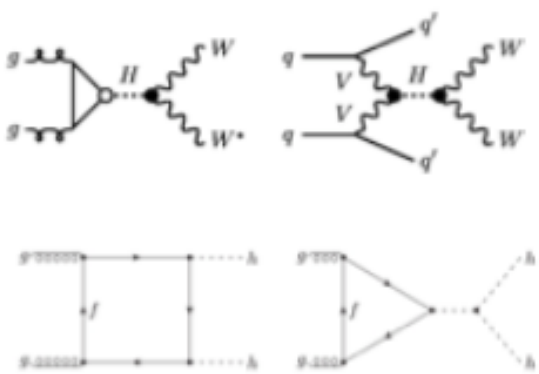
ATLAS

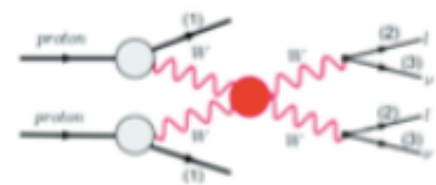


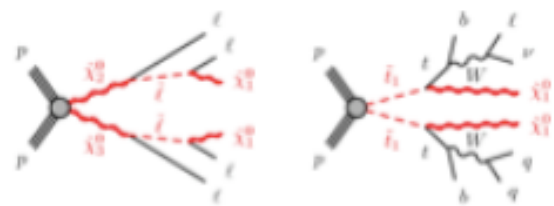
LHC alta Luminosidade



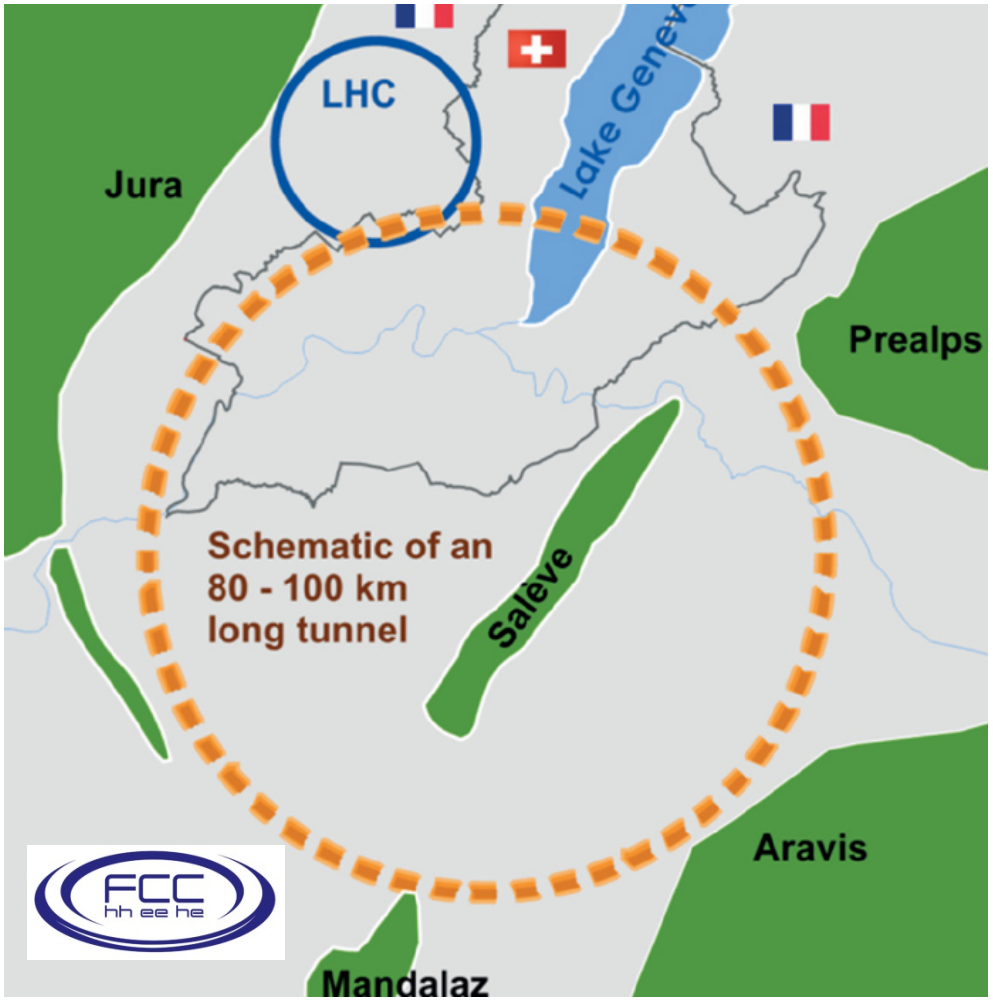








Depois do LHC ?



- FCC-hh:
  100 TeV pp collider
- FCC-ee :
  High luminosity e^+e^- collider
- FCC-he :
  ep collider

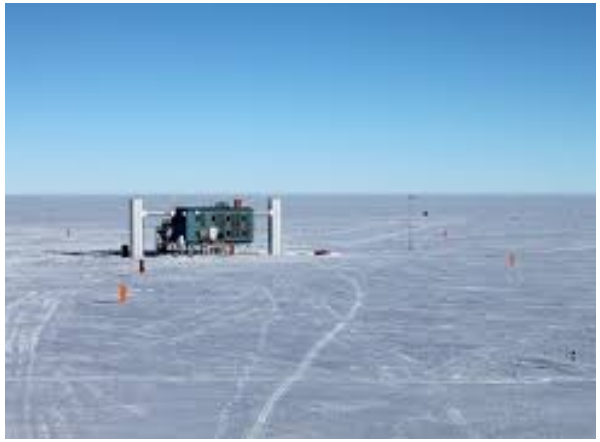
>> 2035 !!!

Da Terra aos Céus ...

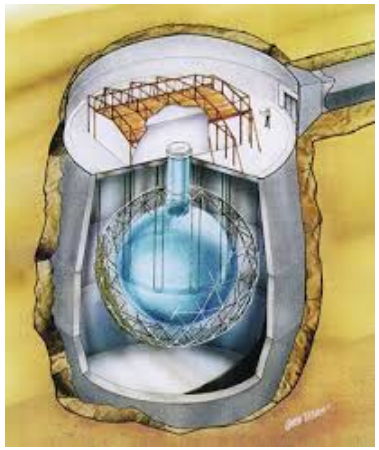
AMS

Fermi

LIGO



Ice Cube

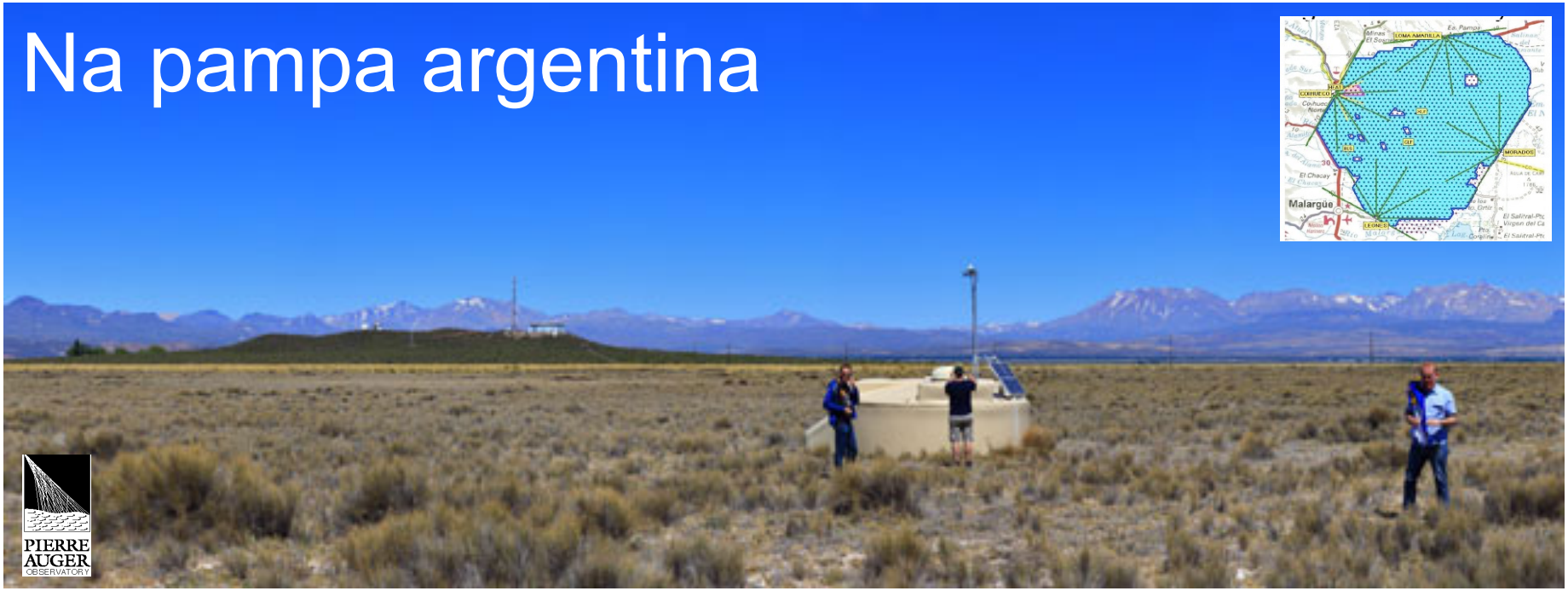


SNO^{+}

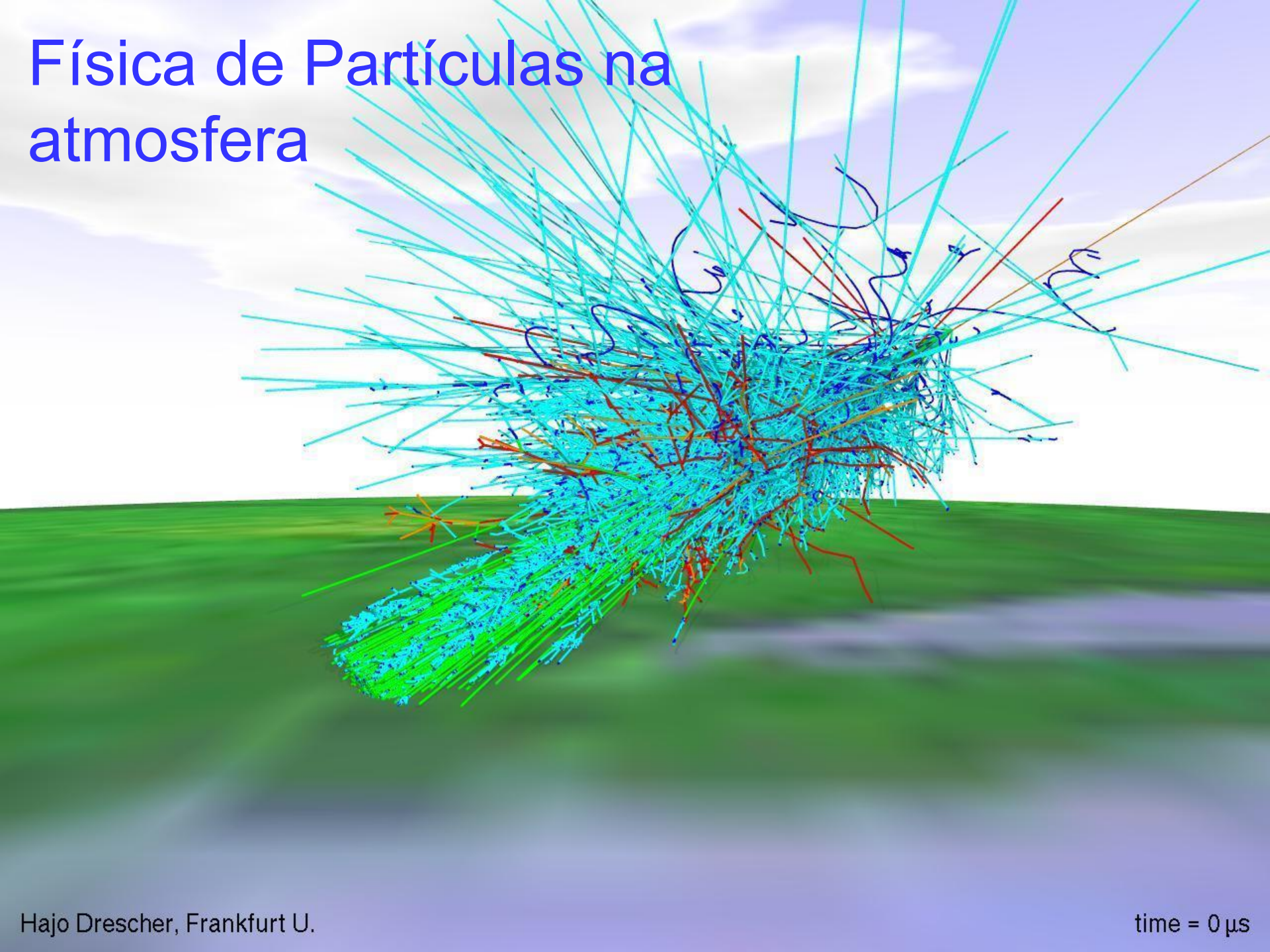
LST - CTA

E muitos mais .....

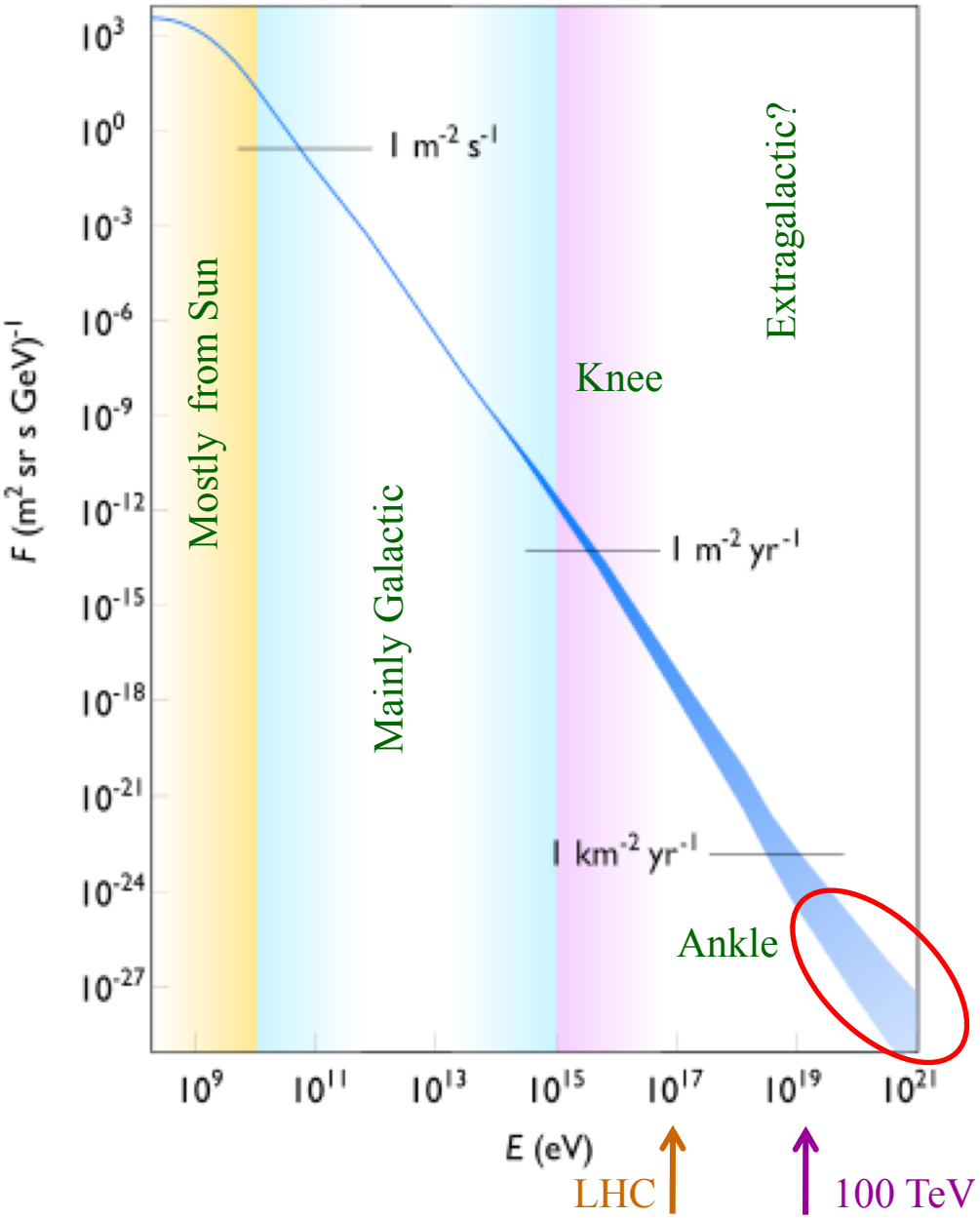
Na pampa argentina



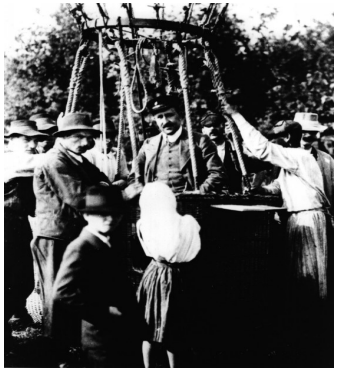
Física de Partículas na atmosfera

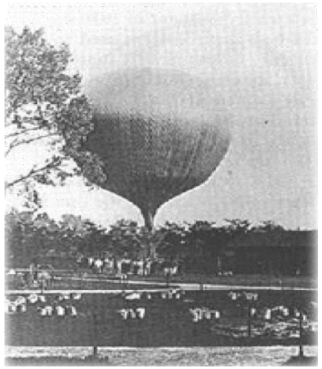


Raios cósmicos carregados



Viktor Hess, 1912





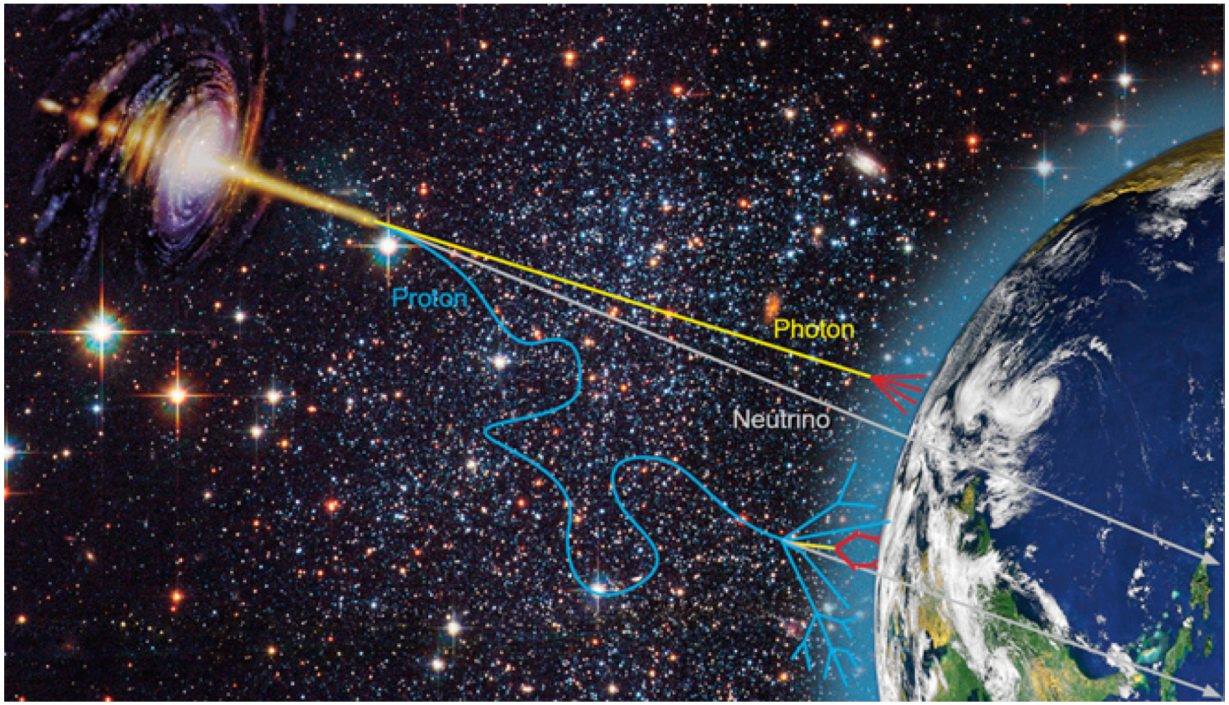
$$\frac{dN}{dE} \propto E^{-\alpha}$$

$$\alpha = \begin{cases} 2.7 & E < 10^{16} \\ 3.0 & 10^{16} < E < 10^{18} \\ 2.7? & E > 10^{18} \end{cases}$$

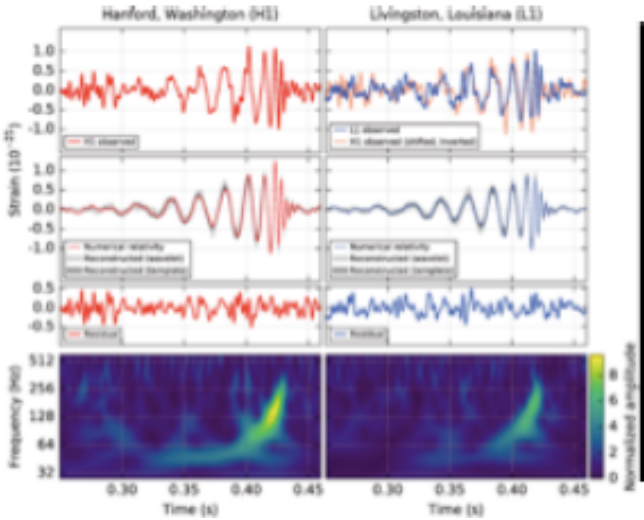
Um LHC do tamanho da órbita de Mercúrio !!!

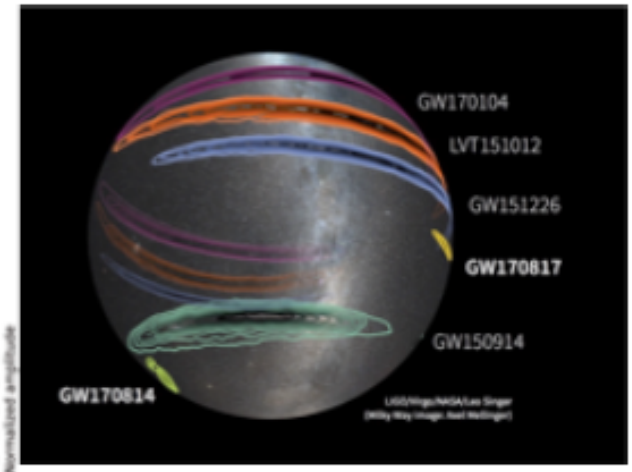
Mensageiros do Universo

γ, p, nuclei, ν

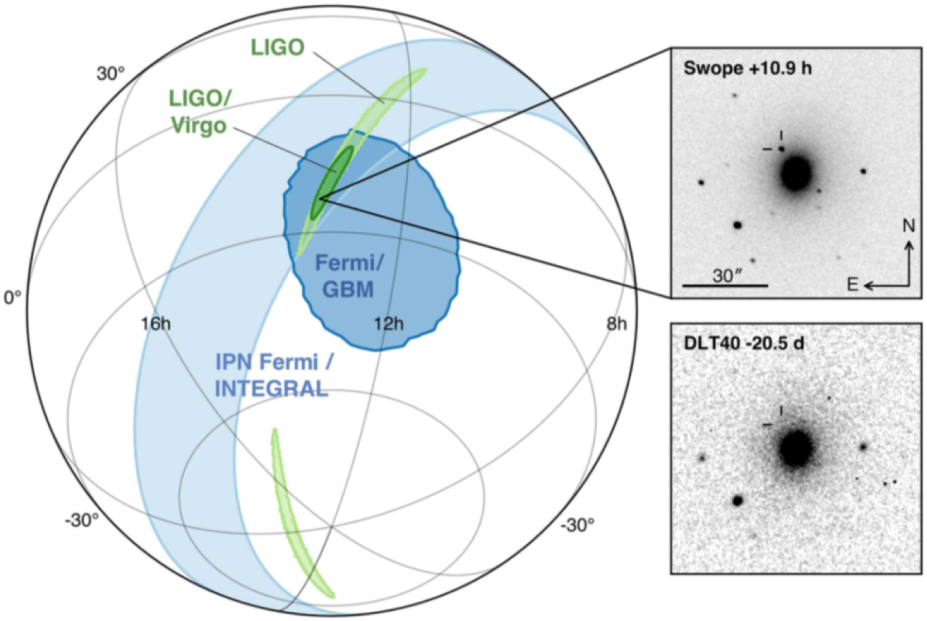


GW

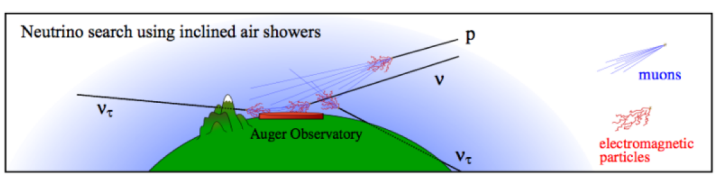


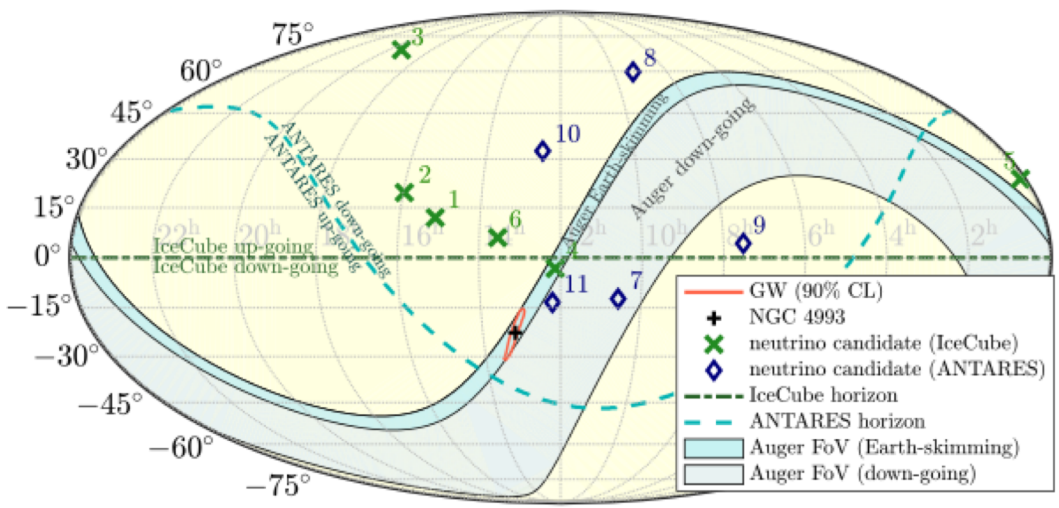


GW170817

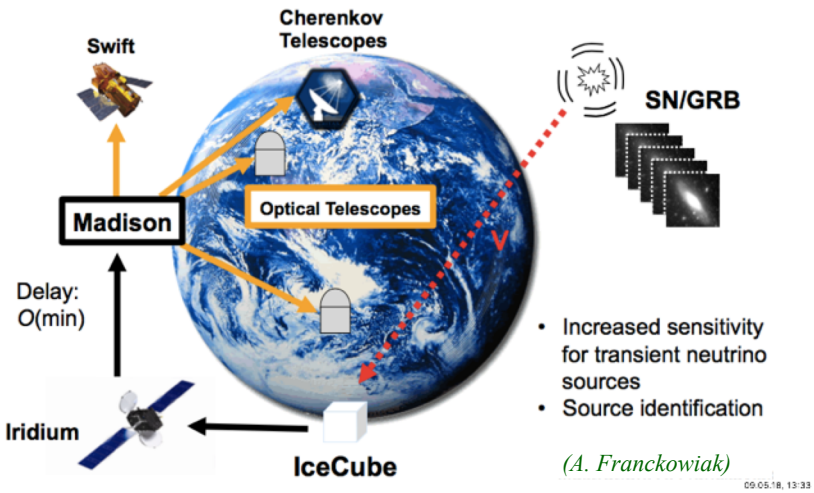


A primeira observação "multimessenger" da fusão de duas estrelas de neutrões

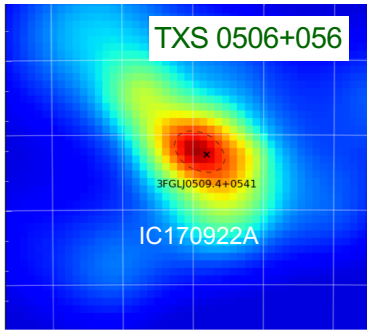




A primeira fonte de neutrinos astrofísicos de alta energia

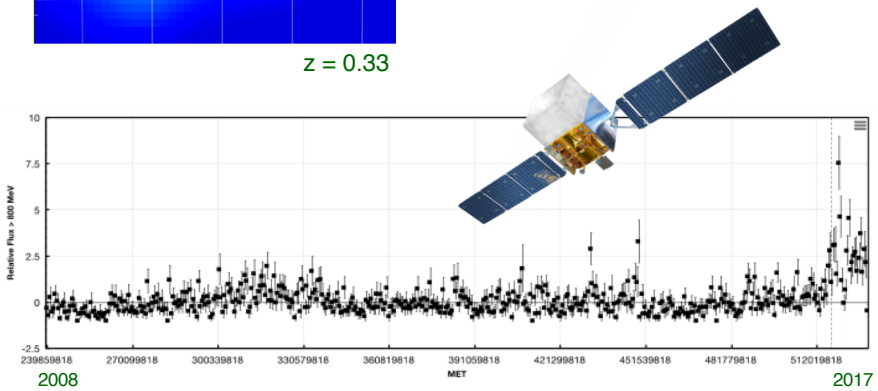



```
TITLE:   GCN CIRCULAR
NUMBER:  21916
SUBJECT: IceCube-170922A - IceCube observation of a high-energy neutrino candidate event
DATE:    17/09/23 01:09:26 GMT
FROM:    Erik Blaufuss at U. Maryland/IceCube  <blaufuss@icecube.umd.edu>

Claudio Kopper (University of Alberta) and Erik Blaufuss (University of  Maryland) report on
behalf of the IceCube Collaboration (http://icecube.wisc.edu/).

On 22 Sep, 2017 IceCube detected a track-like, very-high-energy event with a high probability
of being of astrophysical origin. The event was identified by the  Extremely High Energy
(EHE) track event selection. The IceCube detector was in a normal operating state. EHE events
typically have a neutrino interaction vertex that is outside the detector, produce a muon
that traverses the detector volume, and have a high light level (a proxy for energy).

After the initial automated alert
(https://gcn.gsfc.nasa.gov/notices_amon/50579430_130033.amon), more
sophisticated reconstruction algorithms have been applied offline, with the direction refined
to:

Date: 22 Sep, 2017
Time: 20:54:30.43 UTC
RA: 77.43 deg (-0.80 deg/+1.30 deg  90% PSF containment) J2000
Dec: 5.72 deg (-0.40 deg/+0.70 deg 90% PSF containment) J2000

We encourage follow-up by ground and space-based instruments to help identify a possible
astrophysical source for the candidate neutrino.
```



z = 0.33

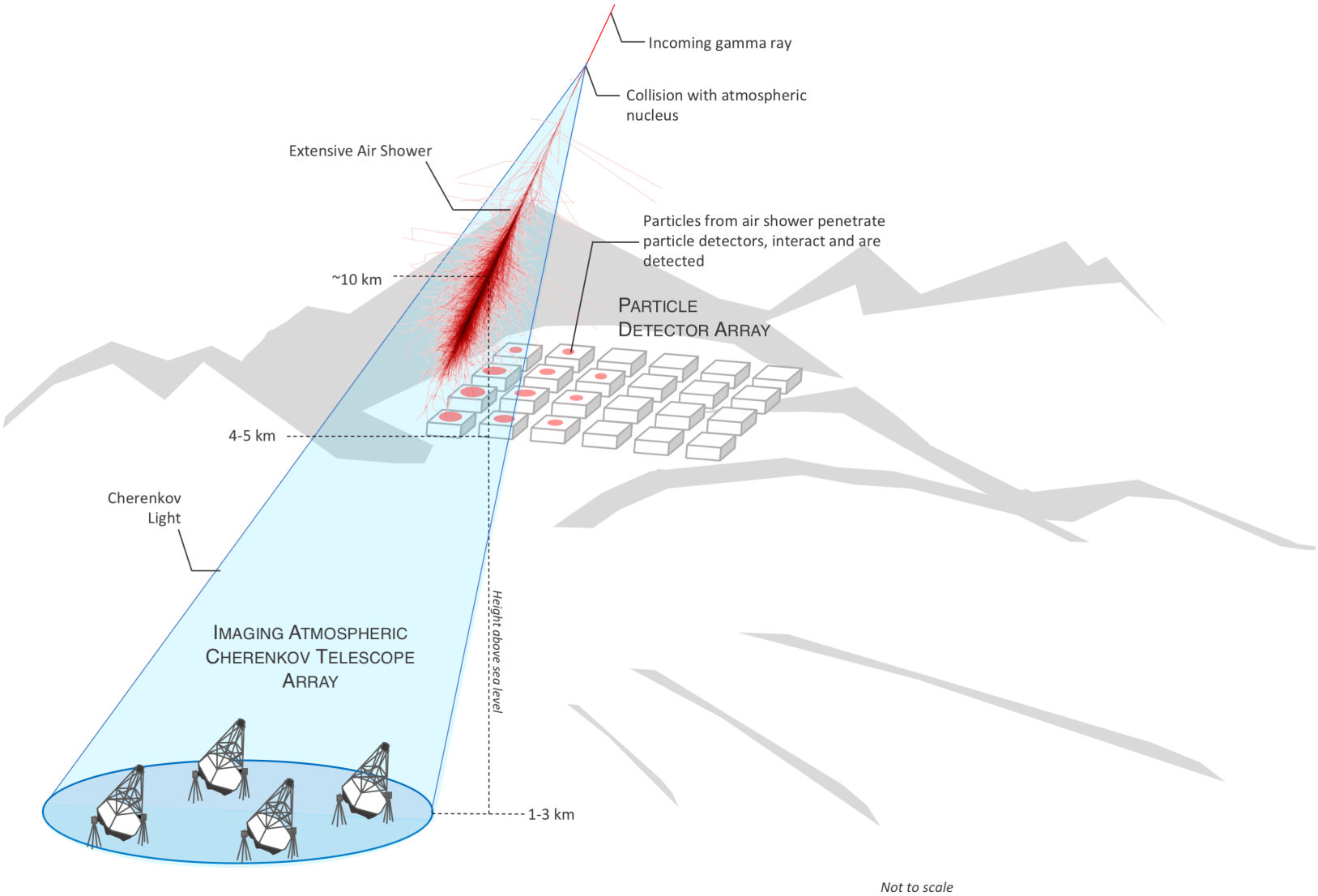
MAGIC: flare E > 100 GeV



FERMI: flare (found 6 days later)

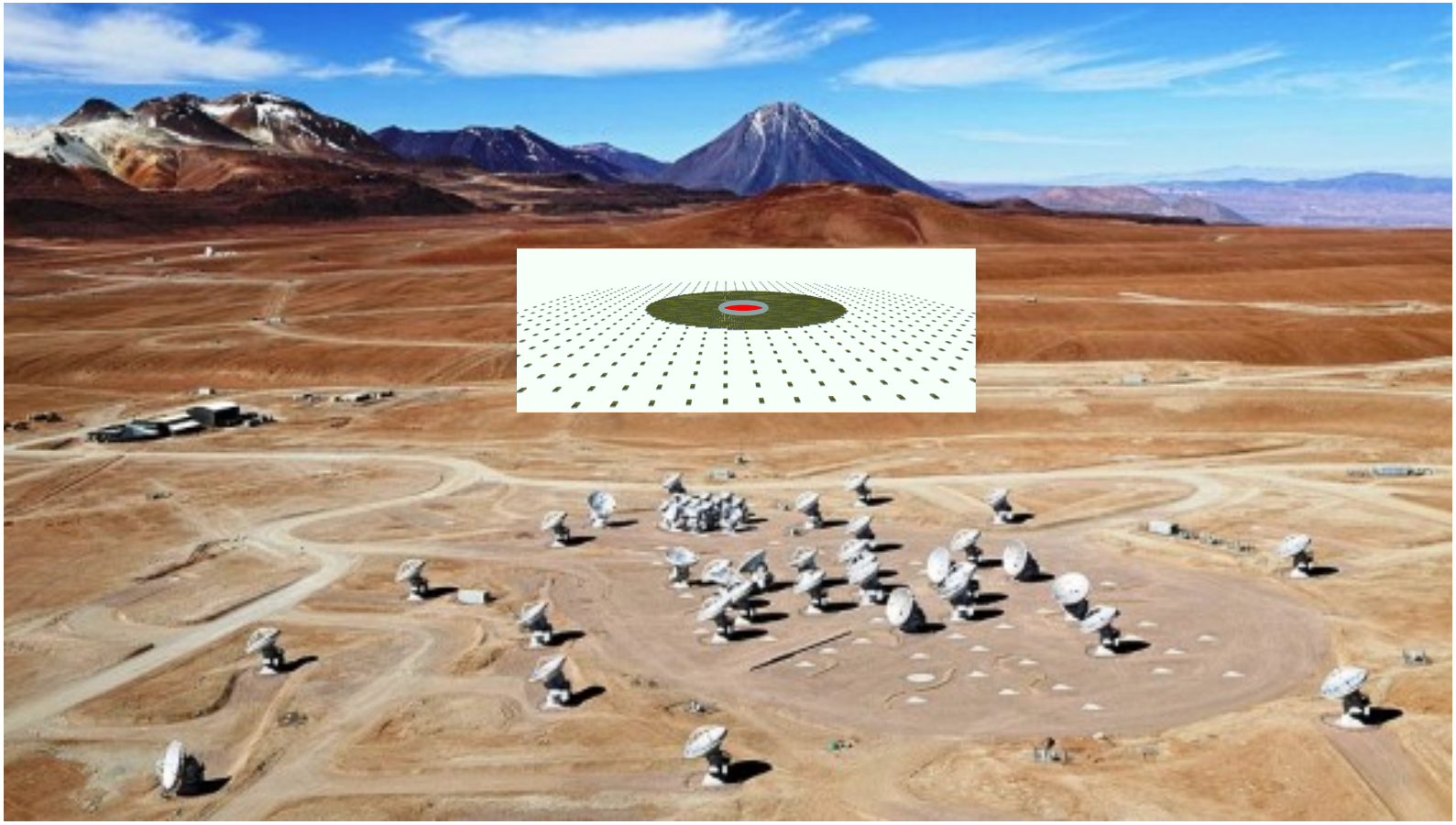
IceCube 1709922A, publications in preparation

Detectar fotões no alto das montanhas ..

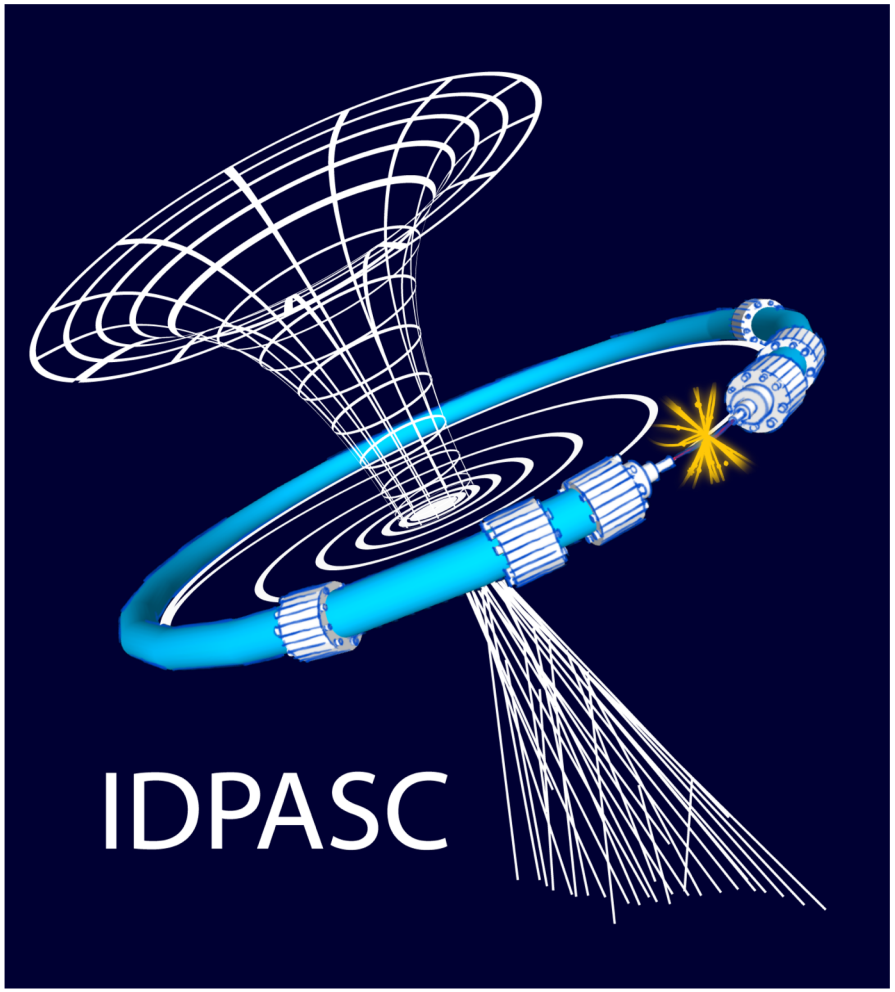


Arranque da colaboração SWGO

1 Julho 2019



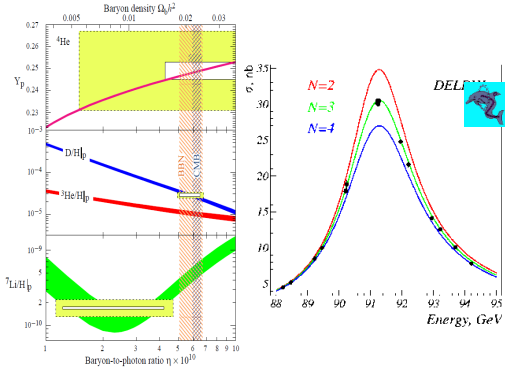
Olhar para o centro da galáxia e para o Universo a 5000 m de altitude na América do Sul com um detector de fotões energéticos

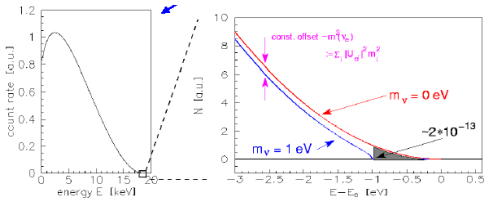


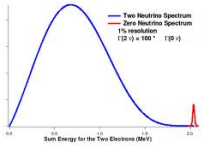
International Doctorate Network in Particle Physics, Astrophysics and Cosmology

Neutrinos

BBN







?

$1.95K$

$\cdots$

N_ν

θ_{ij}

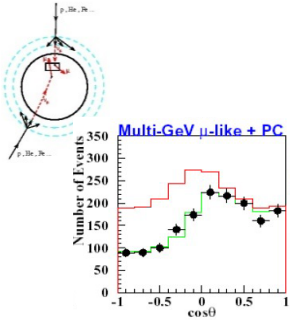
ν_i

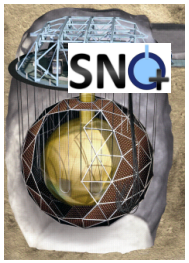
m_ν

2β

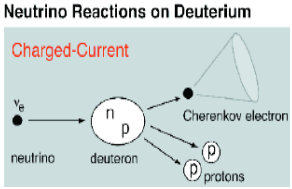
$> 10^{15} eV$

θ_{23}

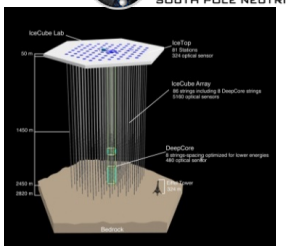


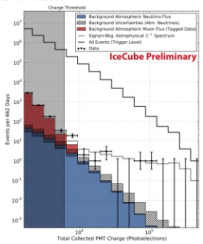


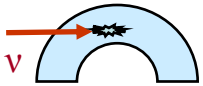
1/3 !

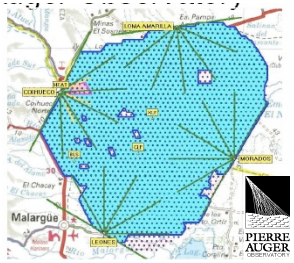


θ_{12}

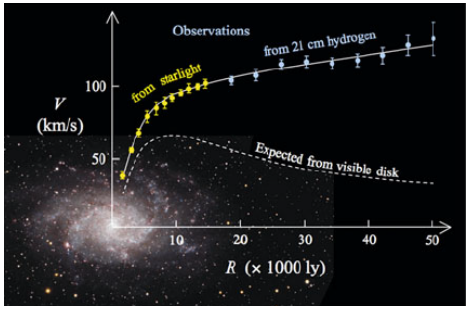


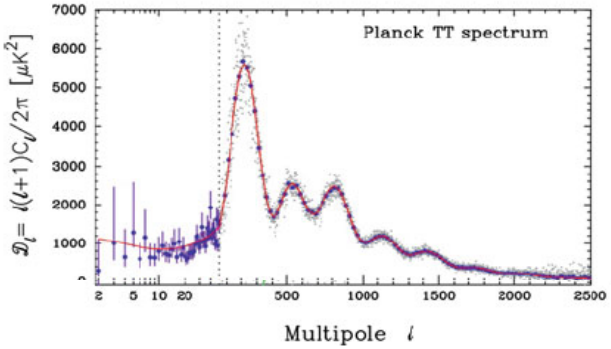


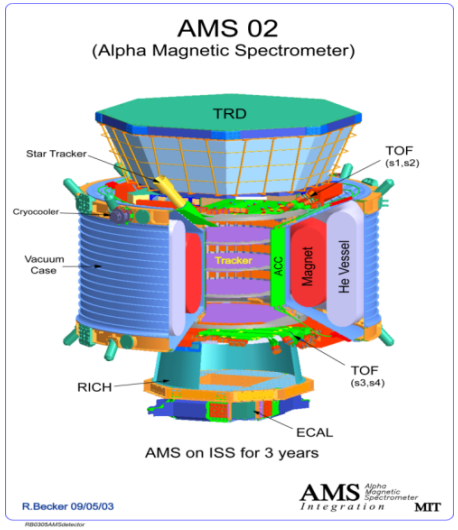


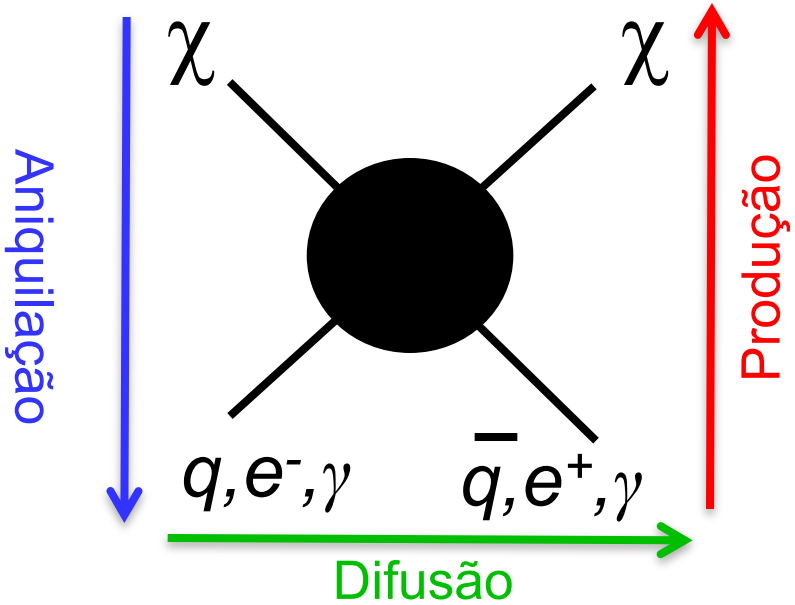


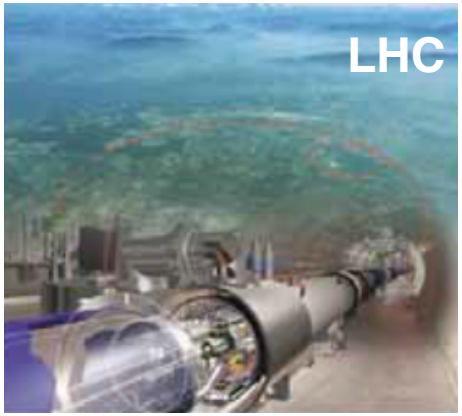
Matéria Escura



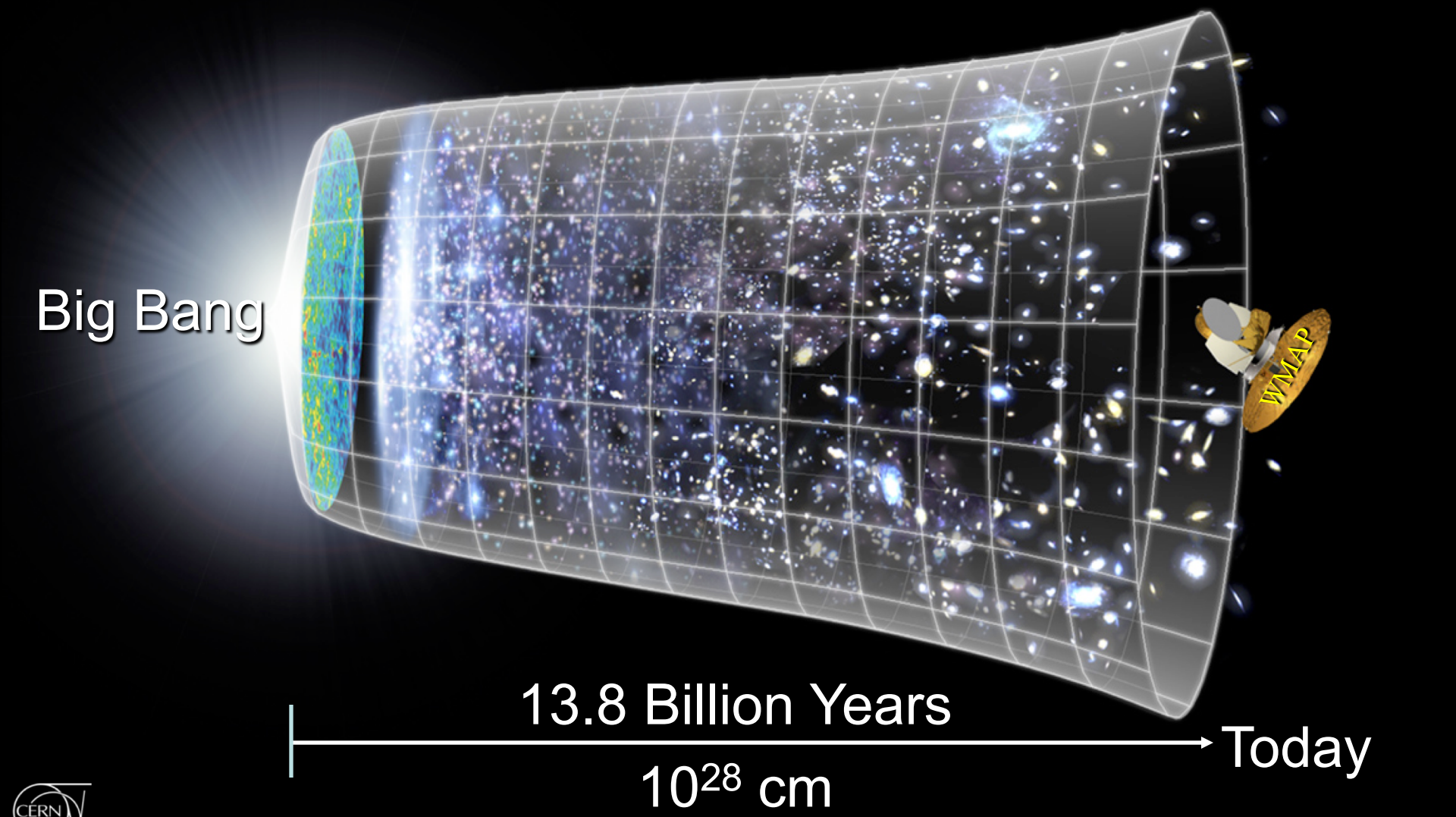




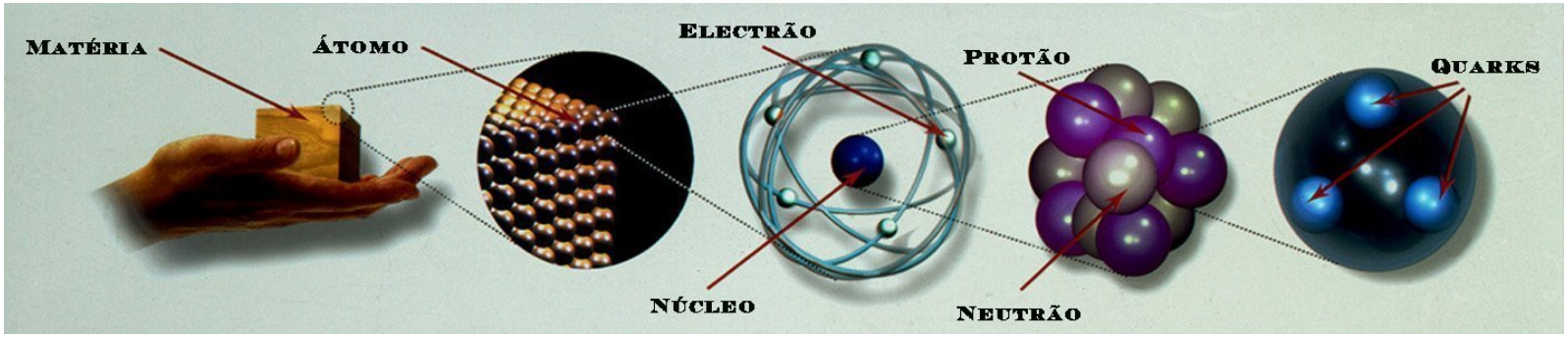


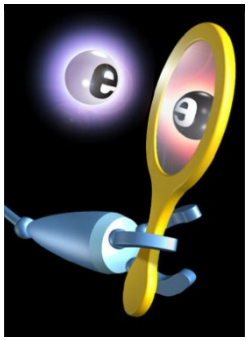


O Universo para compreender, ...



“Matter”



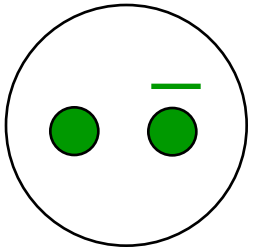


Leptons:

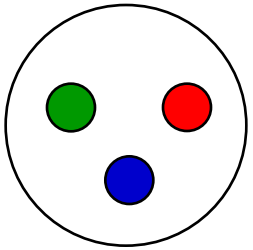
$$\begin{pmatrix} \nu_e \\ e^- \end{pmatrix} \begin{pmatrix} \nu_\mu \\ \mu^- \end{pmatrix} \begin{pmatrix} \nu_\tau \\ \tau^- \end{pmatrix}$$

Quarks:

$$\begin{pmatrix} u \\ d \end{pmatrix} \begin{pmatrix} c \\ s \end{pmatrix} \begin{pmatrix} t \\ b \end{pmatrix}$$

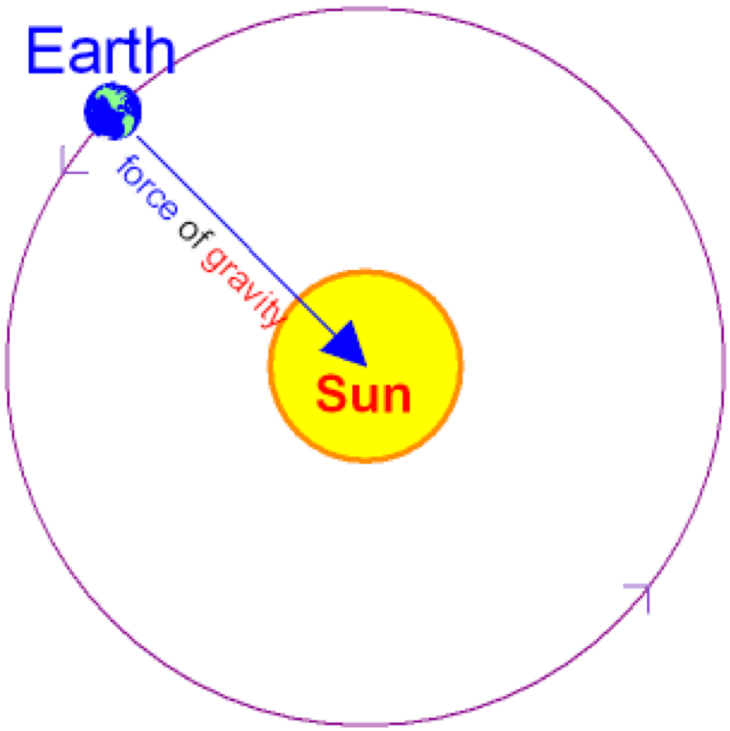


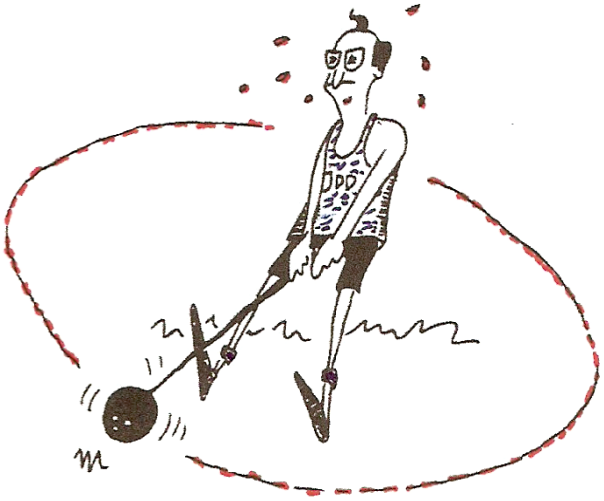
Meson = $(q\,\bar{q})$

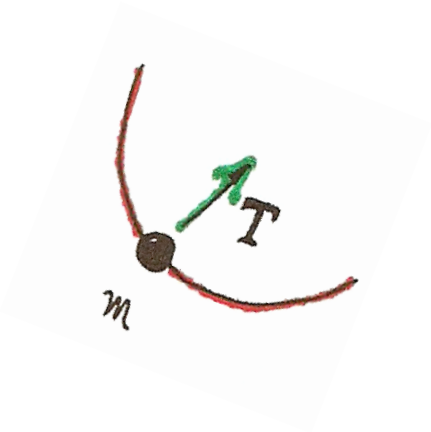


Baryon = $(q\,q\,q)$

A massa do Sol





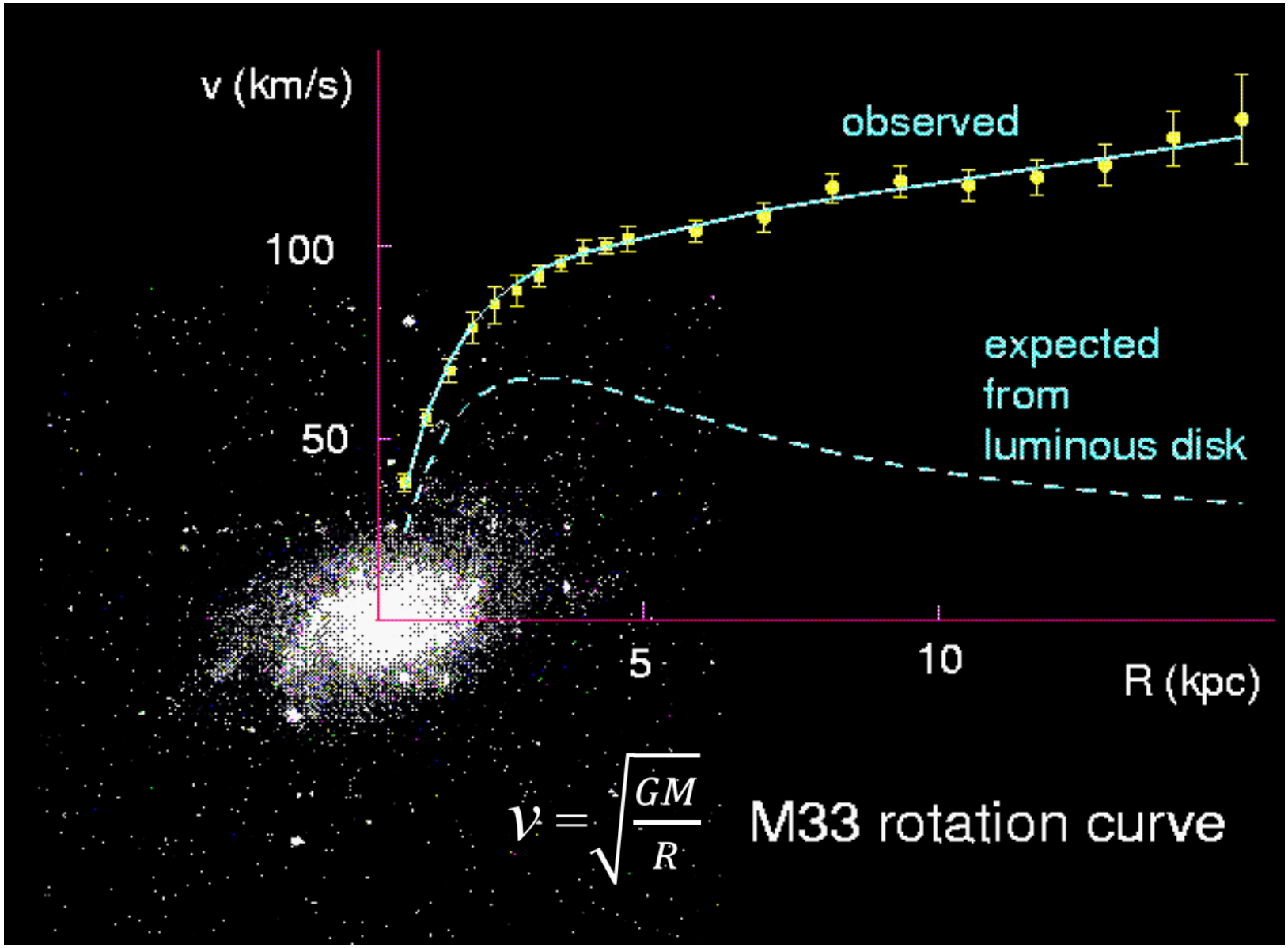


$$F_c = \frac{m\ v^2}{r}$$

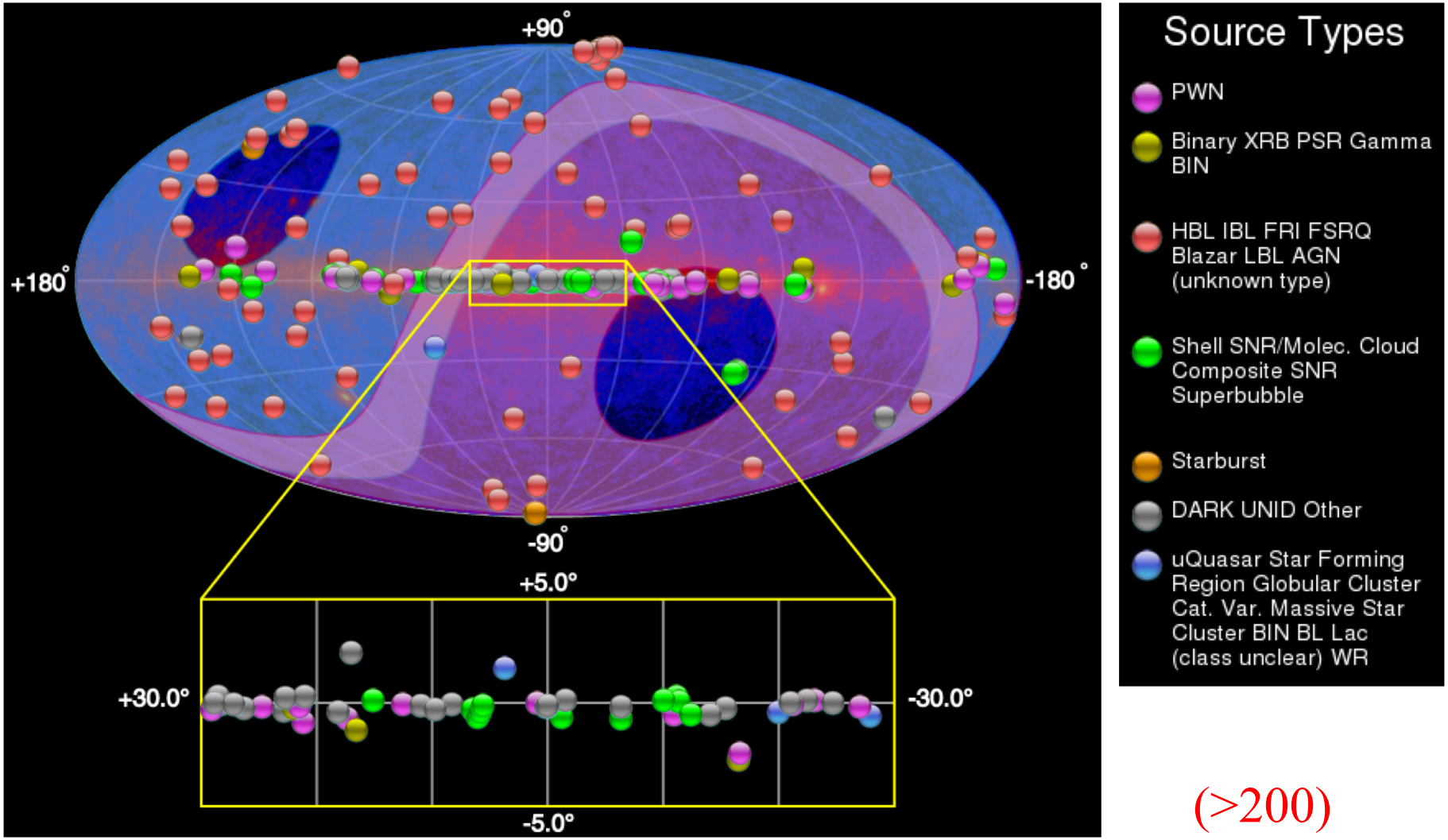
$$\frac{m_T\ v^2}{R} \approx G\ \frac{m_T\ M_S}{R^2}$$

$$M_S \sim 1.98\ 10^{30}\ kg$$

A velocidade de rotação das estrelas periféricas

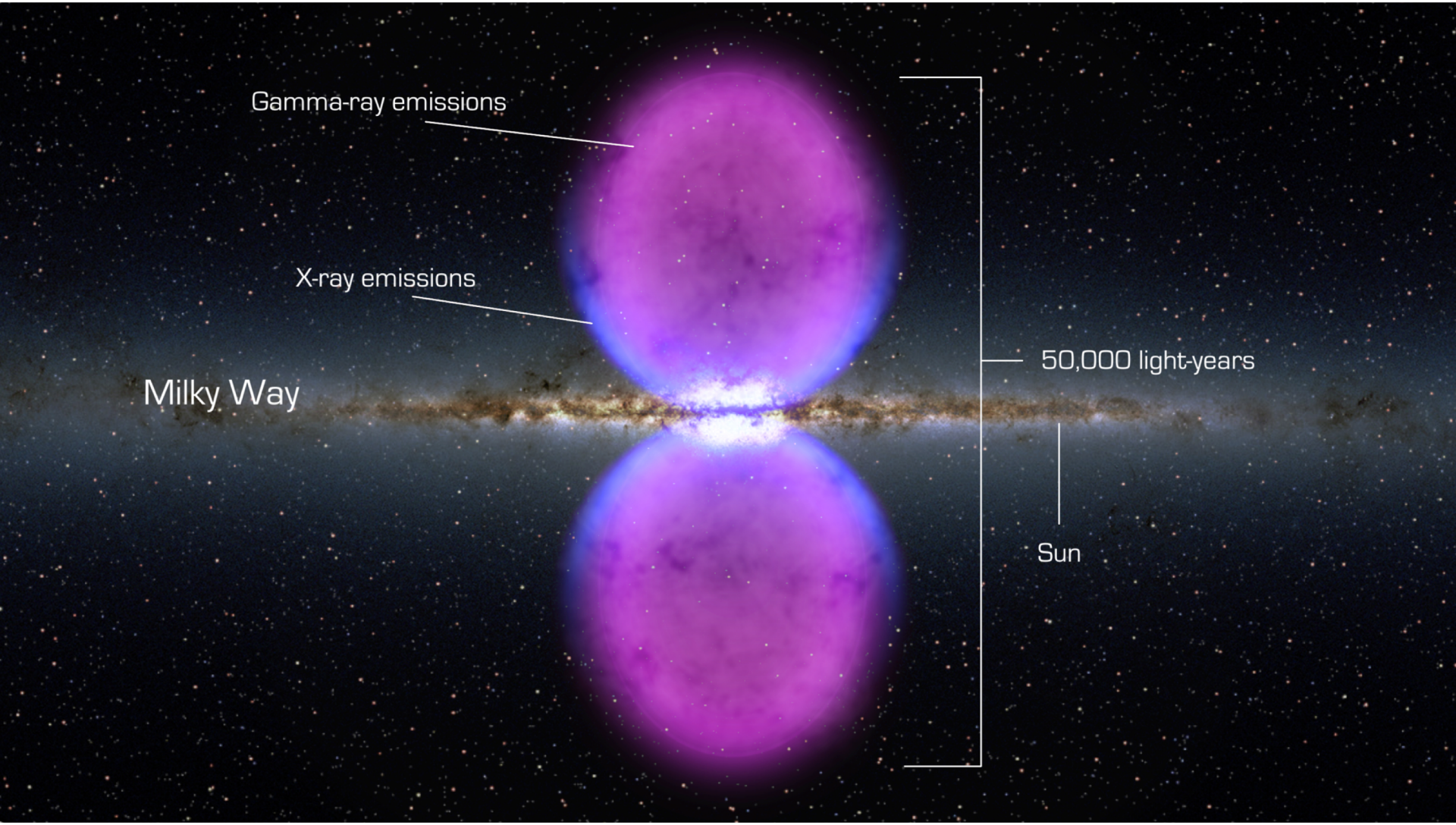


Fontes raios gamma de alta energia (TeV)



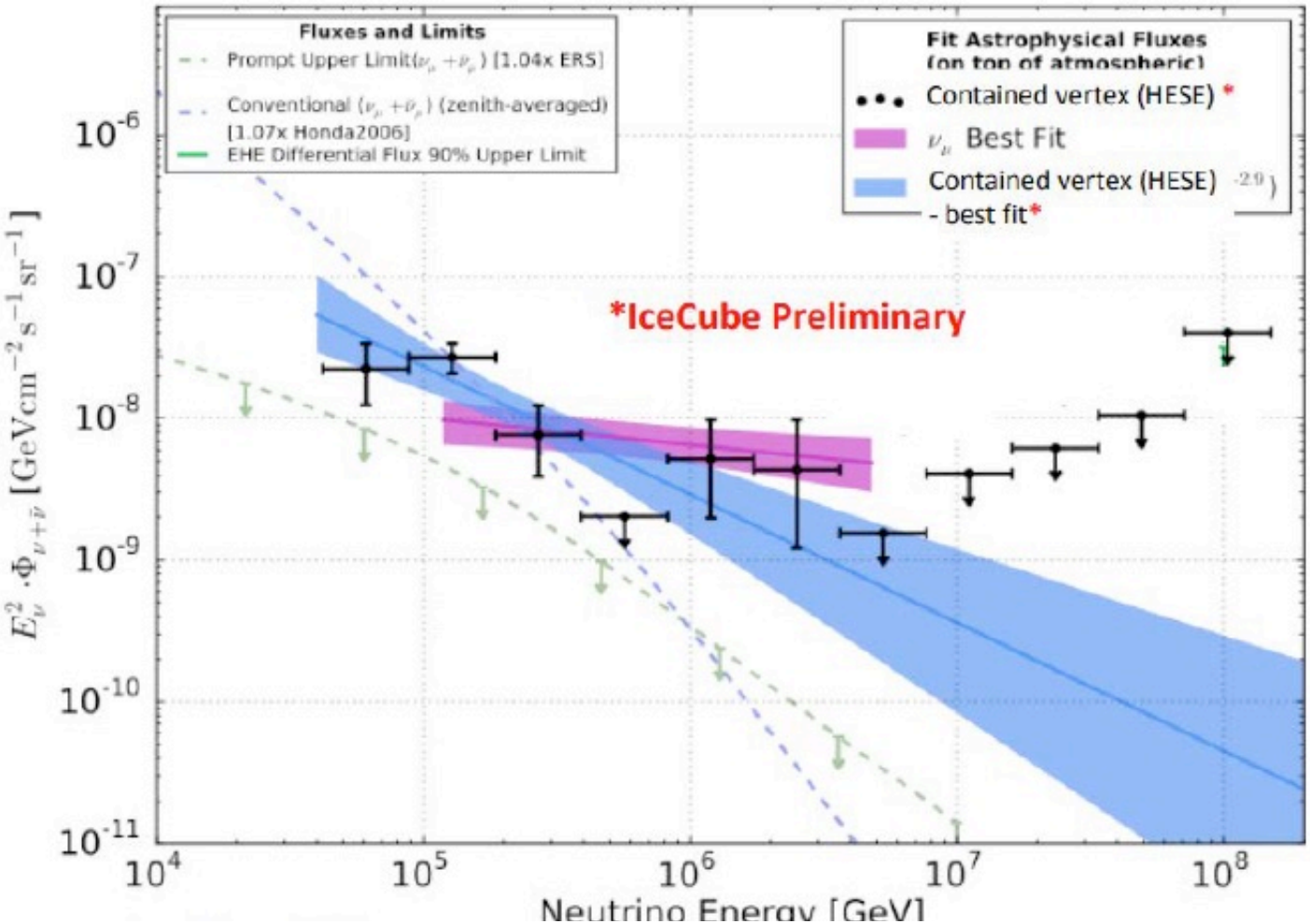
(>200)

As bolhas de Fermi

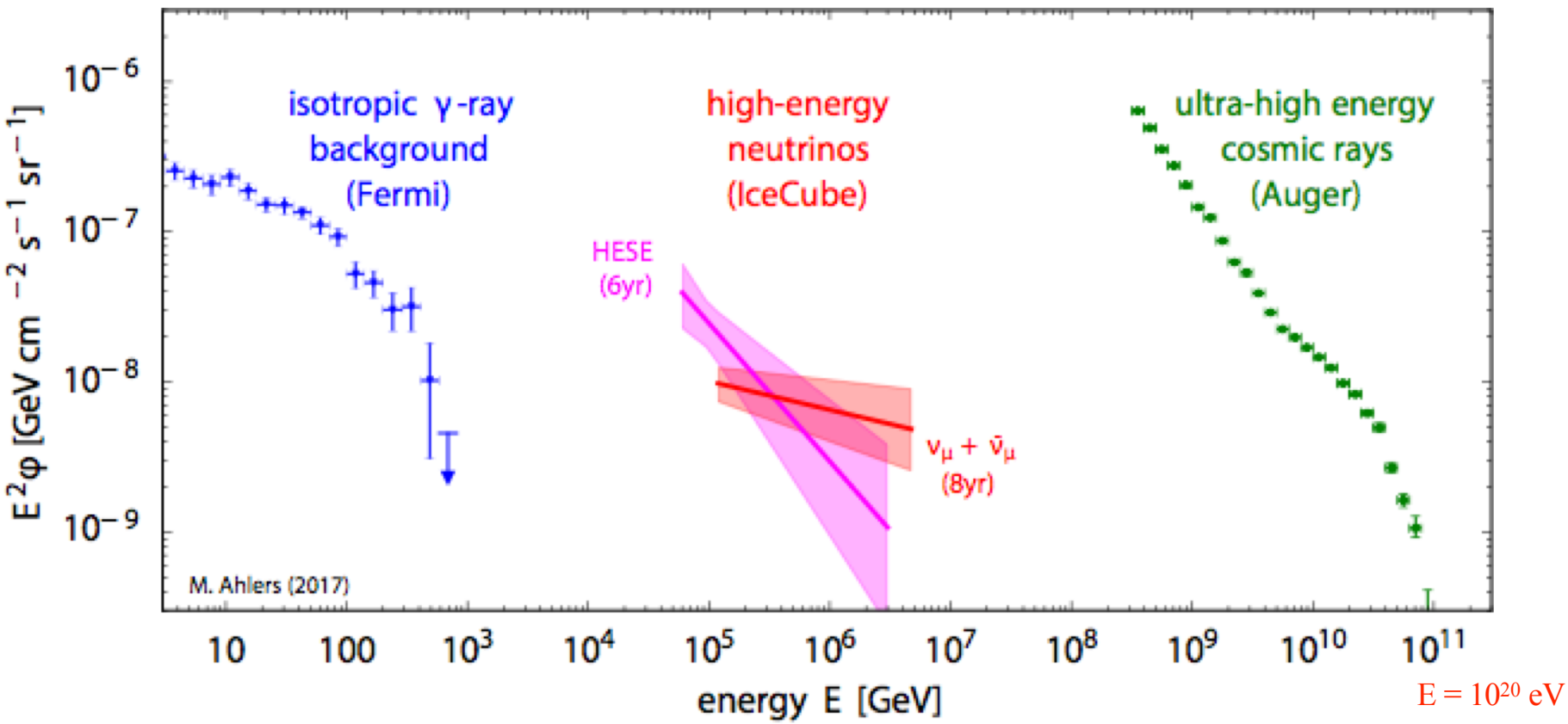


Neutrinos astrofísicos de energia elevada

Ice Cube



The Universe at the highest energies !



Energy density per decade similar in all three messenger particles