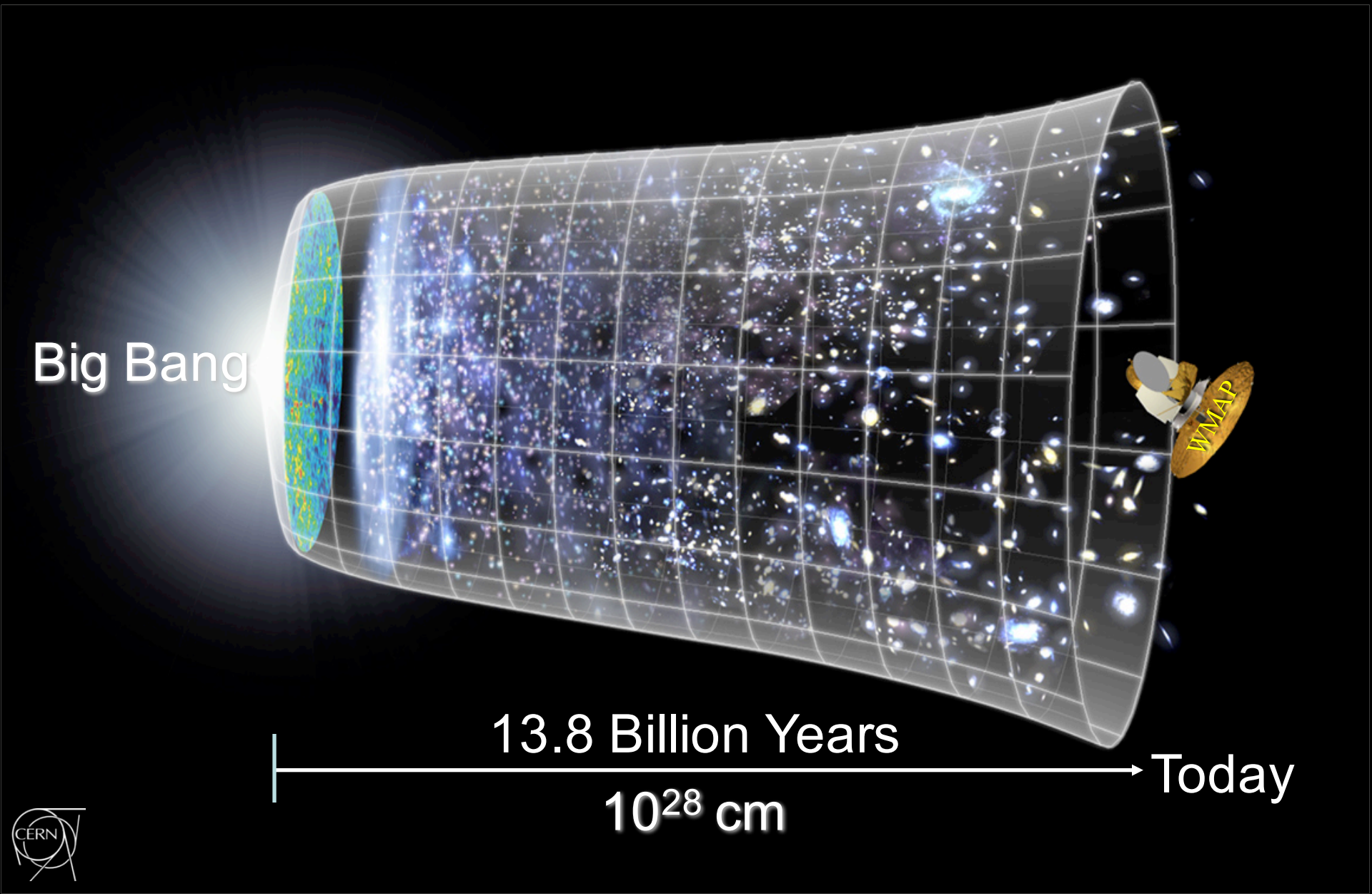
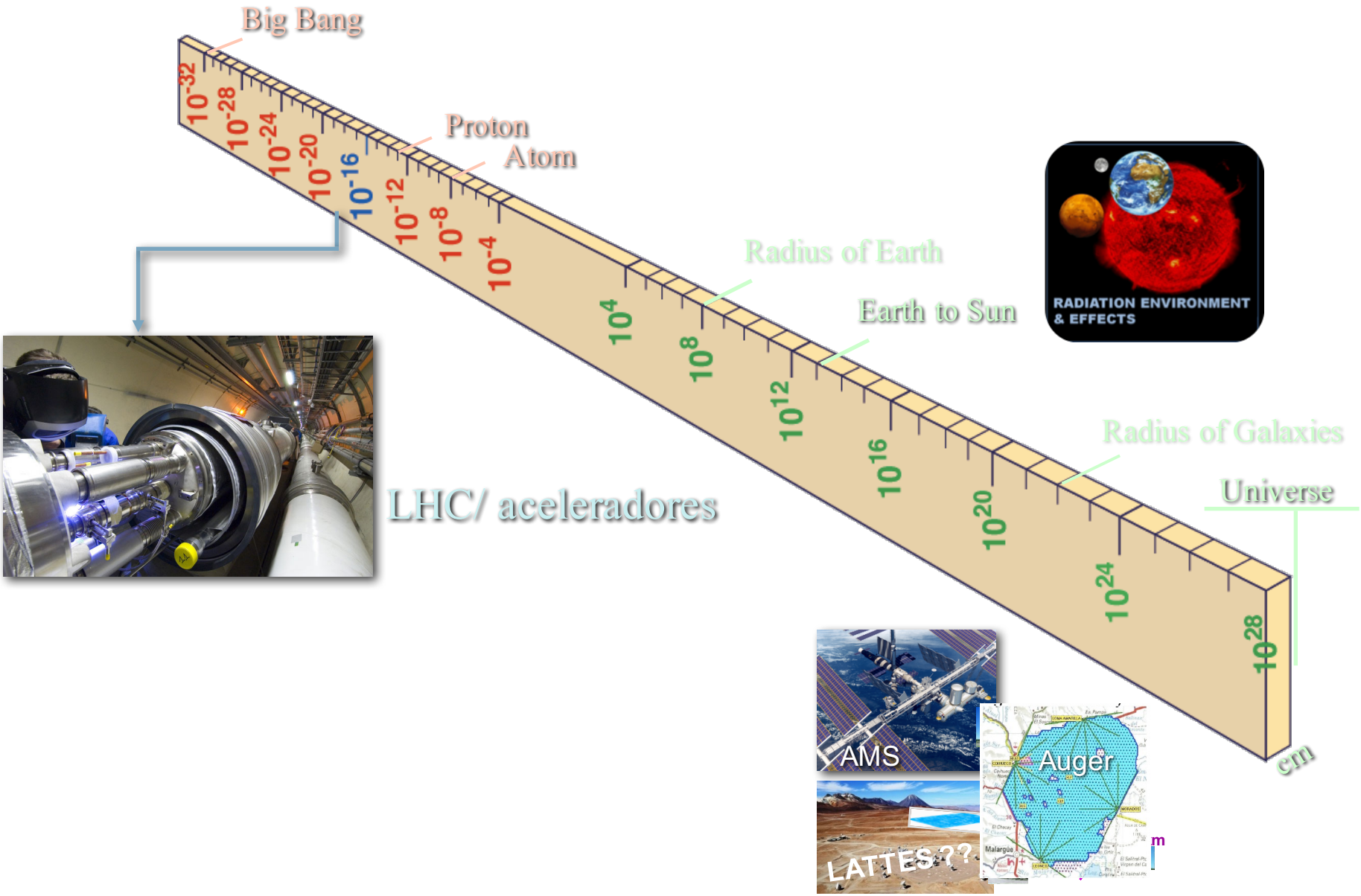
A aventura da Física de Partículas e Astropartículas

Mário Pimenta
Lisboa, Julho 2018

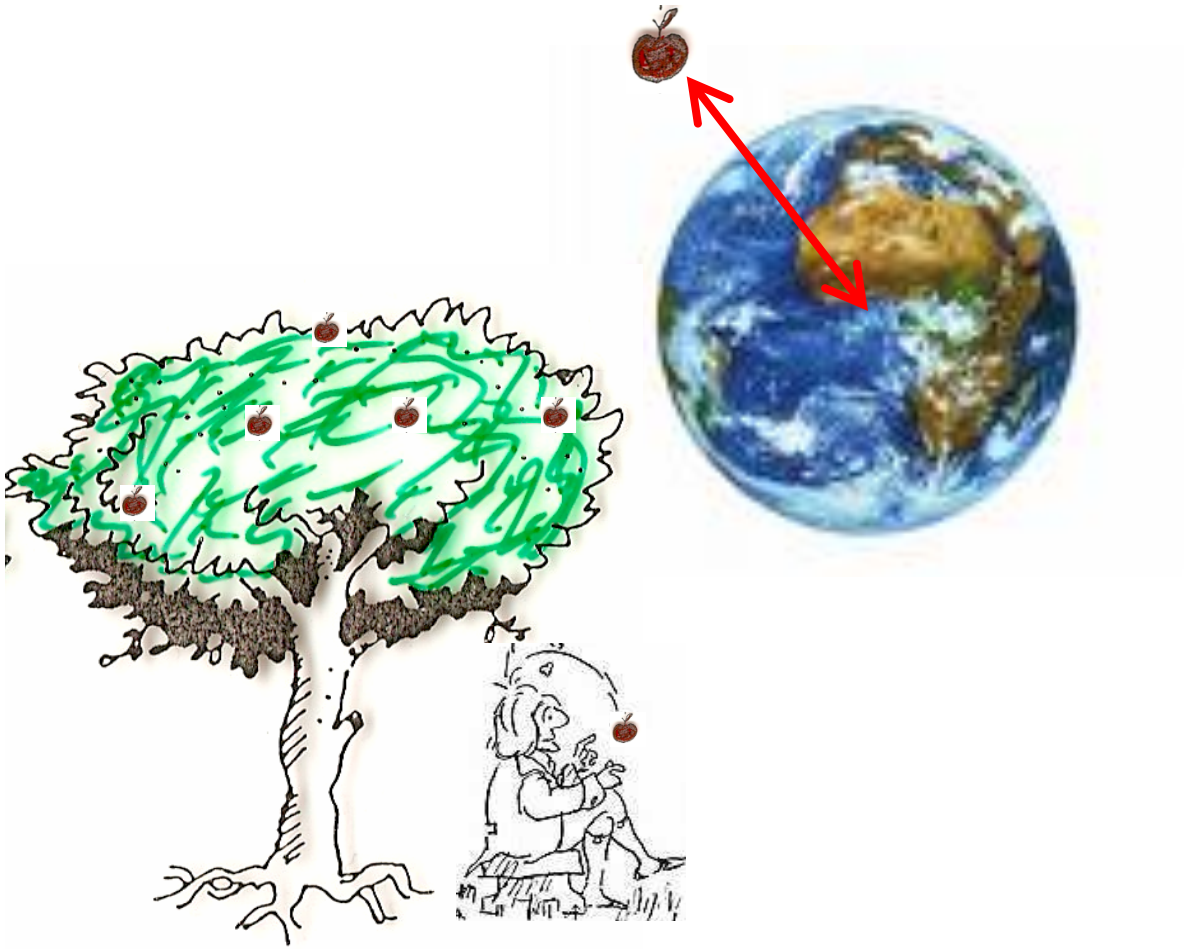
O Universo para compreender, ...



Escalas, ...

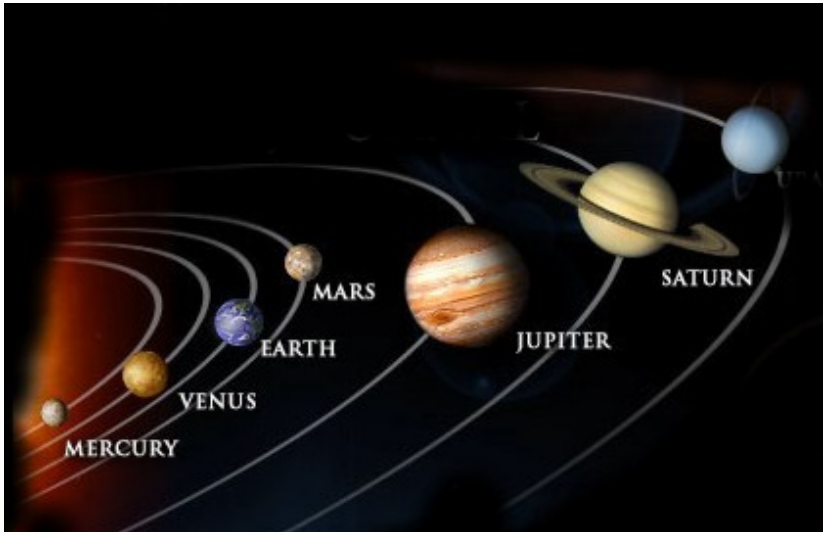

Big Bang
Proton
Atom
Radius of Earth
Earth to Sun
Radius of Galaxies
Universe
10^{-32}
10^{-28}
10^{-24}
10^{-20}
10^{-16}
10^{-12}
10^{-8}
10^{-4}
10^{4}
10^{8}
10^{12}
10^{16}
10^{20}
10^{24}
10^{28}
cm
m
LHC/ aceleradores
RADIATION ENVIRONMENT & EFFECTS
AMS
Auger
LATTES ??
Malargüe

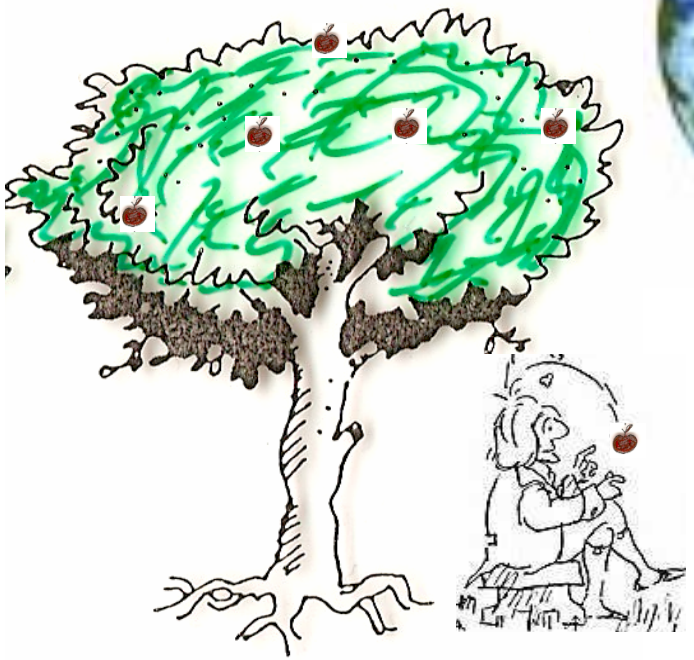
Da maçã ao Universo



I. Newton

Da maçã ao Universo





I. Newton

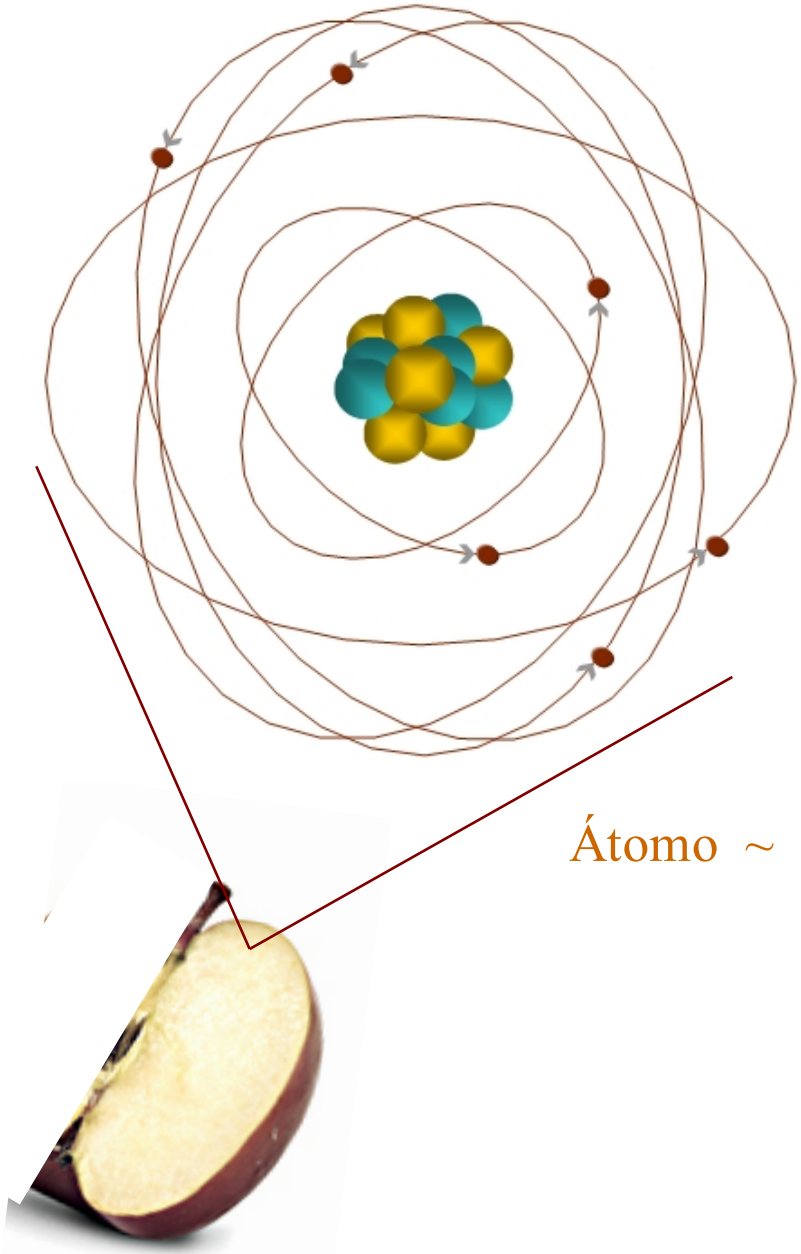
Lei da atracção Universal:

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

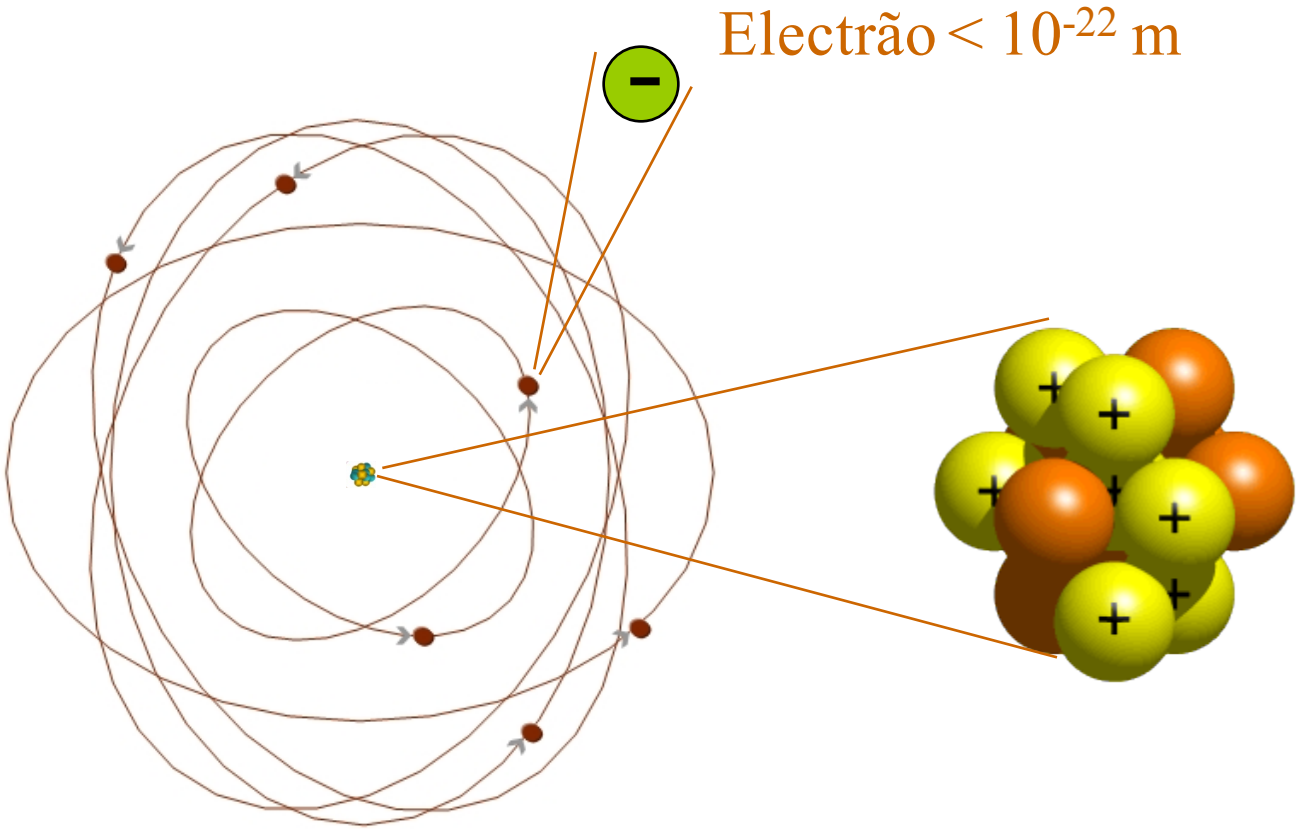
A gravidade !

Será que a maçã é elementar?

Será que a maçã é elementar?



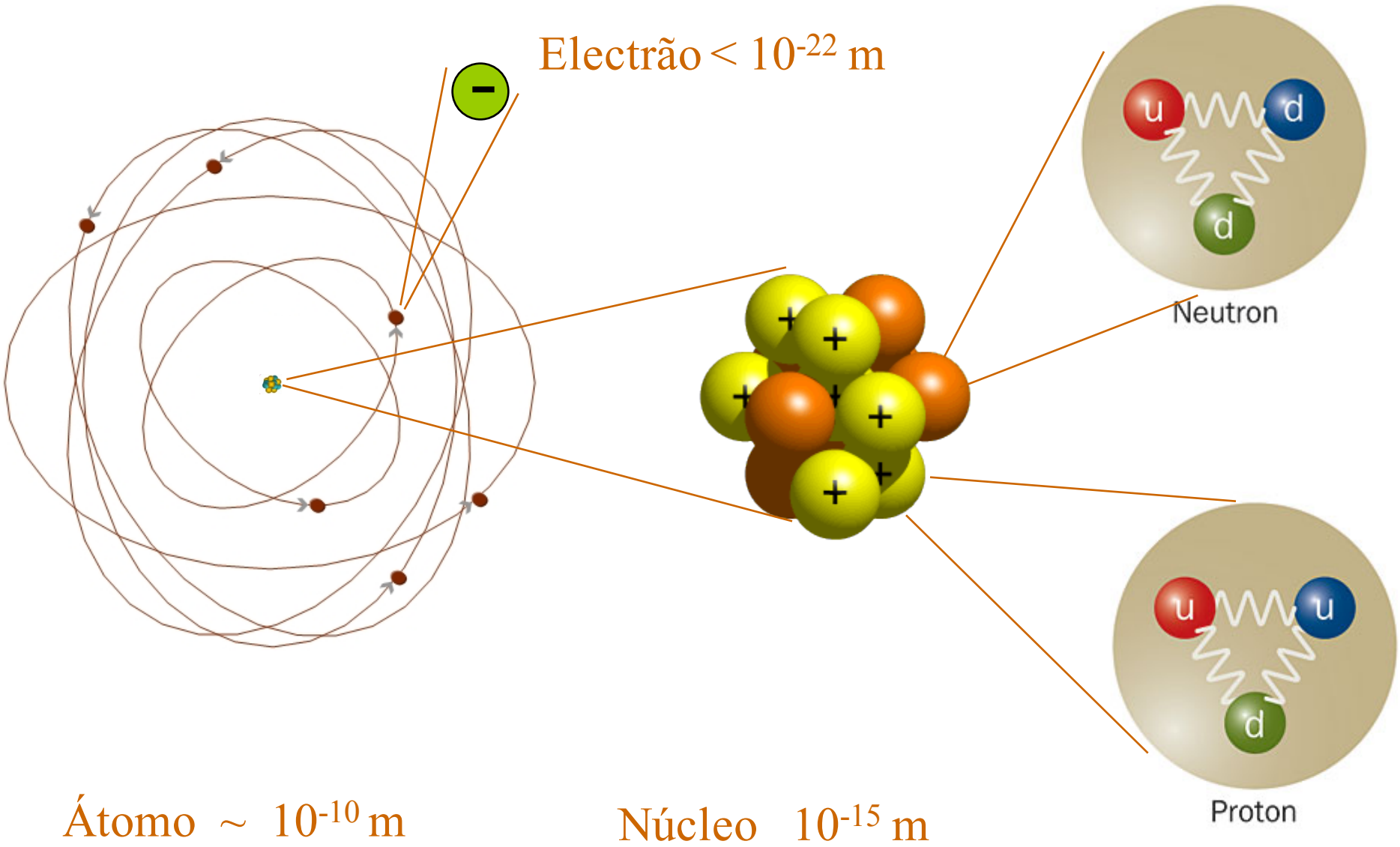
No interior dos átomos



Átomo ~ 10^{-10} m

Núcleo 10^{-15} m

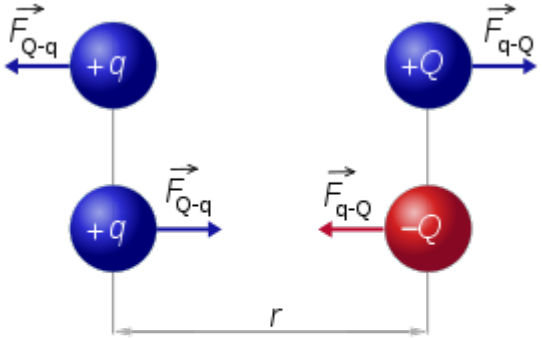
No interior dos átomos



A Força electromagnética

J. Maxwell

Atracção / Repulsão



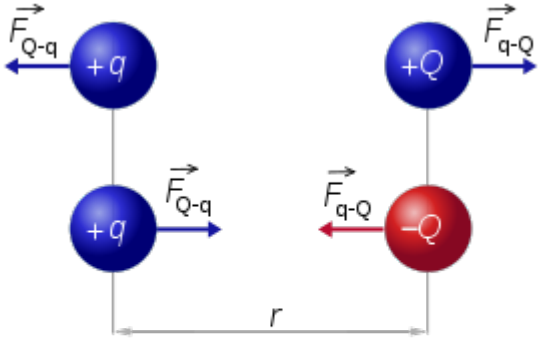
$$F_C = K \frac{q_1 \, q_2}{r_{12}^{\,2}}$$

campo eléctrico

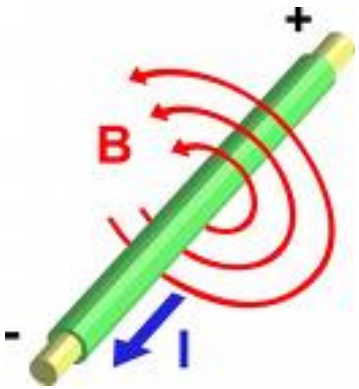
A Força electromagnética

J. Maxwell

Atracção / Repulsão



correntes



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

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

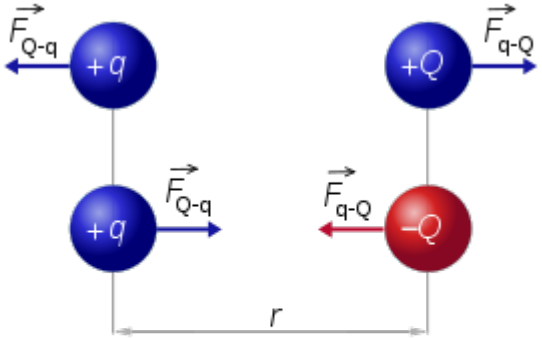
campo eléctrico

campo magnético

A Força electromagnética

J. Maxwell

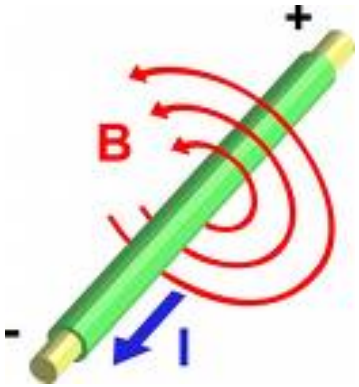
Atracção / Repulsão



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

campo eléctrico

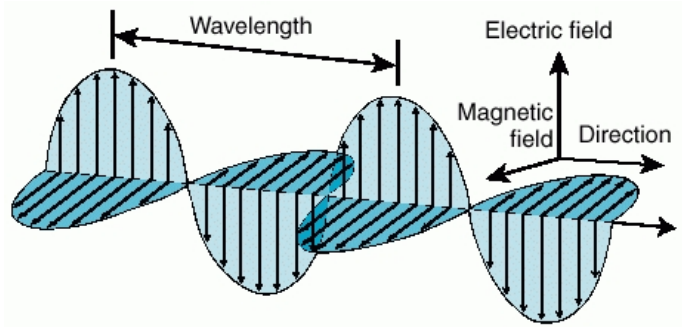
correntes



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

campo magnético

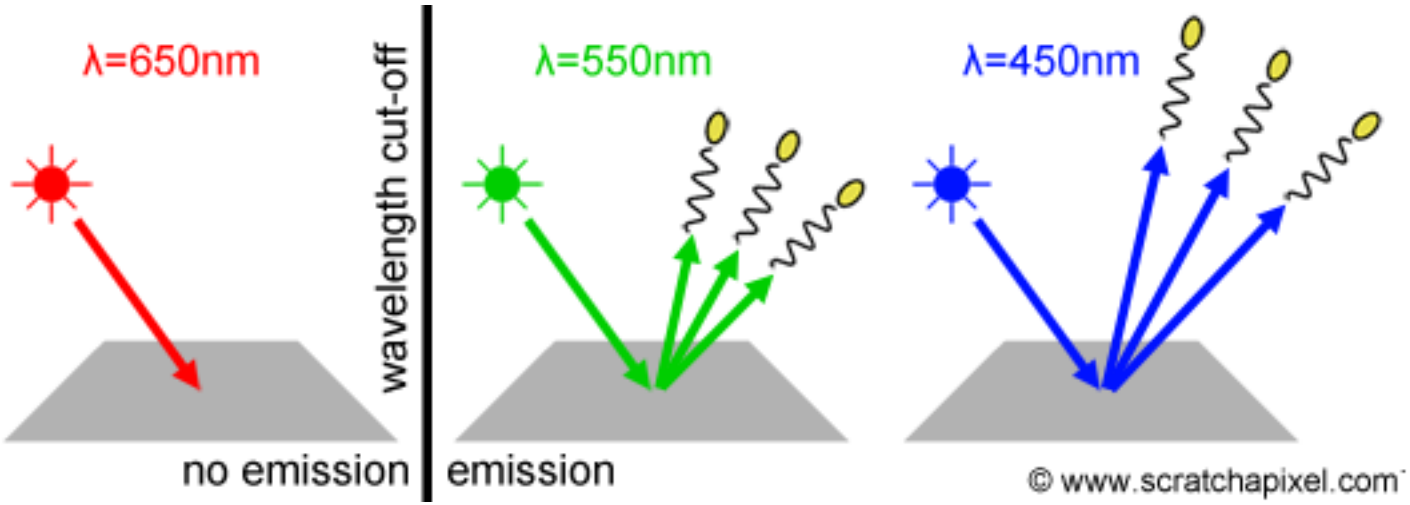
ondas



campo electromagnético

O Fotão

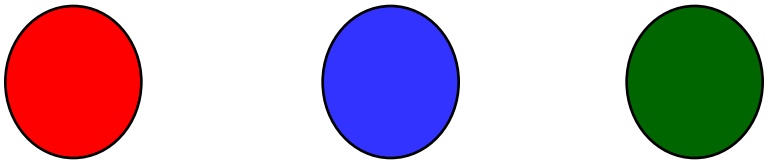
O efeito foto-eléctrico!



$$E = h\,\nu$$

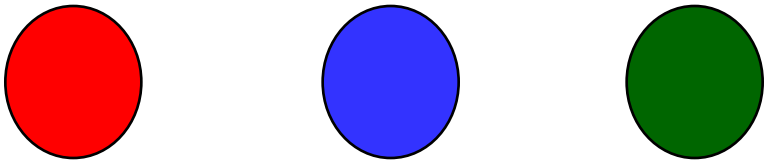
A força forte

Quarks de três cores:

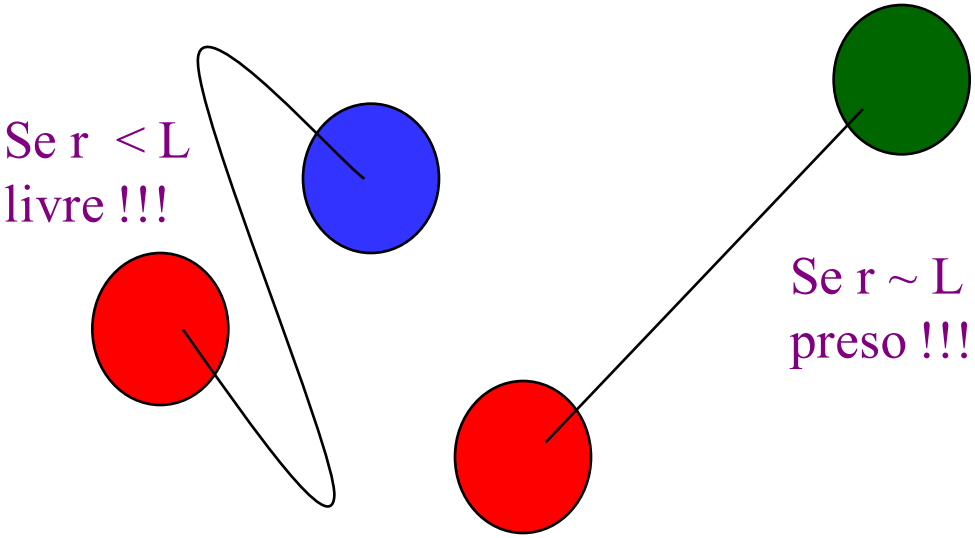


A força forte

Quarks de três cores:

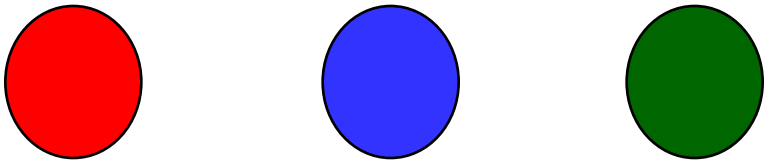


Ligados por “cordas”

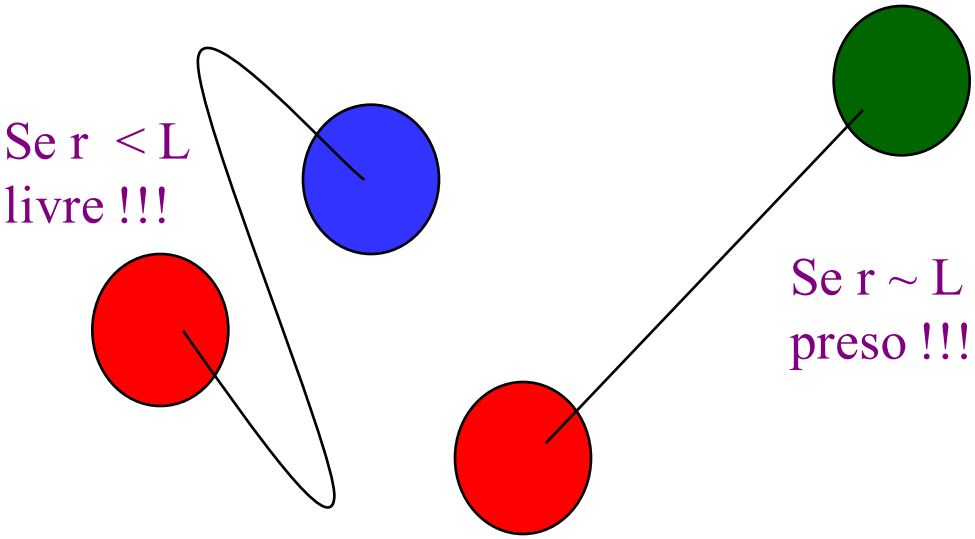


A força forte

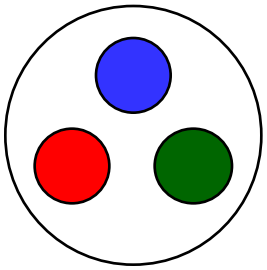
Quarks de três cores:



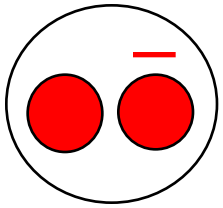
Ligados por “cordas”



Partículas “sem cor”



Bariões



Mesões

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:

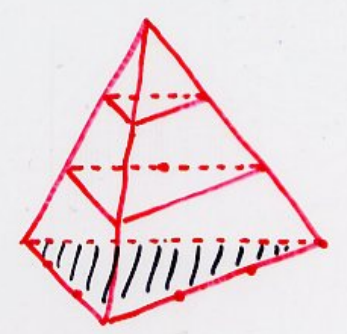
$$\begin{pmatrix} u \\ d \end{pmatrix} \begin{pmatrix} c \\ s \end{pmatrix} \begin{pmatrix} t \\ b \end{pmatrix} \begin{pmatrix} ? \end{pmatrix}$$

Q = + 2/3

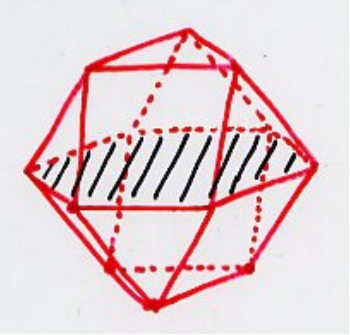
Q = - 1/3

Combinar

$q_i q_j q_k$



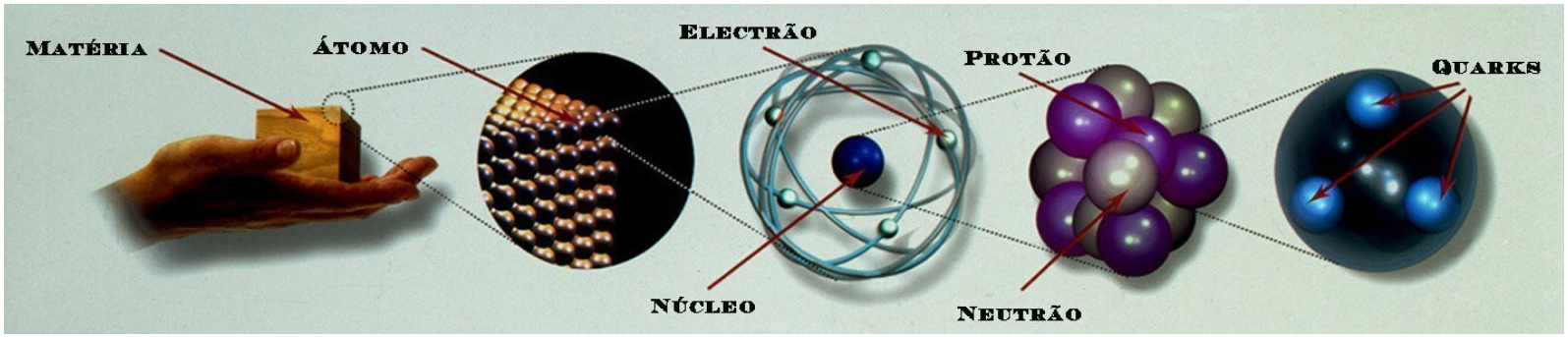
$q_i \vec{q}_i$

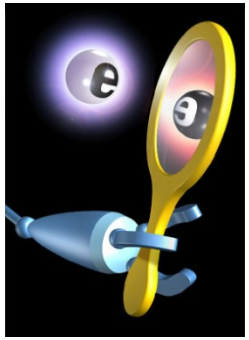


$p\ ,n\ ,\Sigma\ ,\lambda\ ,\Xi\ ,\Delta\ ,\ldots$

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

“Matter”



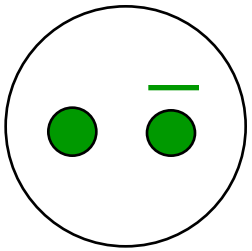


Leptons:

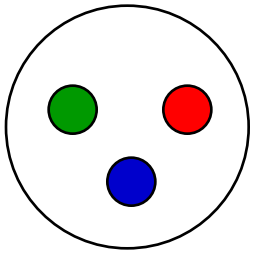
$$\begin{pmatrix} \nu_e \\ e^- \end{pmatrix} \begin{pmatrix} \nu_\mu \\ \mu^- \end{pmatrix} \begin{pmatrix} \nu_\tau \\ \tau^- \end{pmatrix}$$

Quarks:

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

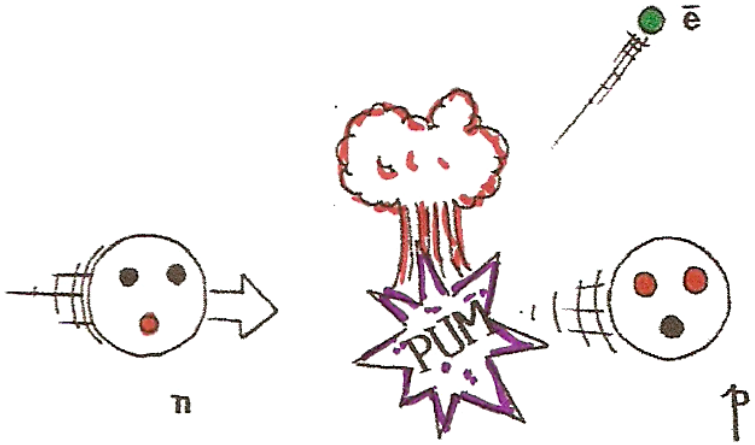


Meson = $(q\,\bar{q})$

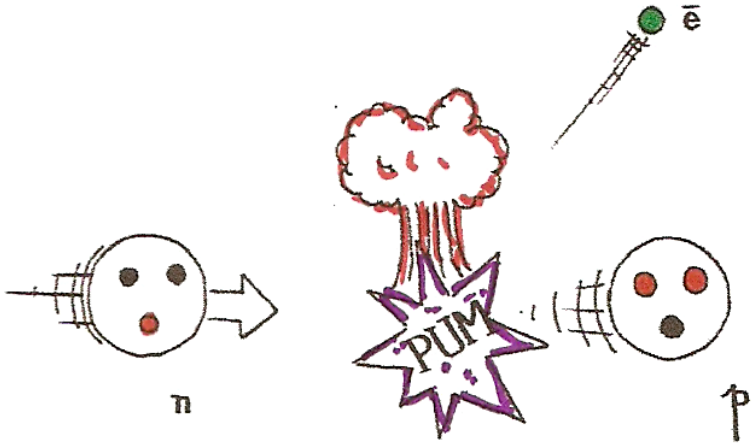


Baryon = $(q\,q\,q)$

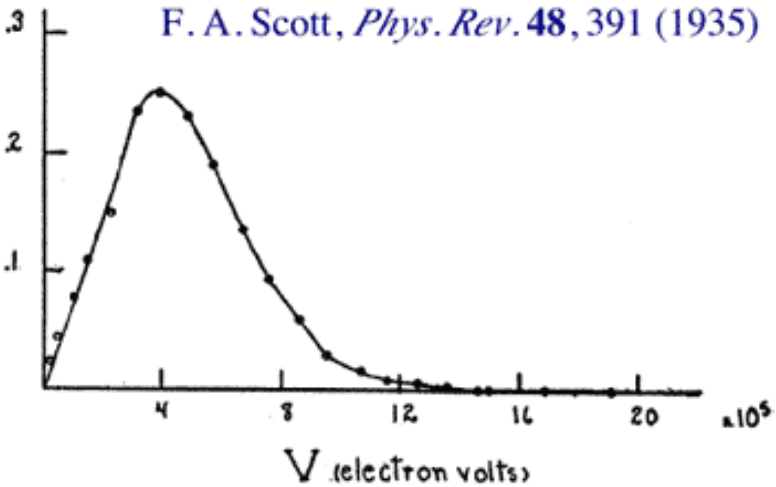
O neutrão decai…



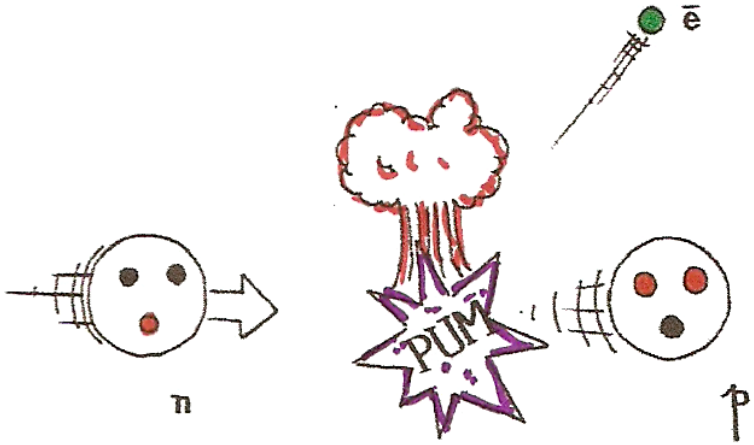
O neutrão decai…



conservação o E e $\vec{P}$???



O neutrão decai…



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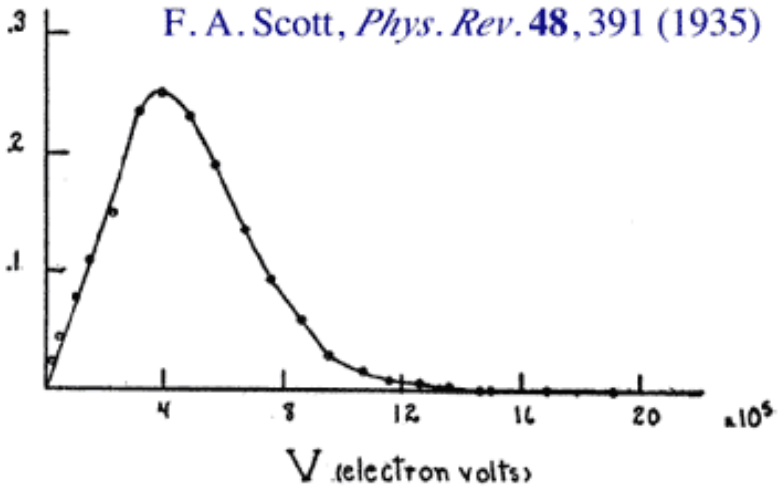
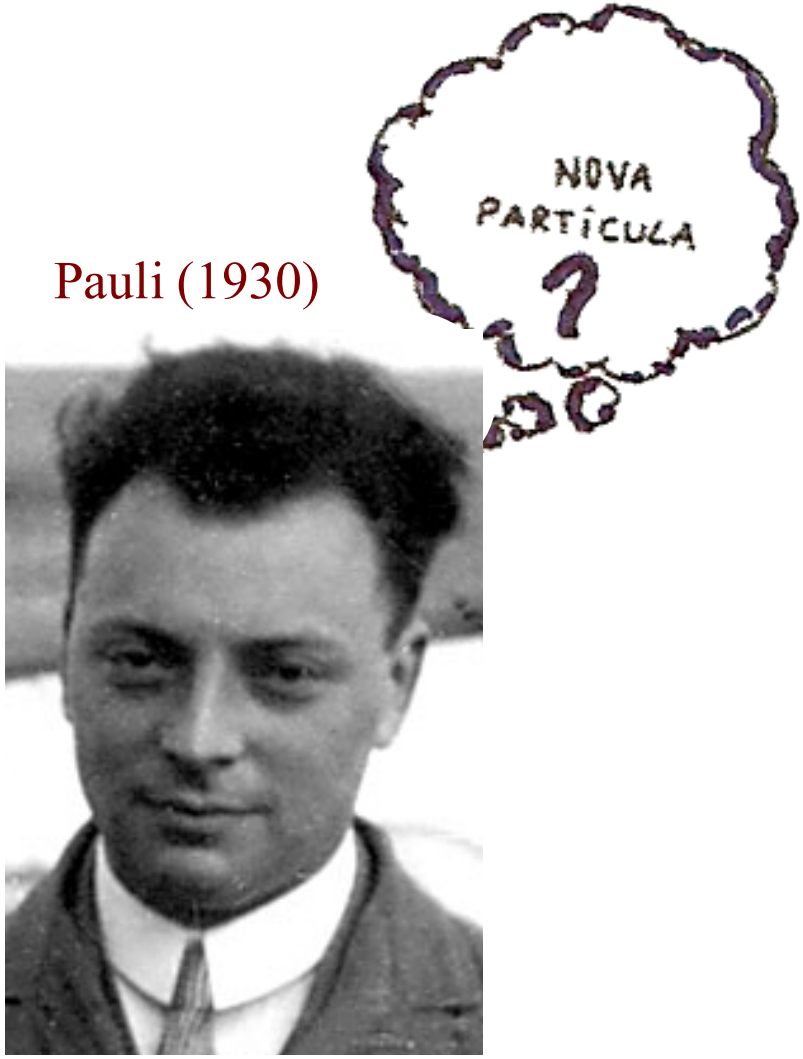


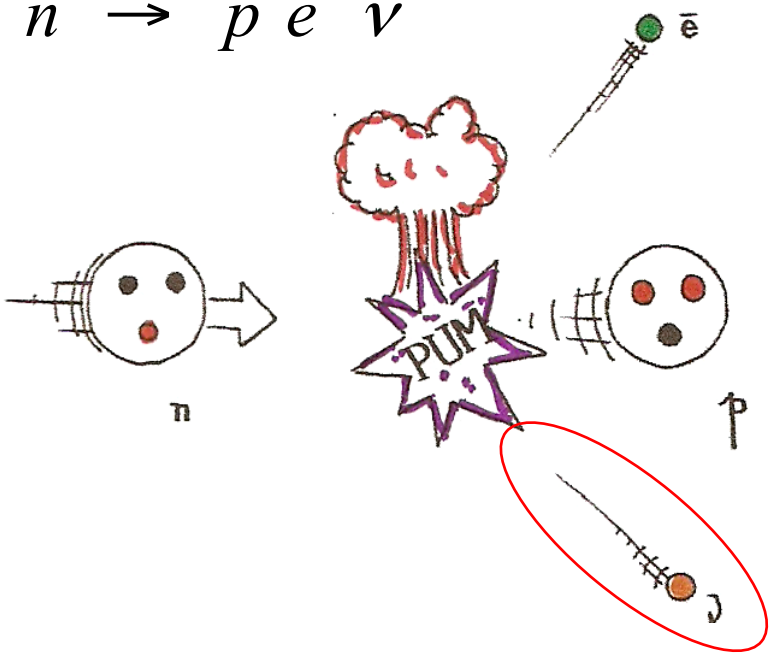


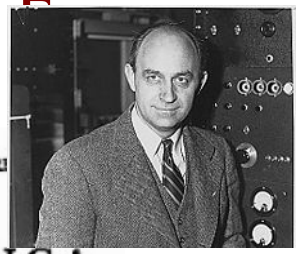
Pauli (1930)

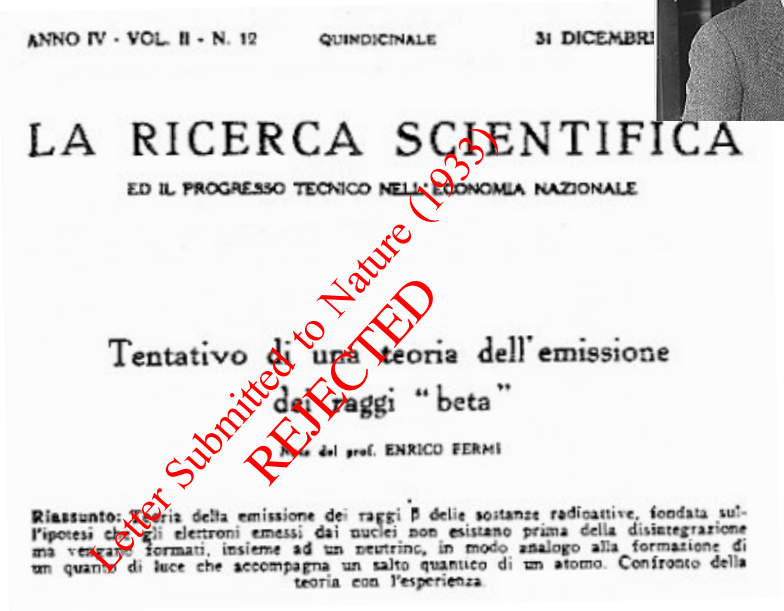
O neutrino !!!

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

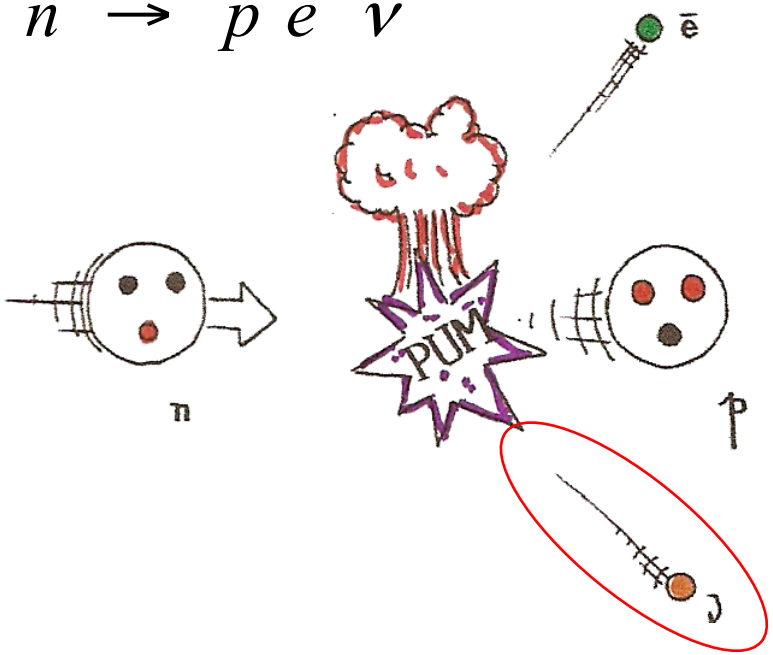
Riassunto: Teoria della emissione dei raggi β delle sostanze radioattive, fondata sull'ipotesi che gli elettroni emessi dai nuclei non esistano prima della disintegrazione ma vengano formati, insieme ad un neutrino, in modo analogo alla formazione di un quanto di luce che accompagna un salto quantico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

Letter Submitted to Nature (1934)
REJECTED

Nuovo Cimento and Zeitschrift fur Physik

A força fraca

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



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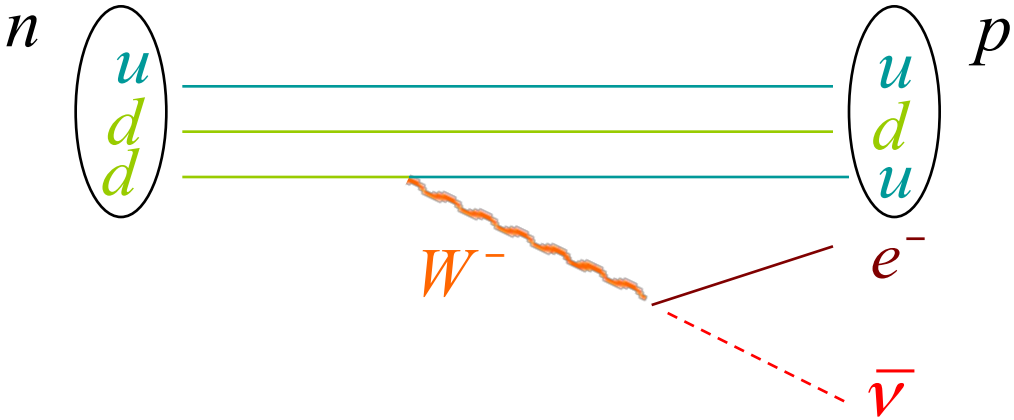
Nuovo Cimento and Zeitschrift fur Physik

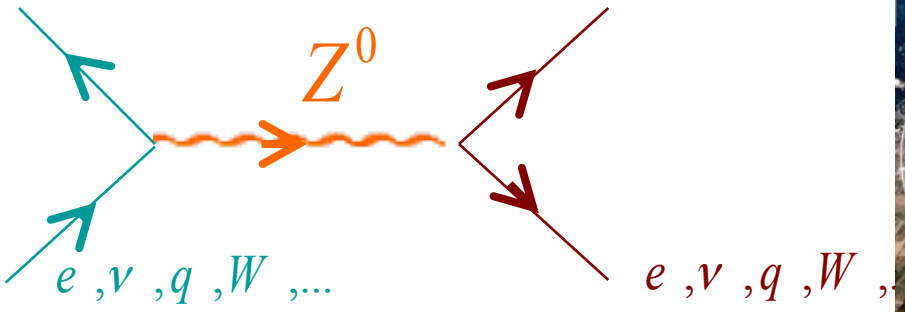
A visão moderna !

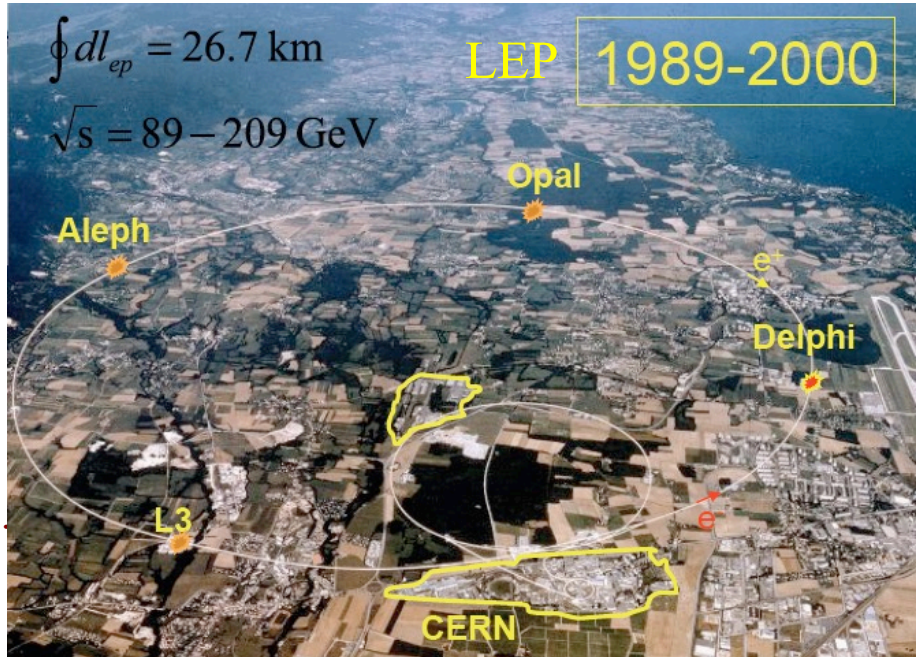
Um quark d transforma-se num quark u emitindo um bosão W que "decai" num par electrão, anti-neutrino



O Z^0

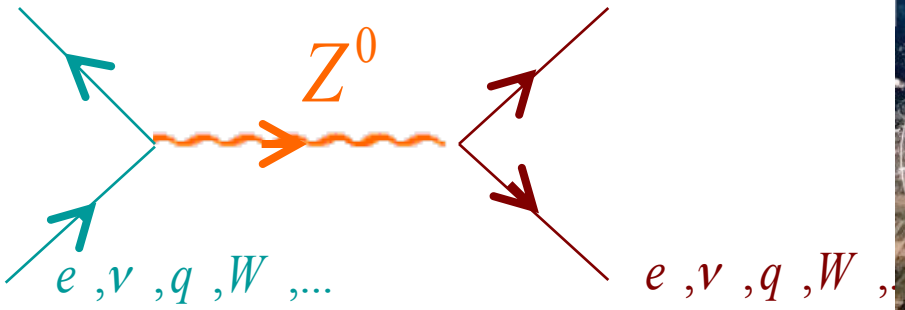
Parceiro neutro dos W´s

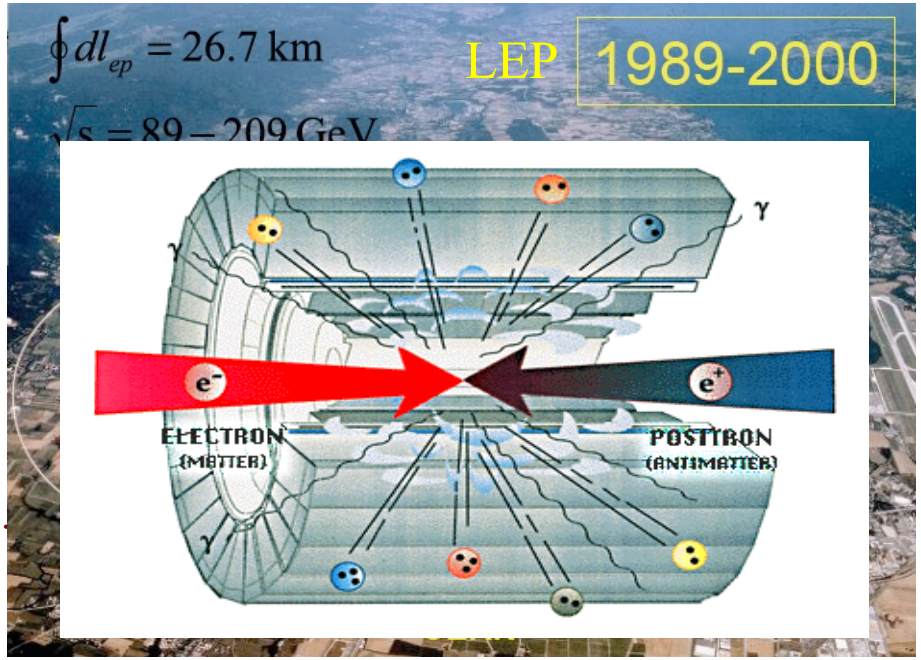




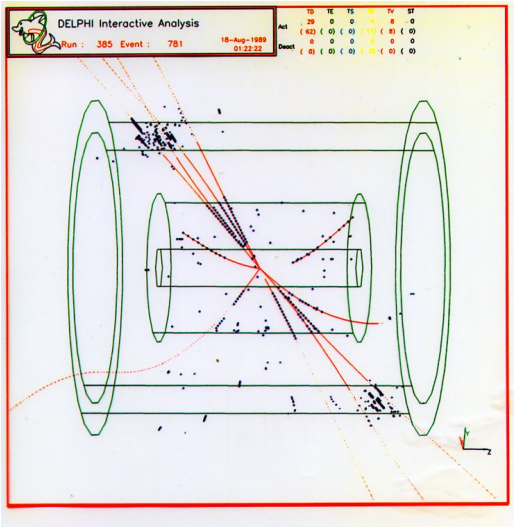
O Z^0

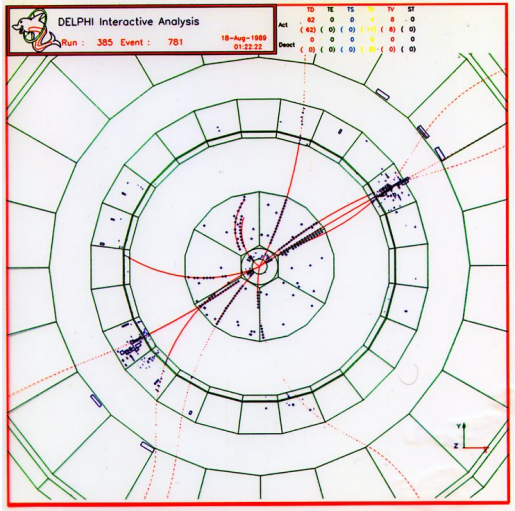
Parceiro neutro dos W´s

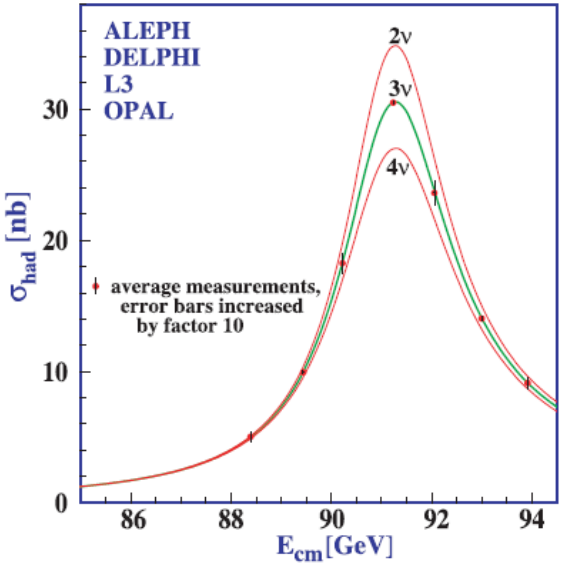




$e^+e^- \rightarrow q\bar{q}$



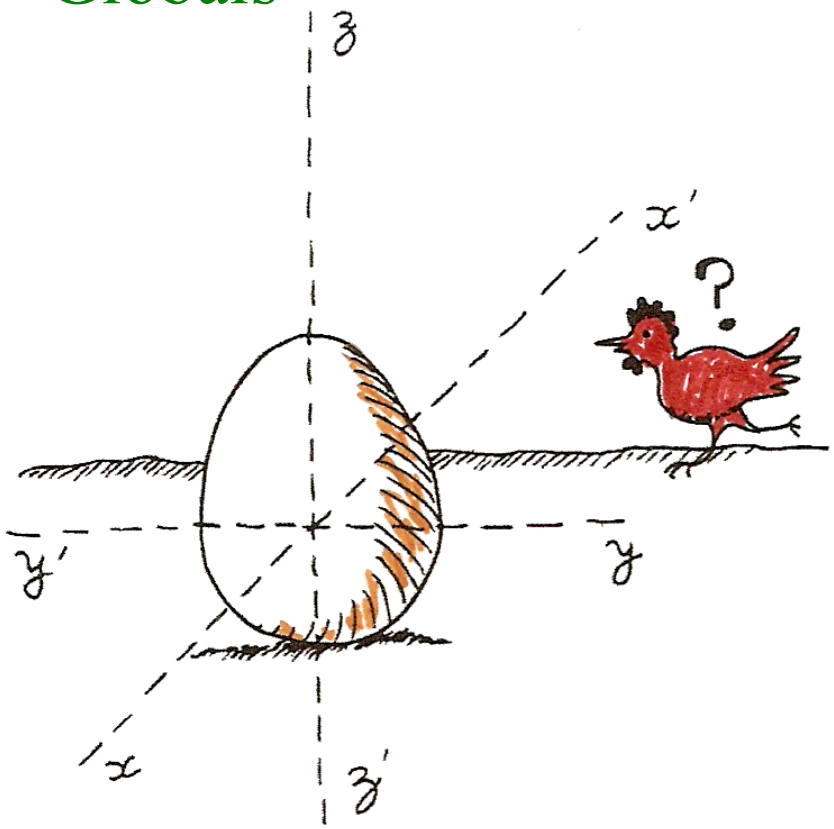




$M_z = 91.1875 \pm 0.0021$ GeV/c^2

Simetrias !!!

Globais

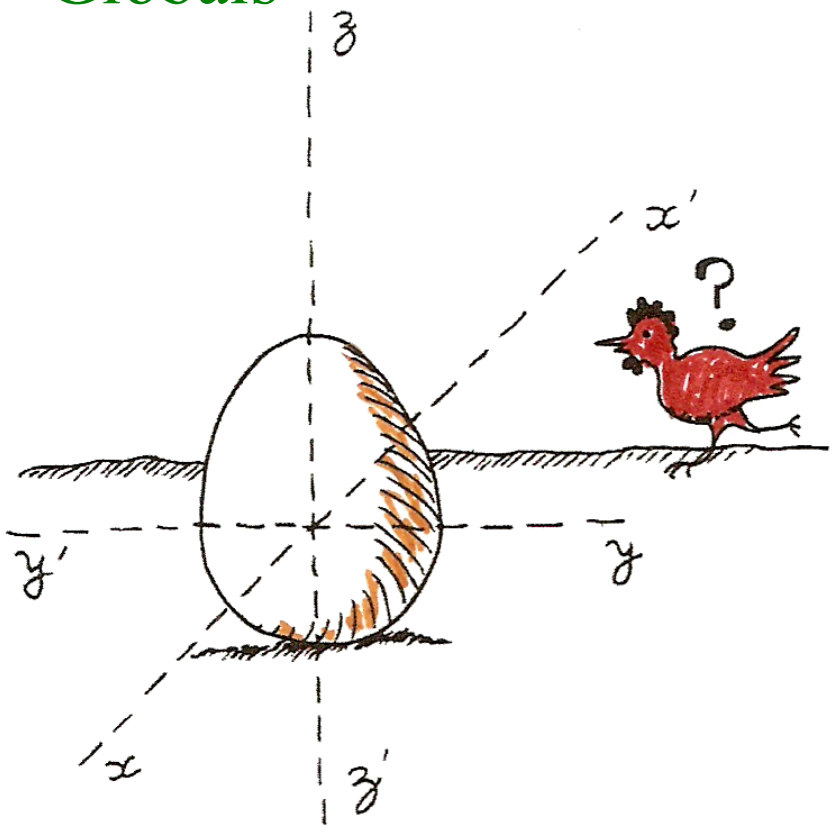


Leis de conservação:

Energia, Momento linear,
Momento Angular

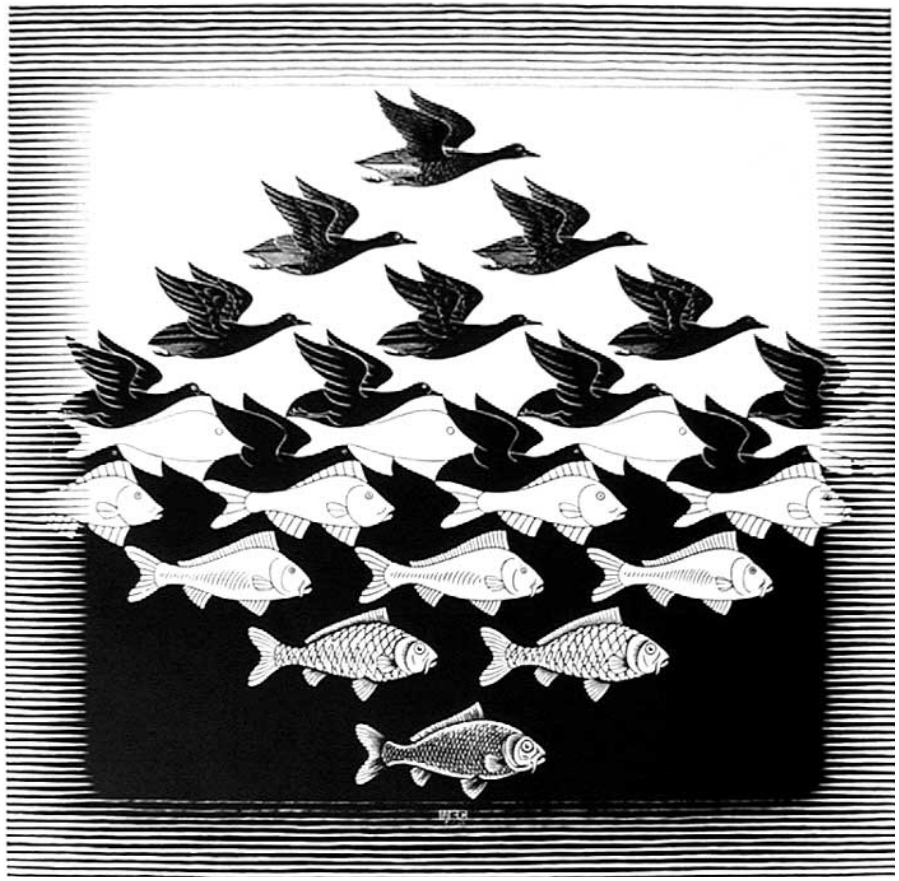
Simetrias !!!

Globais



Locais

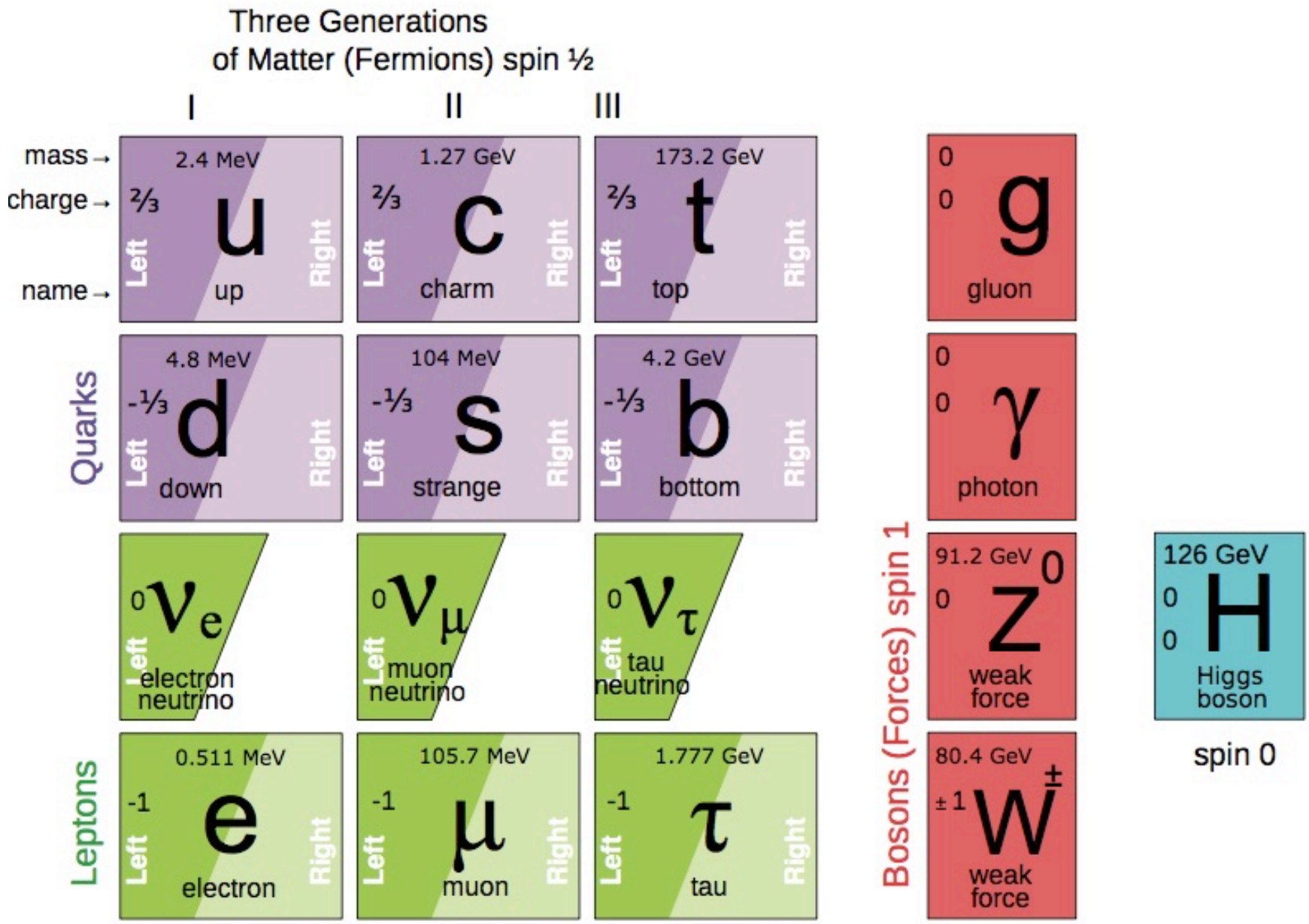
M.C.Escher



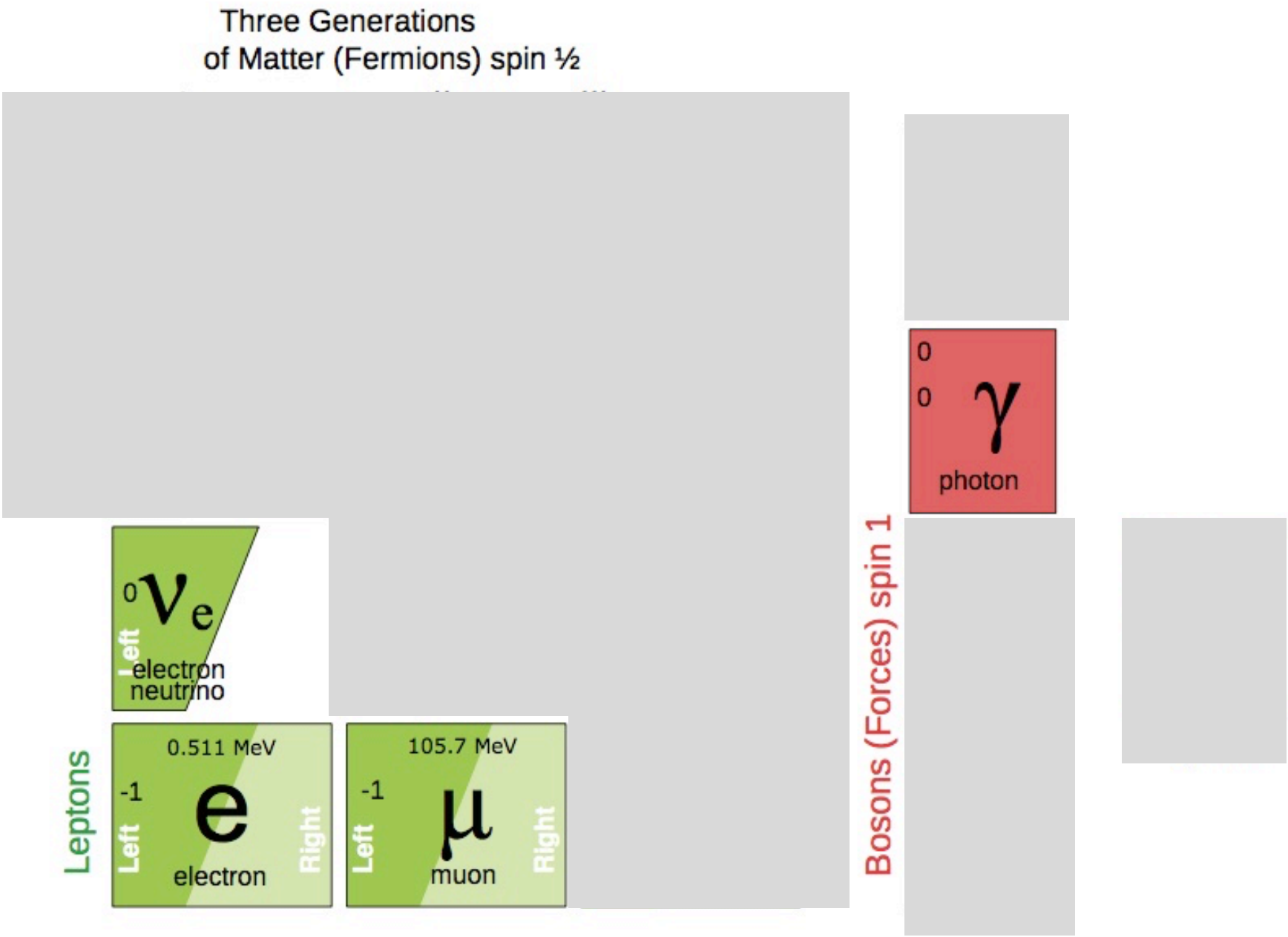
Leis de conservação:
Energia, Momento linear,
Momento Angular

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

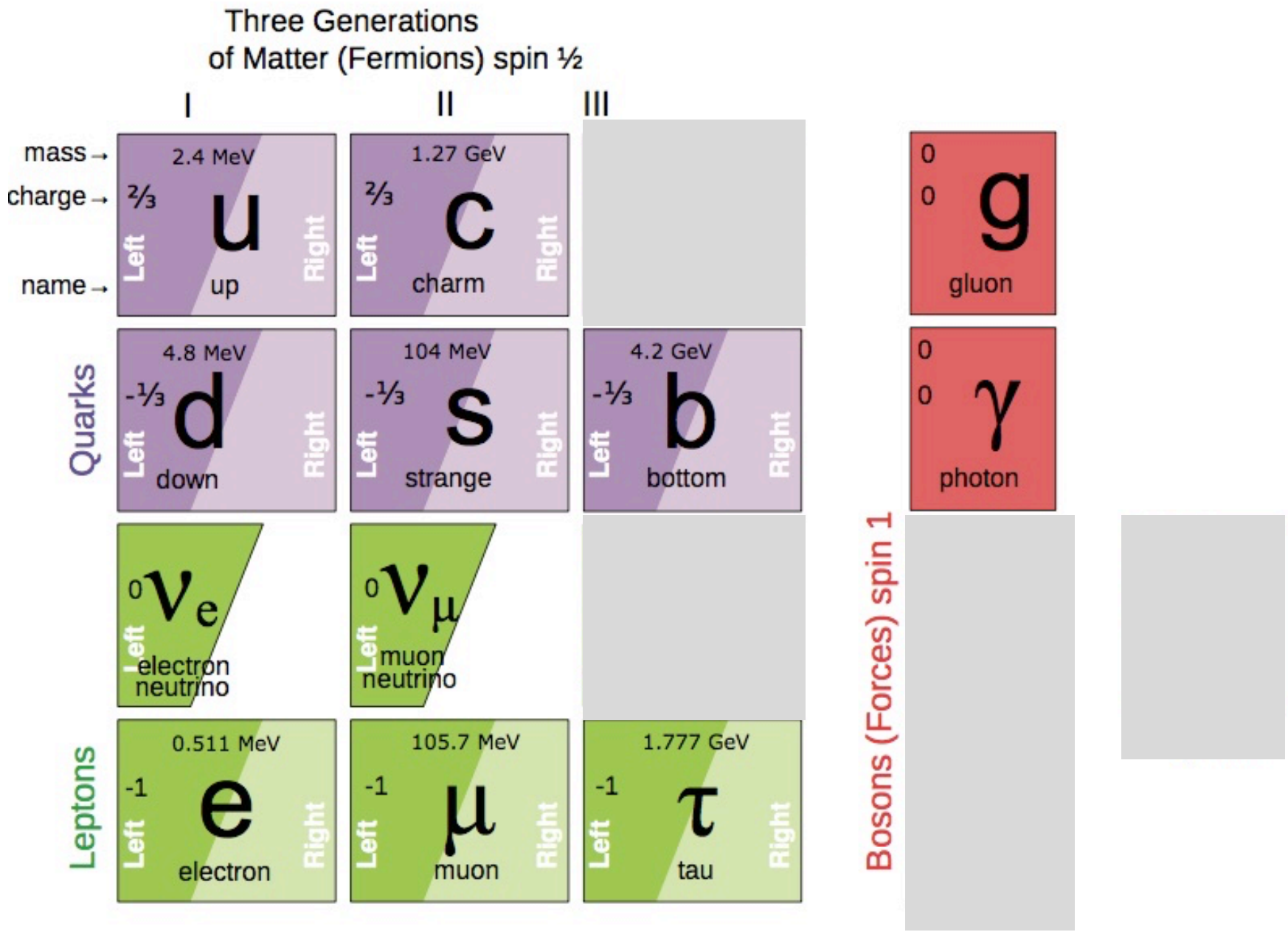
As partículas elementares hoje!



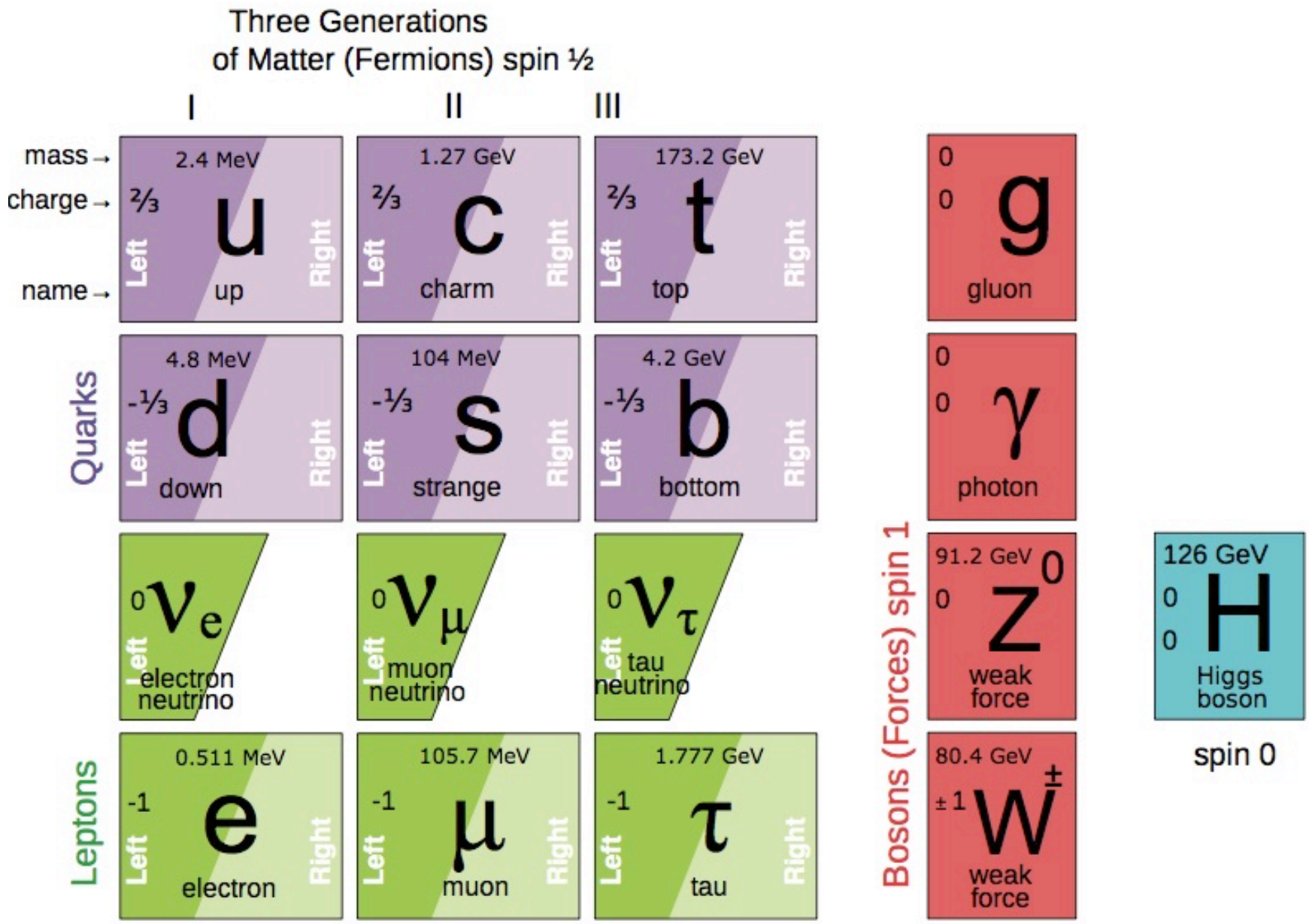
As partículas elementares em 1957



As partículas elementares em 1980

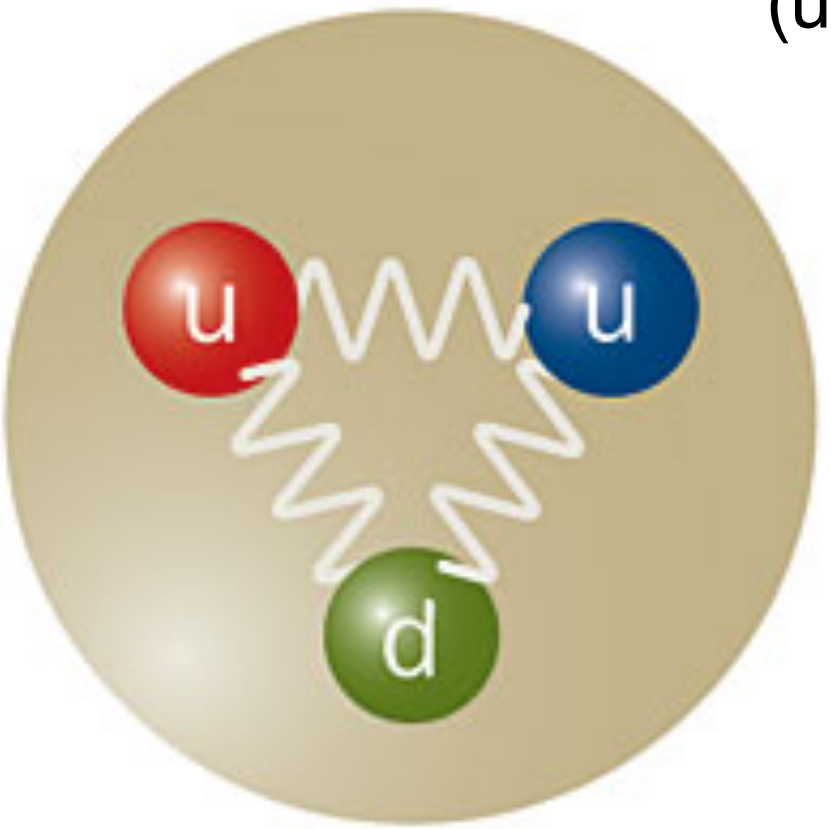


As partículas elementares hoje!



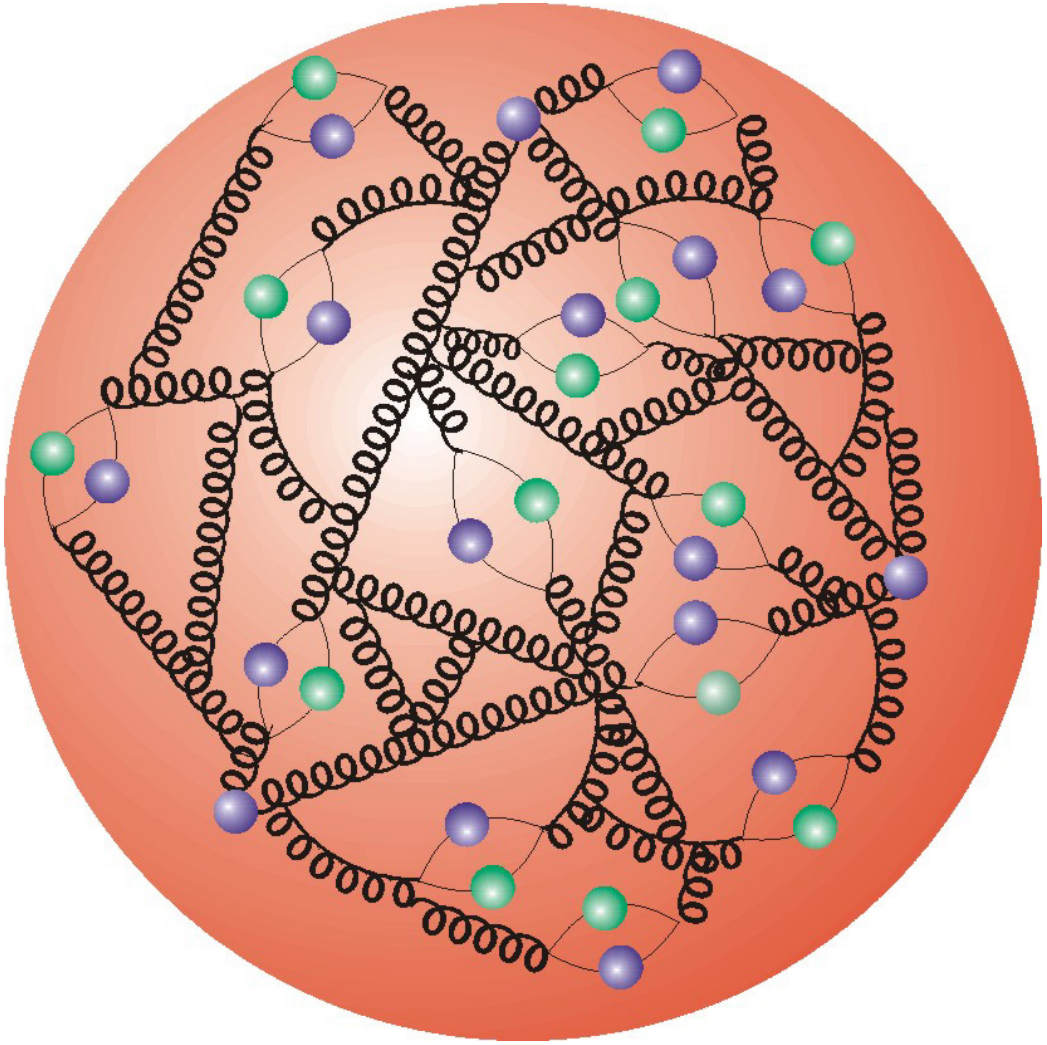
O Protão

(uud)



10^{-14} m

O Protão



A massa do Protão

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

A massa do Protão

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

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

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

As Partículas têm massa

em eV/c^2

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

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

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

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

…

$m_\gamma = 0$

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

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

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

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

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Como é que as massas são geradas ???

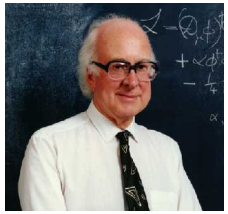
Por é que são tão diferentes ???

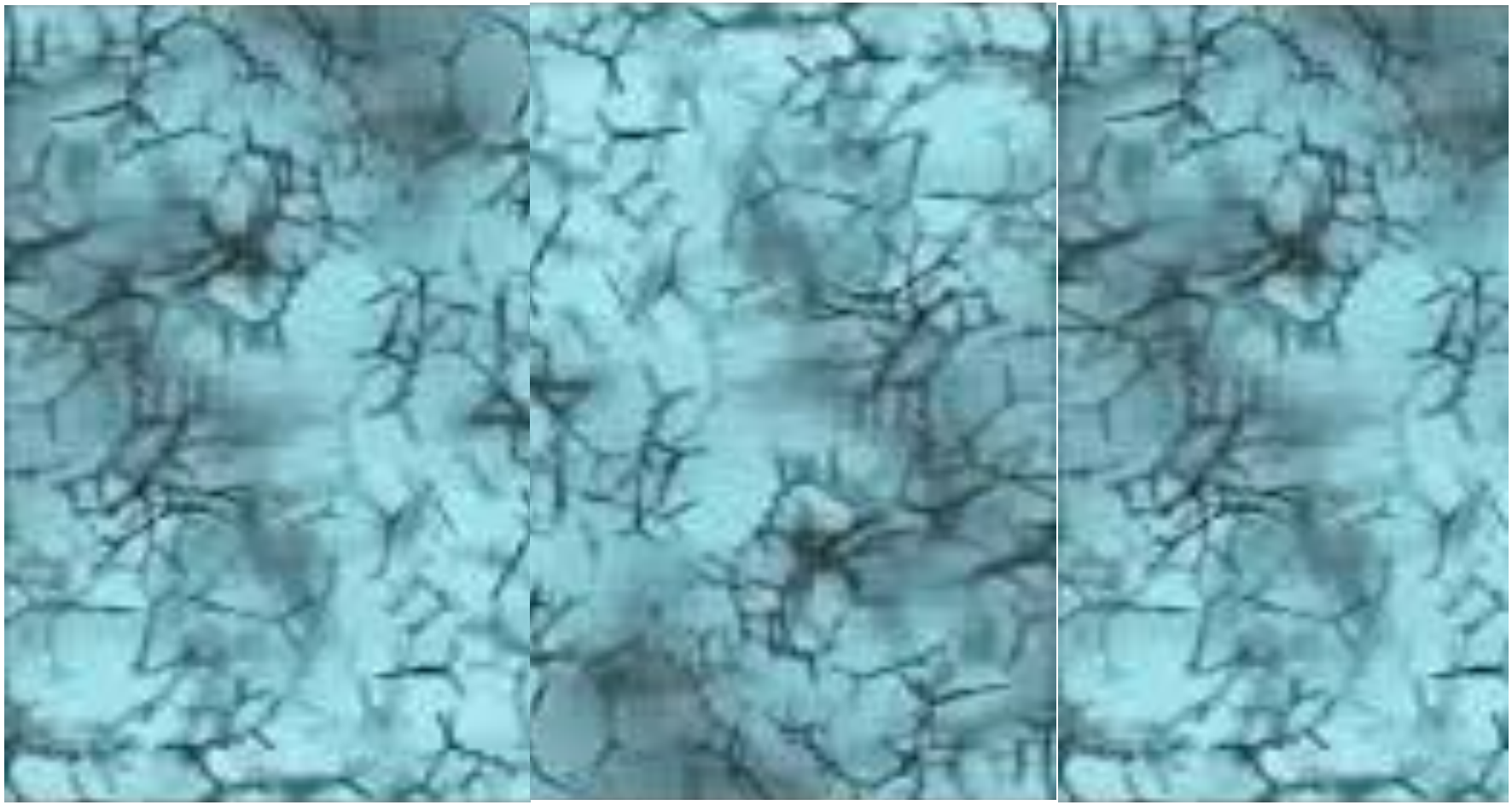
$1\ eV \sim 1.8\ 10^{-36} Kg$

O campo de Higgs

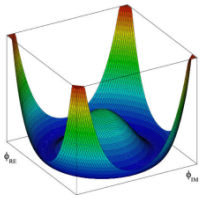
Higgs, Englert, Brout - 1964

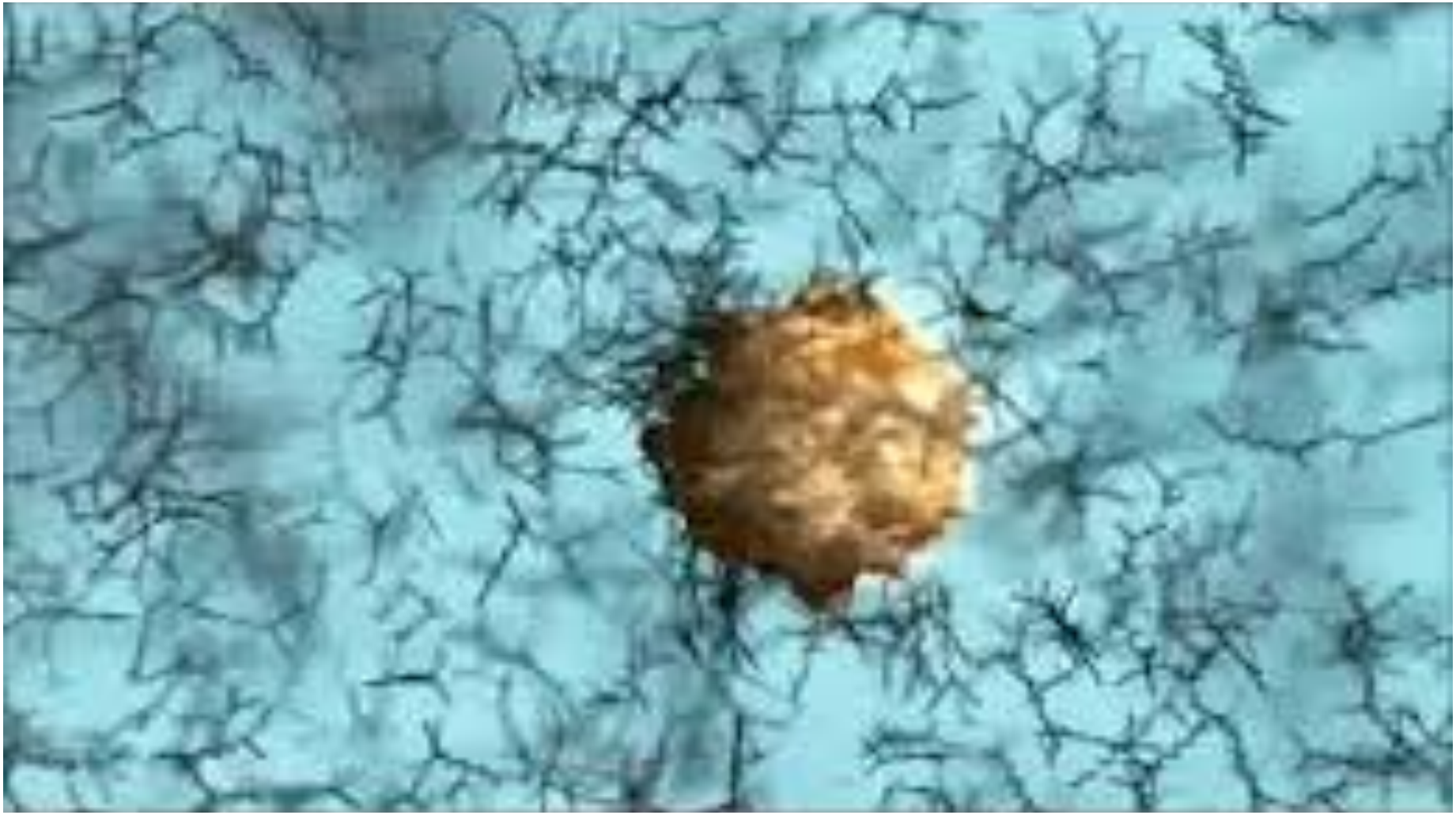
Peter Higgs





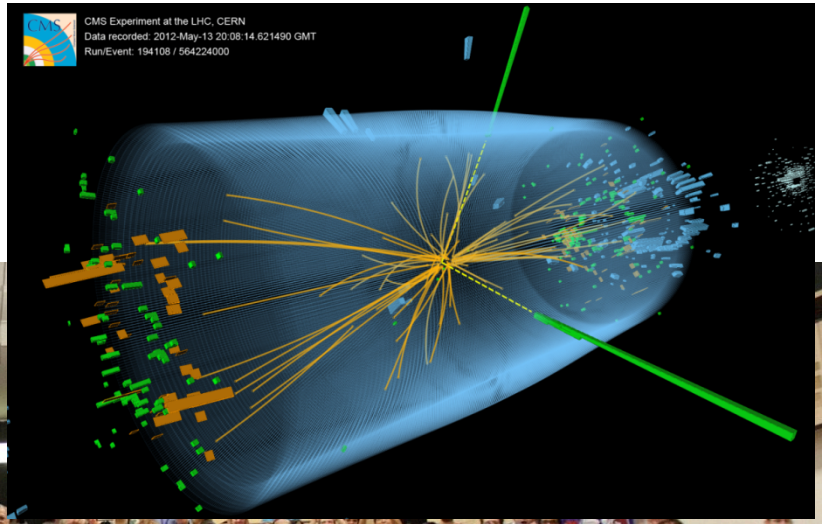
O mecanismo de Higgs





A massa é gerada na interacção com o campo

O bosão de Higgs



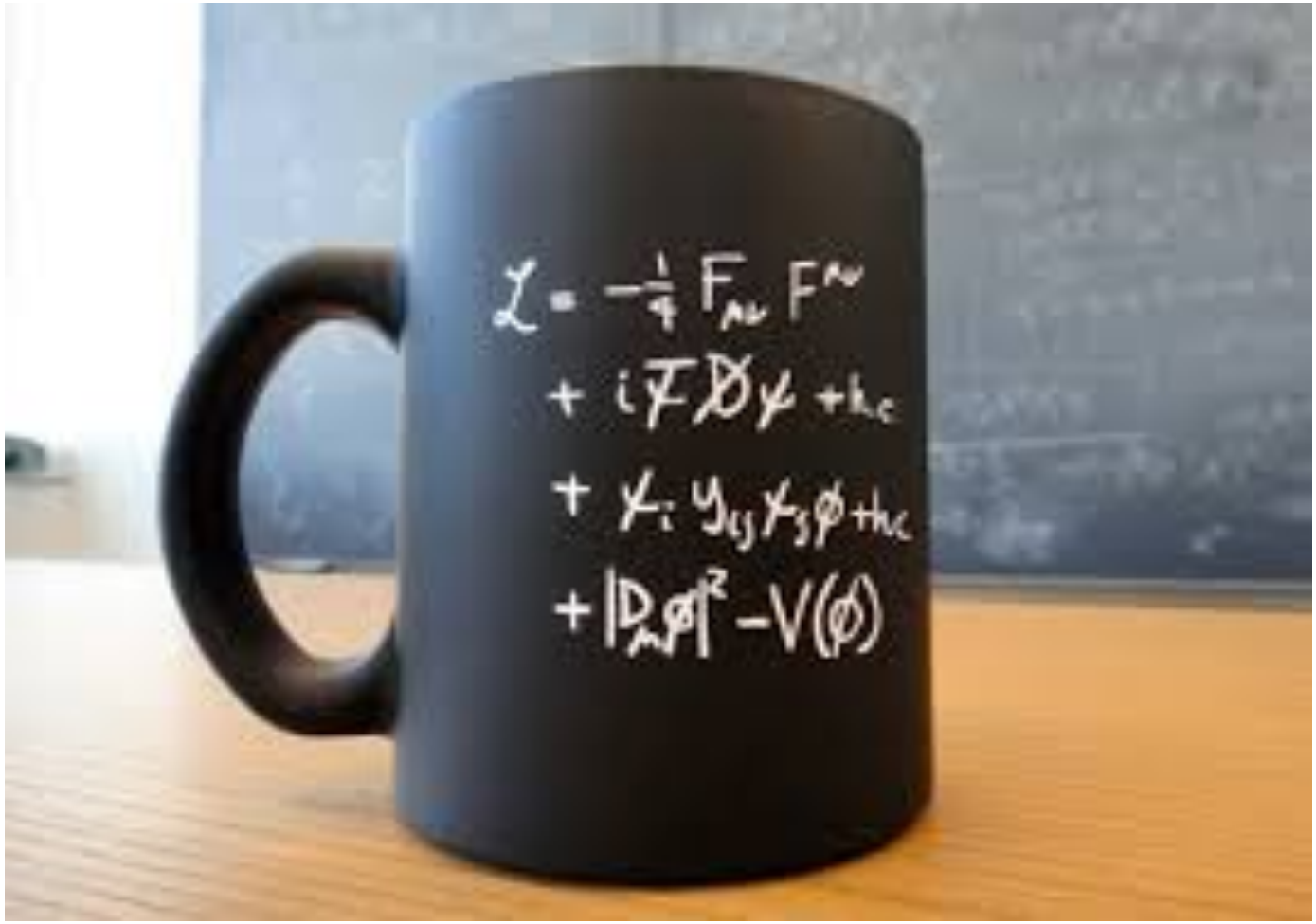
4 Julho 2012: CERN

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

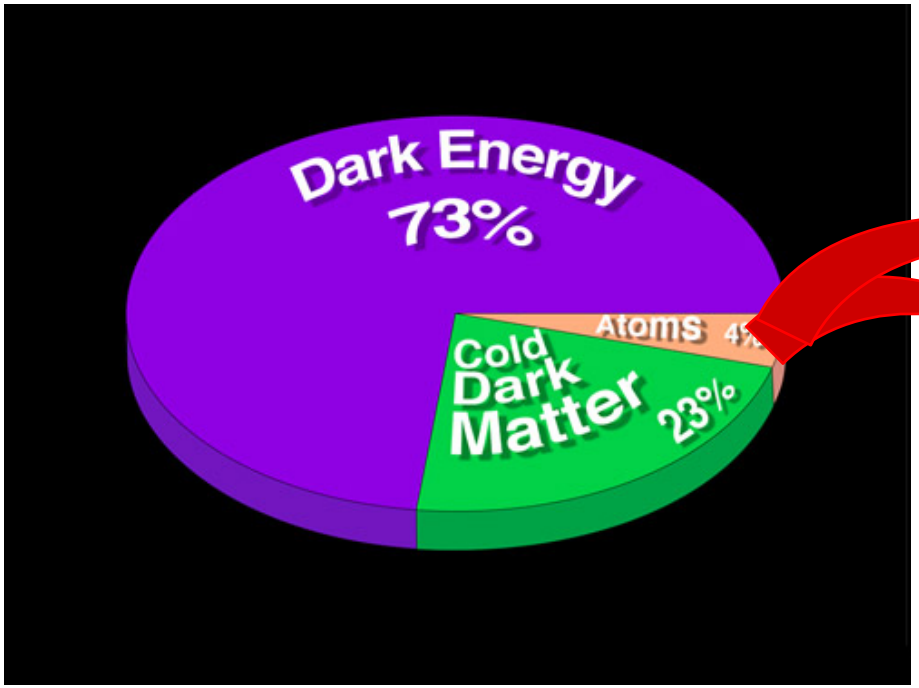
Glashow

Salam

Weinberg



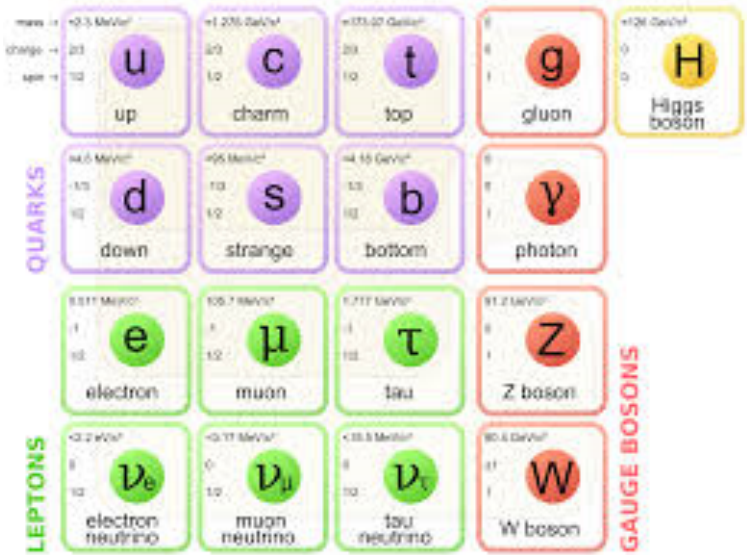
Fronteiras do nosso (des)conhecimento

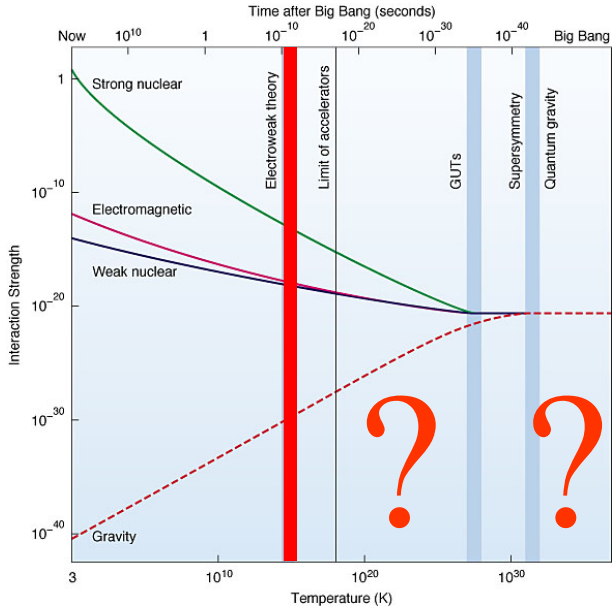


O modelo padrão

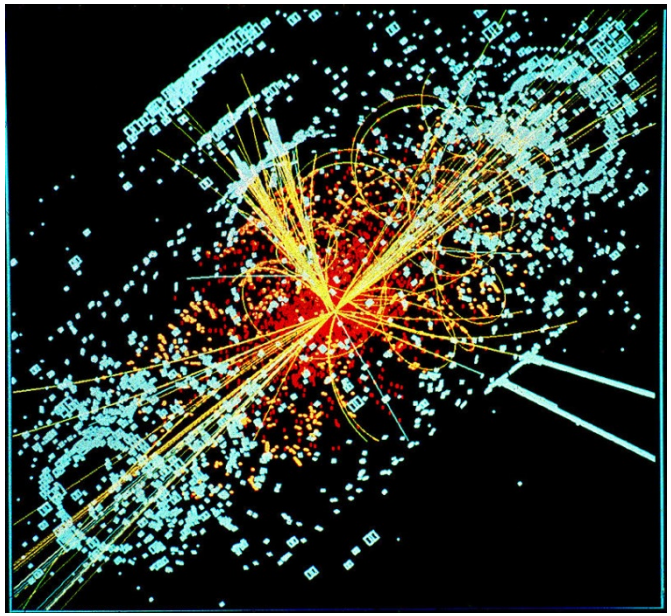
E_{CM} ~ 1 TeV

R ~ 10^{-18} m

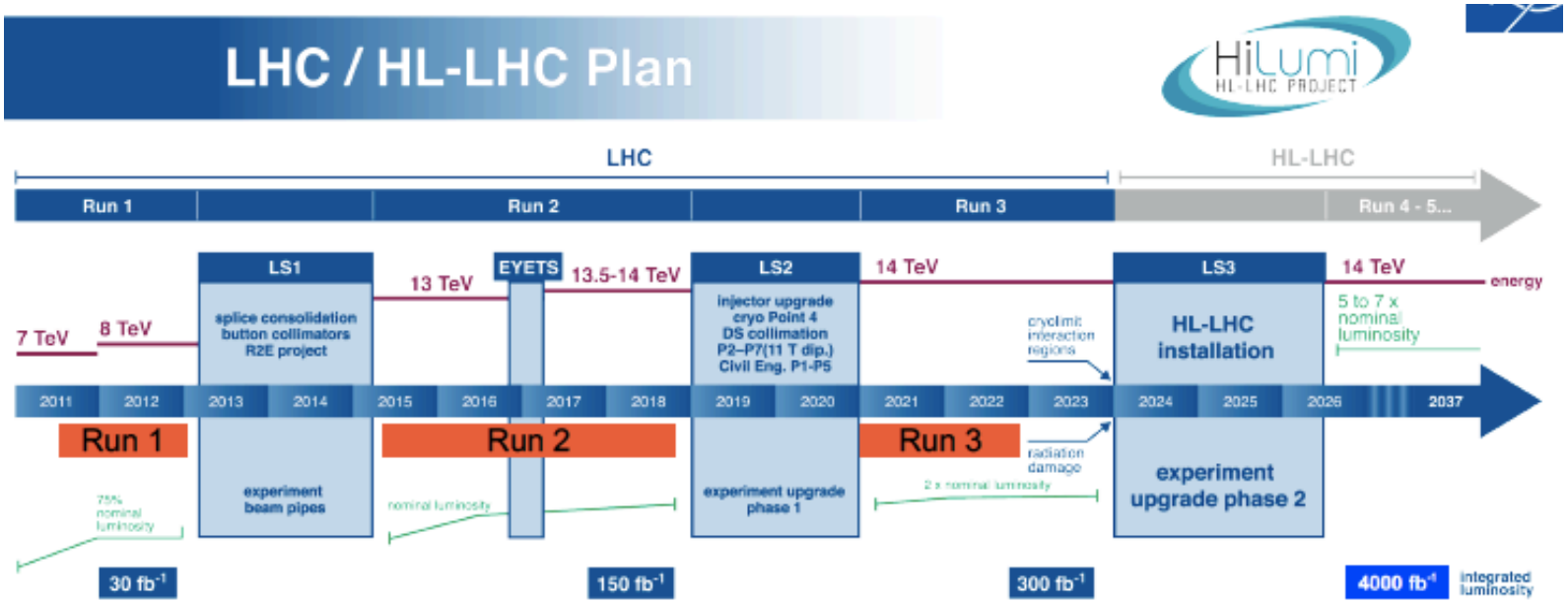


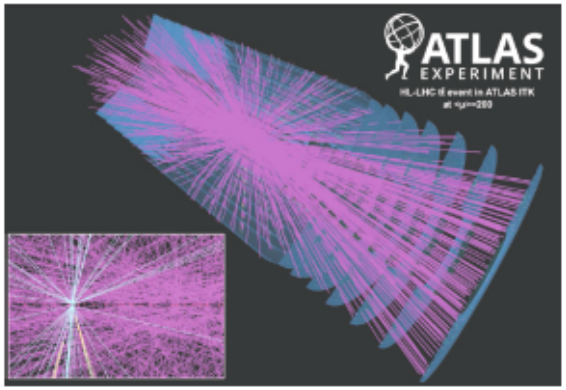


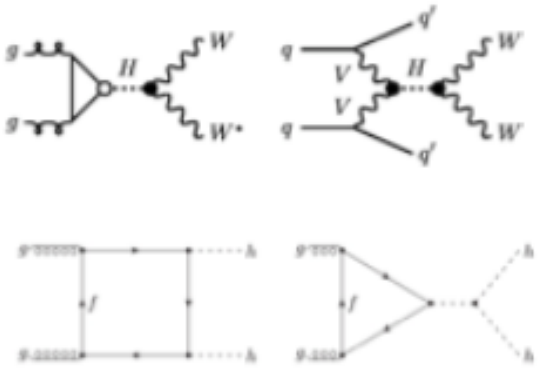
Olhar o Universo no sec. XXI

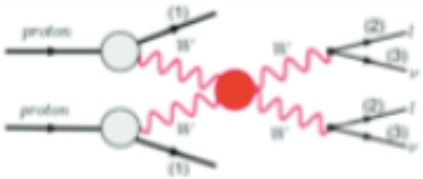


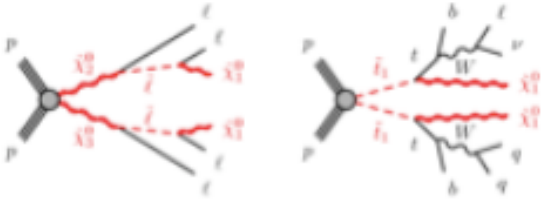
LHC alta Luminosidade



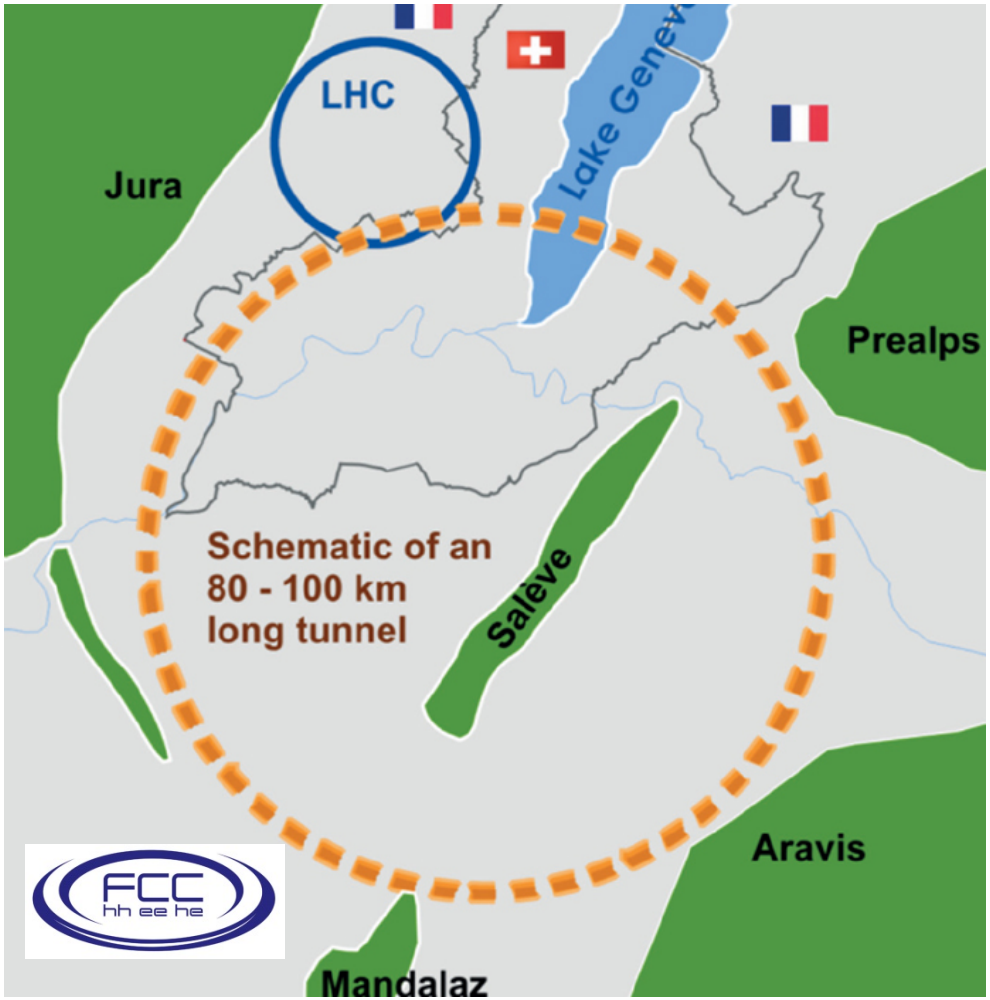








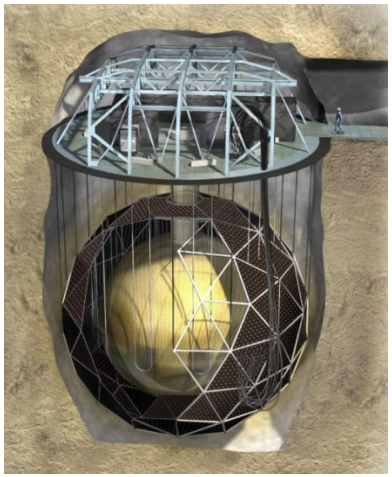
Depois do LHC ?



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

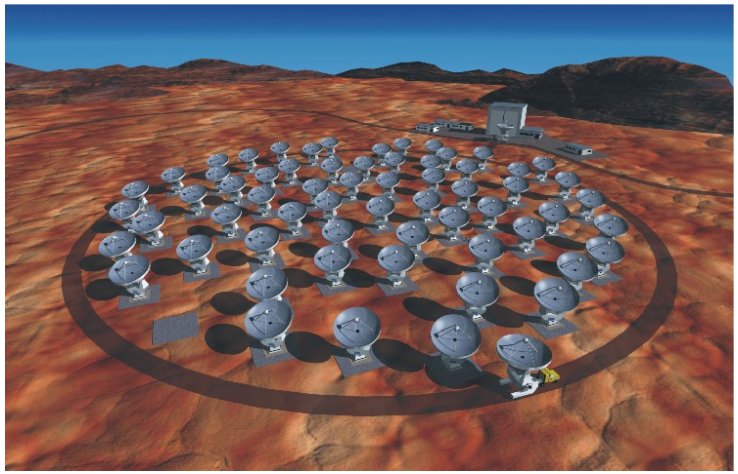
>> 2035 !!!

Das profundezas da Terra aos Céus …

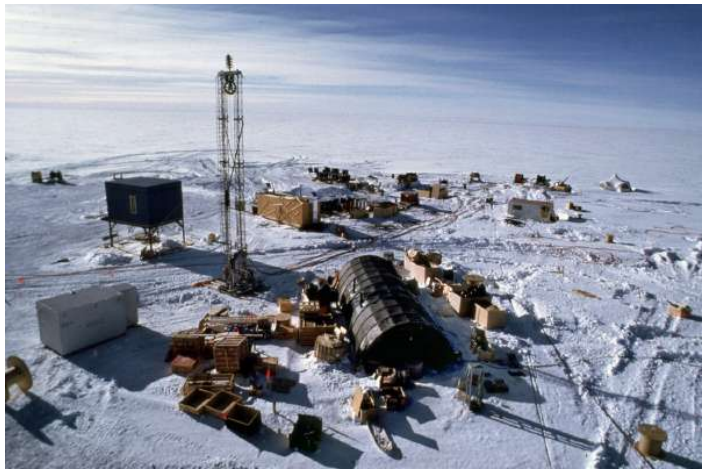


SNO/SNO^{+}

LIGO

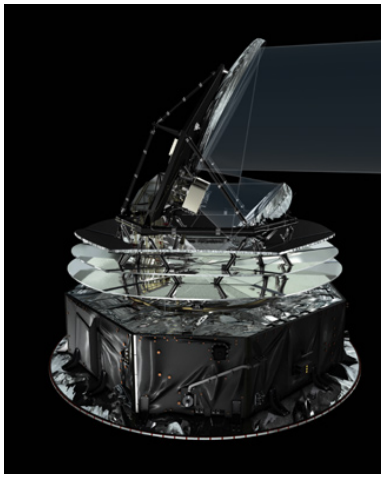


ALMA



Amanda / Ice Cube

MAGIC 2

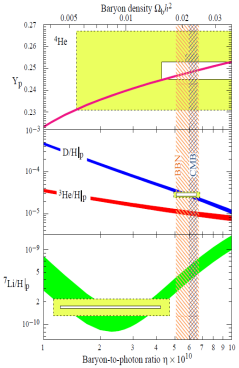


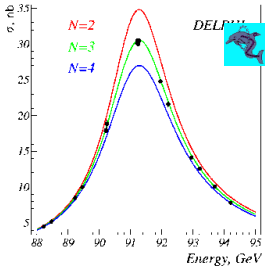
Planck

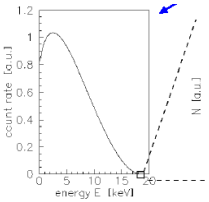
E muitos mais! – DUNE, SK, T2K, CDMS, CTA, Virgo, LISA, SNAP, SKA, …

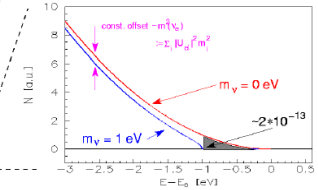
Neutrinos

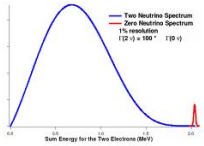
BBN

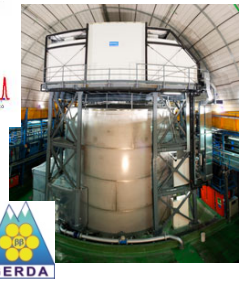


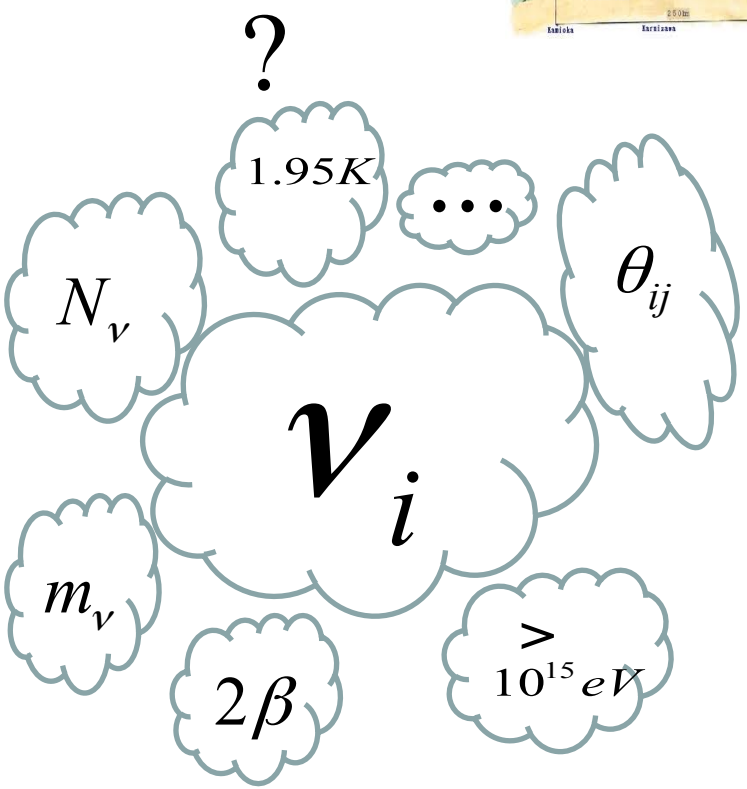




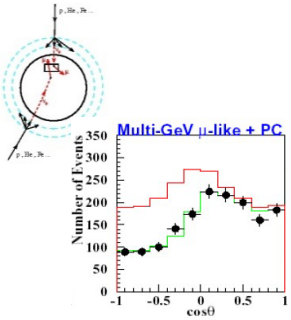


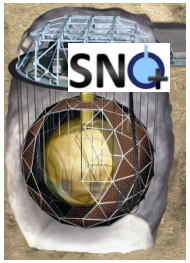




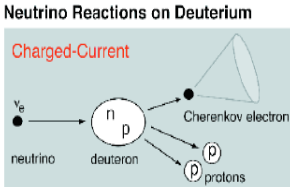


θ_{23}

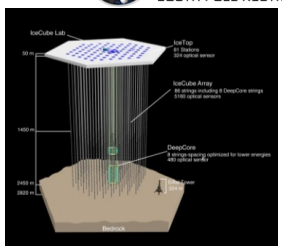


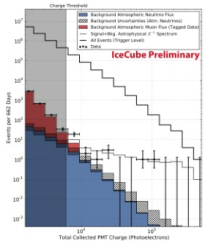


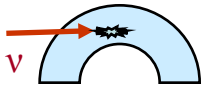
1/3 !

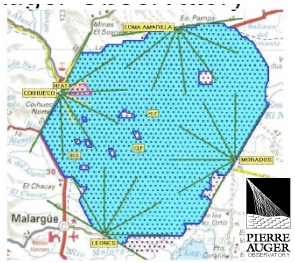


θ_{12}

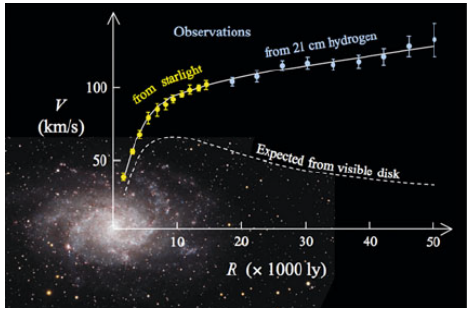


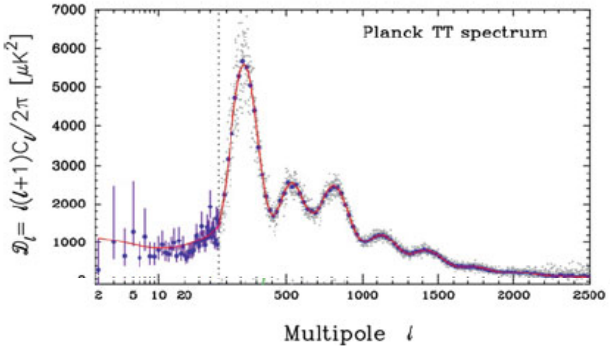


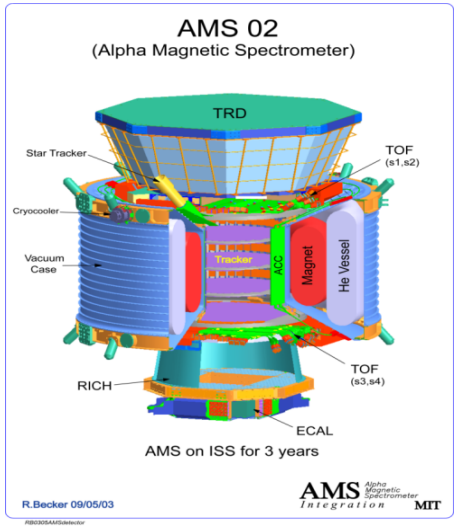


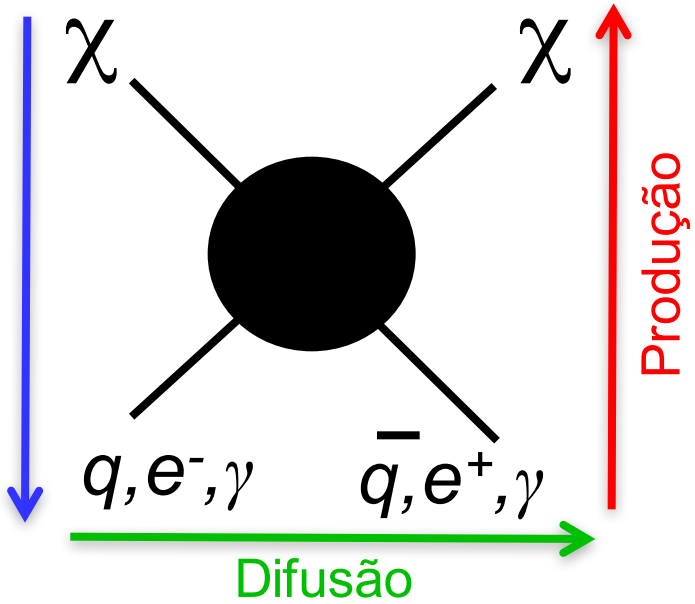


Matéria Escura



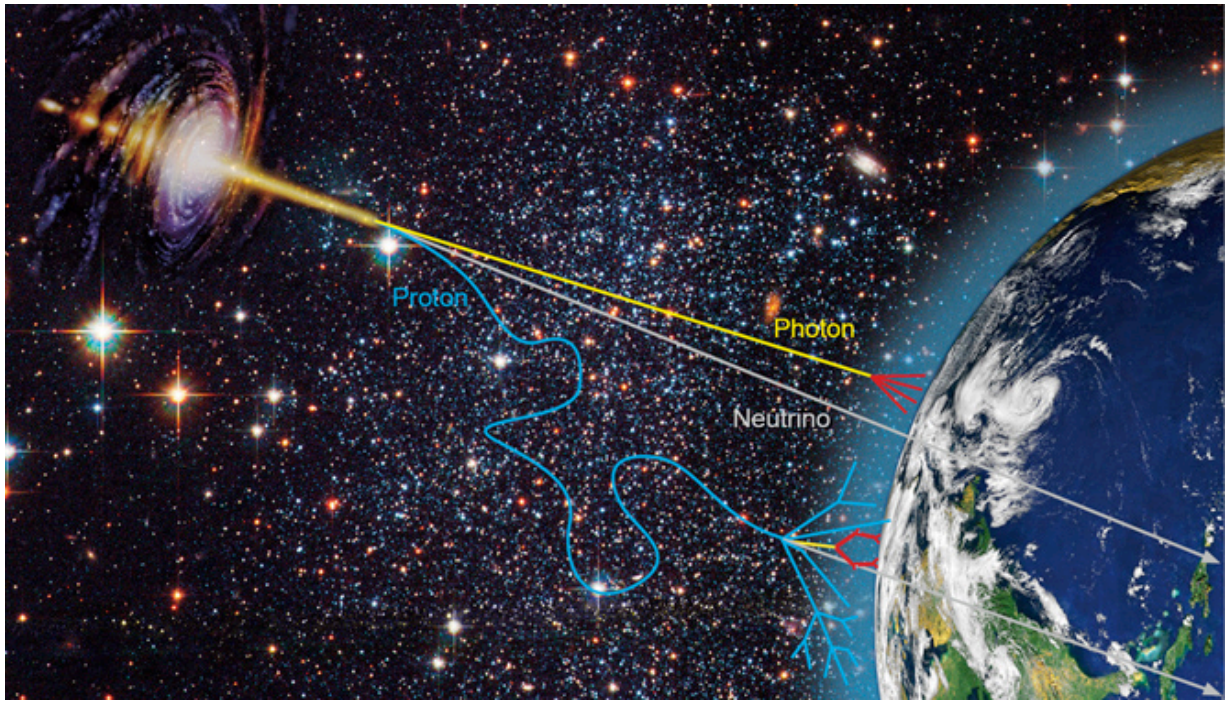




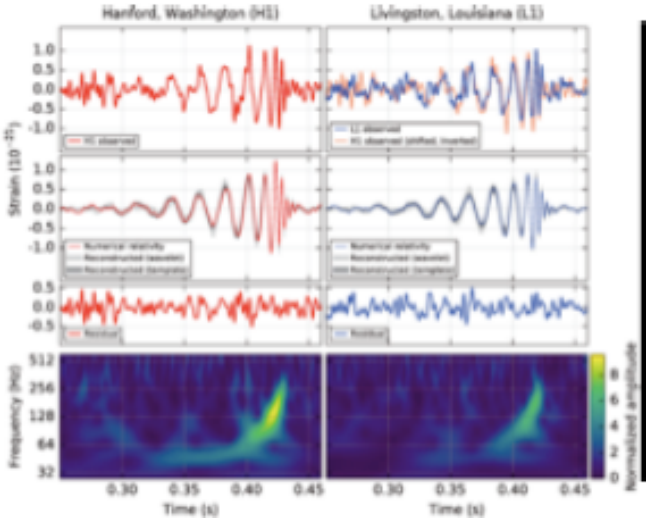


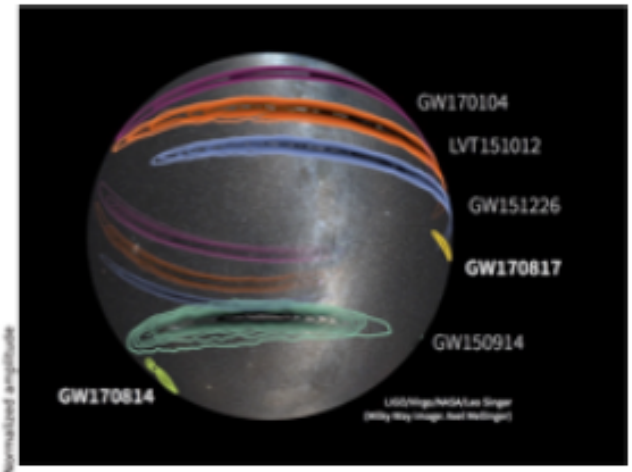
Mensageiros do Universo

γ, p, nuclei, ν

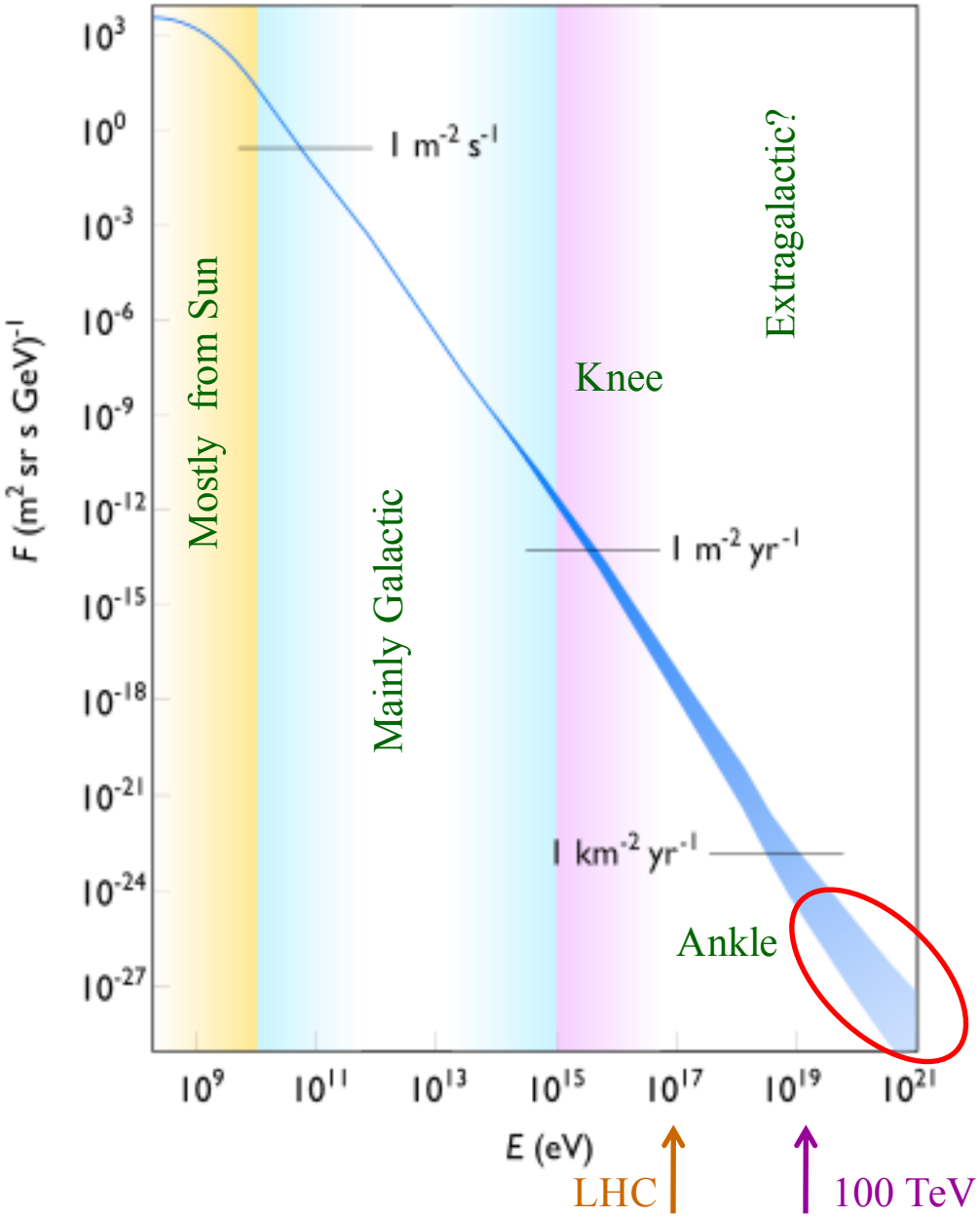


GW

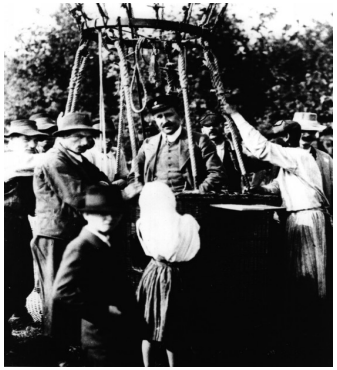


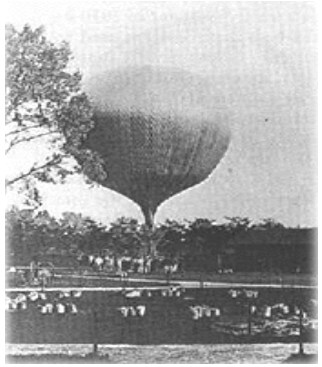


Charged cosmic rays (p/nucleus)



Viktor Hess, 1912



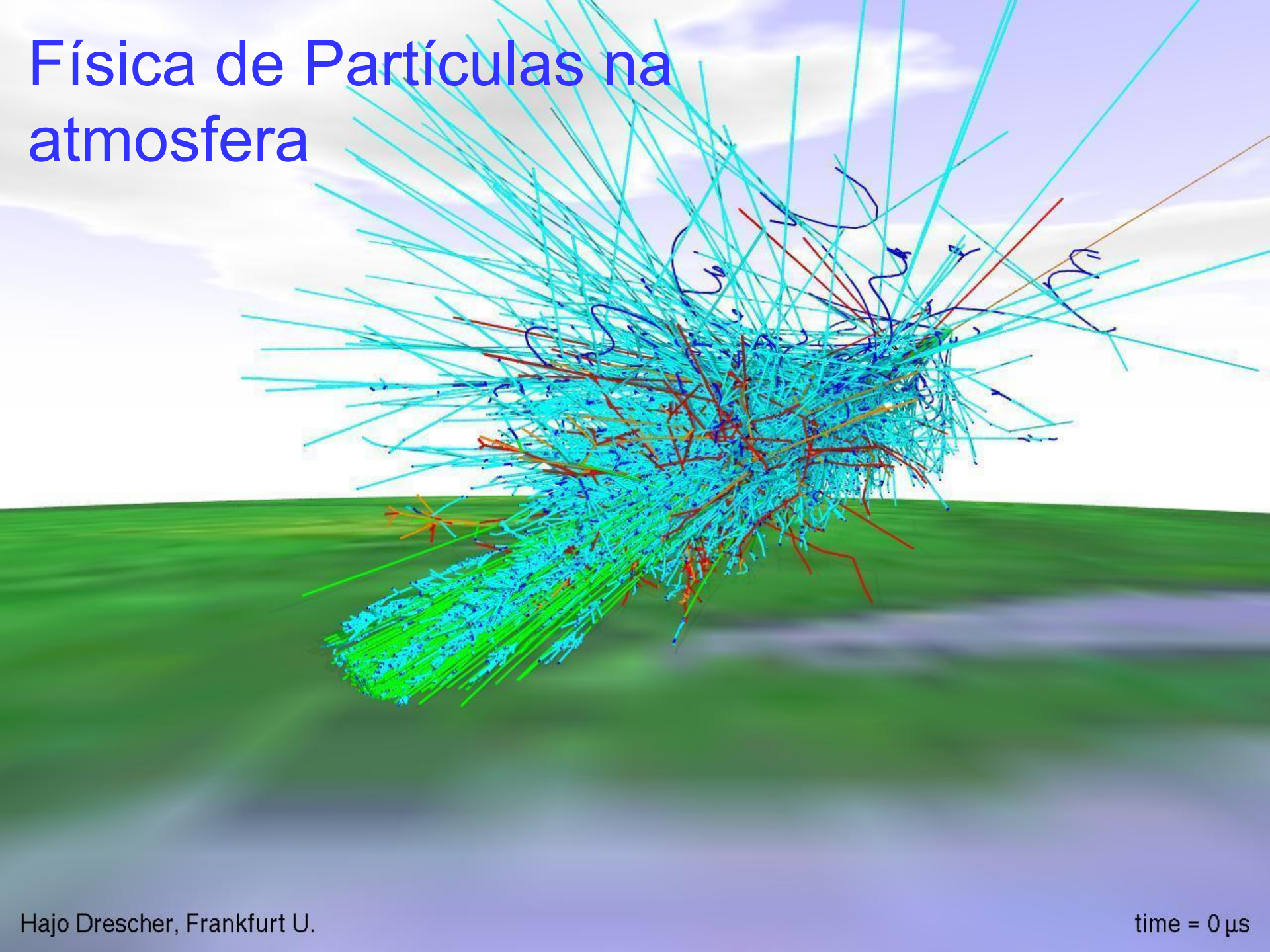


$$\frac{dN}{dE} \propto E^{-\alpha}$$

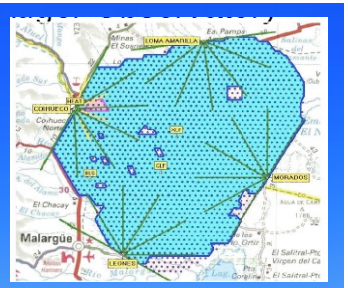
$$\alpha = \begin{cases} 2.7 & E < 10^{16} \\ 3.0 & 10^{16} < E < 10^{18} \\ 2.7? & E > 10^{18} \end{cases}$$

Um LHC do tamanho da órbita de Mercúrio !!!

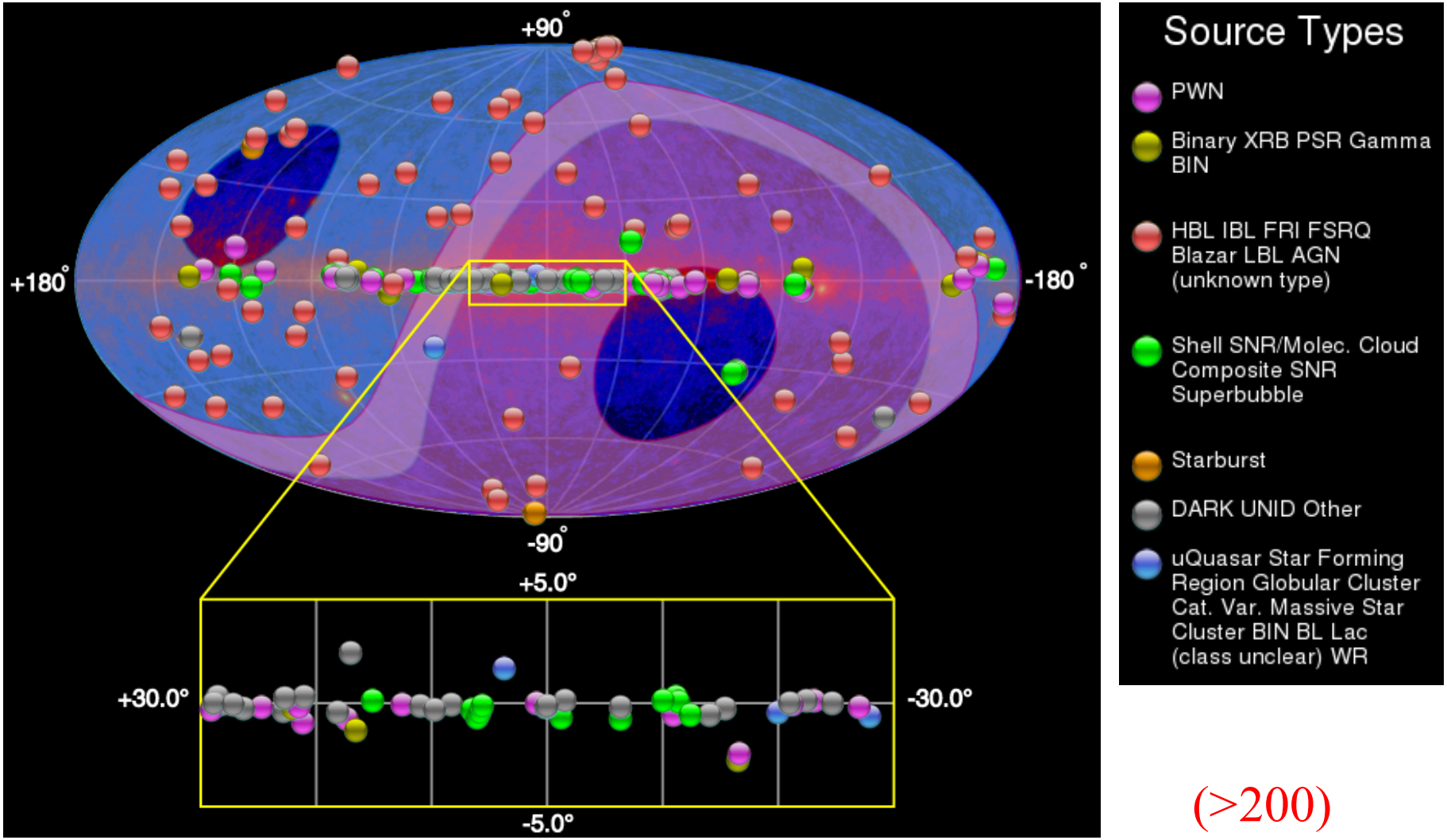
Física de Partículas na atmosfera



Na pampa argentina

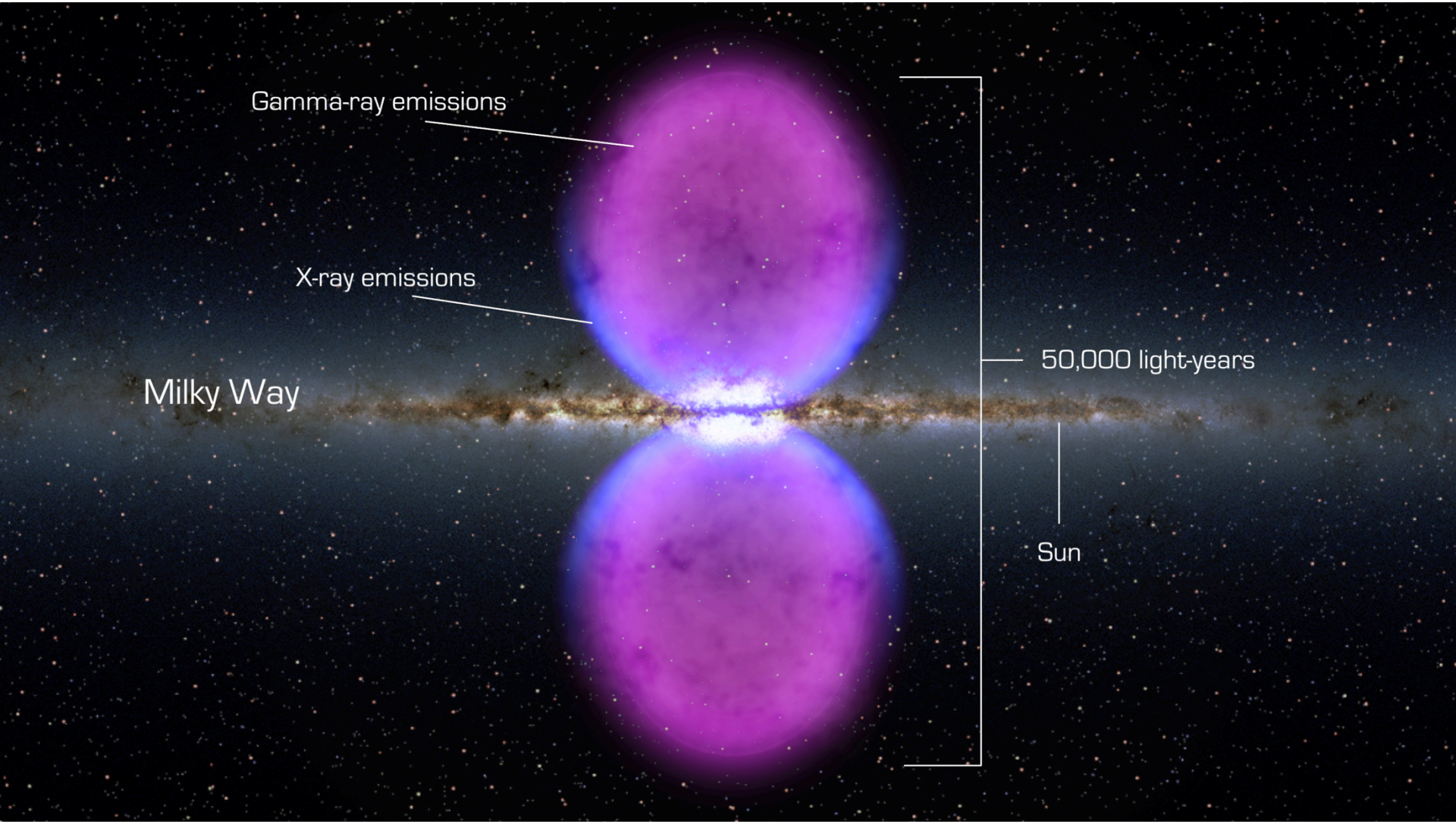


Fontes raios gamma de alta energia (TeV)



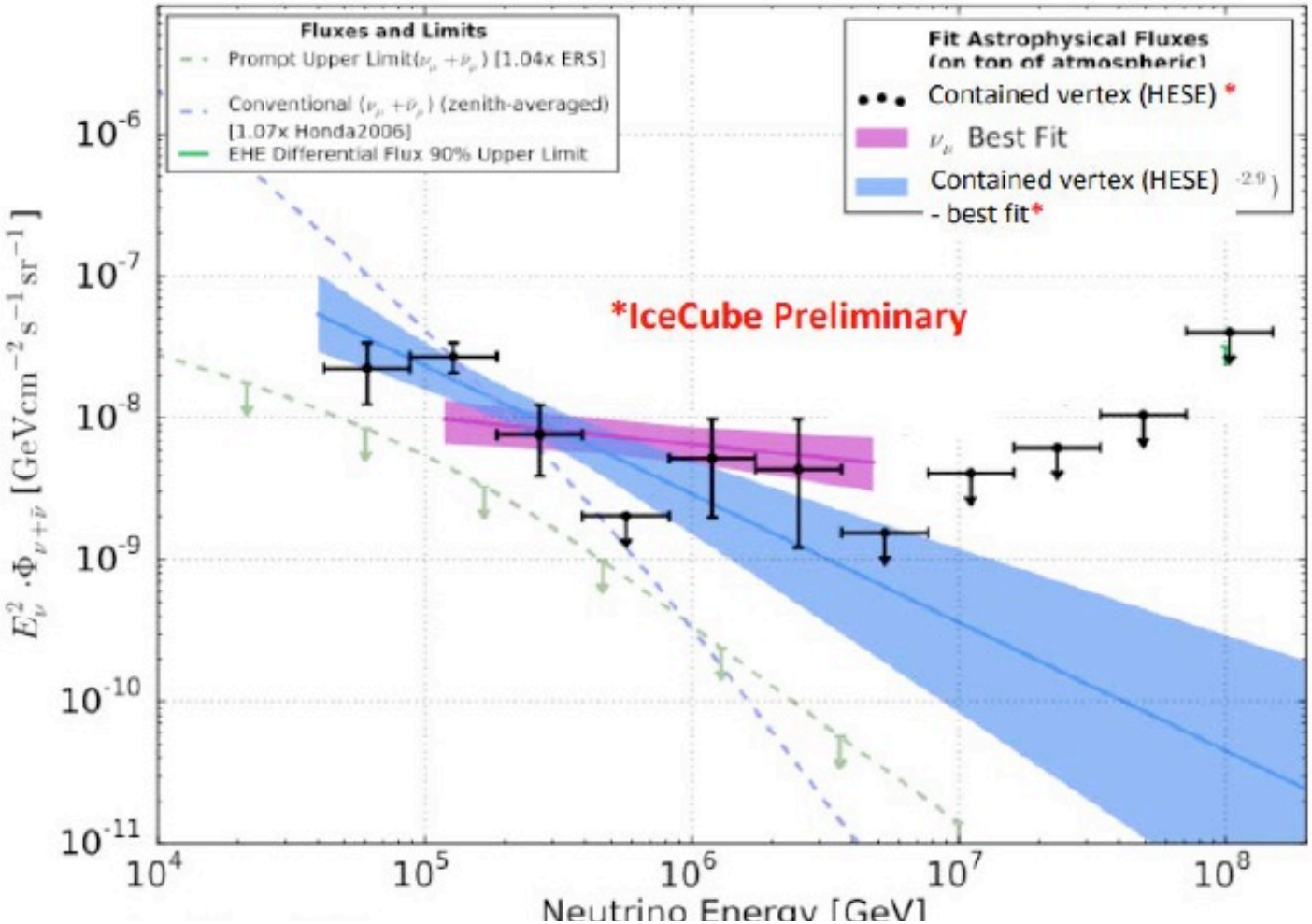
(>200)

As bolhas de Fermi

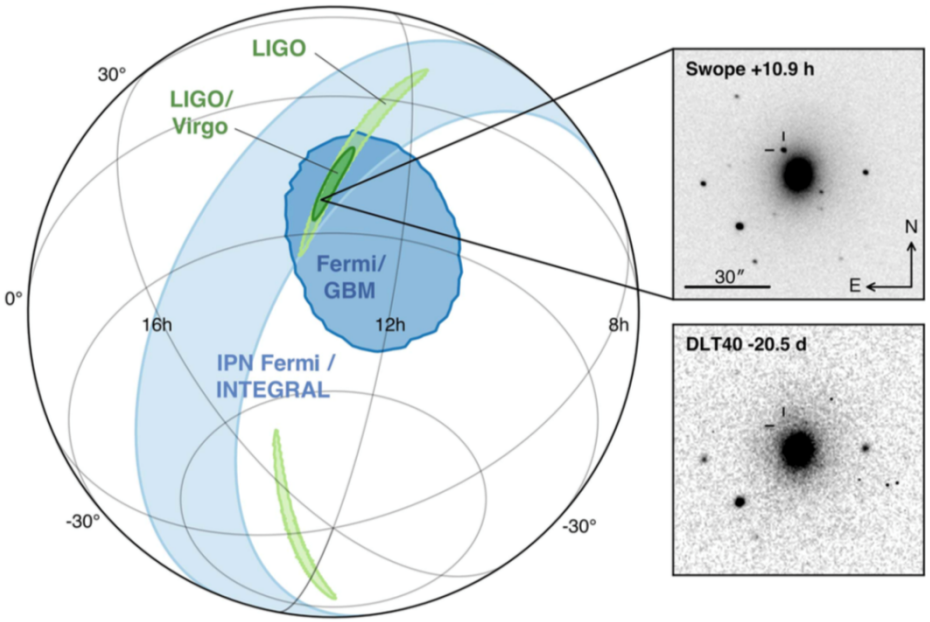


Neutrinos astrofísicos de energia elevada

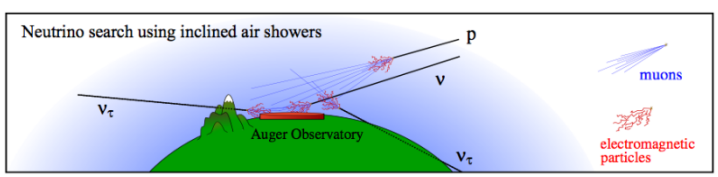
Ice Cube

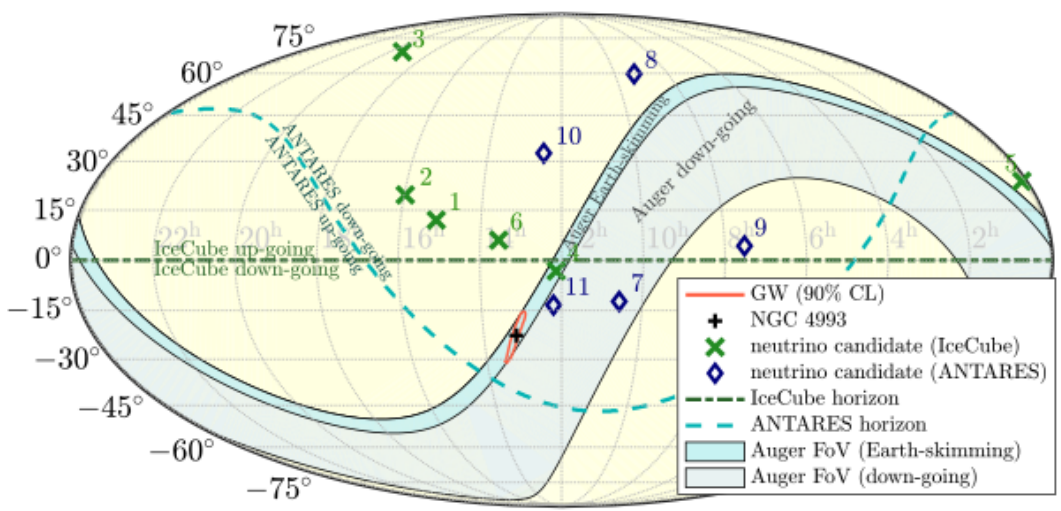


GW170817



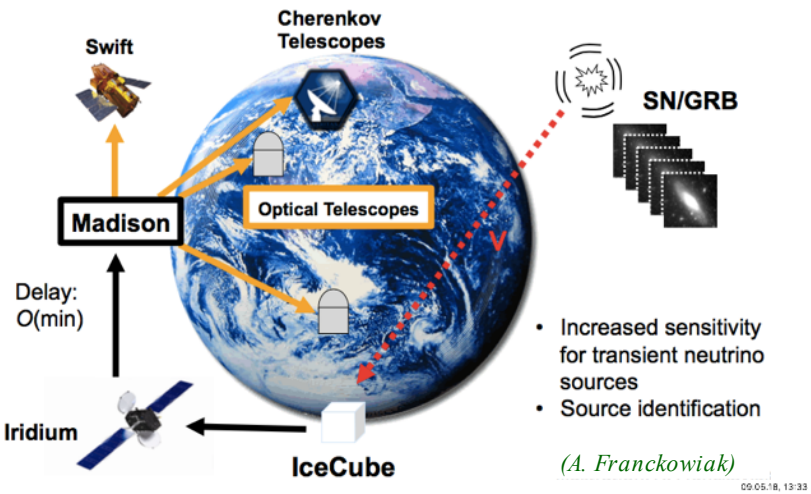
A primeira observação "multimessenger" da fusão de duas estrelas de neutrões





First source of astrophysical neutrinos at high energy

Conferência de imprensa quinta 12/7 !!!

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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.
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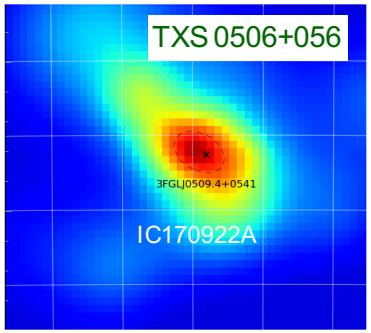
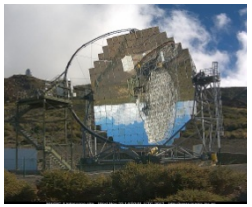
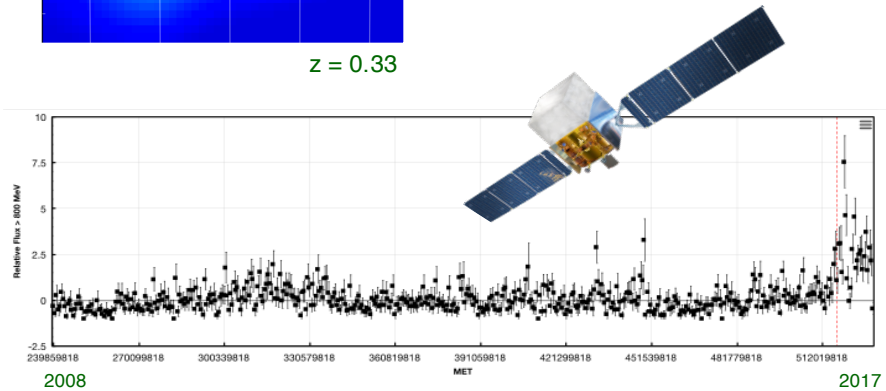


z = 0.33



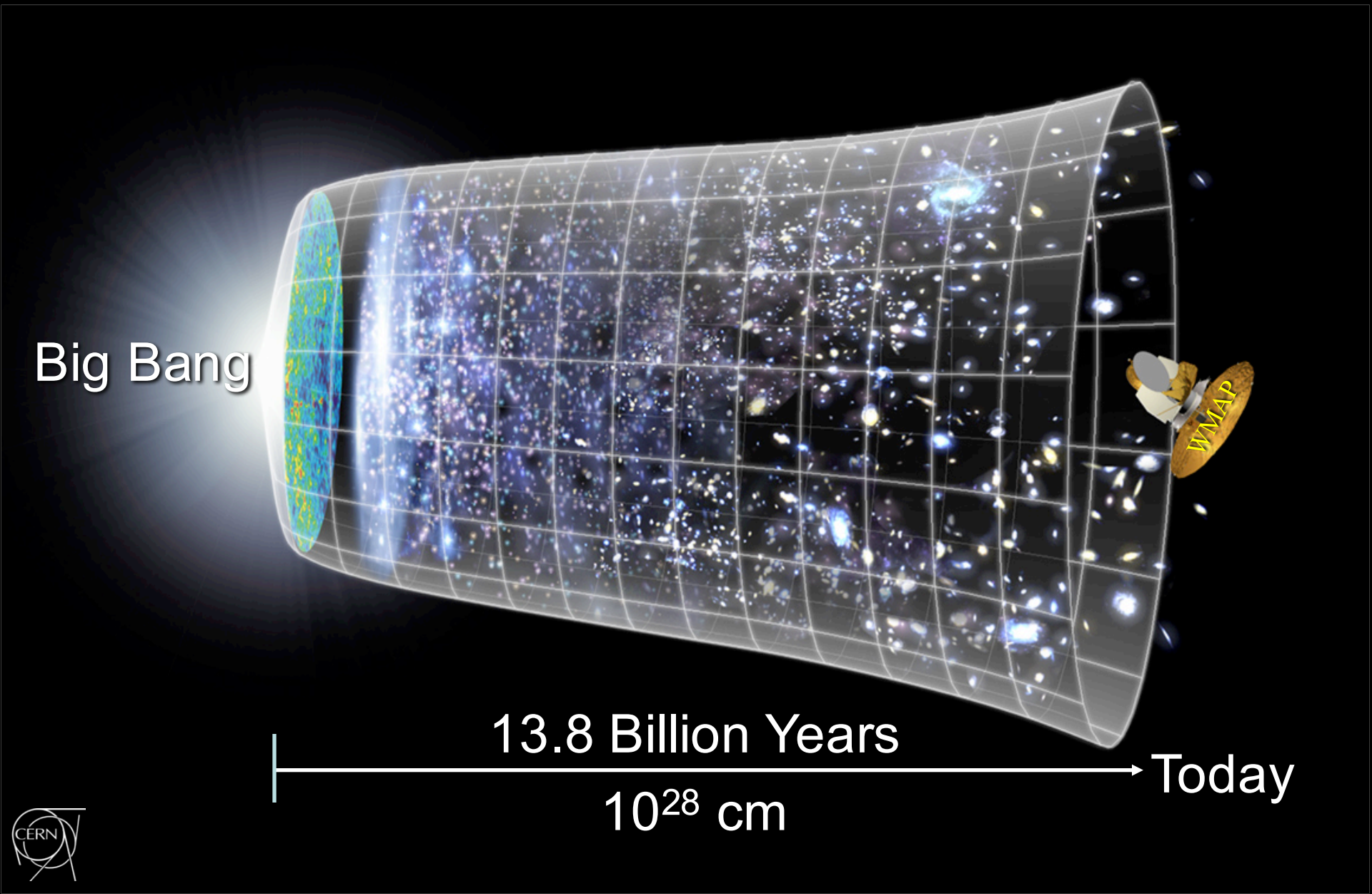
MAGIC: flare E > 100 GeV



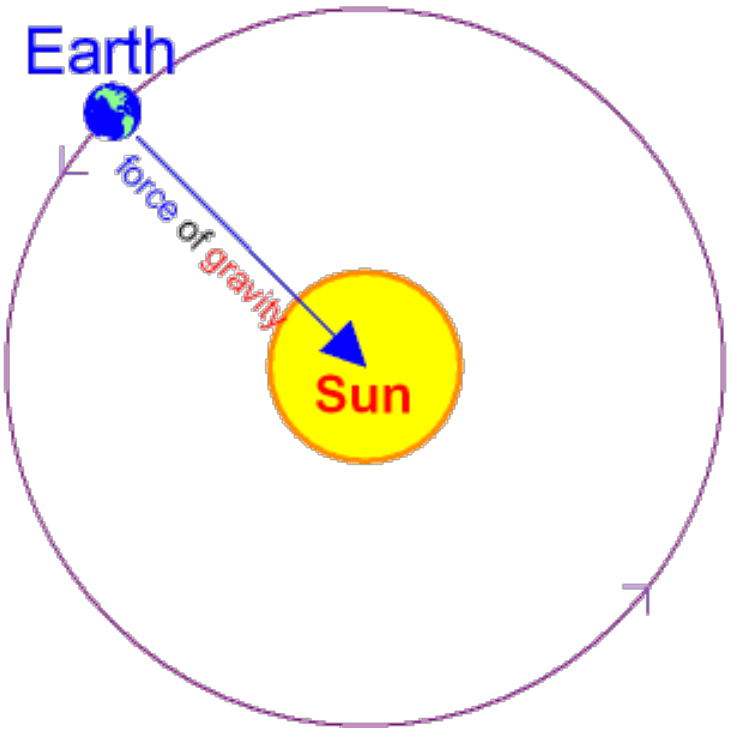
FERMI: flare (found 6 days later)

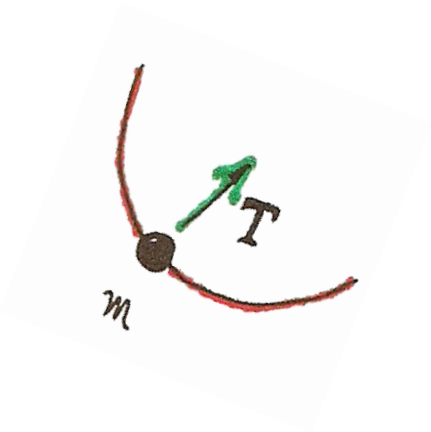
IceCube 1709922A, publications in preparation

O Universo para compreender, ...



A massa do Sol



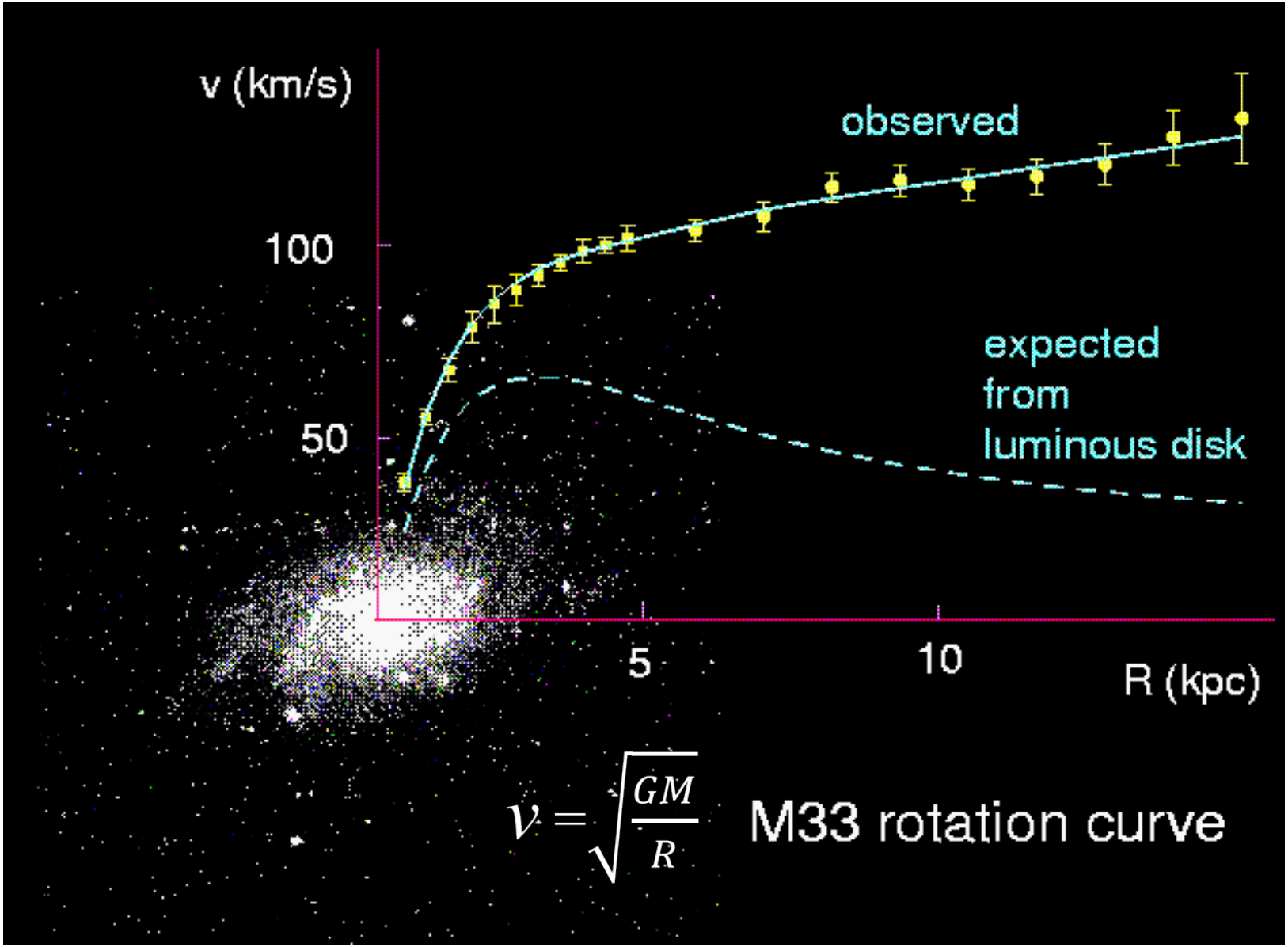


$$F_c = \frac{m\ v^2}{r}$$

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

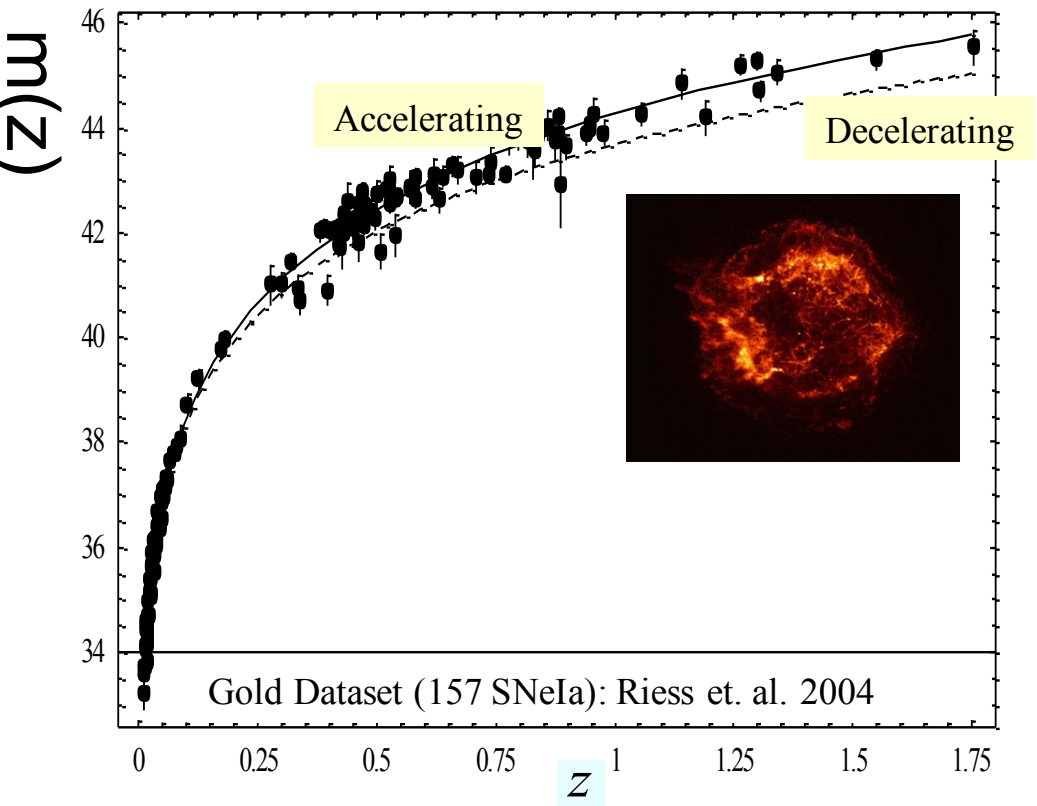
$$M_S \sim 1.98\ 10^{30}\ kg$$

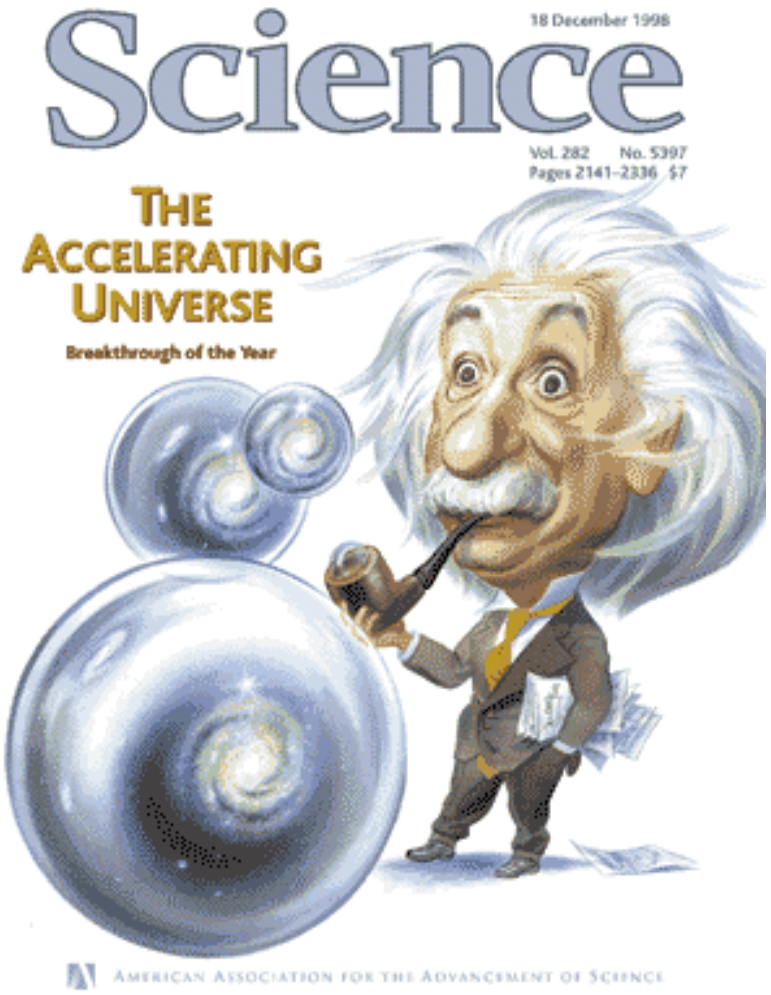
A velocidade de rotação das estrelas periféricas



A energia escura !

Diagrama de Huble

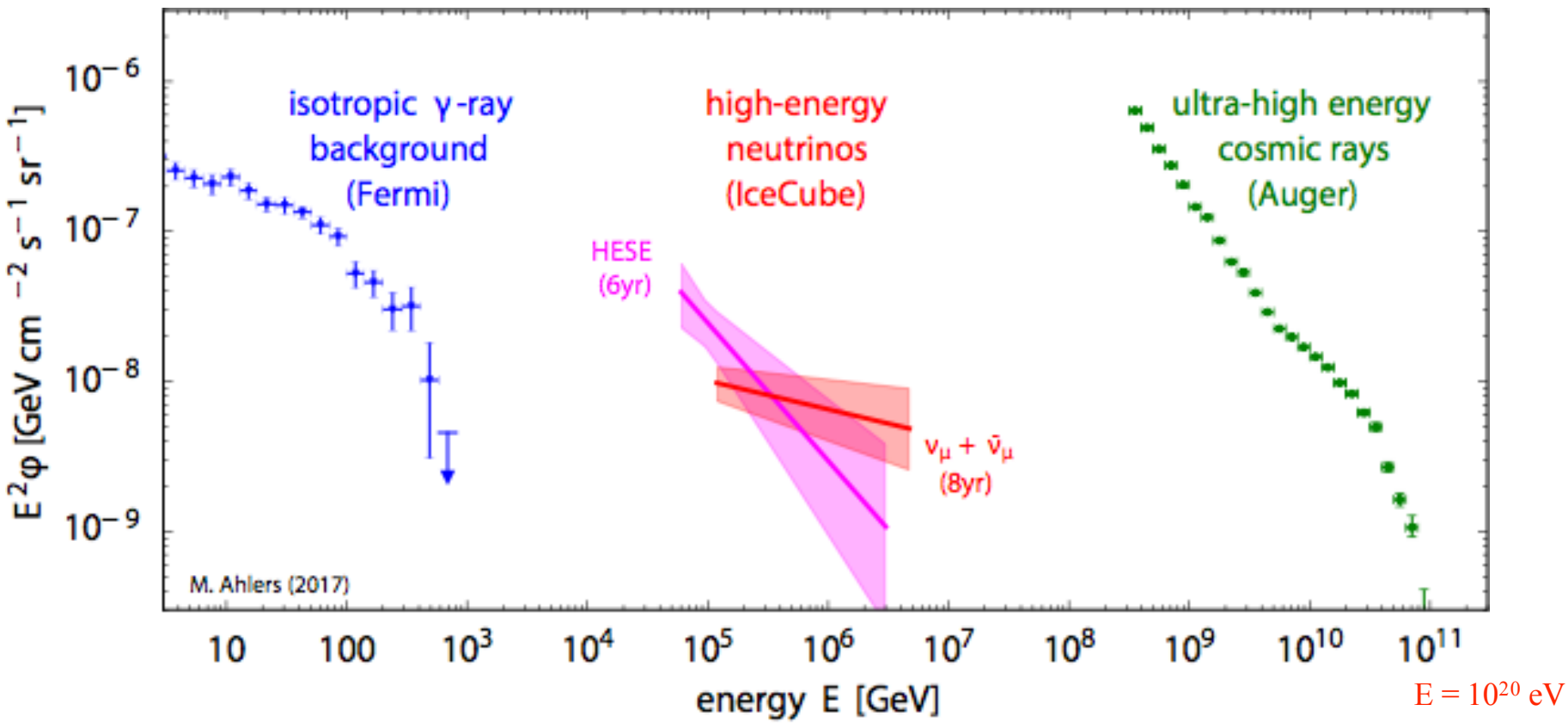




O Universo encontra-se numa expansão acelerada !!!

Energia escura – anti-gravítica

The Universe at the highest energies !



Energy density per decade similar in all three messenger particles