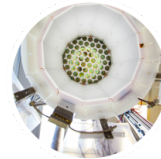


# Bem vindos (remotamente ...) ao LIP !



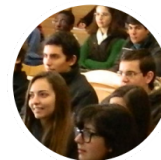
**Experimental particle and  
astroparticle physics**



**Development of new  
instruments and methods**



**Scientific computing**



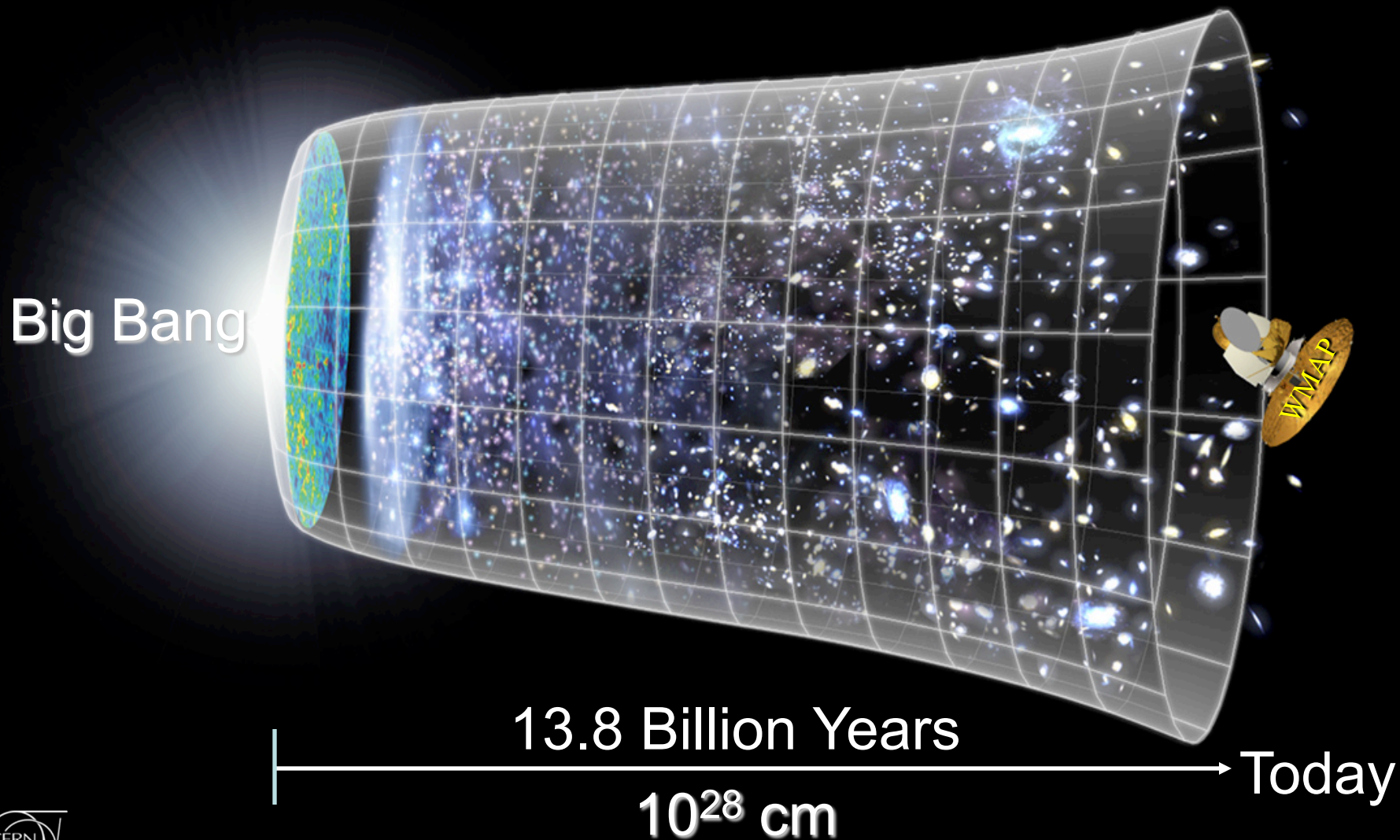
**Knowledge transfer,  
education and outreach**

# A aventura da Física de Partículas e Astropartículas

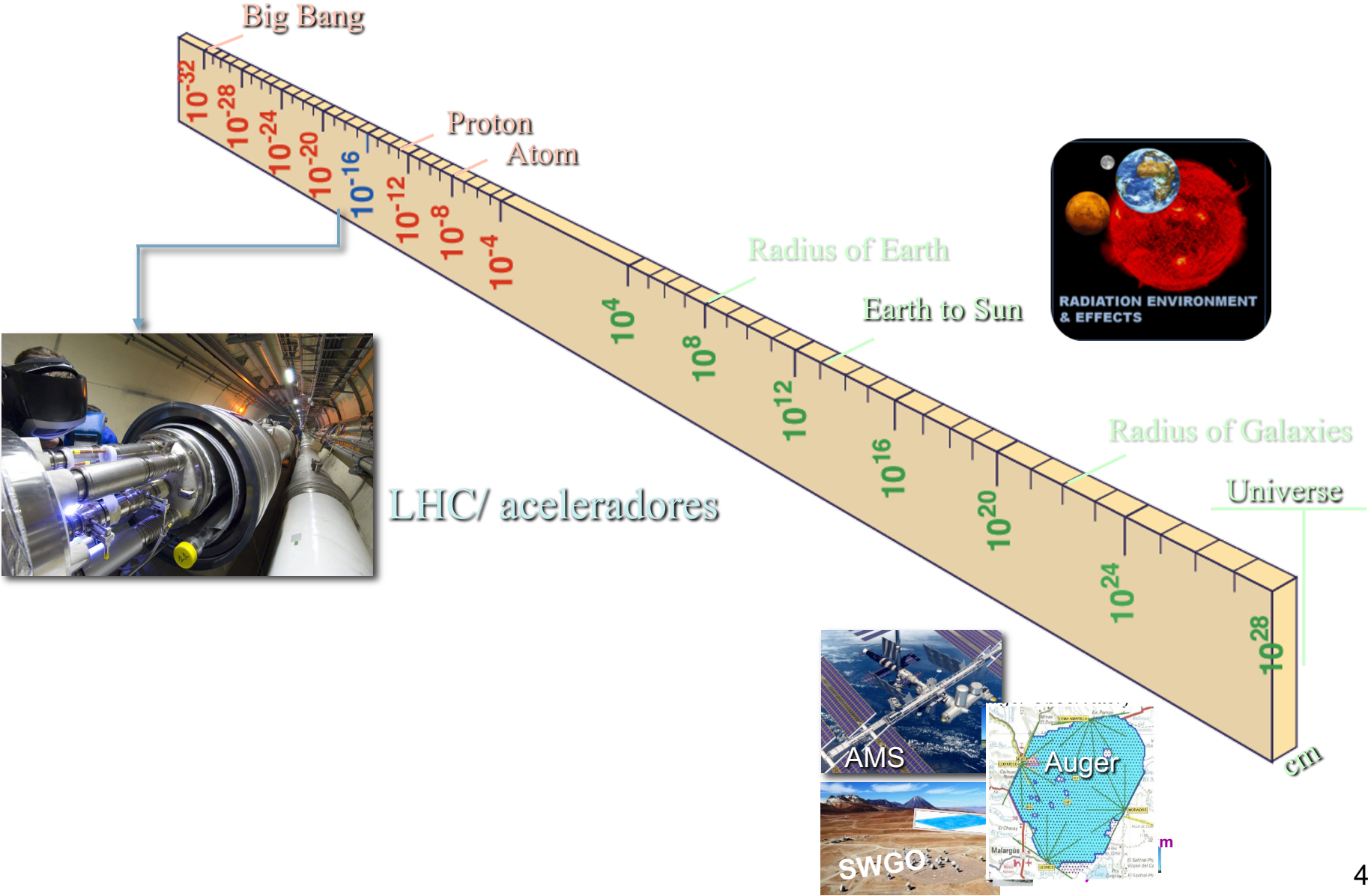


Mário Pimenta  
Lisboa, Julho 2020

# O Universo para compreender, ...

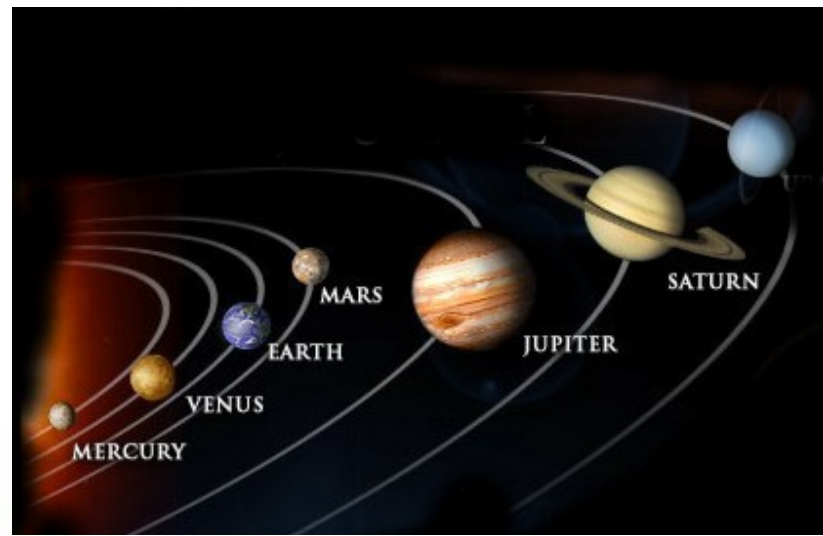


# Escalas, ...





# Da maçã ao Universo



I. Newton

Lei da atracção  
Universal:

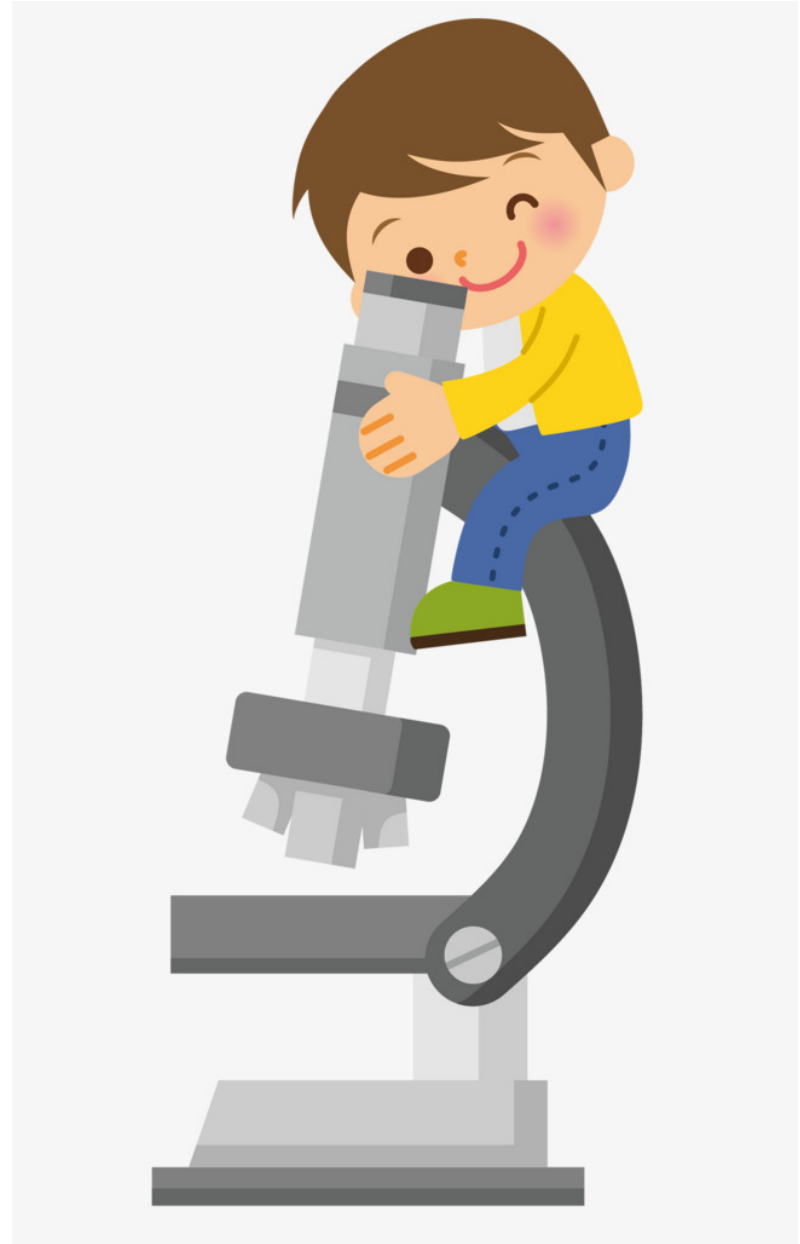
$$F = G \frac{m_{1g} m_{2g}}{r_{12}^2}$$

A gravidade !

Será que a maçã é  
elementar?



Ver o interior da  
maçã ???



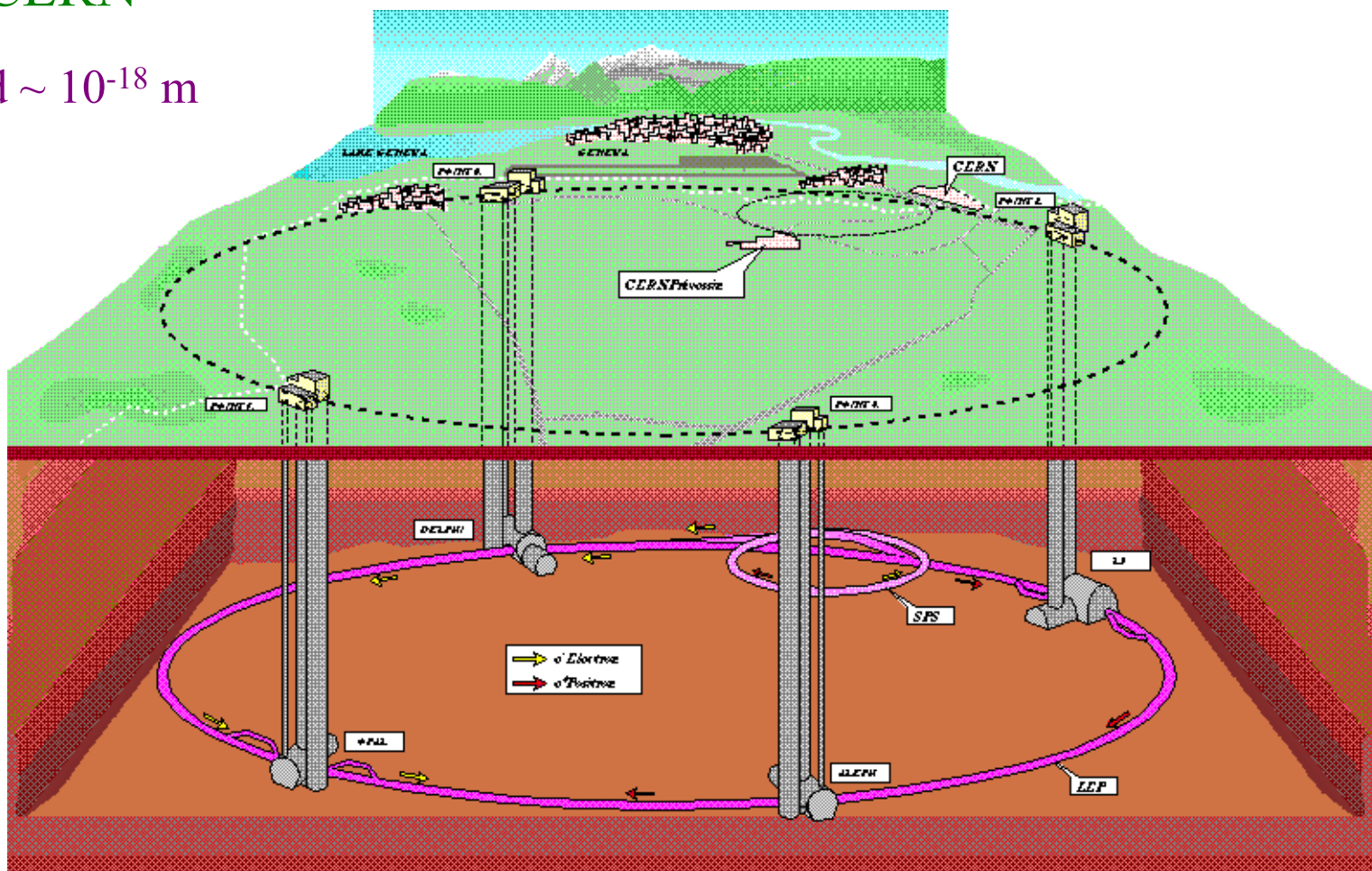
# Ver com partículas

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

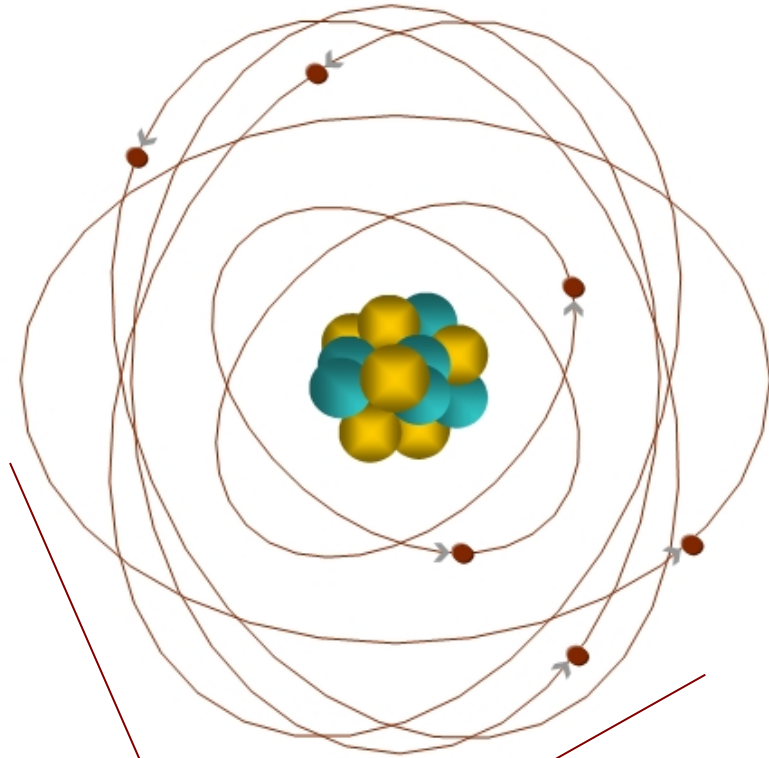


## CERN

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



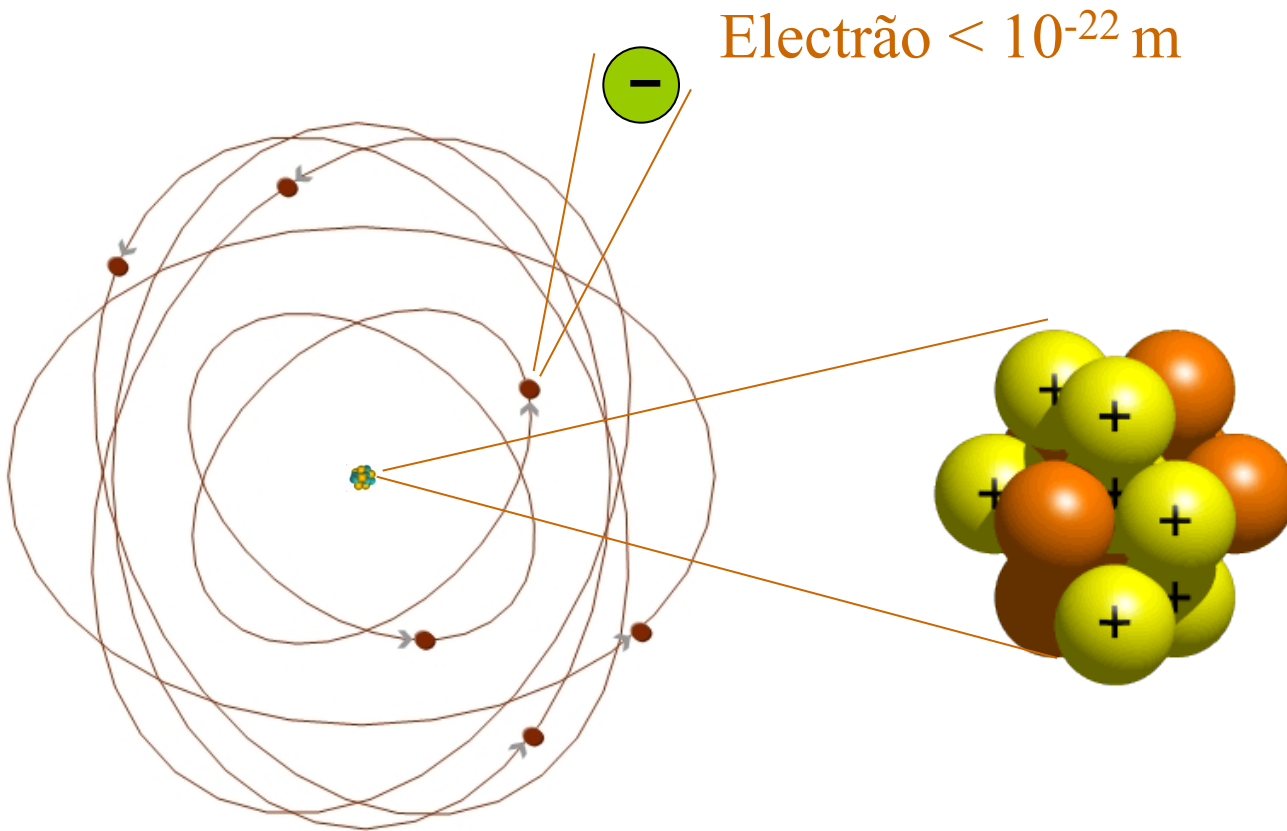
# Será que a maçã é elementar?



Átomo  $\sim 10^{-10}$  m



# No interior dos átomos

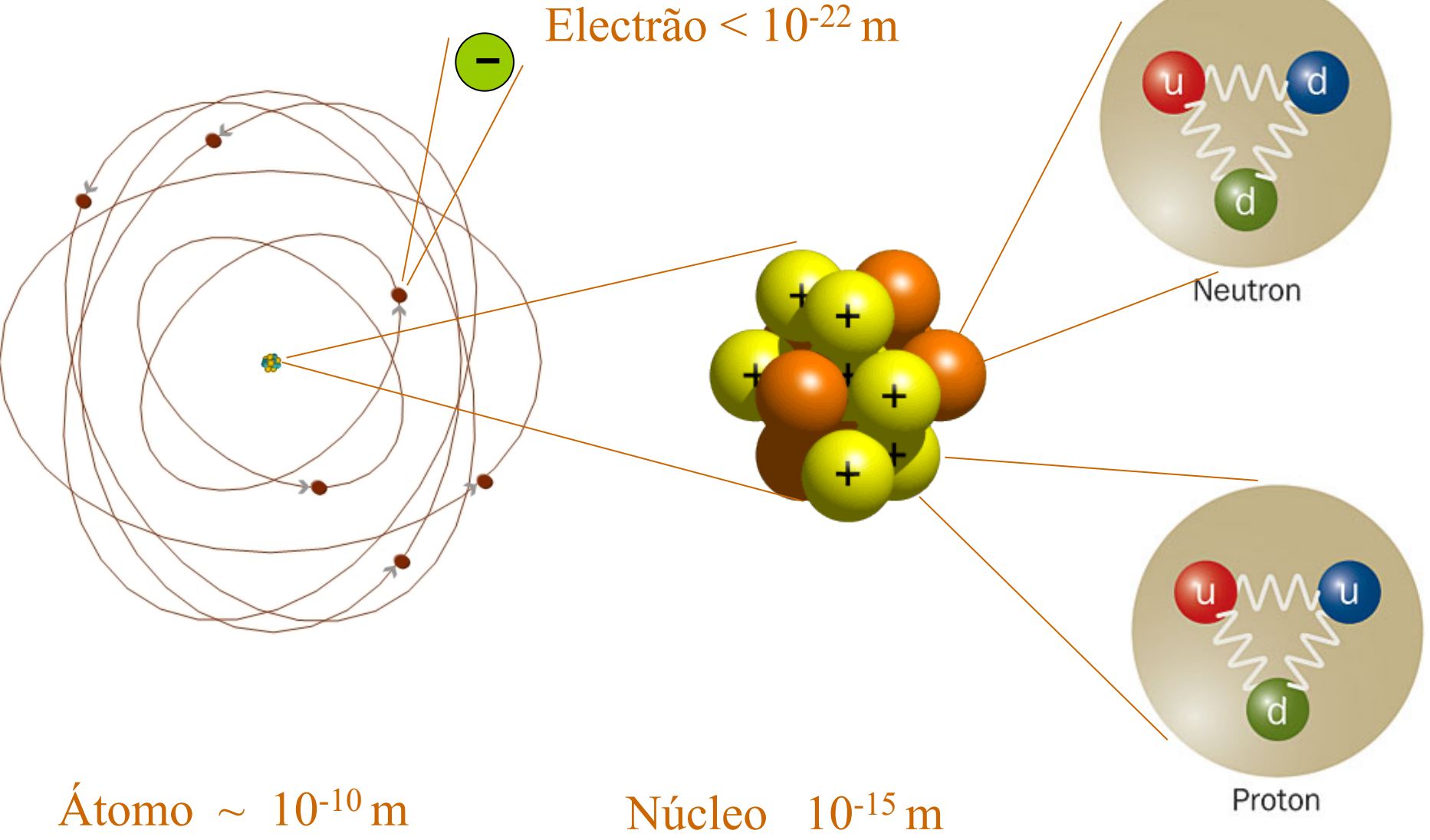


Electrão  $< 10^{-22}$  m

Átomo  $\sim 10^{-10}$  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:

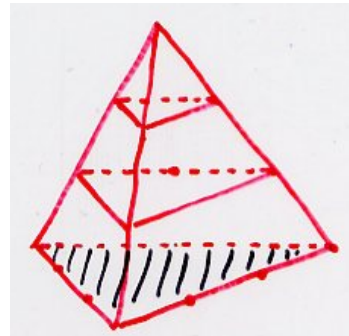


$$\begin{pmatrix} u \\ d \end{pmatrix} \quad \begin{pmatrix} c \\ s \end{pmatrix} \quad \begin{pmatrix} t \\ b \end{pmatrix} \quad \begin{pmatrix} ? \\ ? \end{pmatrix} \quad \begin{matrix} Q = + 2/3 \\ Q = - 1/3 \end{matrix}$$

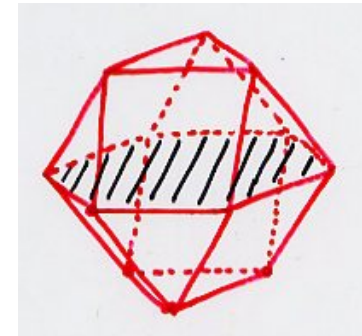
Combinar



$$q_i q_j q_k$$



$$q_i \bar{q}_i$$

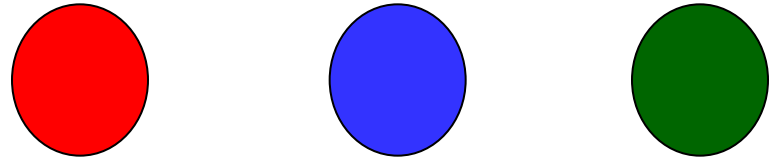


$$p, n, \Sigma, \lambda, \Xi, \Delta, \dots$$

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

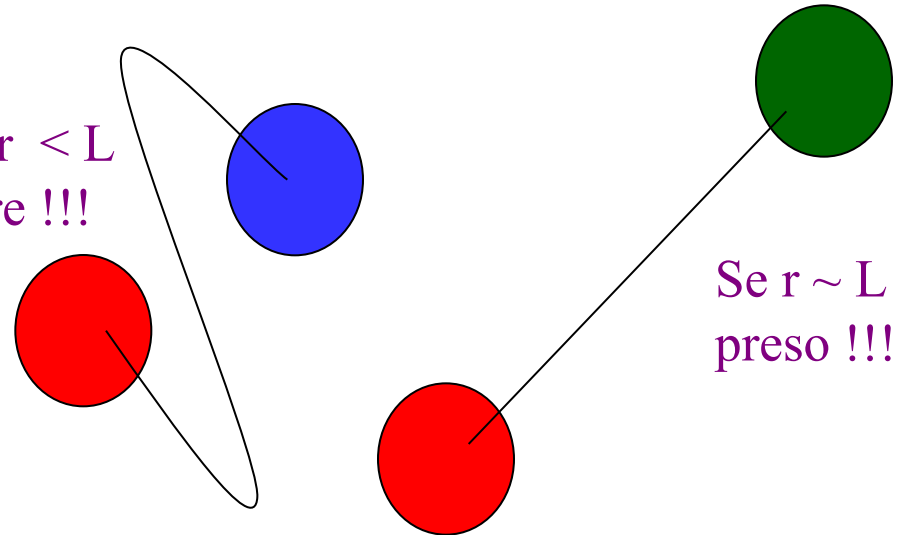
# A força forte

Quarks de três cores:

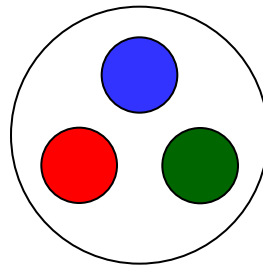


Ligados por “cordas”

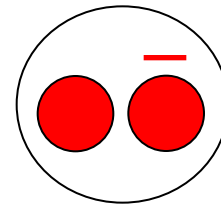
Se  $r < L$   
livre !!!



Partículas “sem cor”



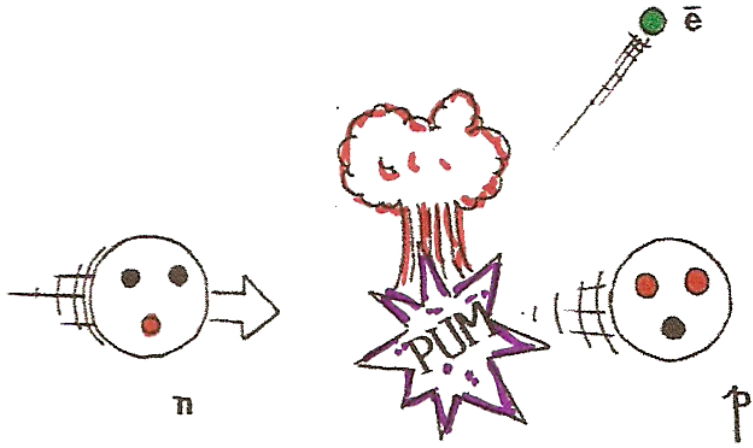
Bariões



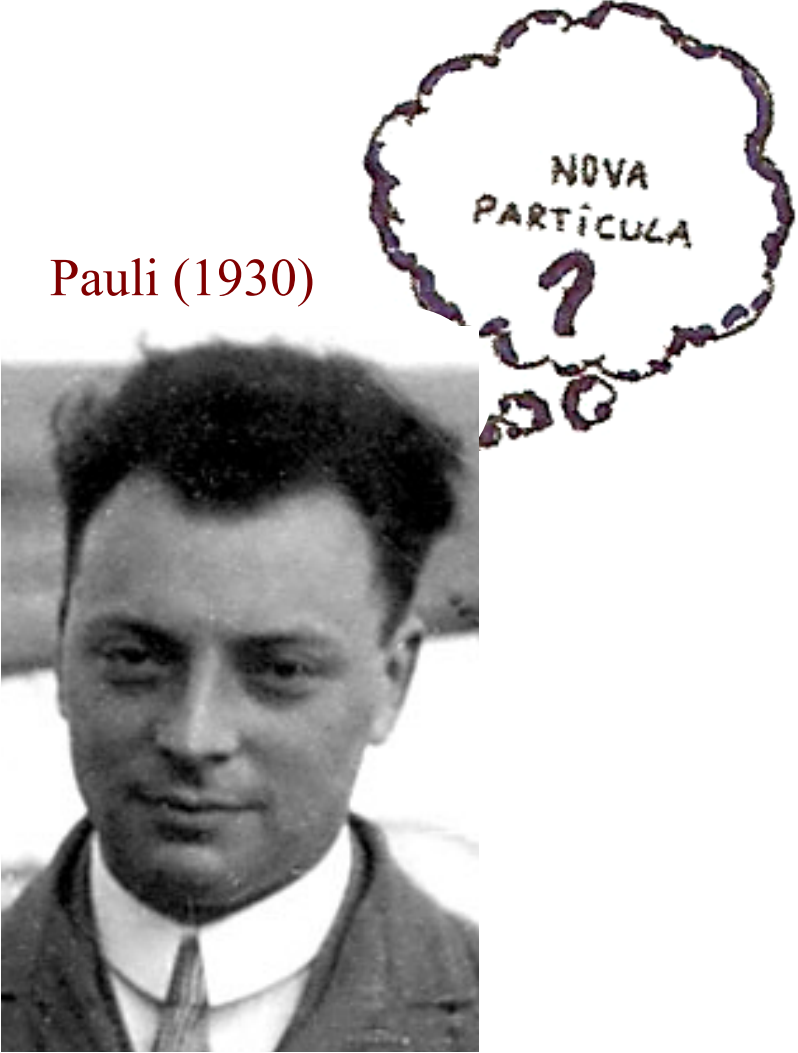
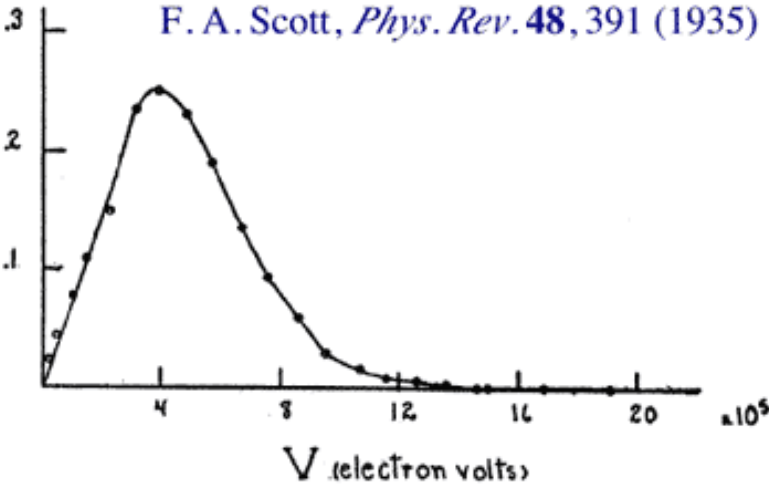
Mesões



# O neutrão decai...



conservação  $E$  e  $\vec{P}$  ???

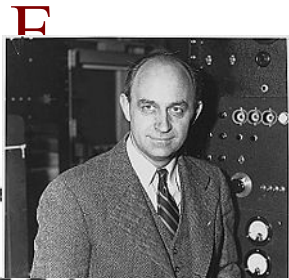
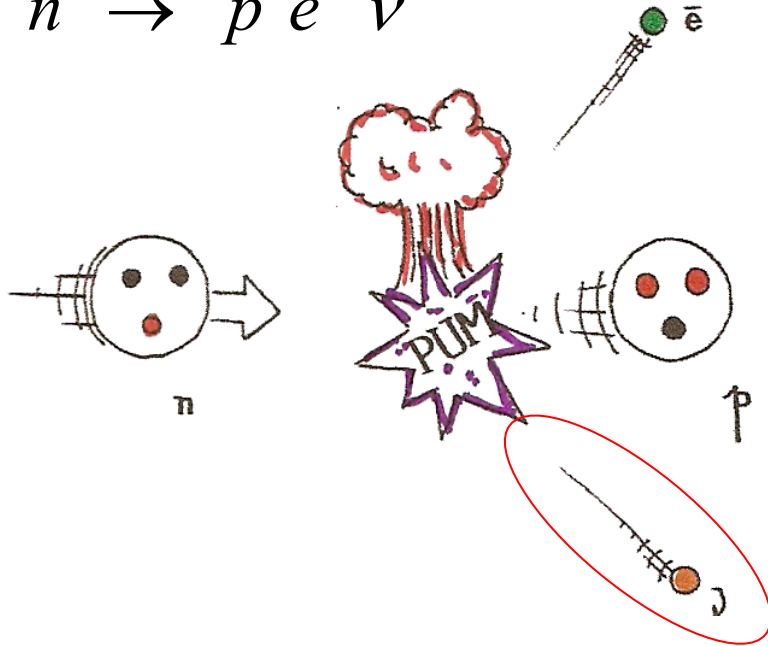


Pauli (1930)

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

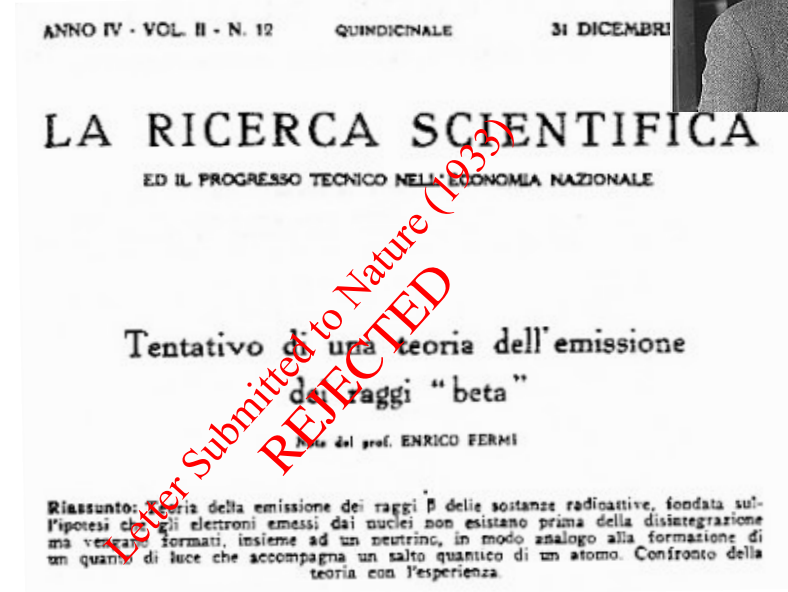
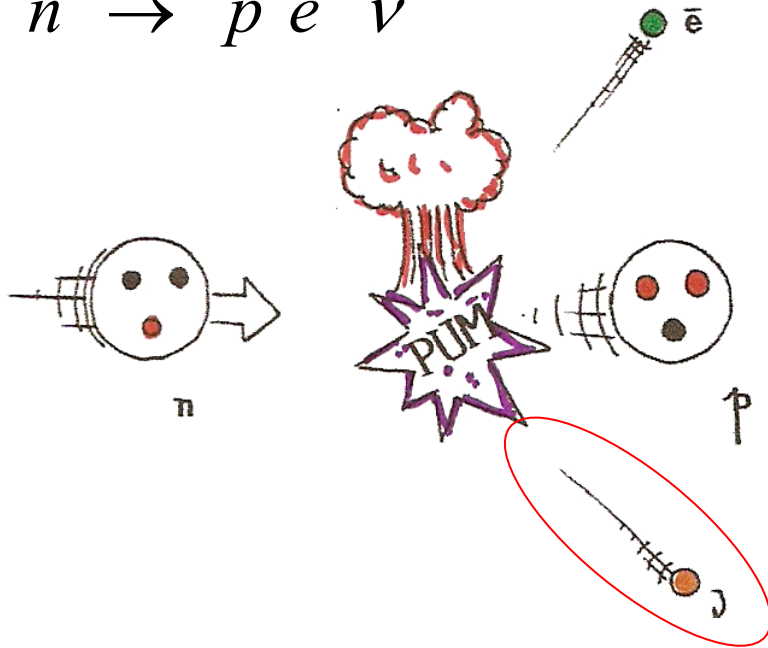
Riassunto: Teoria della emissione dei raggi  $\beta$  delle sostanze radioattive, fondata sull'ipotesi che gli elettroni emessi dai nuclei non esistano prima della disintegrazione ma vengano formati, insieme ad un neutrino, in modo analogo alla formazione di un quanto di luce che accompagna un salto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

Nuovo Cimento and Zeitschrift fur Physik

# A força fraca



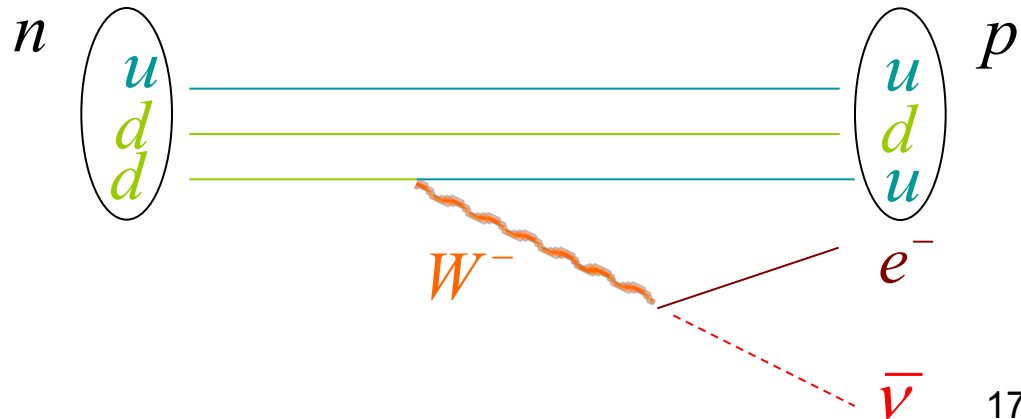
$$n \rightarrow p e^- \bar{\nu}$$



Nuovo Cimento and Zeitschrift fur Physik

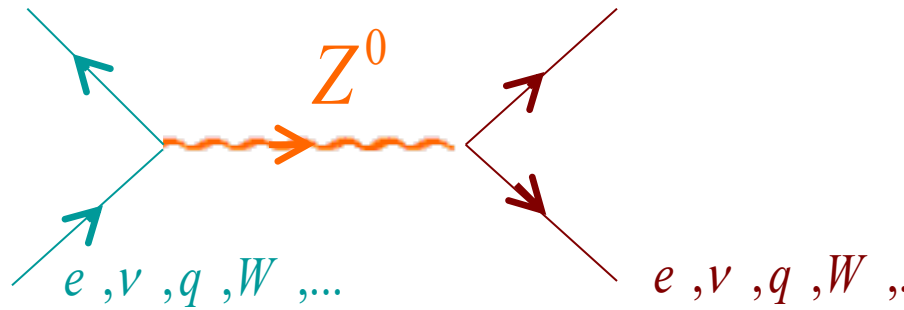
## A visão moderna !

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

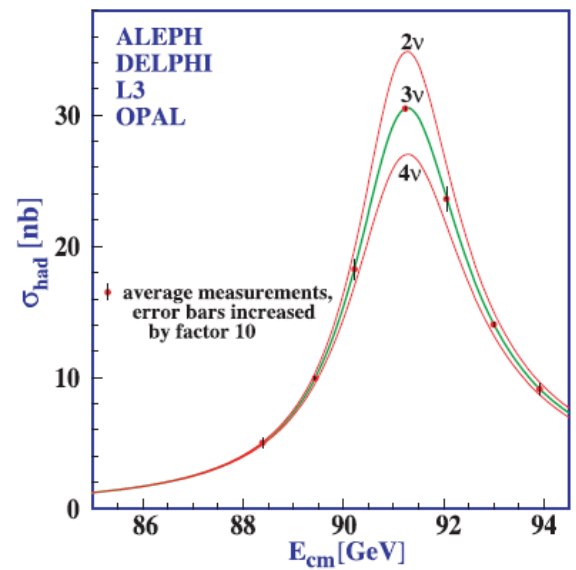
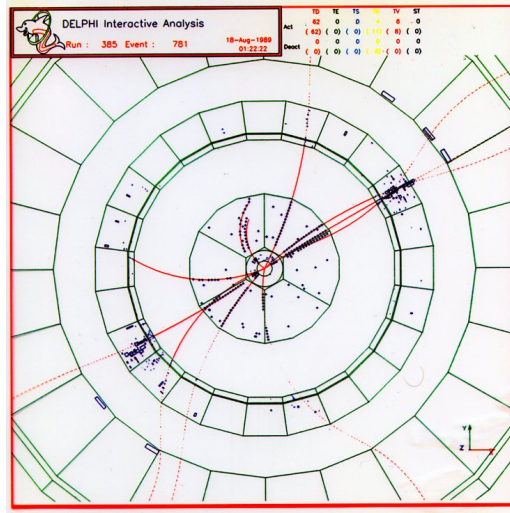
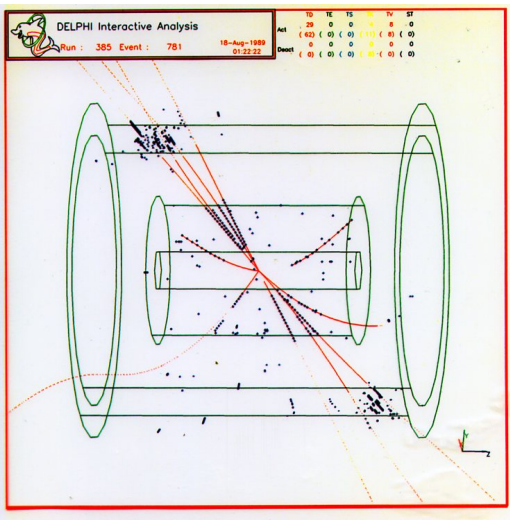
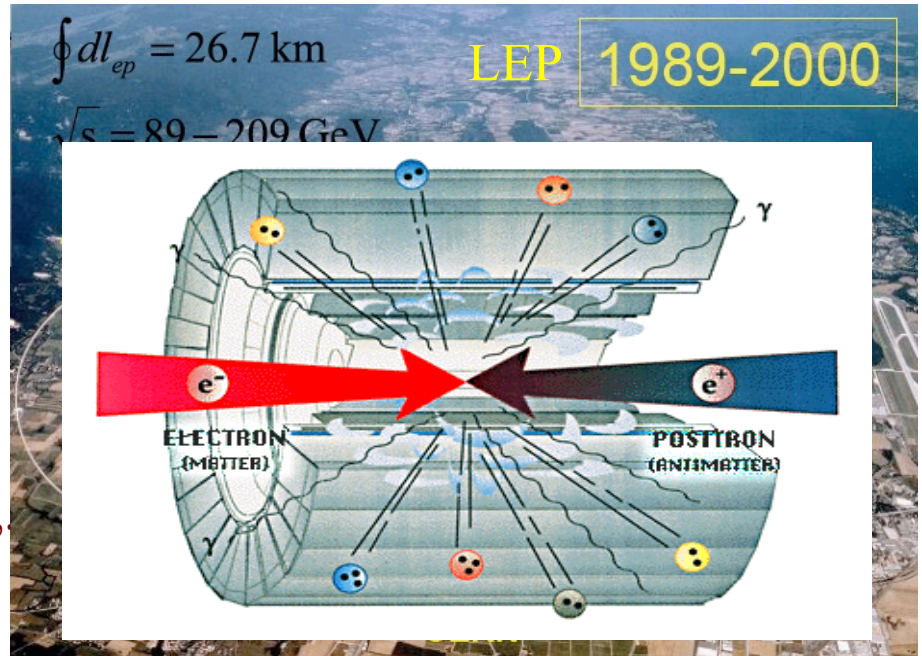


$Z^0$

Parceiro neutro dos  $W$ 's



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

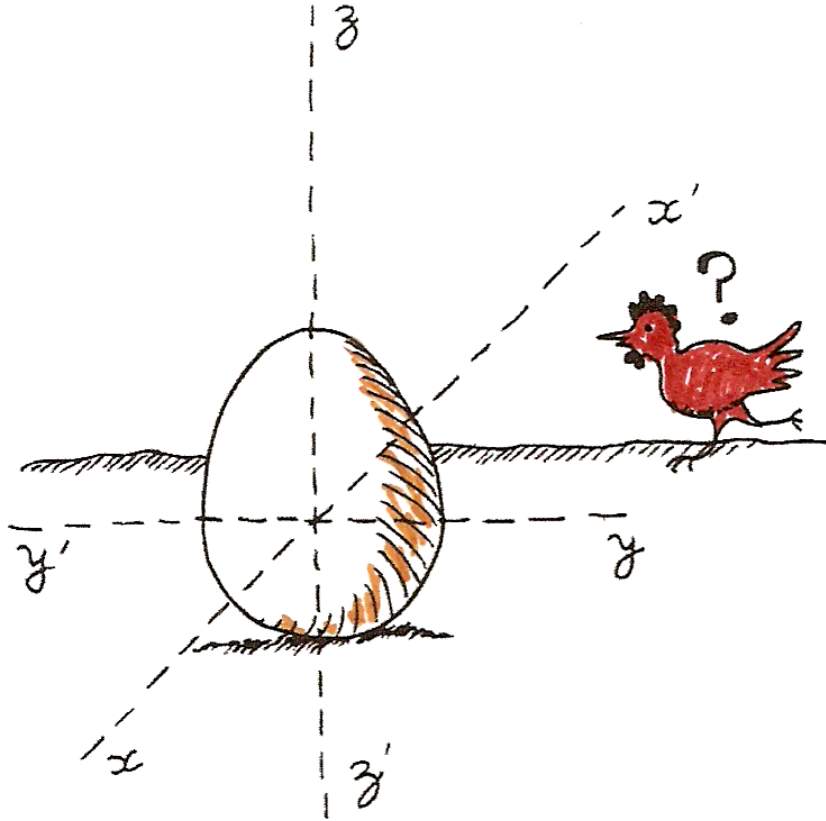


$$M_Z = 91.1875 \pm 0.0021 \text{ GeV}/c^2$$



# Simetrias !!!

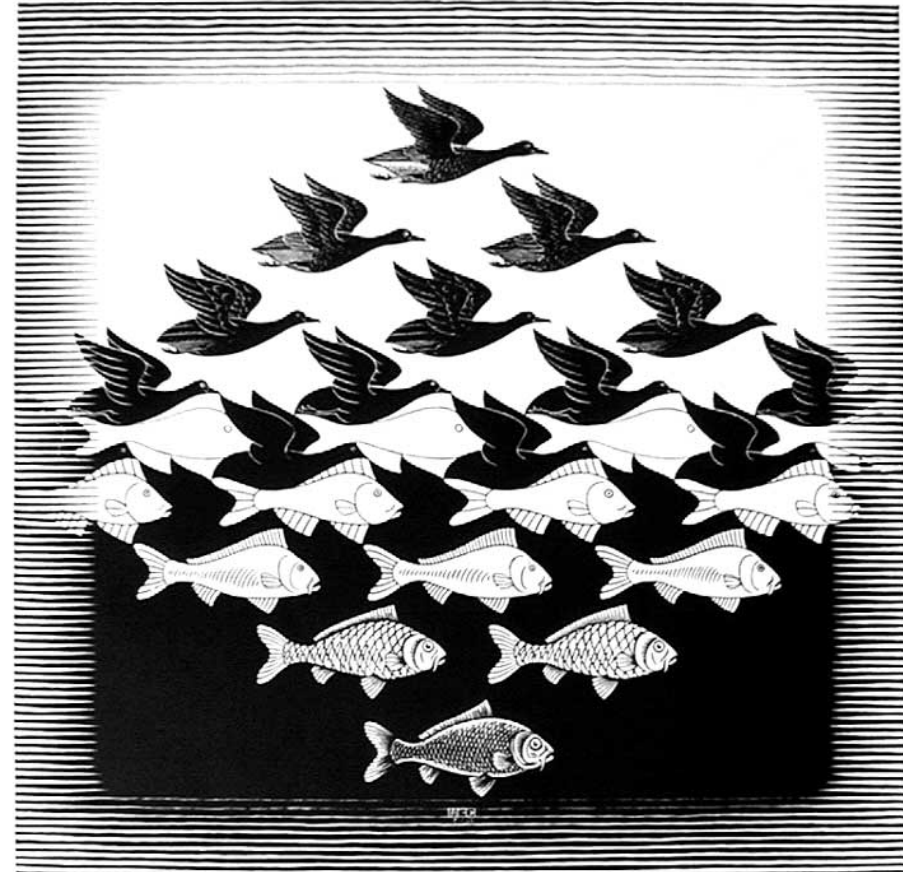
## Globais



Leis de conservação:  
Energia, Momento linear,  
Momento Angular

## Locais

M.C. Escher



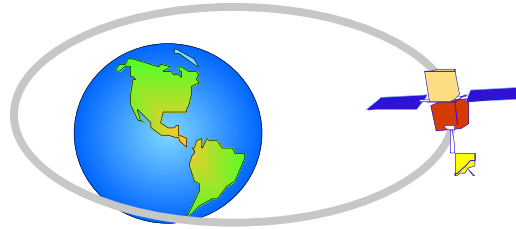
Campos de interacção:  
Electromagnético, fraco, forte,  
gravítico???,



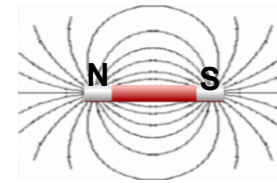
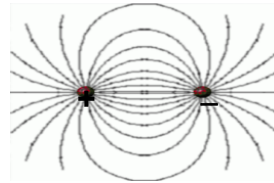
# As interações

## Unificação e Simetrias (locais)

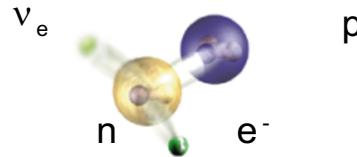
gravíticas



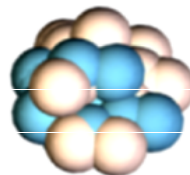
electromagneticas



fracas



fortes



# Mas as Partículas têm massa

em  $eV/c^2$

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

$$m_\gamma = 0$$

$$m_e \sim 500 \cdot 10^3$$

$$m_W \sim 80 \cdot 10^9$$

$$m_u \sim 5 \cdot 10^6$$

$$m_Z \sim 91 \cdot 10^9$$

$$m_t \sim 174 \cdot 10^9$$

$$m_H \sim 125 \cdot 10^9$$

...

Como é que as massas são geradas ???

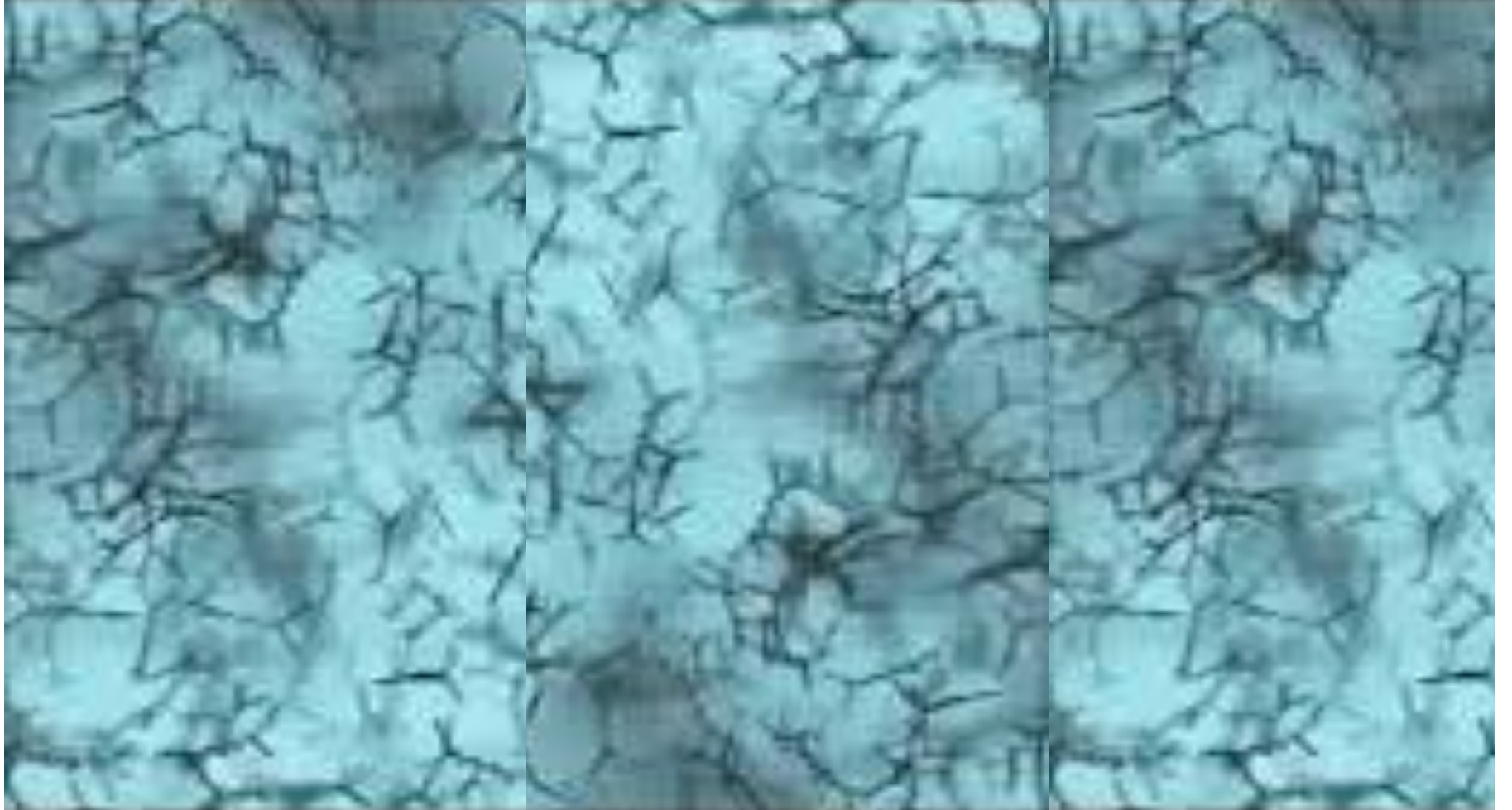
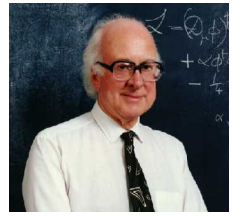
Por é que são tão diferentes ???

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

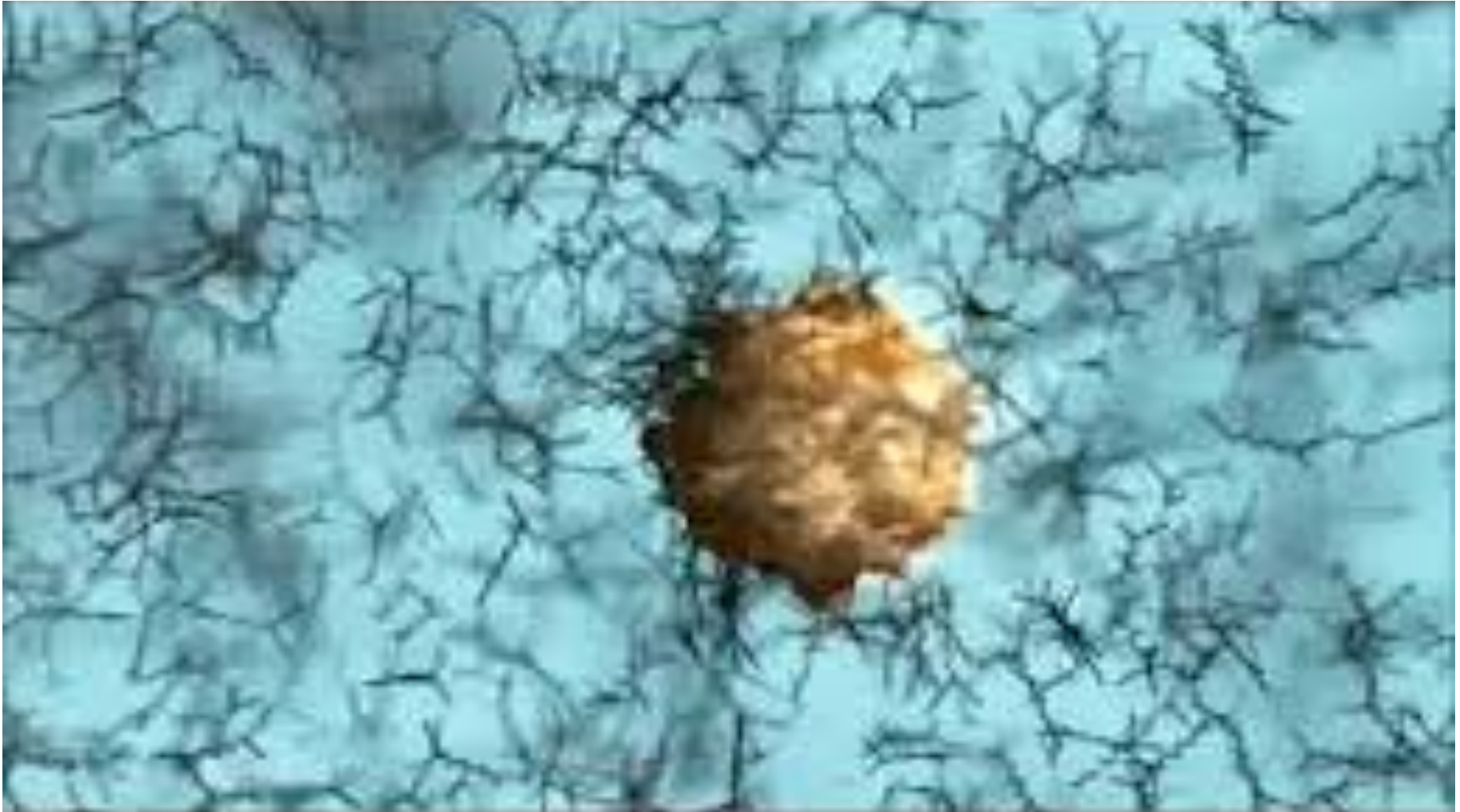
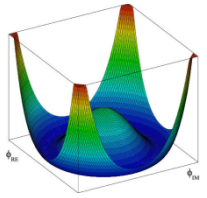
# O campo de Higgs

Higgs, Englert, Brout - 1964

Peter Higgs



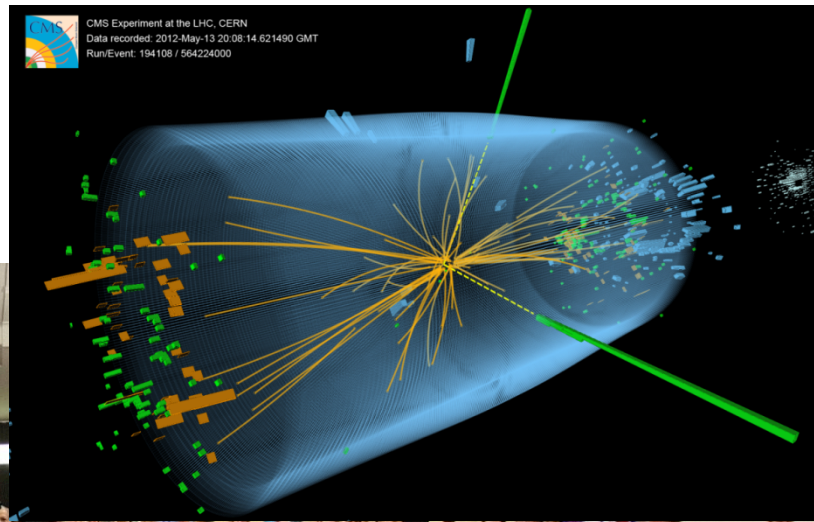
# O mecanismo de Higgs



A massa é gerada na interacção com o campo



# O bóson de Higgs



4 Julho 2012: CERN



# As partículas elementares hoje!

Three Generations  
of Matter (Fermions) spin  $\frac{1}{2}$

	I	II	III
mass →	2.4 MeV	1.27 GeV	173.2 GeV
charge →	$\frac{2}{3}$	$\frac{2}{3}$	$\frac{2}{3}$
name →	<b>u</b> up	<b>c</b> charm	<b>t</b> top
	Left Right	Left Right	Left Right
Quarks	4.8 MeV	104 MeV	4.2 GeV
	$-\frac{1}{3}$	$-\frac{1}{3}$	$-\frac{1}{3}$
	<b>d</b> down	<b>s</b> strange	<b>b</b> bottom
	Left Right	Left Right	Left Right
Leptons	$0$	$0$	$0$
	<b><math>\nu_e</math></b> electron neutrino	<b><math>\nu_\mu</math></b> muon neutrino	<b><math>\nu_\tau</math></b> tau neutrino
	Left Right	Left Right	Left Right
	0.511 MeV	105.7 MeV	1.777 GeV
	$-1$	$-1$	$-1$
	<b>e</b> electron	<b><math>\mu</math></b> muon	<b><math>\tau</math></b> tau
	Left Right	Left Right	Left Right

0  
0  
**g**  
gluon

0  
0  
 **$\gamma$**   
photon

91.2 GeV  
0  
**Z<sup>0</sup>**  
weak force

80.4 GeV  
 $\pm 1$   
**W<sup>±</sup>**  
weak force

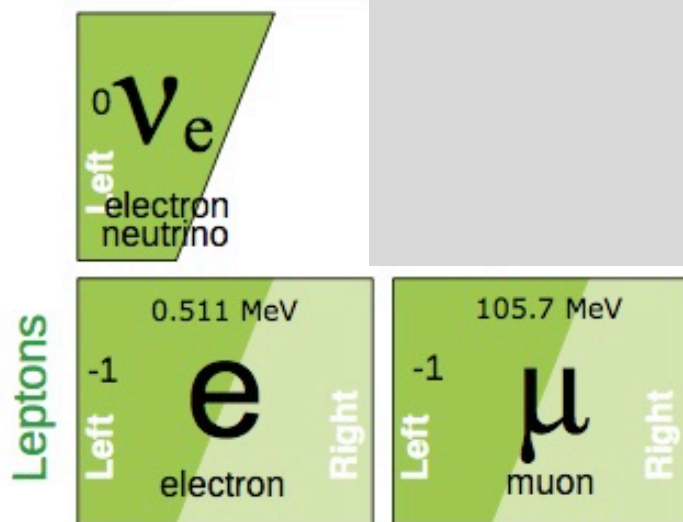
126 GeV  
0  
0  
**H**  
Higgs boson

spin 0

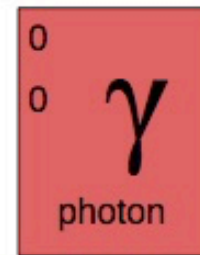
Bosons (Forces) spin 1

# As partículas elementares em 1957

Three Generations  
of Matter (Fermions) spin  $\frac{1}{2}$



Bosons (Forces) spin 1



# As partículas elementares em 1980

Three Generations  
of Matter (Fermions) spin  $\frac{1}{2}$

	I	II	III
mass →	2.4 MeV	1.27 GeV	
charge →	$\frac{2}{3}$	$\frac{2}{3}$	
name →	<b>u</b> up	<b>c</b> charm	
Quarks	Left Right	Left Right	
	4.8 MeV	104 MeV	4.2 GeV
	$-\frac{1}{3}$	$-\frac{1}{3}$	$-\frac{1}{3}$
	<b>d</b> down	<b>s</b> strange	<b>b</b> bottom
Leptons			
	$0$	$0$	
	<b><math>\nu_e</math></b> electron neutrino	<b><math>\nu_\mu</math></b> muon neutrino	
	Left Right	Left Right	
	0.511 MeV	105.7 MeV	1.777 GeV
$-1$	$-1$	$-1$	
<b>e</b> electron	<b><math>\mu</math></b> muon	<b><math>\tau</math></b> tau	
Left Right	Left Right	Left Right	

0  
0  
**g**  
gluon

0  
0  
 **$\gamma$**   
photon

Bosons (Forces) spin 1



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

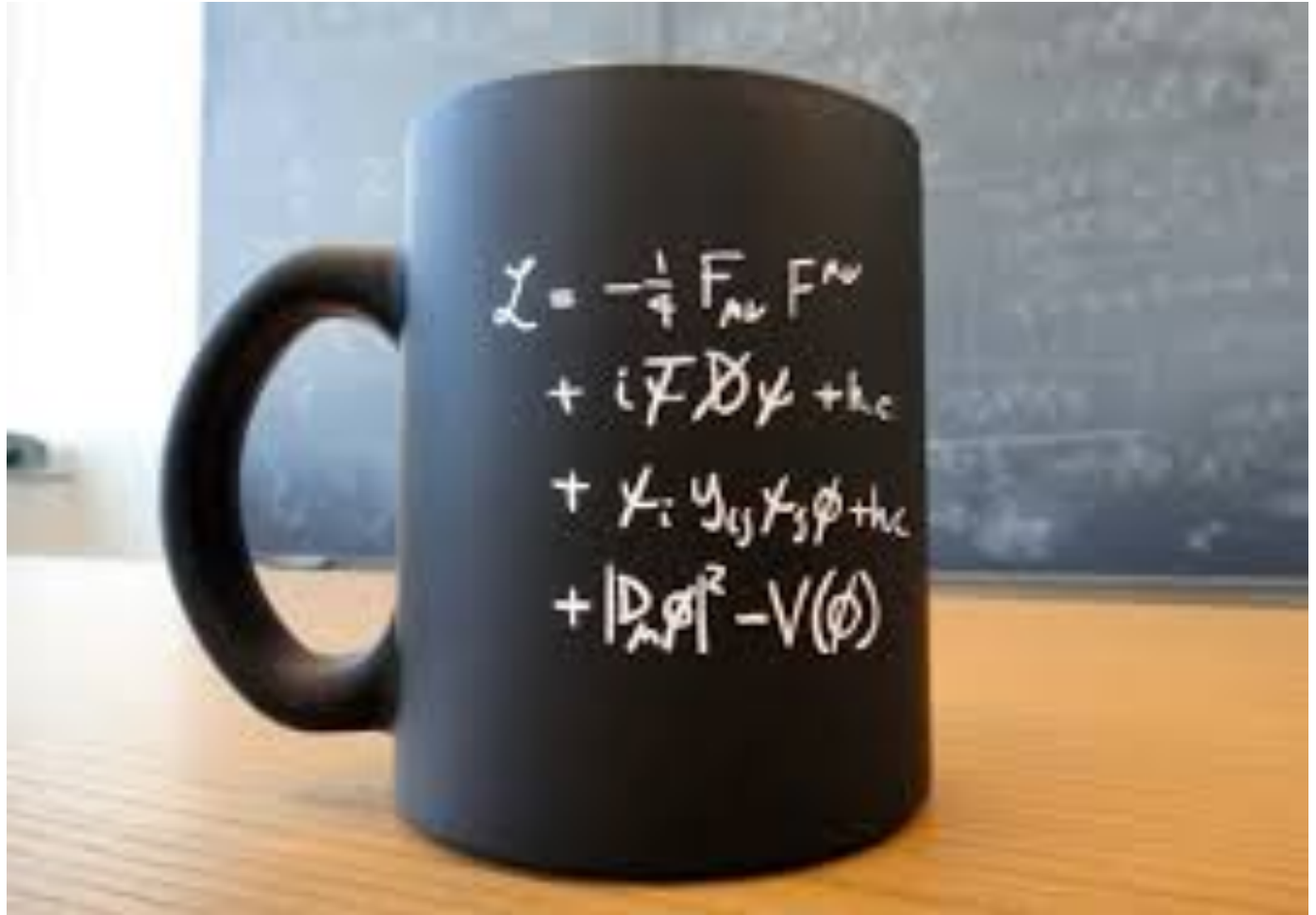
Glashow



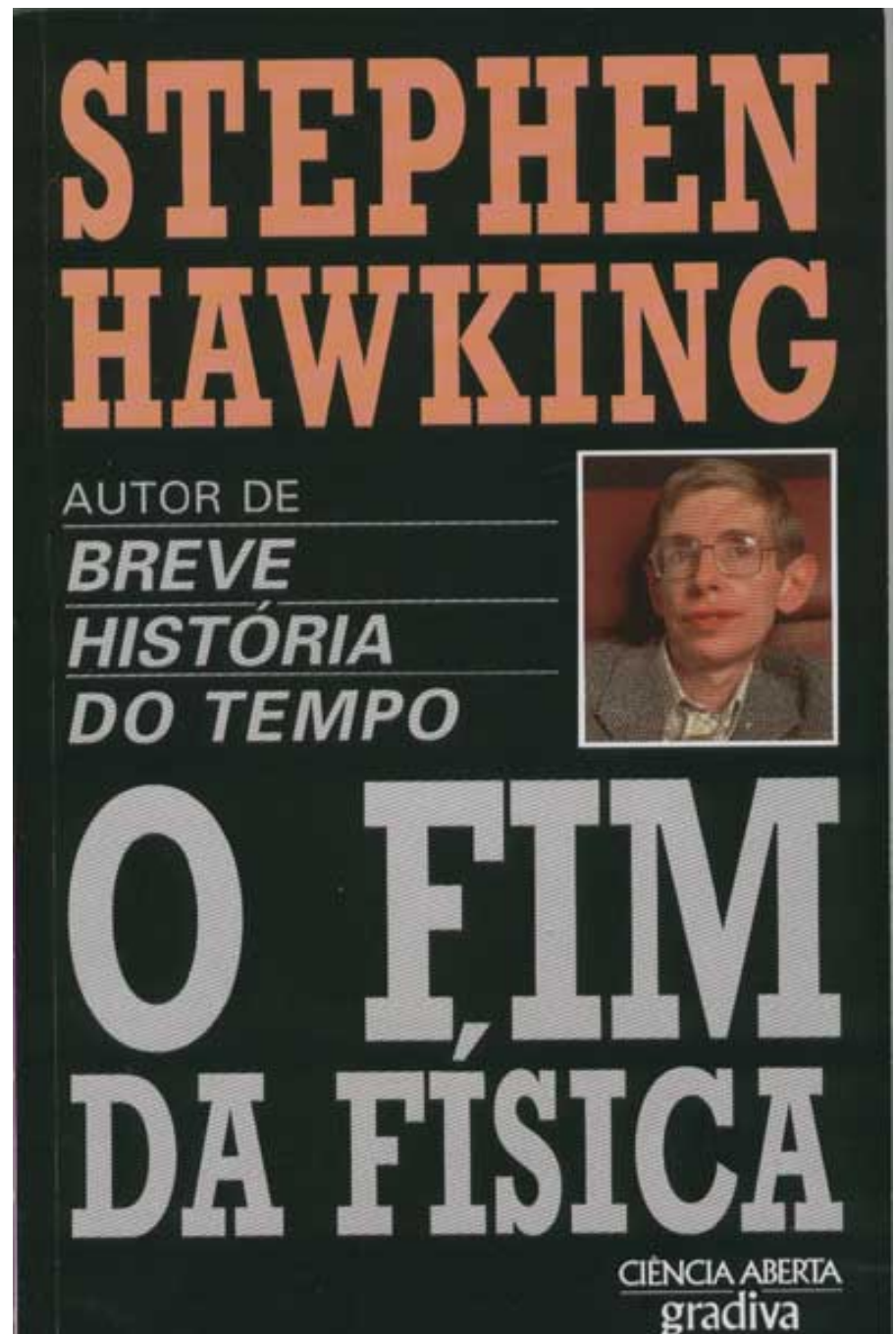
Salam



Weinberg



O fim da Física ?





# A matéria luminosa

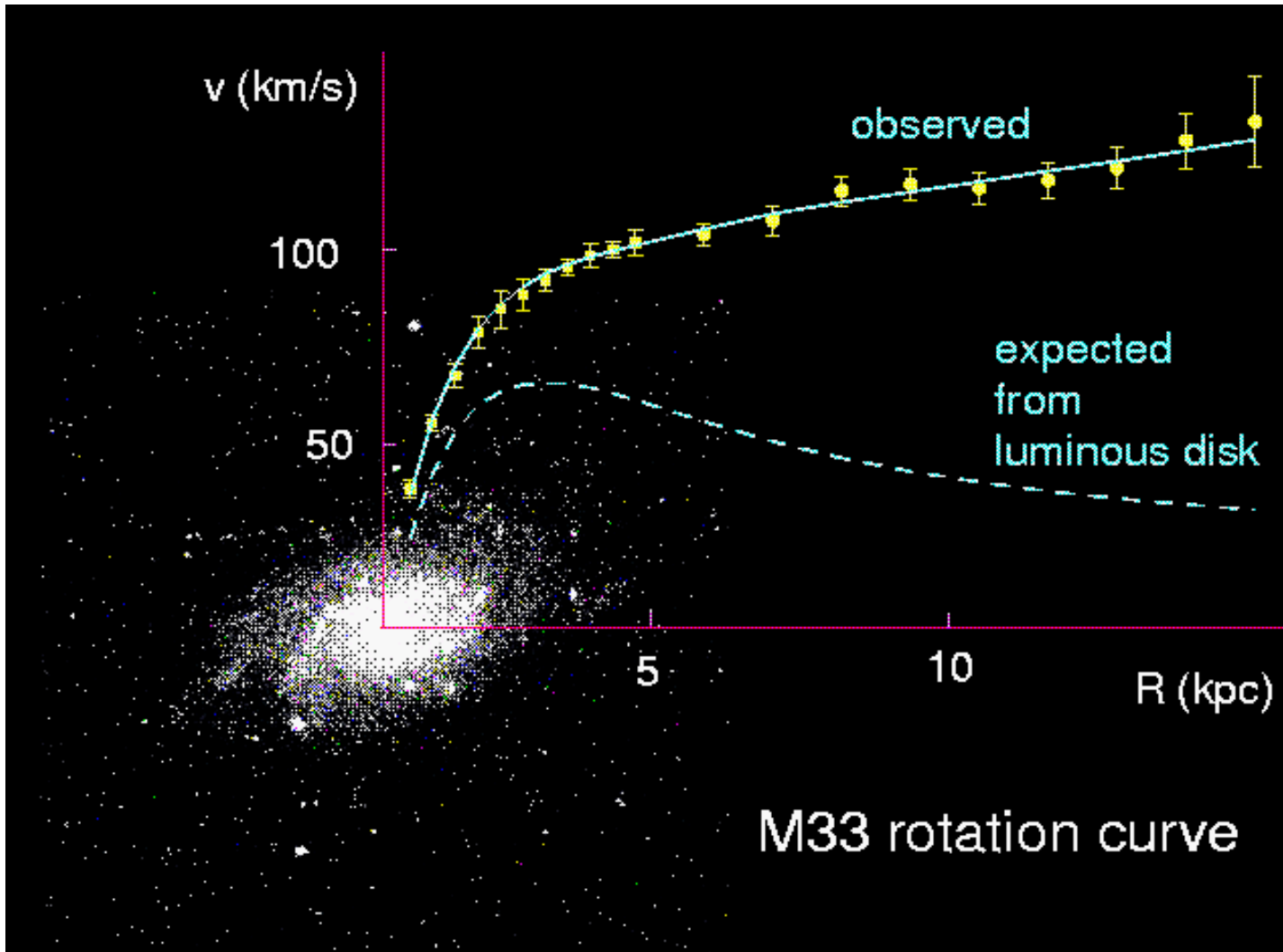




# A velocidade de rotação das estrelas periféricas

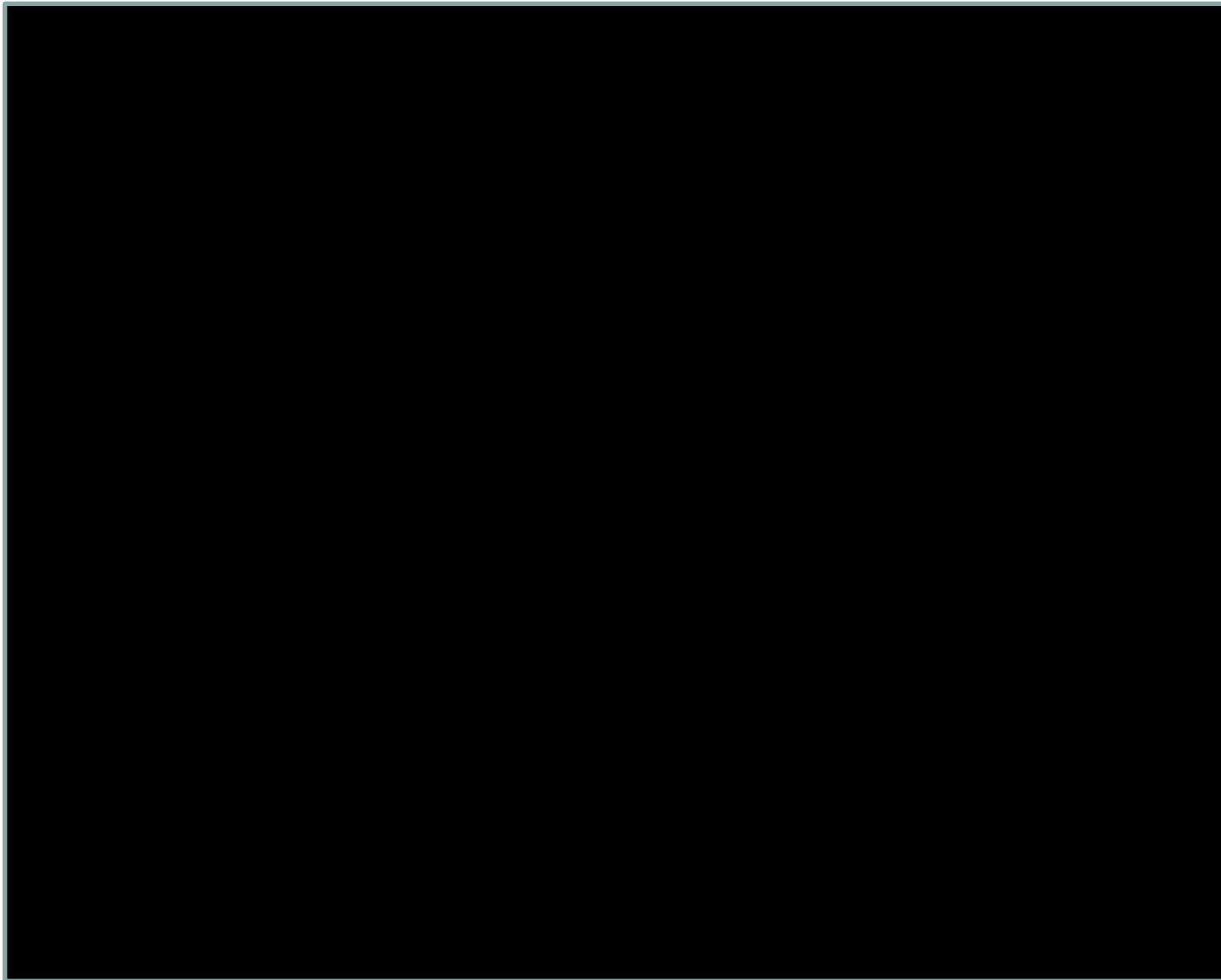
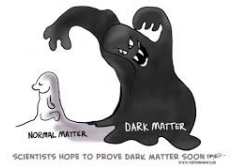


# Rodar em torno do centro da galáxia

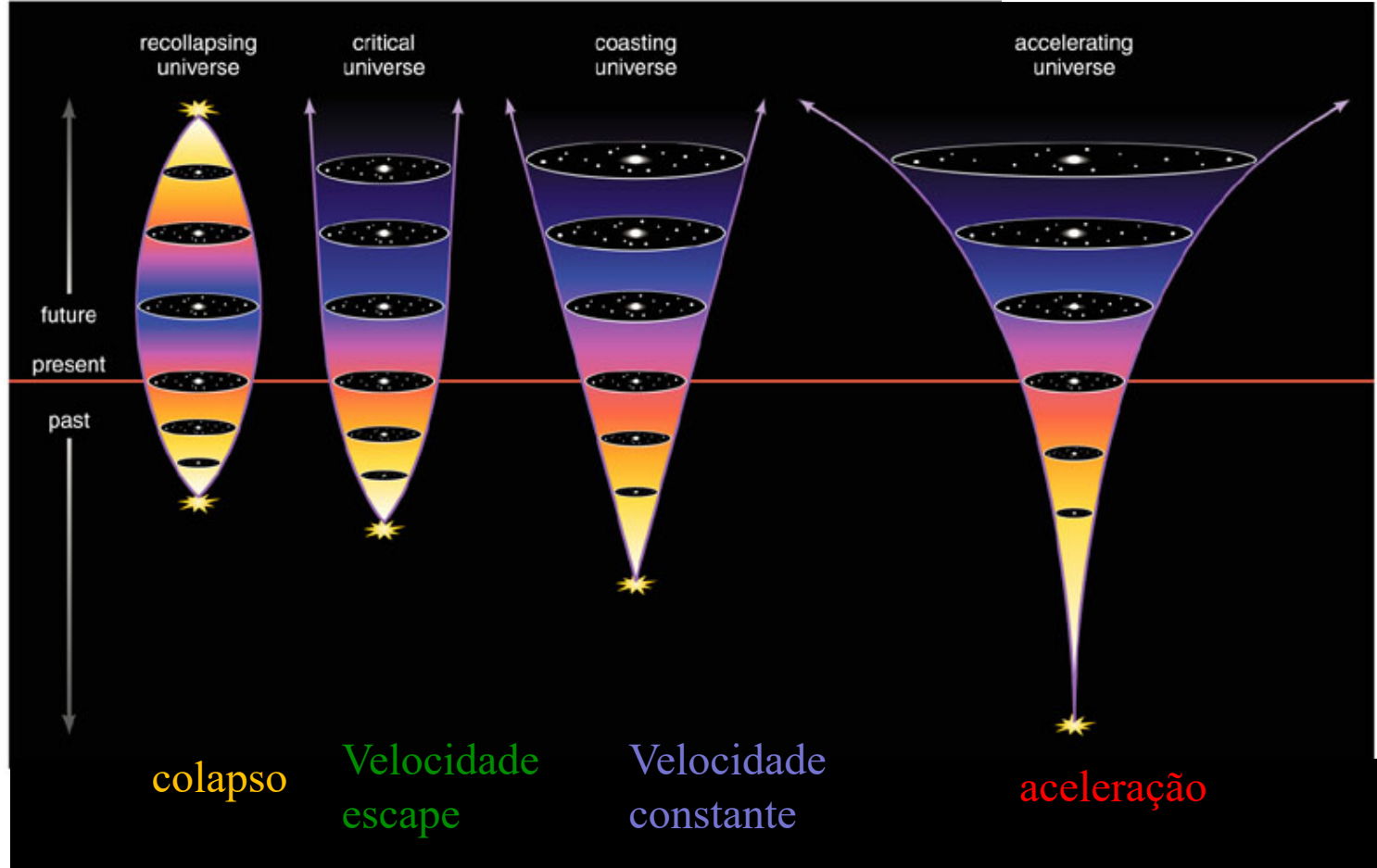
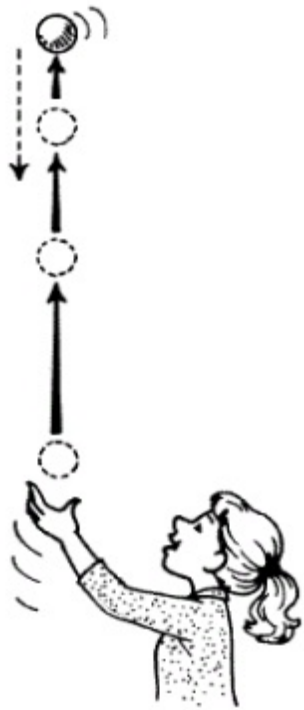
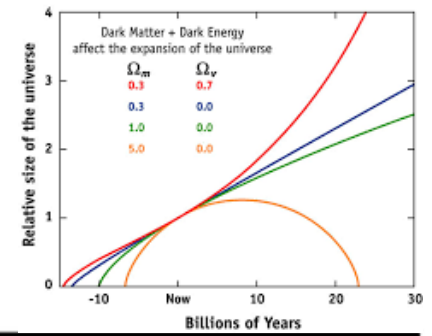


Um halo de matéria escura!

# A matéria escura

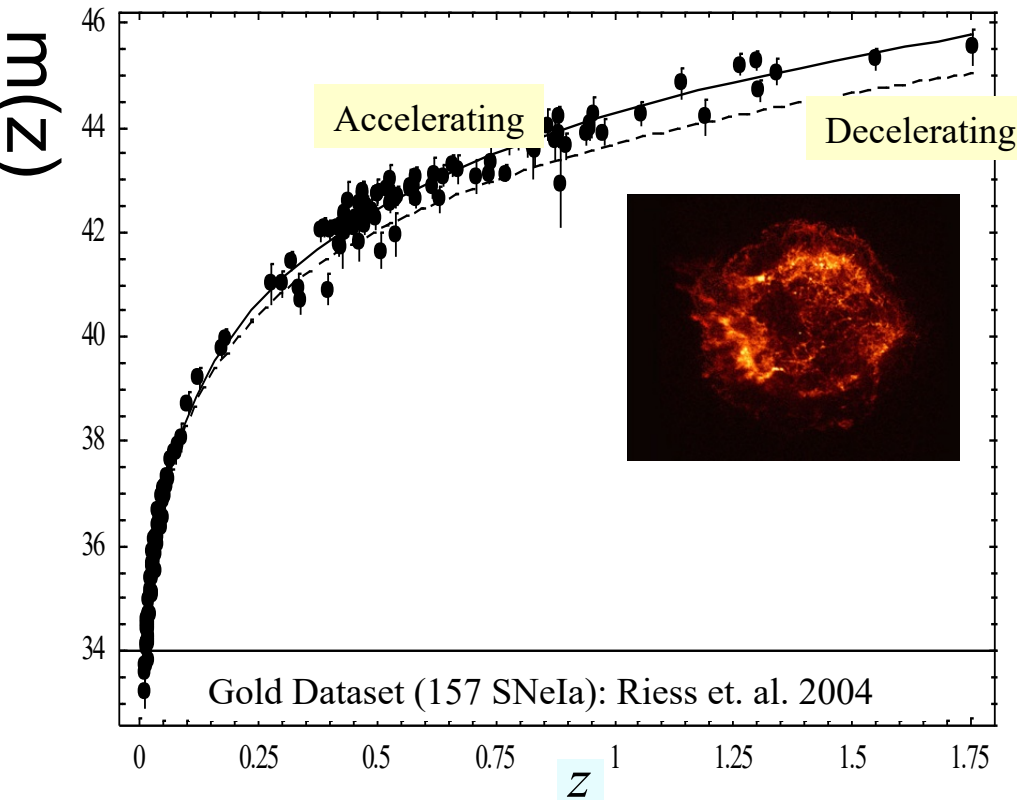


# A expansão do Universo



# A energia escura !

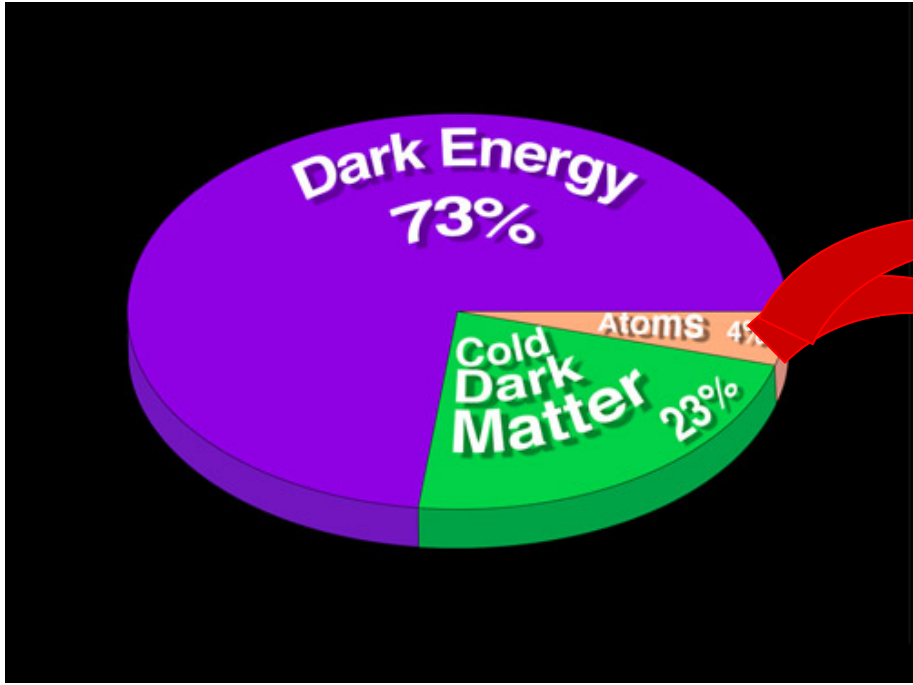
## Diagrama de Hubble



O Universo encontra-se numa expansão acelerada !!!  
Energia escura – anti-gravítica



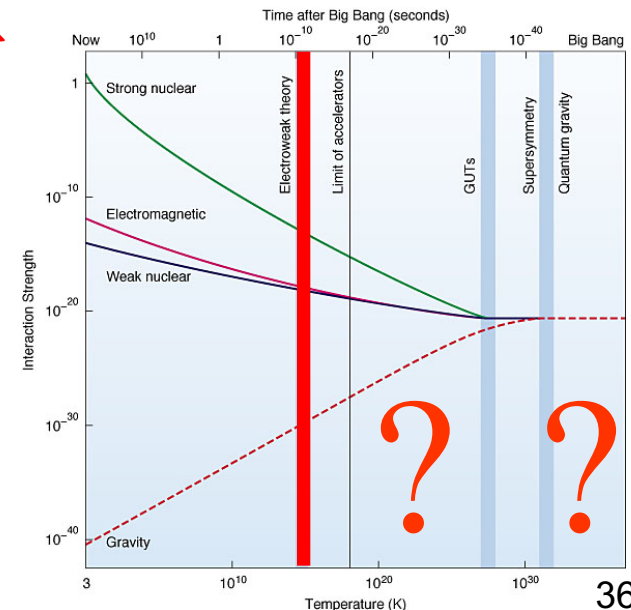
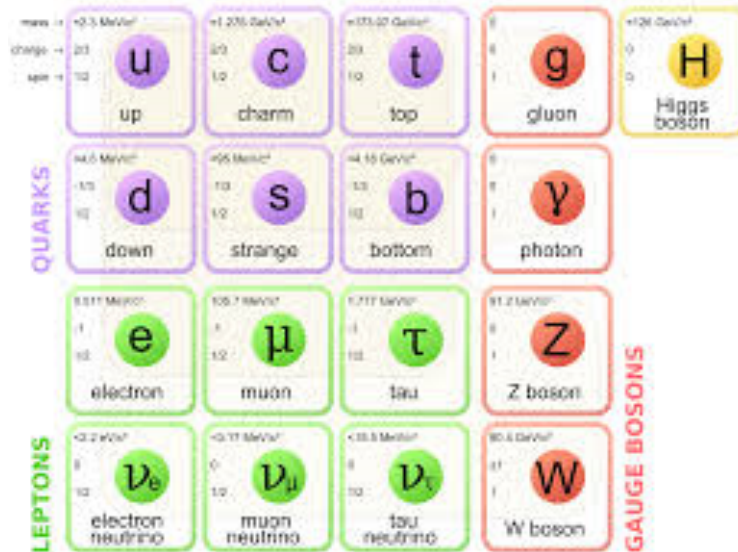
# Fronteiras do nosso (des)conhecimento



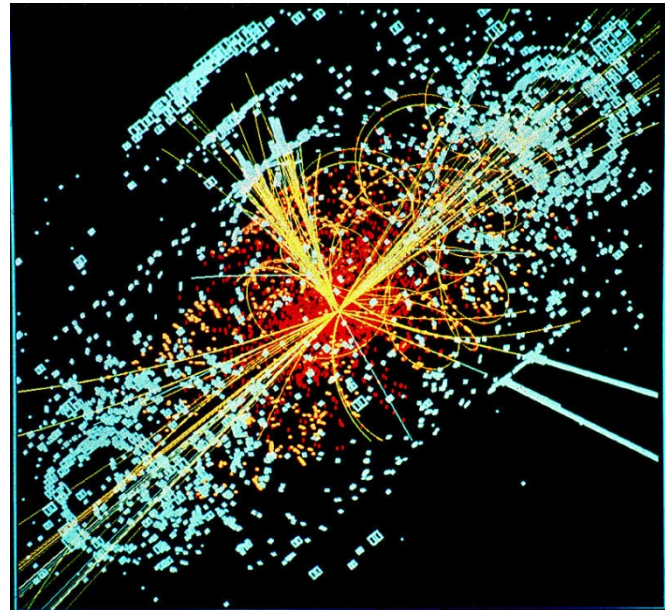
O modelo padrão

$E_{CM} \sim 1 \text{ TeV}$

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



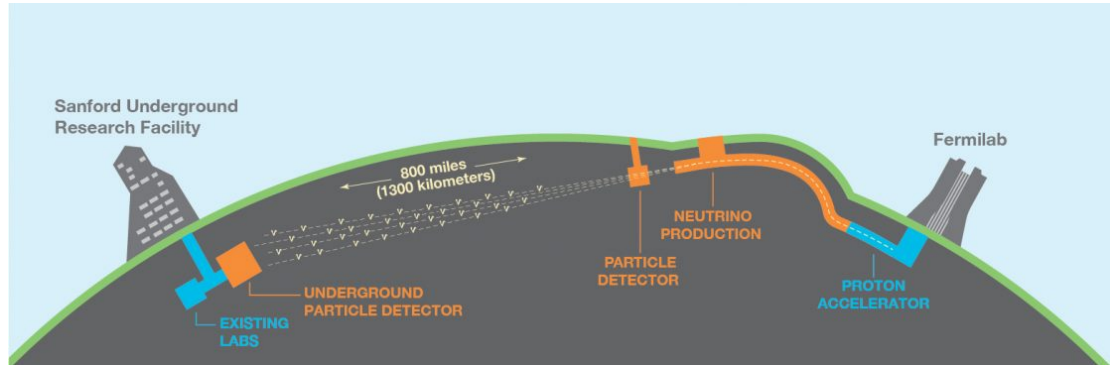
# Olhar o Universo no sec. XXI



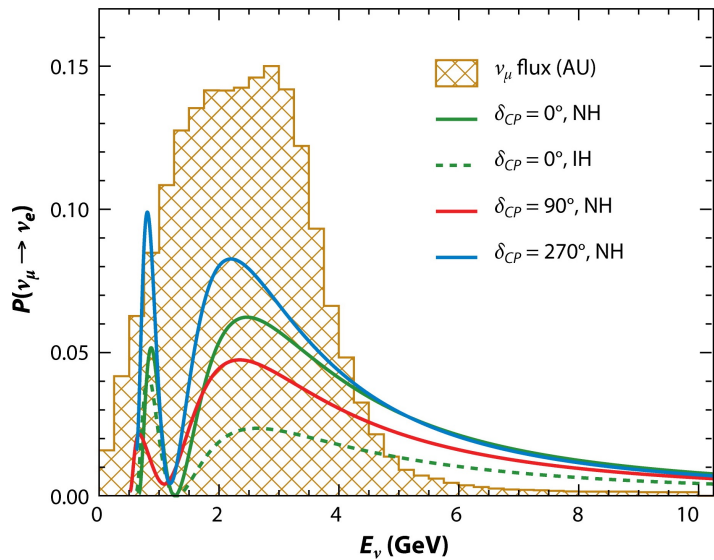


# DUNE

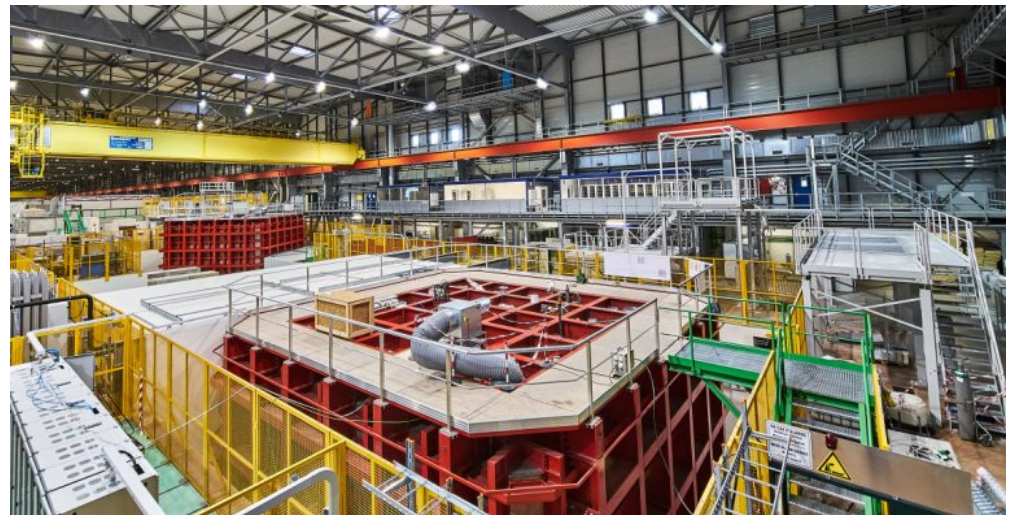
violação de CP no  
sector dos neutrinos ???



## Padrões de Oscilação



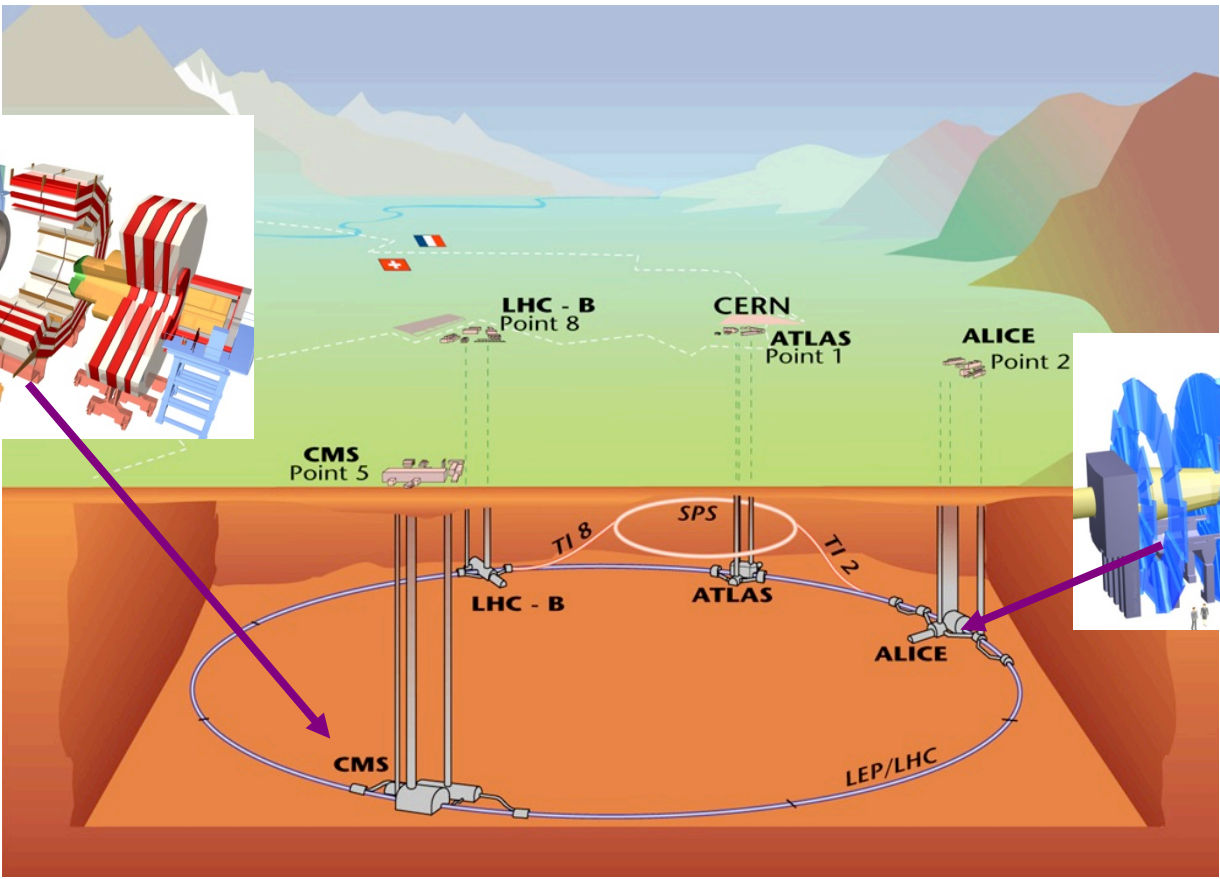
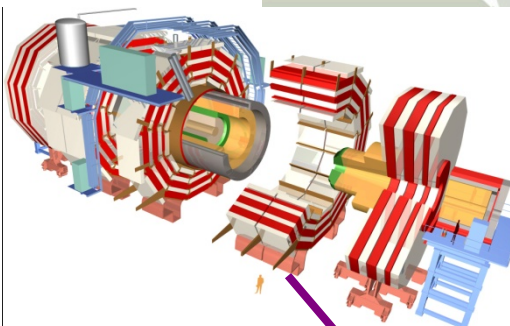
## Proto-DUNE @ CERN



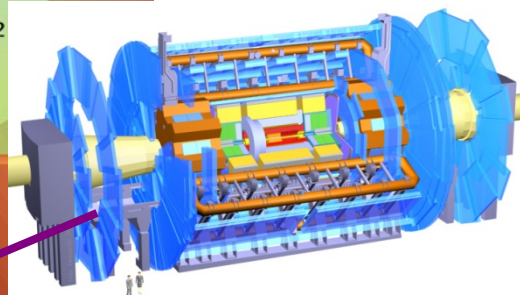
# O LHC no CERN



CMS



ATLAS

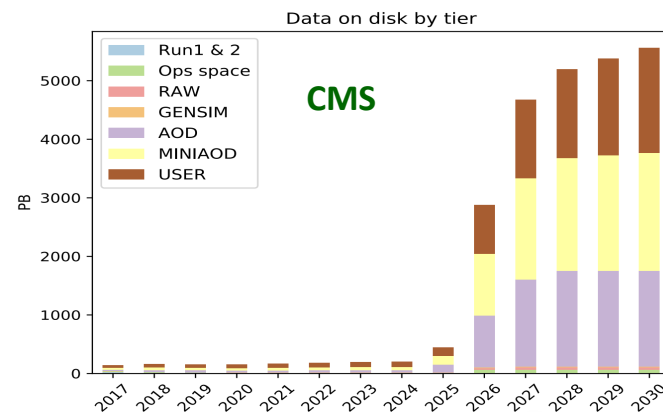
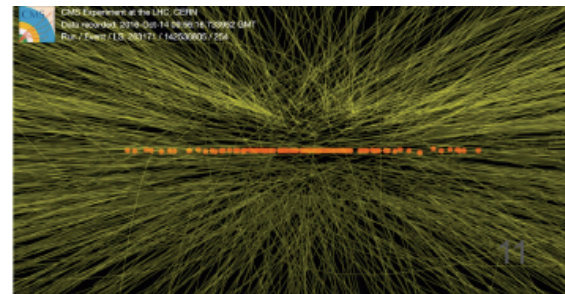


# Os próximos 50 anos no CERN!

Até 2038 - LHC – alta intensidade

Inicia-se agora o caminho para novos aceleradores (em estudo o FCC )

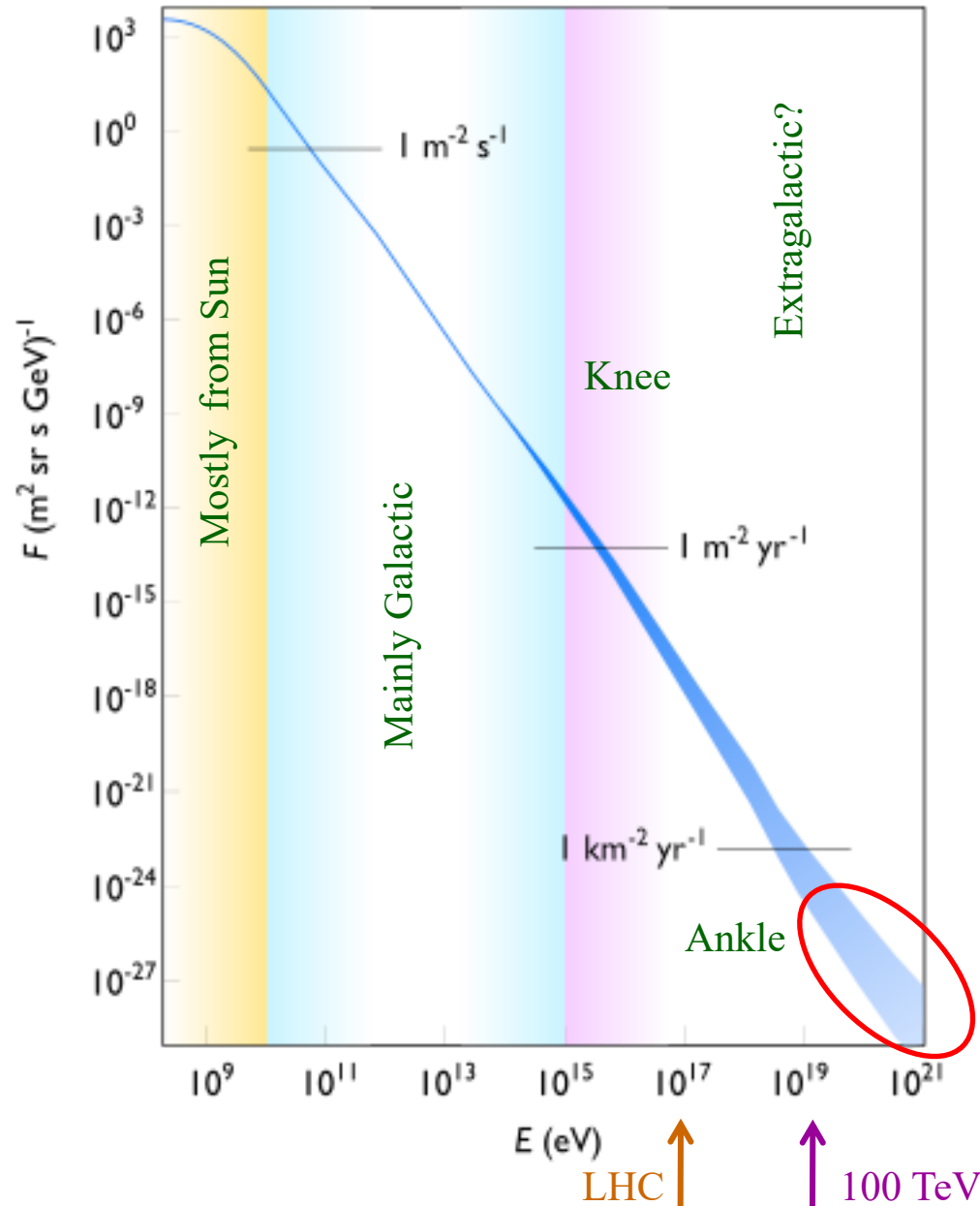
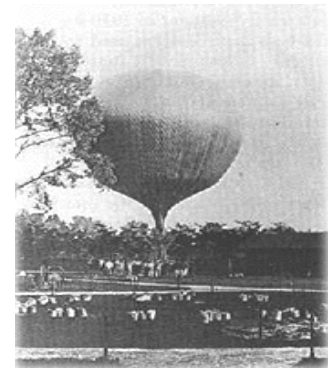
E muito R&D e desafios tecnológicos a vencer !





# Raios cósmicos carregados

Viktor Hess, 1912



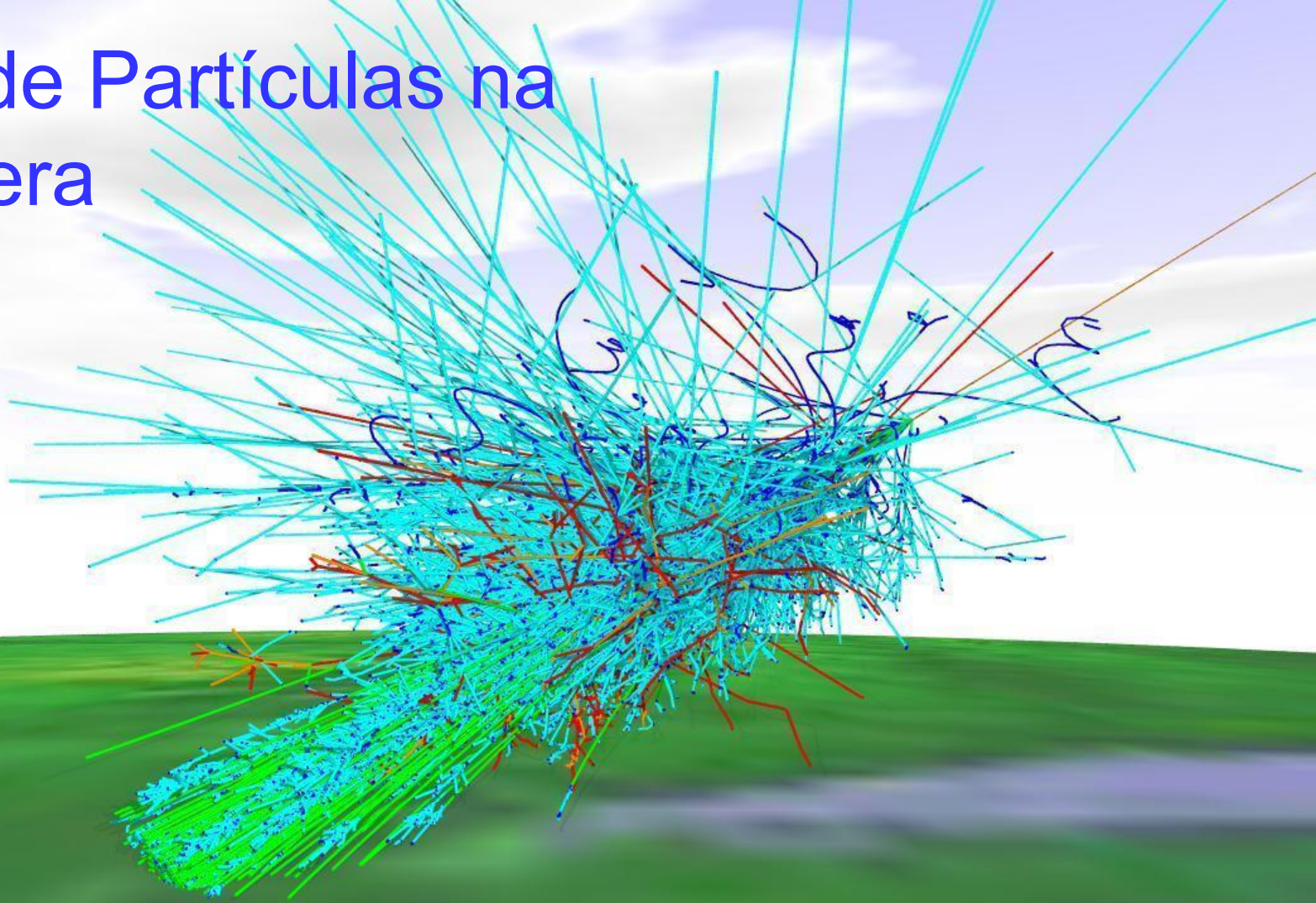
$$\frac{dN}{dE} \propto E^{-\alpha}$$

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

# Um LHC do tamanho da órbita de Mercúrio !!!

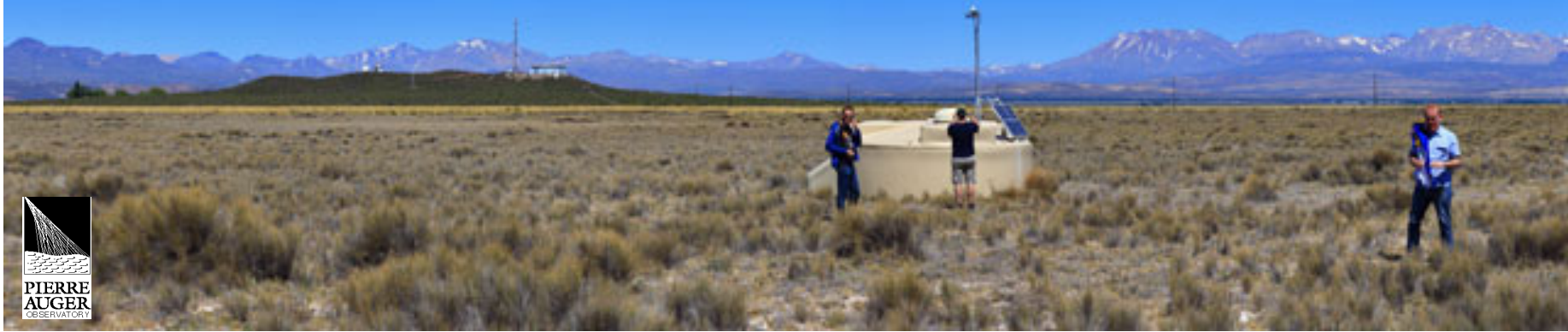
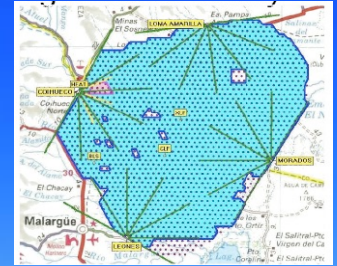


# Física de Partículas na atmosfera





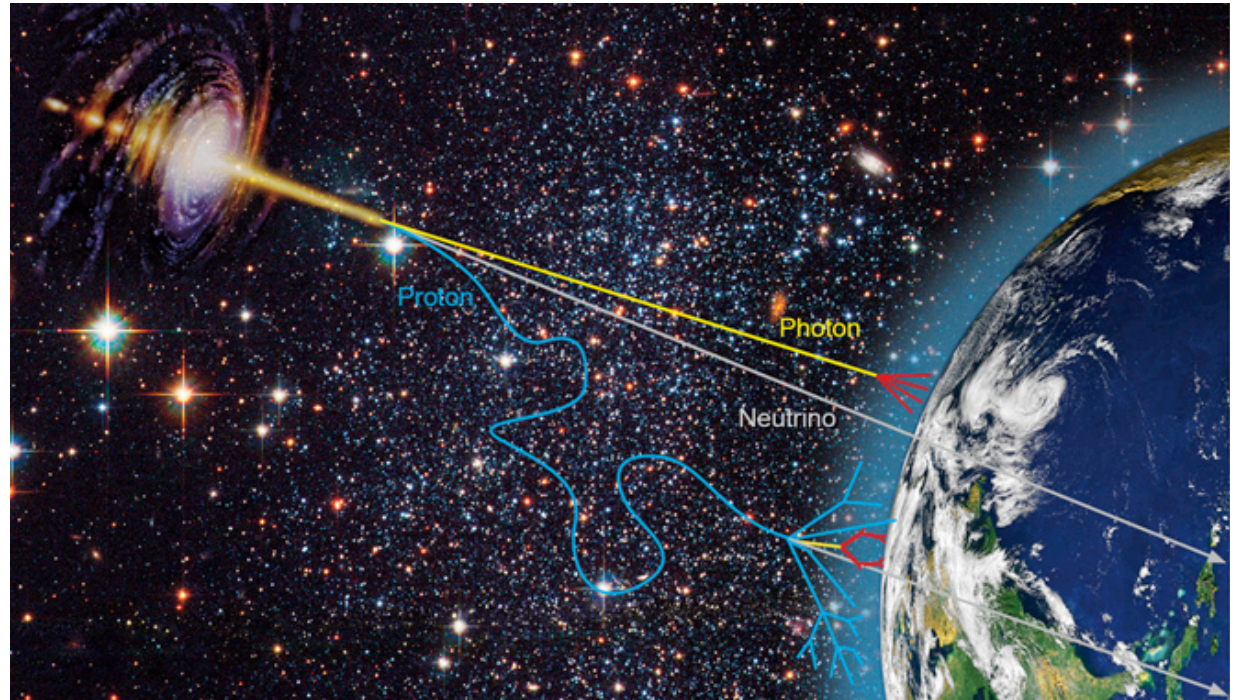
# Na pampa argentina



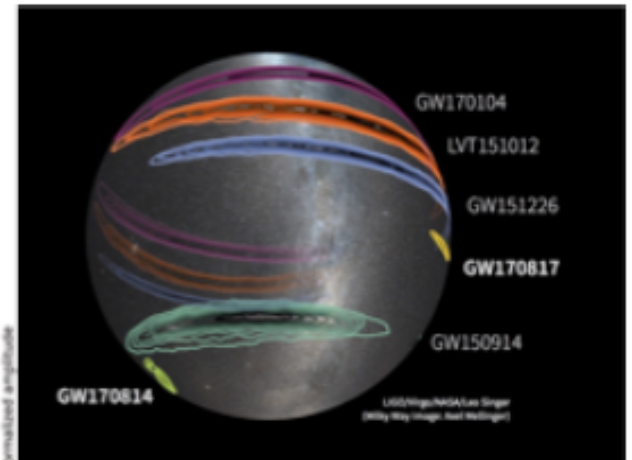
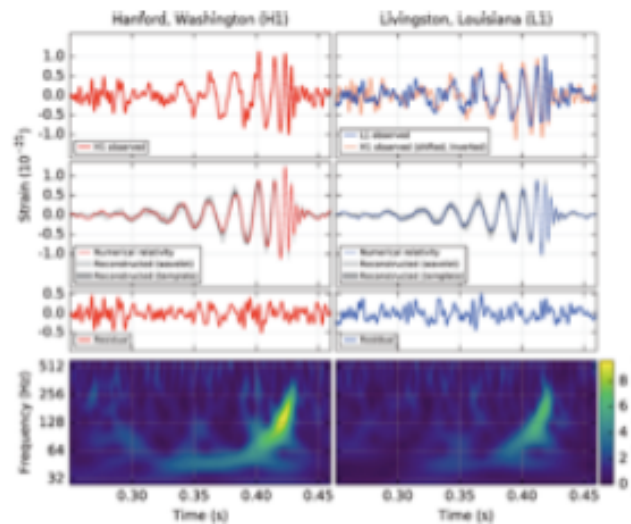


# Mensageiros do Universo

$\gamma$ , p, nuclei,  $\nu$

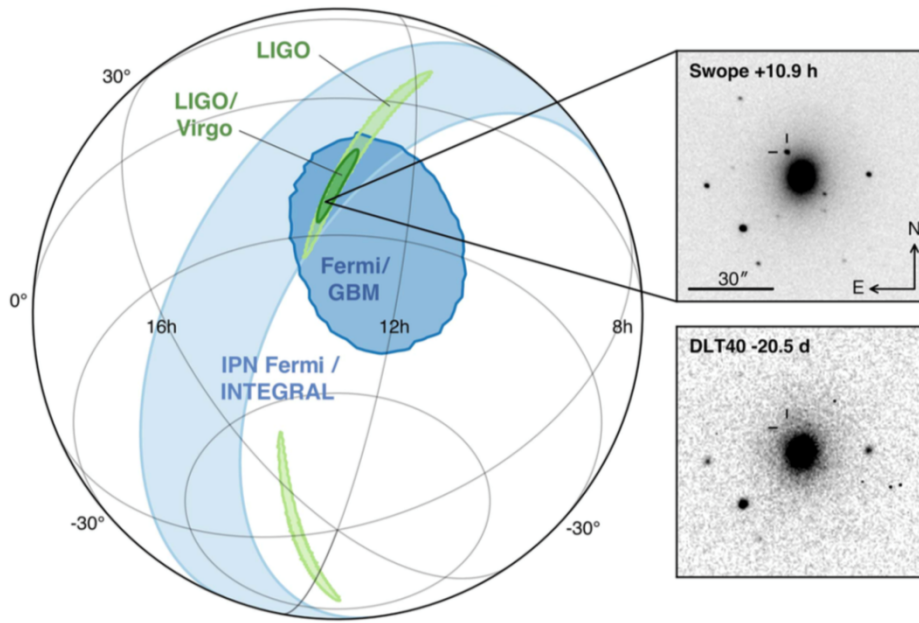


GW

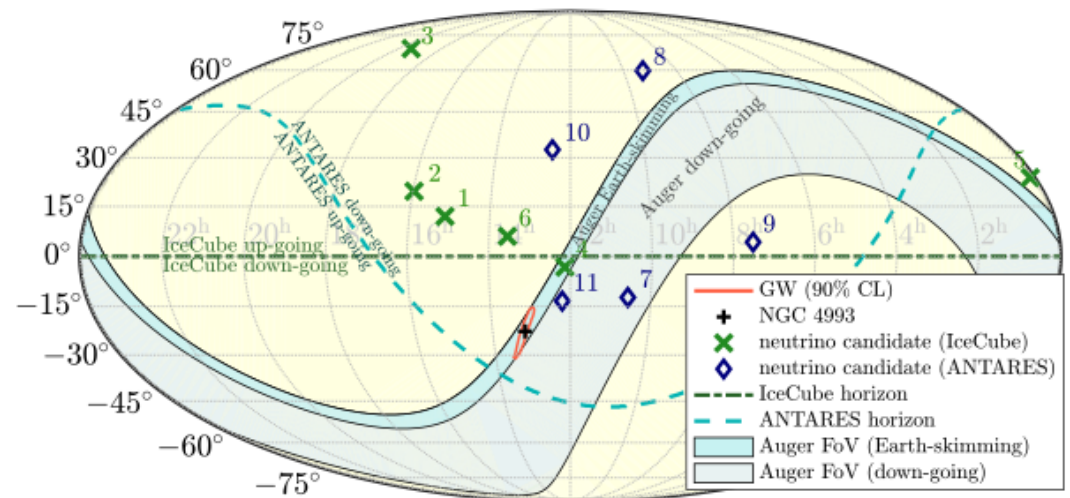
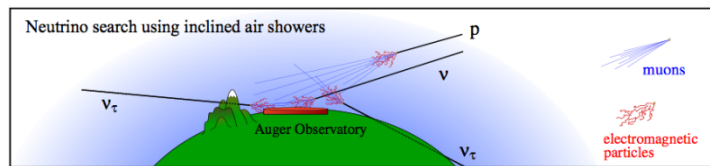




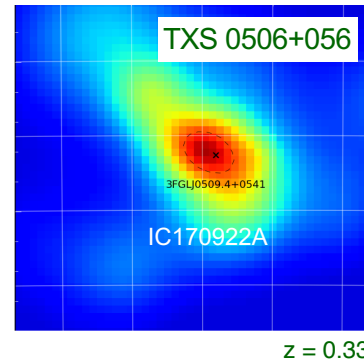
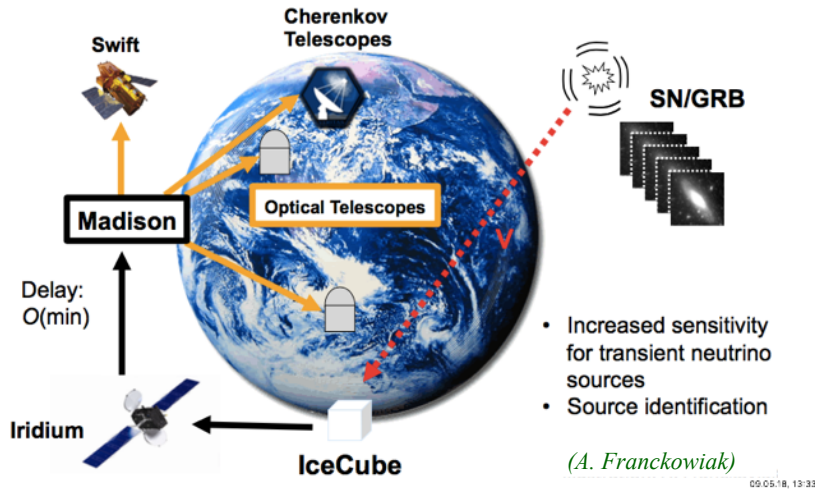
# GW170817



A primeira observação  
“multimessenger” da  
fusão de duas estrelas  
de neutrões



# A primeira fonte de neutrinos astrofísicos de alta energia



MAGIC: flare E > 100 GeV

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

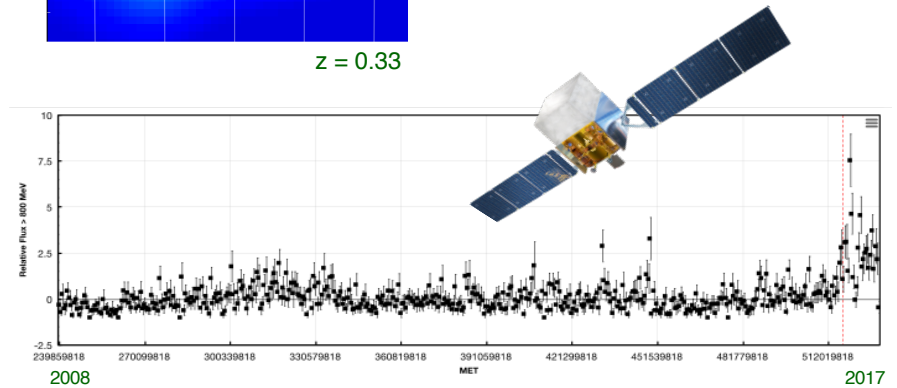
On 22 Sep, 2017 IceCube detected a track-like, very-high-energy event with a high probability of being of astrophysical origin. The event was identified by the Extremely High Energy (EHE) track event selection. The IceCube detector was in a normal operating state. EHE events typically have a neutrino 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](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.

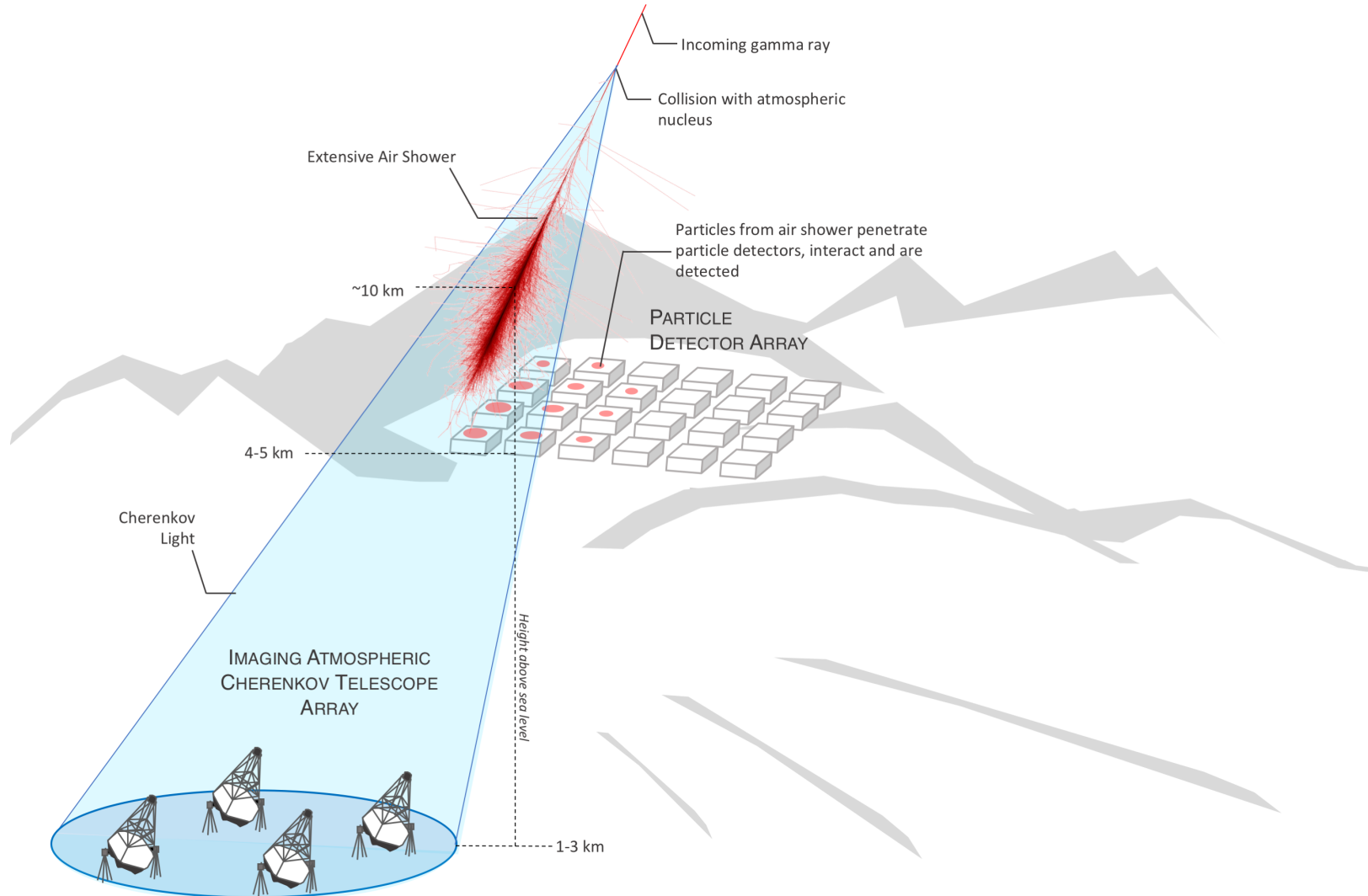
09.05.18, 13:33



FERMI: flare (found 6 days later)

IceCube 170922A, publications in preparation

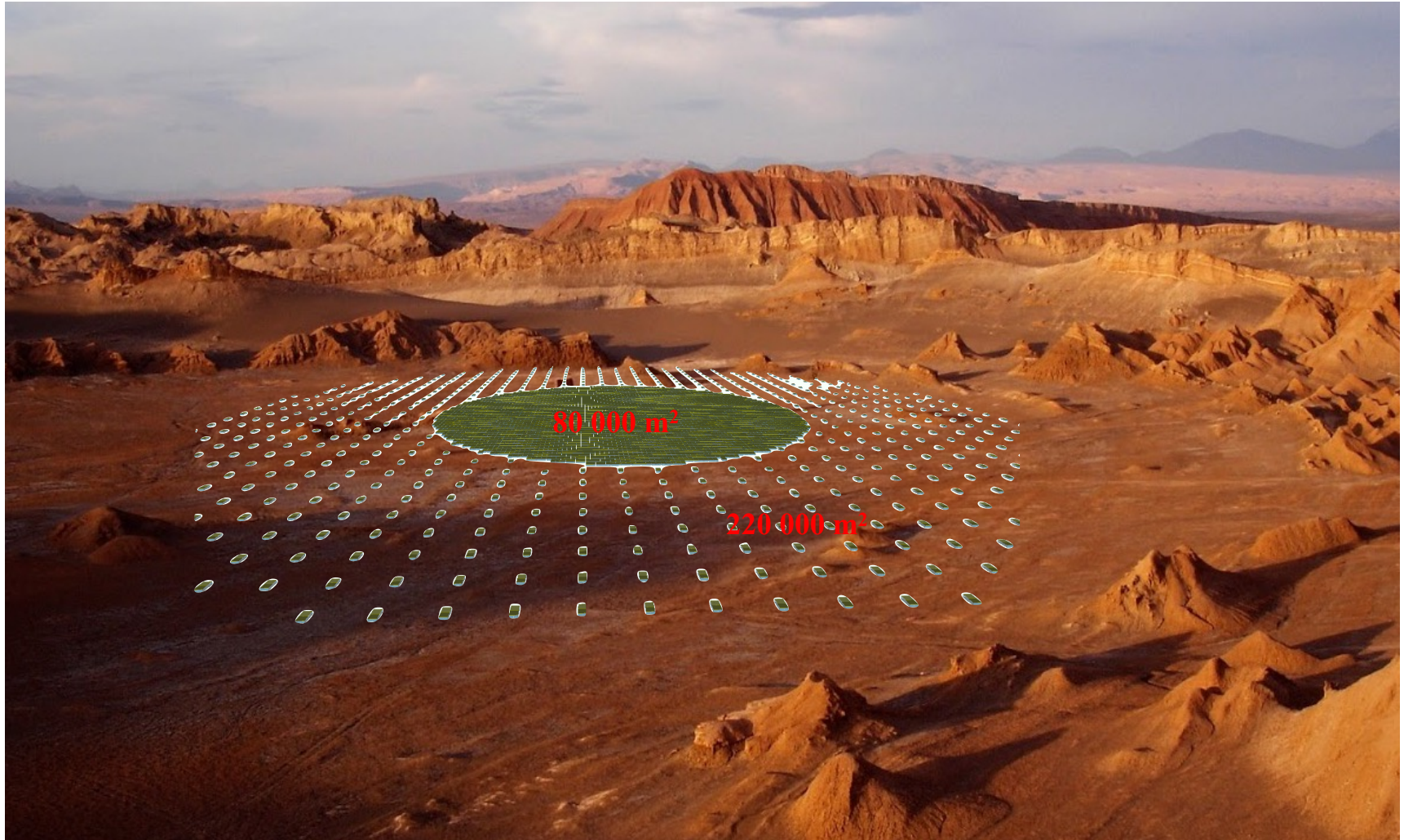
# Detector fotões no alto das montanhas ..



Not to scale



# A colaboração SWGO



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



# Da Terra aos Céus ...



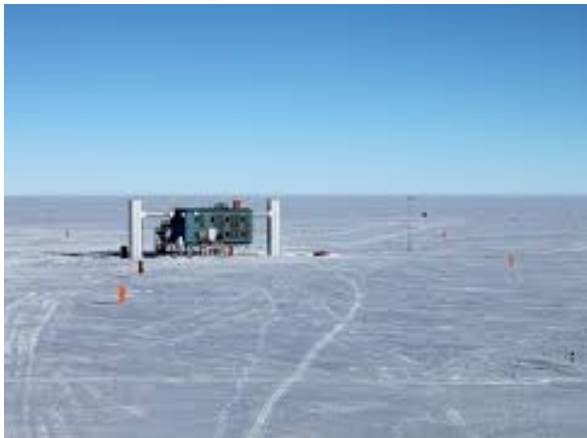
AMS



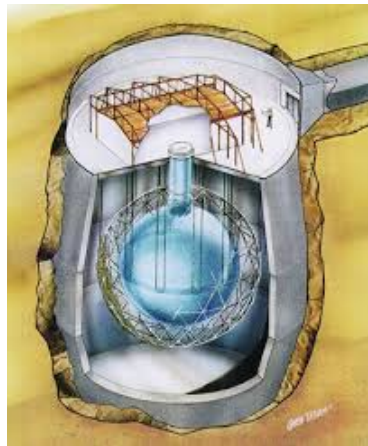
Fermi



LIGO



Ice Cube



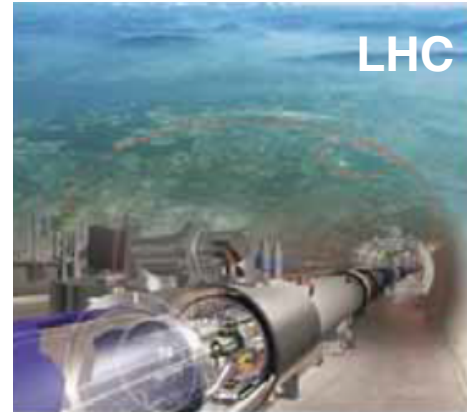
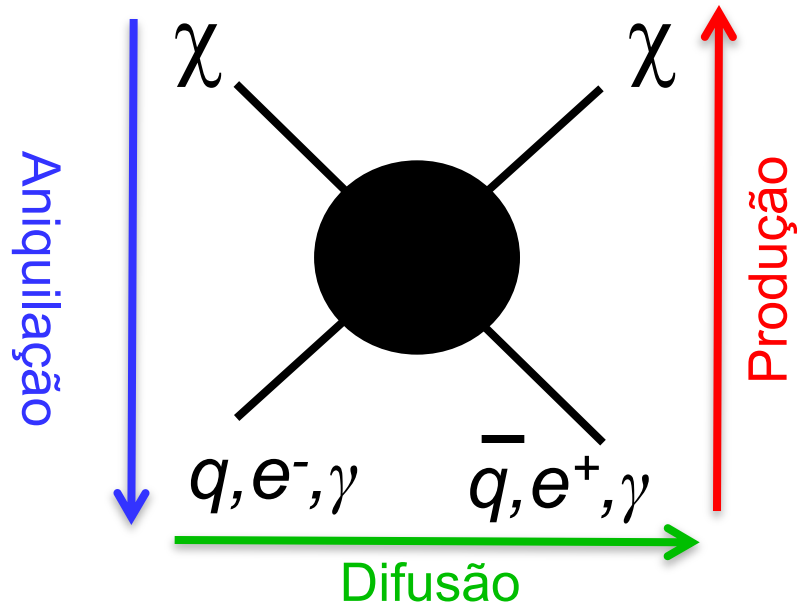
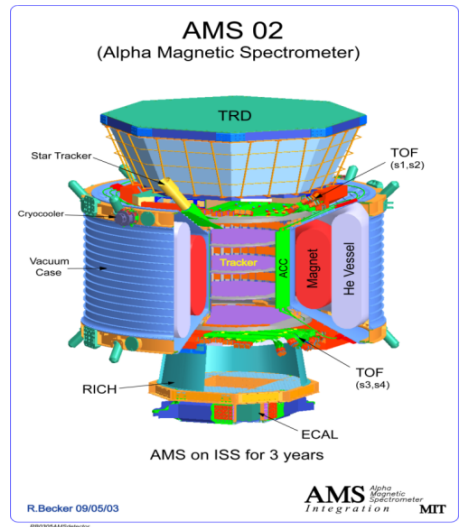
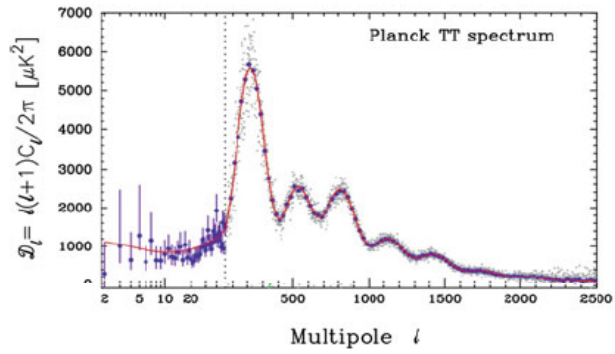
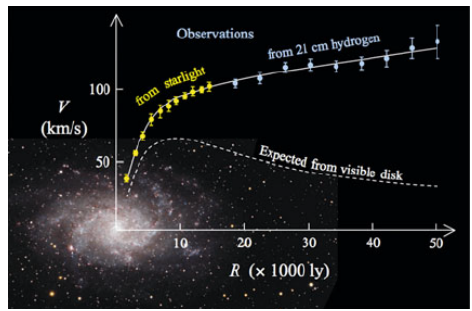
SNO+



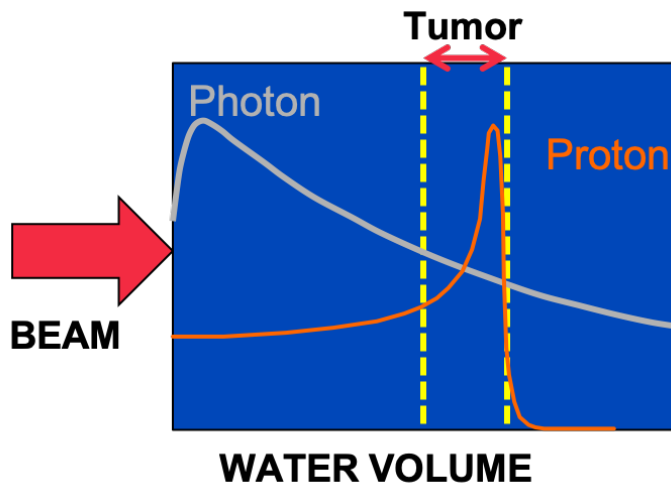
LST - CTA

E muitos mais .....

# Matéria Escura



# Terapia com Protões

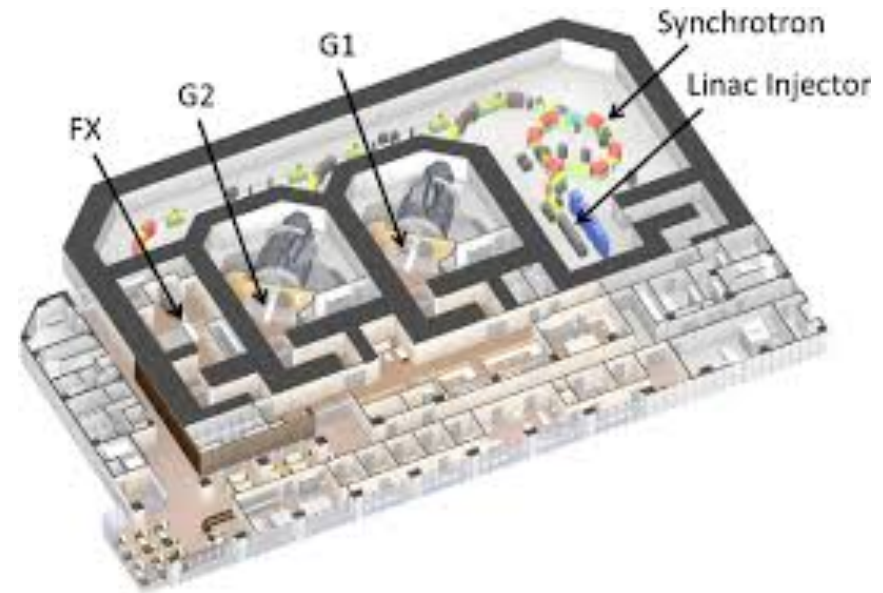


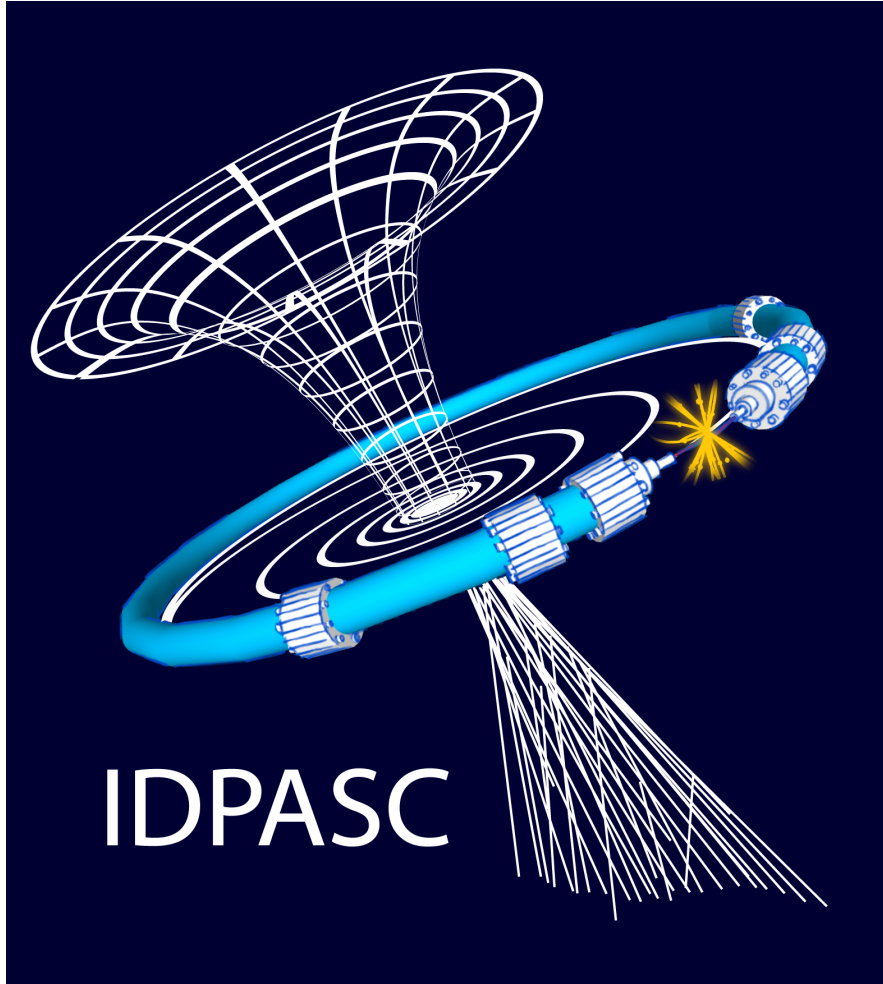
Grupo Hospitalar IPO, IST, LIP, ICNAS (UC)

Associação Portuguesa de Proto-Terapia e Tecnologias Avançadas para a Prevenção e Tratamento do Cancro (ProtoTera)

Loures (CTN): ciclotrão de 250 MeV com duas salas de tratamento e uma sala dedicada a desenvolvimento tecnológico, industrial e científico

Coimbra (ICNAS): ciclotrão de 70 MeV com uma sala de tratamento para tumores oculares e produção de radioisótopos e radiofármacos para diagnóstico e terapia

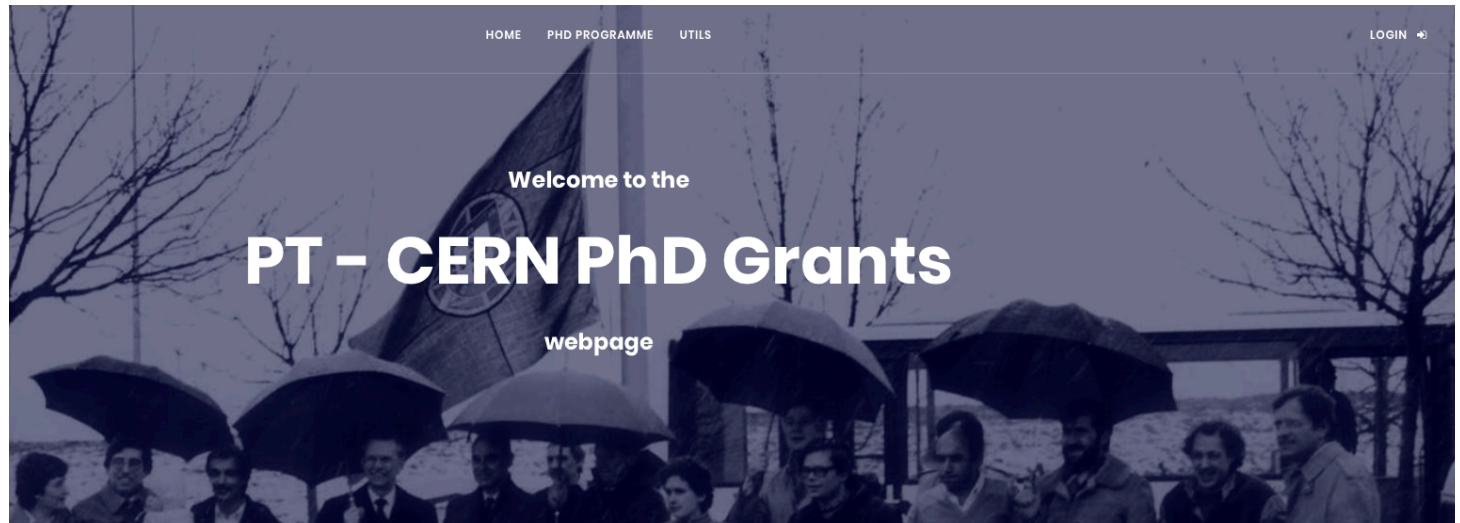




# International Doctorate Network in Particle Physics, Astrophysics and Cosmology

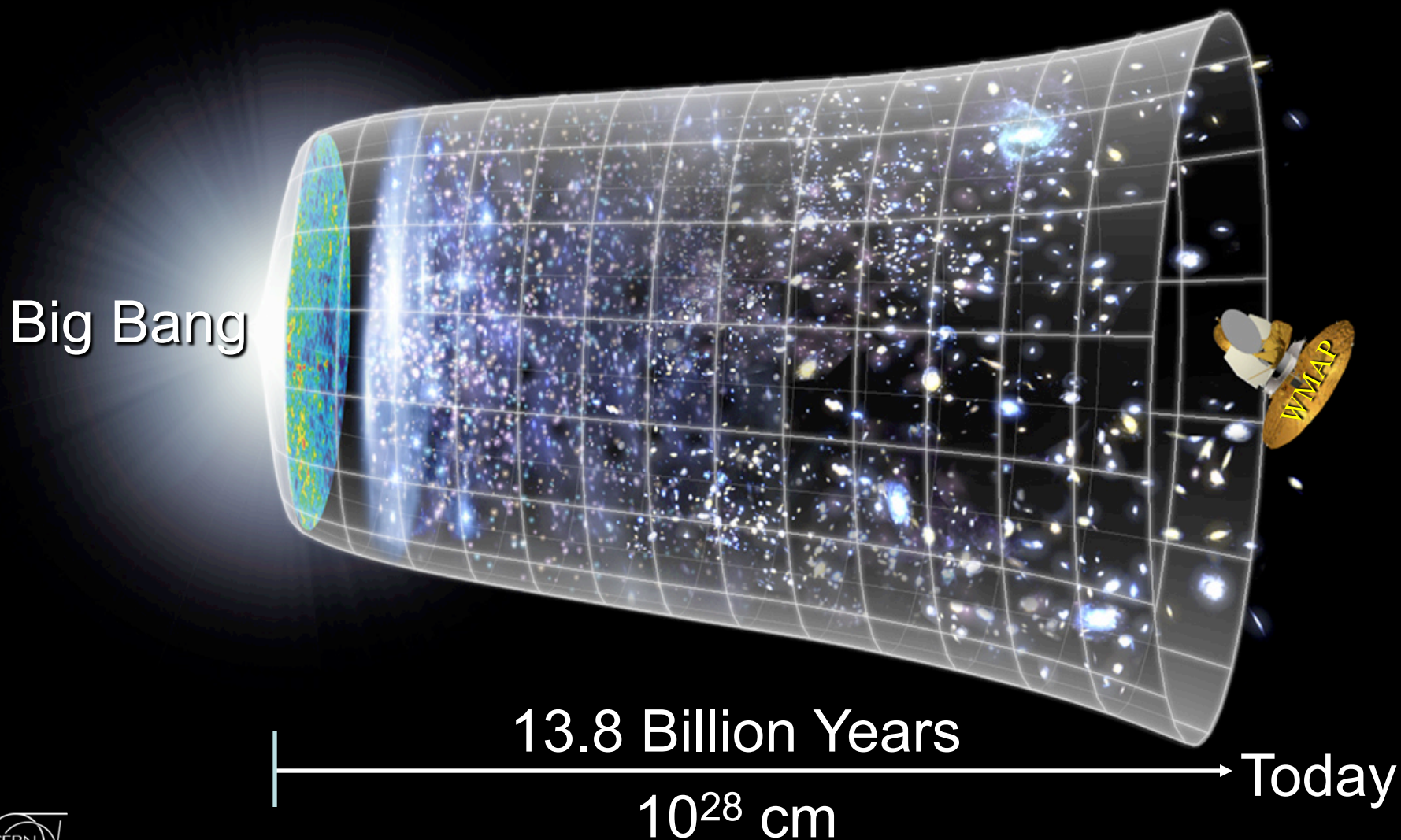


# Bolsas de Doutoramento



FCT – ProtoTera PhD Grants

# O Universo para compreender, ...



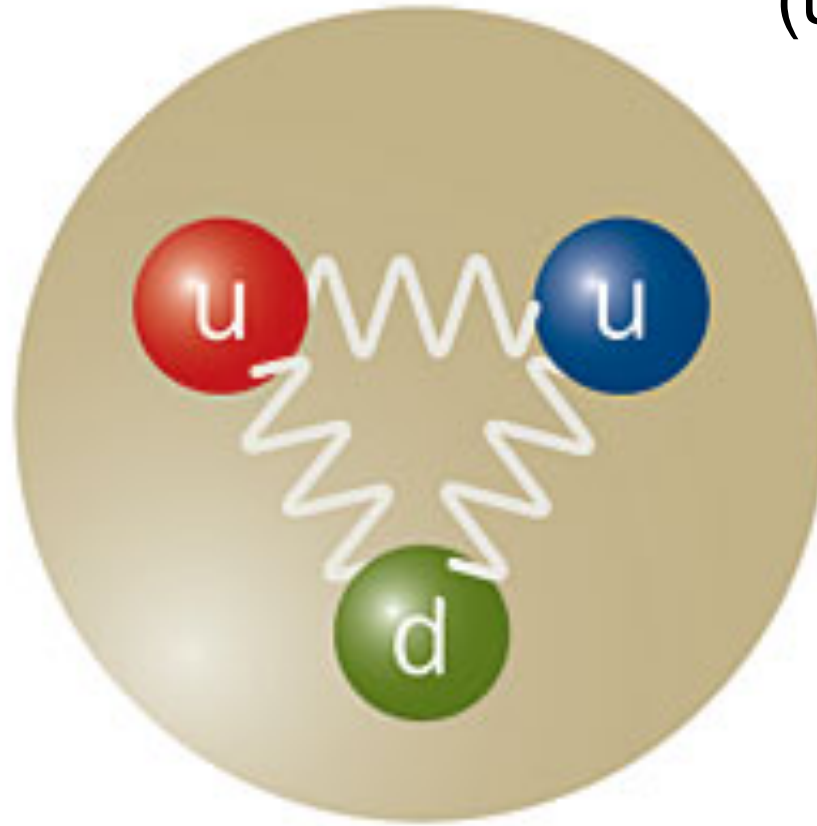






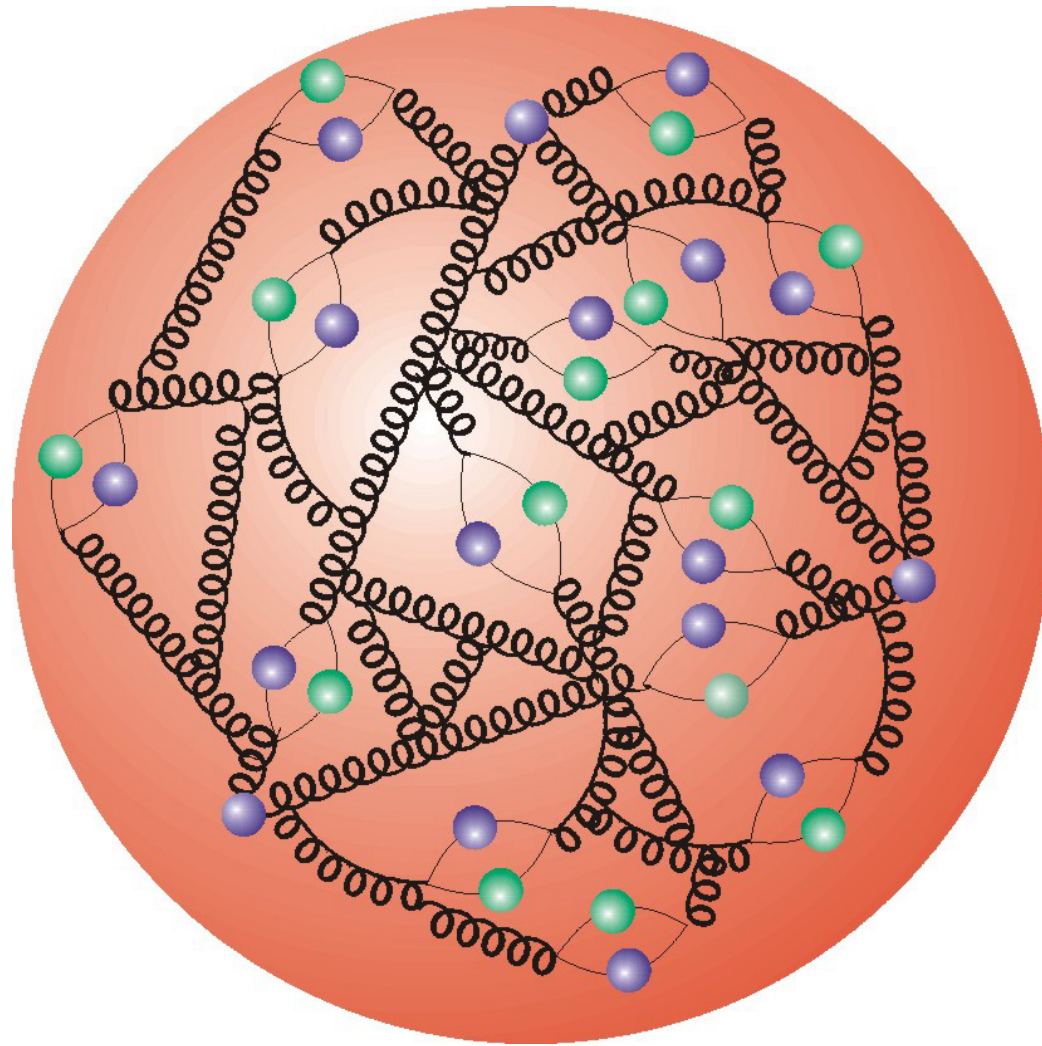
# O Protão

(uud)



$10^{-14}$  m

# O Protão



# A massa do Protão



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



# A massa do Protão



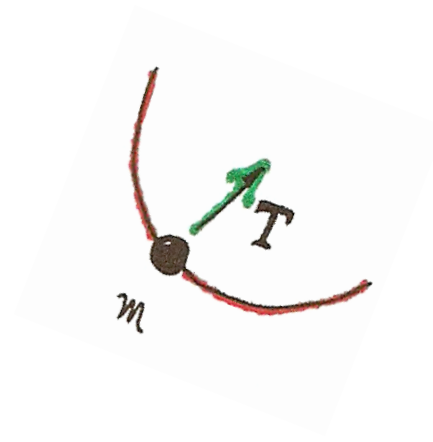
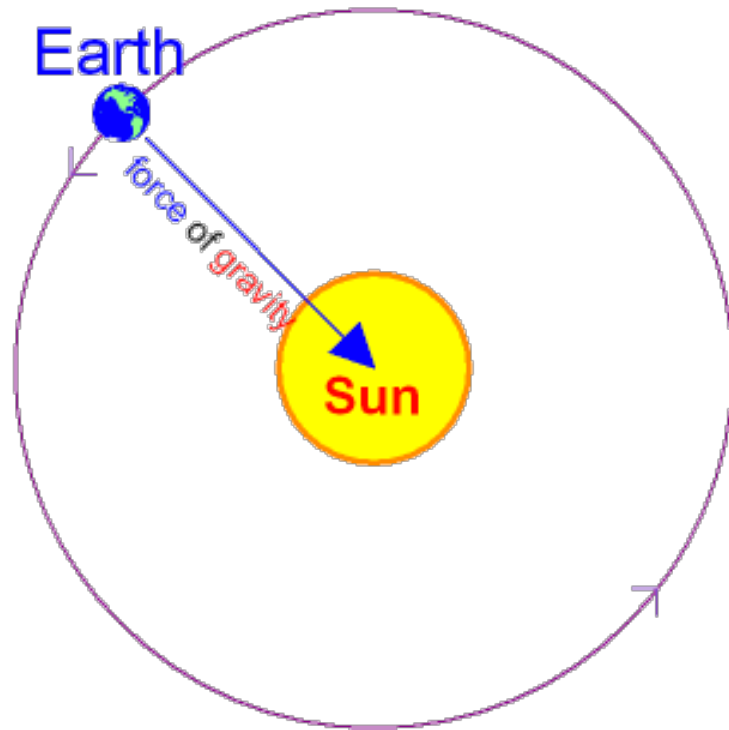
$$M = \sum m_{\text{quarks}} + E_{\text{campo}}/c^2$$

$$938 \sim ( 15 + 925) \text{ MeV}/c^2$$

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



# A massa do Sol

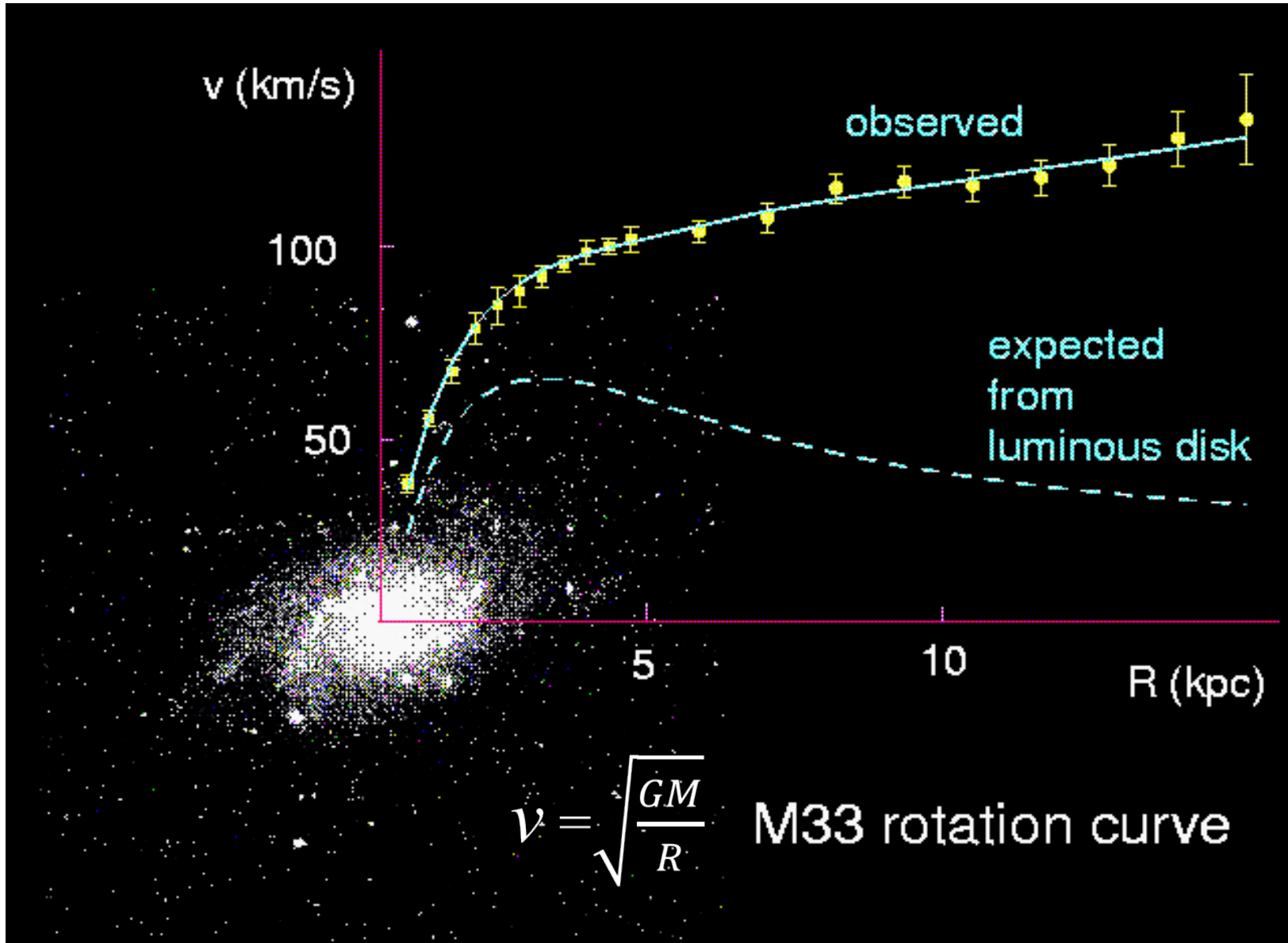


$$F_c = \frac{m v^2}{r}$$

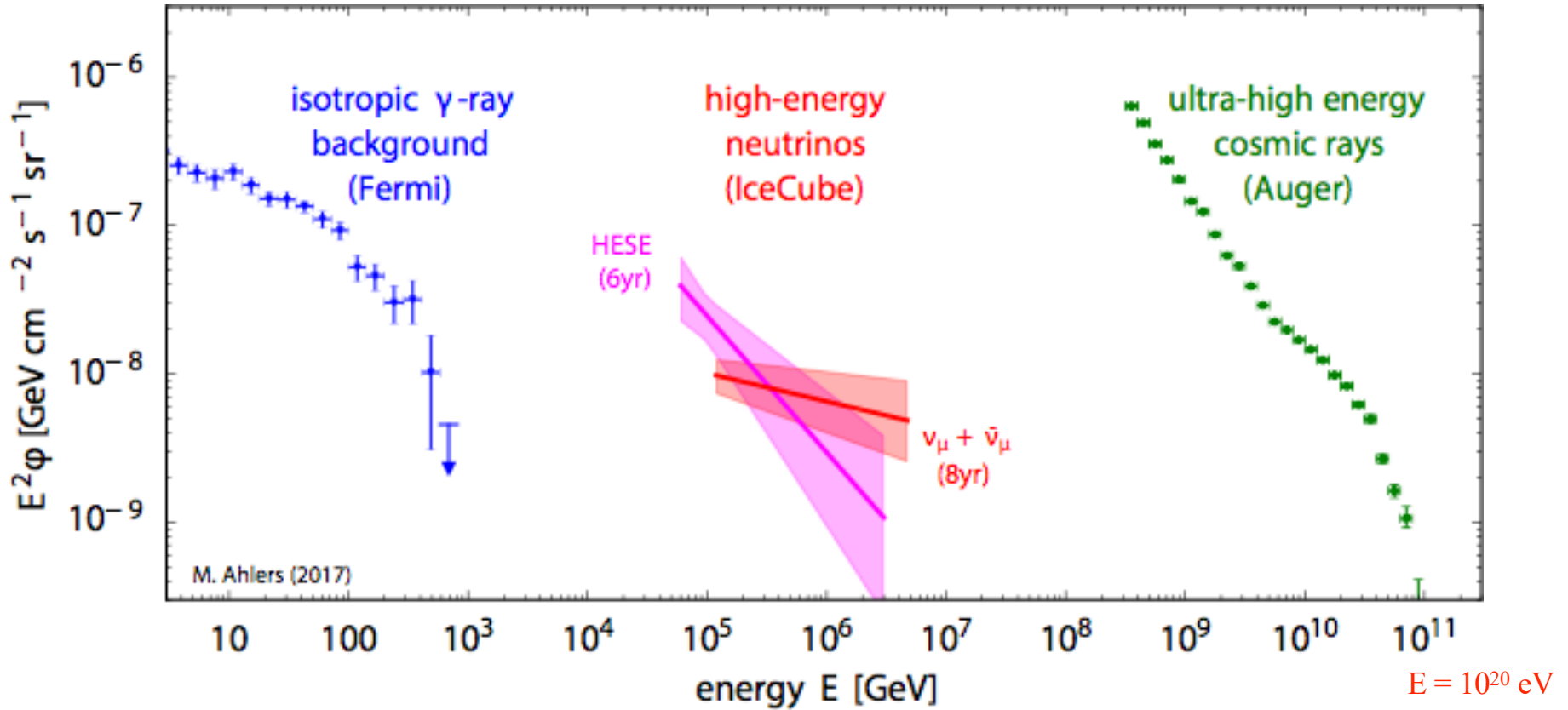
$$\frac{m_T v^2}{R} \approx G \frac{m_T M_S}{R^2}$$

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

# A velocidade de rotação das estrelas periféricas

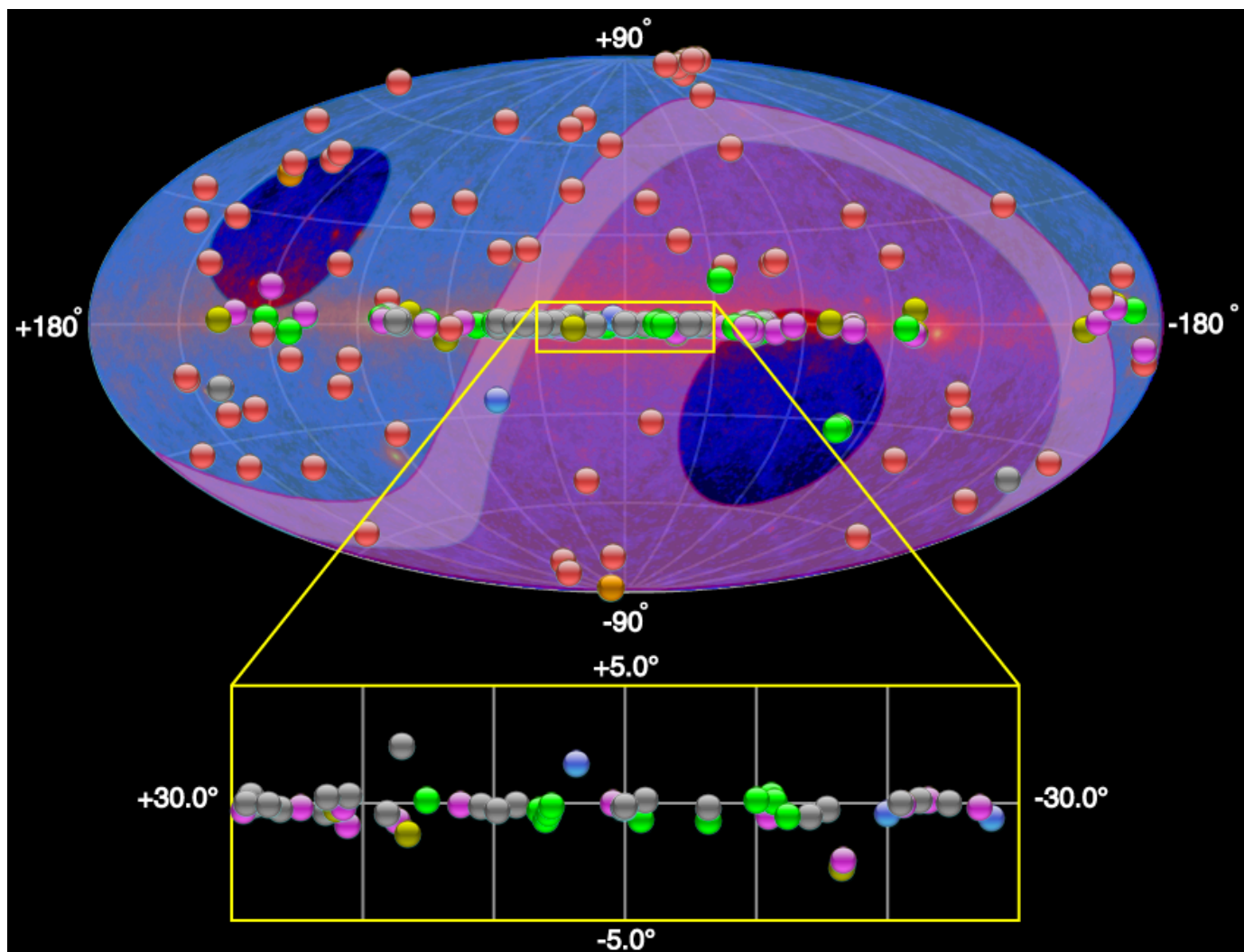


# The Universe at the highest energies !



Energy density per decade similar in all three messenger particles

# Fontes raios gamma de alta energia (TeV)



- ### Source Types
- PWN
  - Binary XRB PSR Gamma BIN
  - HBL IBL FRI FSRQ Blazar LBL AGN (unknown type)
  - Shell SNR/Molec. Cloud Composite SNR Superbubble
  - Starburst
  - DARK UNID Other
  - uQuasar Star Forming Region Globular Cluster Cat. Var. Massive Star Cluster BIN BL Lac (class unclear) WR

(>200)



# As bolhas de Fermi

