



Universidad Nacional de Río Negro

Int. Partículas, Astrofísica & Cosmología - 2016

- **Unidad** 01 – Relatividad
- **Clase** 0105 – 05/16
- **Fecha** 08 Sep 2016
- **Cont** Partículas 2
- **Cátedra** Asorey
- **Web** github.com/asoreyh/unrn-ipac
- **Youtube** www.youtube.com/watch?v=nshZHCdkMUQ
- **Archivo** a-2016-U01-C05-0908-particulas-2



Contenidos: un viaje en el tiempo

HOW DID OUR UNIVERSE BEGIN?

Some 13.8 billion years ago our entire visible universe was contained in an unimaginably hot, dense point, a billion times the size of a nuclear particle. Since then it has expanded—a lot—fighting gravity all the way.

Inflation
The universe expands, cools
A repulsive energy field inflates space faster than light can travel through it with a soup of subatomic particles called quarks.
Age: 10^{-3} milliseconds
Size: Infinitesimal to golf ball

Early building blocks
Quarks clump into protons and neutrons, creating the building blocks of atomic nuclei. Perhaps dark matter forms.
Age: .01 milliseconds
Size: 0.1-millionth present size

First nuclei
As the universe continues to cool, the lightest nuclei of hydrogen and helium arise. A thick fog of particles blocks all light.
Age: .01 to 200 seconds
Size: 1-billionth present size

First atoms, first light
As electrons begin orbiting nuclei, creating atoms, the glow from their infall illuminates the universe. This light is as far back as our instruments can see.
Age: 380,000 years
Size: .0009 to 0.1 present size

The "dark ages"
For 300 million years this cold, dark universe remains in the only light: Glowing dust of dark matter that eventually forms galaxies and stars. Nuclear fusion lights up the stars.
Age: 300 million years
Size: 0.1 present size

Gravity wins: first stars
Dense gas clouds collapse under their own gravity and attract dark matter that will become galaxies and stars. Nuclear fusion lights up the stars.
Age: 10 billion years
Size: .77 present size

Antigravity wins
After being slowed for billions of years by gravity, cosmic expansion accelerates again. The culprit: dark energy. Its nature: unclear.
Age: 13.8 billion years
Size: Present size

Today
The universe continues to expand, becoming ever less dense. As a result, fewer new stars and galaxies are forming.
Age: Present size
Size: Our solar system

COSMIC QUESTIONS

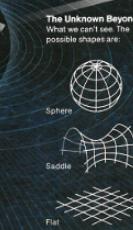
In the 20th century the universe became a story—a scientific one. It had always been seen as static and eternal. Then astronomers observed other galaxies flying away from ours, and Einstein's general relativity theory implied space itself was expanding—which meant the universe had once been denser. What had seemed eternal now had a beginning and an end. But what beginning? What end? Those questions are still open.

WHAT IS OUR UNIVERSE MADE OF?



WHAT IS THE SHAPE OF OUR UNIVERSE?

Einstein discovered that a star's gravity curves space around it. But is the whole universe curved? Might space close up on itself like a sphere or curve the other way, opening out like a saddle? By studying cosmic background radiation, scientists have found that the universe is poised between the two: just dense enough with just enough gravity to be almost perfectly flat, at least the part we can see. What lies beyond we can't know.



DO WE LIVE IN A MULTIVERSE?

What came before the big bang? Maybe other big bangs. The uncertainty principle holds that even the vacuum of space has quantum energy fluctuations. Inflation theory suggests universes exploded from such a fluctuation—a random event that, odds are, had happened many times before. Our cosmos may be one in a sea of others just like ours—or nothing like ours. These other cosmos will very likely remain forever inaccessible to observation; their possibilities limited only by our imagination.

HOW WILL IT END?

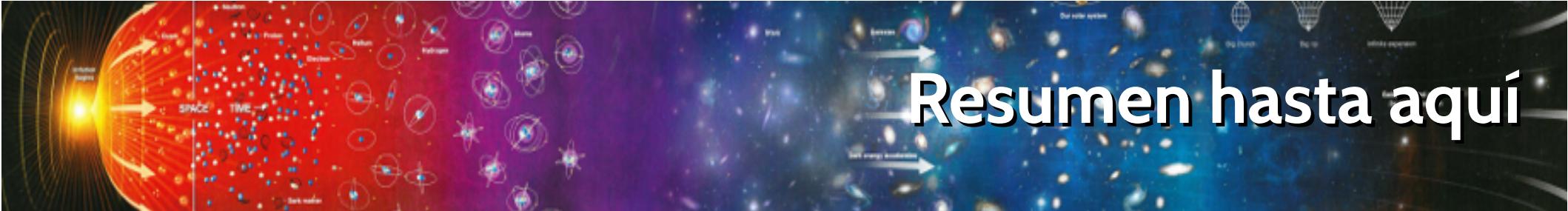
Which will win in the end, gravity or antigravity? Is the density of matter enough for gravity to halt or even reverse cosmic expansion, leading to a big crunch? It seems unlikely—especially given the power of dark energy, a kind of antigravity. Perhaps the acceleration in expansion caused by dark energy will trigger a big rip that shreds everything, from galaxies to atoms. If not, the universe may expand for hundreds of billions of years, long after all stars have died.



Unidad 1 Partículas 1 *todo es relativo*



Fly through the universe on our digital edition.
LONDON PRINTERS, NEWCASTLE FABRIC
GENERAL PRINTERS, ART WORKMANER DESIGN
SOURCES: CHARLES BENNETT, JOHN
HUCHENBERG, ANDREW LAMBERT, UNIVERSITY OF CHICAGO
CONTRIBUTOR: ROBERT STOKE, NATIONAL GEOGRAPHIC SOCIETY



Resumen hasta aquí

- Cantidad de movimiento relativista (correcto siempre):

$$\vec{p} = \gamma m \vec{v}$$

- Energía relativista (correcta siempre):

$$E = \gamma m c^2$$

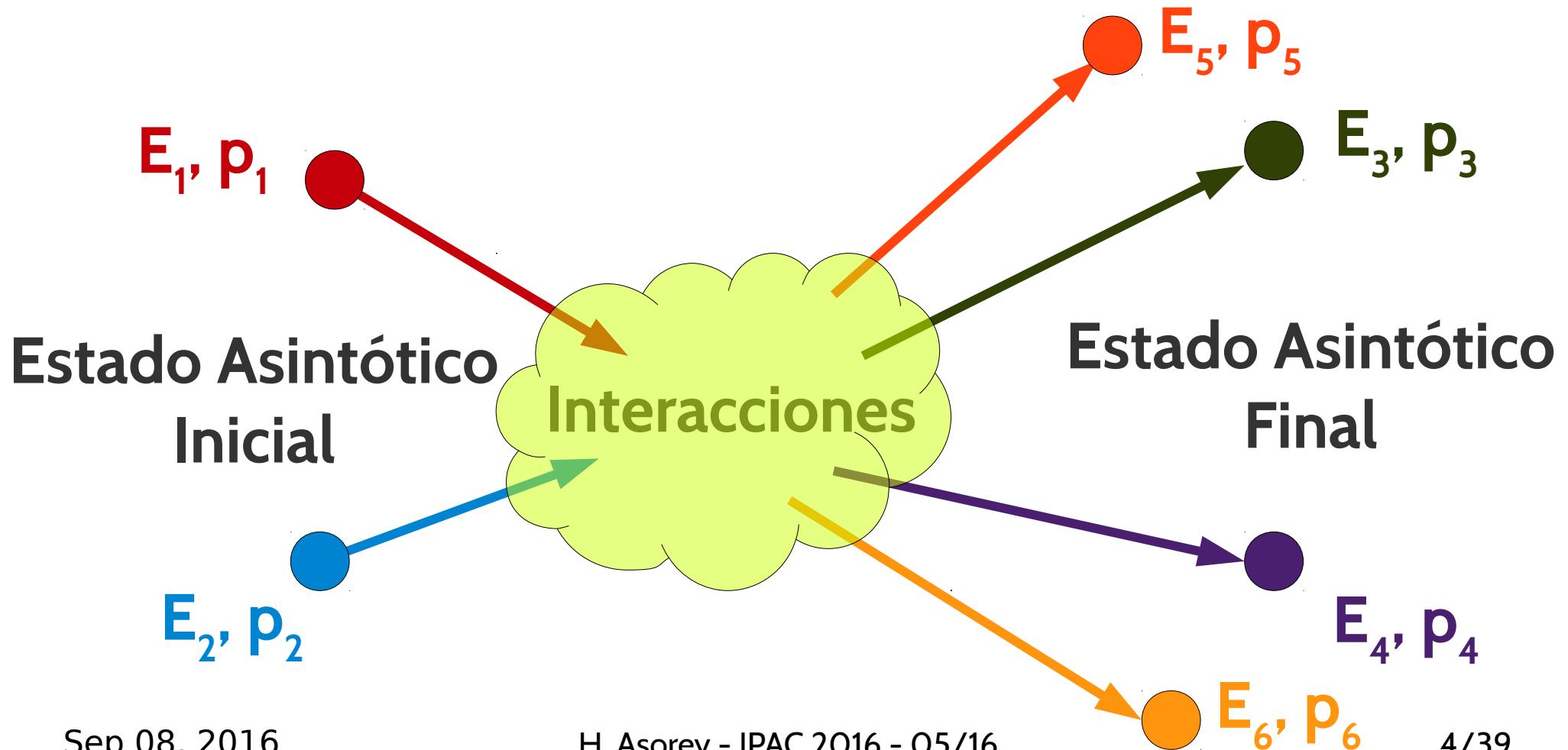
- Un nuevo invariante relativista:

$$E^2 - (pc)^2 = (mc^2)^2$$

Invariante
relativista

¿Cómo funciona la conservación?

- Y todo por pedir que c tiene que tener el mismo valor para todos los observadores inerciales.





Richard Feynman dijo

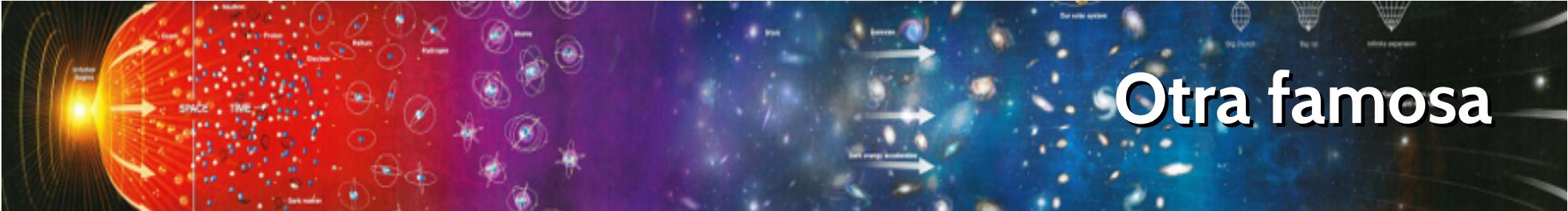
- “For those who want to learn just enough about it so they can solve problems, that is all there is to the [special] theory of relativity - it just changes Newton’s laws by introducing a correction factor to the mass”

- Luego:

$$\vec{F} = \frac{d(m\vec{v})}{dt}$$

- donde

$$m \rightarrow m\gamma = \frac{m}{\sqrt{1-\beta^2}}$$



Otra famosa

- Y ahora

$$p^2 c^2 = \frac{m^2 \beta^2 c^4}{1 - \beta^2} - \left(\frac{m^2 c^4}{1 - \beta^2} \right) + \left(\frac{m^2 c^4}{1 - \beta^2} \right)$$

$$p^2 c^2 = \frac{m^2 c^4 (\beta^2 - 1)}{1 - \beta^2} + m^2 \gamma^2 c^4$$

$$p^2 c^2 = -m^2 c^4 + m^2 \gamma^2 c^4$$

$$p^2 c^2 = -m^2 c^4 + E^2$$

- Entonces:

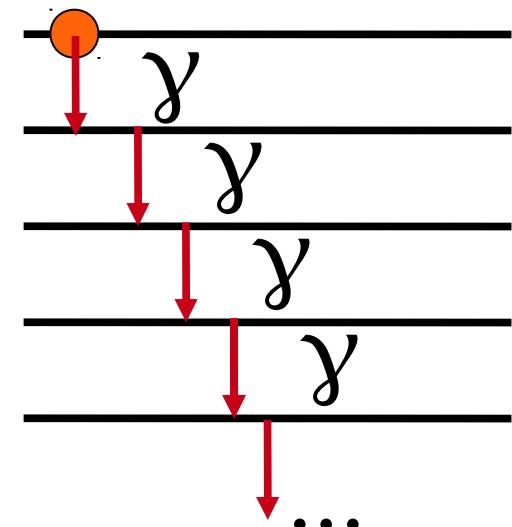
$$E^2 = p^2 c^2 + m^2 c^4 \rightarrow E = \pm \sqrt{p^2 c^2 + m^2 c^4}$$

Peeeero...

- También tenemos

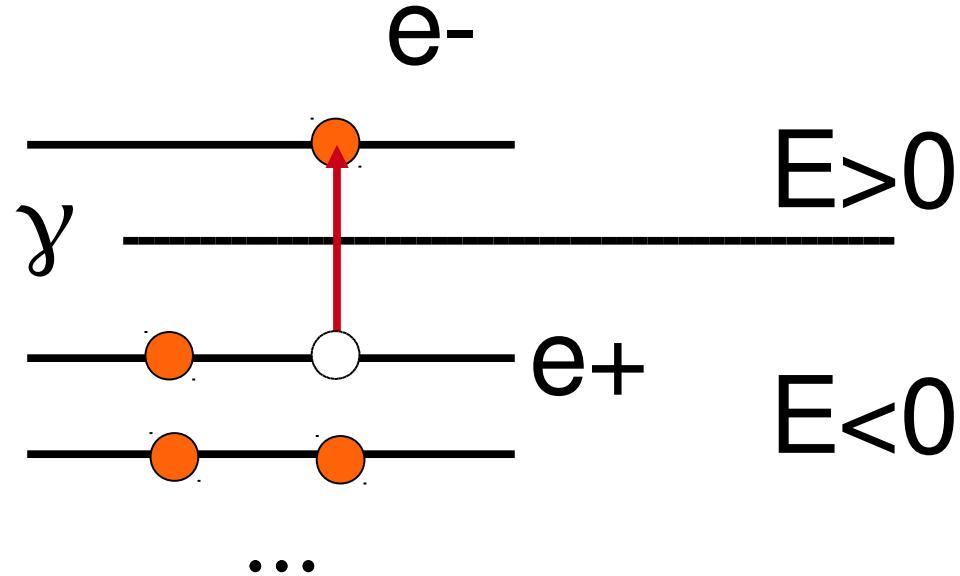
$$E^2 = p^2 c^2 + m^2 c^4 \rightarrow E = -\sqrt{p^2 c^2 + m^2 c^4}$$

- La relatividad anticipa estados con energía total negativa... → **PROBLEMAS**
- Y encima son infinitos → **MÁS PROBLEMAS**
- Aquí no tengo “estado fundamental”
- **COLAPSO**



Materia-Antimateria

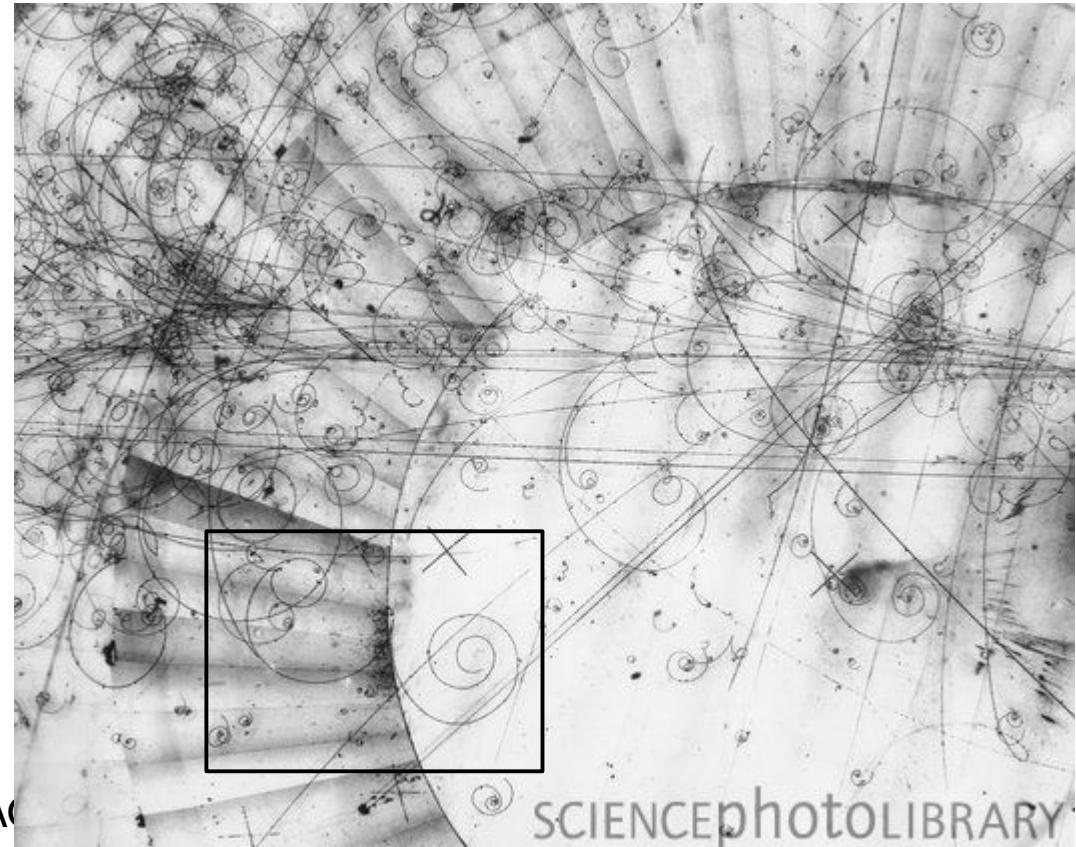
- En una interacción EM (scattering) es posible sacar un electrón del mar
- El “hueco” se ve como un electrón positivo

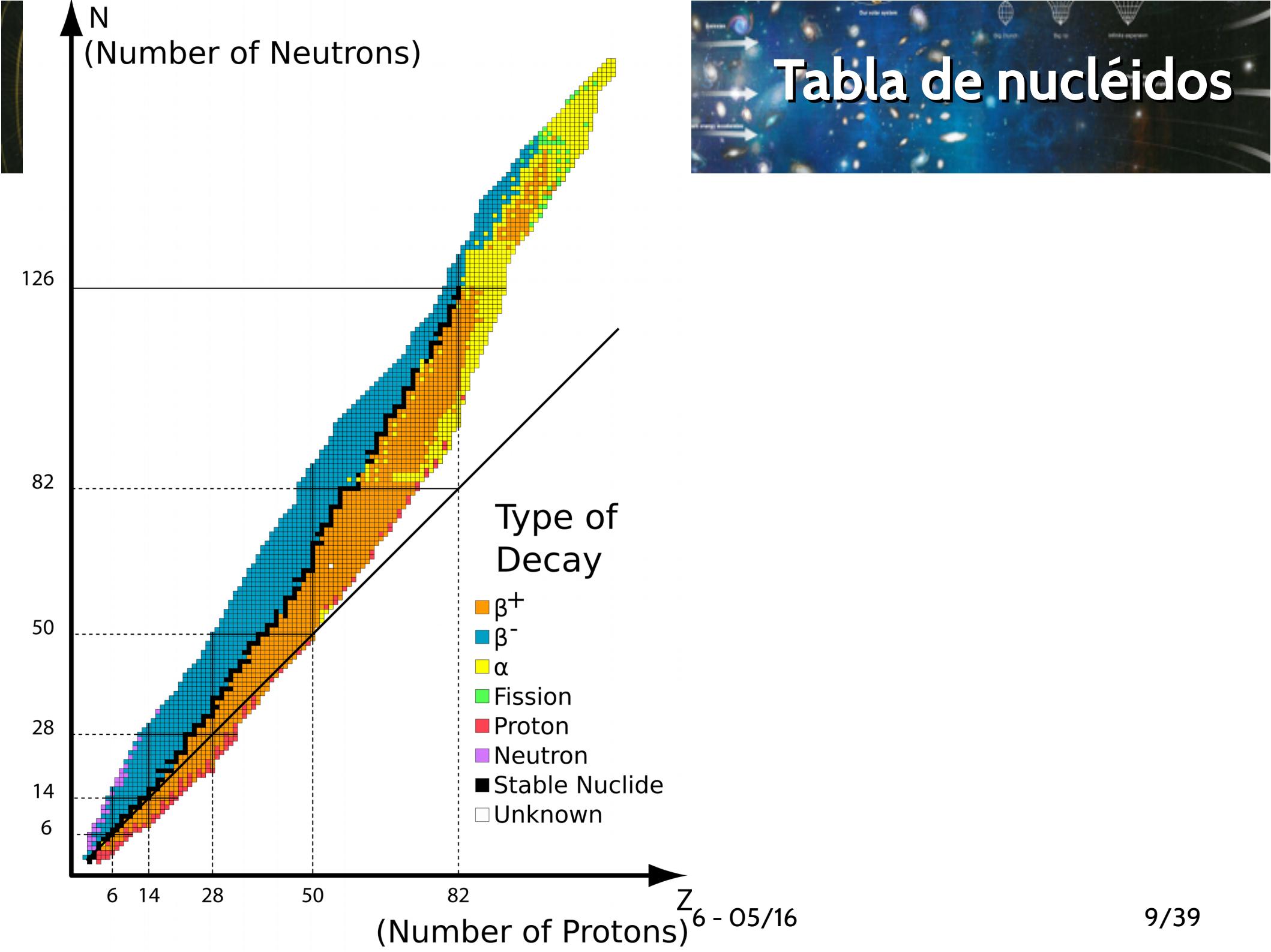


$$E_\gamma \geq 1.022 \text{ MeV}$$

Sep 08, 2016

H. Asorey - IPAC





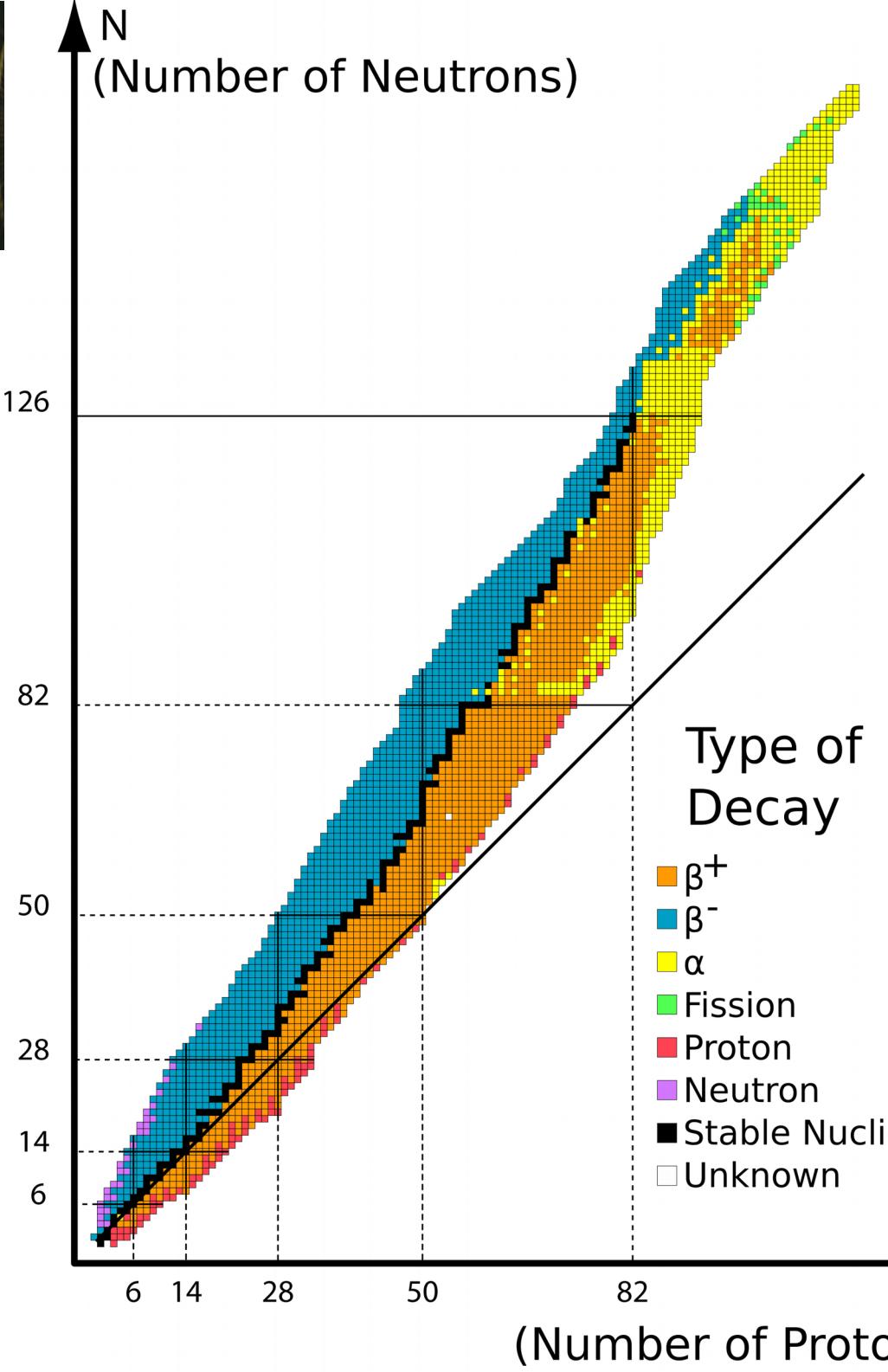


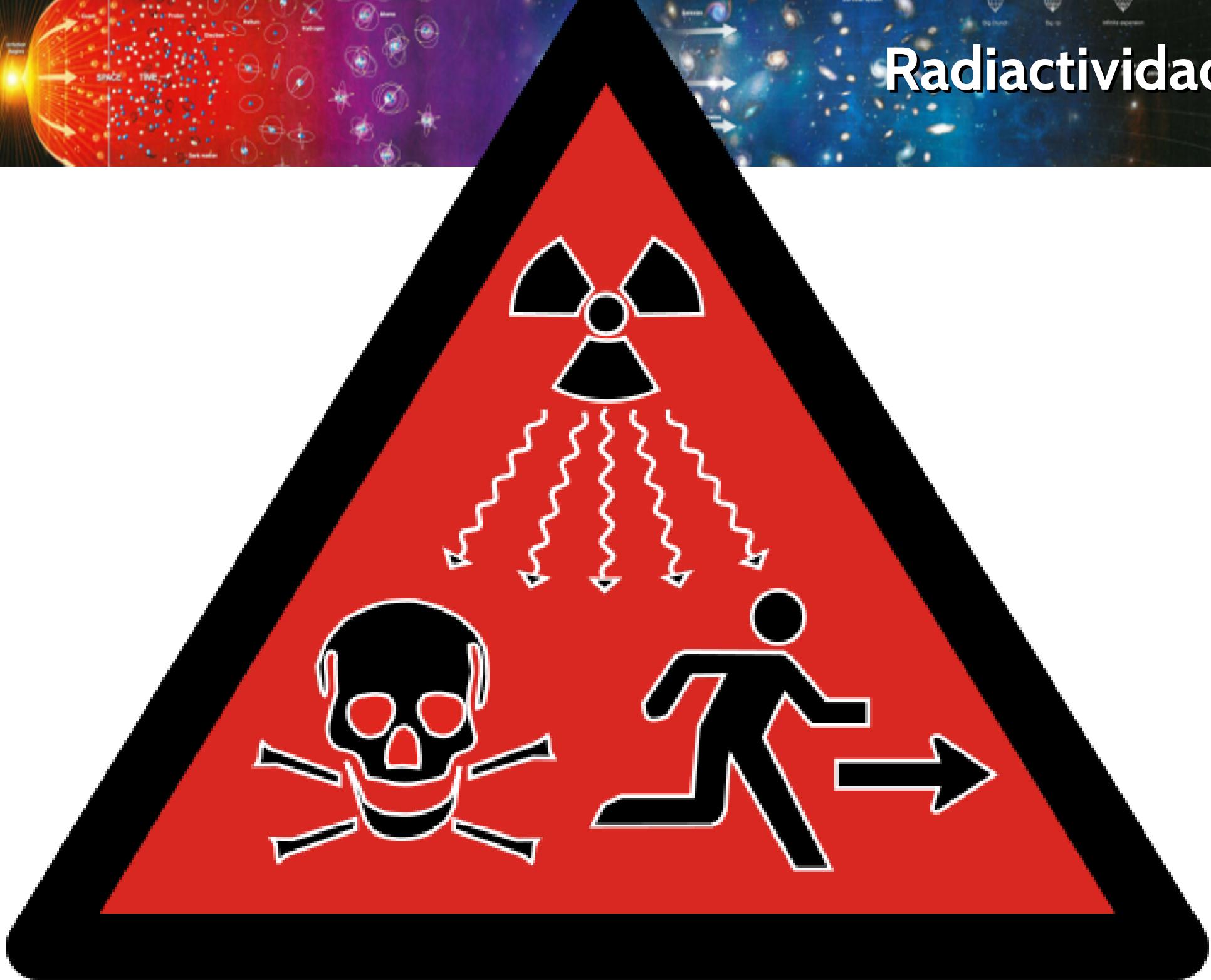
Tabla de nucléidos

- $F_E \sim Z^2$
- Neutrones sin carga eléctrica
- 1H_1 4He_2 ${}^{208}Pb_{82}$

Los neutrones ayudan a la “cohesión” (estabilidad) de los núcleos

Fuerza Fuerte

Radiactividad





Radiactividad

- **Fenómeno físico por el cual algunos elementos inestables decaen en otros más estables emitiendo radiación ionizante (Energías típicas: keV – MeV).**

Tipos:

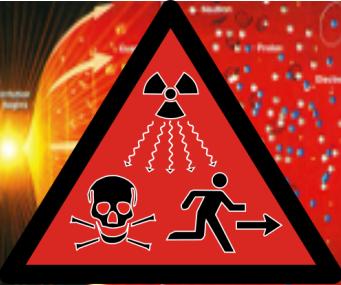
- **Alfa:** emisión de un núcleo de Helio (2 protones, 2 neutrones). Poca capacidad de penetración (las detiene un papel)
- **Beta:** emisión de un electrón o un positrón (media capacidad de penetración: láminas metálicas delgadas)
- **Gamma:** emisión de un fotón de alta energía (alta capacidad de penetración, hasta plomo)
- Otros: neutrones, protones, fisión espontánea, fragmentación



Tipos de decaimiento

- **Emisión de partículas cargadas** (alfa, beta, protón, fisión, fragmentación): implican cambios en el número atómico
- **Emisión de neutrones**: cambios en el número másico
- **Emisión de fotones**: desexcitación nuclear
- En todo decaimiento **se libera energía, Q** , usualmente en forma de energía cinética de los productos del decaimiento. **El decaimiento ocurre si y sólo si $Q>0$**
- En general, **Q es igual a la diferencia de masa entre reactivos y productos.**

$$Q = (m_{\text{reactivos}} - m_{\text{productos}}) c^2$$



Ley de decaimiento radiactivo

- **Suceso cuántico y estadístico:** no podemos saber cuando un átomo particular decaerá.
- Se observa que para un elemento la **tasa de decaimiento es constante**, λ .

$$[\lambda] = \text{s}^{-1}$$



Ley de decaimiento radiactivo

- + Sea una muestra con N_0 núcleos inestables.
- + El núcleo tiene una tasa de decaimientos λ , $[\lambda] = \text{s}^{-1}$

$$\Rightarrow N_0 \xrightarrow{t} N(t) \quad N(t) < N_0 \quad y \quad N(t) = N_0 + dN \Rightarrow dN < 0$$

Luego, en un tiempo dt :

$$\boxed{\frac{dN}{dt} = -\lambda N} \quad \left(\frac{dN}{dt} < 0 \right)$$

Aplicamos el procedimiento usual para esta ecuación diferencial:

$$\Rightarrow \frac{dN}{N} = -\lambda dt \Rightarrow \int \frac{dN}{N} = -\lambda \int dt \Rightarrow \ln N = -\lambda t + C$$

Donde C la constante de integración. Luego:

$$e^{\ln N} = e^{-\lambda t + C} \Rightarrow N(t) = e^{-\lambda t} e^C \quad y \quad \text{para } t=0, N(t)=N_0 \Rightarrow$$

$$N_0 = e^{-\lambda 0} e^C \Rightarrow e^C = N_0. \quad \text{Finalmente:}$$

$$\boxed{N(t) = N_0 e^{-\lambda t}}$$

Ley de Decaimiento Radiactivo.

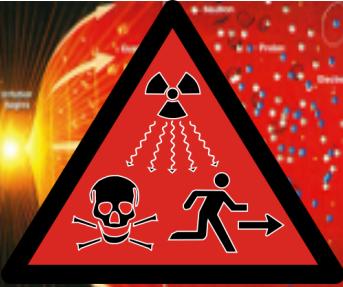


Ley de decaimiento radiactivo

- **Suceso cuántico y estadístico:** no podemos saber cuando un átomo particular decaerá.
- Se observa que para un elemento la **tasa de decaimiento es constante, λ .** $[\lambda] = s^{-1}$
- Luego, en una muestra con N átomos radiactivos, la tasa de decaimiento dN/dt será proporcional a N :

$$\frac{-dN}{dt} = -\lambda N \rightarrow \frac{dN}{N} = -\lambda dt \rightarrow \int \frac{dN}{N} = \int -\lambda dt$$

$$\rightarrow \ln N = -\lambda t + C \rightarrow N(t) = N_0 e^{-\lambda t}$$



Ley de Decaimiento exponencial

- Ocurre con una **tasa de decaimiento constante λ**

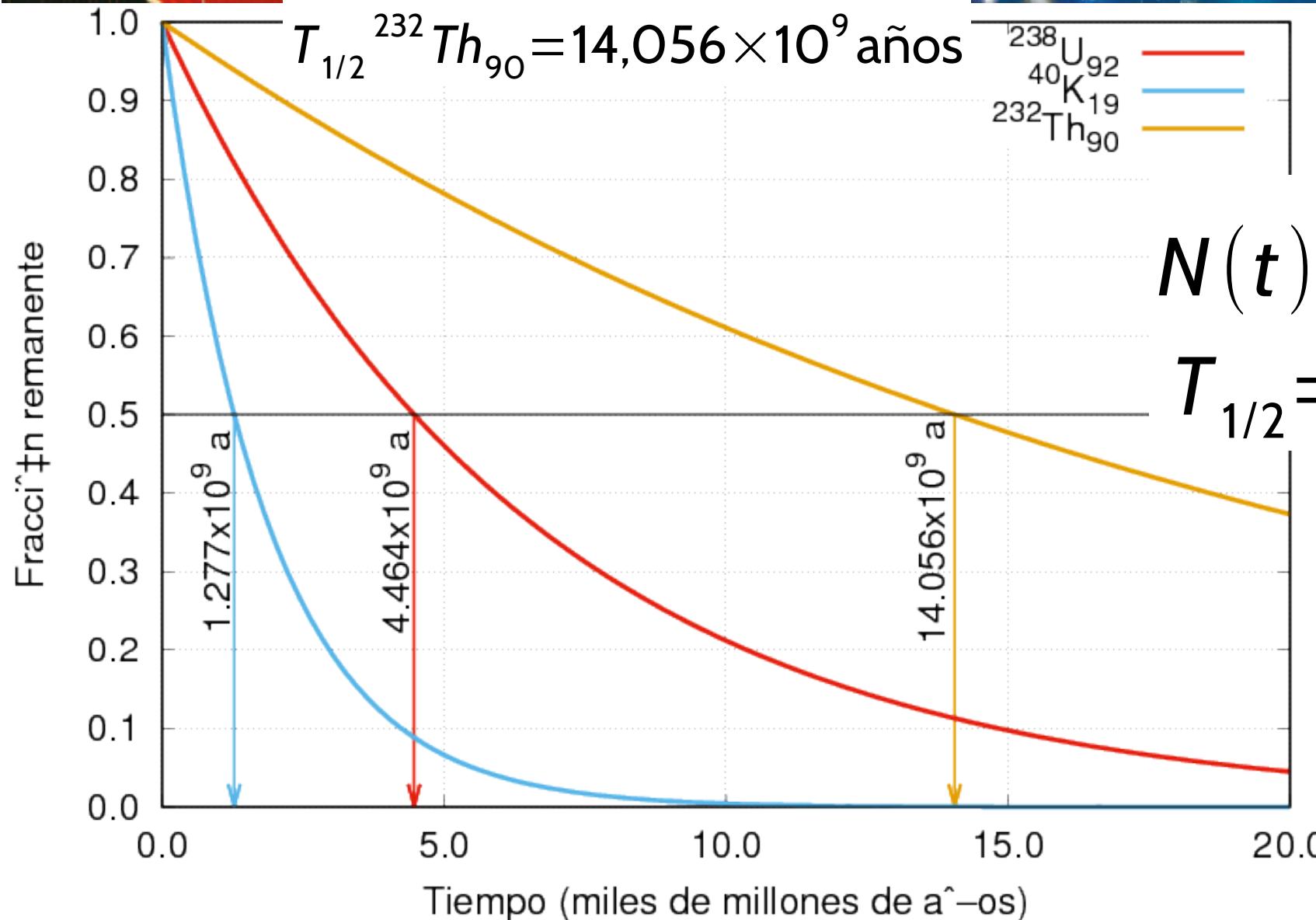
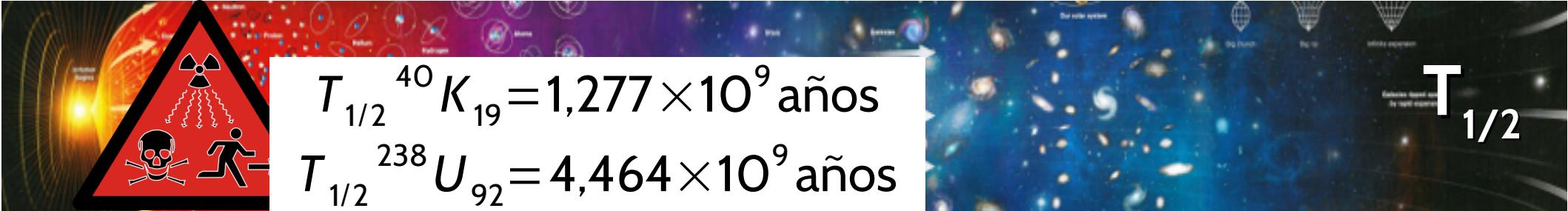
$$N(t) = N_0 e^{-\lambda t} \quad [\lambda] = s^{-1}$$

- A partir de λ , definimos la **vida media τ**

$$\tau \equiv \frac{1}{\lambda} \Rightarrow N(t) = N_0 e^{-\frac{t}{\tau}} \quad [\tau] = s$$

- Y además, el **período de semi-desintegración**, como el **tiempo que debe transcurrir para que la cantidad del elemento en una muestra se reduzca a la mitad**

$$T_{1/2} \text{ es tal que } N(T_{1/2}) = \frac{N_0}{2} = N_0 e^{-\frac{T_{1/2}}{\tau}} \Rightarrow \frac{1}{2} = e^{-\frac{T_{1/2}}{\tau}}$$
$$\Rightarrow T_{1/2} = \ln(2) \tau$$



En un mol de $^{232}_{90}\text{Th}$, ¿Cuántos decaimientos se producen en un segundo?

+ Sea un mol de $^{232}_{90}\text{Th}$ ($\Rightarrow N_0 = 6.02 \times 10^{23}$ átomos de Thorio)

+ La masa del mol es 232 g.

$$+ T_{1/2} = 14,056 \times 10^9 \text{ s} = 4,43 \times 10^{17} \text{ s}$$

$$+ \tau_{1/2} = \ln(2) \tau \Rightarrow \tau = T_{1/2} / \ln(2) \Rightarrow \tau = 6,39 \times 10^{17} \text{ s}$$

Con lo cual $\lambda = \frac{1}{\tau} = 1,56 \times 10^{-18} \text{ s}^{-1}$

+ Luego cada segundo esperamos medir $\Delta N = N_0 \cdot \lambda$

$$\frac{\Delta N}{\Delta t} = -N_0 \cdot 1,56 \times 10^{-18} \text{ s}^{-1} \quad \text{para el primer segundo}$$

$$\Rightarrow \frac{\Delta N}{\Delta t} = 6,02 \times 10^{23} \cdot 1,56 \times 10^{-18} \text{ s}^{-1}$$

Aproximación válida si
 $\Delta t \ll \tau$

$$\Rightarrow \frac{\Delta N}{\Delta t} \approx -10^6 \text{ at/s} \quad \text{para el primer segundo.}$$

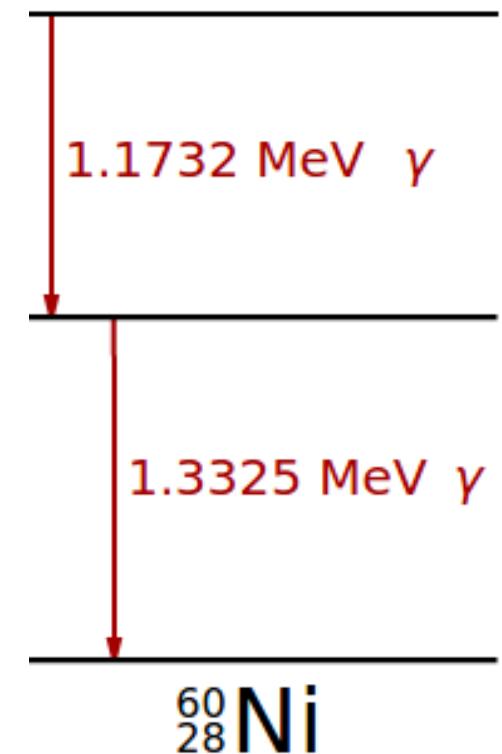
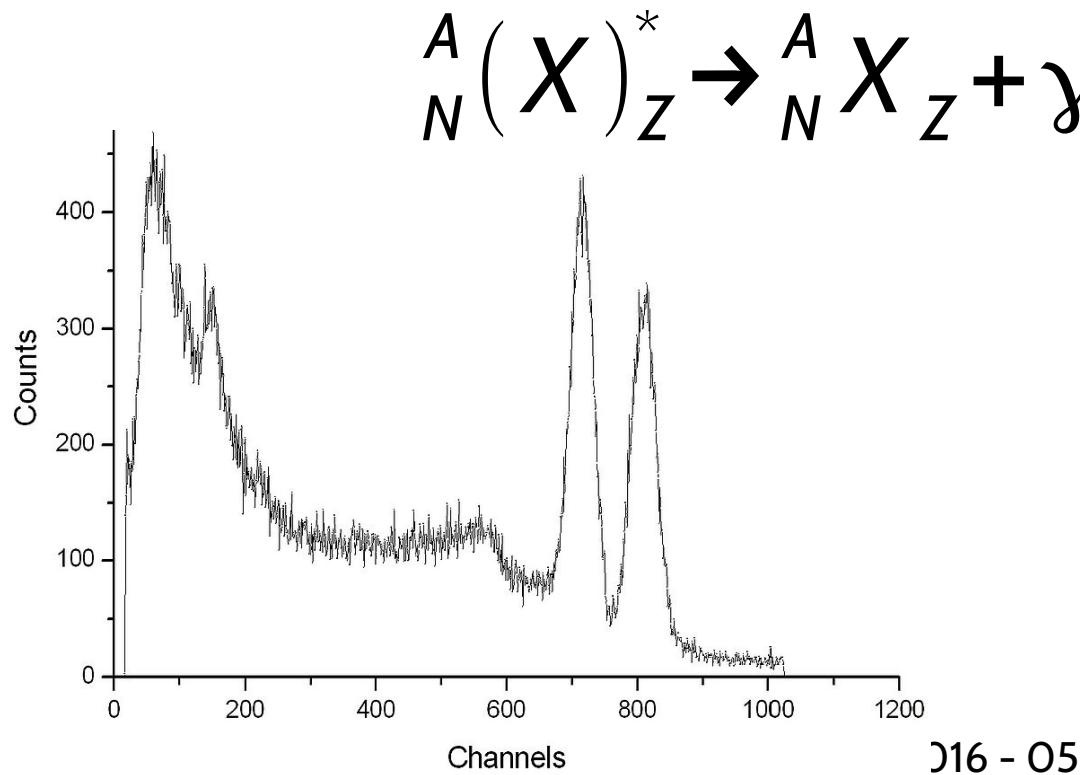
para tiempos largos $\Rightarrow N(t) = N_0 e^{-t/\tau} \Rightarrow \Delta N = N(t) - N_0$

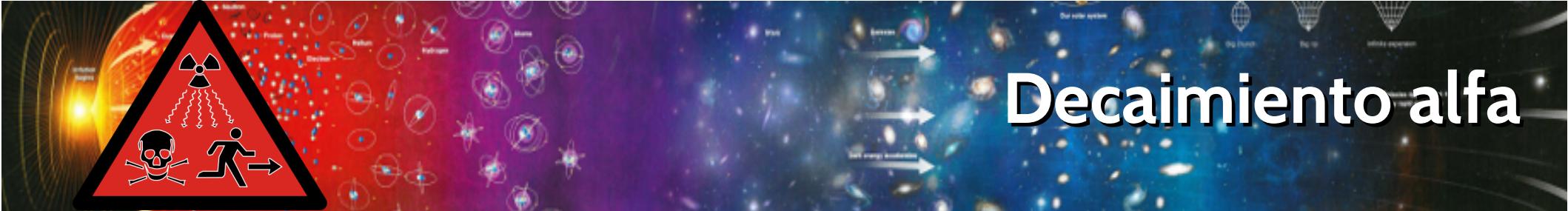
$$\Rightarrow \Delta N = N_0 (e^{-t/\tau} - 1) \Rightarrow \Delta N \approx -10^{16} \text{ at para } t = 1 \text{ s.}$$



Emisión Gamma

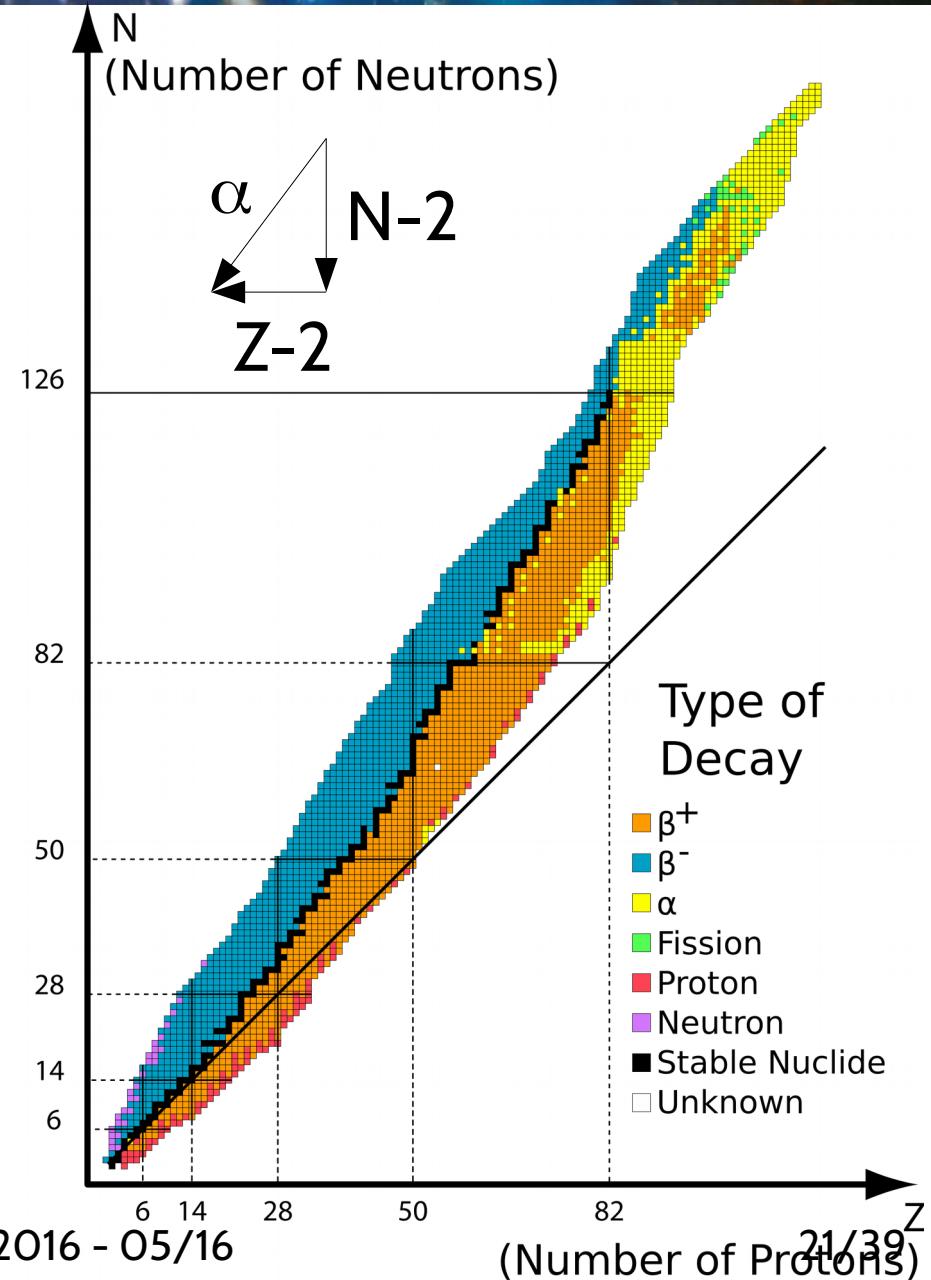
- El núcleo tiene niveles de energía
- El núcleo en un estado excitado se desexcita a través de la emisión de un fotón (gamma) con energía igual a la diferencia de energía entre los estados inicial y final

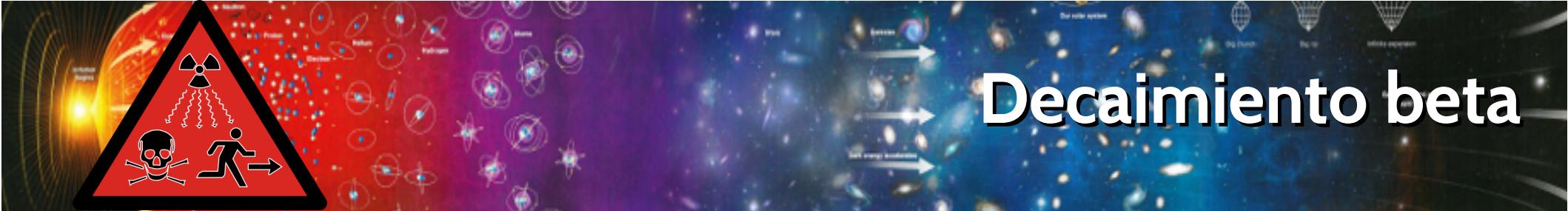




Decaimiento alfa

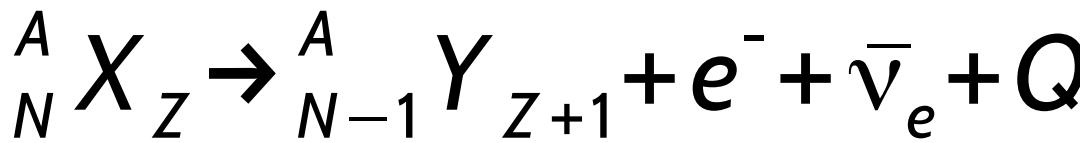
- Corresponde a la emisión espontánea de un núcleo de Helio ${}^4\text{He}_2$ (partícula alfa, 2 neutrones, 2 protones)
- El núcleo pierde dos protones \rightarrow otro elemento!



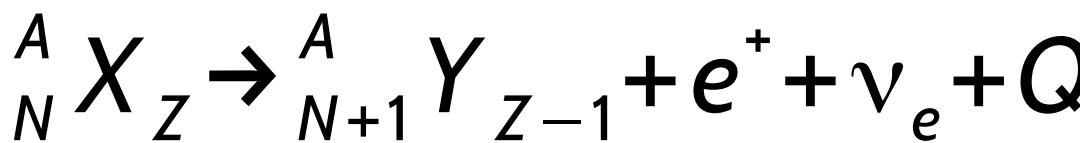


Decaimiento beta

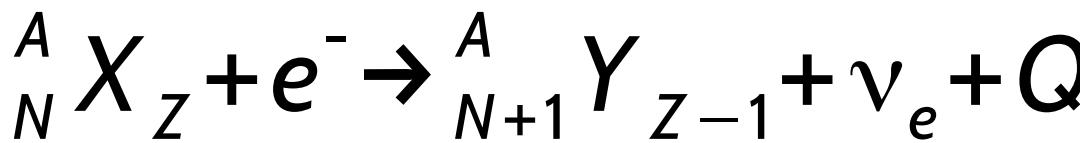
- β^- : emisión de un **electrón**



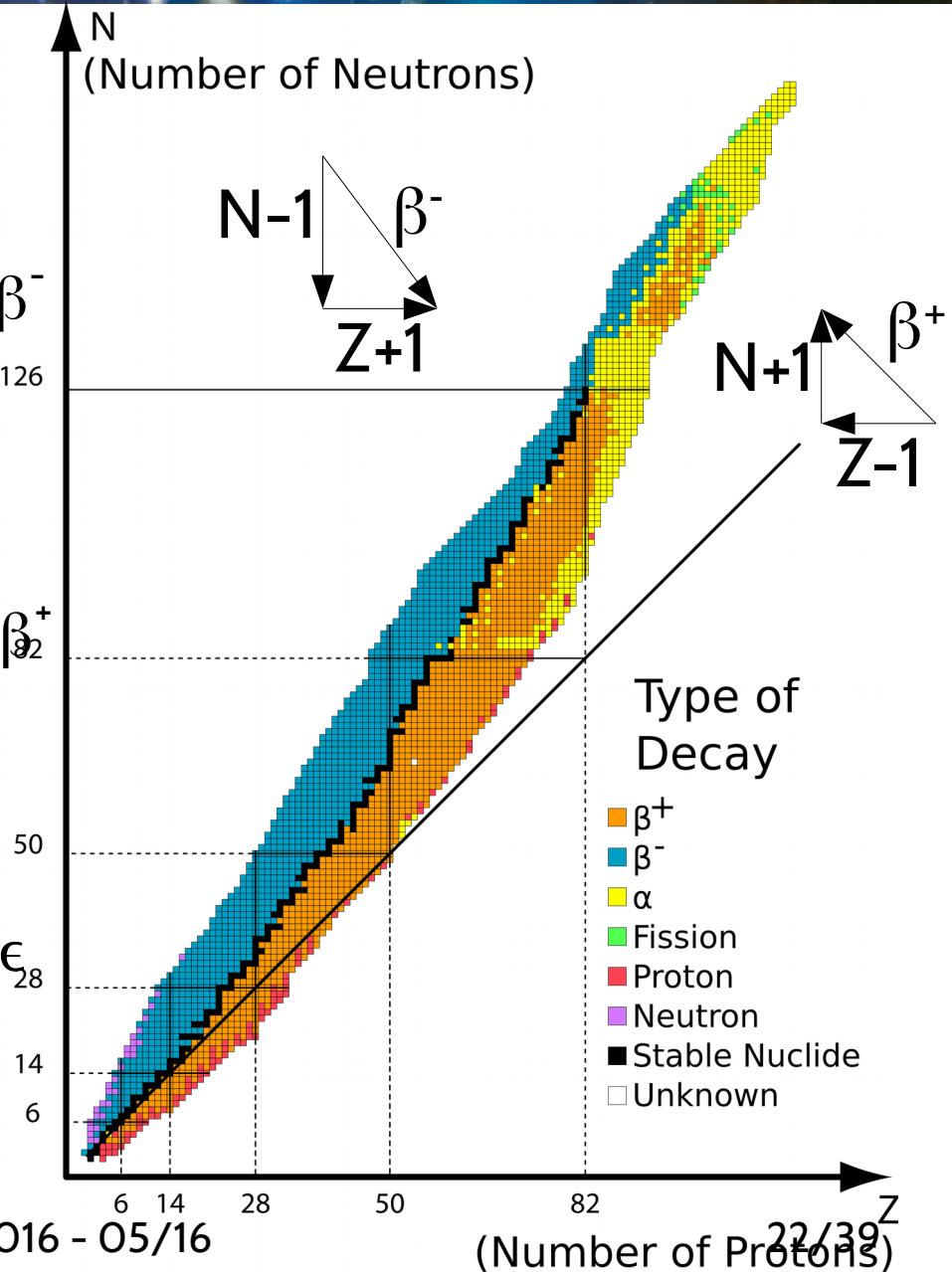
- β^+ : emisión de un **positrón**

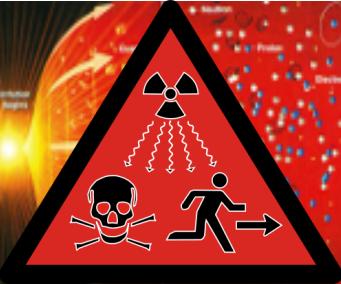


- ϵ : **captura electrónica**



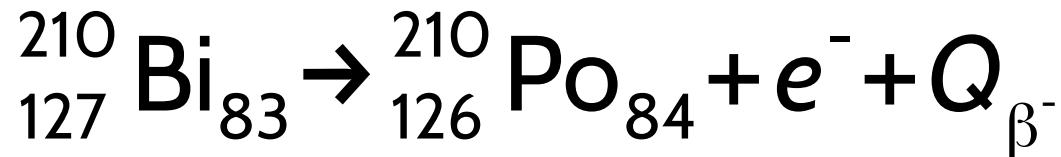
- **¿Qué es ν_e ?**





Decaimiento Beta: Energías

- Propuesta para el decaimiento beta del Bismuto-210



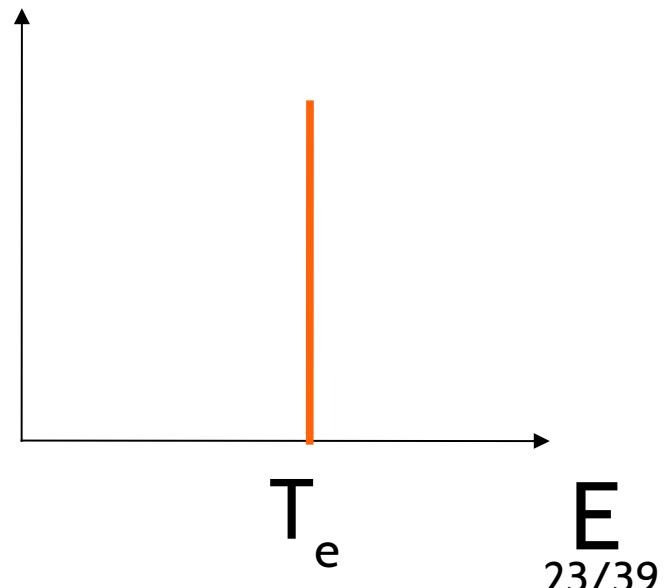
$$\left(n \rightarrow p^+ + e^- + Q_{\beta^-} \right)$$

- Luego, la energía liberada debería ser

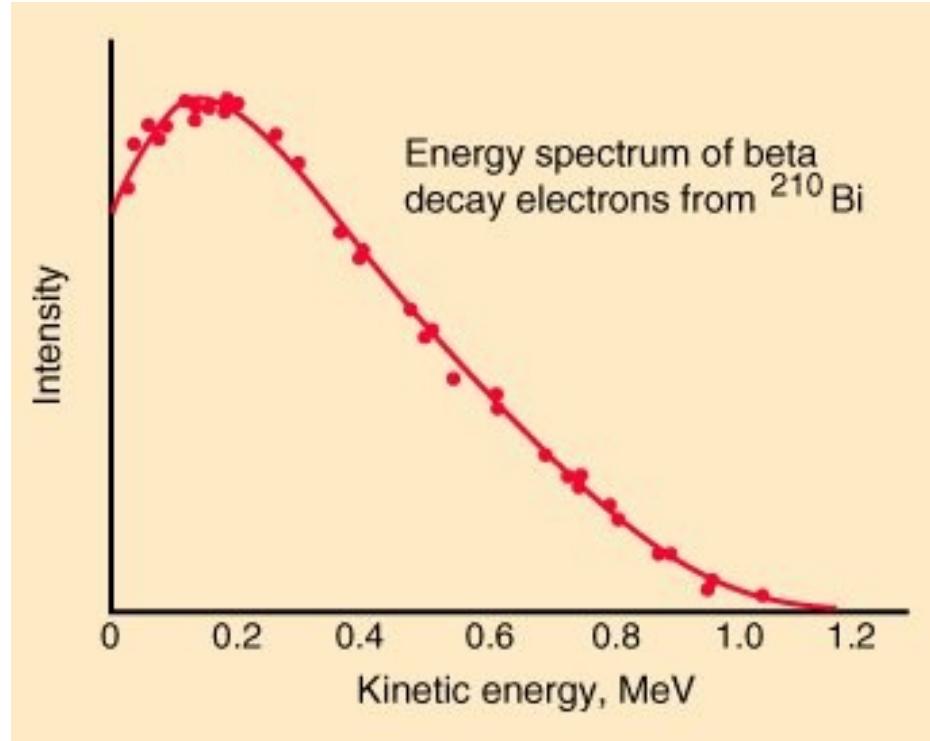
$$m_{\text{Bi}} c^2 = (m_{\text{Po}} + m_e) c^2 + Q \quad \#_e$$

$$Q = (m_{\text{Bi}} - m_{\text{Po}} - m_e) c^2 \approx T_e$$

$$T_e \approx 1.16 \text{ MeV}$$

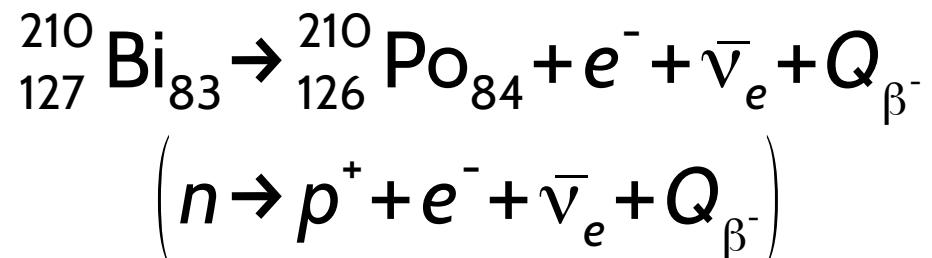


La medición



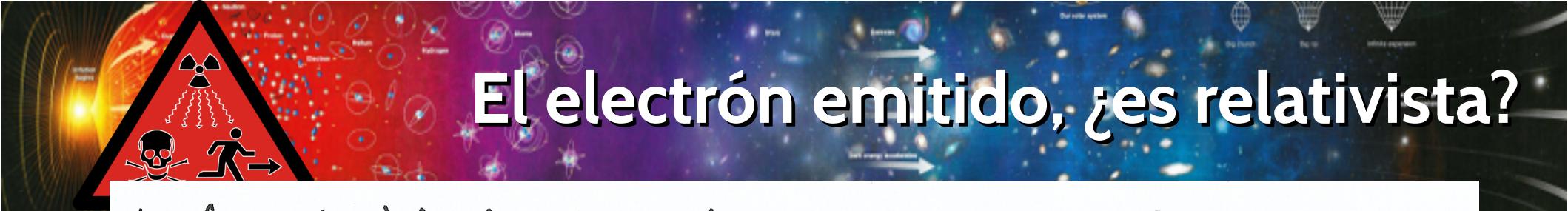
- Bohr: “La energía no se conserva”
- Pauli: La energía se conserva si existe otra partícula: **“neutrino”**

- Decaimiento beta correcto:



$$Q = \left(m_{\text{Bi}} - m_{\text{Po}} - m_e - m_{\bar{\nu}_e} \right) c^2$$

$$Q \approx T_e + T_{\bar{\nu}}$$



El electrón emitido, ¿es relativista?

+ Velocidad del electrón emitido en el descompo β del 20 -Bi

$m_e = 0,511 \text{ MeV}/c^2$ y la energía disponible $Q = 1,16 \text{ MeV}$

Supongamos que $T_e = Q \Rightarrow T_e = 1,16 \text{ MeV}$. Luego.

$$E = m c^2 + T_e \Rightarrow E = 0,511 \frac{\text{MeV}}{c^2} \cdot c^2 + 1,16 \text{ MeV}$$

$$\Rightarrow E = 1,671 \text{ MeV}.$$

$$\text{Pero } E = m \gamma c^2 \Rightarrow \gamma = E/m c^2 \Rightarrow \gamma = \frac{1,671 \text{ MeV}}{0,511 \frac{\text{MeV}}{c^2} c^2} \Rightarrow \gamma = 3,27$$

$$\boxed{\gamma = 3,27}$$

$$\gamma \gamma = \frac{1}{\sqrt{1-\beta^2}} \Rightarrow \gamma^2 = \frac{1}{1-\beta^2} \Rightarrow \beta^2 = 1 - 1/\gamma^2 \Rightarrow \beta = \sqrt{1-1/\gamma^2}$$

$$\Rightarrow \beta = 0,952 \Rightarrow N_e = \beta c \Rightarrow \boxed{N_e = 0,952 c}$$

Mientras tanto, en la atmósfera...

- ... caen rayos cósmicos
- Anderson descubre una partícula $m/q \sim 200 m_e/e$

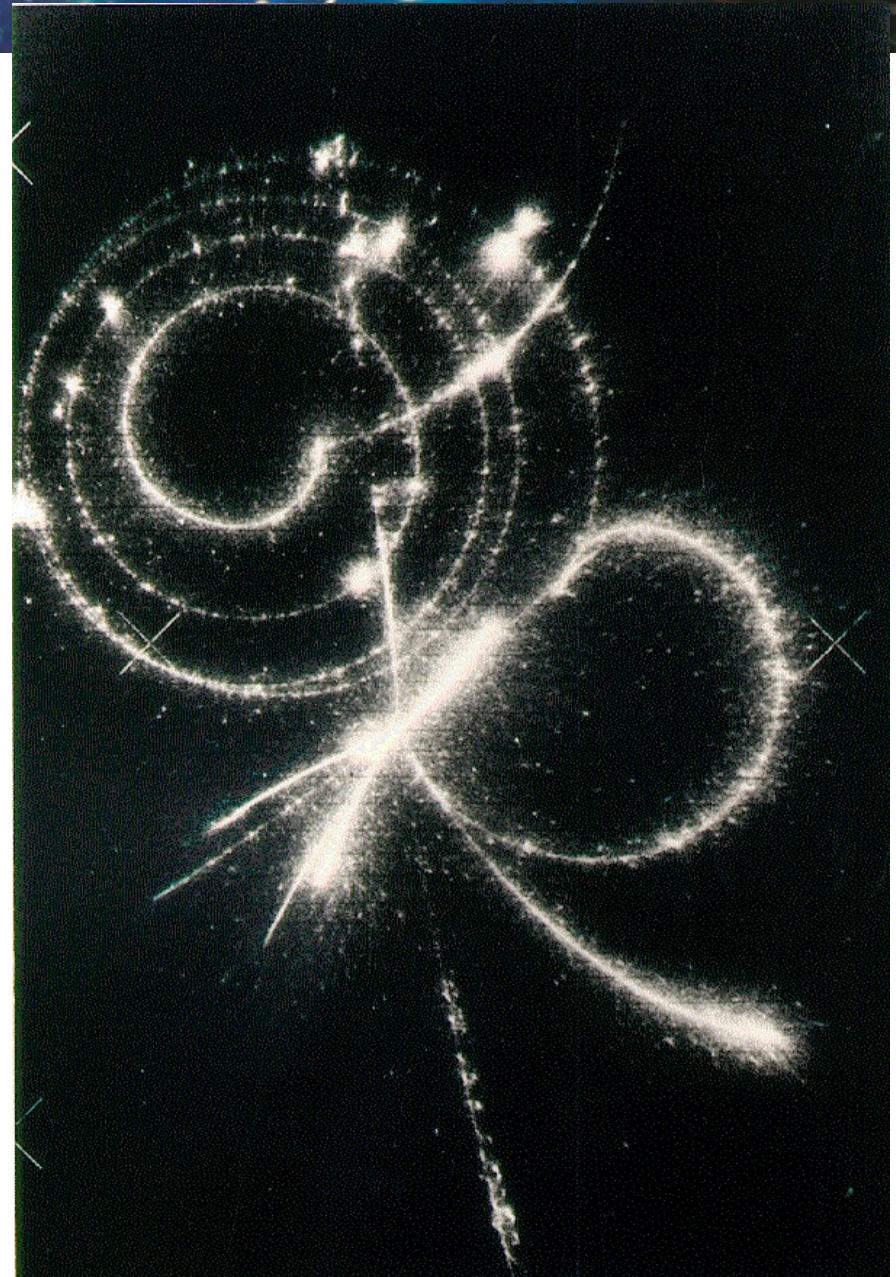
$$\rightarrow m \sim 100 \text{ MeV}$$

- Luego, se observa

$$\pi^\pm \rightarrow \mu^\pm$$

que también violaba la E

$$\Rightarrow \pi^\pm \rightarrow \mu^\pm + \nu_\mu$$



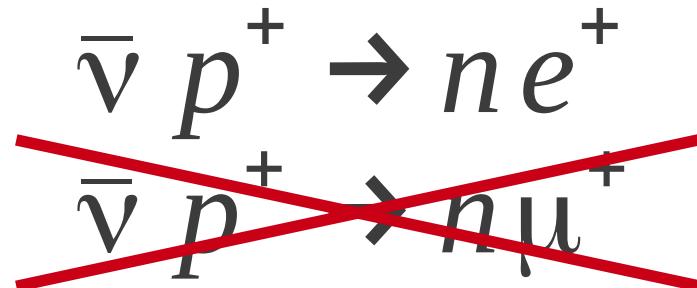
Probemos esto

- Sección eficaz neutrinos

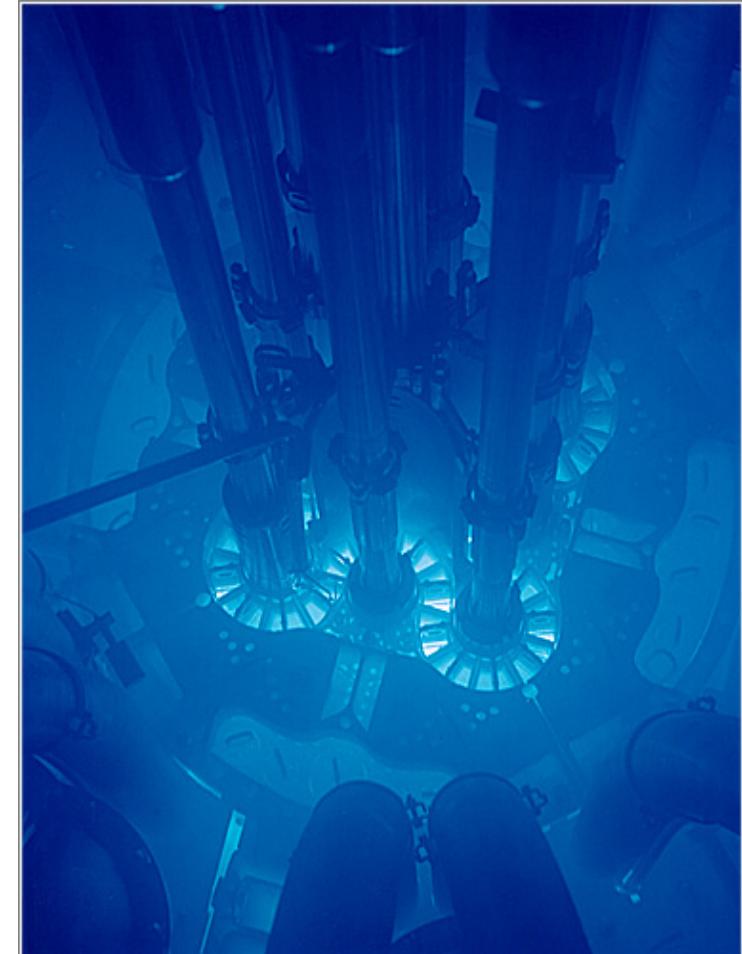
$$\sigma_\nu \simeq 10^{-44} \text{ cm}^2$$

~250 años luz de agua ($\sim 2 \times 10^{20}$ cm)

- Usemos 10^{20} neutrinos en 1 cm de agua



- Tiempos “largos”: Corto alcance. Interaccion Débil





Hasta aquí tenemos:

- Sin fuerza fuerte: e , μ , ν_e , ν_μ , \leftarrow Leptones
- Con fuerza fuerte: p , n , π , \leftarrow Hadrones
- Y sus antipartículas. **Total: 14** (empezamos con **2**)
- Fuerzas: γ , g , W , (G) \leftarrow Mediadores (Calibre)



Con los aceleradores





Con los aceleradores



beensof.com



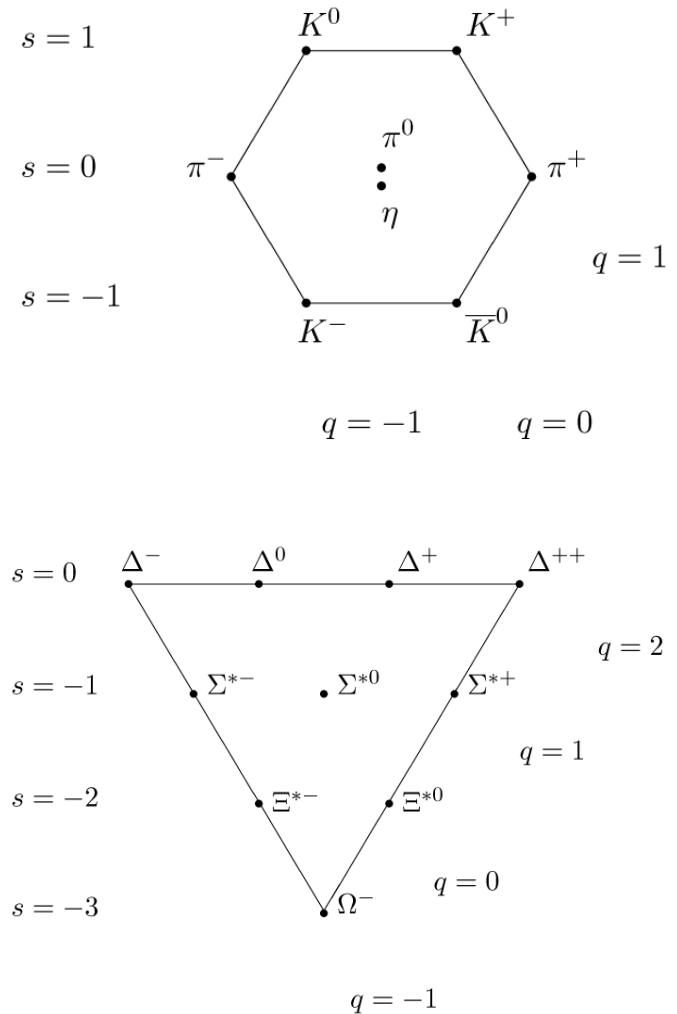
Con los aceleradores



Hoy se conocen ~ 1000 hadrones

Los hadrones no pueden ser elementales

- Luego, debe haber partículas más simples
- Modelo octuple (Gell-mann, 1961)
- Quarks:
 - Se combinan para formar los hadrones
 - Tienen carga fraccionaria
 - Dos por familia



Quarks, primera generación

- Hadrones:
 - 3 quarks: bariones
 - 2 quarks: mesones
- Primera generación
 - “up” y “down”
 - Carga eléctrica
 - u: +2/3 e
 - d: -1/3 e
 - masa
 - m_u : 1.7-3.3 MeV
 - M_d : 4.1-5.8 MeV

- Bariones:

$$p : (uud)$$

$$n : (udd)$$

$$\bar{p} : (\bar{u} \bar{u} \bar{d})$$

- Mesones:

$$\pi^+ : (u \bar{d})$$

$$\pi^- : (\bar{u} d)$$

$$\pi^0 : (u \bar{u} + d \bar{d})$$



Quarks, the next generation

- Segunda generación

- “charm” y “strange”
 - Carga eléctrica
 - c: +2/3 e
 - s: -1/3 e
 - masa
 - $m_c: (1.27 \pm 0.07) \text{ GeV}$
 - $m_s: (101 \pm 29) \text{ MeV}$

- Tercera generación

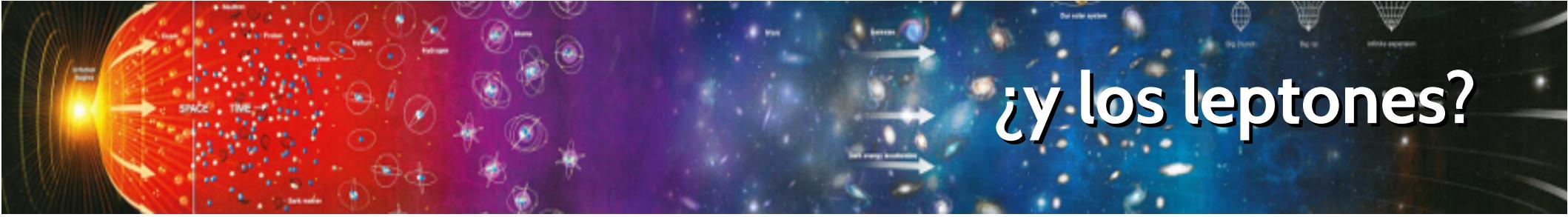
- “top” y “bottom”
 - Carga eléctrica
 - t: +2/3 e
 - b: -1/3 e
 - masa
 - $m_t: (172 \pm 2) \text{ GeV}$
 - $M_b: (4.19 \pm 0.18) \text{ GeV}$



Interacción fuerte: carga de “color”

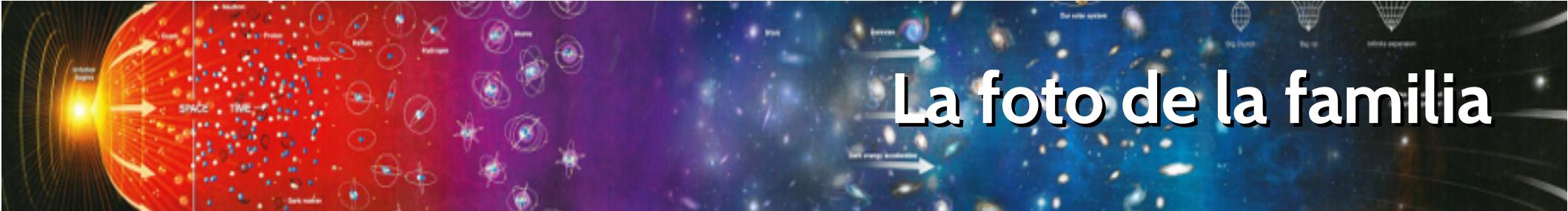
- Fuerzas y cargas
 - G: una carga (masa)
 - EM: dos cargas (+,-)
 - W: “una” carga (w)
 - FF: tres cargas (r,g,b)
- El color no se observa: la naturaleza es “blanca”
- Bariones: (qqq) o ($qq\; qq\; qq$)/3
- Mesones: (qq) (nota: el magenta es el antiverde)
- 8 Gluones: (rojo antiverde), (azul antirojo), ...





¿y los leptones?

- Tenemos 3 generaciones de quarks
- 3 generaciones de leptones:
 - e, ν_e
 - μ, ν_μ
 - τ, ν_τ
- $m_\tau = 1776.99 \text{ MeV}$



La foto de la familia

THE STANDARD MODEL

Fermions				Bosons	Force carriers
Quarks	u up	c charm	t top	γ photon	
	d down	s strange	b bottom	Z Z boson	
Leptons	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	W W boson	
	e electron	μ muon	τ tau	g gluon	

*Yet to be confirmed



Source: AAAS

Para terminar, el Higgs

THE HIGGS MECHANISM

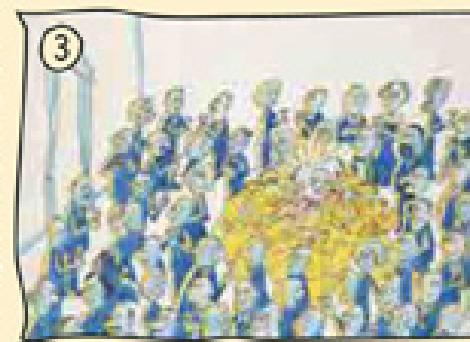
Illustration courtesy of CERN

① TO UNDERSTAND THE HIGGS MECHANISM, IMAGINE THAT A ROOM FULL OF PHYSICISTS QUIETLY CHATTERING IS LIKE SPACE FILLED ONLY WITH THE HIGGS FIELD.

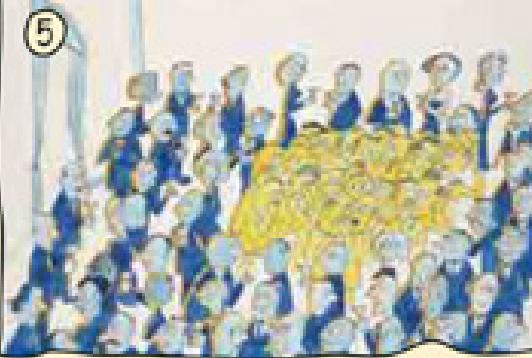


A WELL KNOWN SCIENTIST, ALBERT EINSTEIN, WALKS IN, CREATING A DISTURBANCE AS HE MOVES ACROSS THE ROOM, AND CLUSTERING A CLUSTER OF PEOPLE WITH EACH STEP.

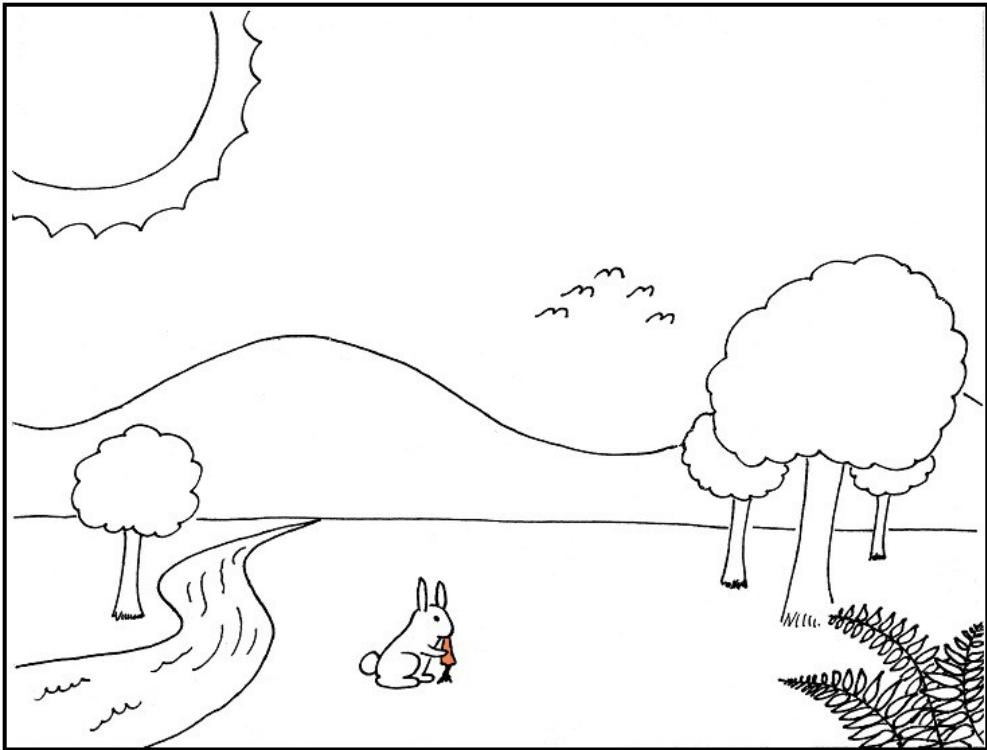
THIS INCREASES HIS RESISTANCE TO MOVEMENT - IN OTHER WORDS, HE ACQUIRES MASS, JUST LIKE A PARTICLE MOVING THROUGH THE HIGGS FIELD.



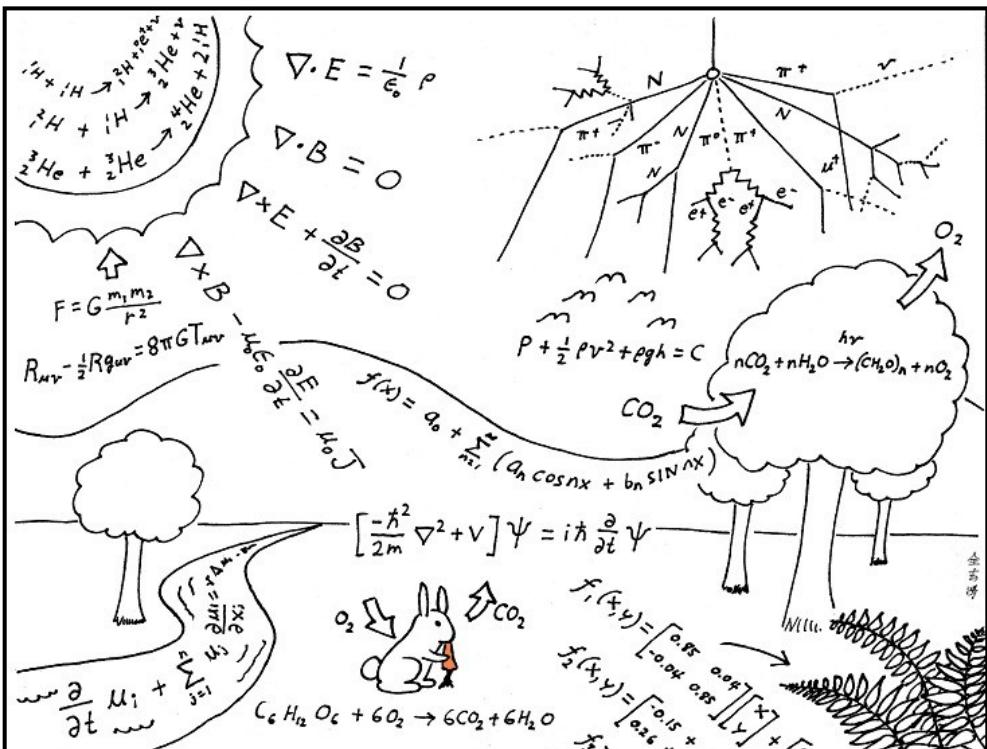
IF A RUMOUR CROSSES THE ROOM ...



IT CREATES THE SAME KIND OF CLUSTERING, BUT THIS TIME AMONG THE SCIENTISTS THEMSELVES. IN THIS ANALOGY, THESE CLUSTERS ARE THE HIGGS PARTICLES.



No se olviden



This is how scientists see the world.

© 2016 - 05/16