

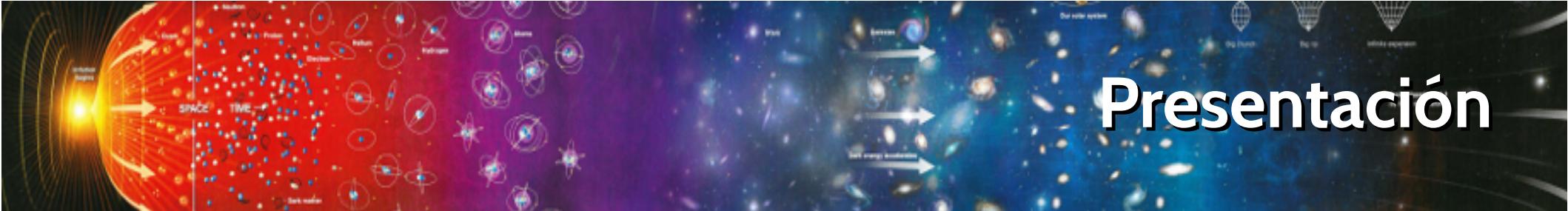


Universidad Nacional de Río Negro

Int. Partículas, Astrofísica & Cosmología - 2016

- **Unidad** 01 – Relatividad
- **Clase** 0101
- **Fecha** 11 Ago 2016
- **Cont** Presentación, introducción, relatividad
- **Cátedra** Asorey
- **Web** github.com/asoreyh/unrn-ipac
www.facebook.com/fisicareconocida/
- **Youtube** www.youtube.com/watch?v=iFaJhcclDpo
- **Archivo** a-2016-U01-C01-0811-introduccion-relatividad-1



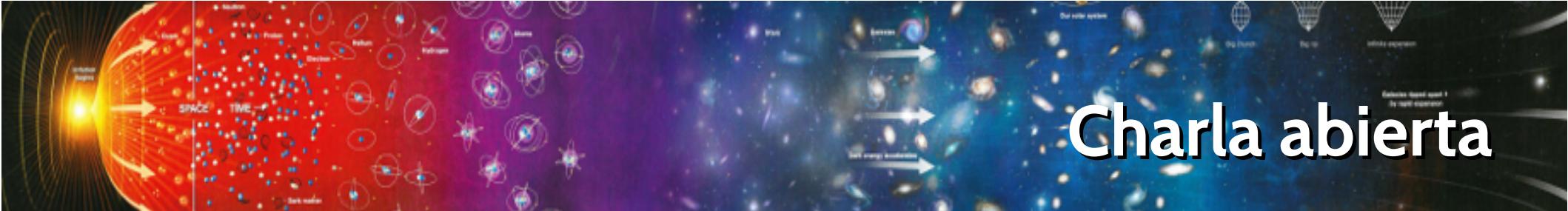


Presentación



Colegas contando algunas experiencias

- Hernán Asorey
 - Centro Atómico Bariloche e Instituto Balseiro:
Investigador Laboratorio Detección Partículas y Radiación
(LabDPR)
líneas: Aplicaciones de Detectores de Partículas: Meteorología Espacial, Muongrafía de Volcanes, Física Médica
 - UNRN
Profesor Asociado, Física 1 A; **Introducción a la Física de Partículas, Astrofísica y Cosmología (IPAC)**



Charla abierta



Objetivos y metodología

- **Objetivos**

- **Adquirir una perspectiva del estado actual de la Física de Partículas, la Astrofísica y la Cosmología, a un nivel introductorio y que produzca las herramientas para su implementación en el aula de escuelas medias.**

- **Metodología (orientada al trabajo grupal)**

- Clases interactivas, virtuales y presenciales
- Prácticas en clase y en casa

Puntos de contacto

- **Las clases:**
 - **Jueves 21 a 23 (HA)**
 - **Una hora a definir**
- **La Bibliografía:**
 - **Depende de la unidad**
 - **Apuntes de clase**
 - **Wikipedia**

The screenshot shows a Facebook group page for 'Física ReConocida'. The header features a landscape image with a tree and mountains. The group name 'Física ReConocida' and 'Grupo público' are displayed. Navigation tabs include 'Debate', 'Miembros', 'Eventos', 'Fotos', and 'Archivos'. A search bar says 'Buscar en este grupo'. Below the tabs is a post from 'Hernán Asorey' with a thumbnail image of a smartphone displaying a 3D hologram. The post text reads: 'Turn your Smartphone into a 3D Hologram | 4K' and includes a link to a YouTube video. Interaction buttons 'Me gusta', 'Comentar', and 'Compartir' are below the post. The sidebar on the right shows '165 miembros' and a list of member profiles. Descriptions, tags, and a 'Crear grupo' button are also visible.



<http://www.facebook.com/groups/fisicareconocida>



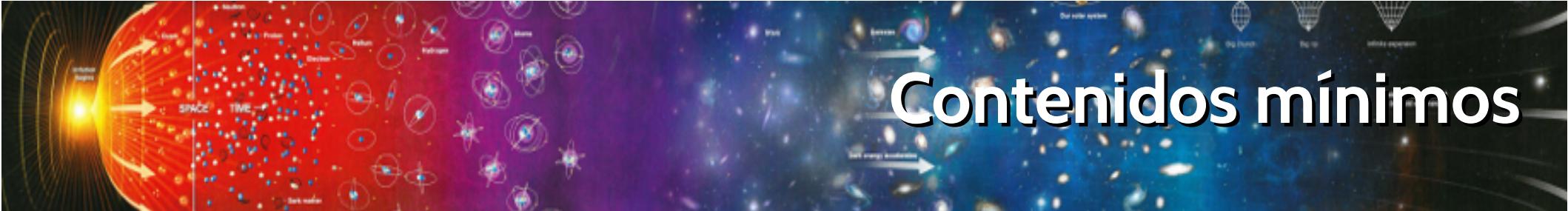
IPAC2016

Formas de Aprobación...

- **Evaluación continua (60%)**
 - Participación en clases y laboratorios
 - Entrega de prácticos
- **Trabajo final integrador, junto con Didáctica de la Física 2 (40%)**
- **Promoción, cumpliendo todas estas condiciones:**
 - Entrega del 100% de los prácticos en tiempo y forma, cumpliendo con las fechas pactadas
 - Entrega del 100% de los informes en tiempo y forma, cumpliendo con las fechas pactadas
 - Nota Evaluación Continua > 7.9
 - Dispone de un (y sólo un) “comodín” para las entregas

Levante su mano derecha y repita conmigo

- Yo, (su nombre aquí), he entendido claramente las condiciones de promoción, las comprendo en toda su profundidad, lo tendré en cuenta para las entregas,
- y no solicitaré excepciones
- Promoción, cumpliendo todas estas condiciones:
 - Entrega del 100% de los prácticos en tiempo y forma, cumpliendo con las fechas pactadas
 - Entrega del 100% de los informes en tiempo y forma, cumpliendo con las fechas pactadas
 - Nota Evaluación Continua > 7.9
 - Dispone de un (y sólo un) “comodín” para las entregas



Contenidos mínimos

- Los contenidos mínimos según su plan:
Estrellas y galaxias. Evolución de las estrellas nacimiento y muerte de las estrellas. Relatividad general: gravedad y la curvatura del espacio. El universo en expansión. El Big-Bang y el fondo cósmico de microondas. El modelo estándar cosmológico. Los primeros tiempos del universo

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 billionth the size of a nuclear particle. Since then it has expanded—a lot—fighting gravity all the way.

Inflation
In less than a nanosecond a repulsive energy field inflates space exponentially until it's 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 blocks of atomic nuclei. Perhaps dark matter forms.

Age: .01 milliseconds
Size: 0.1-million 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 infalling orbits is unveiled. 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 combination of density and light is the only light. Clumps of dark matter will eventually form 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: 300 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: 10 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: 13.8 billion years
Size: Present size

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.



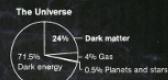
Galaxies ripped apart by rapid expansion

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 dented. What had seemed eternal had now had a beginning and an end. But what beginning? What end? Those questions are still open.

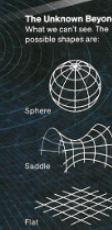
WHAT IS OUR UNIVERSE MADE OF?

Stars, dust, and gas—the stuff we can discern—make up less than 5 percent of the universe. Their gravity can't account for how galaxies hold together. Scientists figure about 23 percent of the universe is a mysterious dark matter—perhaps exotic particles formed right after inflation. The rest is dark energy, an unknown energy field or property of space that counters gravity, providing an explanation for observations that the expansion of space is accelerating.



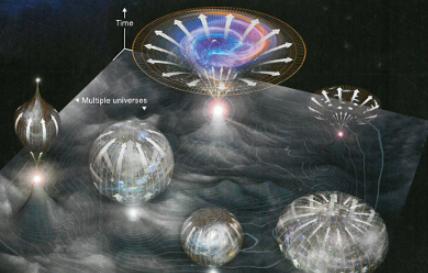
WHAT IS THE SHAPE OF OUR UNIVERSE?

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.



Fly through the universe on our digital edition.
LONDON PRINTERS, NEWCASTLE FABRICK
GENERALISTS, ART WORKSHOP DESIGN
SOURCES: CHARLES BENNETT, JOHN
HUCHENBERG, ANDREW LAMBERT,
UNIVERSITY OF CHICAGO
CONTRIBUTOR: JEFFREY MAYER, NATIONAL
GEOGRAPHIC SOCIETY

Contenidos: un viaje en el tiempo

HOW DID OUR UNIVERSE BEGIN?

In less than a nanosecond a repulsive energy field inflates space 10²⁶ times and fills it with a soup of subatomic particles called quarks.

Infation
The universe expands, cools As the universe continues to cool, the first atomic nuclei form. Perhaps dark matter forms.
Age: 10⁻³ milliseconds
Size: Infinitesimal to golf ball

Early building blocks
Quarks clump into protons and neutrons, creating the first atomic nuclei. Perhaps dark matter forms.
Age: 10⁻² milliseconds
Size: 0.1-millionth present size

First nucle
As the universe continues to cool, the first atomic nuclei form. Perhaps dark matter forms.
Age: .01 milliseconds
Size: 1-billionth present size

Unidad 4
El Big Bang
Allá lejos y hace tiempo

COSMIC QUESTIONS

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WHAT IS OUR UNIVERSE MADE OF?

Matter, dust, and gas—the stuff we can discern—make up less than 5 percent of the universe. Their gravity can't account for how galaxies rotate so fast. Scientists figure about 23 percent of the universe is a mysterious dark matter—perhaps exotic particles formed right after inflation. The rest is dark energy, an unknown cosmic field or property of space that counters gravity, providing an explanation for observations that the expansion of space is accelerating.

The Universe

71.5%	Dark energy
24%	Dark matter
4%	Gas
0.5%	Planets and stars

First atoms, first light
Quarks begin forming atoms. This light is as far back as our instruments can see.
Age: 380,000 years
Size: .0009 present size

The "dark ages"
For 300 million years this continues, creating atoms but no light. This is the only light. Clumps of dark matter will become galaxies and stars.
Age: 380,000 to 300 million years
Size: .0009 to 0.1 present size

Gravity wins: first stars
Dense gas clouds collapse under their own gravity. They begin to heat up, forming galaxies and stars.
Age: 300 million years
Size: 0.1 present size

Antigravity wins
After being slowed for billions of years, gravity, cosmic expansion accelerates again. The culprit: dark energy. Its nature: unclear.
Age: 10 billion years
Size: .77 present size

Today
The universe continues to expand, becoming ever less dense. As a result, fewer new stars and galaxies are forming.
Age: 13.8 billion years
Size: Present size

Unidad 3
Cosmología
*No es lo que se ve
Sino lo que se palpa*

WHAT IS THE SHAPE OF OUR UNIVERSE?

Einstein discovered that a star's gravity curves space around it. 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.

Dark energy acc

Unidad 2
Astrofísica
Cálido y frío

DO WE LIVE IN A MULTIVERSE?

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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.

Big crunch
Big rip
Infinite expansion

Galaxies ripped apart by rapid expansion

Unidad 1
Partículas 1
todo es relativo

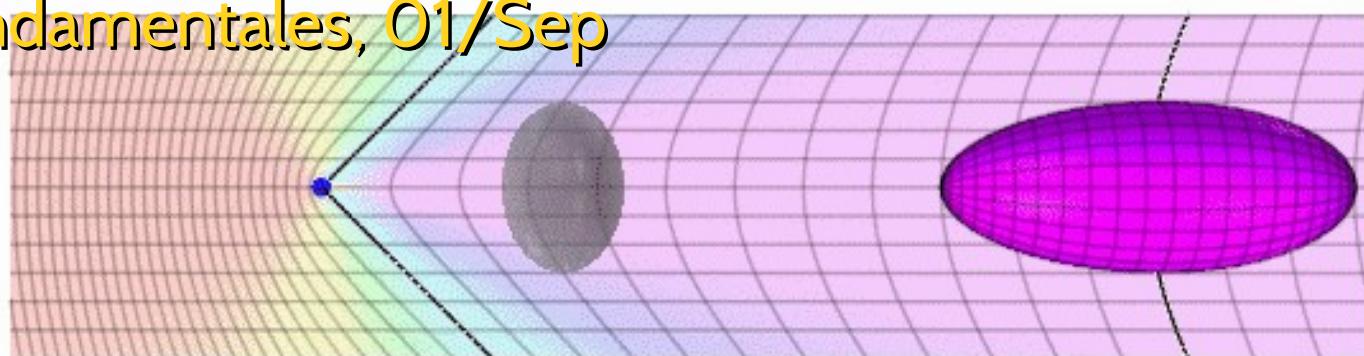
Fly through the universe on our digital edition

LONDON PHOTOS: ANDREW STONE; FERNE GOODMAN; ART: MONTAGNA DESIGN; SOURCES: CHARLES BENNETT, JOHN HESTER, ANDREW LAMBERT, ANDREW LISTER, UNIVERSITY OF CHICAGO; COURTESY OF NATIONAL GEOGRAPHIC SOCIETY

U1: Todo es relativo (11/Ago - 01/Sep)



- Relatividad Especial
- Introducción, 11/Ago
- Cinemática y Dinámica Relativista, 18/Ago
- Física de Partículas, 1^{ra} parte
- Planck, Bosones y Fermiones, 25/Ago
- Modelo de Fermi, 25/Ago
- Ec. de Klein-Gordon y Dirac, 01/Sep
- Interacciones fundamentales, 01/Sep



U2: Cálido y Frío (08/Sep – 29/Sep)

- Estrellas
 - Radiación de Cuerpo Negro, 08/Sep
 - Modelo del Politropo de Lane-Emdem, 08/Sep
 - Ley de Eddington, Clasificación estelar, Diagrama H-R, 15/Sep
 - Objetos Compactos y evolución estelar, 15/Sep
- Planetas
 - Planetas y Exoplanetas, 22/Sep
 - Zona de Habitabilidad, Vida en el Universo: Astrobiología, 22/Sep
- Galaxias
 - Modelos y formación, 29/Sep
 - Ejemplos: La Vía Láctea, Otras Galaxias, GalaxyZoo(*), 29/Sep

U3: no es lo que se ve, sino lo que se palpa (06/Oct - 27/Oct)

- Relatividad General
 - Introducción y conceptos básicos, 06/Oct
 - Modelo de Friedman-Lemaître-Robertson-Walker, 13/Oct
 - El error de Einstein, 13/Oct
- Modelos del Universo
 - Formación de estructuras, 20/Oct
 - Midiendo distancias, 20/Oct
 - Corrimiento al rojo, 27/Oct
 - El universo en expansión, 27/Oct

U4: Allá lejos y hace tiempo (03/Nov – 24/Nov)

- El modelo cosmológico estándar
 - Modelo de Alpher, Bethe & Gamow, 03/Nov
 - El fondo de microondas, 03/Nov
 - Modelo Λ CDM, 10/Nov
- Historia térmica del universo
 - El Big Bang, 10/Nov
 - Primeros segundos del universo, 17/Nov
 - Épocas térmicas de tiempo, inflación, recombinação, 17/Nov
 - Evolución futura del universo, 24/Nov
 - ¿El fin?, 24/Nov



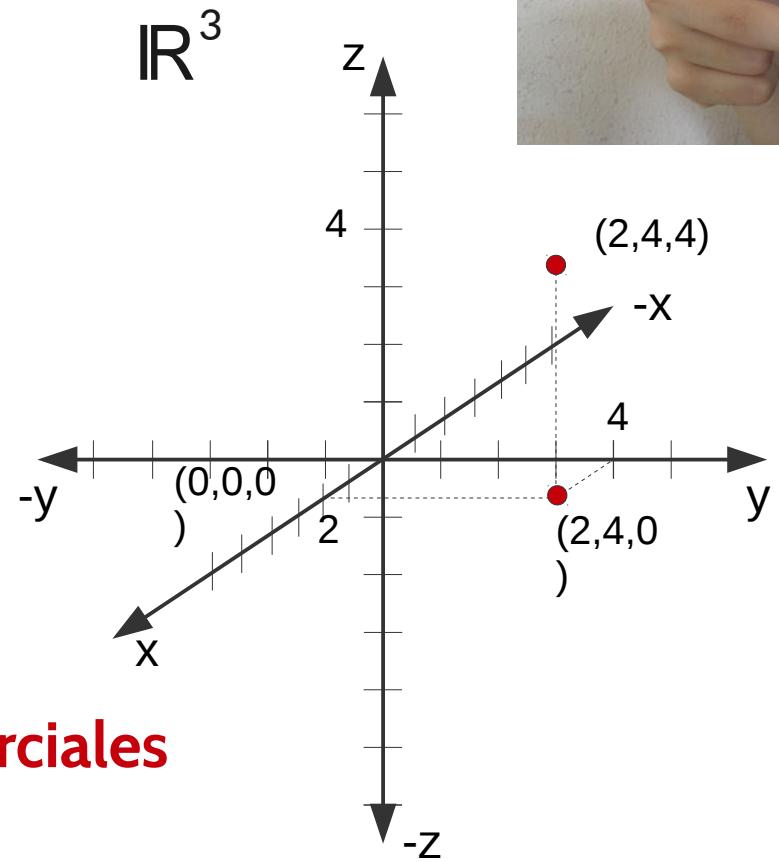
U1: Todo es relativo (11/Ago - 01/Sep)

- ¿Marco de referencia?
-
-
- ¿Marco de referencia inercial?
-
-
-

Marco de referencia

- **Marco de referencia**

- Sistema de coordenadas que fija la posición de objetos físicos de manera unívoca (localización y orientación)
- Existe un conjunto de medidas estandarizadas (una regla)
- Distintos tipos:
 - Fijos al cuerpo, fijos al espacio, **inerciales** y no inerciales

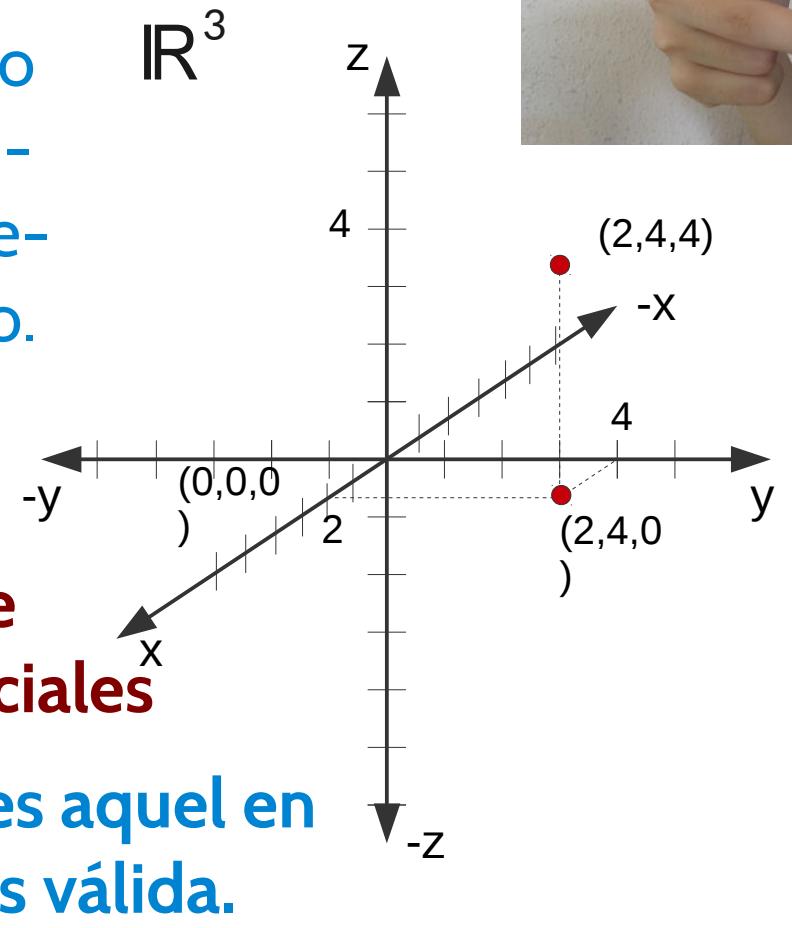


3-tupla: (x,y,z)

Marco de referencia inercial

- **Marco de referencia inercial**

- Describe el espacio homogéneo (no hay lugares privilegiados) e isotrópicamente (no hay direcciones privilegiadas) e independiente del tiempo.
- Las leyes físicas tienen la “misma forma” en todo sistema inercial. Decimos que la física es **covariante frente a cambios de sistemas inerciales**
- Un sistema de referencia inercial es aquel en el que la primera ley de Newton es válida.



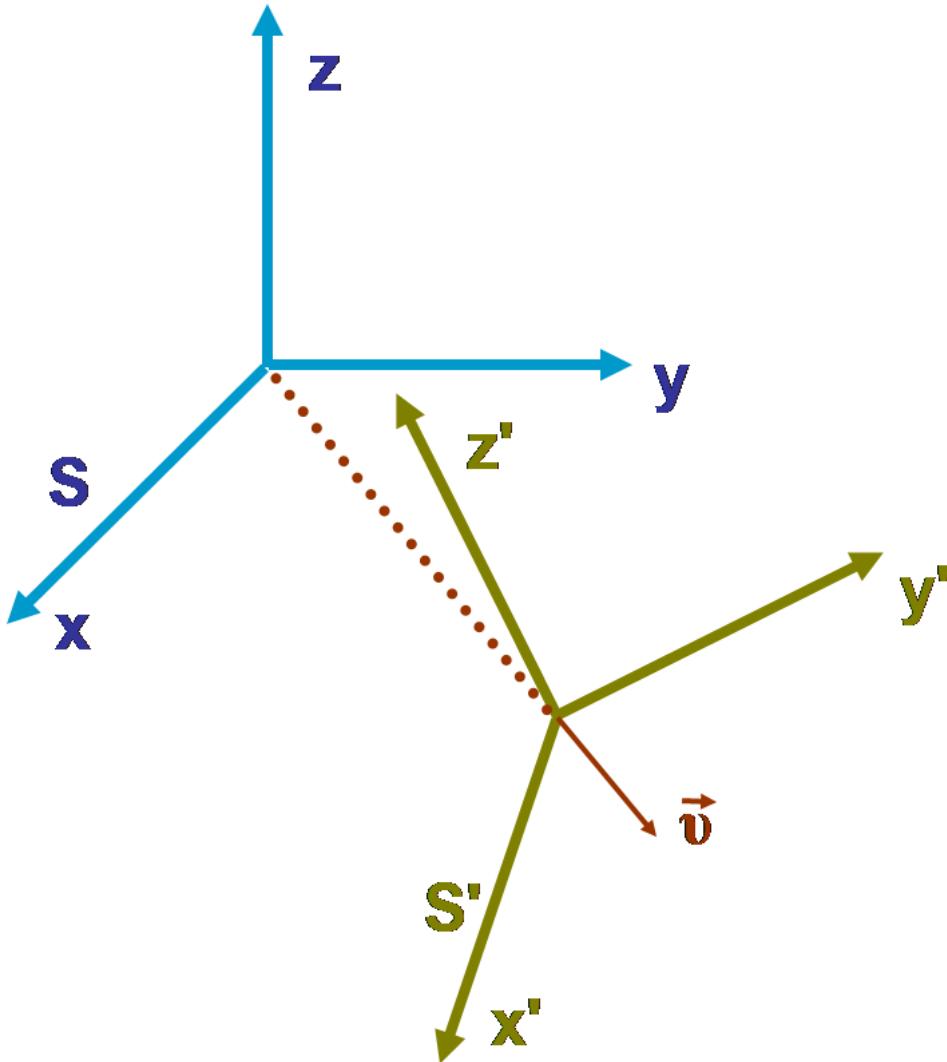
U1: Todo es relativo (11/Ago - 01/Sep)

- ¿Qué es la relatividad?
 -
 -
 -
 - ¿Quién la descubrió?
 -
 -
 -

Relatividad de Galileo

- Si la ley de la inercia es válida, las aceleraciones son provocadas sólo por fuerzas internas, no externas (p. ej. un sistema rotante)
- **El tiempo y el espacio están claramente desacoplados** (¡vida diaria!)
- **Las leyes de la mecánica son invariantes en el tiempo**
 - → **El espacio es absoluto**
 - → **Todos los sistemas inerciales comparten el mismo tiempo**
- No hay forma de “saber” si estamos en movimiento
 - Propongan un ejemplo ahora

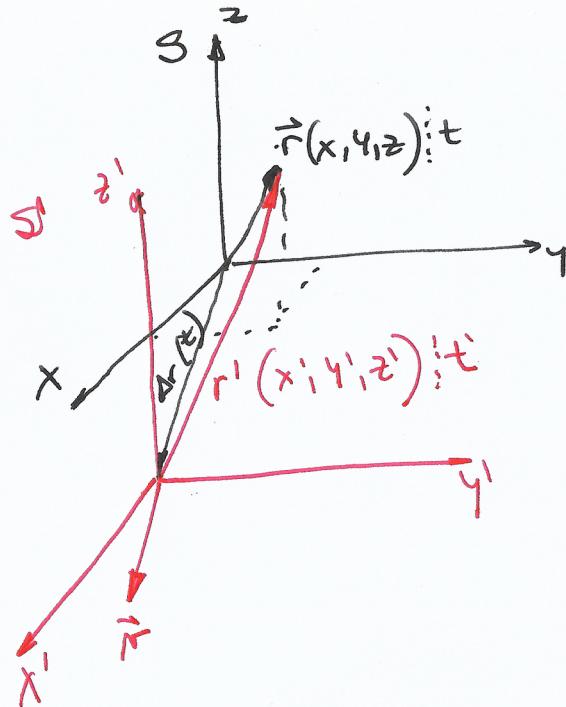
Relatividad de Galileo



- Sea un sistema S' que se mueve con velocidad constante v respecto a otro sistema S .
- Luego, un objeto en r , a tiempo t en S , tendrá posición $r'(t)$ dada por:

$$\vec{r}'(t) = \vec{r}(t) - \vec{v}t$$

Derivación



Ahora bien, por (2) postulado

$$t = t'$$

y por (1) en algún momento t_0

$$\vec{r}(t_0) = \vec{r}'(t_0) \Rightarrow \vec{r}(t_0) = \vec{r}'(t_0)$$

Eso ocurrió hace un tiempo $(t - t_0)$
 \Rightarrow En ese tiempo, S' se desplazó $\Delta \vec{r} \neq \vec{v} \cdot (t - t_0)$

Llego a tiempo t , y visto desde S

$$\vec{r}(t) - \vec{r}'(t) = \Delta \vec{r}(t)$$

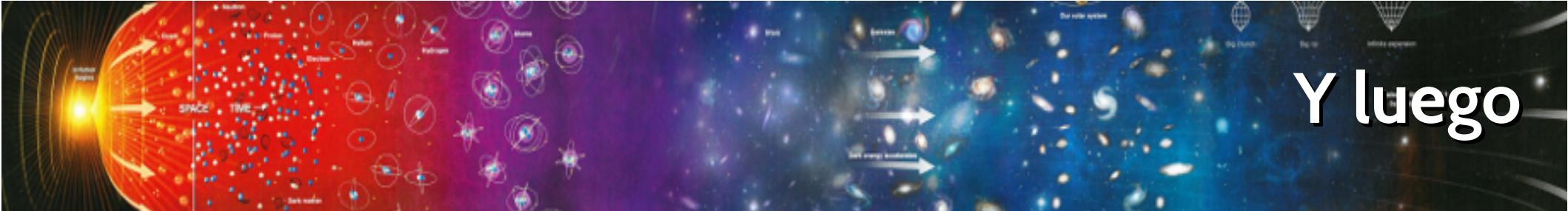
$$\Rightarrow \vec{r}'(t) = \vec{r}(t) - \Delta \vec{r}(t)$$

$$\Rightarrow \vec{r}'(t) = \vec{r}(t) - \vec{v}(t-t_0)$$

Haciendo $t_0 = 0 \Rightarrow$

$$\vec{r}'(t) = \vec{r}(t) - \vec{v}t$$

$$\boxed{\vec{r}'(t) = \vec{r}(t) - \vec{v}t}$$



Y luego

Entonces.

Si el objeto en $\vec{r}(t)$ se está moviendo, en S' será:

Recordar
 $\vec{r} = \text{cte}$

$$\vec{v}'(t) = \frac{d}{dt} \vec{r}'(t) = \frac{d}{dt} (\vec{r}(t) - \vec{r}_0 t) = \frac{d\vec{r}(t)}{dt} - \vec{r}_0$$

$$\Rightarrow \vec{v}'(t) = \vec{v}(t) - \vec{r}_0 \Rightarrow \boxed{\vec{v}'(t) = \vec{v}(t) - \vec{r}_0}$$

Regla de
velocidades

$$\vec{u}'(t) = \vec{u}(t) - \vec{v}$$

Si el objeto se calora \Rightarrow su aceleración $\vec{a}'(t)$ neta desde S' será:

$$= \vec{a}(t)$$

$$\vec{a}'(t) = \frac{d}{dt} \vec{v}'(t) = \frac{d}{dt} (\vec{v}(t) - \vec{r}_0) = \frac{d\vec{v}(t)}{dt} - \cancel{\frac{d\vec{r}_0}{dt}}$$

$$\vec{a}'(t) = \vec{a}(t) \Rightarrow \boxed{\vec{a}'(t) = \vec{a}(t)}$$

Aceleraciones iguales !!



Pero entonces... Invariancia de Galileo

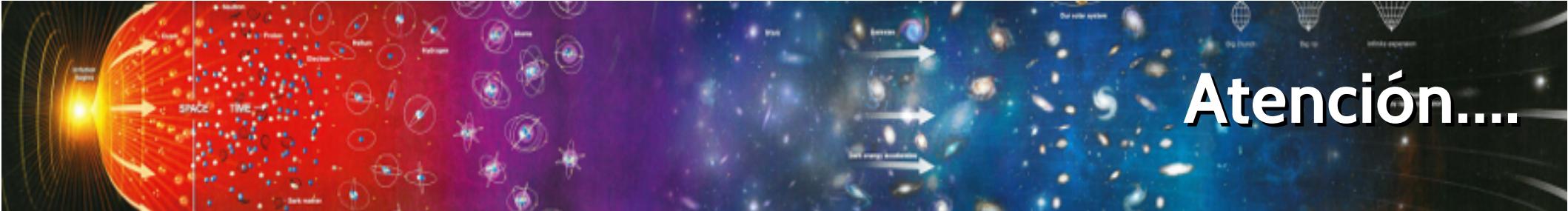
- Este último resultado es crucial, ya que si

$$\vec{a}'(t) = \vec{a}(t)$$

- Y suponemos que la masa m es un invariante, $m=m'$

$$m\vec{a}'(t) = m\vec{a}(t) \Rightarrow \vec{F}'(t) = \vec{F}(t)$$

- ¡La segunda ley de Newton no cambia frente a cambios entre sistemas de referencias inerciales! (la primera ya valía)
- **Si las leyes de la mecánica valen en un marco inercial, valen en todos**



Atención....

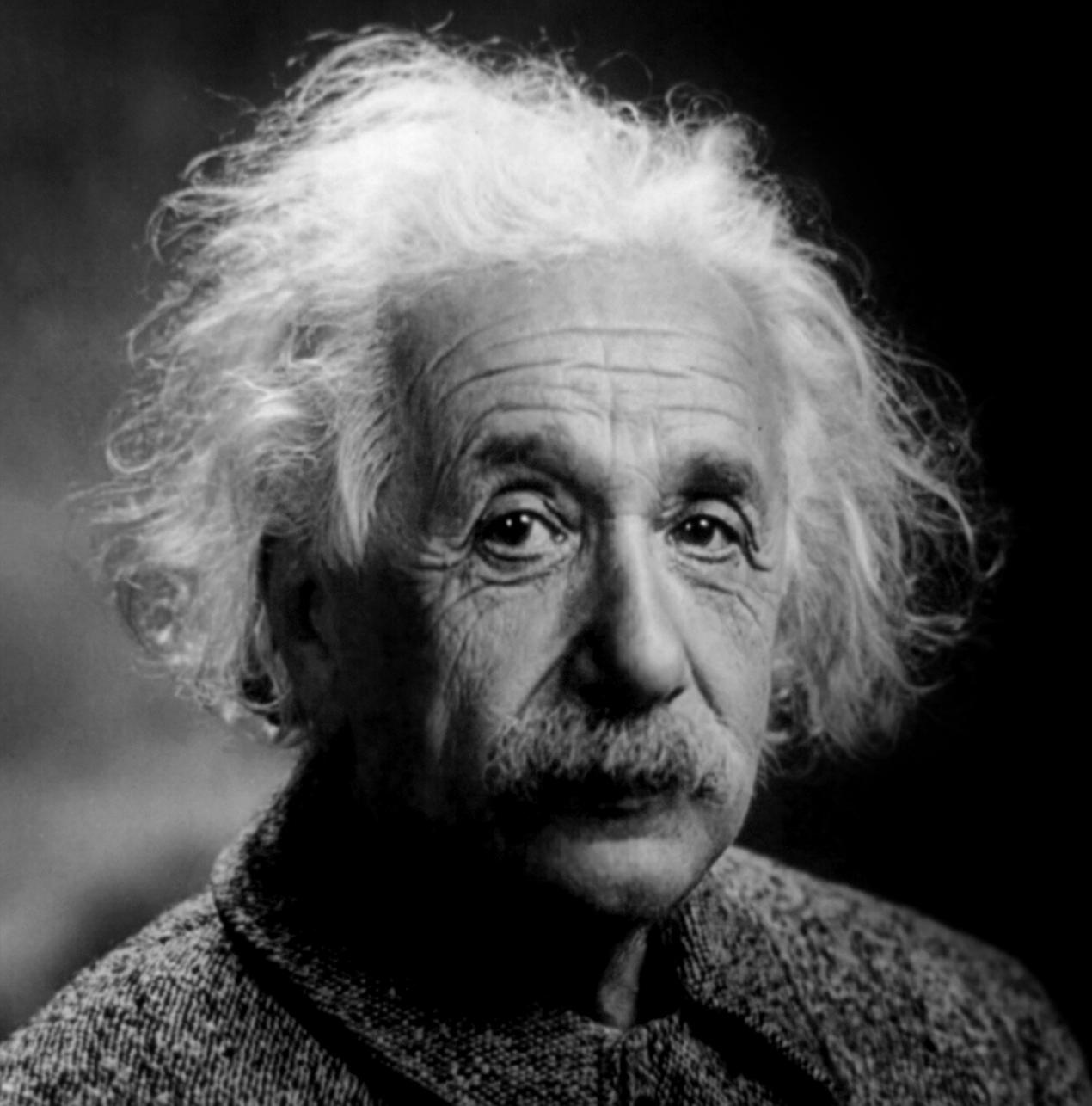
- Para llegar a este importante resultado, dimos por sentado algo que no es trivial:

**En todos los casos, derivamos respecto a t,
ya que en Galileo,
 $t=t' \rightarrow dt = dt'$**

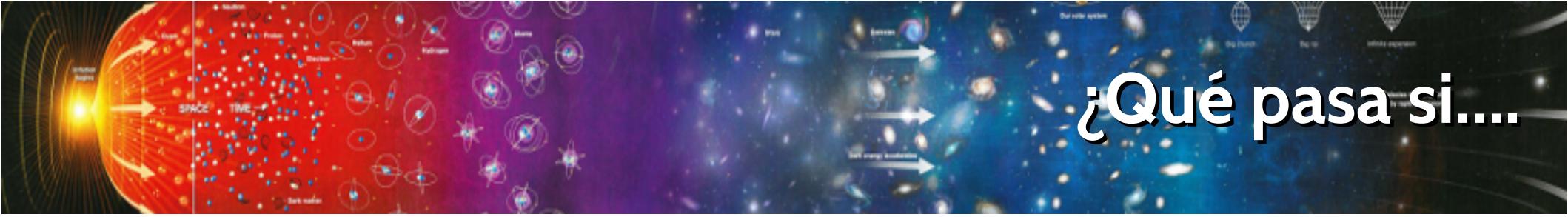
- Esto parece obvio, pero ¡no lo es!
- Y además, sólo vale para las leyes de Newton, en el electromagnetismo, esto no vale ($\rightarrow F-4B$)
 \rightarrow Transformaciones de Lorentz (ya vienen)



El genial Albert Einstein

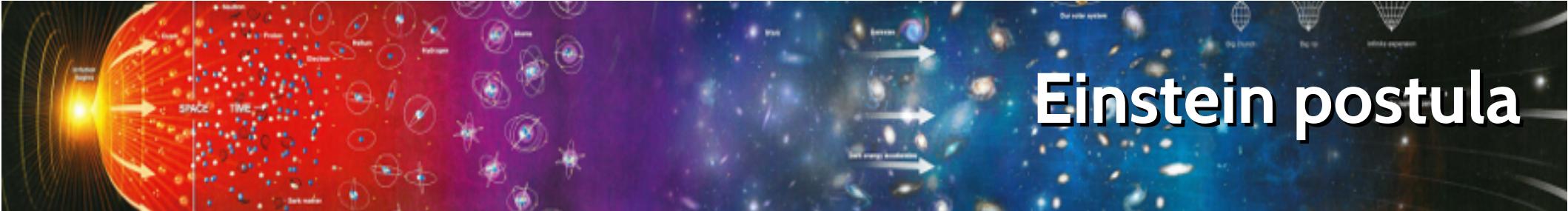


Albert Einstein



¿Qué pasa si....

- Ondas mecánicas necesitan un medio
→ Ondas electromagnéticas también → Éter
- Hay una fuerte inconsistencia entre las leyes de Newton y las leyes de Maxwell
- Michelson & Morley (1887) querían medir la velocidad del “viento del éter” (la Tierra se mueve a una velocidad de 30km/s ~ 0.0001 c) → **fallan estrepitosamente...**
- ... y esto es un **éxito rotundo**: demuestran que no hay necesidad de plantear la existencia del éter
- Pero además, vieron que la velocidad de la luz era la misma



Einstein postula

- **El principio de la relatividad:**

Las leyes que gobiernan los cambios en los estados de los sistemas físicos son iguales para todos los observadores inerciales

- **El principio de la invarianza de la velocidad de la luz**

La luz se propaga en el vacío siempre con la misma velocidad, sin importar la velocidad de la fuente emisora de luz