¿SE PUEDE VIAJAR EN EL TIEMPO?

J. J. Ruiz-Lorenzo

Dep. Física,
Instituto de Computación Científica Avanzada(ICCAEx),
Universidad de Extremadura
http://www.unex.es/fisteor/juan/juan_talks.html

Badajoz, 25 de Noviembre 2015

- *The most incomprehensible thing about the world is that it is comprehensible.*

  (Albert Einstein)

- *It seems that there is a Chronology Protection Agency which prevents the appearance of closed timelike curves and so makes the universe safe for historians.*

  (Stephen Hawking)

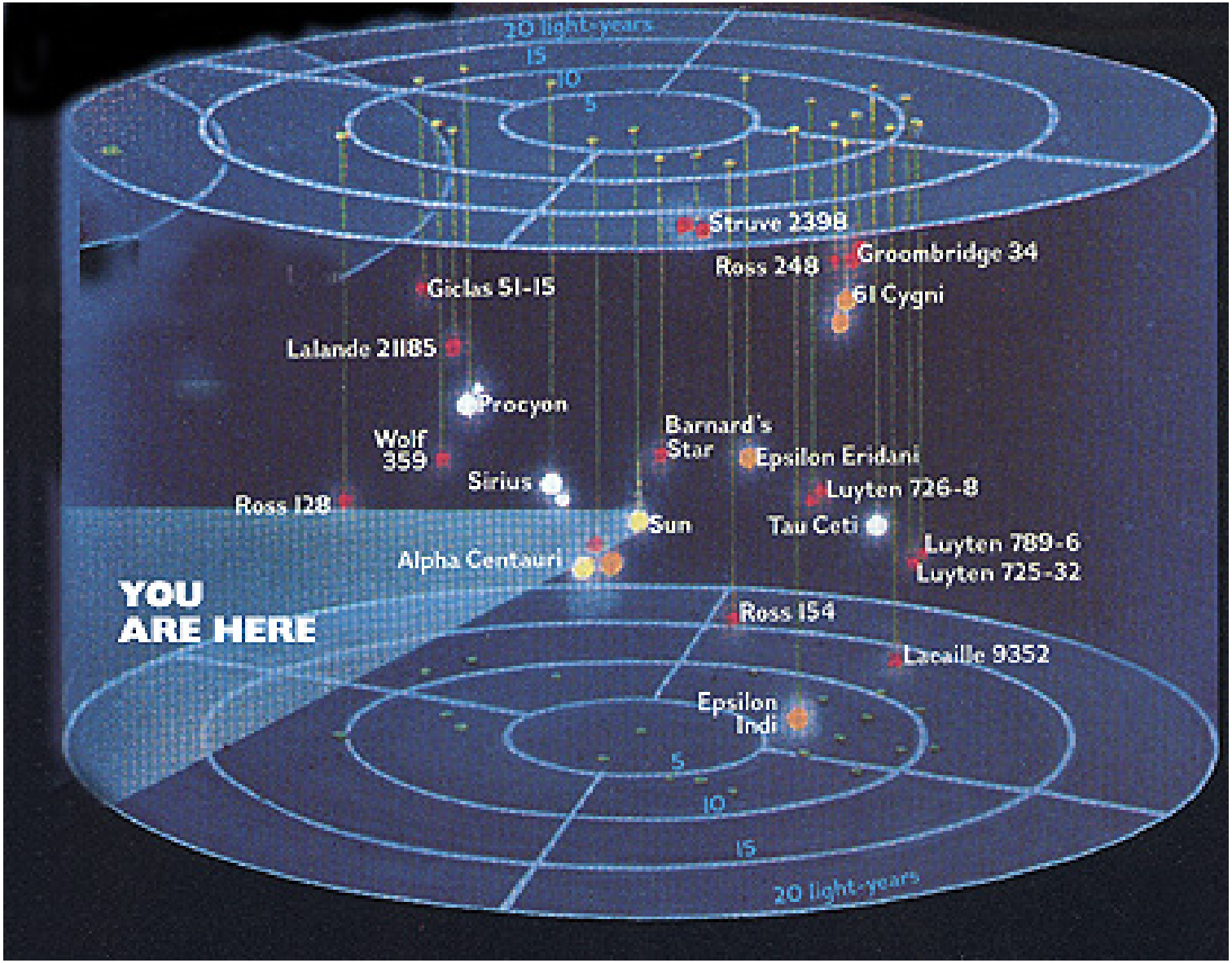
- *...Warp speed.*

  (Star Trek)

H. G. Wells


METRO-GOLDWYN-MAYER presents
A GEORGE PAL PRODUCTION
H.G. WELLS'
THE TIME MACHINE
in futuristic METROCOLOR
YOU WILL ORBIT INTO THE FANTASTIC FUTURE!
STARRING
ROD TAYLOR
ALAN YOUNG · YVETTE MIMIEUX
SEBASTIAN CABOT · TOM HELMORE
Screen Play by DAVID DUNCAN · Based on the Novel by H. G. WELLS · Directed by GEORGE PAL

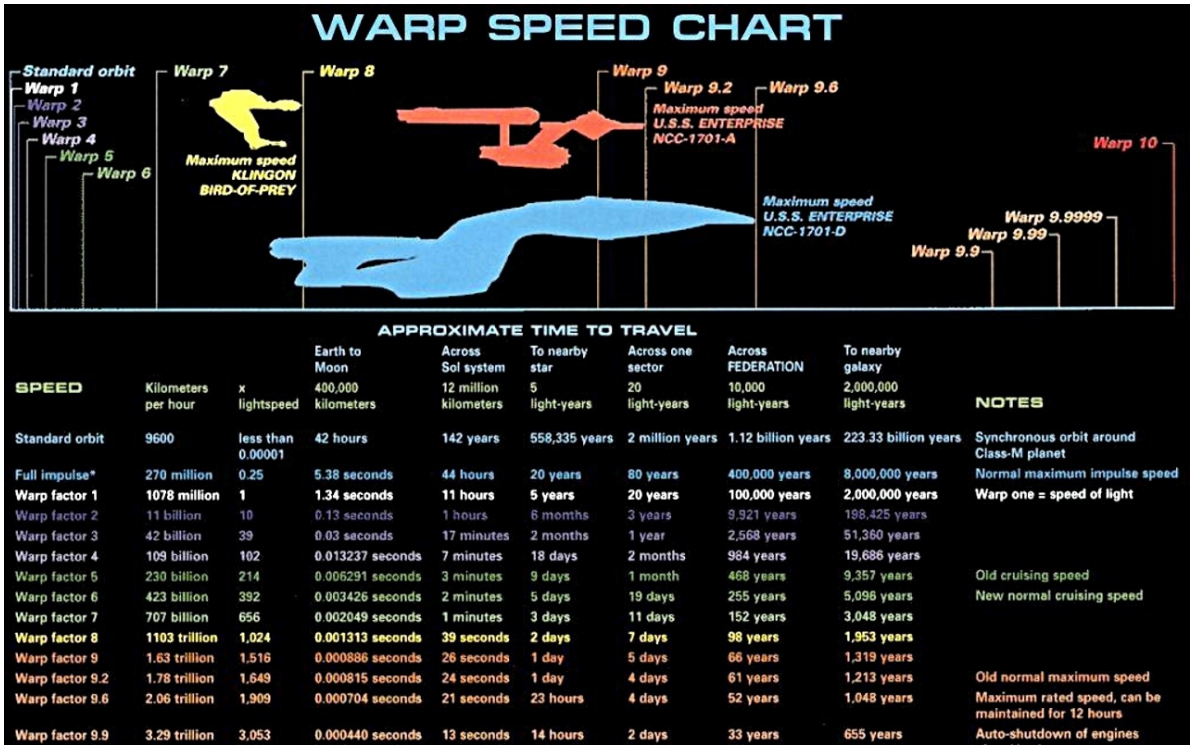
Viajes Interestelares



Física de los Viajes Interestelares

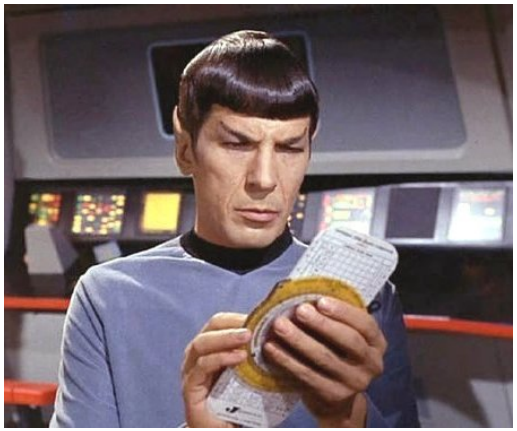
- Una nave espacial, con aceleración de 10 $\mathrm{m/s^2}$, necesita 3.6 años (en el reloj de la nave) para alcanzar $v = 0.999c$, partiendo del reposo. En la Tierra pasarán 21.3 años.
- Necesitaría casi 11 años en llegar al centro de la galaxia (50000 años-luz). En la Tierra habrán pasado 50001 años.
- Si el cohete conviertiera su masa en energía (usando $E = mc^2$) como forma de propulsión, al final del trayecto le quedaría *solo* 1/10000 de su masa!

Star Trek



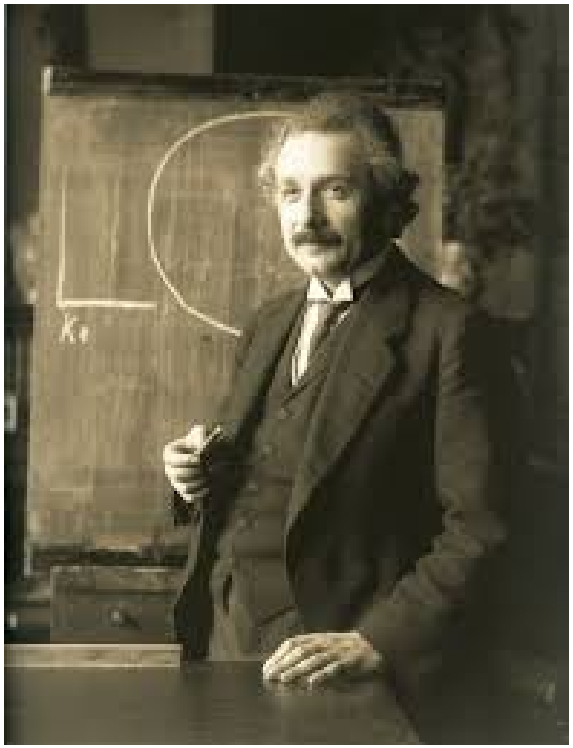
APPROXIMATE TIME TO TRAVEL

SPEED	Kilometers per hour	x lightspeed	Earth to Moon 400,000 kilometers	Across Sol system 12 million kilometers	To nearby star 5 light-years	Across one sector 20 light-years	Across FEDERATION 10,000 light-years	To nearby galaxy 2,000,000 light-years	NOTES
Standard orbit	9600	less than 0.00001	42 hours	142 years	558,335 years	2 million years	1.12 billion years	223.33 billion years	Synchronous orbit around Class-M planet
Full impulse*	270 million	0.25	5.38 seconds	44 hours	20 years	80 years	400,000 years	8,000,000 years	Normal maximum impulse speed
Warp factor 1	1078 million	1	1.34 seconds	11 hours	5 years	20 years	100,000 years	2,000,000 years	Warp one = speed of light
Warp factor 2	11 billion	10	0.13 seconds	1 hours	6 months	3 years	9,921 years	198,425 years	
Warp factor 3	42 billion	39	0.03 seconds	17 minutes	2 months	1 year	2,568 years	51,360 years	
Warp factor 4	109 billion	102	0.013237 seconds	7 minutes	18 days	2 months	984 years	19,686 years	
Warp factor 5	230 billion	214	0.006291 seconds	3 minutes	9 days	1 month	468 years	9,357 years	Old cruising speed
Warp factor 6	423 billion	392	0.003426 seconds	2 minutes	5 days	19 days	255 years	5,096 years	New normal cruising speed
Warp factor 7	707 billion	656	0.002049 seconds	1 minutes	3 days	11 days	152 years	3,048 years	
Warp factor 8	1103 trillion	1,024	0.001313 seconds	39 seconds	2 days	7 days	98 years	1,953 years	
Warp factor 9	1.63 trillion	1,516	0.000886 seconds	26 seconds	1 day	5 days	66 years	1,319 years	
Warp factor 9.2	1.78 trillion	1,649	0.000815 seconds	24 seconds	1 day	4 days	61 years	1,213 years	Old normal maximum speed
Warp factor 9.6	2.06 trillion	1,909	0.000704 seconds	21 seconds	23 hours	4 days	52 years	1,048 years	Maximum rated speed, can be maintained for 12 hours
Warp factor 9.9	3.29 trillion	3,053	0.000440 seconds	13 seconds	14 hours	2 days	33 years	655 years	Auto-shutdown of engines



Albert Einstein

- Albert Einstein (1879-1955).
- Graduado en el ETH Zúrich.
- Doctorado ETH Zúrich.
- Efecto Fotoeléctrico (Premio Nobel, 1921).
- Movimiento Browniano.
- Calores específicos.
- Mecánica Estadística.
- Relatividad Especial.
- Relatividad General.
- Teorías clásicas unificadas.
- Profesor en Berna, Zúrich, Praga, Berlín y Pricenton.

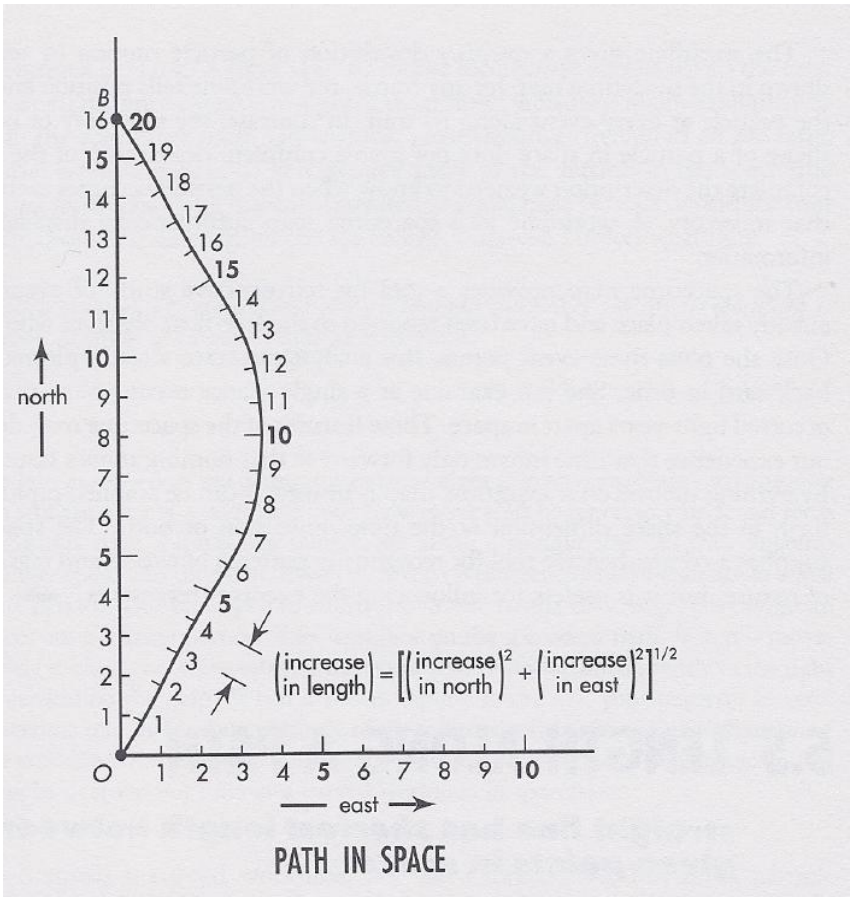


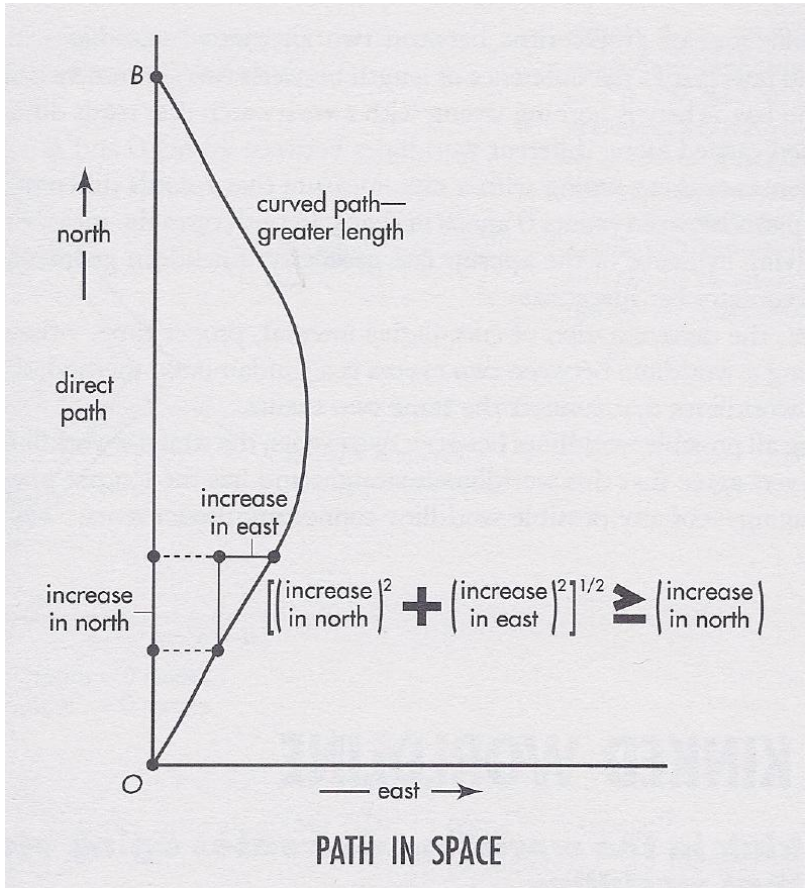
Principio de Relatividad Especial

- Las leyes de la Física son las mismas en todos los sistemas inerciales.
- Por lo tanto, la velocidad de la luz es la misma para todos los sistemas inerciales ($c = 3 \times 10^5$ km/h).

Una partícula sobre la que no actúa ninguna fuerza, en un sistema inercial, o está en reposo o se mueve con velocidad uniforme.

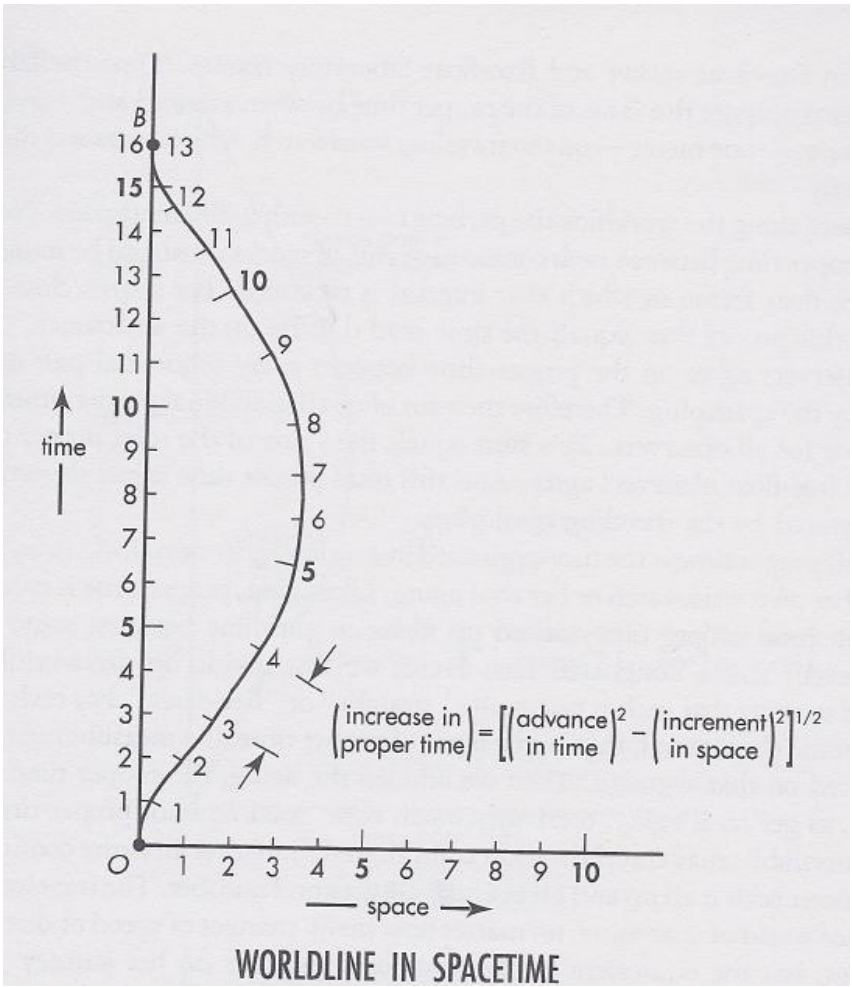
Teorema de Pitágoras

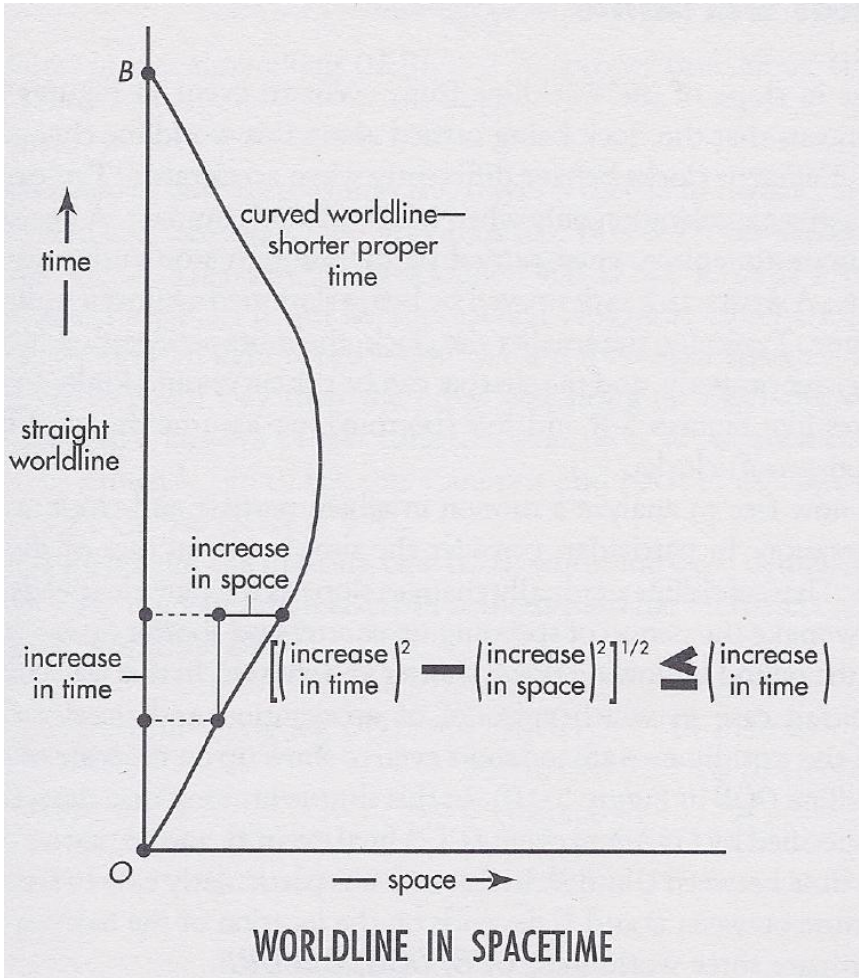




(Taylor-Wheeler, Spacetime Physics)

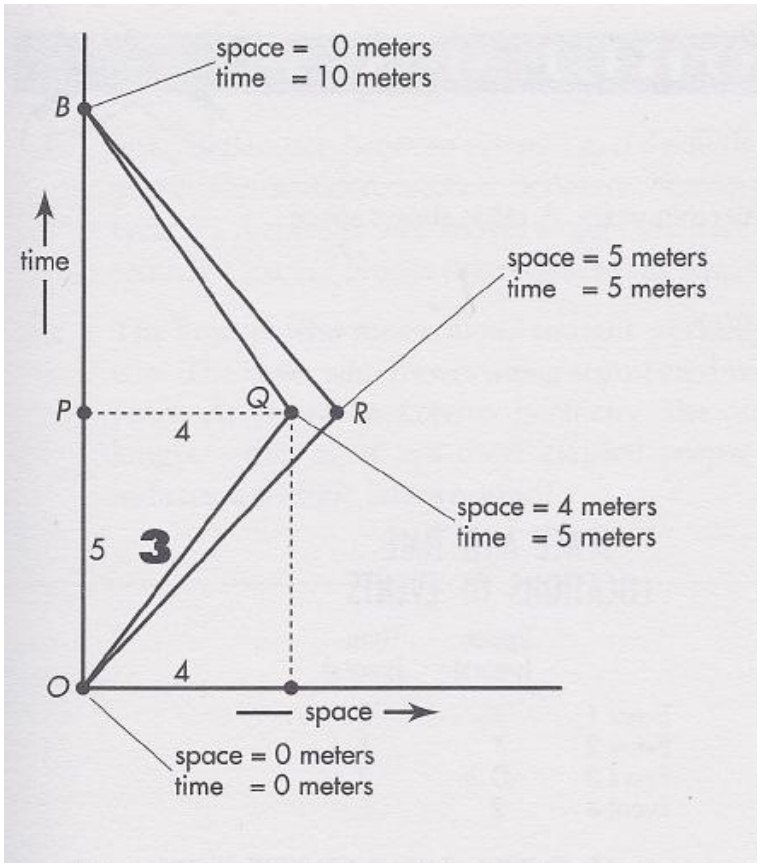
El intervalo





(Taylor-Wheeler, Spacetime Physics)

Paradoja de los gemelos



(Taylor-Wheeler, Spacetime Physics)

El intervalo

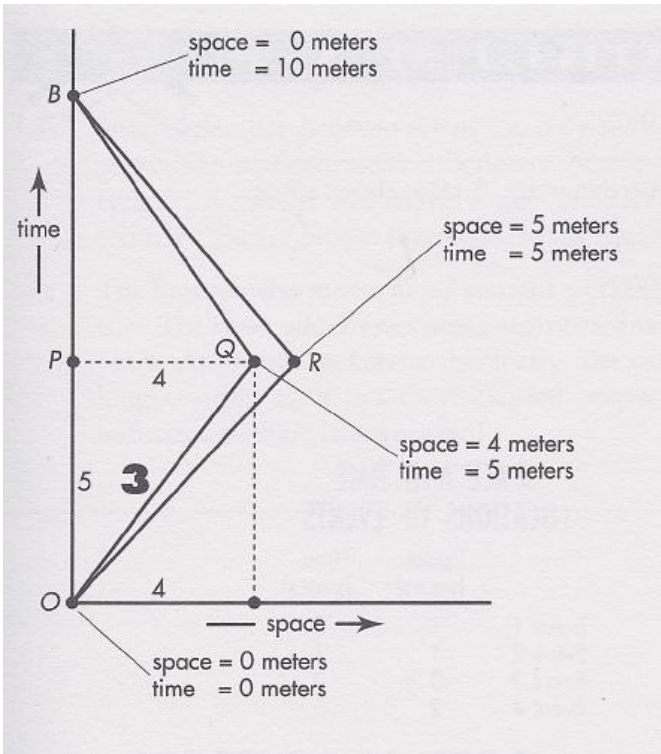
$\Delta\tau$: Incremento en tiempo propio.

(Incremento en tiempo propio)^2 =
(Avance en tiempo)^2 − (Incremento en espacio)^2

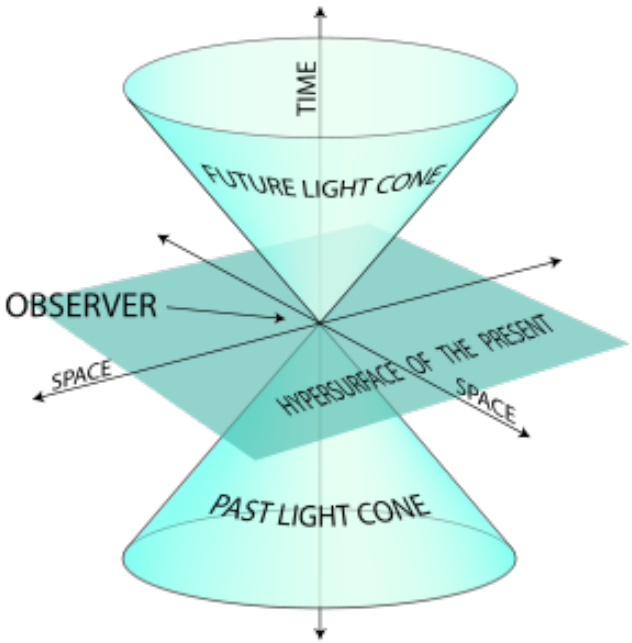
- **OP**: $\Delta\tau^2 = 5^2 - 0^2 \rightarrow \Delta\tau = 5$
- **OQ**: $\Delta\tau^2 = 5^2 - 4^2 \rightarrow \Delta\tau = 3$
- **OR**: $\Delta\tau^2 = 5^2 - 5^2 \rightarrow \Delta\tau = 0$

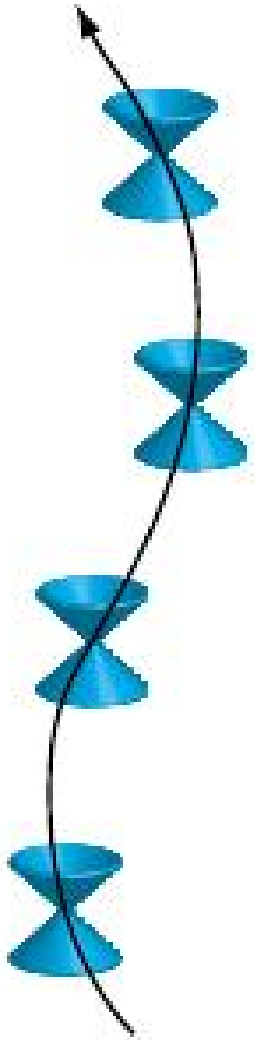
- **OPB**: $\Delta\tau = 2 \times 5 = 10$ m
- **OQB**: $\Delta\tau = 2 \times 3 = 6$ m
- **ORB**: $\Delta\tau = 2 \times 0 = 0$ m

1 m de espacio= c× “1 m de tiempo”.
“1 m de tiempo”= 3.333 ns.



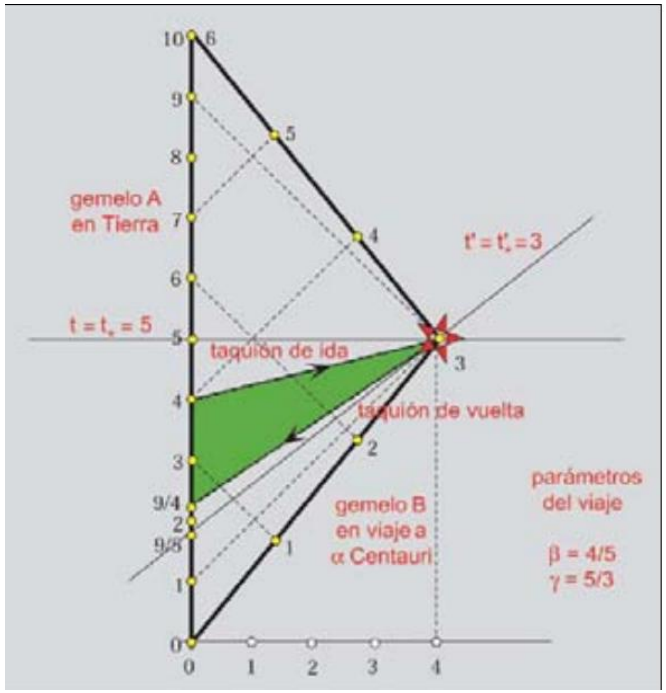
Cono de luz


TIME
FUTURE LIGHT CONE
OBSERVER
SPACE
HYPERSURFACE OF THE PRESENT
SPACE
PAST LIGHT CONE



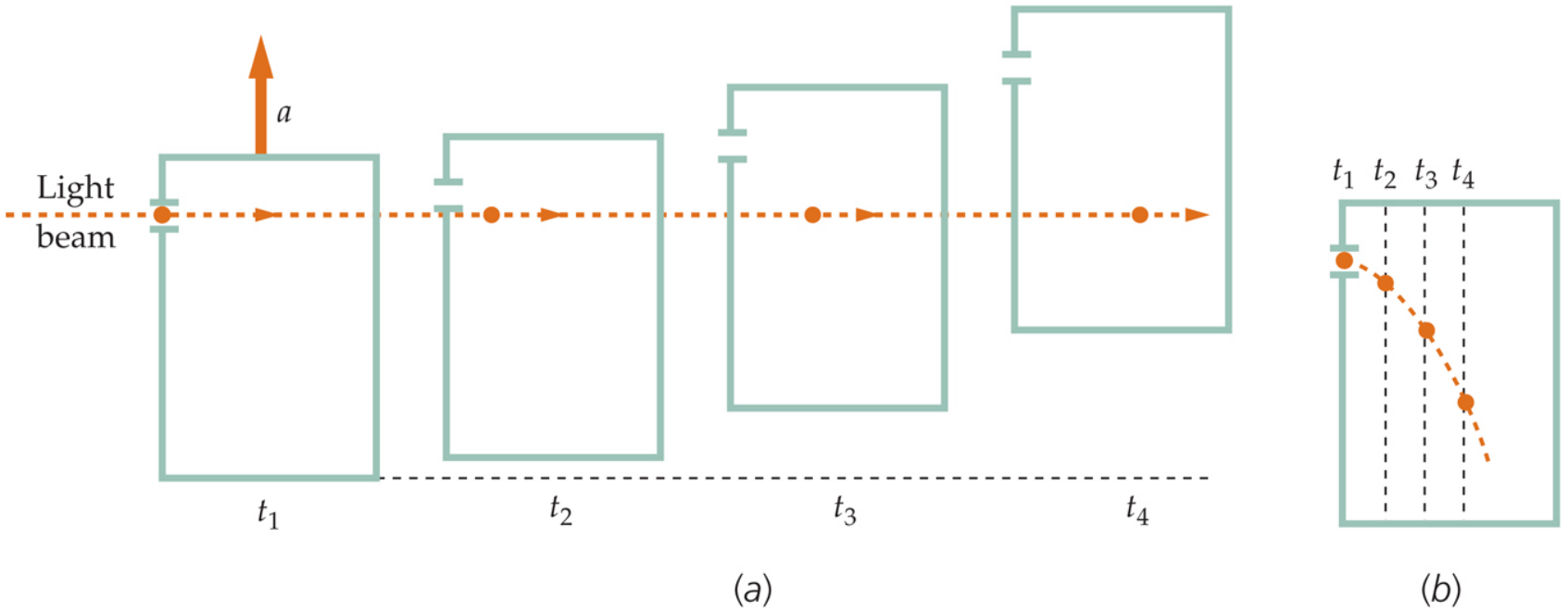
Taquiones

- Partículas que se pueden mover con velocidades siempre superiores a c.
- Desde A se manda, en $t = 4$, un taquión a B ($v = 4c$) y B lo recibe cuando llega a la estrella.
- B lo reenvia ($v' = 4c$) a A, que lo recibe en $t = 9/4 < 4$!!!
- Materia inestable!!



(Galindo, RAC-2013)

Acensores acelerados y rayos laser

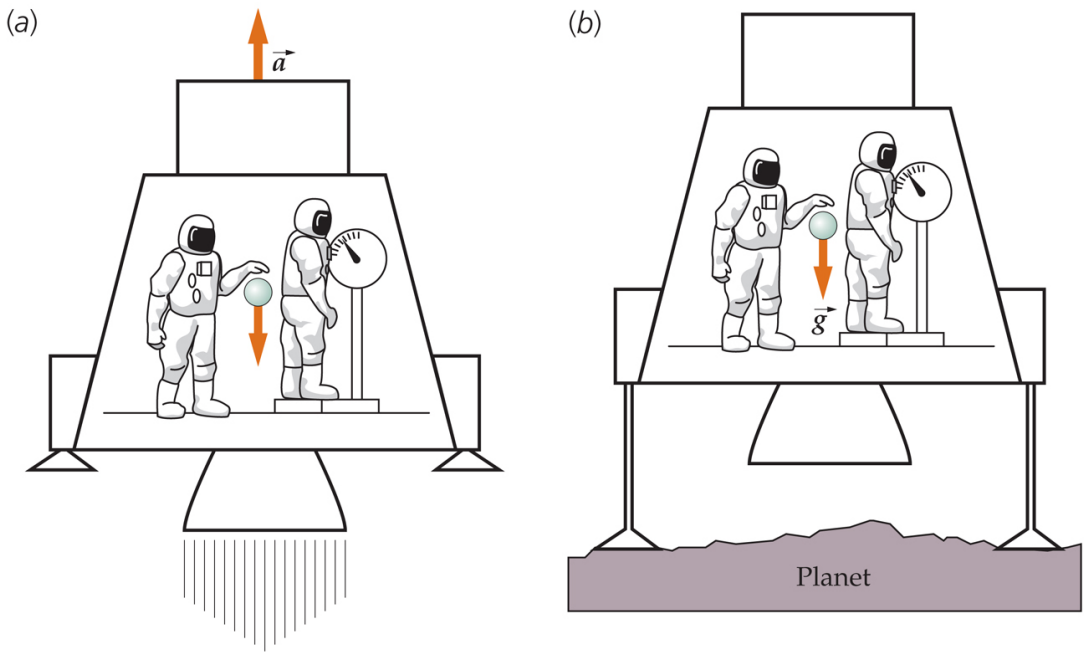


(Tipler-Mosca, Física)

Principio de Equivalencia

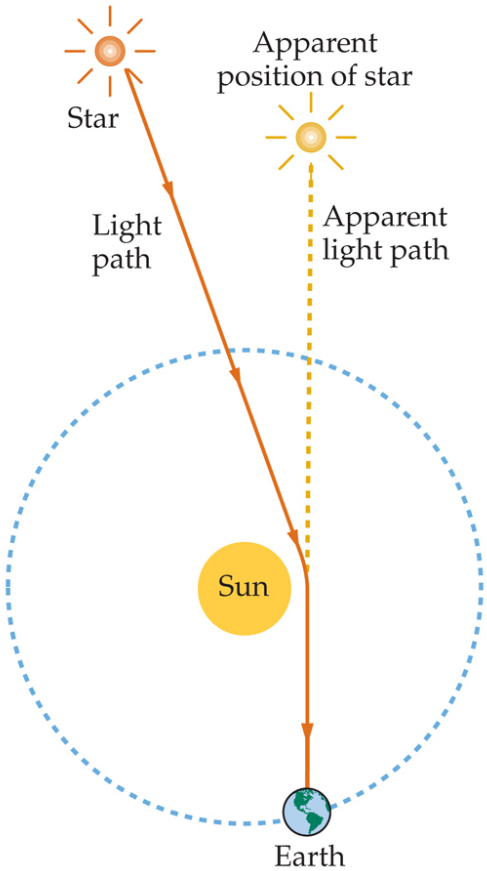
- Un campo gravitatorio homogéneo es completamente equivalente a un sistema de referencia uniformemente acelerado.

Natural en Mecánica Newtoniana si asumimos $m_{\text{inercial}} = m_{\text{gravitacional}}$.
Einstein lo generalizó a todas las ramas de la Física.



(Tipler-Mosca, Física)

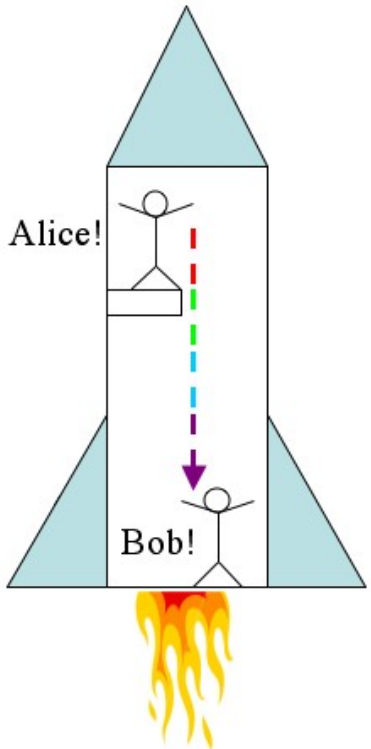
Principio de Equivalencia



(Tipler-Mosca, Física)

Dilatación gravitacional del tiempo

- Fotones: $h\nu_{\text{arriba}} < h\nu_{\text{abajo}}$.
- $T_{\text{abajo}} < T_{\text{arrriba}}$, ya que $\nu = 1/T$.
- Entonces, $(\Delta\tau)^2 = A(t,x,y,z)(\Delta t)^2 - \ldots$.



(Tipler-Mosca, Física)

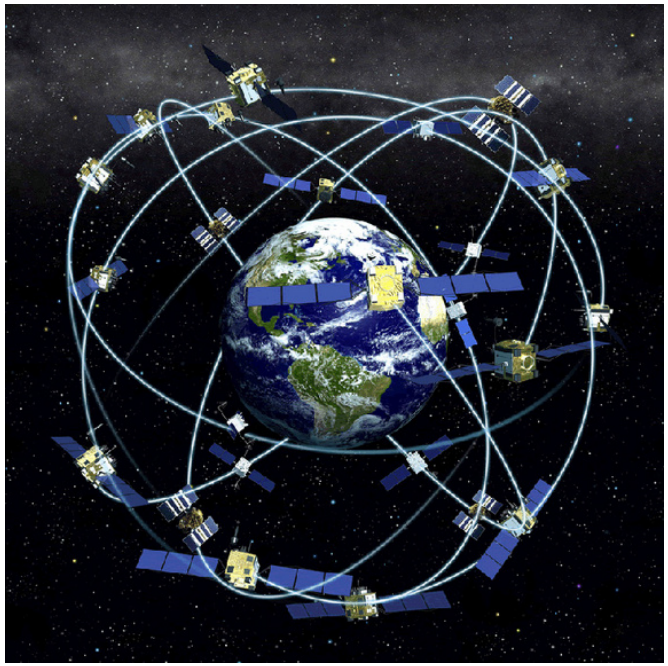
Relojes Viajeros (Hafele y Keating)

- Vuelo Boeing-747
- Reloj de Referencia: USNO.
- Vuelo Este:
  Retraso: -59 ± 10 ns.
  [G.=144 ns, C.=-184 ns, T.=-40 ± 23 ns]
- Vuelo Oeste:
  Adelanto: 273 ± 21 ns.
  [G.=179 ns, C.=96 ns, T.=275 ± 21 ns]
- Se ha comprobado, Chou et al 2010, con una precisión de 10^{-16} ($v < 36$ km/h, $h \sim 3$ cm).

Relojes más precisos: 10^{-16} (Cs), 10^{-17} (Al), 2×10^{-18} (Sr).

GPS

- Constelación formada por 24 satélites.
- Orbitan en 6 planos orbitales diferentes.
- 12 horas (sidéreas) de periodo.
- $h \simeq 20000$ km.
- $i \simeq 55°$.
- $v \simeq 14000$ km/h.
- $\delta_C \simeq -8.4 \times 10^{-11}$. En 1 día: -7.3 μs.
- $\delta_G \simeq 5.7 \times 10^{-10}$. En 1 día: $+49.4$ μs.
- $\delta_T = \delta_C + \delta_G \simeq 4.9 \times 10^{-10}$. En 1 día: $+42.1$ μs.



Espacios Curvos

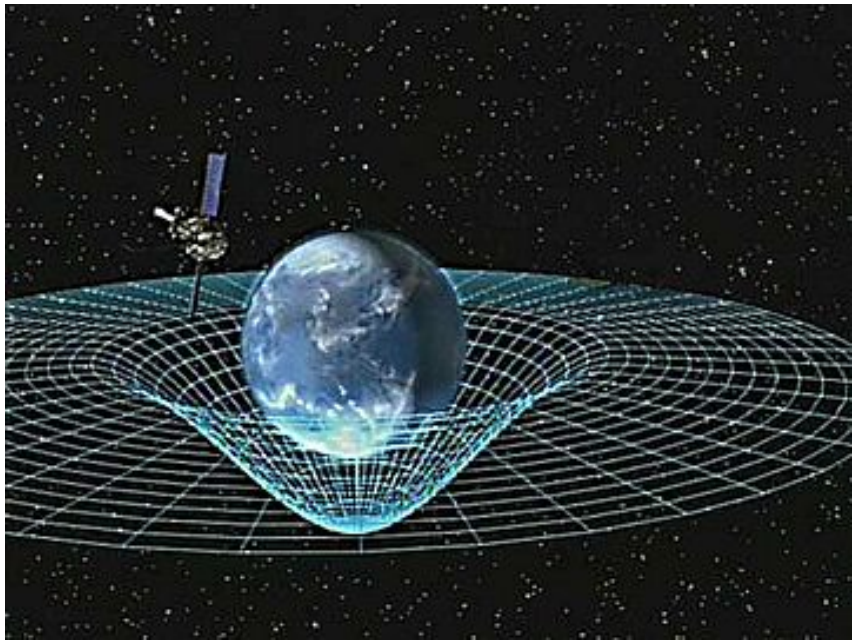
- $$(\Delta s)^2 = (\Delta x)^2 + (\Delta y)^2$$
- $$(\Delta s)^2 = A(x,y)(\Delta x)^2 + C(x,y)(\Delta y)^2$$
- $$(\Delta s)^2 = A(x,y)(\Delta x)^2 + 2B(x,y)\Delta x \Delta y + C(x,y)(\Delta y)^2$$

Ecuaciones de Einstein (1915)

$$ds^2 = -c^2 d\tau^2 = g_{\alpha\beta} dx^\alpha dx^\beta$$

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = \frac{8\pi G}{c^4} T_{\mu\nu}$$

$$\frac{d^2 x^\mu}{d\tau^2} + \Gamma^\mu_{\rho\gamma} \frac{dx^\rho}{d\tau} \frac{dx^\gamma}{d\tau} = 0$$



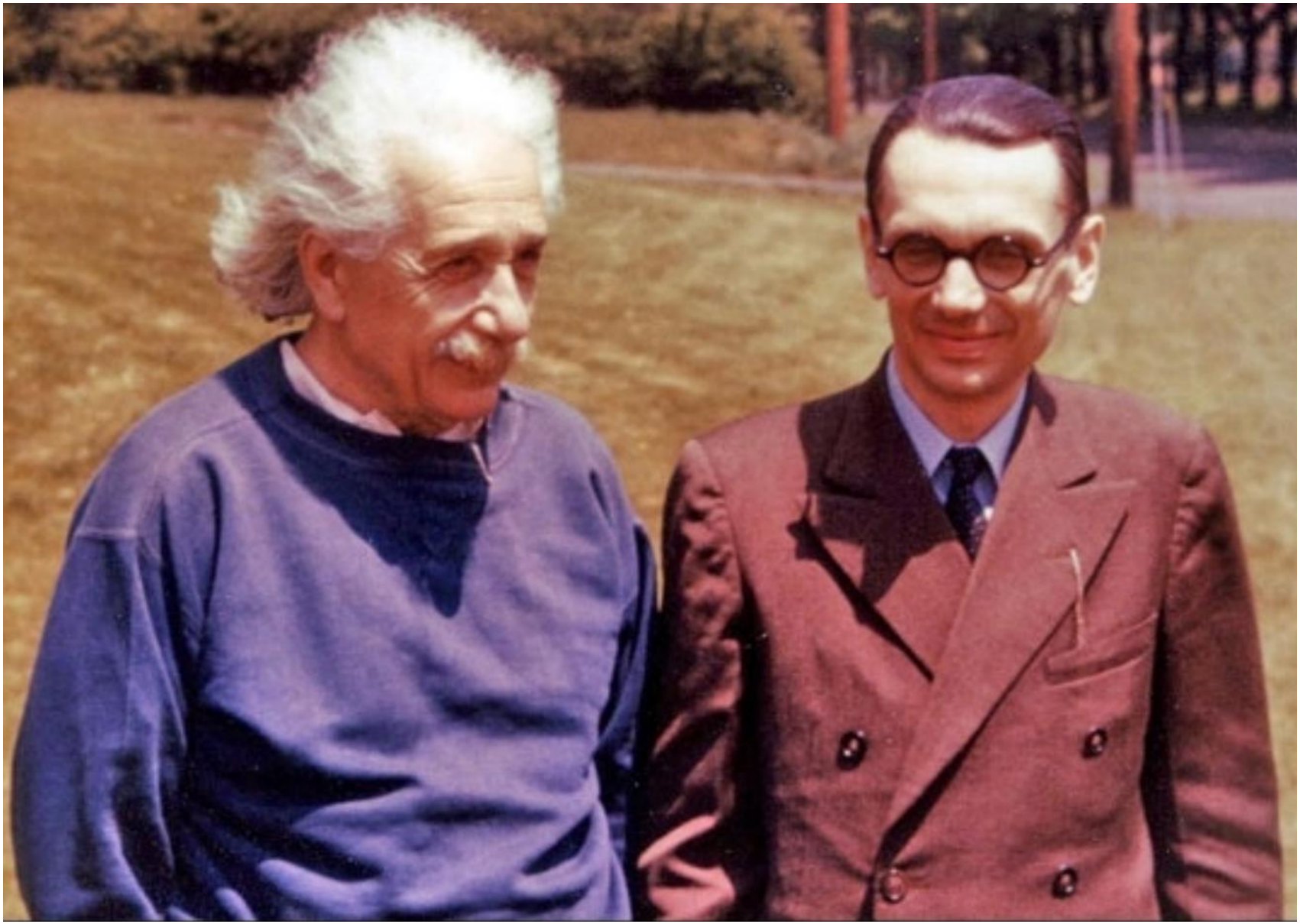
(Algunas) Máquinas del tiempo

- Van Stockum (Cilindro infinito rotatorio)
- Gödel (Universo rotatorio con constante cosmológica negativa)
- Gott (Cuerdas Cósmicas)
- Alcubierre (Deformación del espacio)
- Krasnikov
- Agujeros de gusano

Kurt Gödel

- Kurt Gödel (1906-1978).
- Graduado en la Universidad de Viena.
- Doctorado en la Universidad de Viena.
- Uno de los mayores lógicos del siglo XX.
- Teoremas de incompletitud.

Einstein y Gödel



Universo de Gödel (el iniciador)

LETTERS TO THE EDITORS

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Rotating Universe ?

ONE of the most mysterious results of the astronomical studies of the universe lies in the fact that all successive degrees of accumulation of matter, such as planets, stars and galaxies, are found in the state of more or less rapid axial rotation. In various cosmogonical theories the rotation of planets has been explained as resulting from the rotation of stars from which they were formed. The rotation of stars themselves (in particular that of *B*-stars) can be presumably reduced to their origin from the rotating gas-masses which form the spiral arms of various galaxies. But what is the origin of galactic rotation ?

If, according to the current theories, we consider the galaxies as the result of gravitational instability of the originally uniform distribution of matter in space, we will find it very difficult to understand why such condensations are in most cases found in the state of rather fast rotation. In fact, on the basis of statistical distribution of angular momentum, we would rather expect such condensations to show no more rotation than the water droplets in a fog formed from oversaturated vapour. Barring the possible explanation of the rotation of galaxies on the basis of the alleged irregular turbulent motion of the masses of the universe, we can ask ourselves whether it is not possible to assume that *all matter in the visible universe is in a state of general rotation around some centre located far beyond the reach of our telescopes ?*

The answer to such, at first sight fantastic, question need not wait until much larger telescopes shall have been built. It can be, in fact, settled by present means of observation. We know that the rotation of the stars of our system around the galactic centre can be proved by the study of the so-called Oort-effect in the radial velocities of comparatively near stars. In fact, due to the phenomenon of differential rotation, the mean radial velocities of stars located along the galactic plane show a double-sine periodicity with nodal axes directed parallel and perpendicular to the line connecting the sun with the centre of rotation. Thus if the realm of galaxies as seen through Mt. Wilson telescope represents only a small part of a much larger system (a 'super-galaxy' in the super-Shapley sense) rotating around a distant centre, careful observations of mean radial velocities of galaxies located in different regions of the sky should reveal similar periodicity.

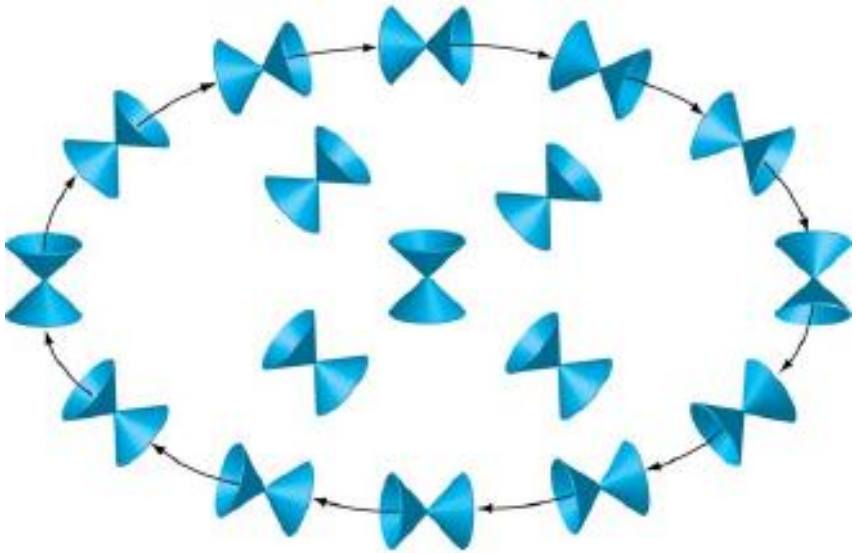
The existence of this effect would prove general rotation of the universe and indicate the direction towards the rotation centre without, however, giving us its distance. Thus, it seems that the answer to the problem of universal rotation lies within the grasp of modern astronomical technique.

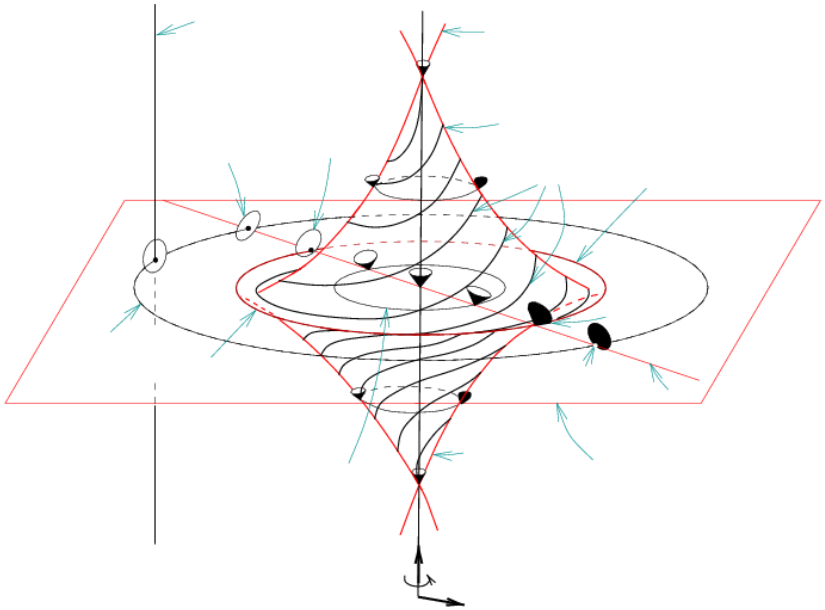
It must be added in conclusion that in the language of the general theory of relativity such a rotating universe can be probably represented by the group of anisotropic solutions of the fundamental equations of cosmology.

G. GAMOW

Department of Physics,
George Washington University,
Washington, D.C.
Sept. 13.

Universo de Gödel





Einstein y Gödel

.. disturbed me at the time of the building up of the general theory of relativity, without me having succeeded in clarifying it. It will be interesting to weigh whether these solutions are not to be excluded on physical grounds.

(Albert Einstein)

Propulsión por deformación (warp drive): Motor de curvatura de Miguel Alcubierre

Class. Quantum Grav. **11** (1994) L73–L77. Printed in the UK

LETTER TO THE EDITOR

The warp drive: hyper-fast travel within general relativity

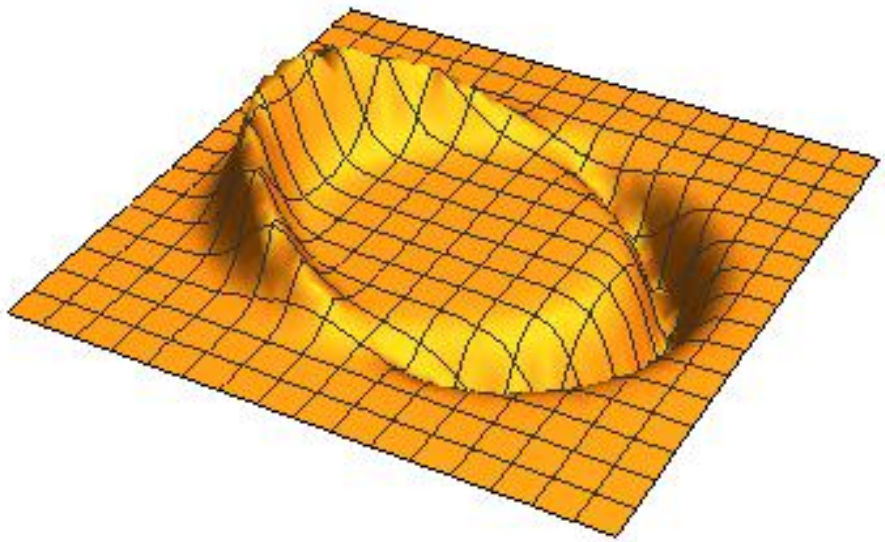
Miguel Alcubierre

Department of Physics and Astronomy, University of Wales,
College of Cardiff, PO Box 913, Cardiff CF1 3YB, UK

Received 19 January 1994, in final form 24 February 1994

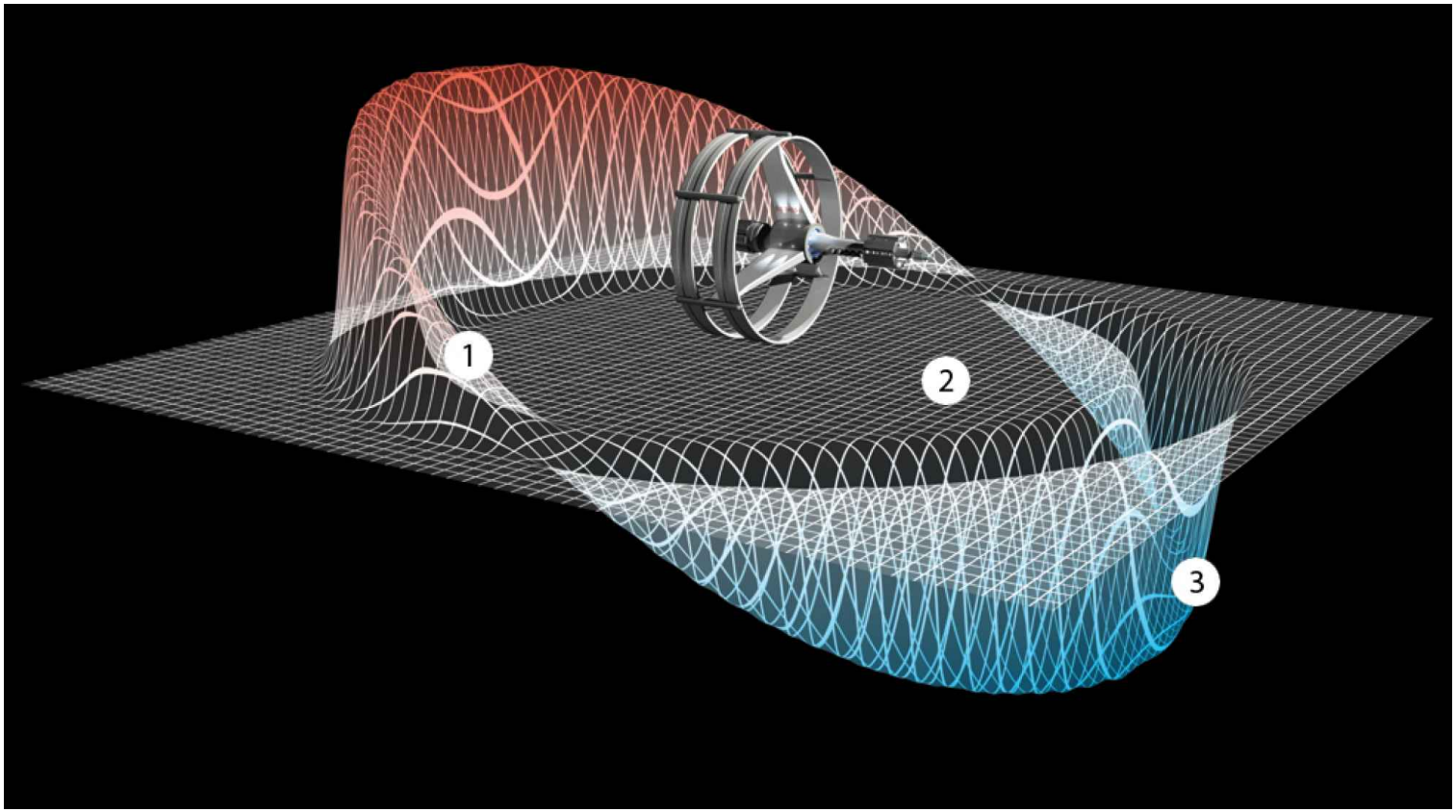
Abstract. It is shown how, within the framework of general relativity and without the introduction of wormholes, it is possible to modify a spacetime in a way that allows a spaceship to travel with an arbitrarily large speed. By a purely local expansion of spacetime behind the spaceship and an opposite contraction in front of it, motion faster than the speed of light as seen by observers outside the disturbed region is possible. The resulting distortion is reminiscent of the 'warp drive' of science fiction. However, just as happens with wormholes, exotic matter will be needed in order to generate a distortion of spacetime like the one discussed here.

Propulsión por deformación

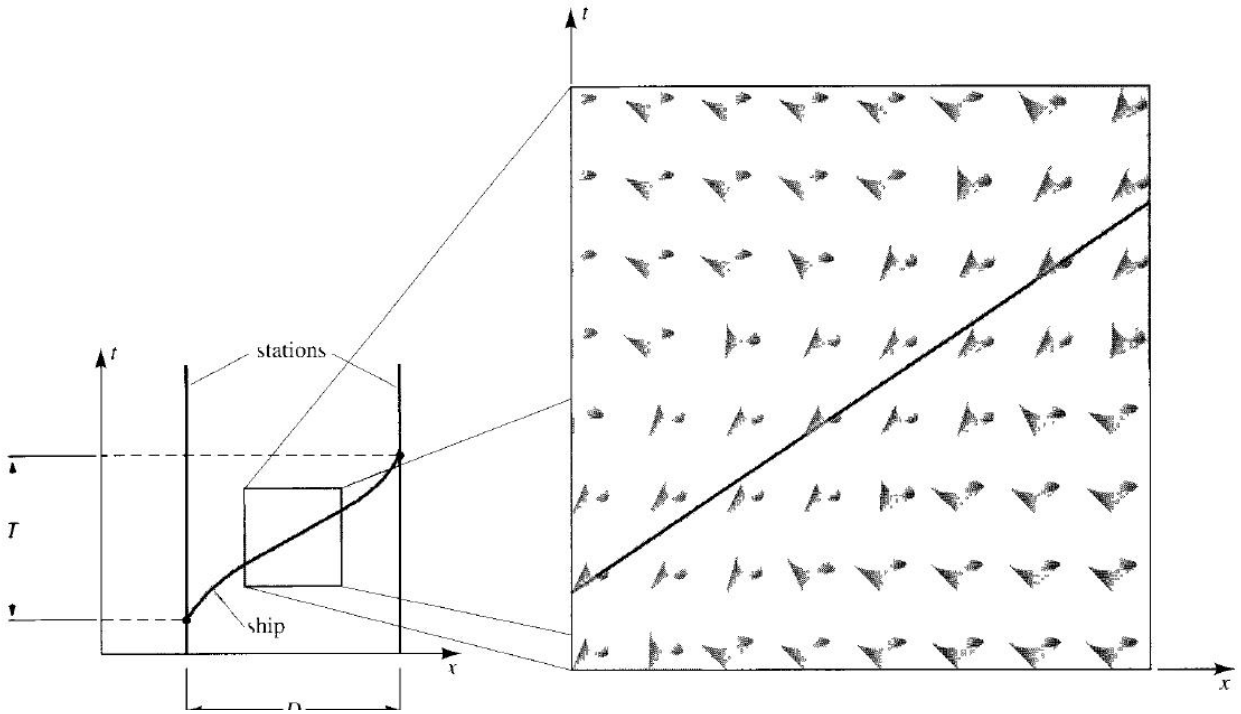


$\theta =$ Expansión del elemento de volumen

Propulsión por deformación

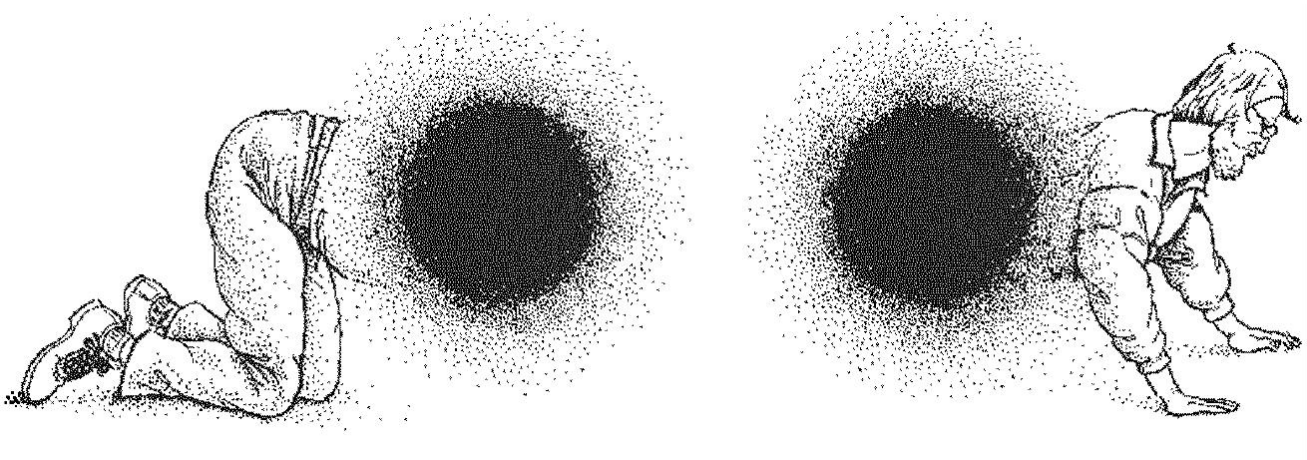


Propulsión por deformación: Conos de luz



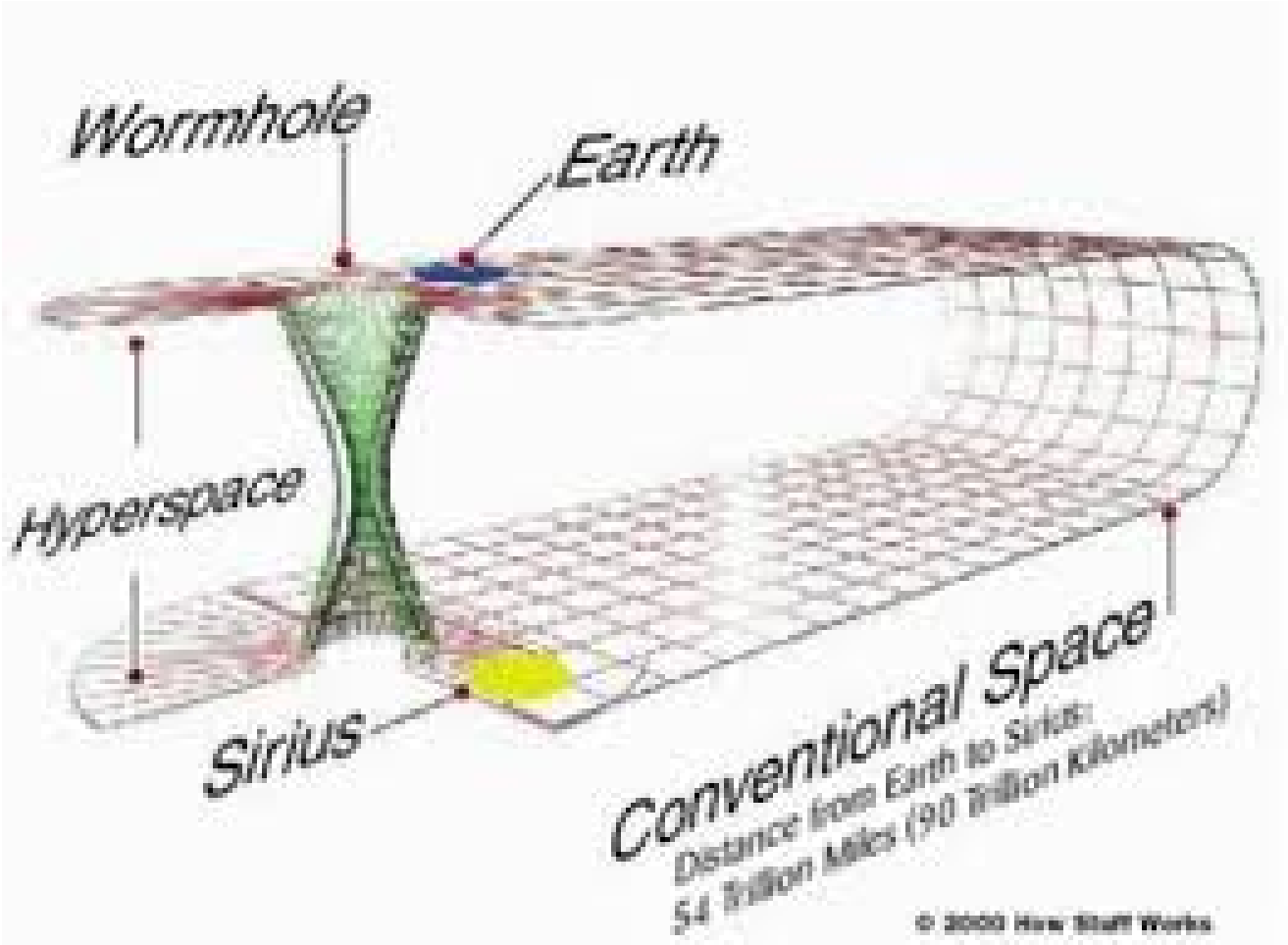
(Hartle, Gravity)

Agujeros de gusano: Kip Thorne



(Thorne, Black Holes)

Agujeros de gusano

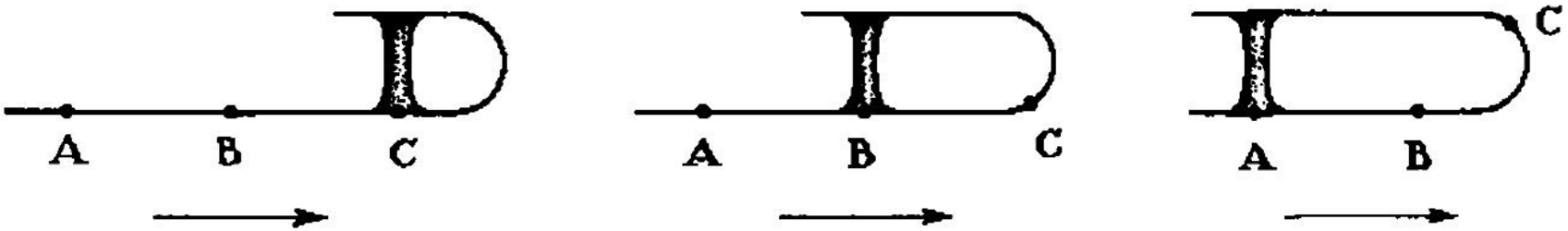


Agujeros de gusano

Agujeros de gusano. Mquina del tiempo

- Sean S y I las dos bocas del AG, que están en reposo relativo en un sistema inercial. Consideremos el día 1 de Diciembre de 2015.
- La boca inferior, I, se acelera hasta alcanzar una velocidad de $4c/5$, $\gamma = 5/3$), para luego frenar y posteriormente regresar a la misma velocidad a donde estaba inicialmente.
- Como al moverse se atrasan los relojes, si el viaje ha durado para los observadores externos a la boca I, 25 días, para los relojes del AG solo habrán pasado 15 días ($25/\gamma$).
- El proceso de recarga empezó el 1/12/2015 y finalizó el 25/12/2015, para los observadores externos a la zona I, mientras que para el AG, comenzó el 1/12/2015 y finalizó el día 15/12/2015.
- Los relojes del AG siempre están sincronizados, ya que ni se alarga ni cambia la distribución de masa.
- Por lo tanto si entramos en el AG desde S a I, pasamos del 15/12/2015 al 25/12/2015. Miramos el número del "Gordo" y volvemos a pasar de I a S, el mismo 25/12/2015, llegando a S el 15/12/2015. Compramos la loteria de Navidad y a esperar!!

Agujeros de gusano: Sincronización relojes



(Thorne, Black Holes)

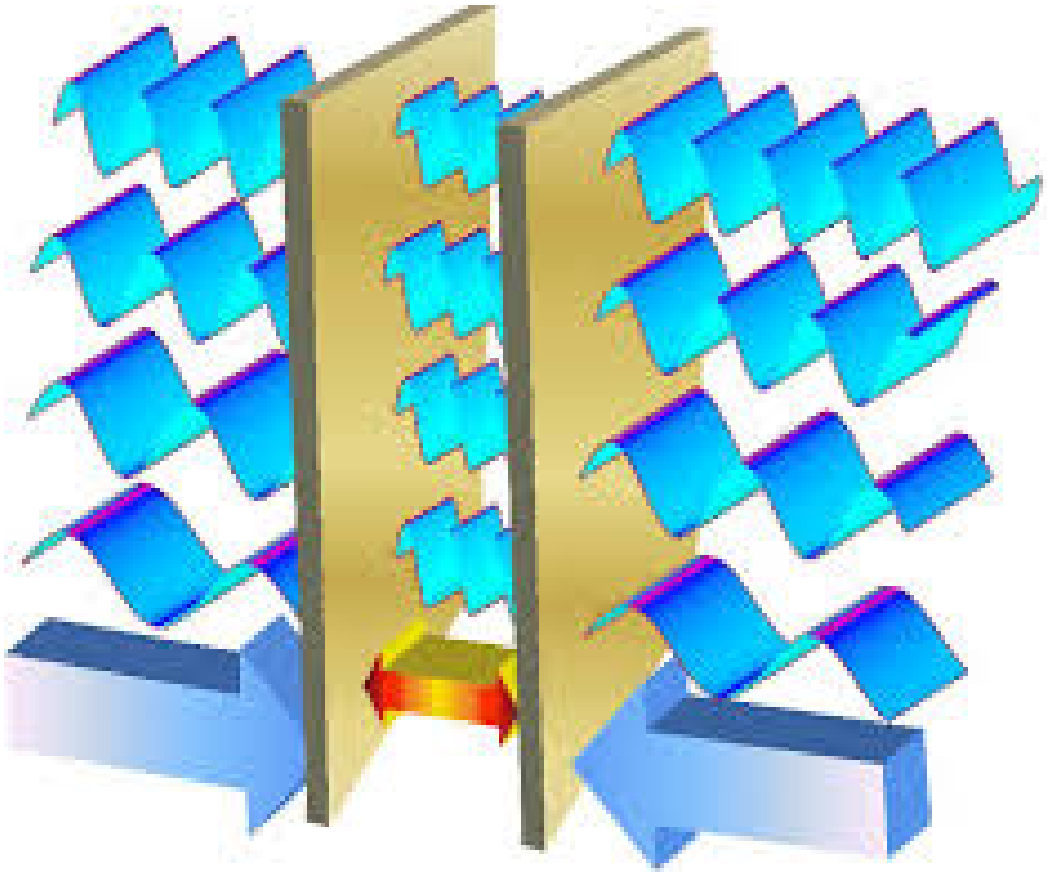
Materia Exótica

Tanto la propulsión por deformación como los agujeros de gusano necesitan materia exótica!

- Materia que no verifica la condición débil de energía.
- $\rho > 0$ y $\rho + p_i \geq 0$. $(i = 1, 2, 3)$.

Toda la materia que conocemos verifica la condición débil de la energía.
Y los efectos cuánticos?

Efecto Casimir



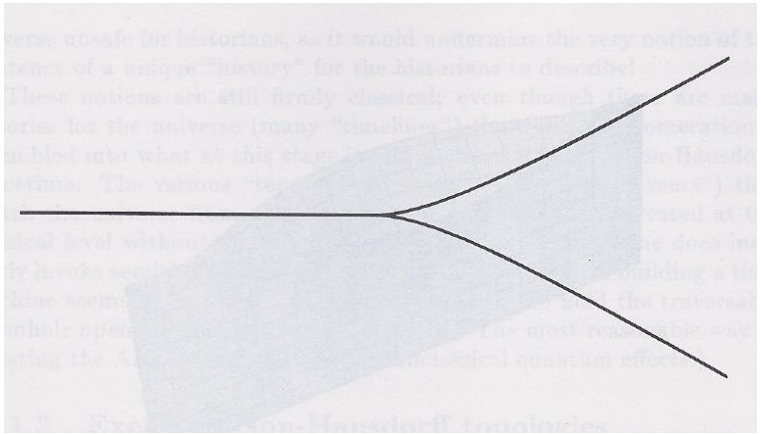
$$\rho = -\frac{\pi^2}{720}\frac{\hbar}{a^4} < 0!$$

Paradojas

- Paradojas de consistencia: Podemos cambiar el curso de la historia. Ejemplo. La paradoja del "abuelo"
- Paradoja "Boostrap": Información y objetos creados de la nada. Eventualmente pueden generar paradojas de consistencia.

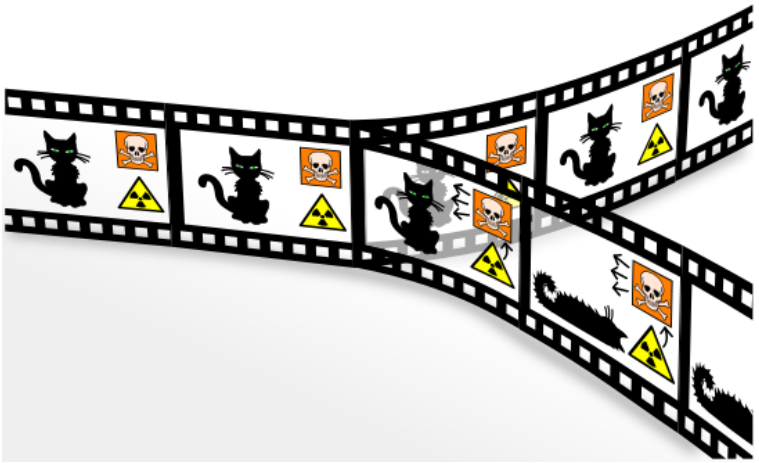
Posibles Soluciones (historias múltiples)

- A nivel clásico: Usar espacios que no sean Hausdorff (separables):



(Visser, Lorenzian wormholes)

- A nivel cuántico: Interpretación de Everett ("muchos mundos").



Stephen Hawking

- Stephen Hawking (8/1/1942).
- Graduado en la Universidad de Oxford.
- Doctorado en la Universidad de Cambridge.
- Cátedra Lucasiana.
- Teoremas de singularidad(con R. Penrose).
- Radiación de Hawking (evaporación de agujeros negros).

Principio de Protección de la Cronología

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Chronology protection conjecture

S. W. Hawking
Department of Applied Mathematics and Theoretical Physics, University of Cambridge, Silver Street, Cambridge CB3 9EW, United Kingdom
(Received 23 September 1991)

It has been suggested that an advanced civilization might have the technology to warp spacetime so that closed timelike curves would appear, allowing travel into the past. This paper examines this possibility in the case that the causality violations appear in a finite region of spacetime without curvature singularities. There will be a Cauchy horizon that is compactly generated and that in general contains one or more closed null geodesics which will be incomplete. One can define geometrical quantities that measure the Lorentz boost and area increase on going round these closed null geodesics. If the causality violation developed from a noncompact initial surface, the averaged weak energy condition must be violated on the Cauchy horizon. This shows that one cannot create closed timelike curves with finite lengths of cosmic string. Even if violations of the weak energy condition are allowed by quantum theory, the expectation value of the energy-momentum tensor would get very large if timelike curves become almost closed. It seems the back reaction would prevent closed timelike curves from appearing. These results strongly support the chronology protection conjecture: *The laws of physics do not allow the appearance of closed timelike curves.*