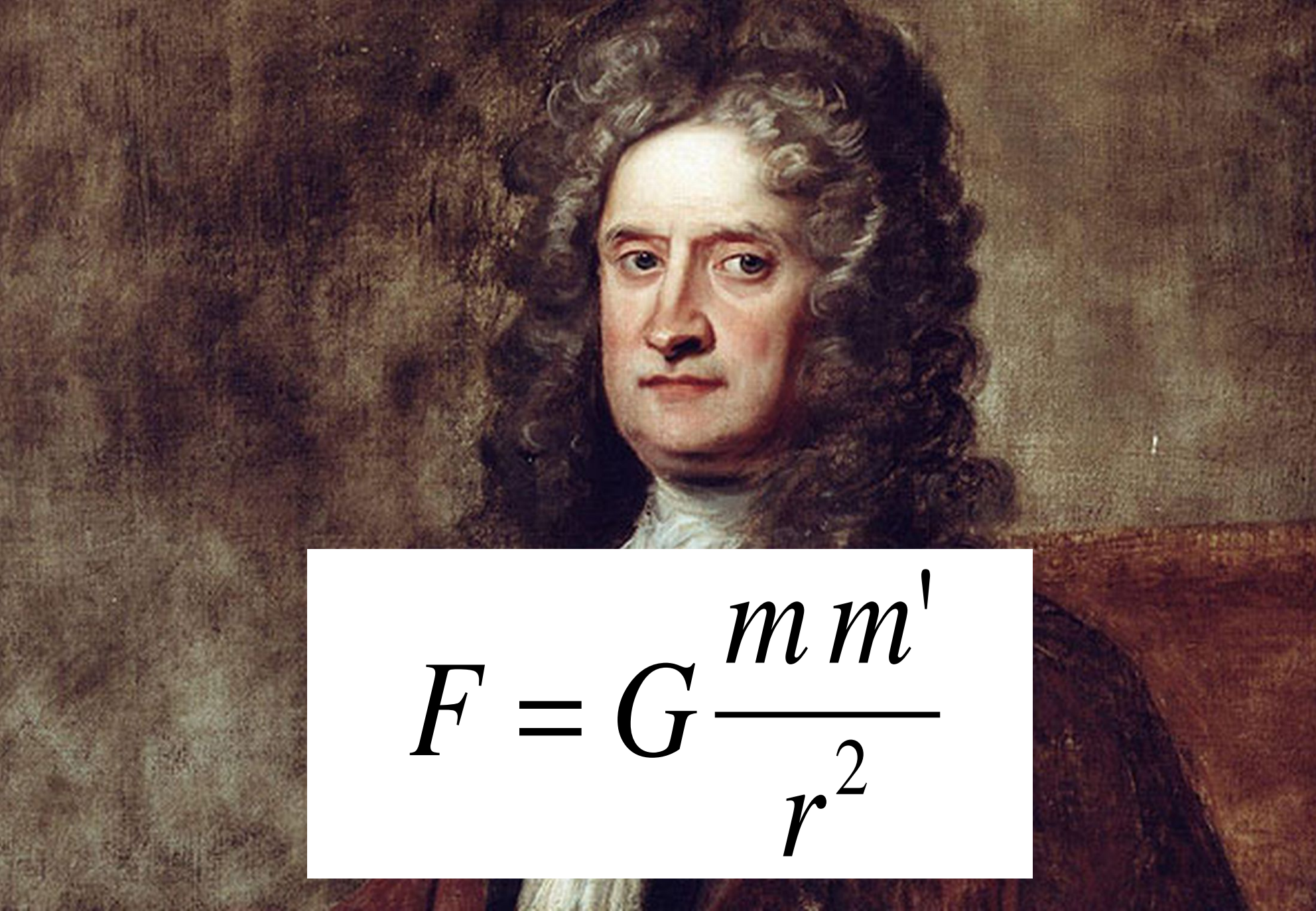


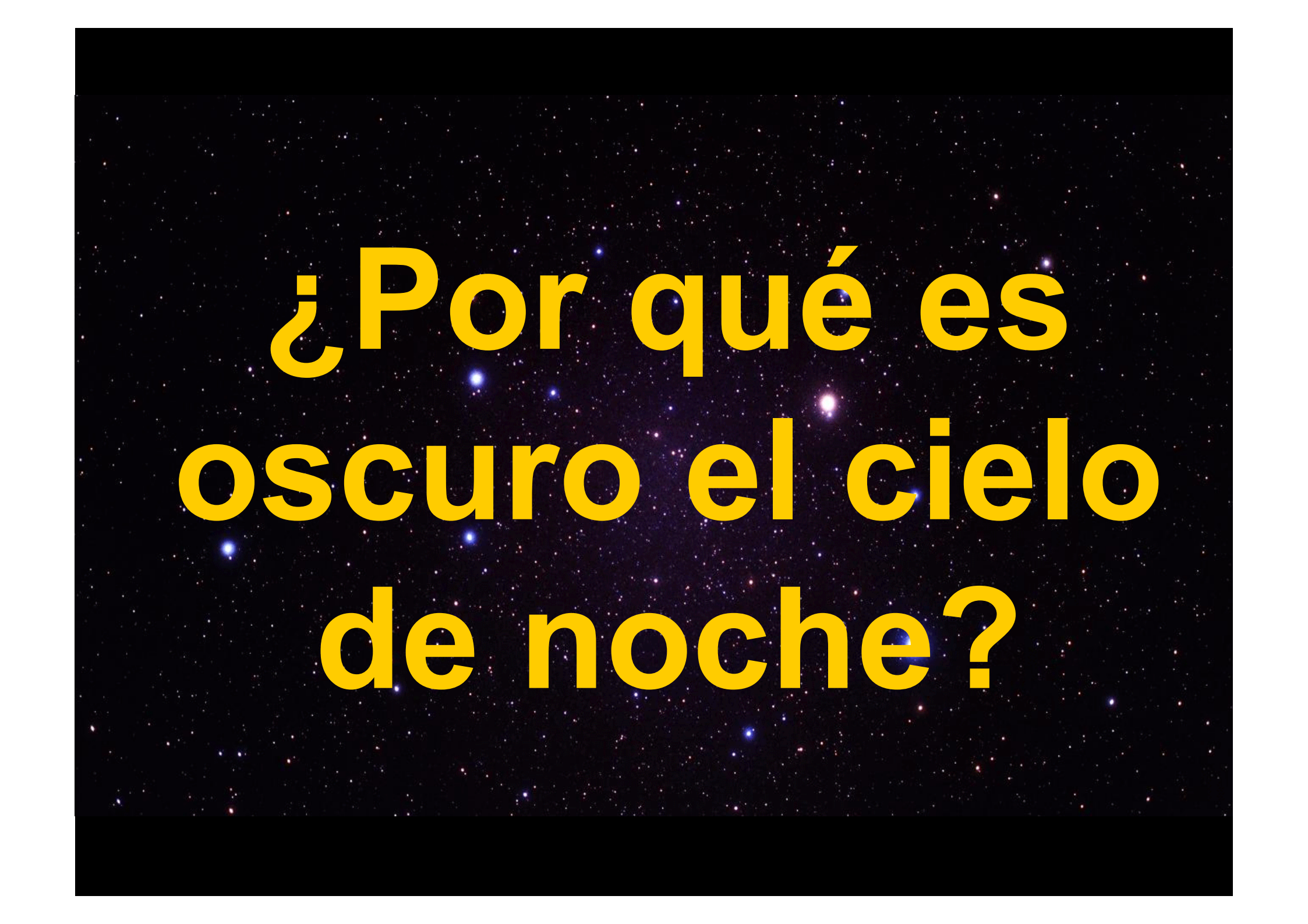
Relatividad General y Cosmología

The background of the slide is a composite image of cosmic phenomena. In the upper right, there is a bright, multi-colored (blue, green, yellow, red) circular structure resembling a quasar or a distant galaxy cluster. The rest of the background is a deep space scene filled with numerous stars and several large, glowing blue and white galaxy clusters. In the bottom left corner, a portion of the Earth's horizon is visible, showing the blue atmosphere and white clouds.

Juan García-Bellido
IFT-UAM/CSIC

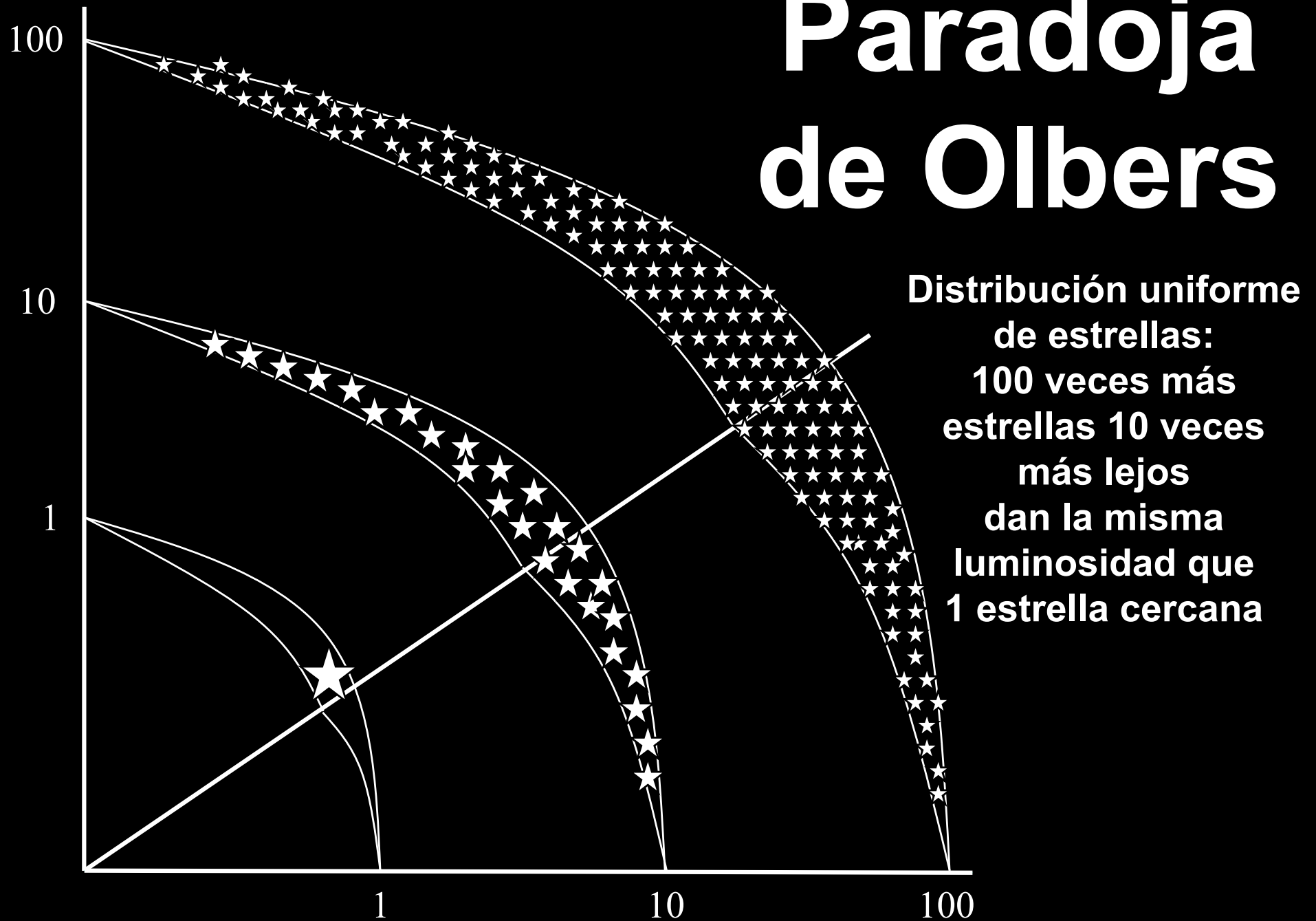
La Relatividad General, 100 años después
8 de Mayo de 2015
Salón de Actos del CSIC

A portrait of Isaac Newton, showing him with long, curly hair, looking slightly to the right. The background is a textured, brownish-grey.
$$F = G \frac{m m'}{r^2}$$

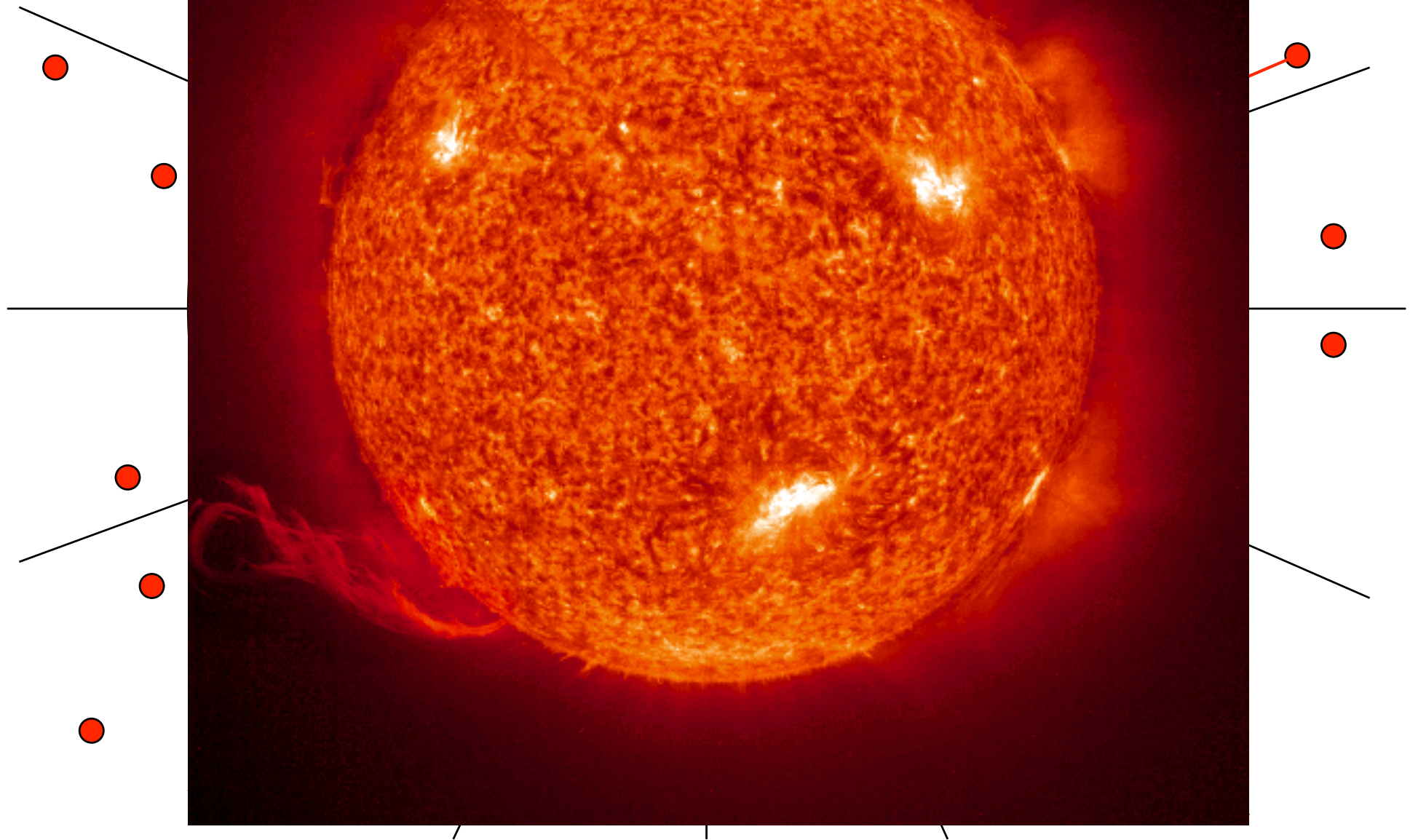


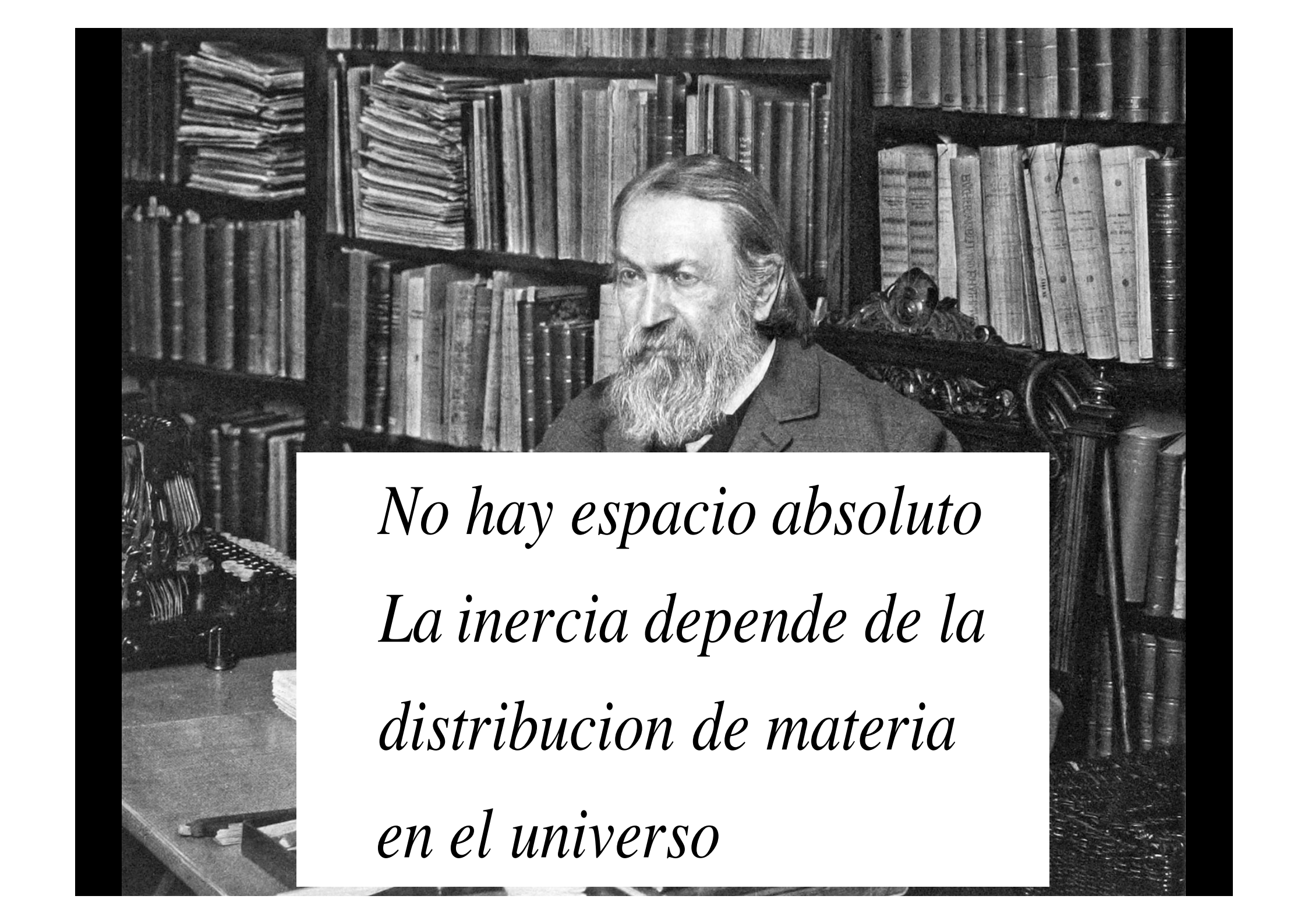
**¿Por qué es
oscuro el cielo
de noche?**

Paradoja de Olbers



- **Distribución uniforme de estrellas**

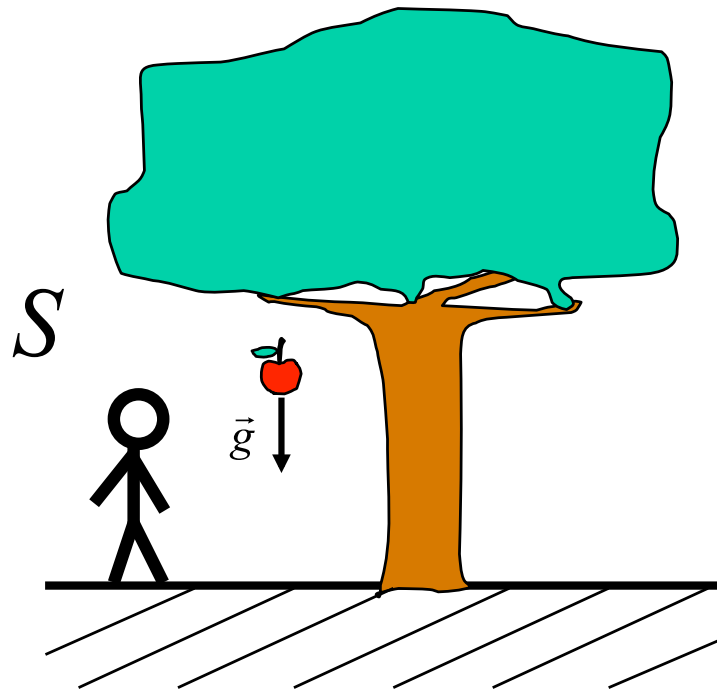


A black and white photograph of Heinrich Heine, a German poet, writer, and philosopher. He is shown from the chest up, seated at a desk in a library. He has a long, full beard and is wearing a dark suit. Behind him are tall bookshelves filled with books. On the desk in front of him are some papers and a small object. The text is overlaid on a white rectangular background in the lower right portion of the image.

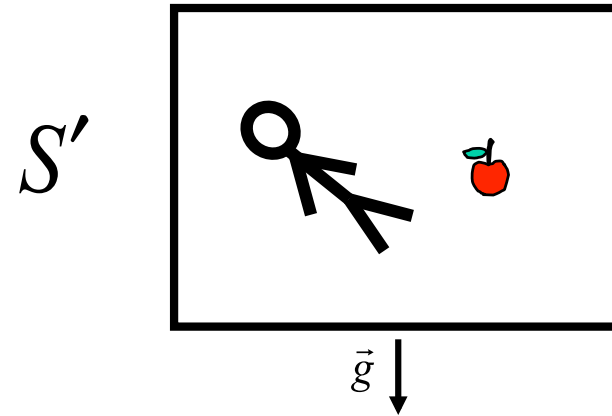
*No hay espacio absoluto
La inercia depende de la
distribucion de materia
en el universo*

Principio de Equivalencia entre Gravitación e Inercia

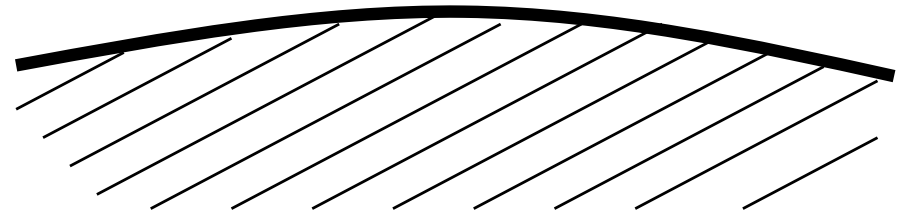
Todos los cuerpos caen con la misma aceleración



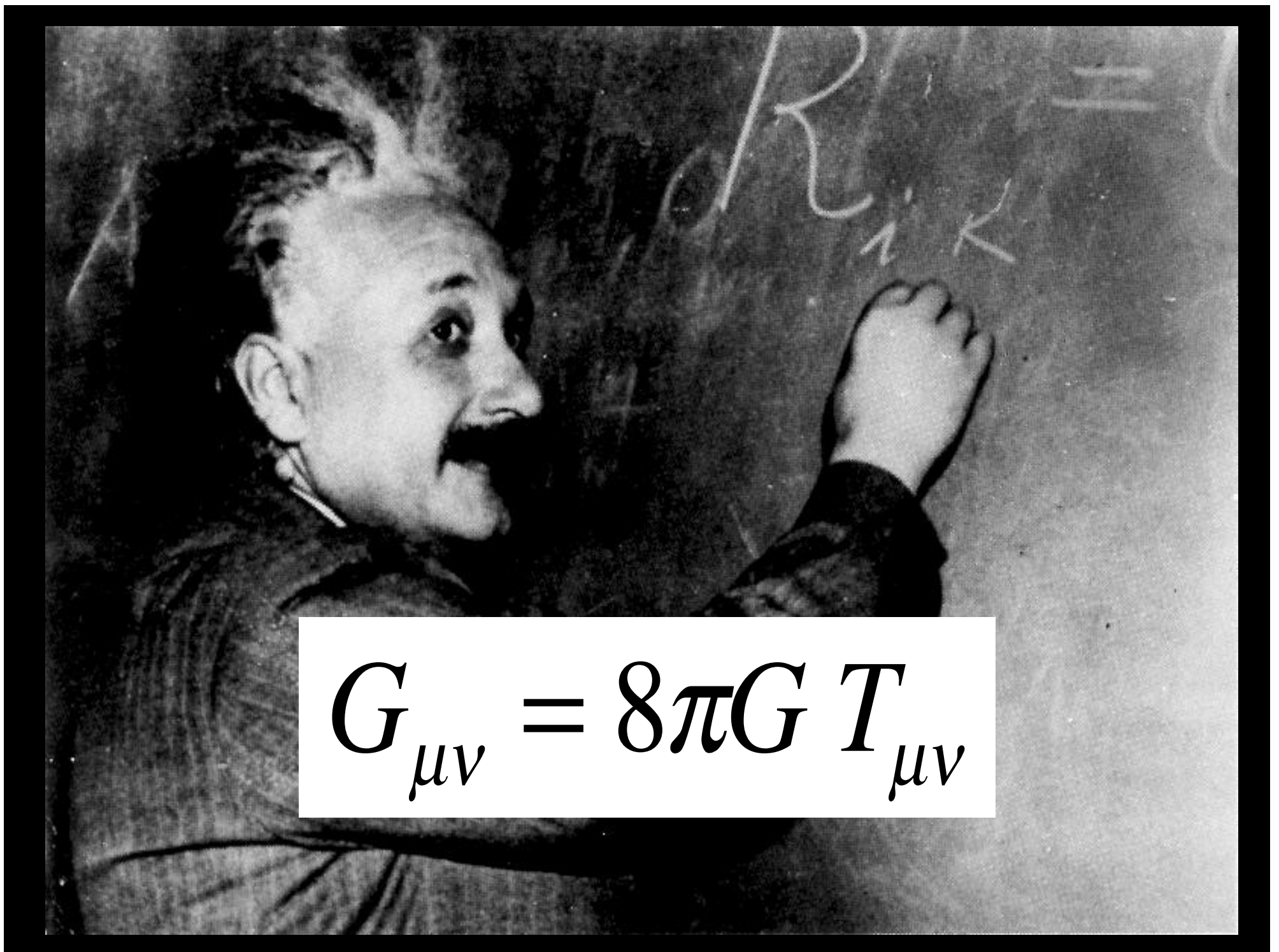
Newton



En caída libre desaparece la fuerza de la gravedad



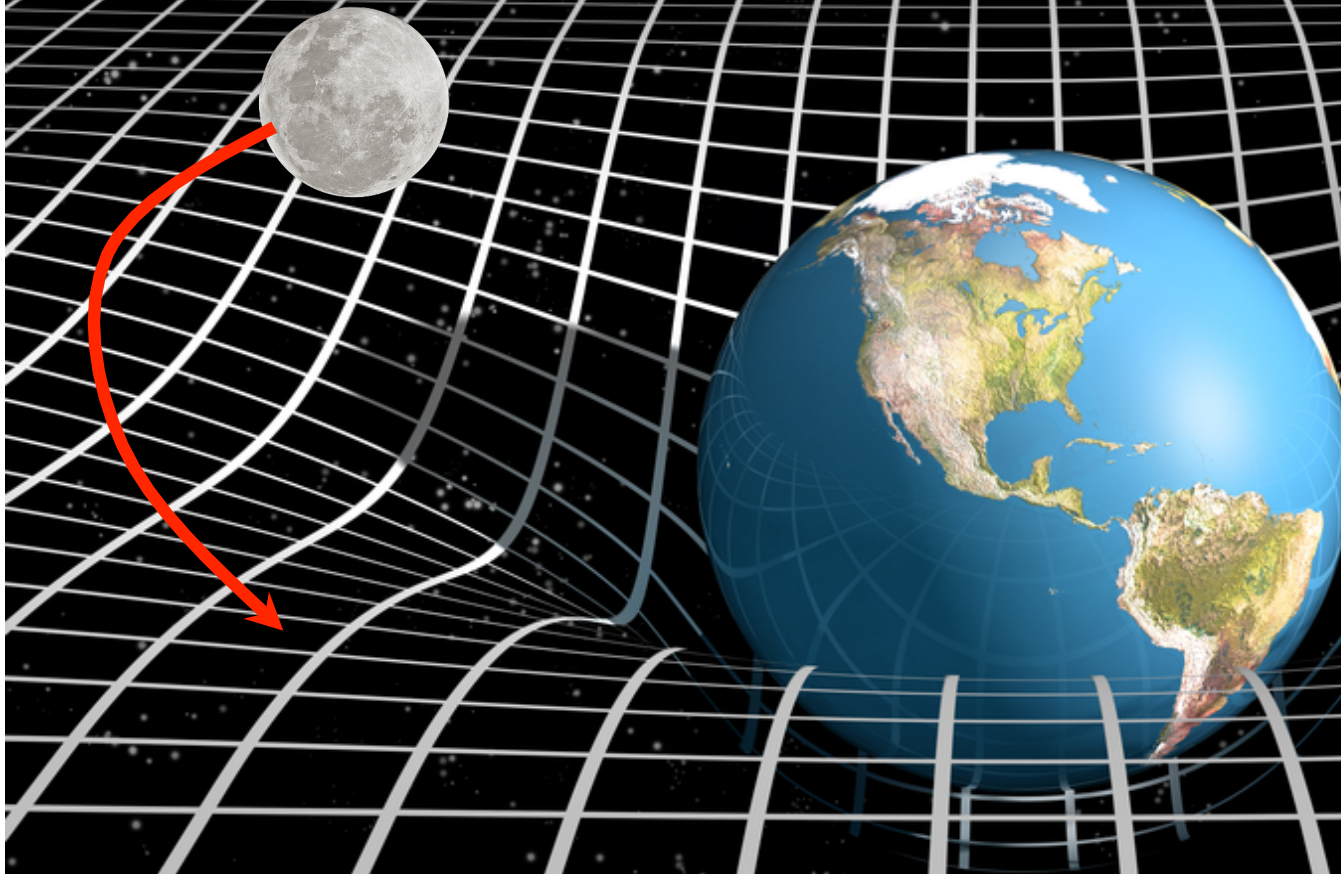
Einstein



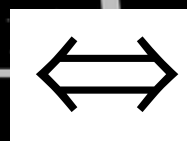
$$G_{\mu\nu} = 8\pi G T_{\mu\nu}$$

**El espacio-tiempo
es dinámico,
se curva con la
materia y energía
del universo**

Gravitación = Inercia



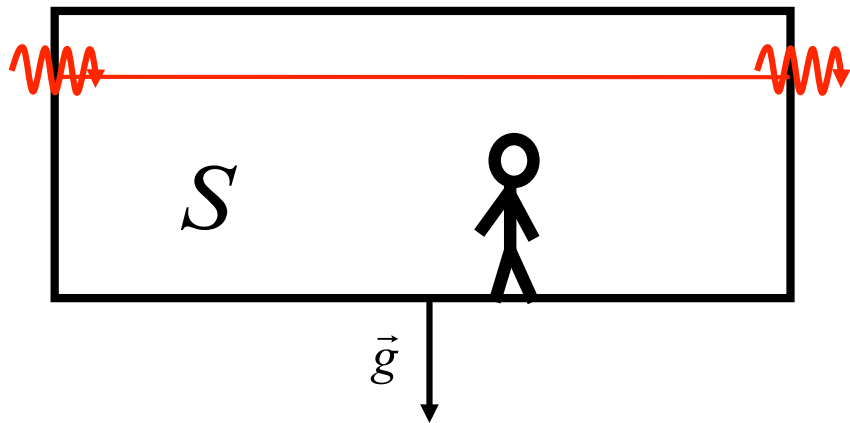
Geometría



Materia

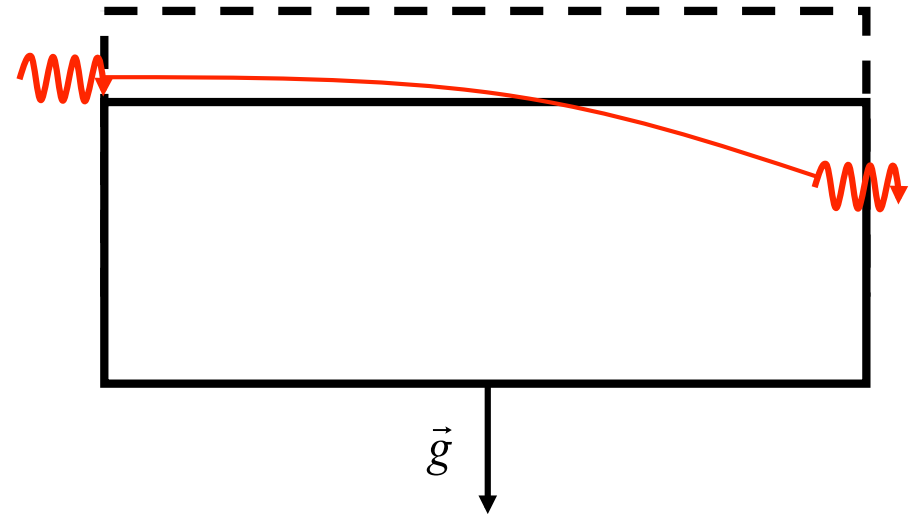
Deflexión gravitacional de la luz

a)



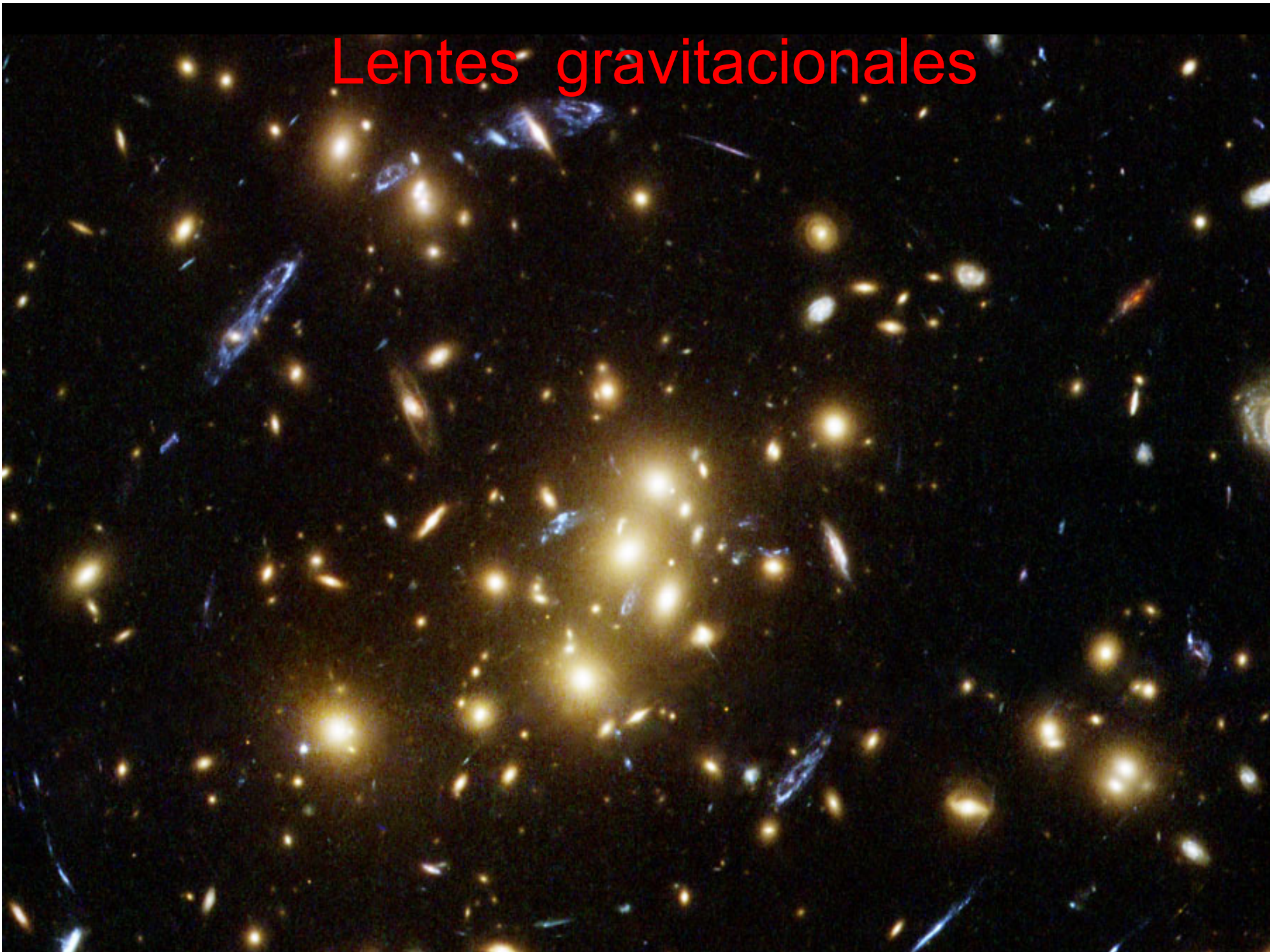
Sistema en caída libre en
un campo gravitacional

b)

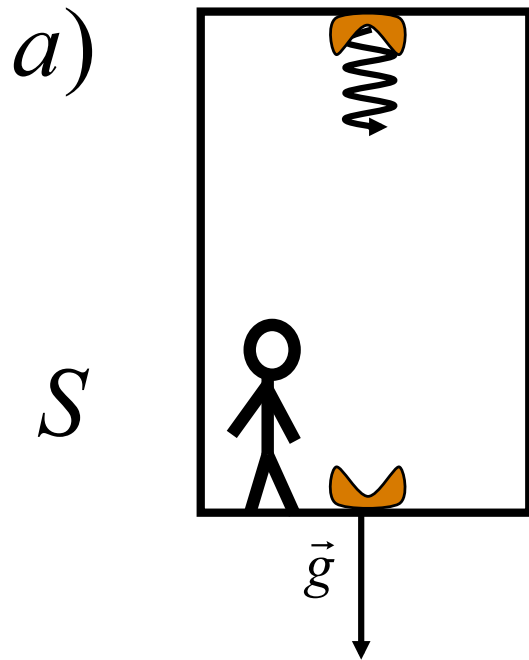


S'

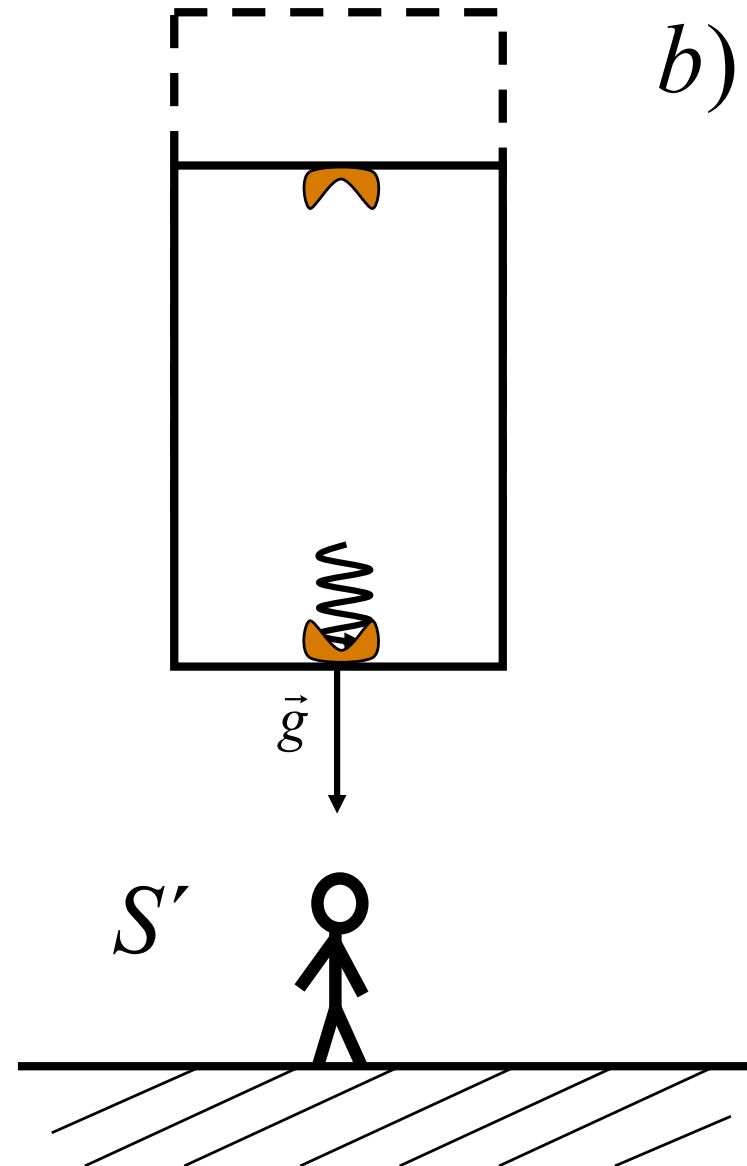
Lentes gravitacionales



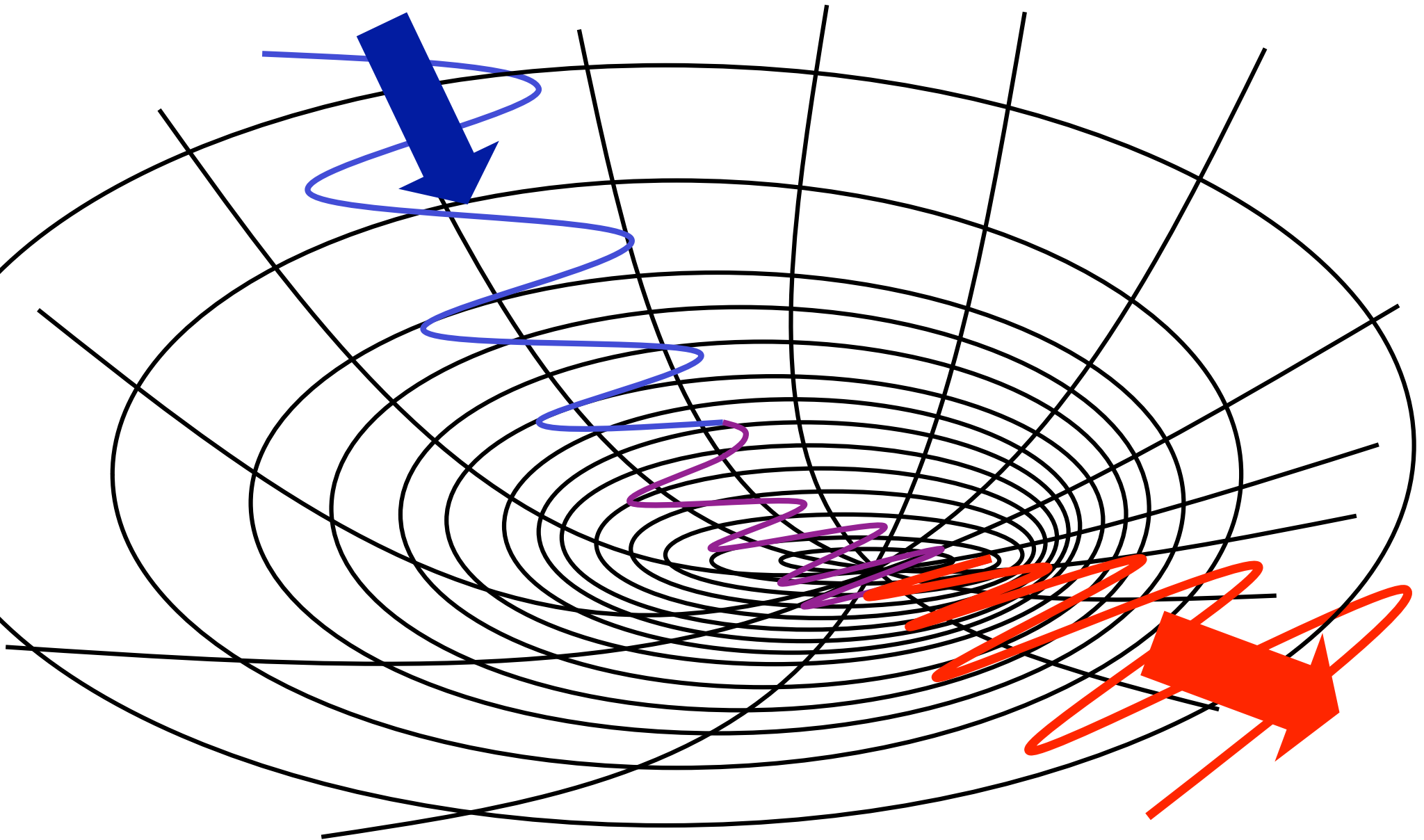
Blue/Redshift gravitacional



Sistema en caída libre en
un campo gravitacional



Blueshift y redshift gravitacional



**En su búsqueda de un
universo estático como
solución de sus
ecuaciones, Einstein
perdió la oportunidad de
predecir la expansión del
universo**

COSMOLOGICAL CONSIDERATIONS ON THE GENERAL THEORY OF RELATIVITY

BY

A. EINSTEIN

Translated from "Kosmologische Betrachtungen zur allgemeinen Relativitätstheorie," Sitzungsberichte der Preussischen Akad. d. Wissenschaften, 1917.

IT is well known that Poisson's equation

$$\nabla^2\phi = 4\pi K\rho \quad . \quad . \quad . \quad (1)$$

in combination with the equations of motion of a material point is not as yet a perfect substitute for Newton's theory of action at a distance. There is still to be taken into account the condition that at spatial infinity the potential ϕ tends toward a fixed limiting value. There is an analogous state of things in the theory of gravitation in general relativity. Here, too, we must supplement the differential equations by limiting conditions at spatial infinity, if we really have to regard the universe as being of infinite spatial extent.

In my treatment of the planetary problem I chose these limiting conditions in the form of the following assumption: it is possible to select a system of reference so that at spatial infinity all the gravitational potentials $g_{\mu\nu}$ become constant. But it is by no means evident *a priori* that we may lay down

It seems hardly possible to surmount these difficulties on the basis of the Newtonian theory. We may ask ourselves the question whether they can be removed by a modification of the Newtonian theory. First of all we will indicate a method which does not in itself claim to be taken seriously; it merely serves as a foil for what is to follow. In place of Poisson's equation we write

$$\nabla^2\phi - \lambda\phi = 4\pi\kappa\rho \quad . \quad . \quad . \quad (2)$$

where λ denotes a universal constant. If ρ_0 be the uniform density of a distribution of mass, then

$$\phi = - \frac{4\pi\kappa}{\lambda} \rho_0 \quad . \quad . \quad . \quad (3)$$

is a solution of equation (2). This solution would correspond to the case in which the matter of the fixed stars was distributed uniformly through space, if the density ρ_0 is equal to the actual mean density of the matter in the universe. The solution then corresponds to an infinite extension of the central space, filled uniformly with matter. If, without making any change in the mean density, we imagine matter to be non-uniformly distributed locally, there will be, over and above the ϕ with the constant value of equation (3), an additional ϕ , which in the neighbourhood of denser masses will so much the more resemble the Newtonian field as $\lambda\phi$ is smaller in comparison with $4\pi\kappa\rho$.

**El espacio es
homogéneo
e isótropo
(a gran escala)**

5 billion years

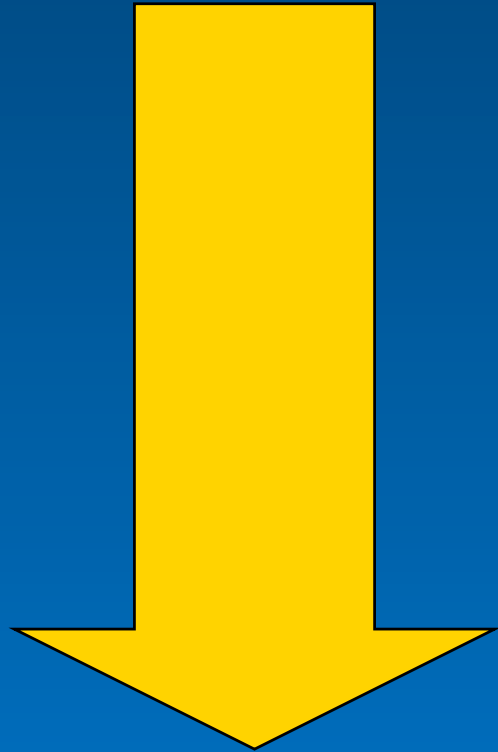
(you are here)



AllPosters

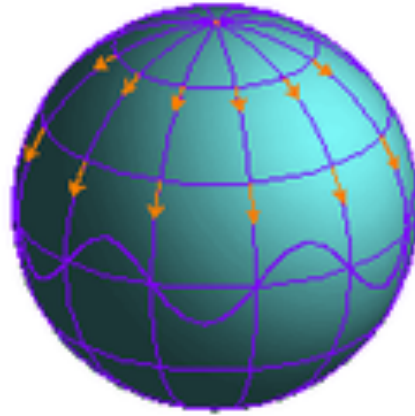


Relatividad General



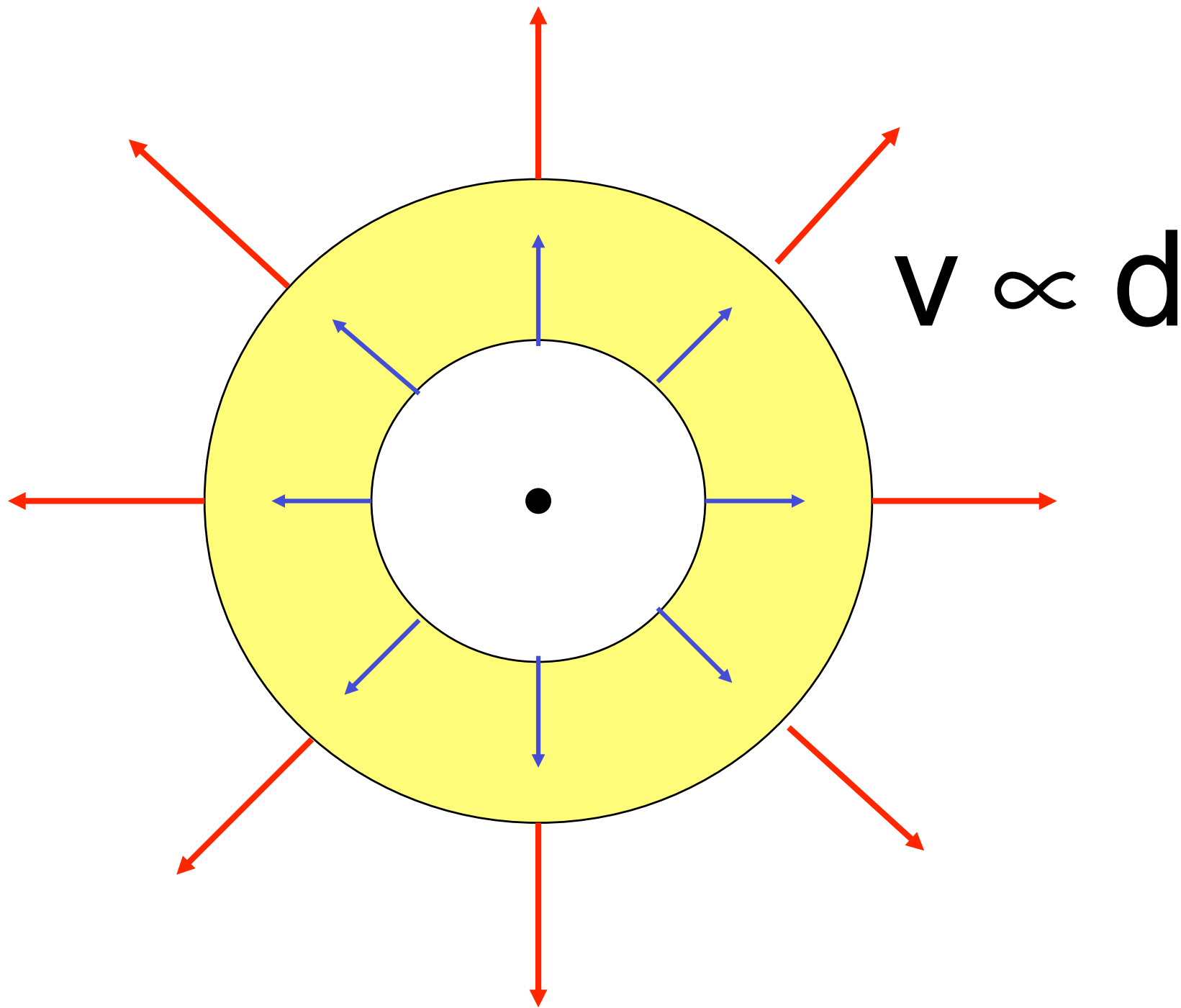
Homogeneidad
e Isotropía

Expansión Universo



redshift

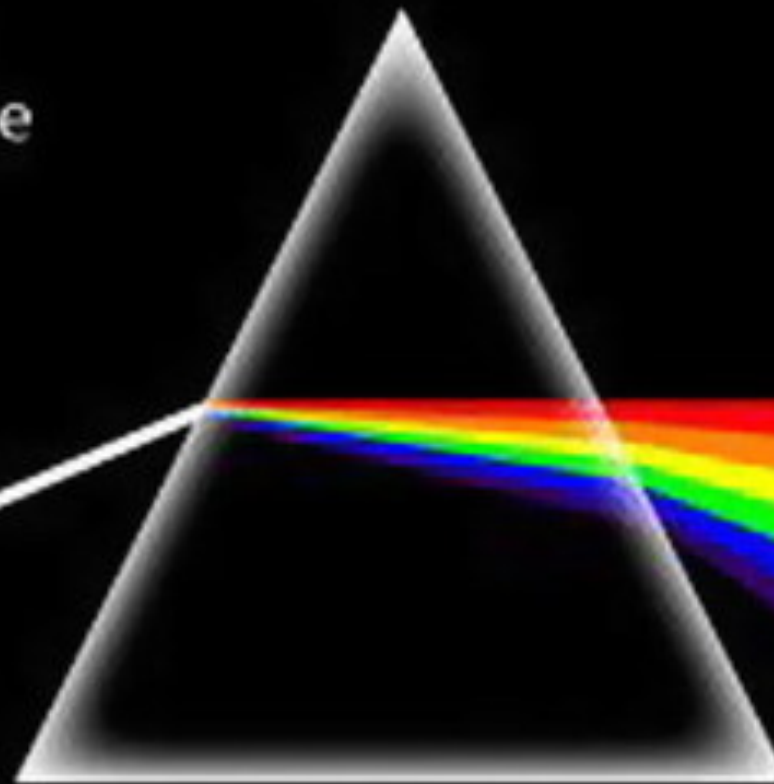
$$\frac{\lambda_{obs}}{\lambda_{em}} = \frac{a_0}{a_1} = 1 + z$$



Espectro visible: del violeta al rojo

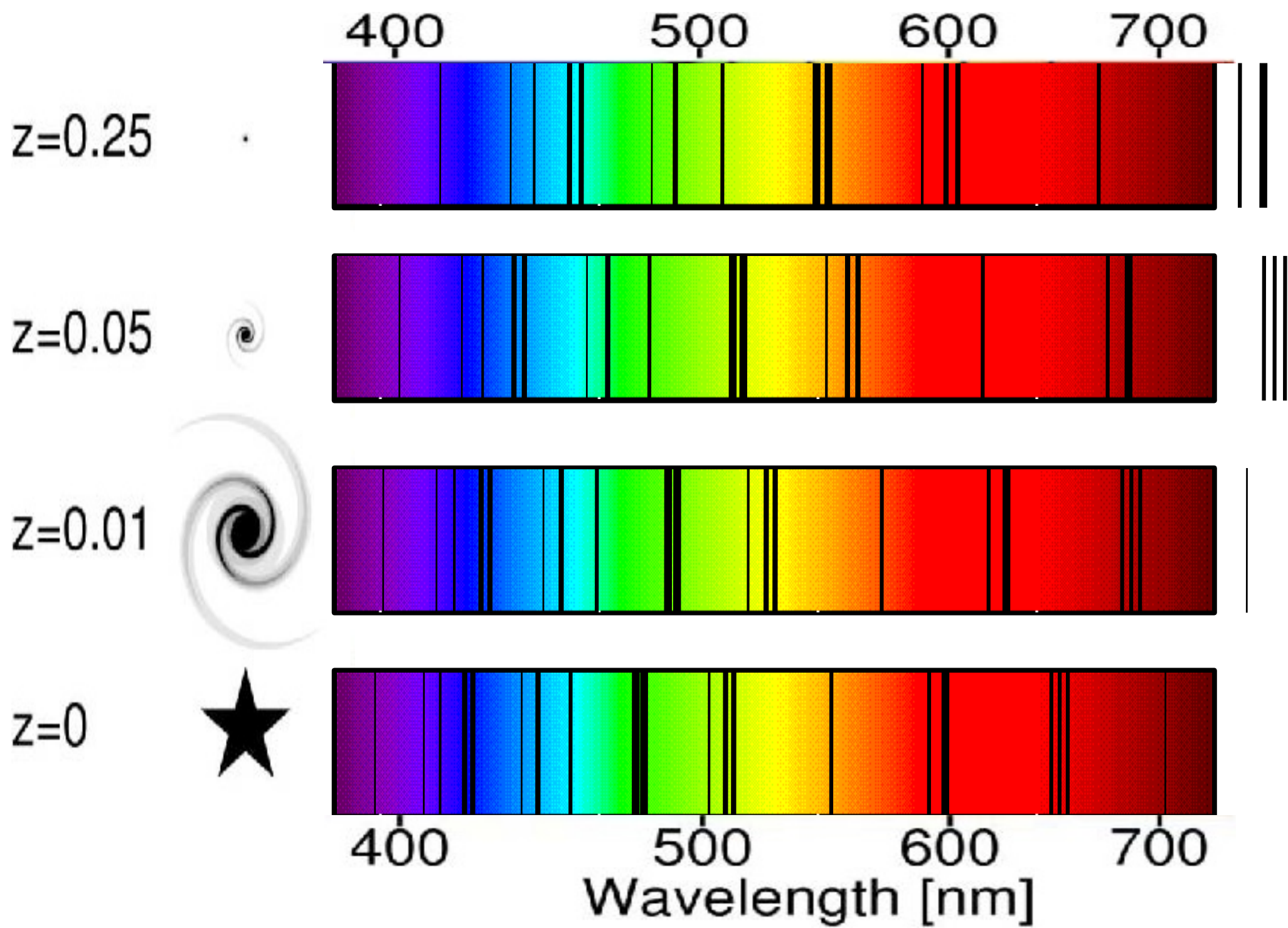
La Luz blanca
se descompone
al pasar por
un prisma

Luz blanca



Prisma de cristal

Rojo	
Naranja	
Amarillo	
Verde	
Azul	
Violeta	



Edwin P. Hubble

Mount Wilson



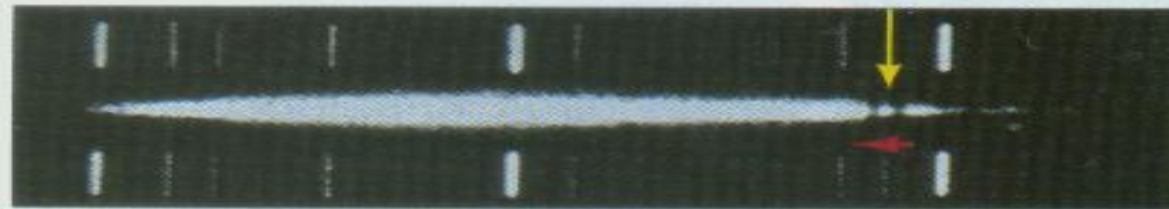
Mount Palomar



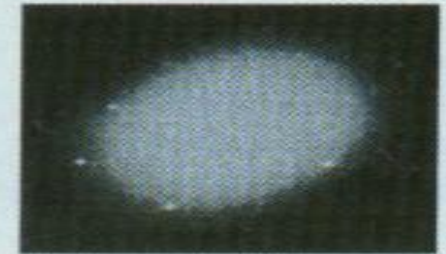
Radial velocities in km/s

Distance in
megaparsecs

Cluster
galaxy in



17

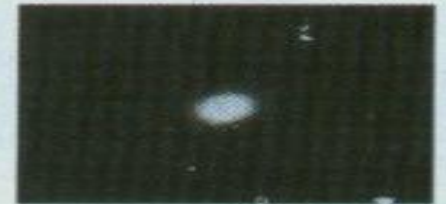


Virgo

1210



210



Ursa Major

15,000



310



Corona Borealis

21,600

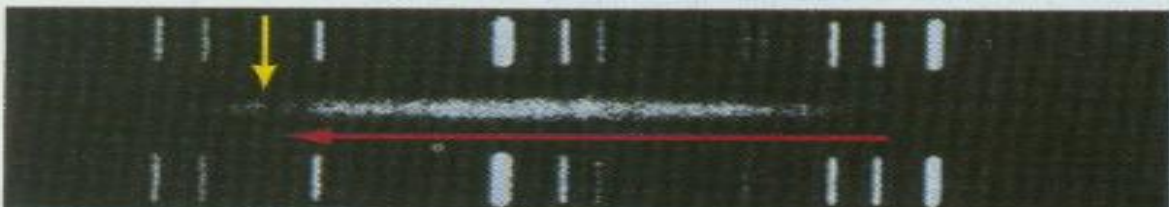


560



Bootes

39,300



870



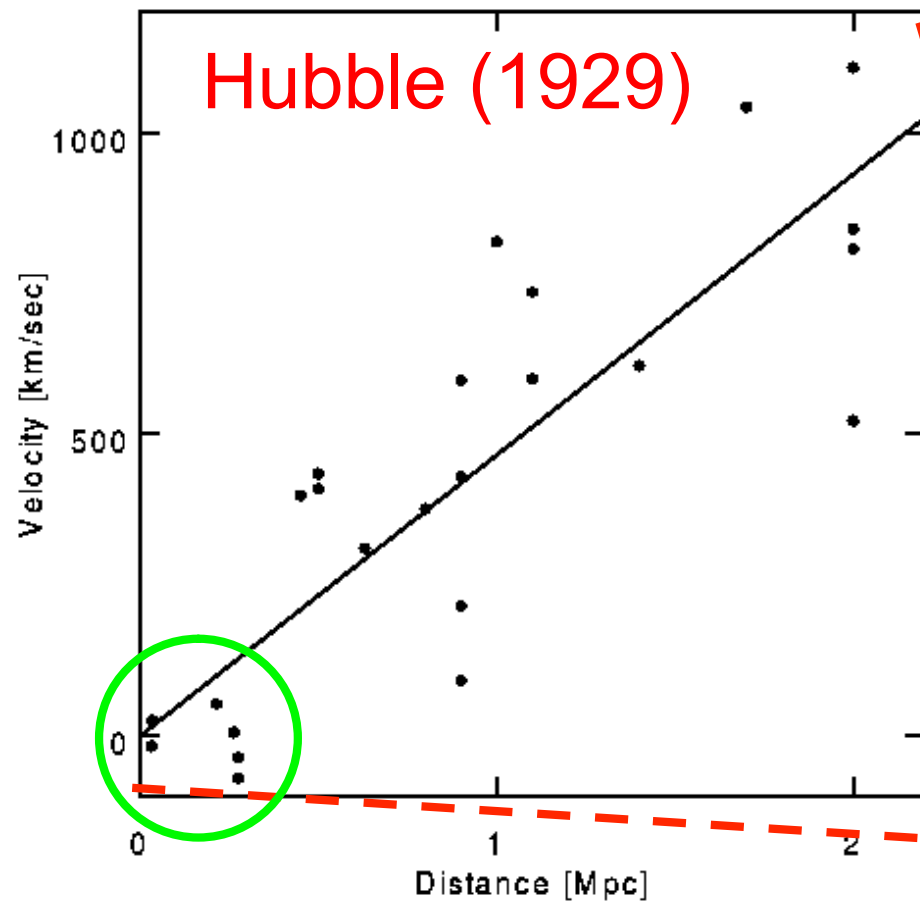
Hydra

61,200

Hubble Space Telescope

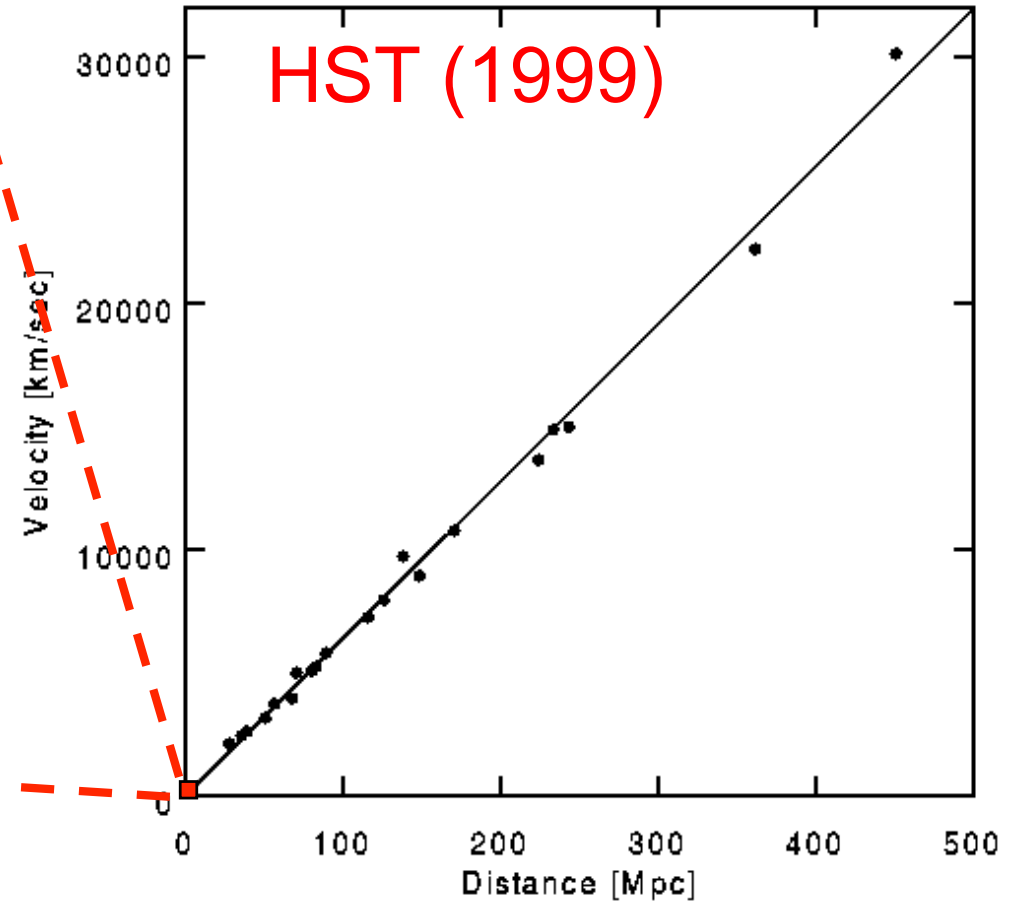
25th Anniversary
Happy Birthday HST!





$$H_0 = 500 \text{ km/s/Mpc}$$

Dominado por
errores sistemáticos!



$$H_0 = 70 \text{ km/s/Mpc}$$

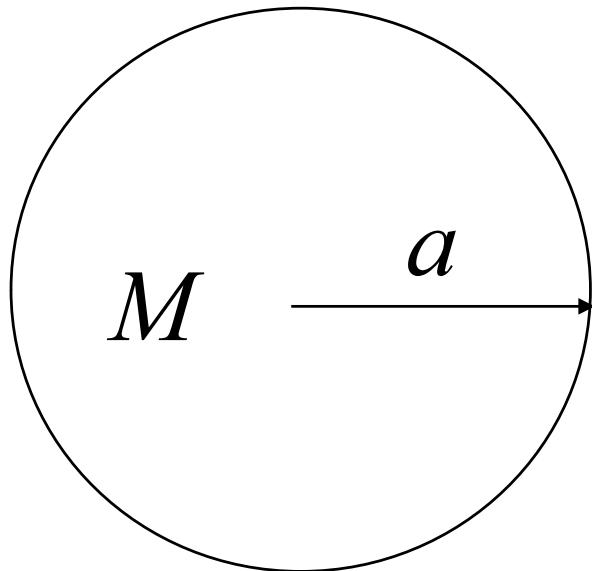
$$z \leq 0.1$$

Ecuación de Einstein-Friedmann

$$\frac{1}{2}\dot{a}^2 - \frac{GM}{a} = -\frac{K}{2}$$

$$T + V = E$$

$$M = \frac{4\pi}{3} \rho a^3 = \text{const.}$$



$K = 0$ velocidad escape

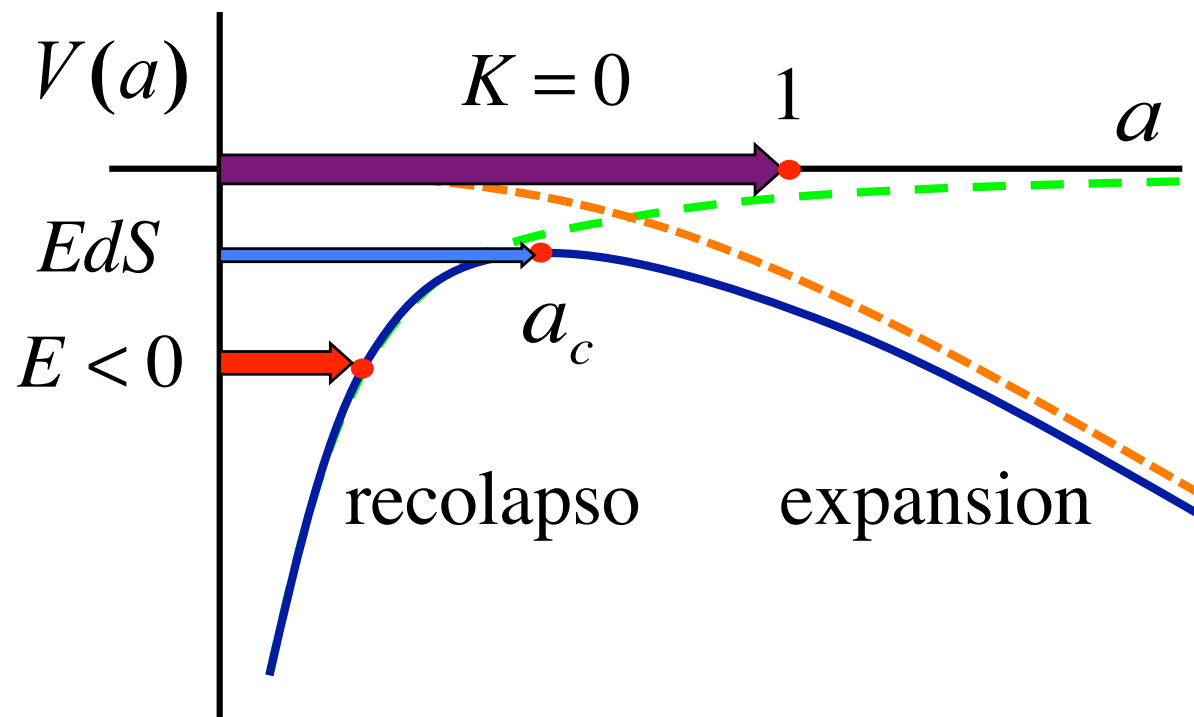
$K > 0$ recolapso

$K < 0$ expansion eterna

Modelo Einstein-de Sitter (1917)

$$\frac{1}{2}\dot{a}^2 - \frac{GM}{a} - \frac{\Lambda}{6}a^2 = -\frac{K}{2}$$

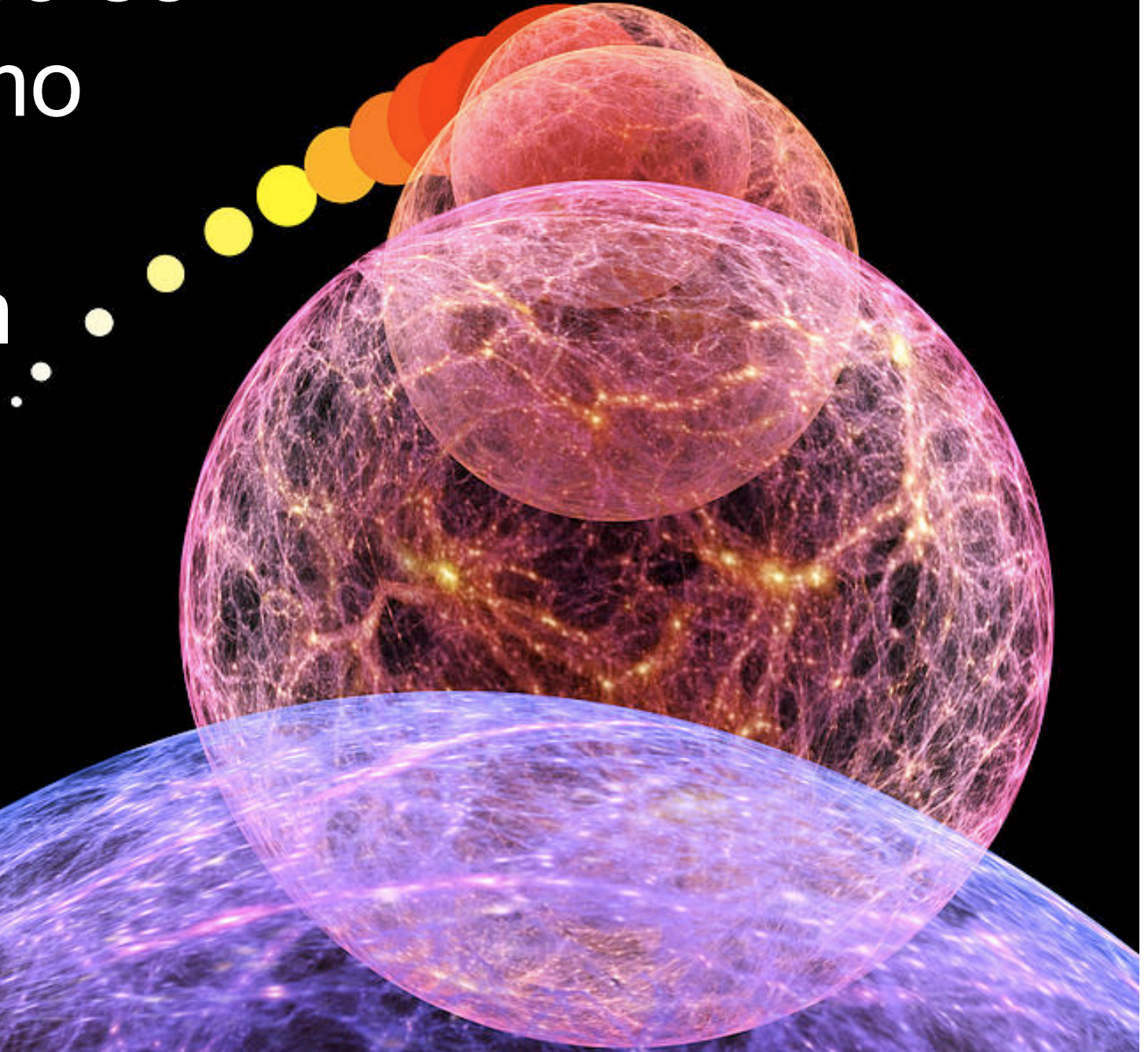
$$T + V = E$$



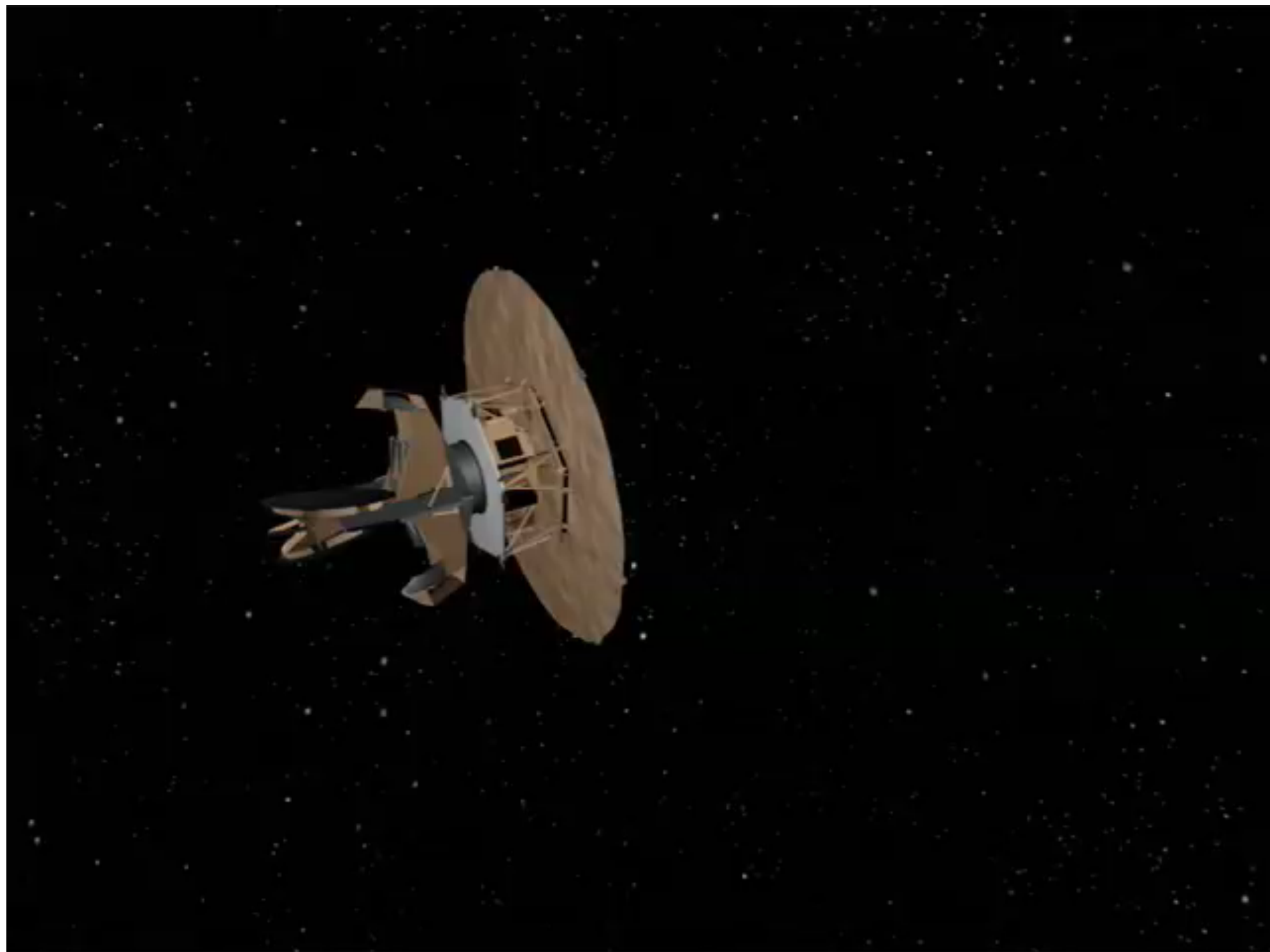
$$a_c = \left(\frac{3GM}{\Lambda} \right)^{1/3}$$

punto de
equilibrio
(inestable)

El Universo se
enfía como
un gas en
expansión

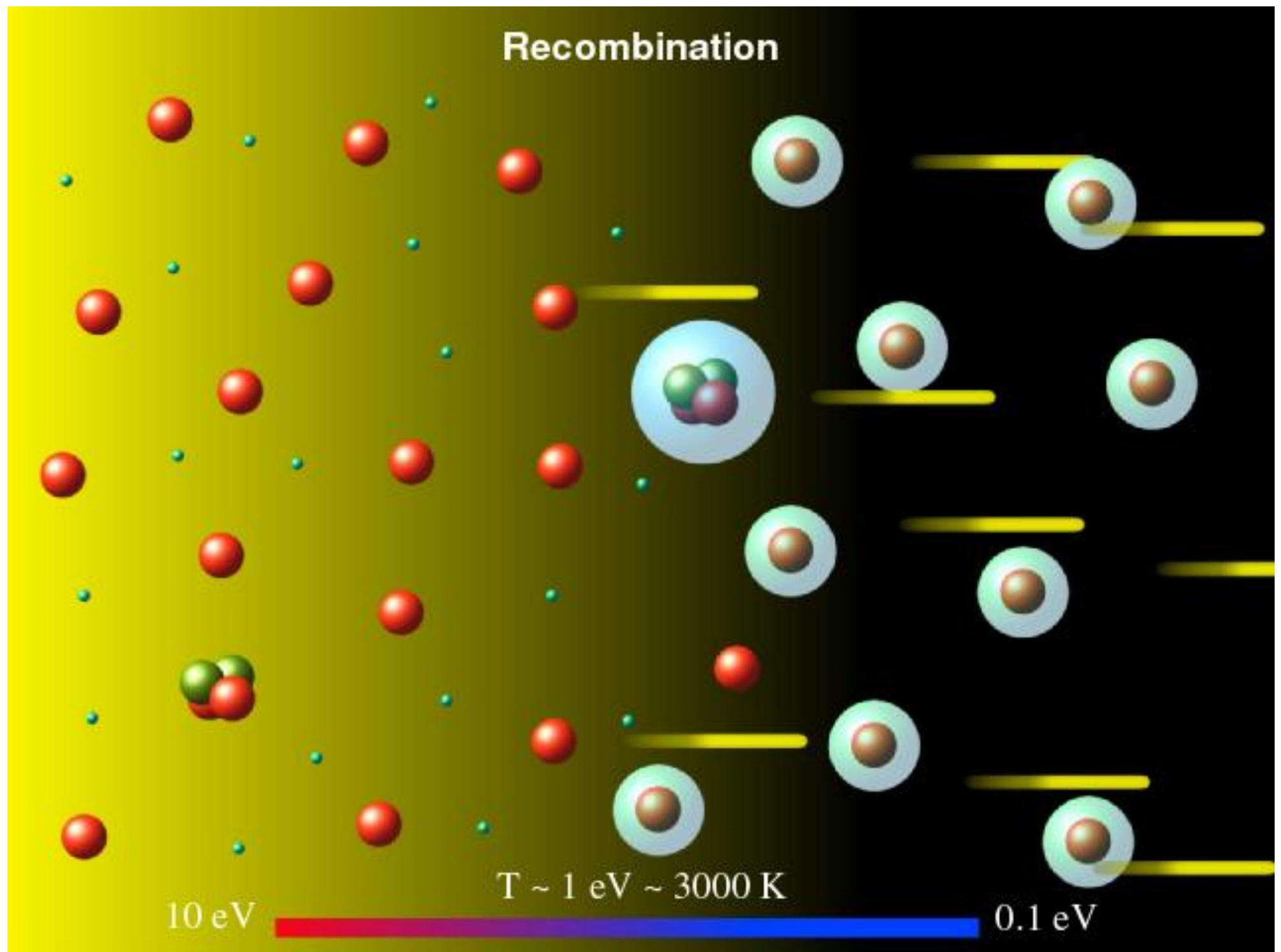


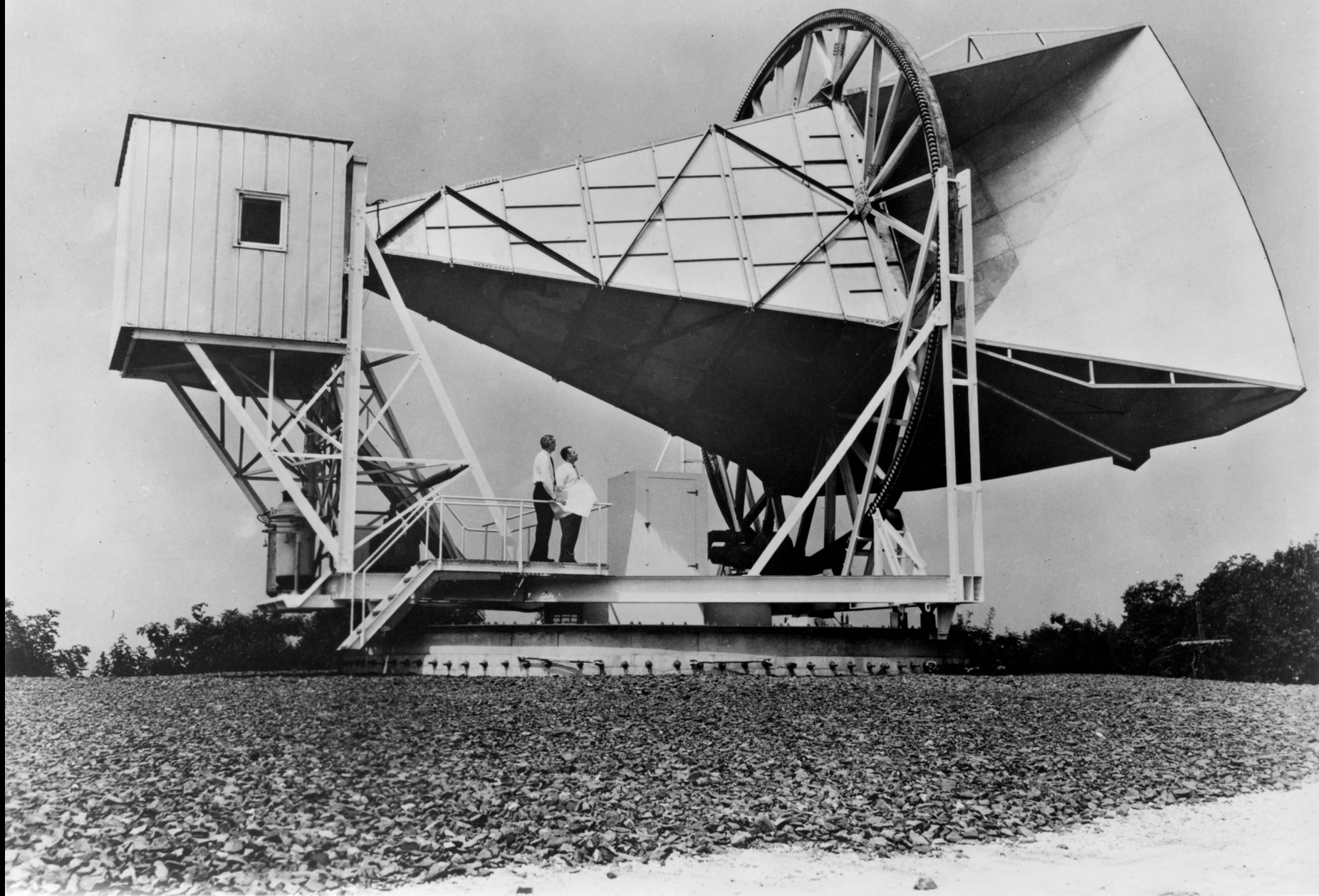




Fondo de Radiación de Microondas

Recombination







The Nobel Prize in Physics 1978

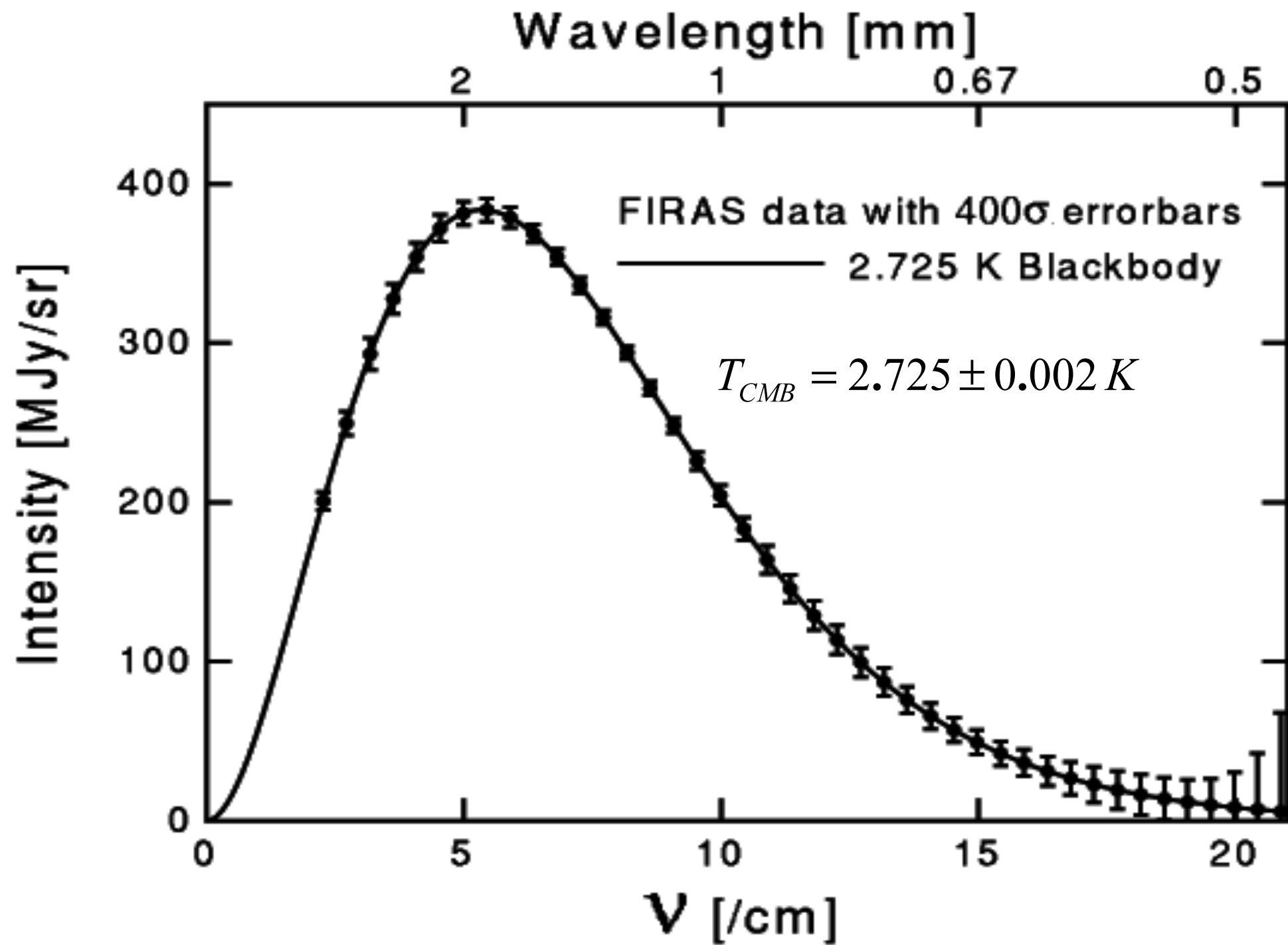
"for their discovery of the cosmic microwave background radiation"



Arno A. Penzias



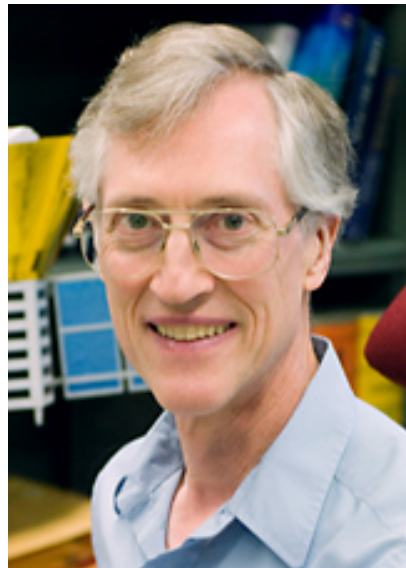
Robert W. Wilson



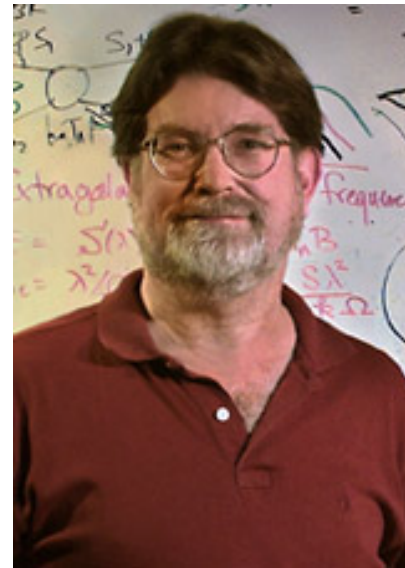


The Nobel Prize in Physics 2006

"for their discovery of the blackbody form and anisotropy of the cosmic microwave background radiation"

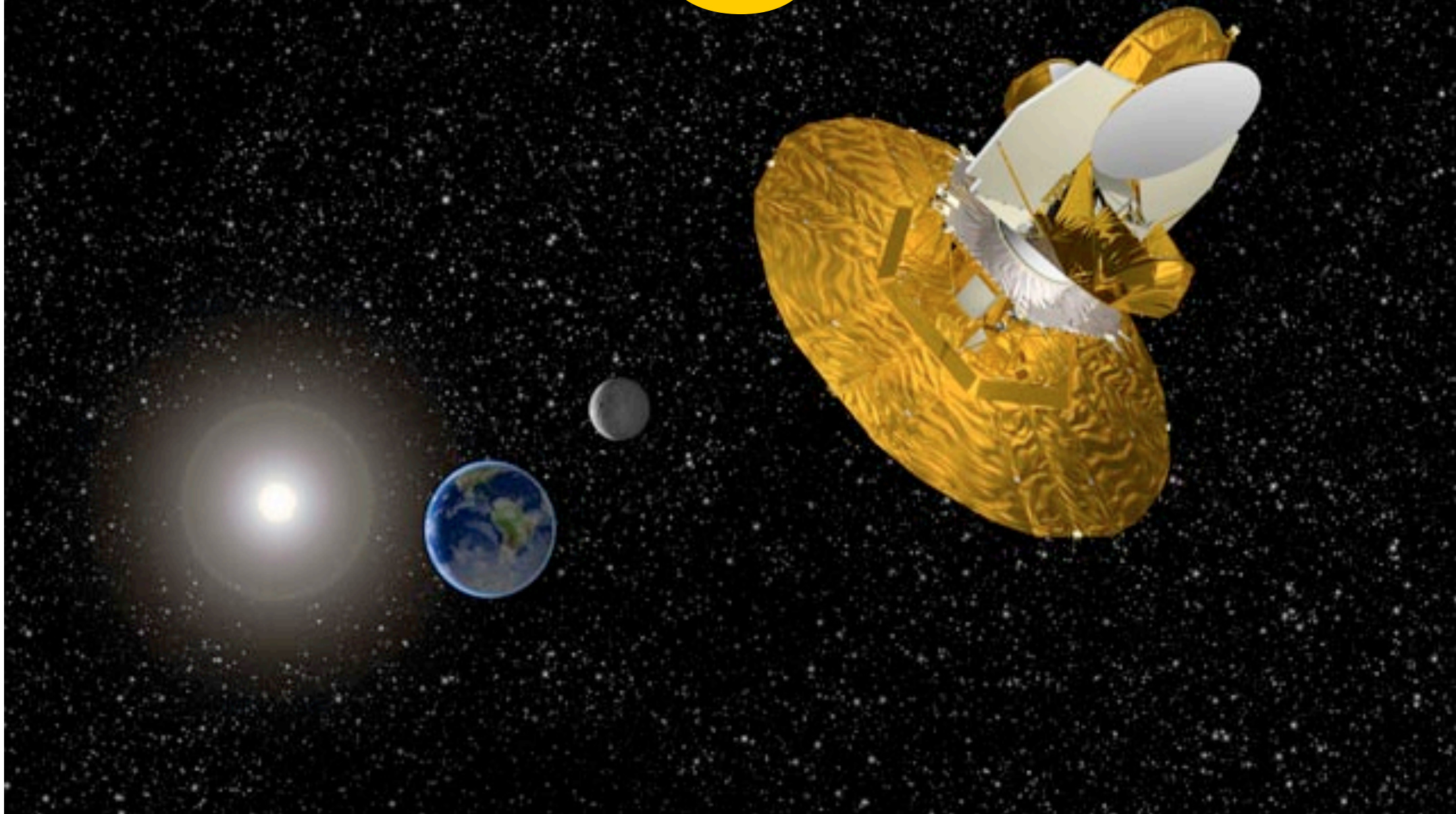


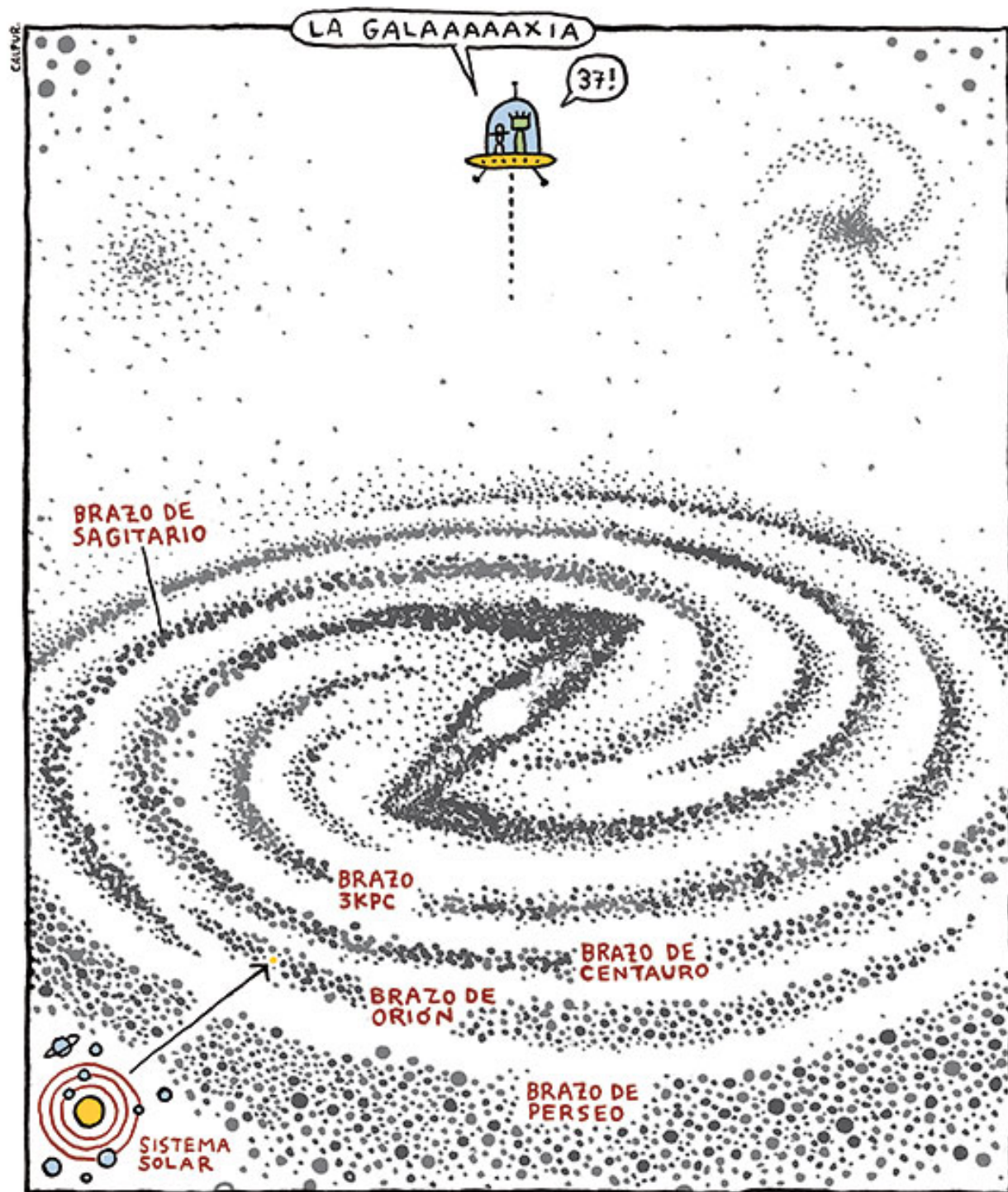
John C. Mather

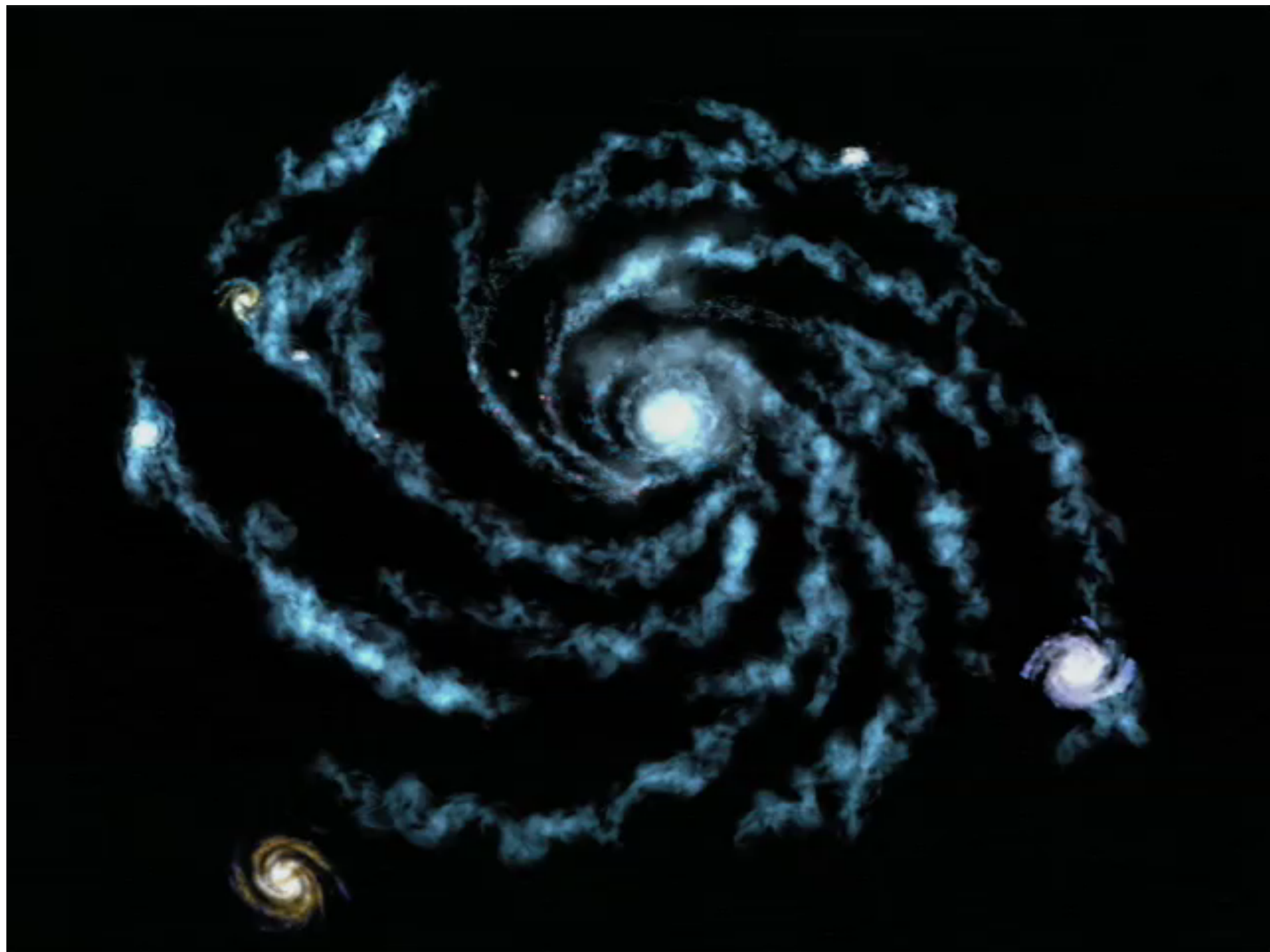


George F. Smoot

WMAP @ L2



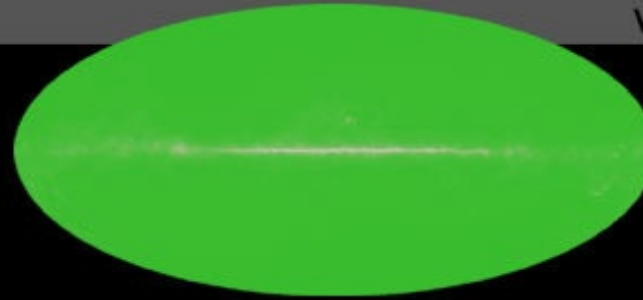




1965



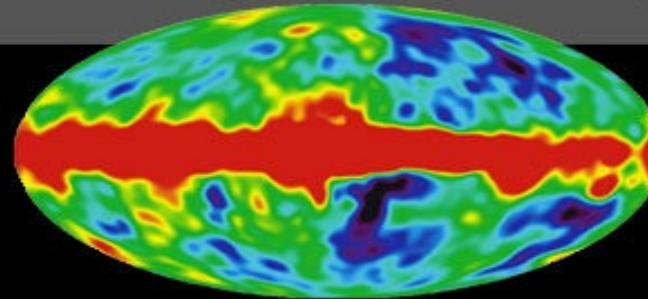
Penzias and
Wilson



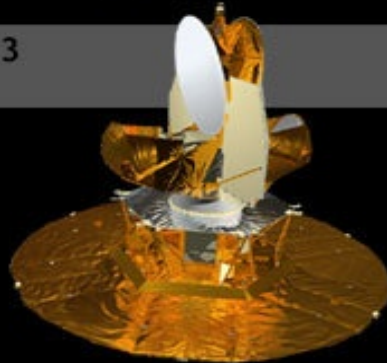
1992



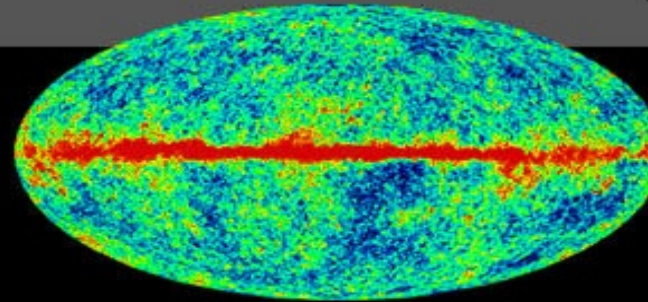
COBE



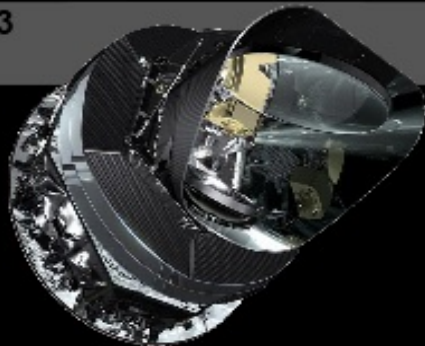
2003



WMAP

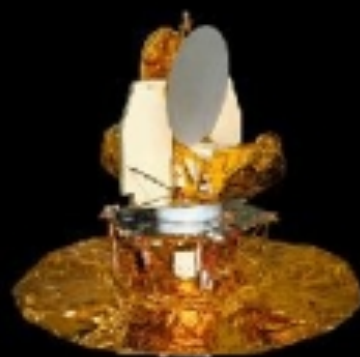


2013

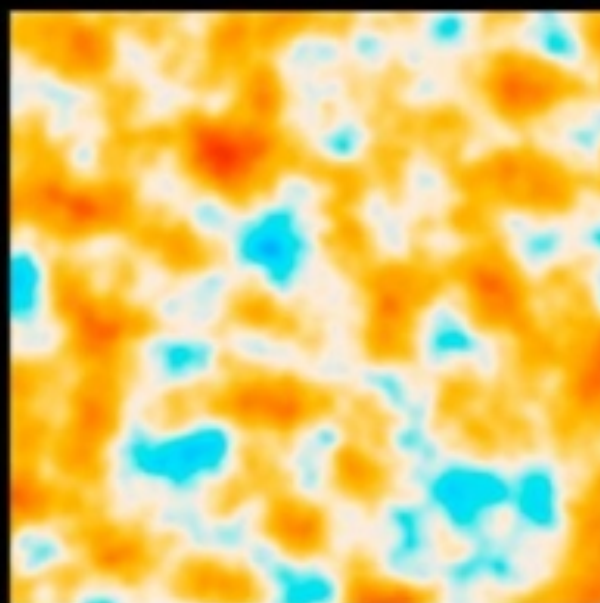


Planck

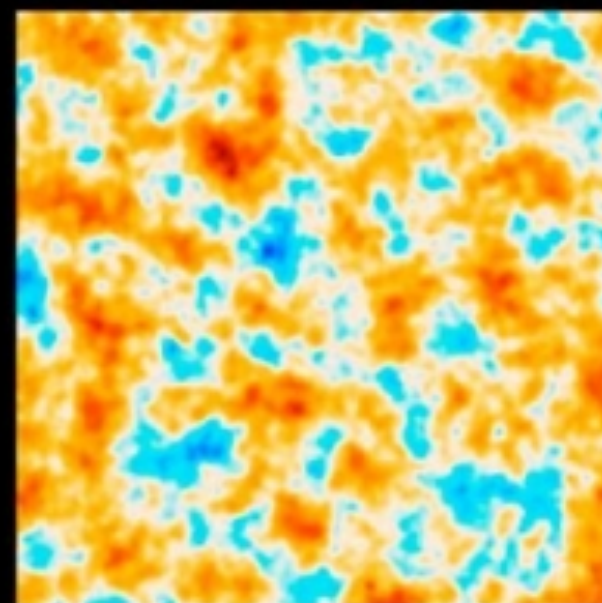




COBE

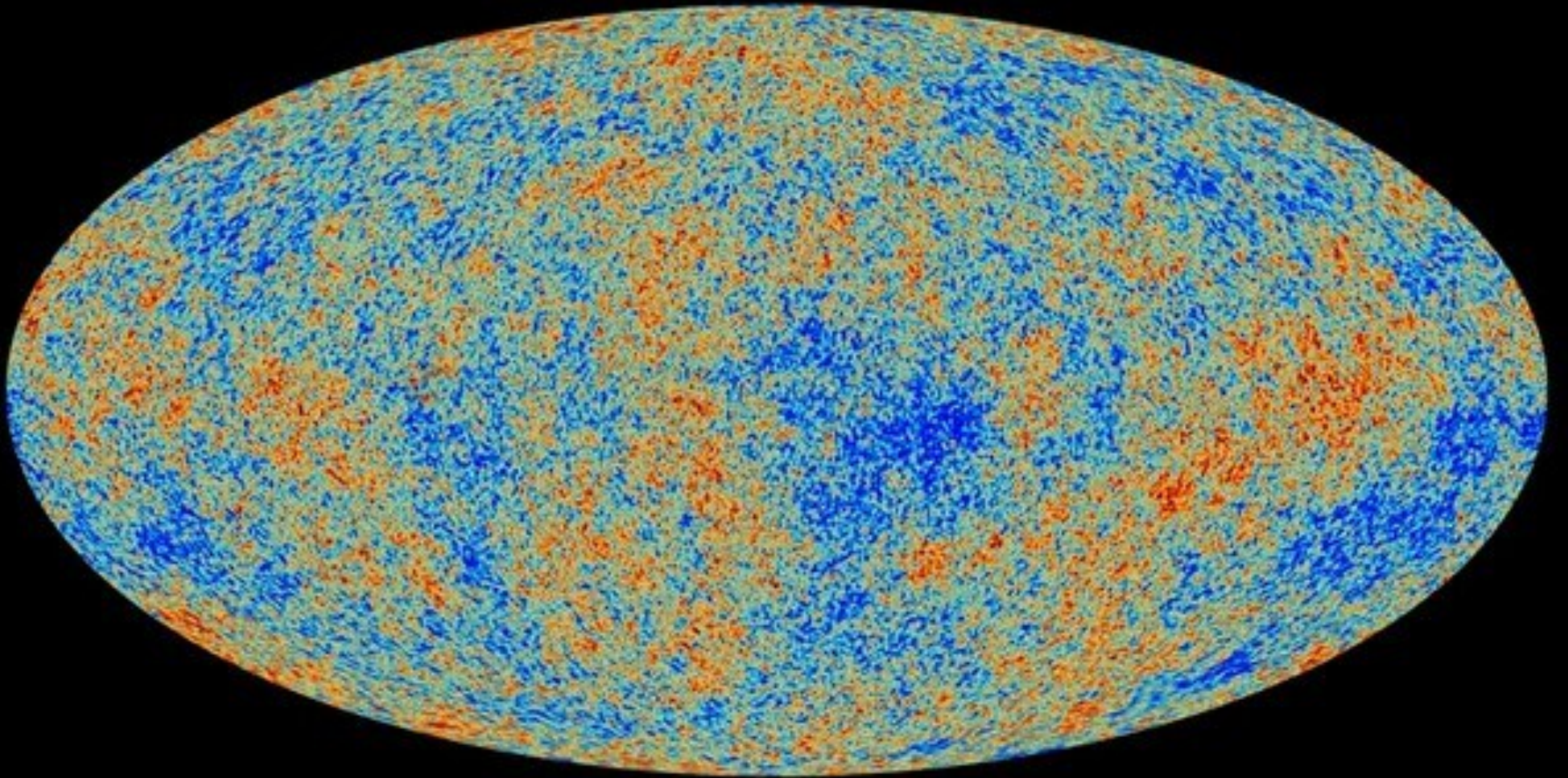


WMAP

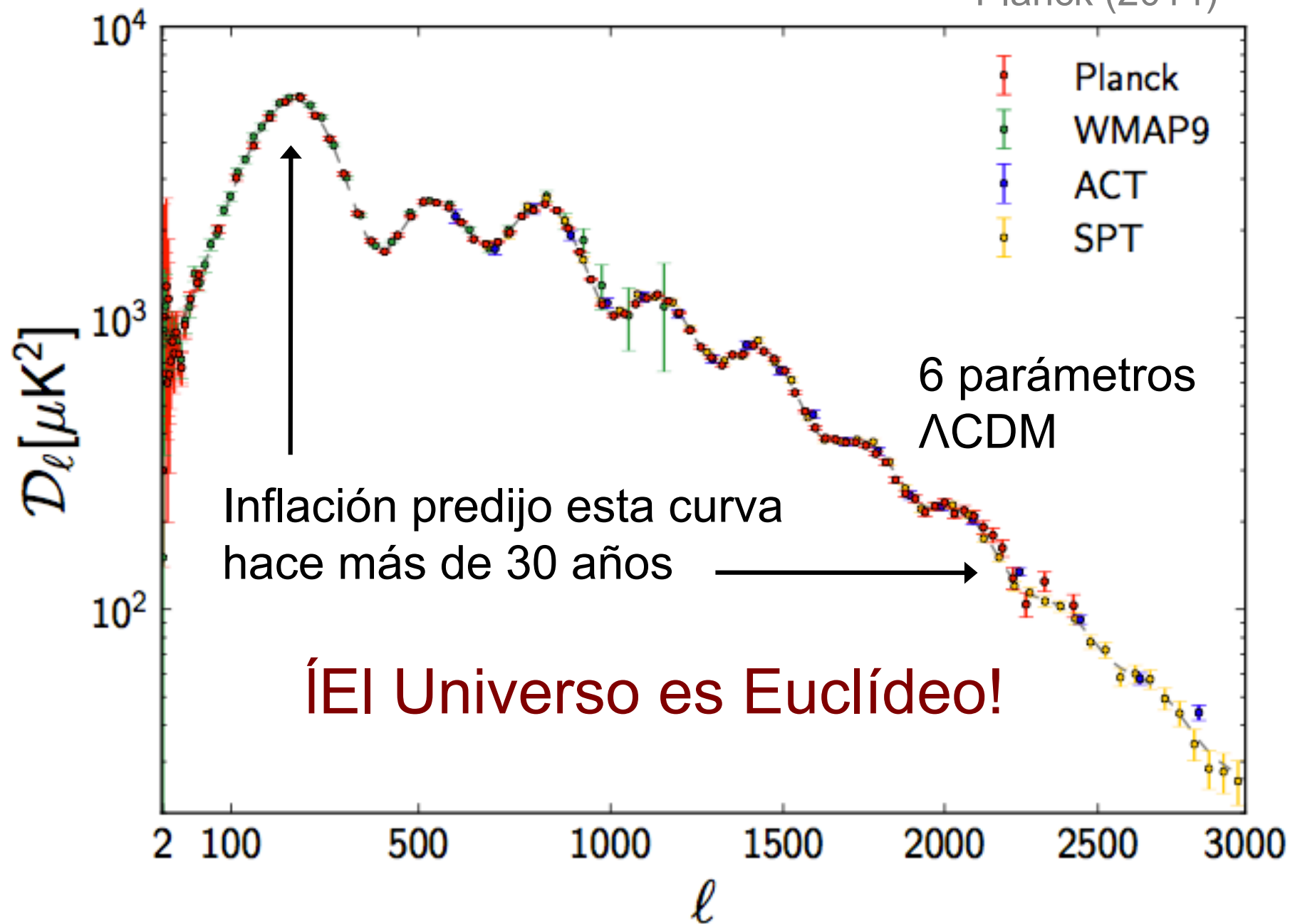


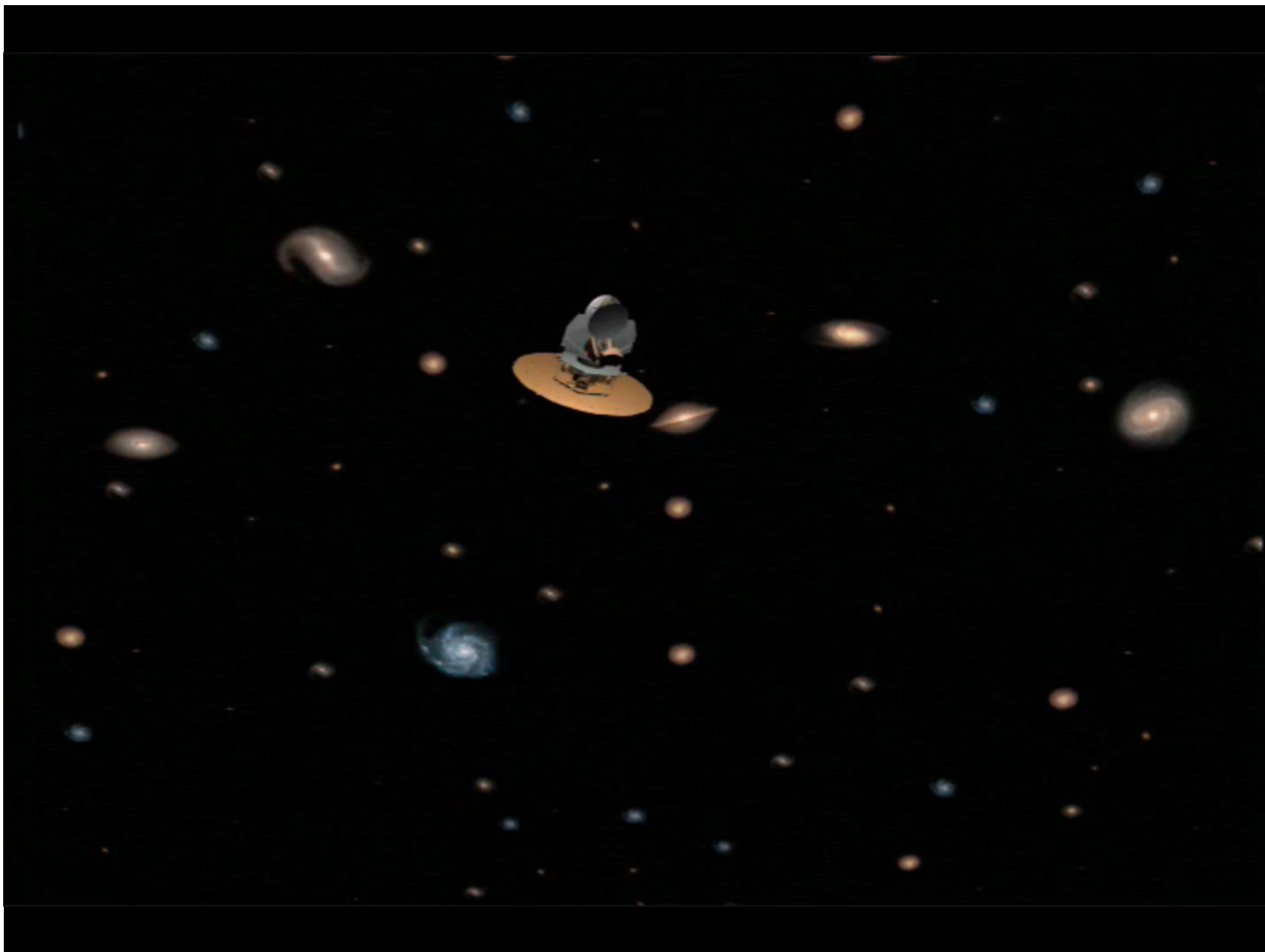
Planck

Planck (2014)

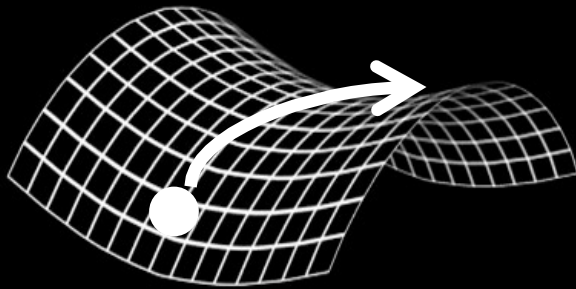
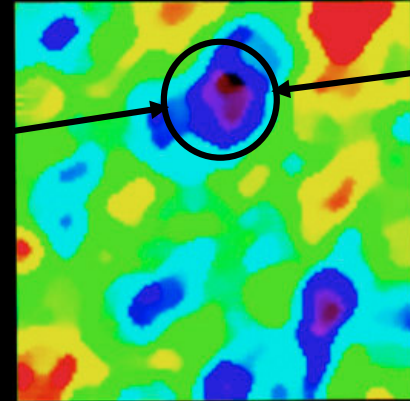
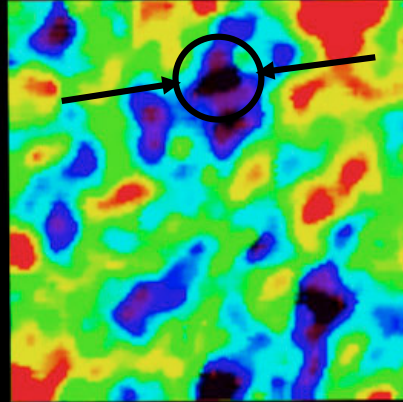
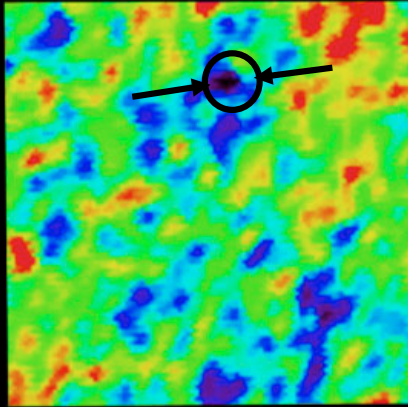


Planck (2014)

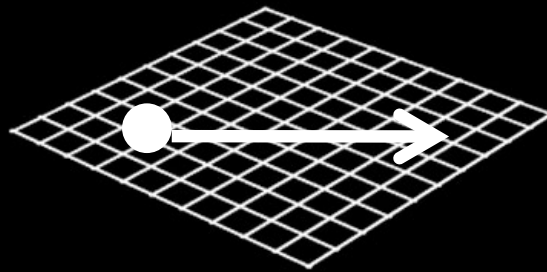




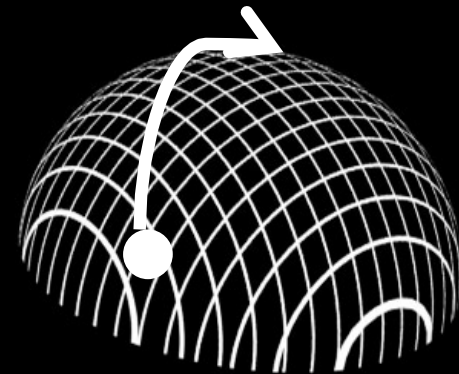
GEOMETRY OF THE UNIVERSE



OPEN



FLAT



CLOSED

Predicciones de Inflación

BIG BANG

Fluctuaciones cuánticas

Inflación

380.000 años
después del Big Bang

Anisotropías de la
radiación de fondo

fotones

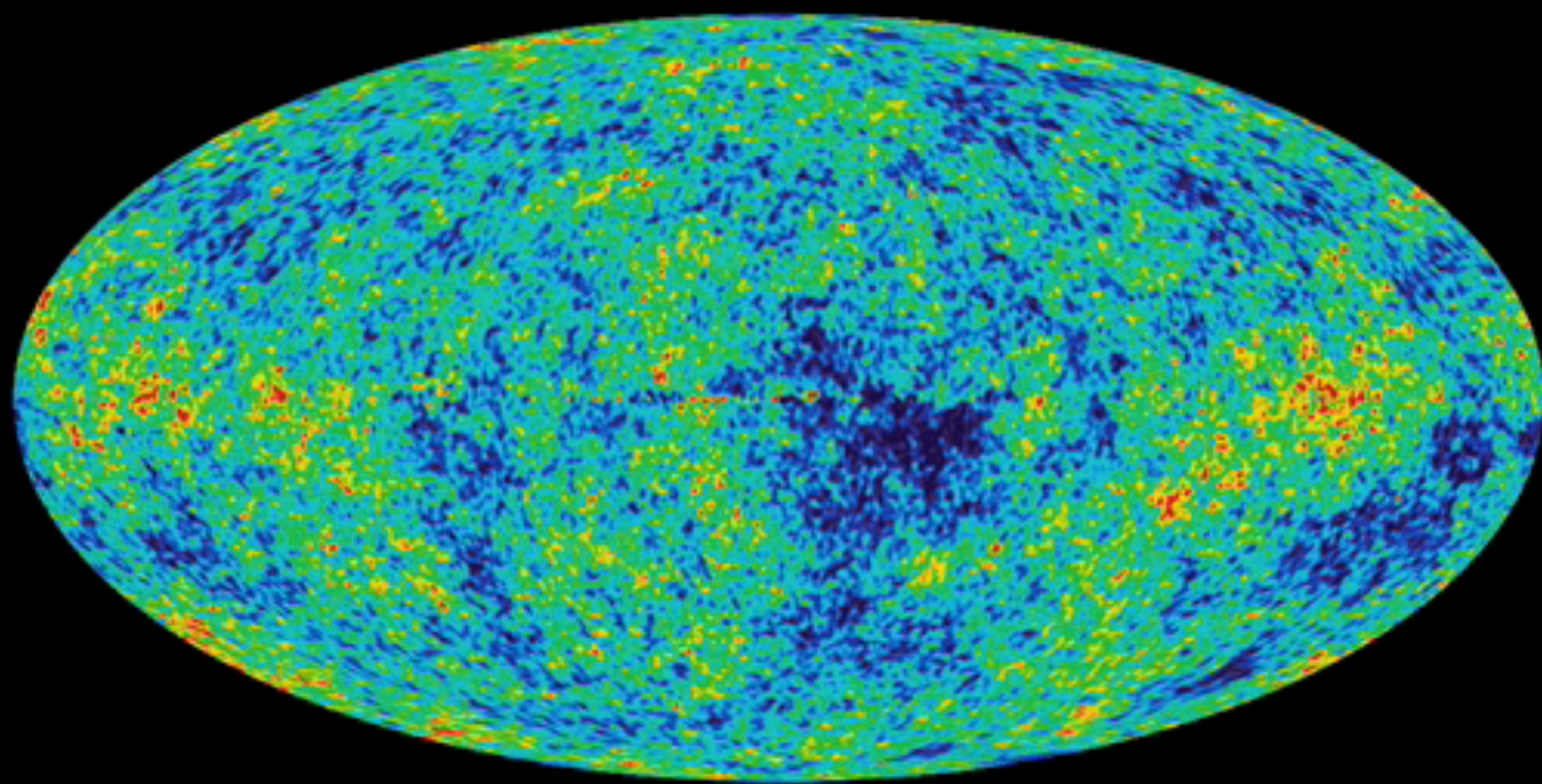
Ondas gravitacionales

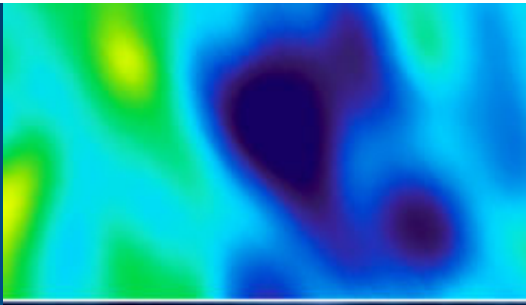
13.800 millones años
después del Big Bang

Formación
estructura



Formación de Estructura a Gran Escala





$z \approx 1100$

Anisotropías CMB



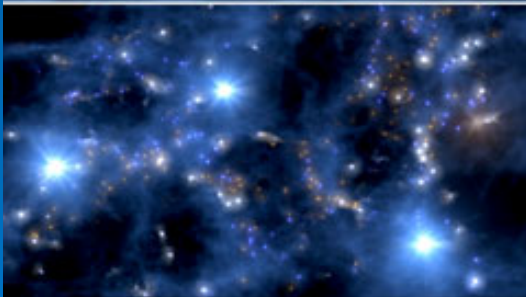
$z \approx 100$

Epoca oscura



$z \approx 20$

Primeras estrellas



$z \approx 10$

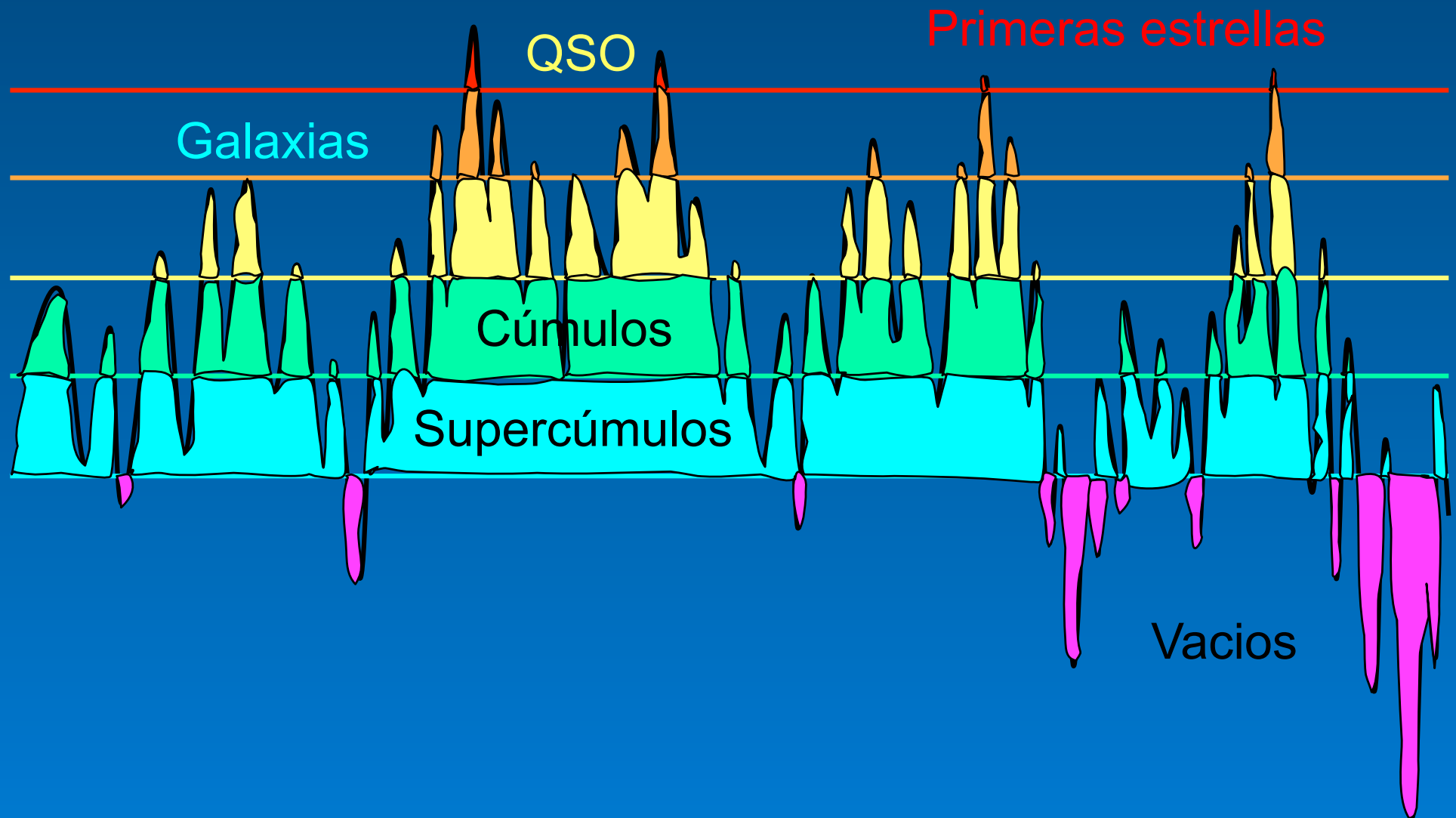
Galaxias & Quásares



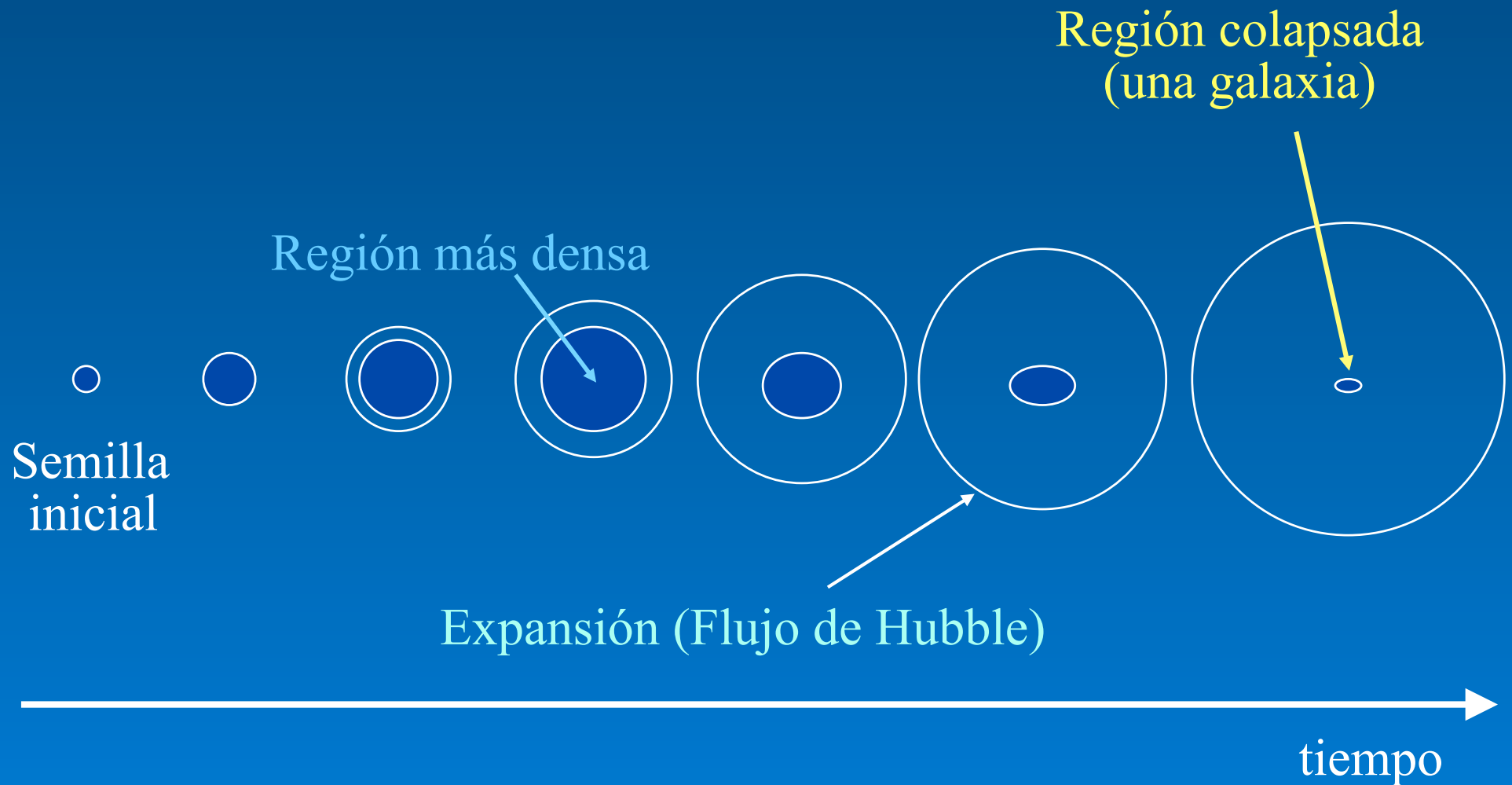
$z \approx 1$

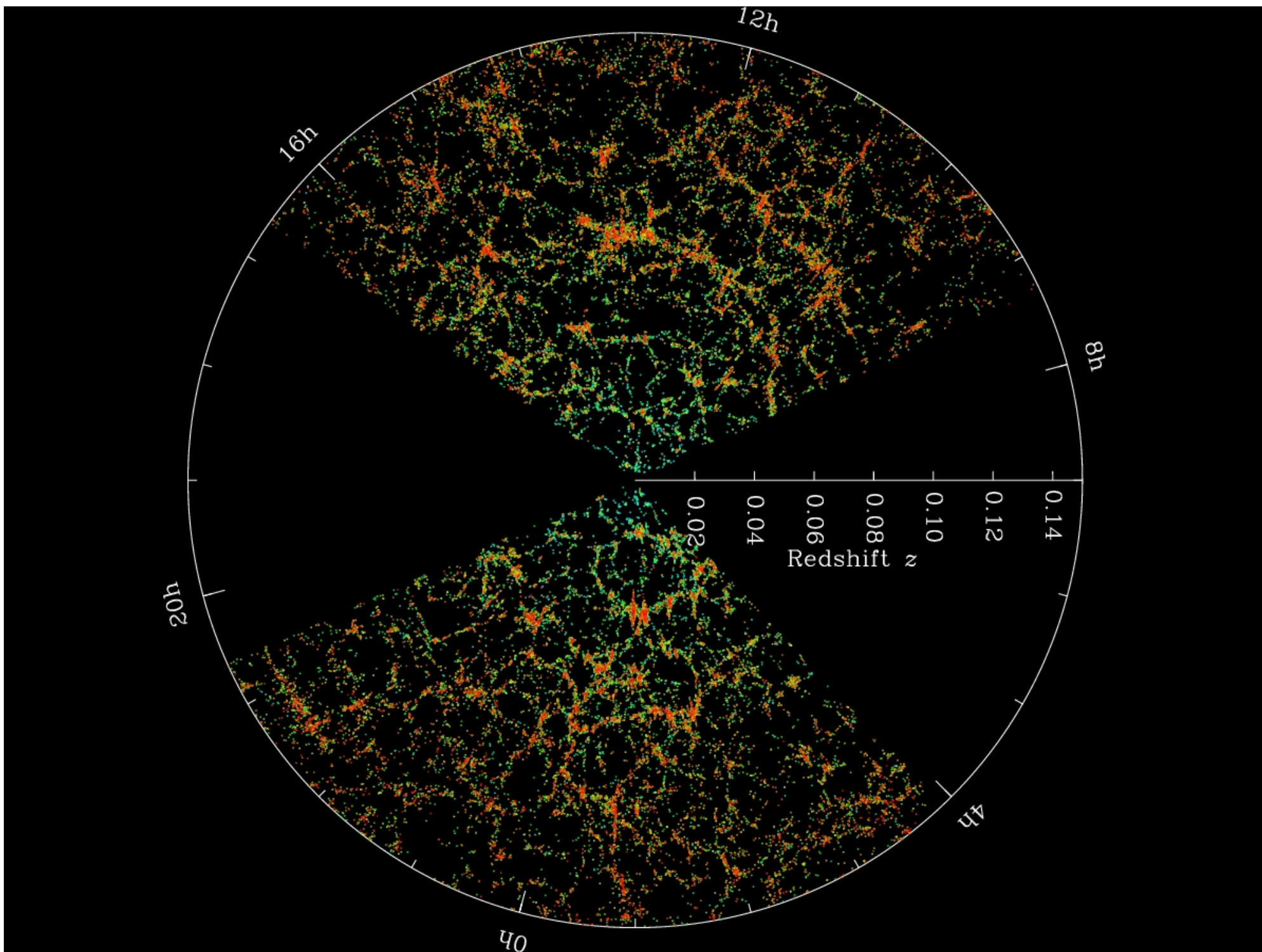
Cúmulos & Supercúmulos

Umbrales de contraste de densidad



Colapso Gravitacional





El Universo acelerado: Energía Oscura

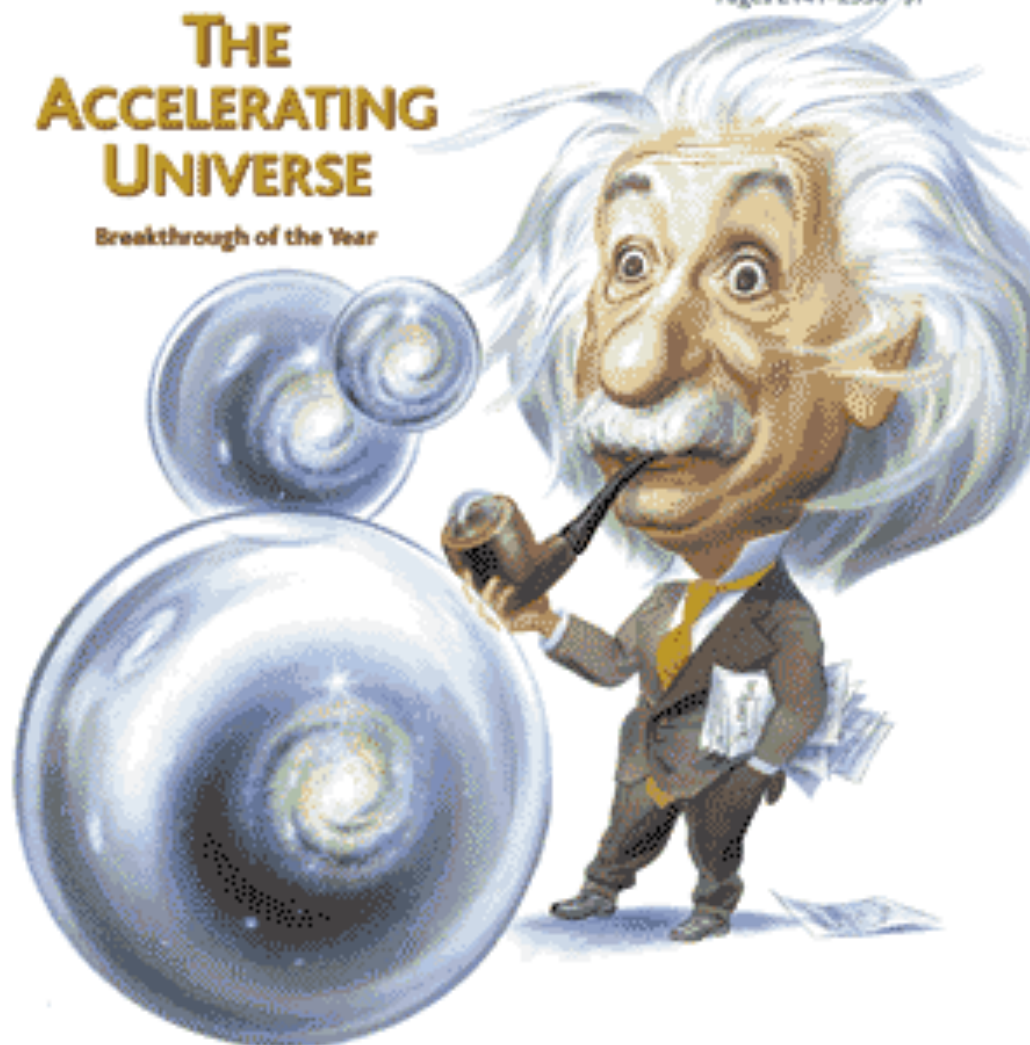
Science

18 December 1998

Vol. 282 No. 5397
Pages 2141-2336 \$7

THE ACCELERATING UNIVERSE

Breakthrough of the Year



AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

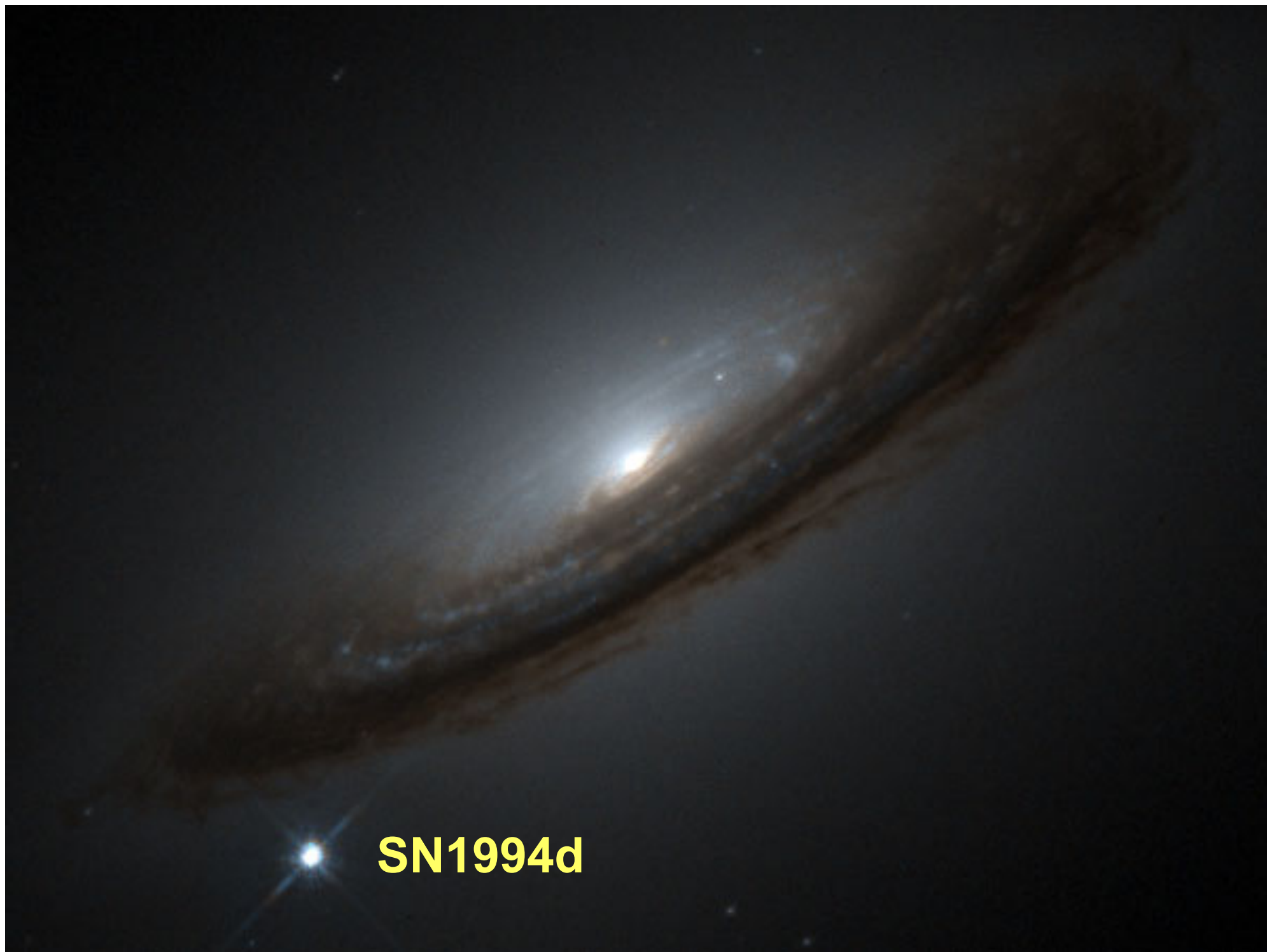


The Nobel Prize in Physics 2011

"for the discovery of the accelerating expansion of the Universe through observations of distant supernovae"



Saul Perlmutter Brian P. Schmidt Adam G. Riess



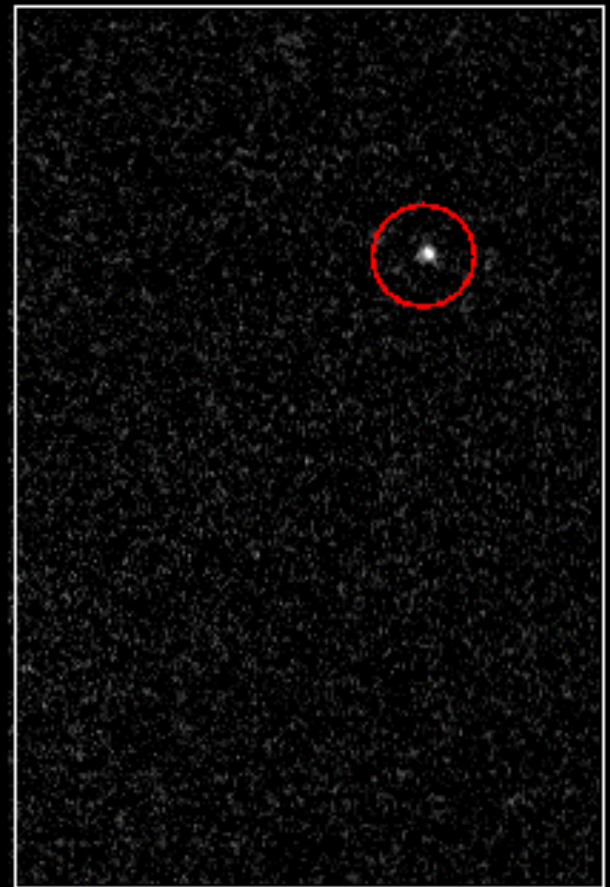
Epoch 1

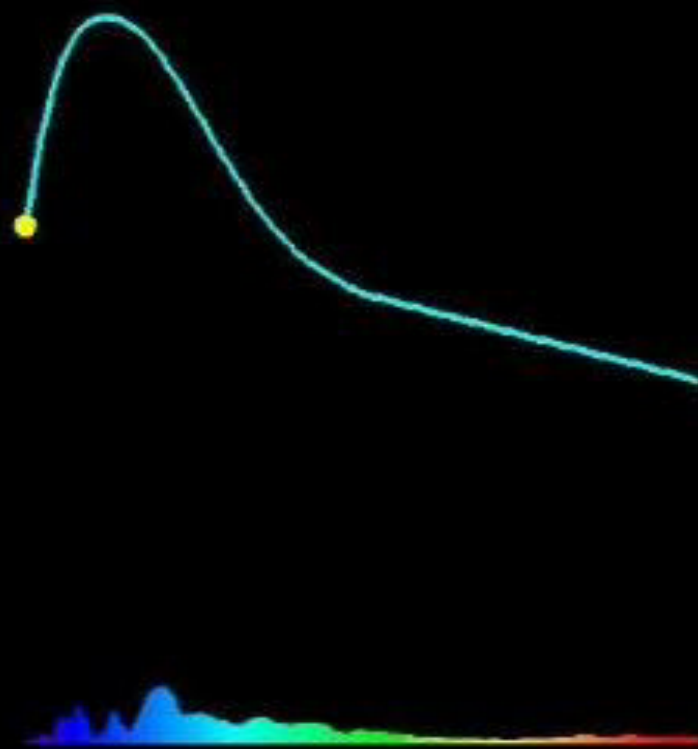


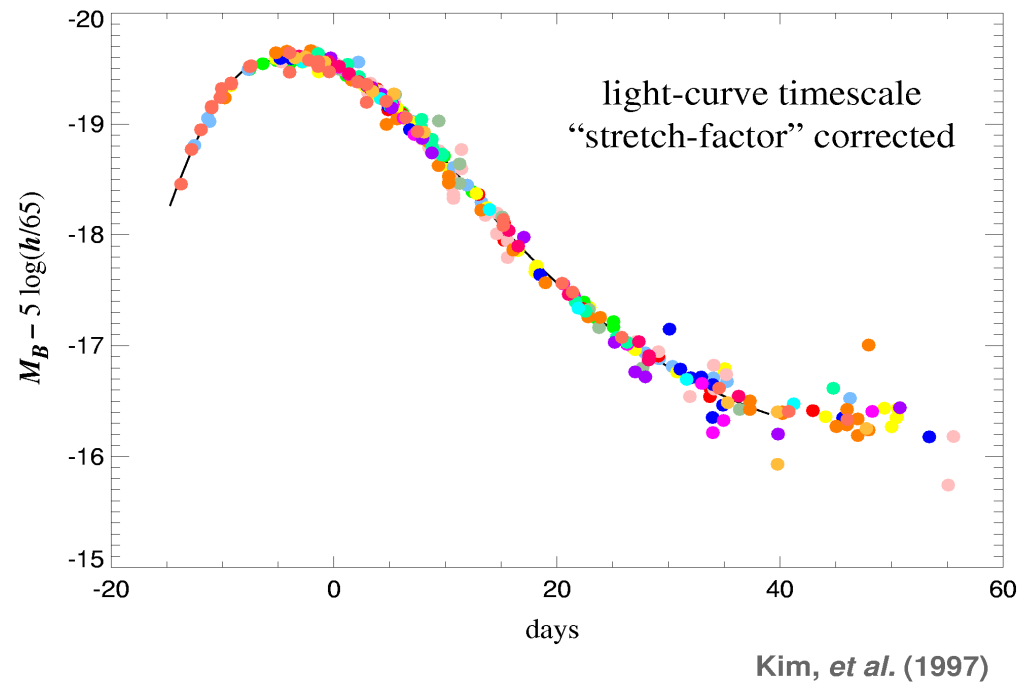
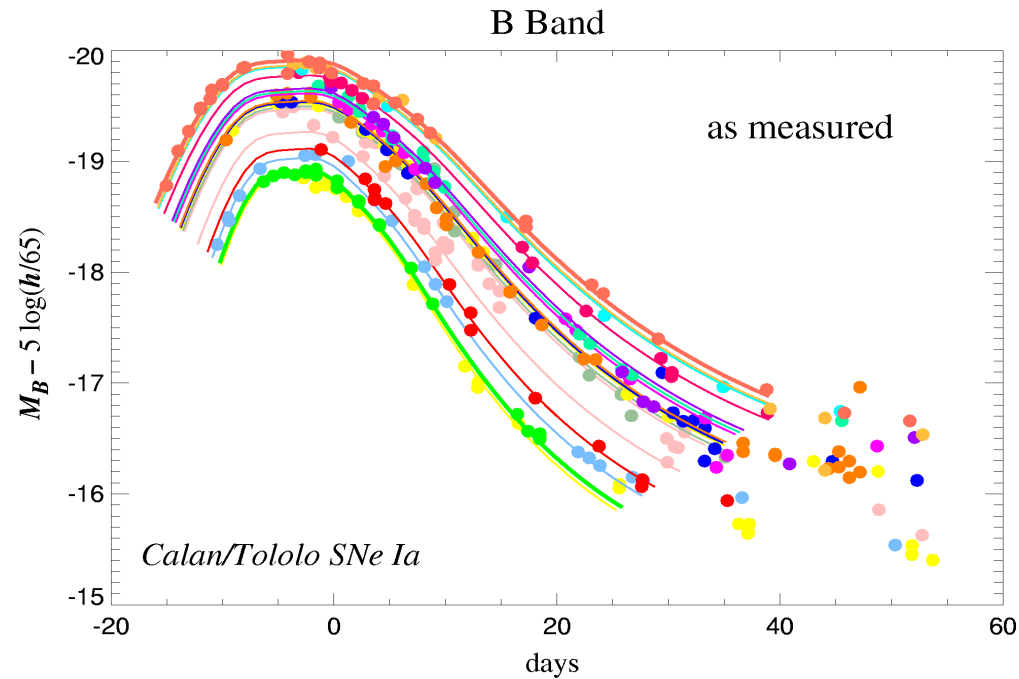
Epoch 2



Epoch 2 - Epoch 1

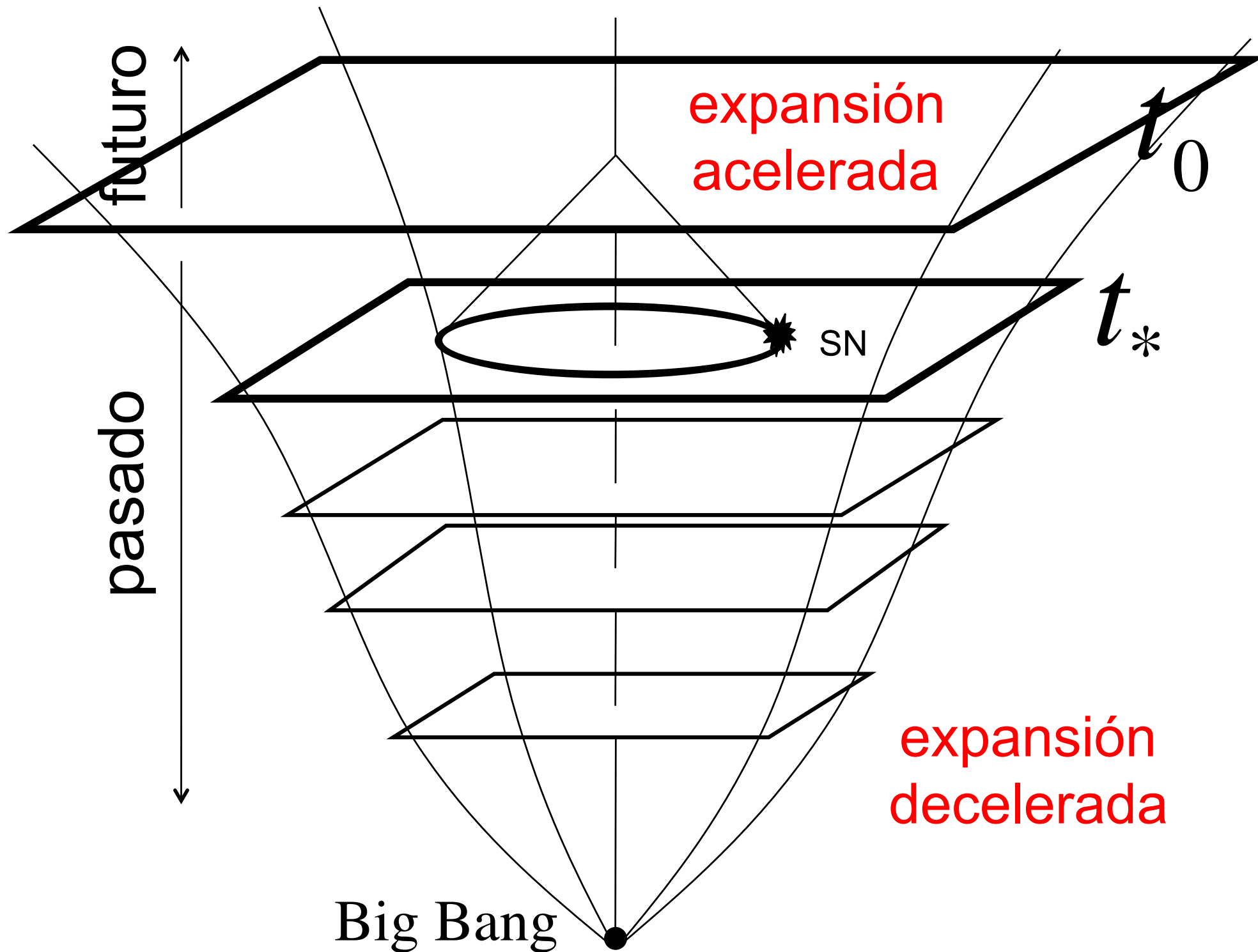






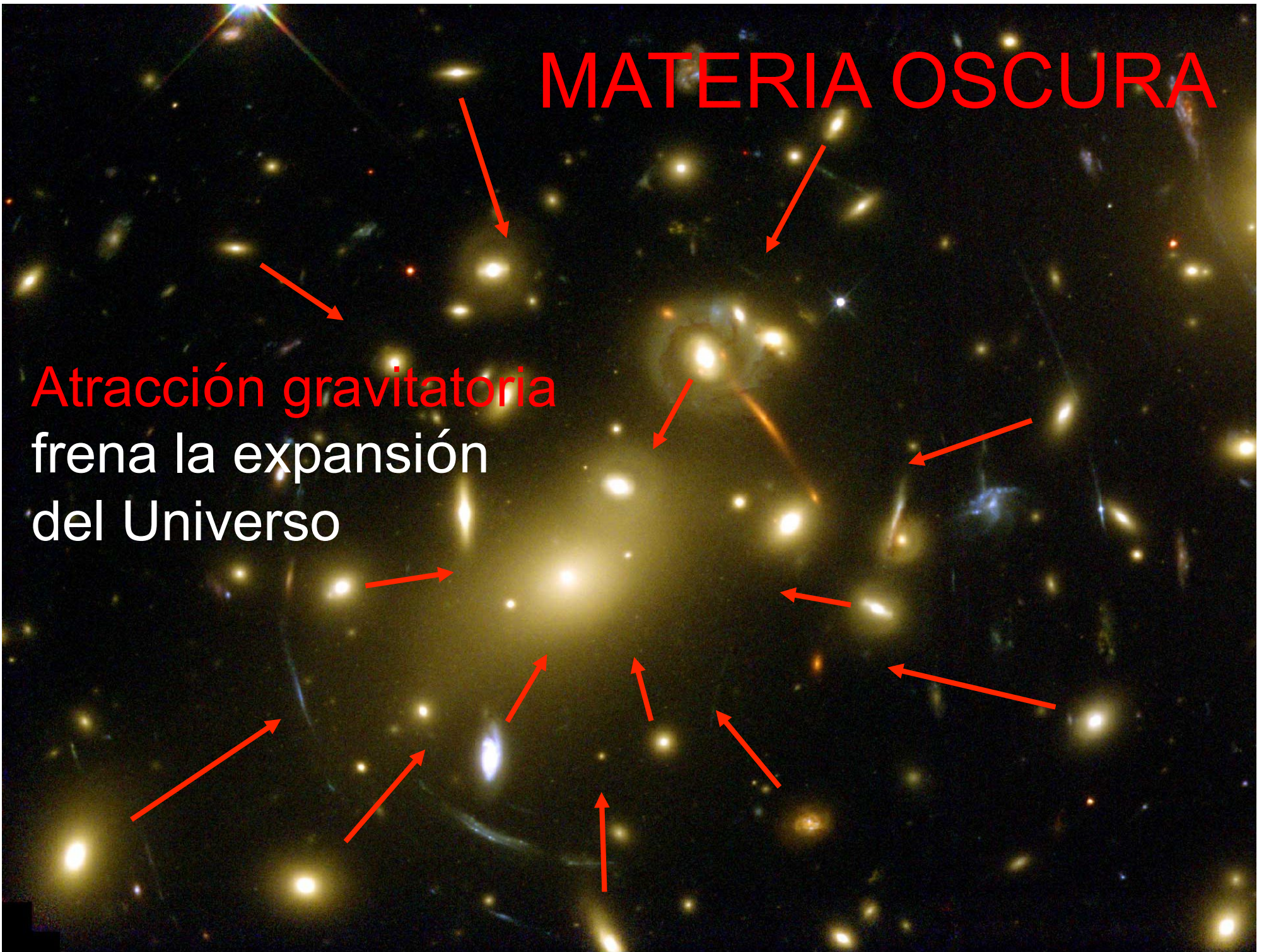
Supernovae
Lightcurves

SN-Ia as
Standard
Candels



MATERIA OSCURA

Atracción gravitatoria
frena la expansión
del Universo





Algo hace que las galaxias
se alejen unas de otras

ENERGIA OSCURA

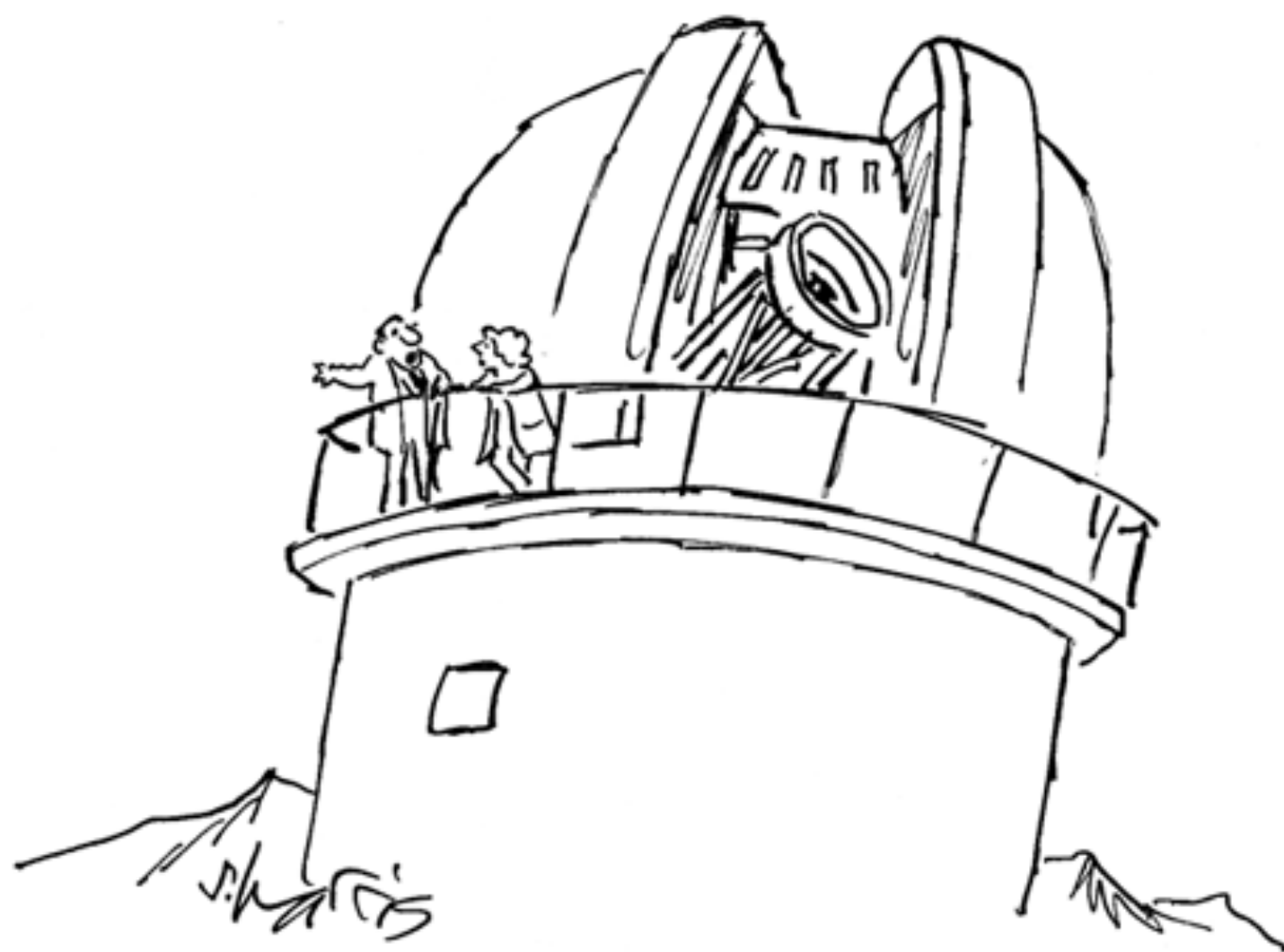
¿Cuánto es la aceleración del universo hoy en día?

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}(\rho + 3p) + \frac{\Lambda}{3} \quad \text{Friedmann}$$

$$\ddot{a}_0 = \left(-\frac{\Omega_M}{2} + \Omega_\Lambda \right) a_0 H_0^2$$

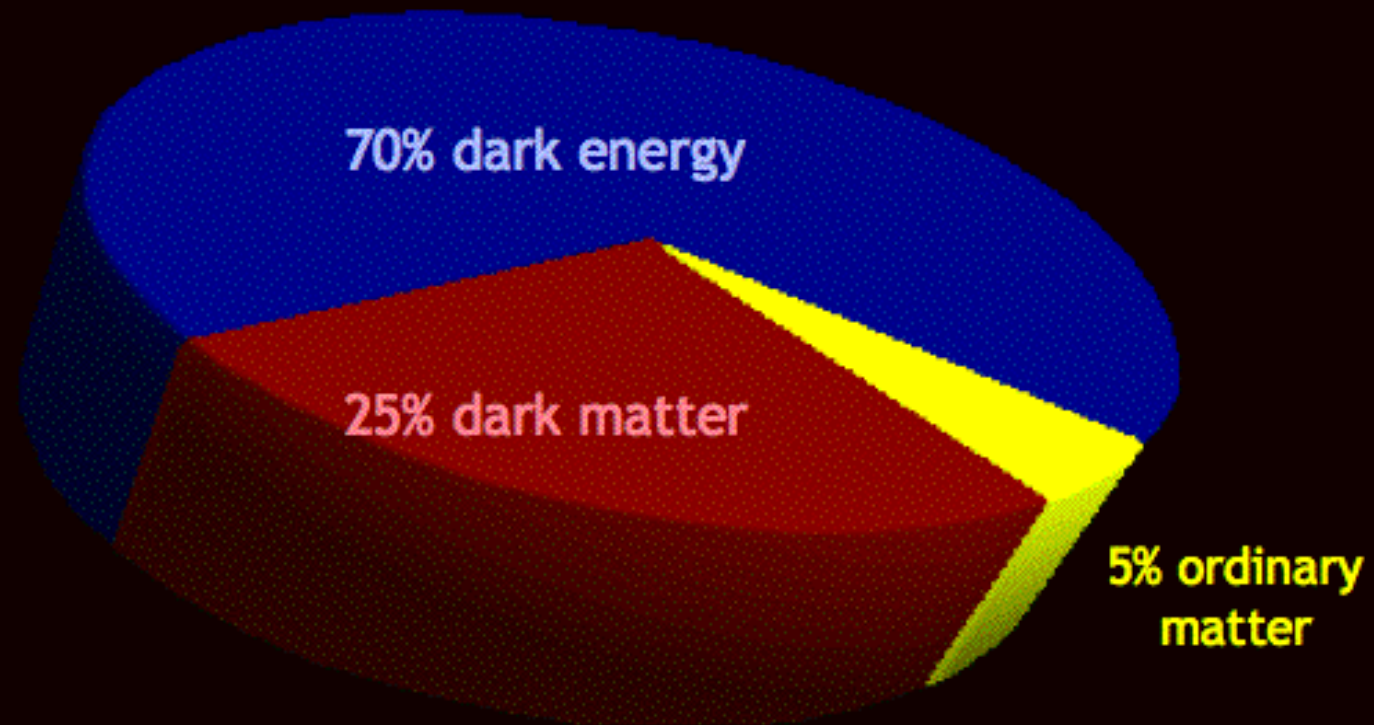
$$= 0.5863 a_0 t_0^{-2}$$

$$= 9.2 \times 10^{-10} \text{ ms}^{-2}$$

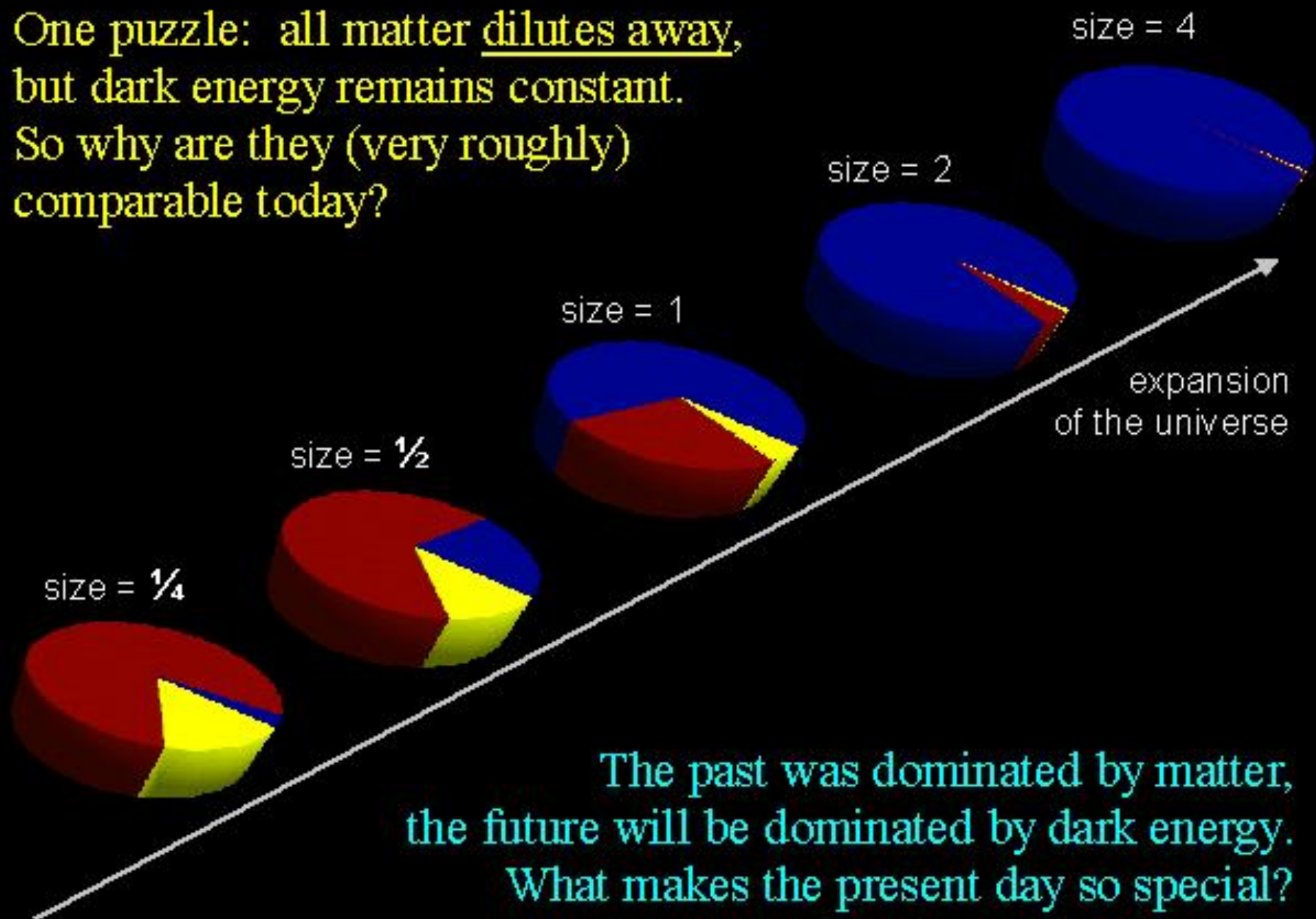


"THE UNIVERSE IS EXPANDING FASTER THAN EVER, AND
I DON'T EVEN FEEL A BREEZE."

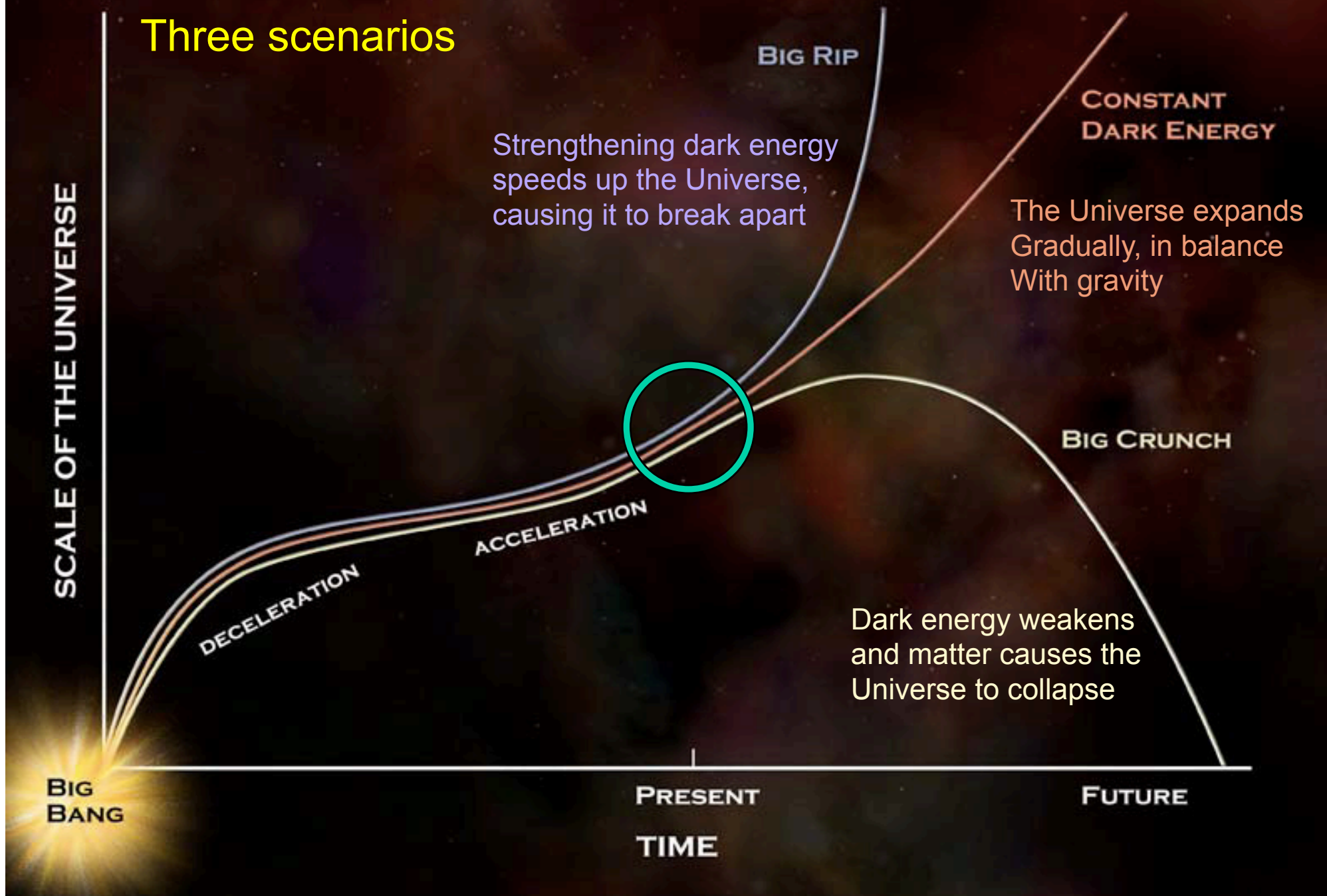
We have a complete inventory of the universe.



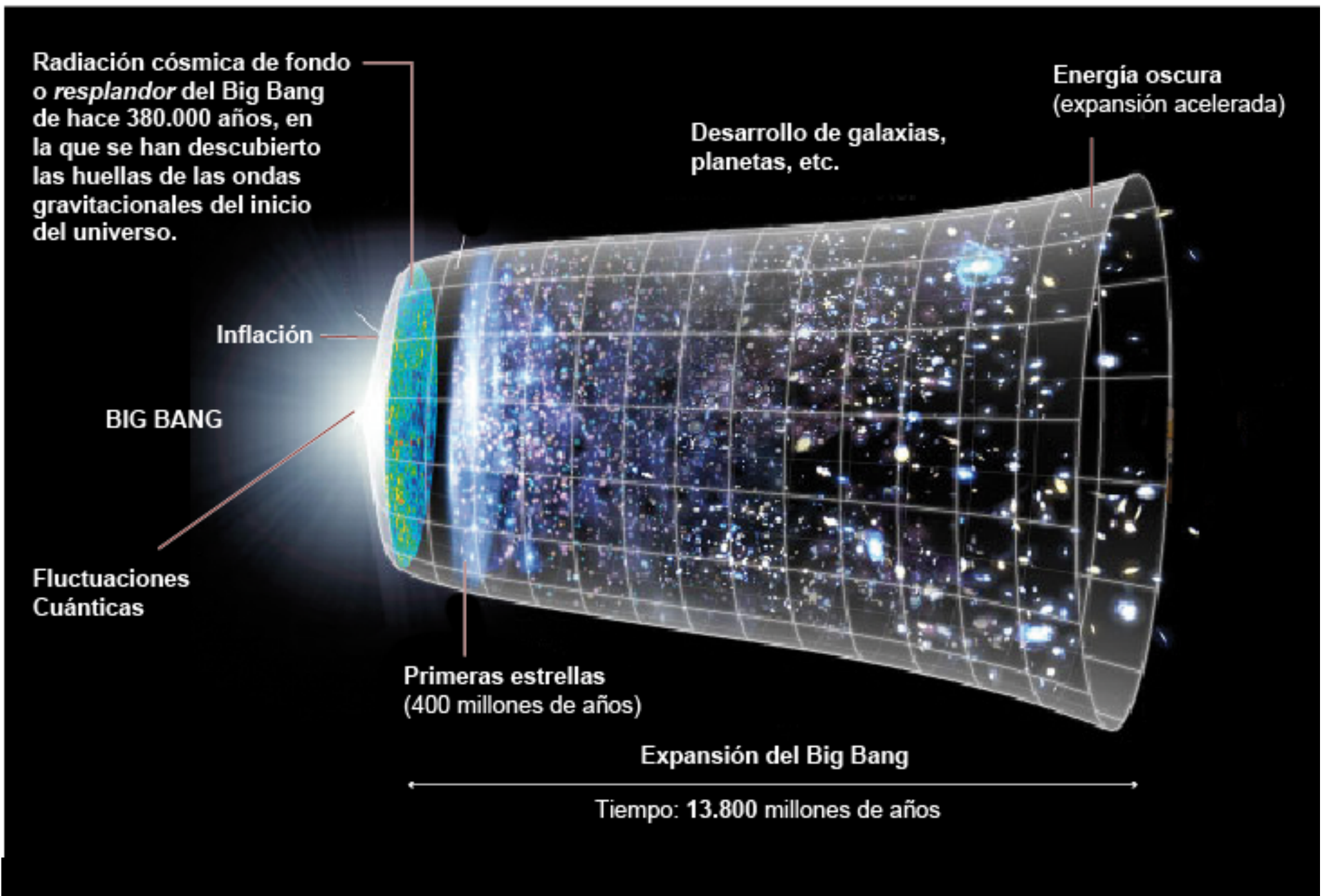
One puzzle: all matter dilutes away,
but dark energy remains constant.
So why are they (very roughly)
comparable today?



The fate of the universe: Three scenarios



EVOLUCIÓN DEL COSMOS



Blog : Investigación y Ciencia



<http://www.investigacionyciencia.es/blogs/astronomia>

Cosmología de precisión



Juan García-Bellido Capdevila