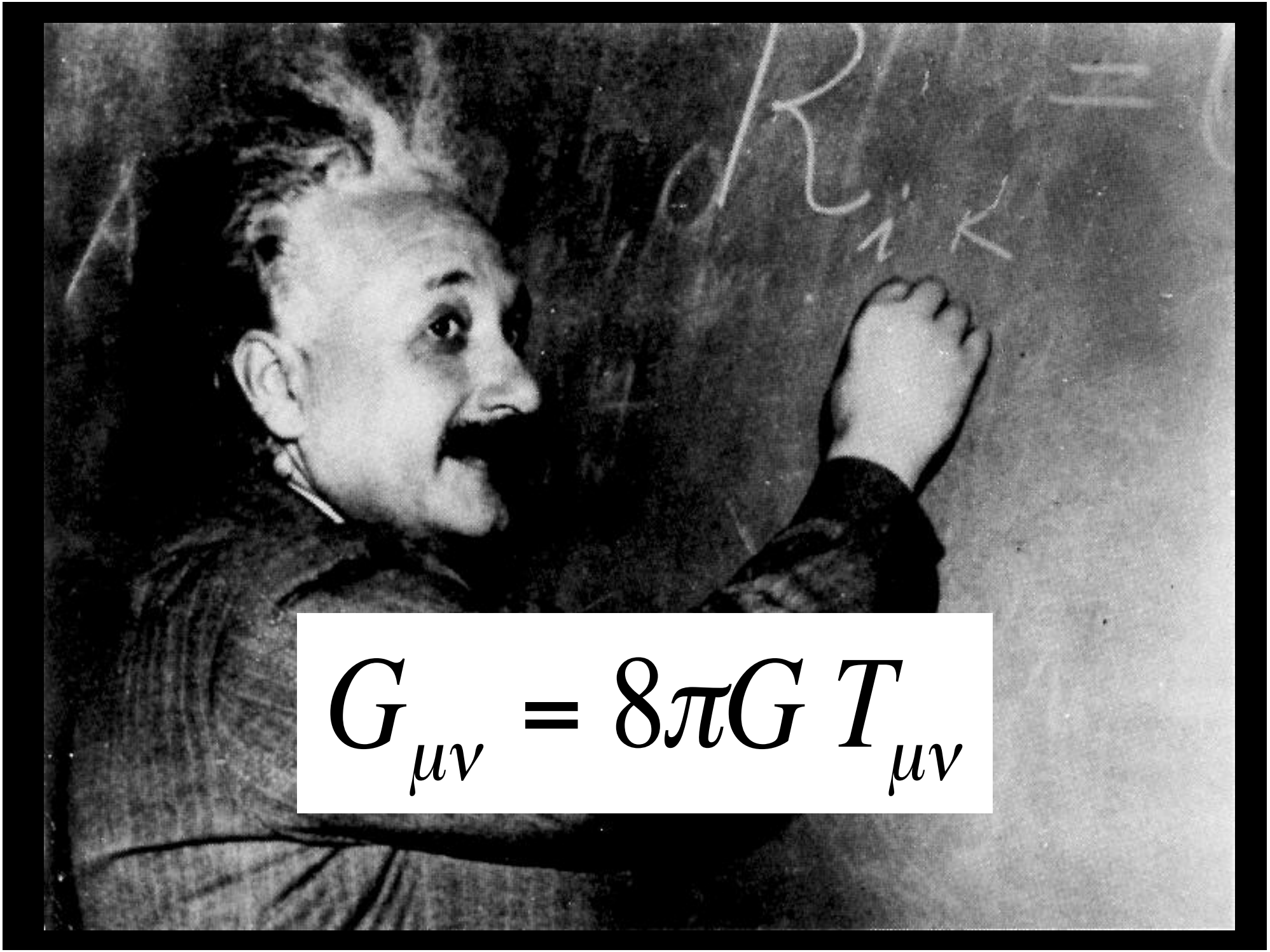
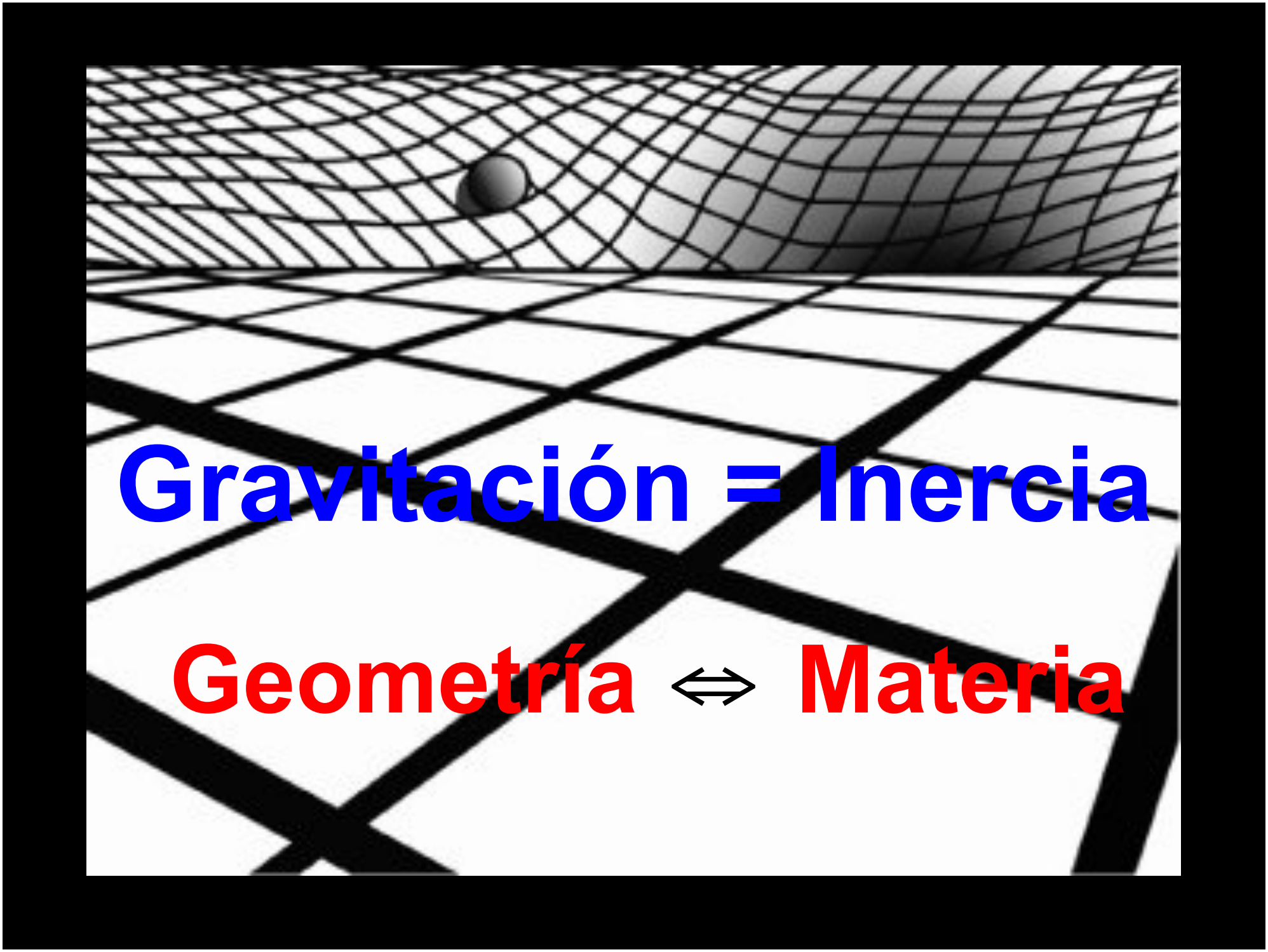
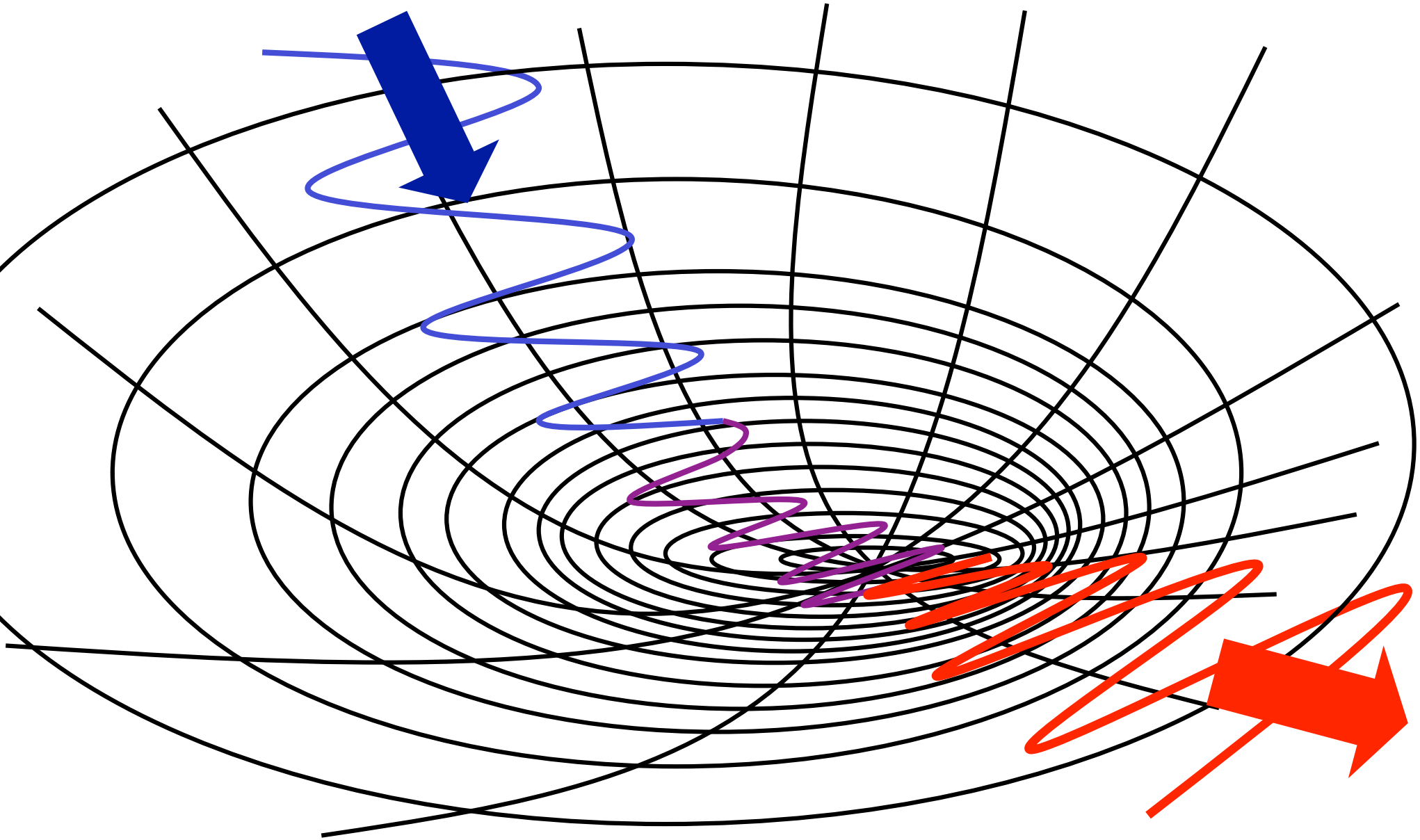

La cosmología moderna
del Big Bang al futuro del Universo
Residencia de Estudiantes
16 Noviembre 2013
Juan García-Bellido
Inst. Física Teórica UAM


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

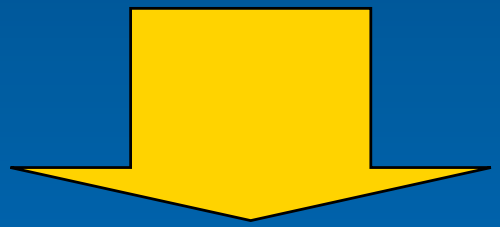

Gravitación = Inercia
Geometría ⇔ Materia

Blueshift y redshift gravitacional



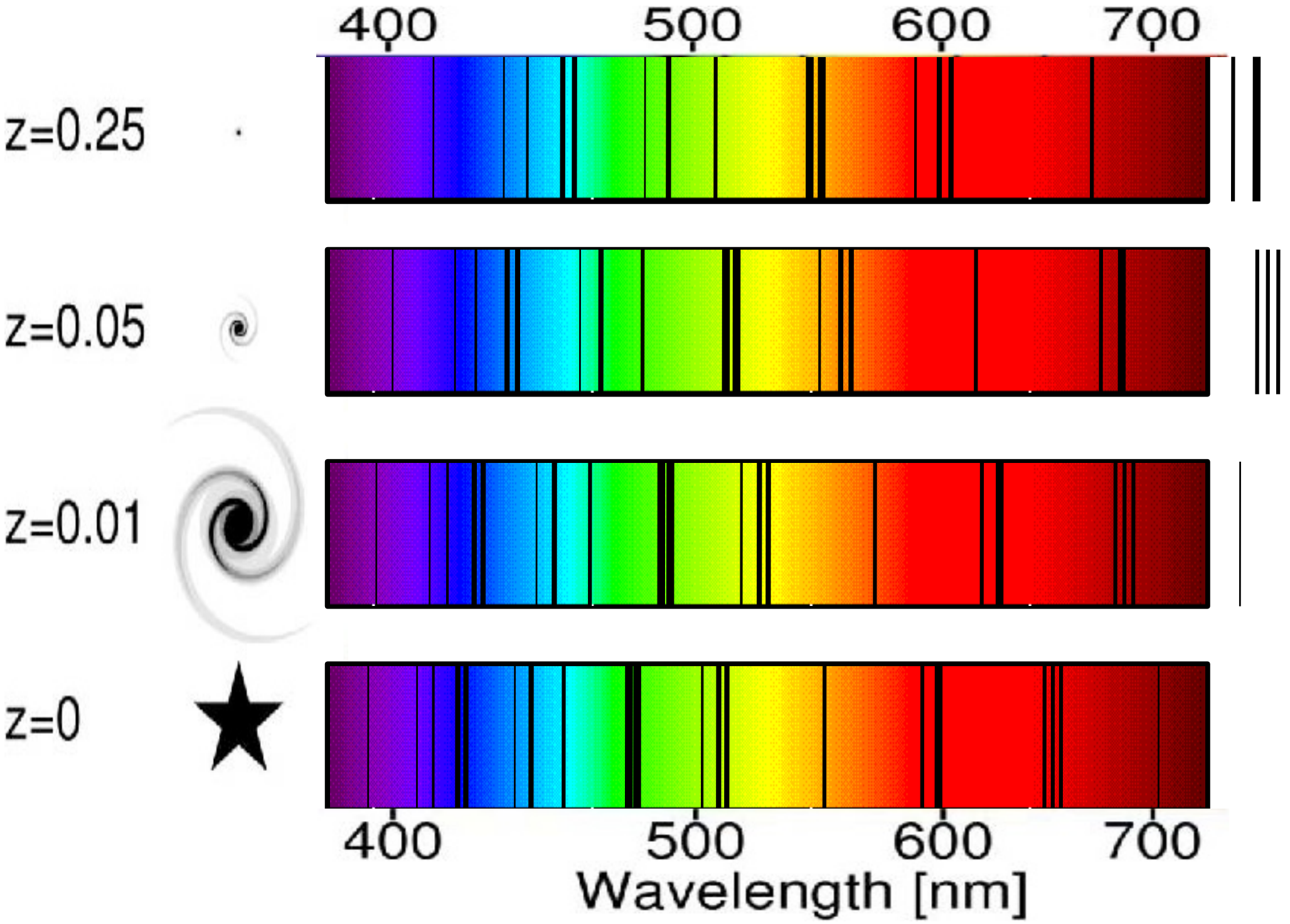

El espacio es homogéneo e isótropo (a gran escala)
5 billion years
(you are here)
RA
40
30
20
10
0

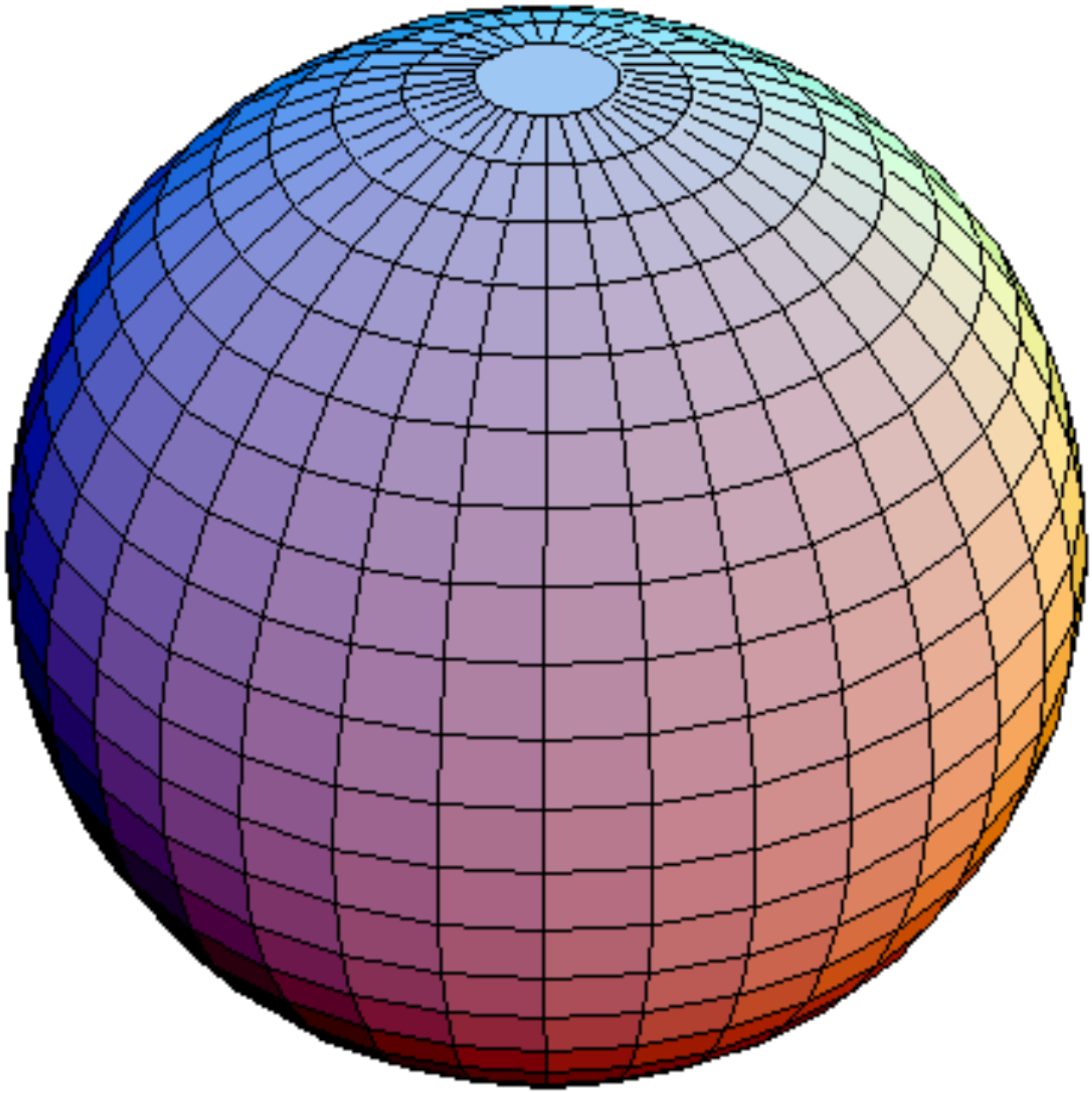
Relatividad General

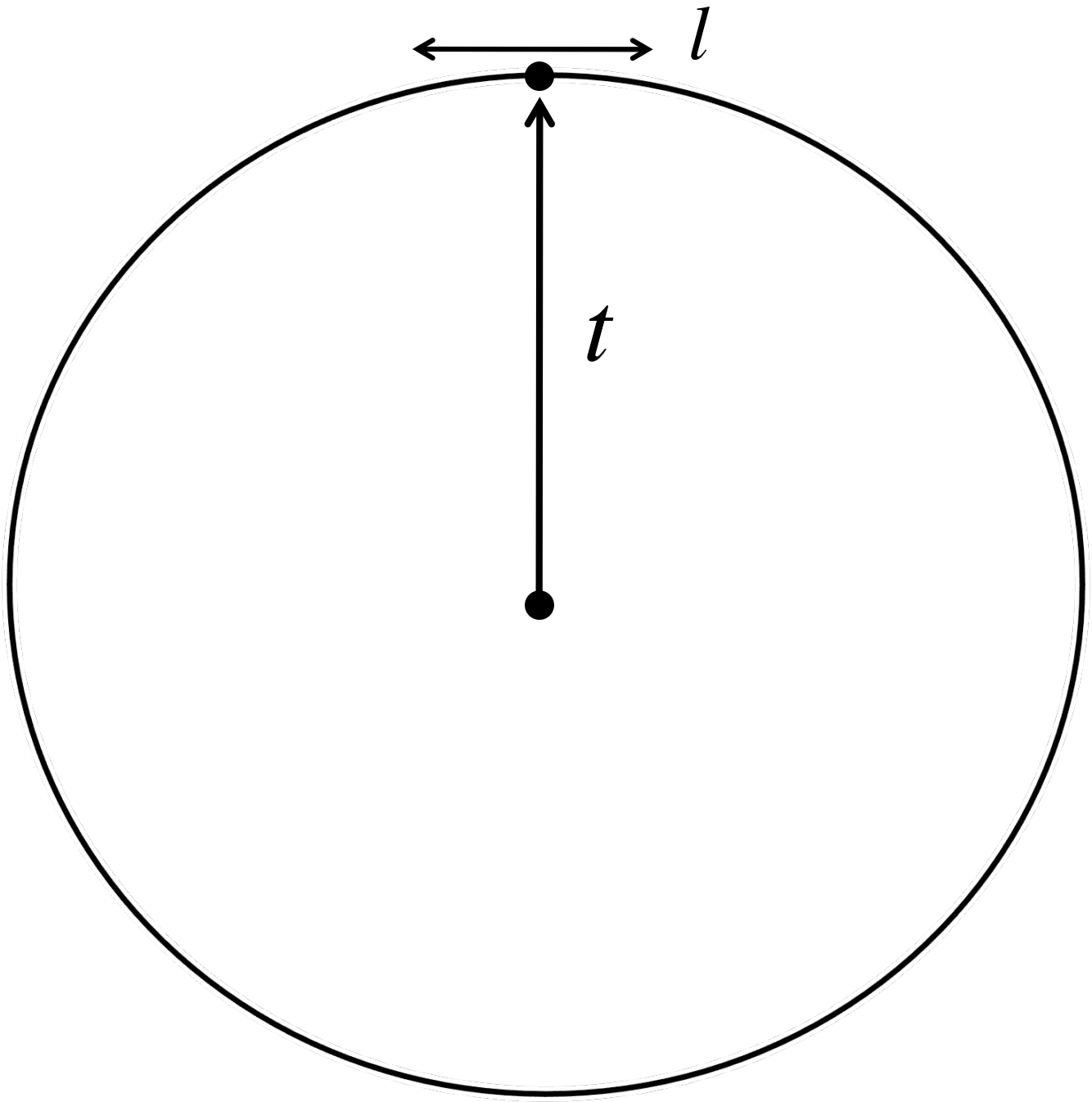


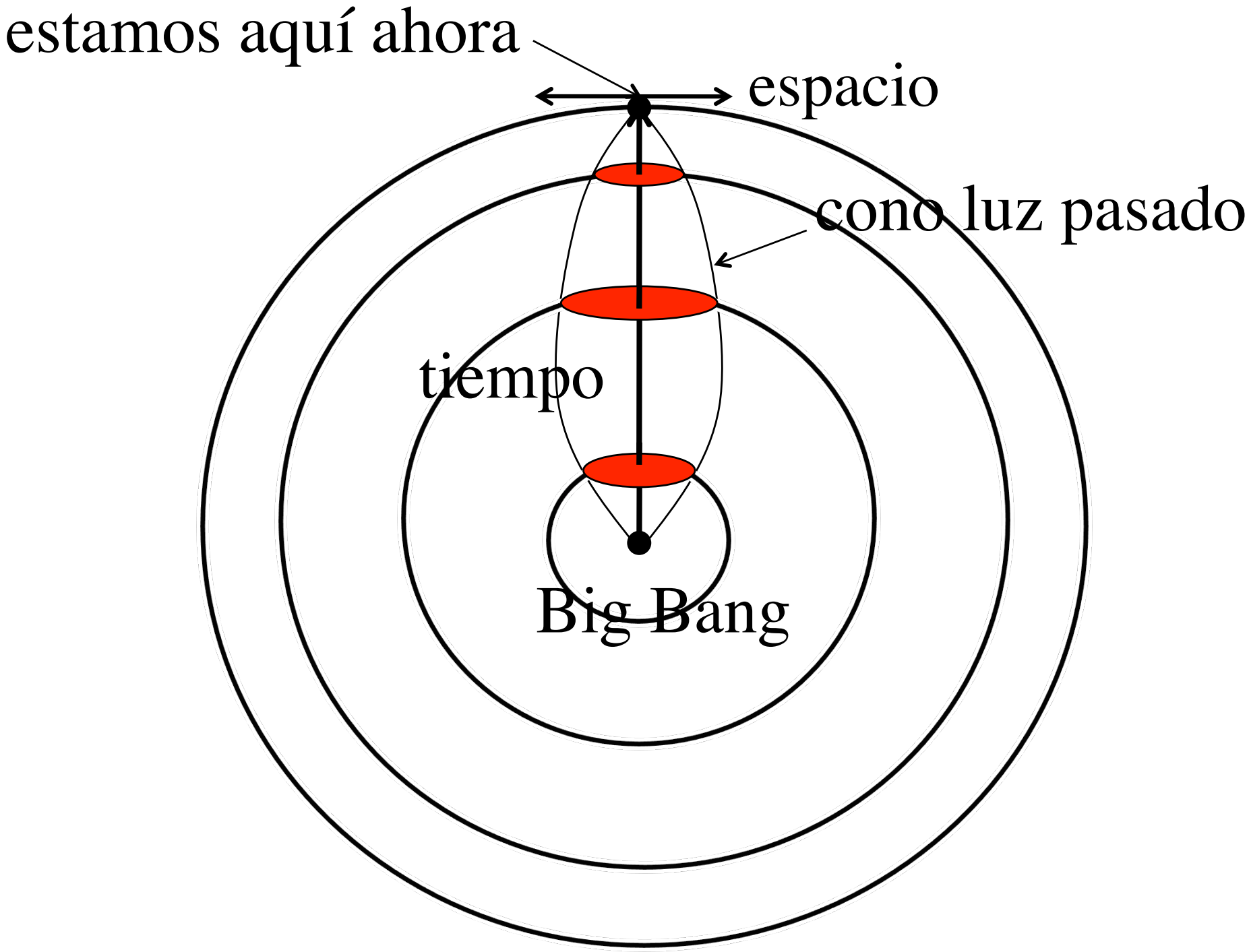
Universo en expansión

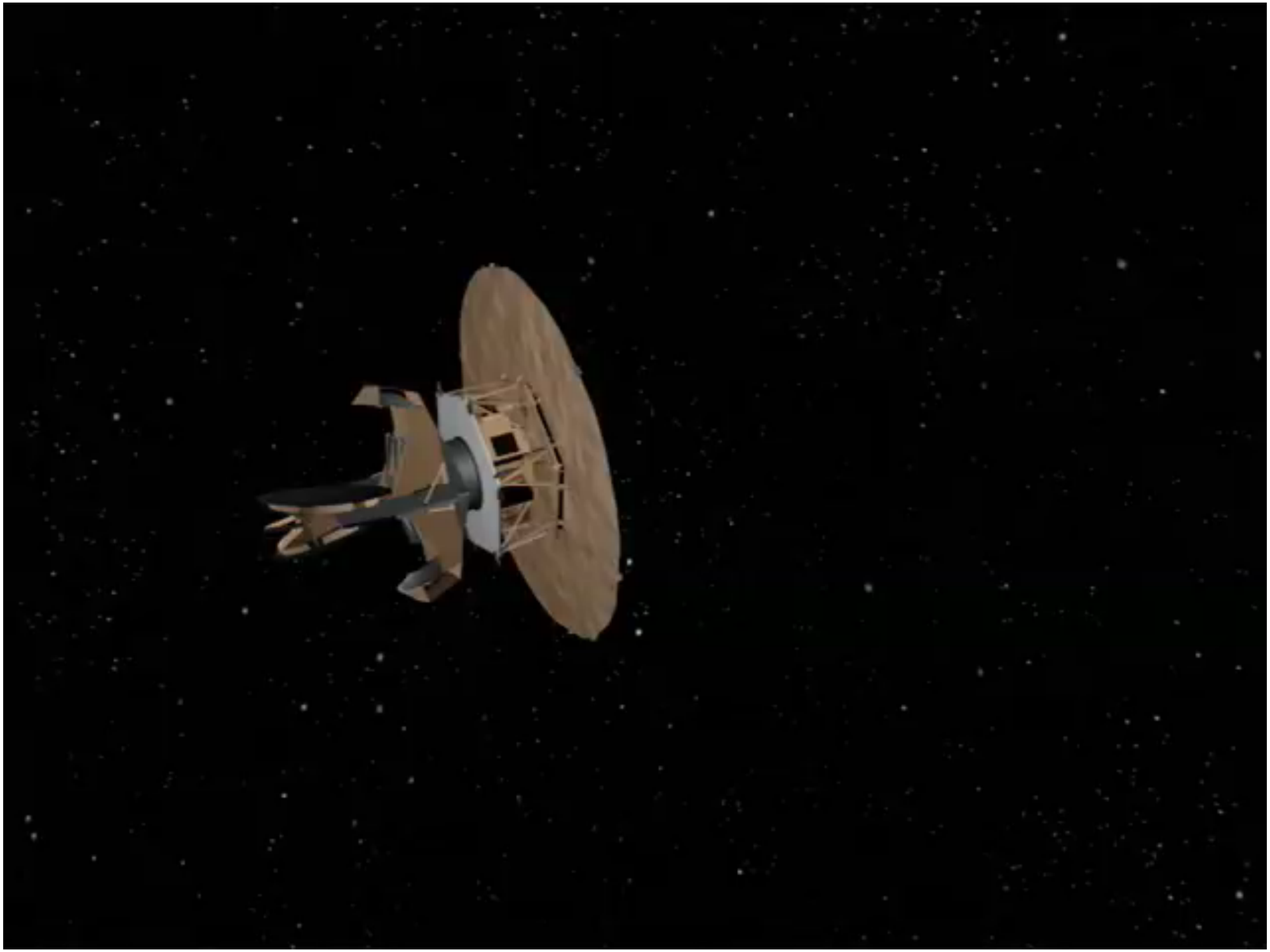
redshift $$\frac{\lambda_{obs}}{\lambda_{em}} = \frac{a_0}{a_1} = 1 + z$$


400
500
600
700
z=0.25
z=0.05
z=0.01
z=0
400
500
600
700
Wavelength [nm]




l
t


estamos aquí ahora
espacio
cono luz pasado
tiempo
Big Bang

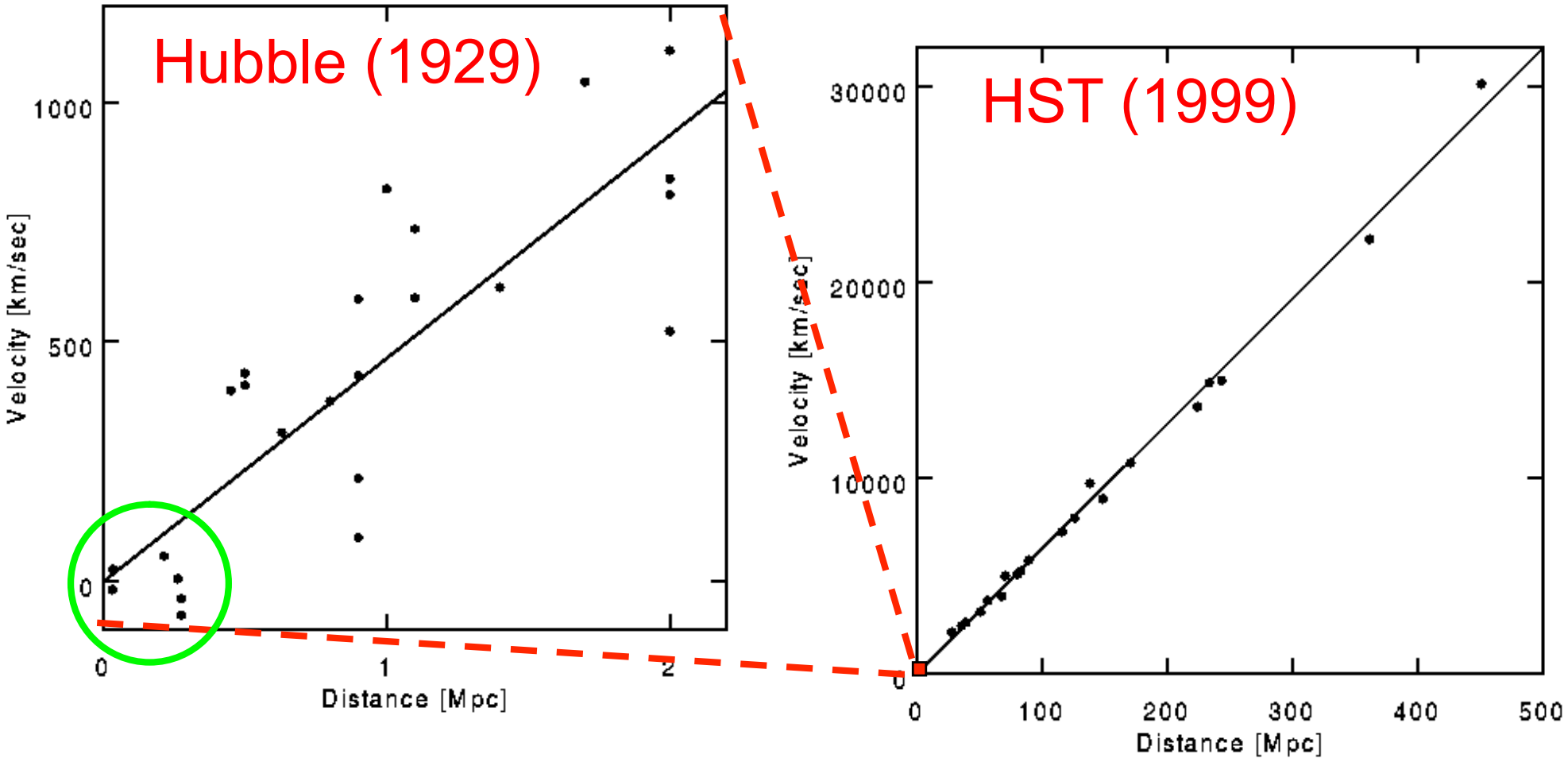


Edwin P. Hubble

Mount Wilson

Mount Palomar

Hubble Space Telescope



$H_0 = 500$ km/s/Mpc

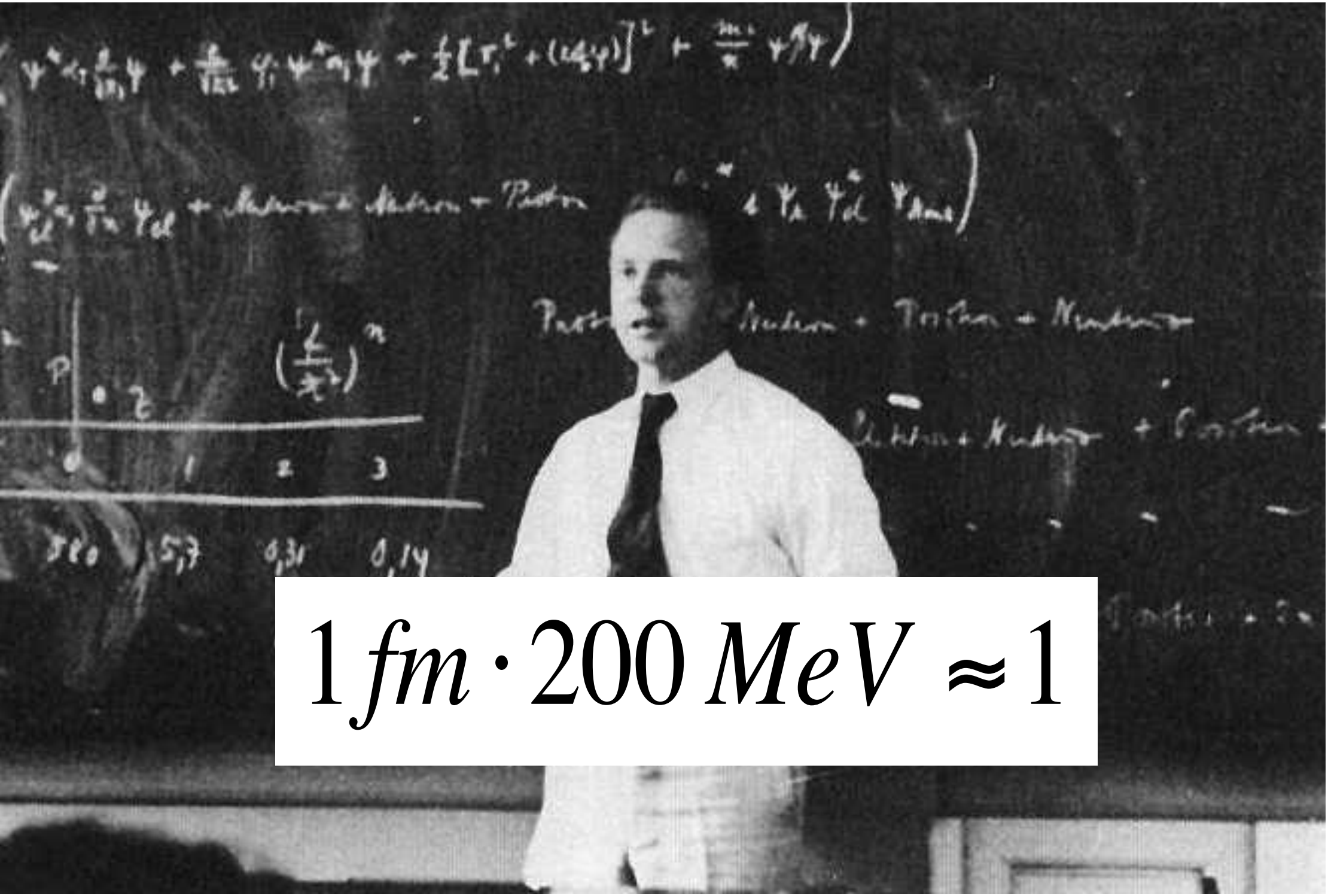
Dominado por
errores sistematicos !

$H_0 = 70$ km/s/Mpc

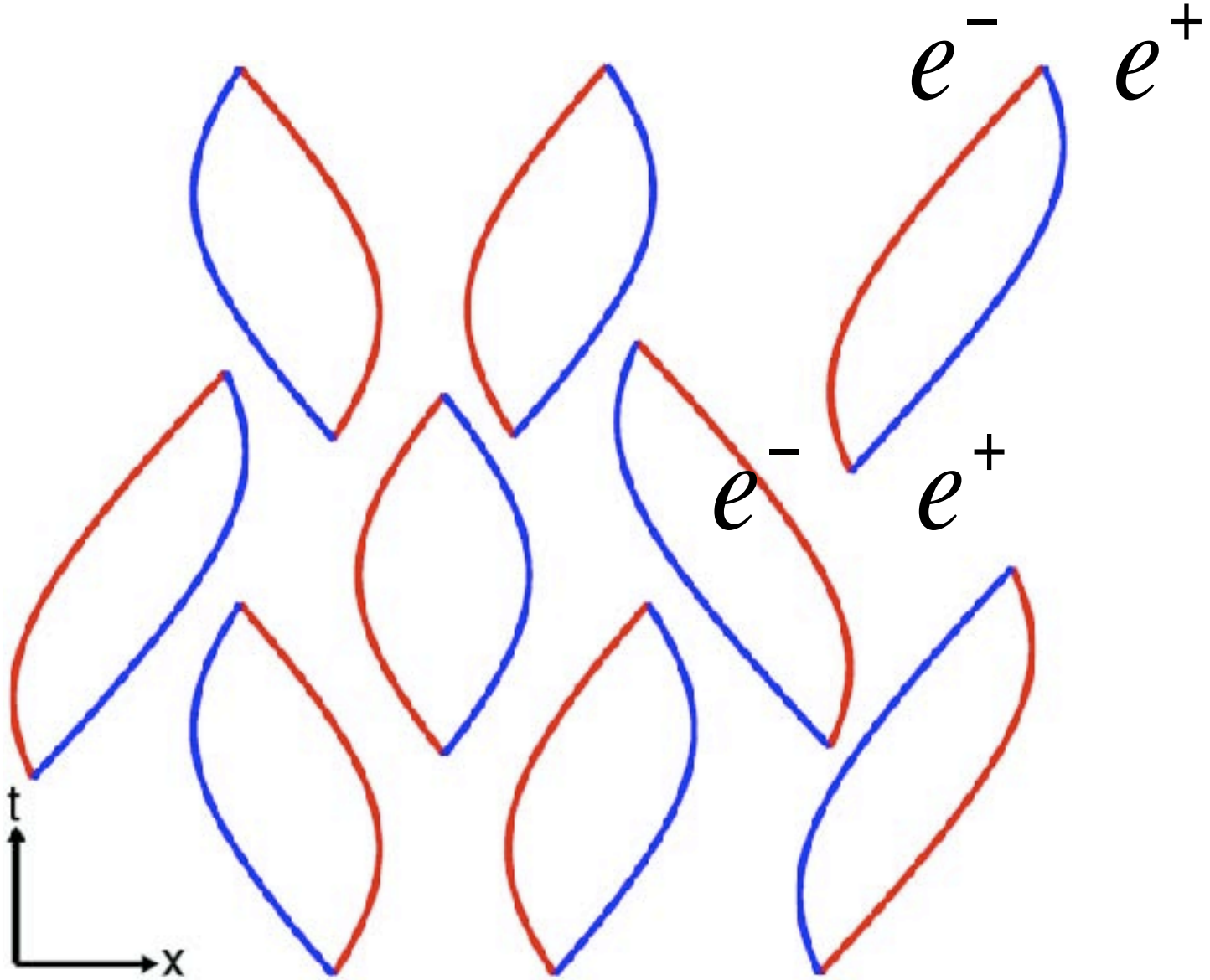
$z \leq 0.1$

El Universo se enfría como un gas en expansión

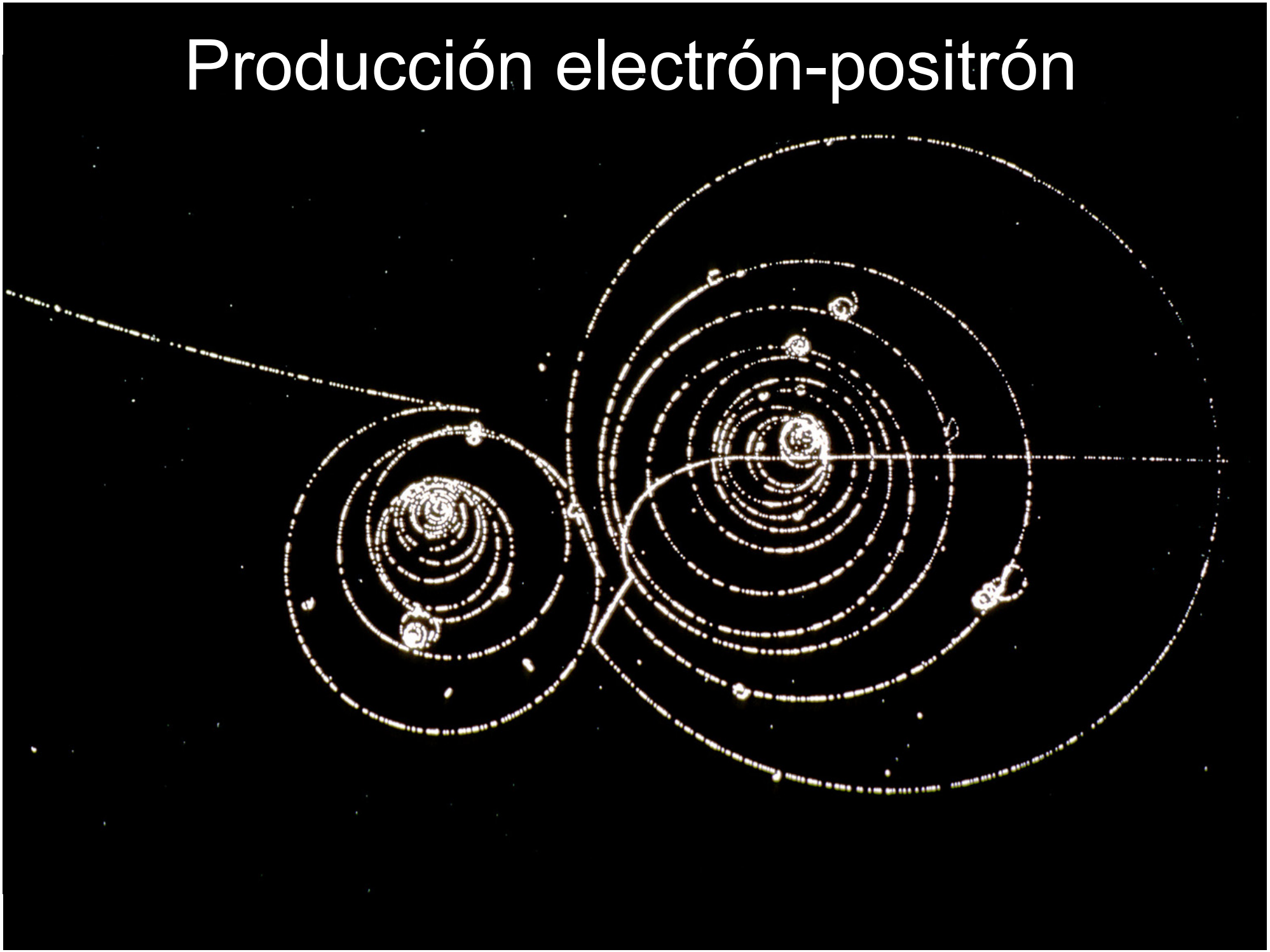

Estudiando la historia pasada
del Universo, entramos en la
era de la física atómica,
nuclear y de las altas energías,
que se estudia con los grandes
aceleradores de partículas
como el LHC del CERN

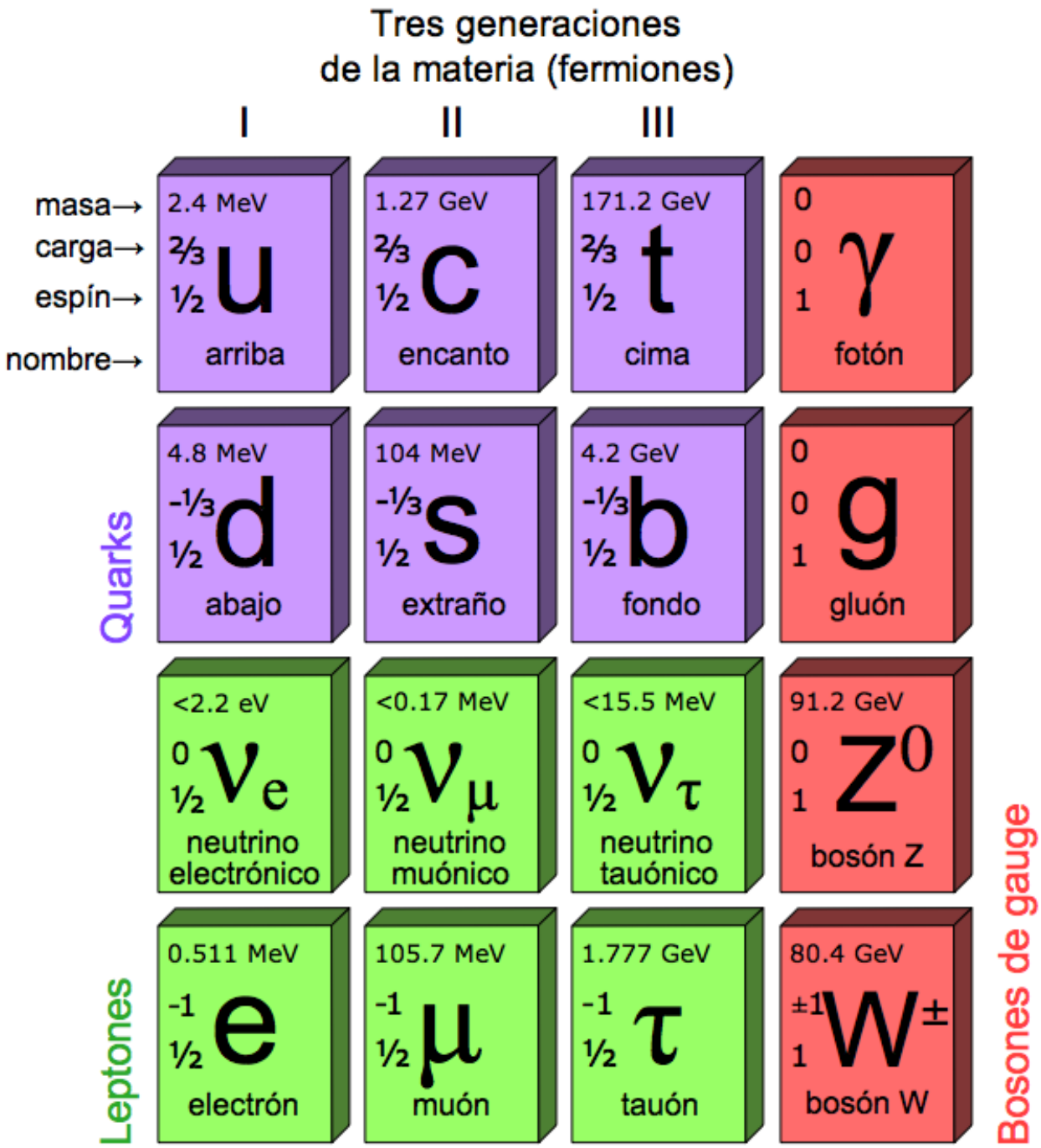

$1\,fm \cdot 200\,MeV \approx 1$

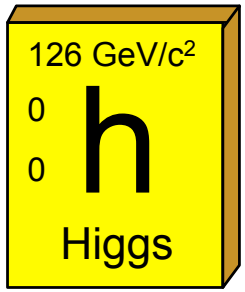
Fluctuaciones del vacío



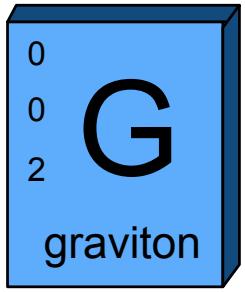
Producción electrón-positrón



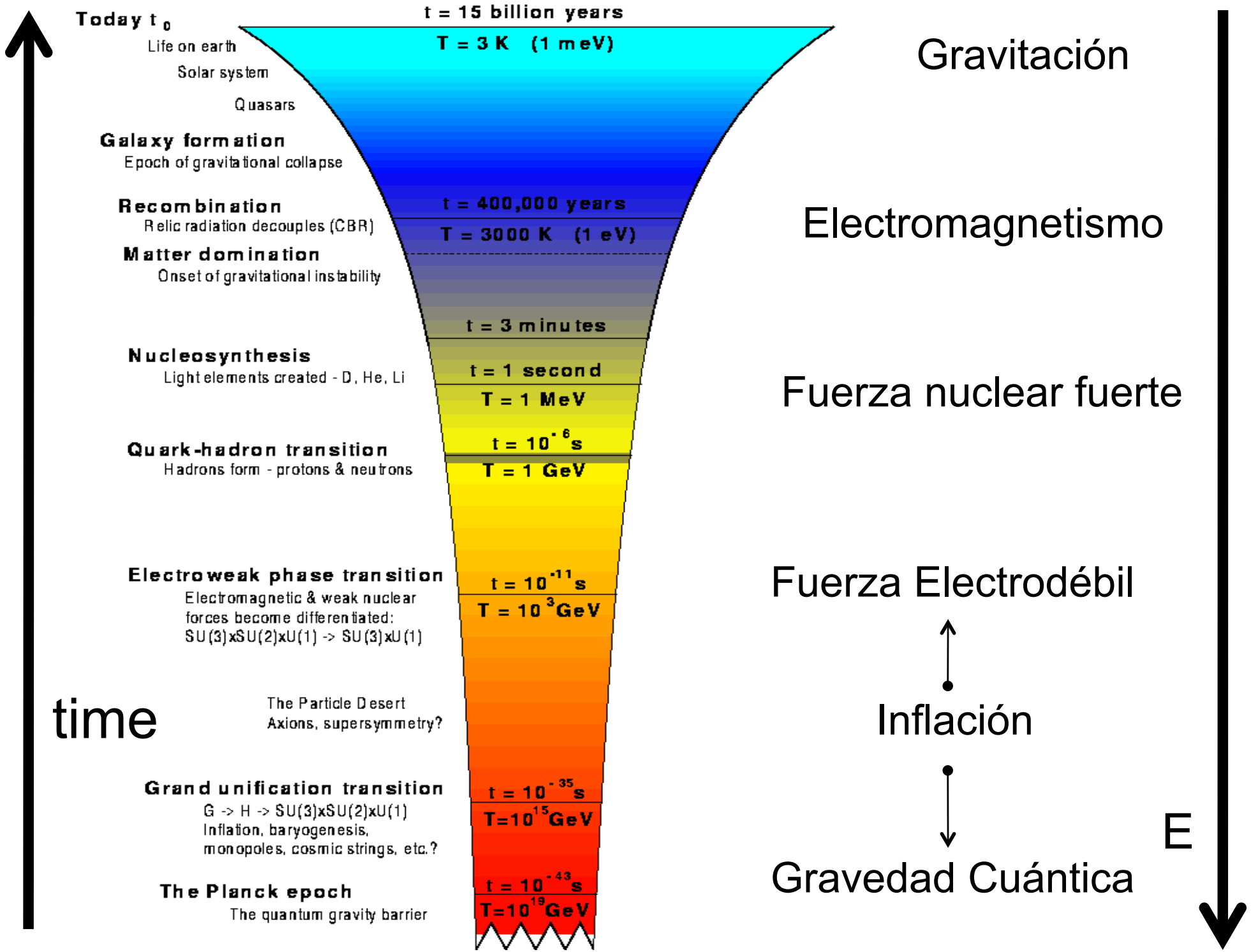




scalar

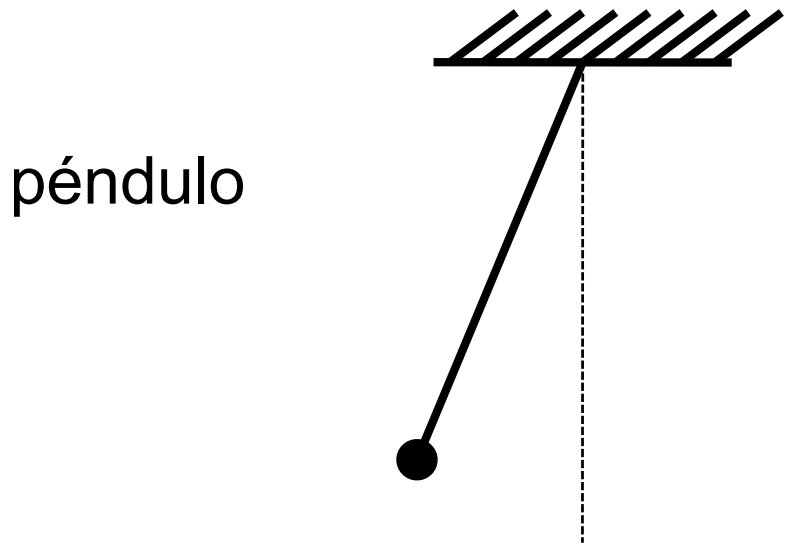


tensor


Today t_0
Life on earth
Solar system
Quasars
Galaxy formation
Epoch of gravitational collapse
Recombination
Relic radiation decouples (CBR)
Matter domination
Onset of gravitational instability
Nucleosynthesis
Light elements created - D, He, Li
Quark-hadron transition
Hadrons form - protons & neutrons
Electroweak phase transition
Electromagnetic & weak nuclear forces become differentiated:
SU(3)xSU(2)xU(1) -> SU(3)xU(1)
The Particle Desert
Axions, supersymmetry?
Grand unification transition
G -> H -> SU(3)xSU(2)xU(1)
Inflation, baryogenesis, monopoles, cosmic strings, etc.?
The Planck epoch
The quantum gravity barrier
t = 15 billion years
T = 3 K (1 meV)
t = 400,000 years
T = 3000 K (1 eV)
t = 3 minutes
t = 1 second
T = 1 MeV
$t = 10^{-6}$ s
T = 1 GeV
$t = 10^{-11}$ s
$T = 10^{3}$ GeV
$t = 10^{-35}$ s
$T=10^{15}$ GeV
$t = 10^{-43}$ s
$T=10^{19}$ GeV
time
Gravitación
Electromagnetismo
Fuerza nuclear fuerte
Fuerza Electrodébil
Inflación
Gravedad Cuántica
E

COSMOLOGY MARCHES ON

De donde sale toda la energía del Universo?



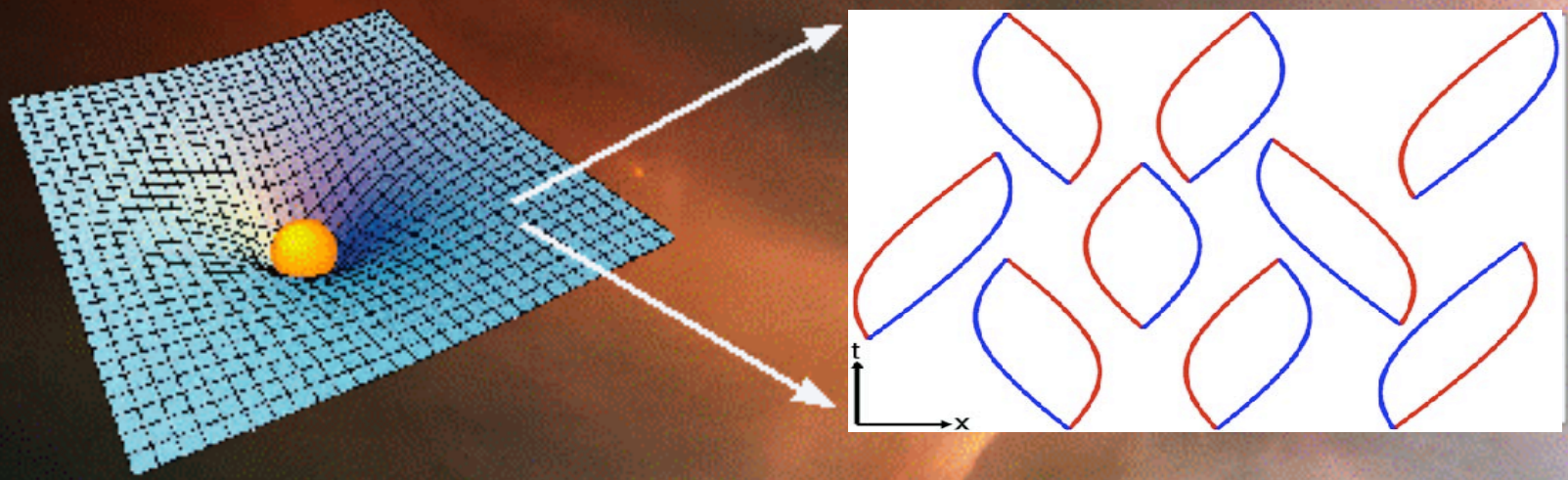
Conversión de energía potencial en energía cinética

La energía total $E=T+V$ se conserva

Inflación : $E = 0$

The universe itself could be a product of quantum uncertainty.

"empty space" is a sea of virtual particles winking in and out of existence:



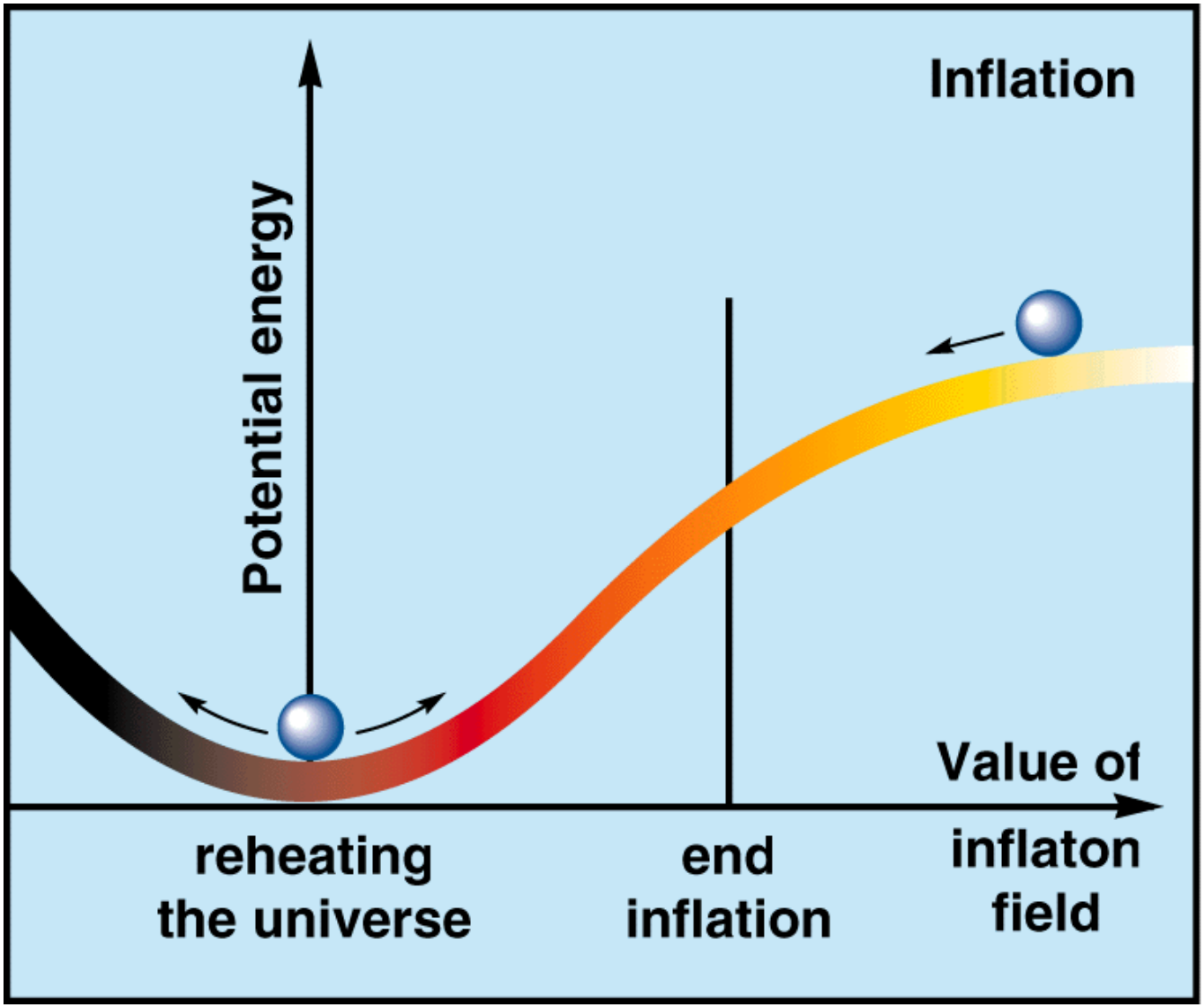
Inflación

El Universo podría ser el resultado de una fluctuación cuántica

Alan Guth

Andrei Linde

Una pequeña burbuja de vacío cuántico se expande rápidamente hasta ocupar todo el Universo

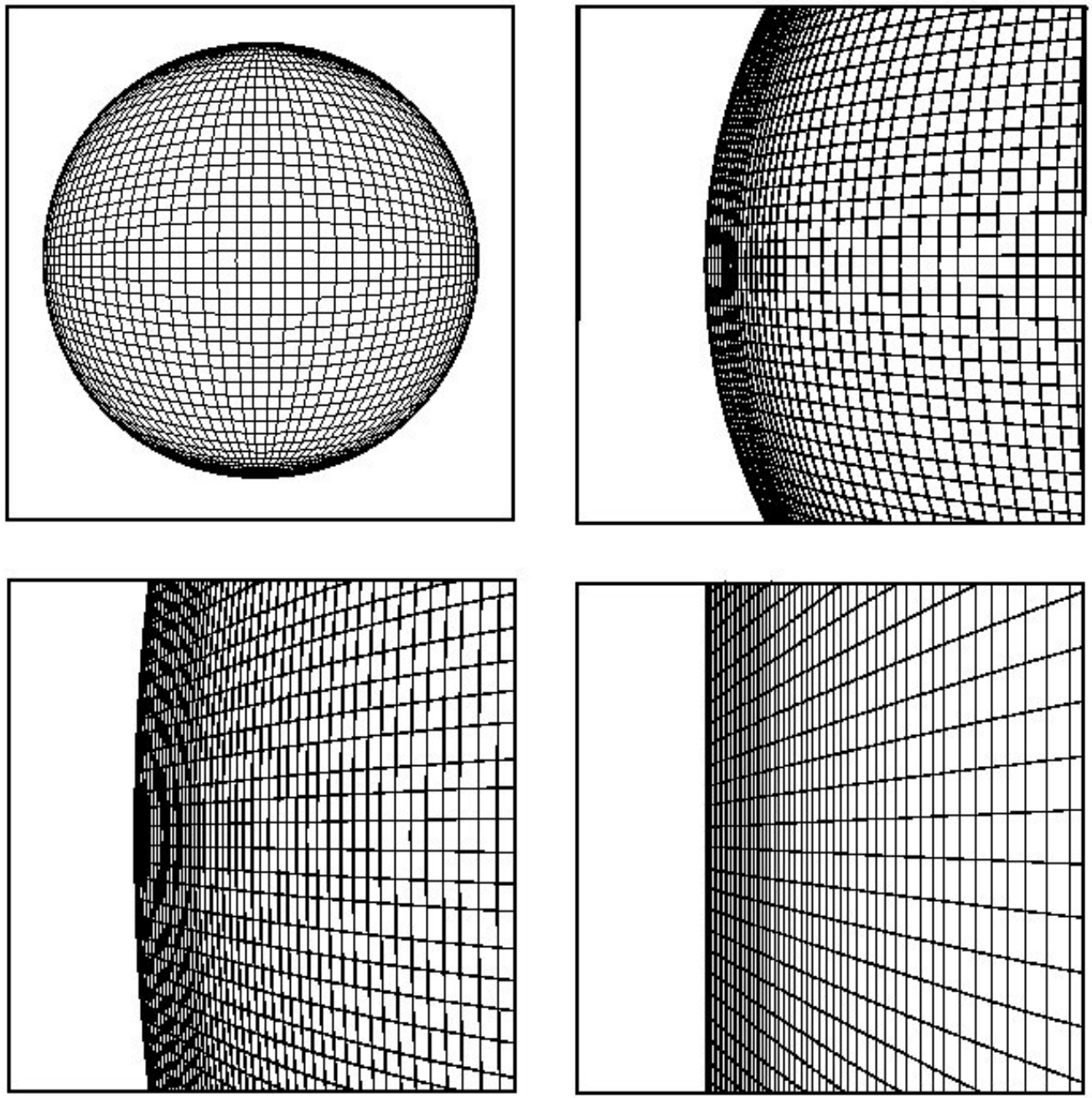


Densidad constante

GR

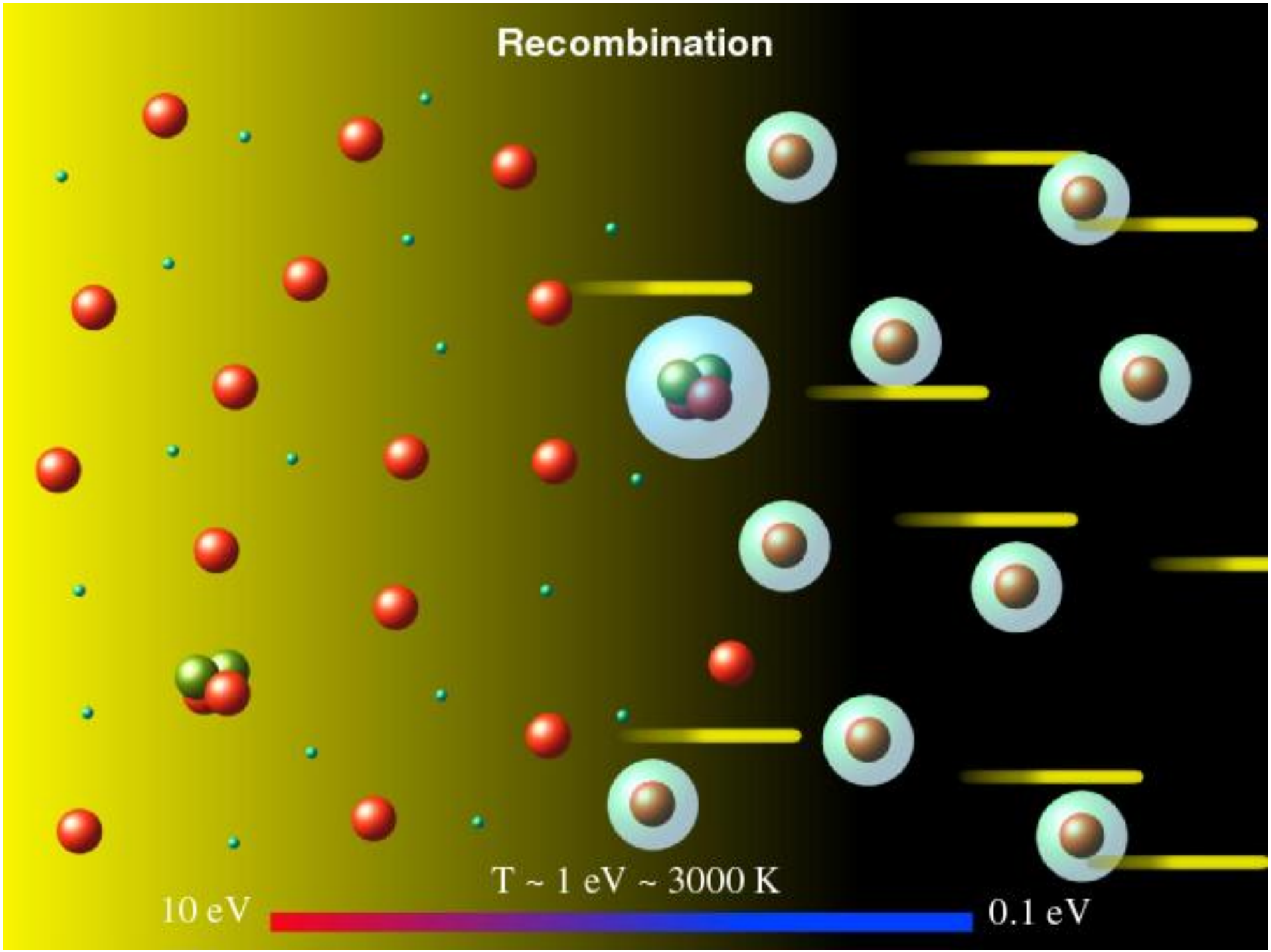
Crecimiento exponential

Secciones espaciales planas y homogéneas



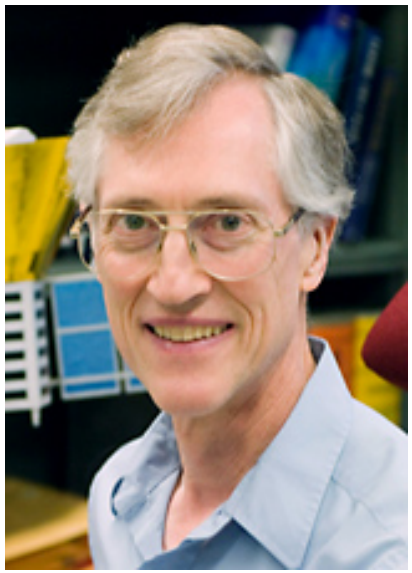
Consecuencias de Inflación

Fondo de Radiación de Microondas

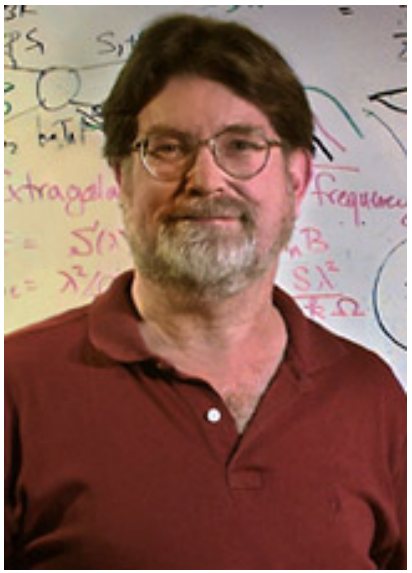

Recombination
T ~ 1 eV ~ 3000 K
10 eV
0.1 eV

The Nobel Prize in Physics 2006

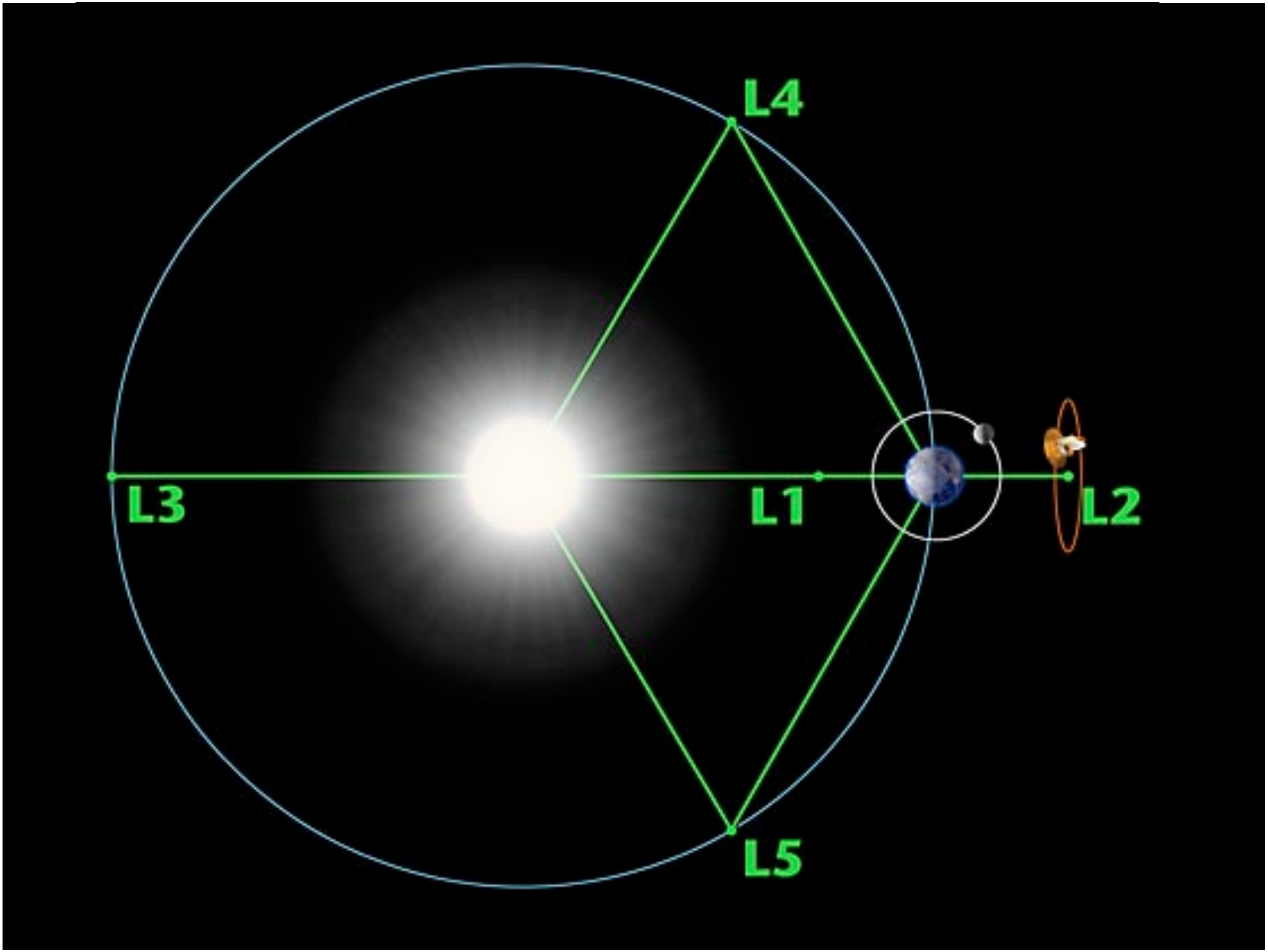
"for their discovery of the blackbody form and anisotropy of the cosmic microwave background radiation"

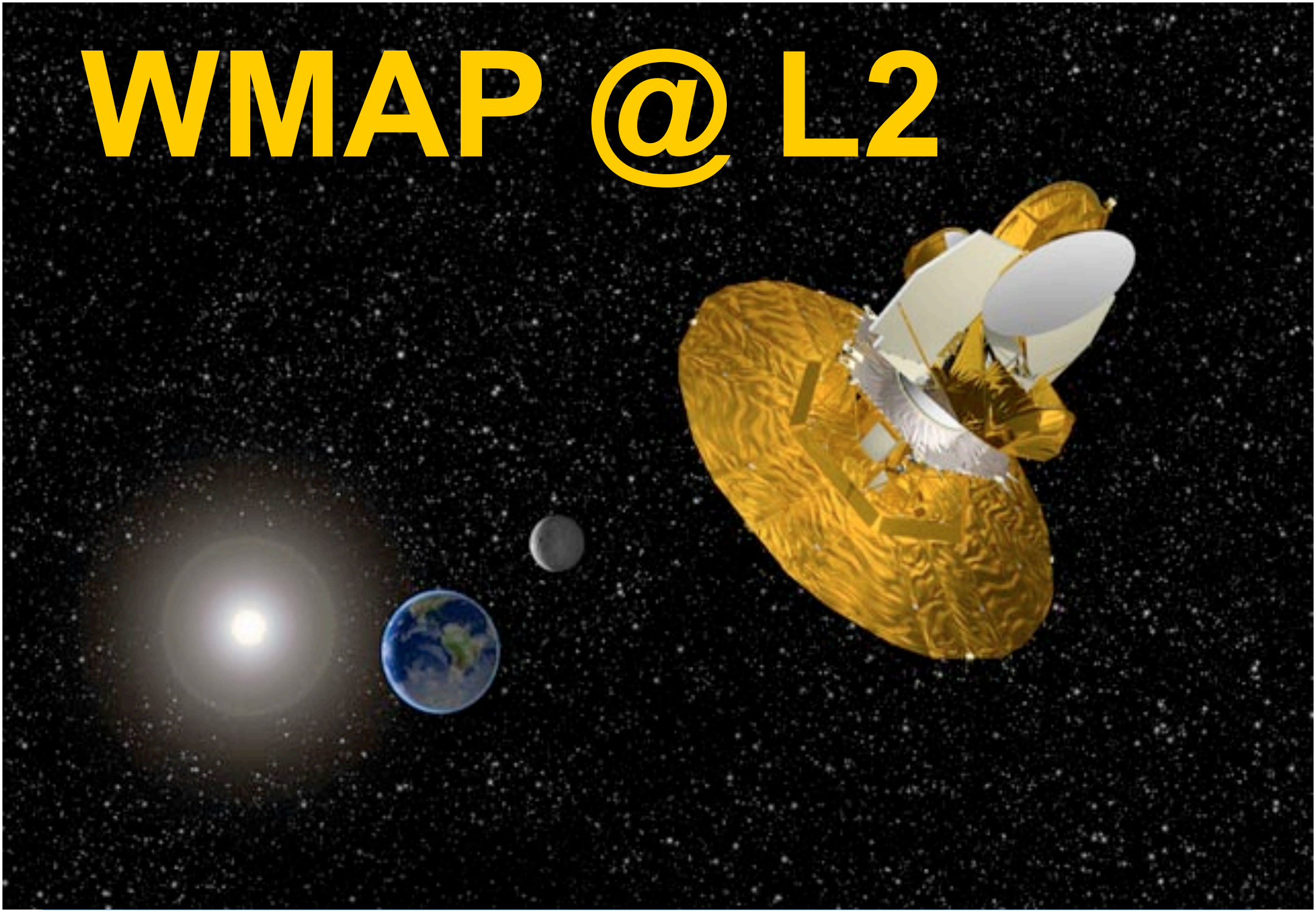


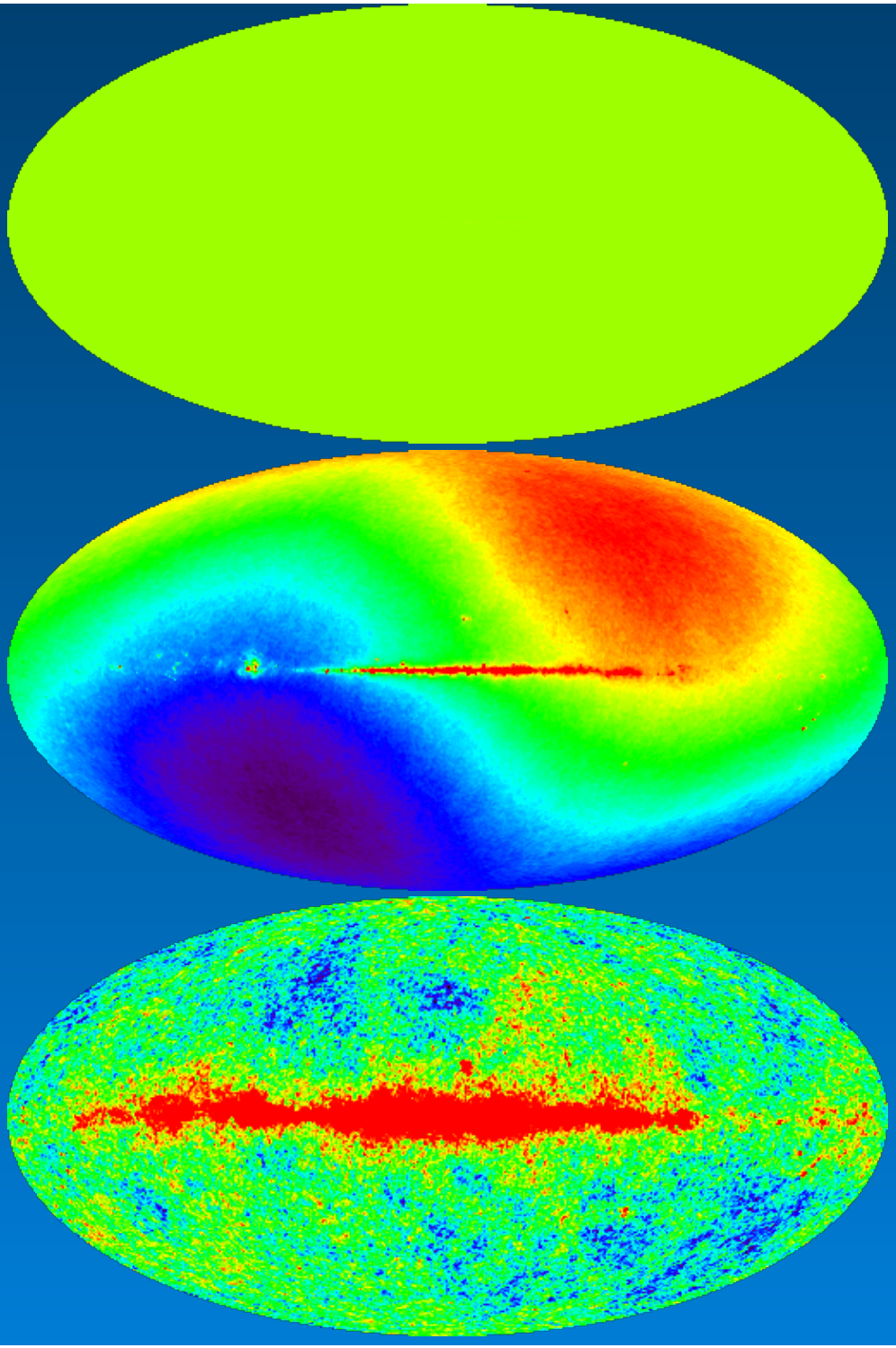
John C. Mather



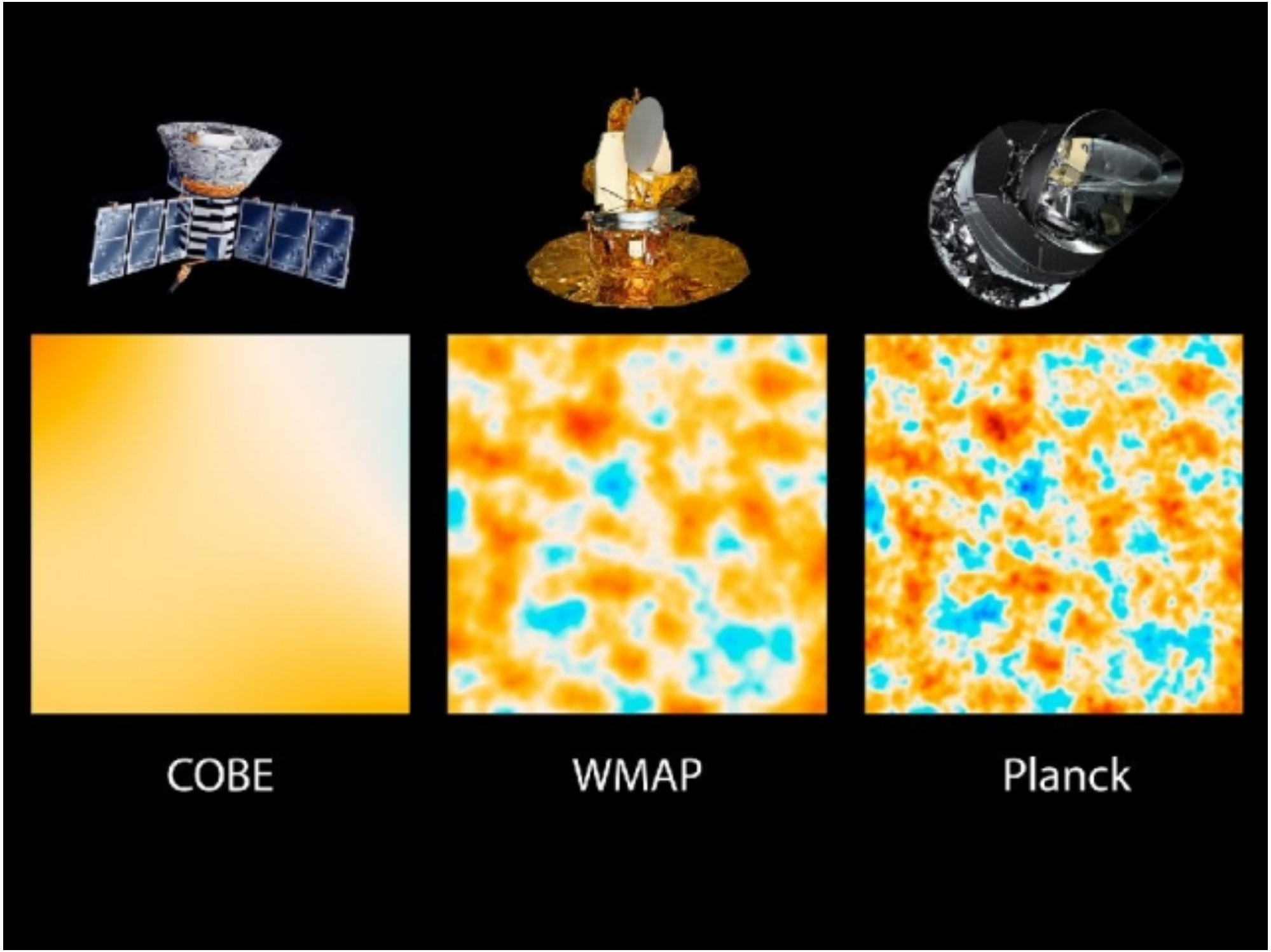
George F. Smoot

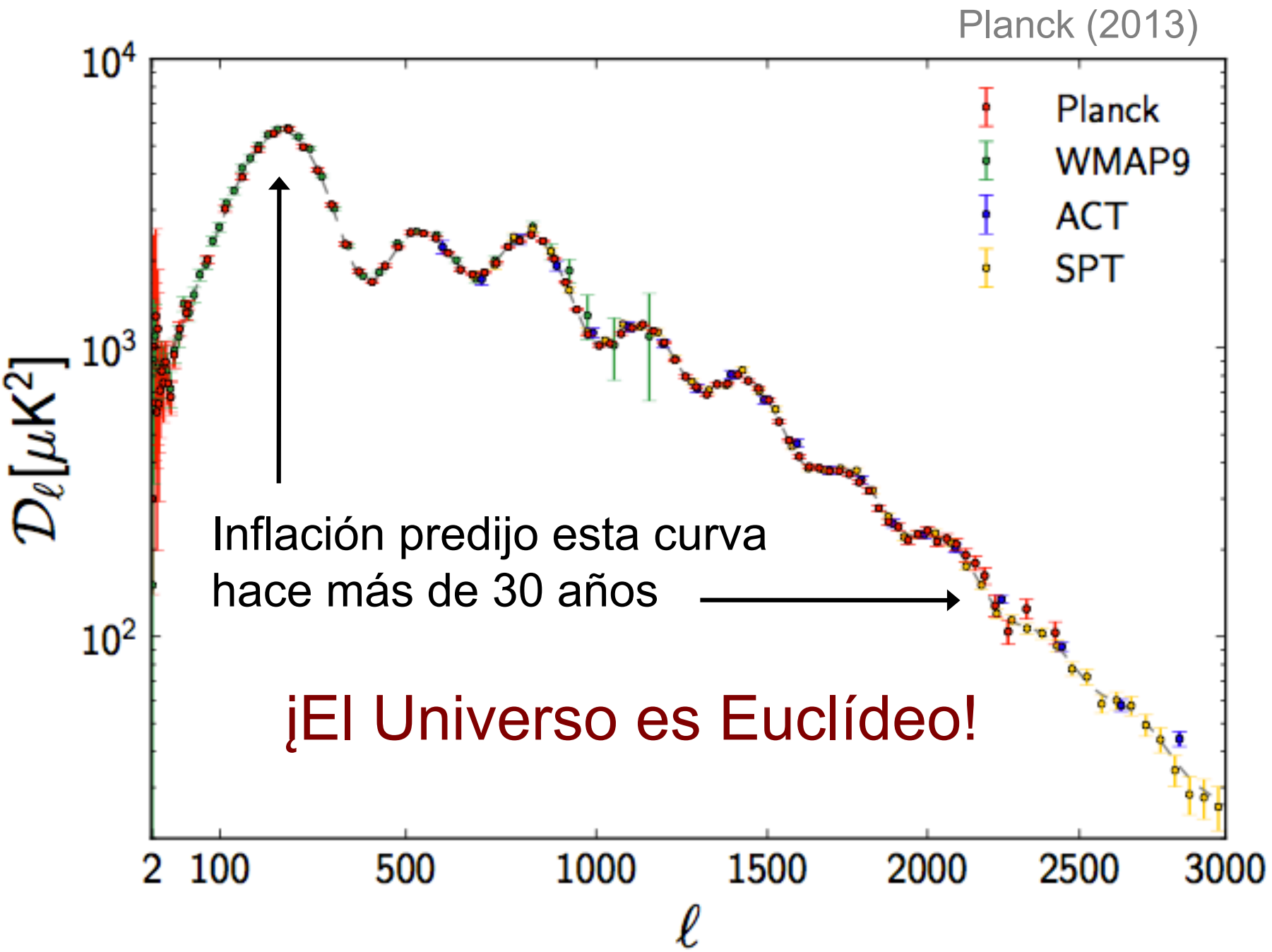

L4
L3
L1
L2
L5


WMAP @ L2

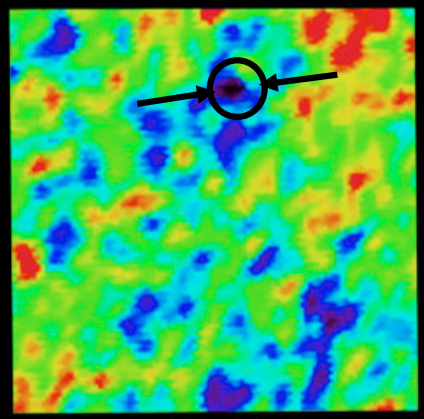


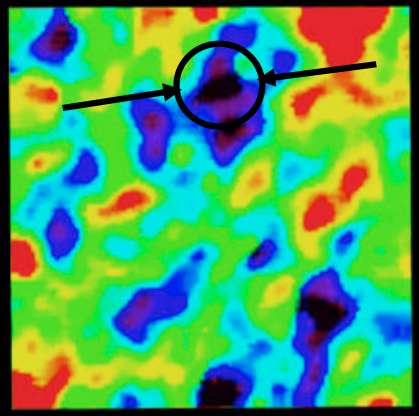
Wilkinson Microwave Anisotropy Probe (2003)

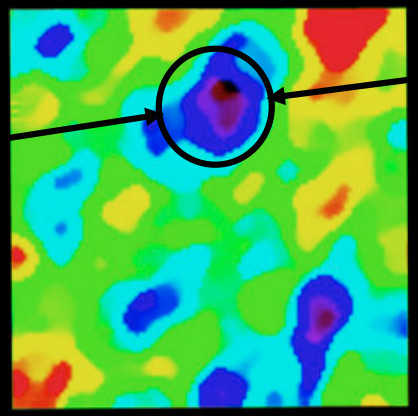

COBE
WMAP
Planck

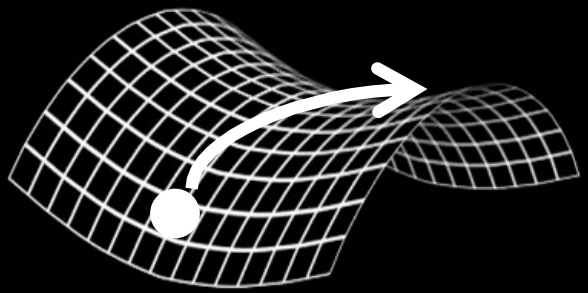

Planck (2013)
10^4
10^3
10^2
$\mathcal{D}_\ell[\mu K^2]$
Planck
WMAP9
ACT
SPT
Inflación predijo esta curva
hace más de 30 años
¡El Universo es Euclídeo!
2
100
500
1000
1500
2000
2500
3000
ℓ

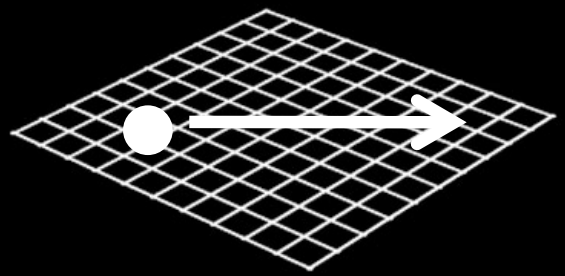
GEOMETRY OF THE UNIVERSE

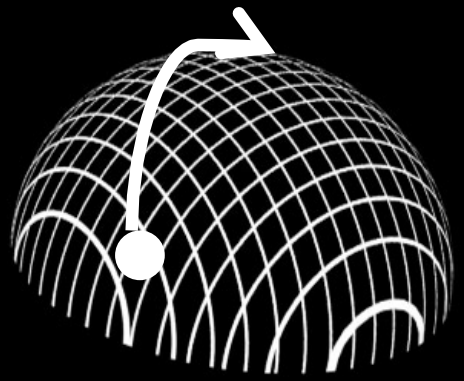










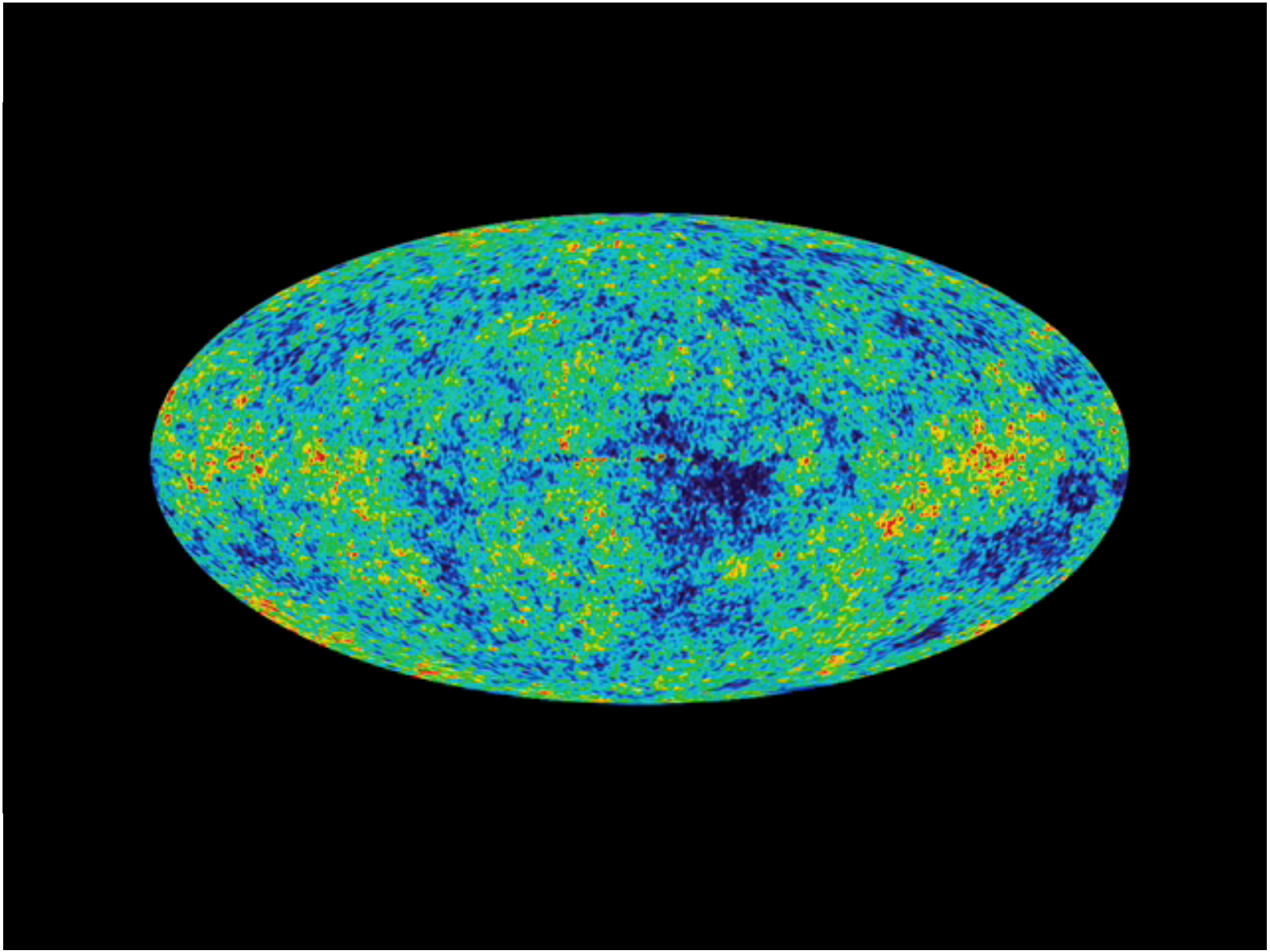


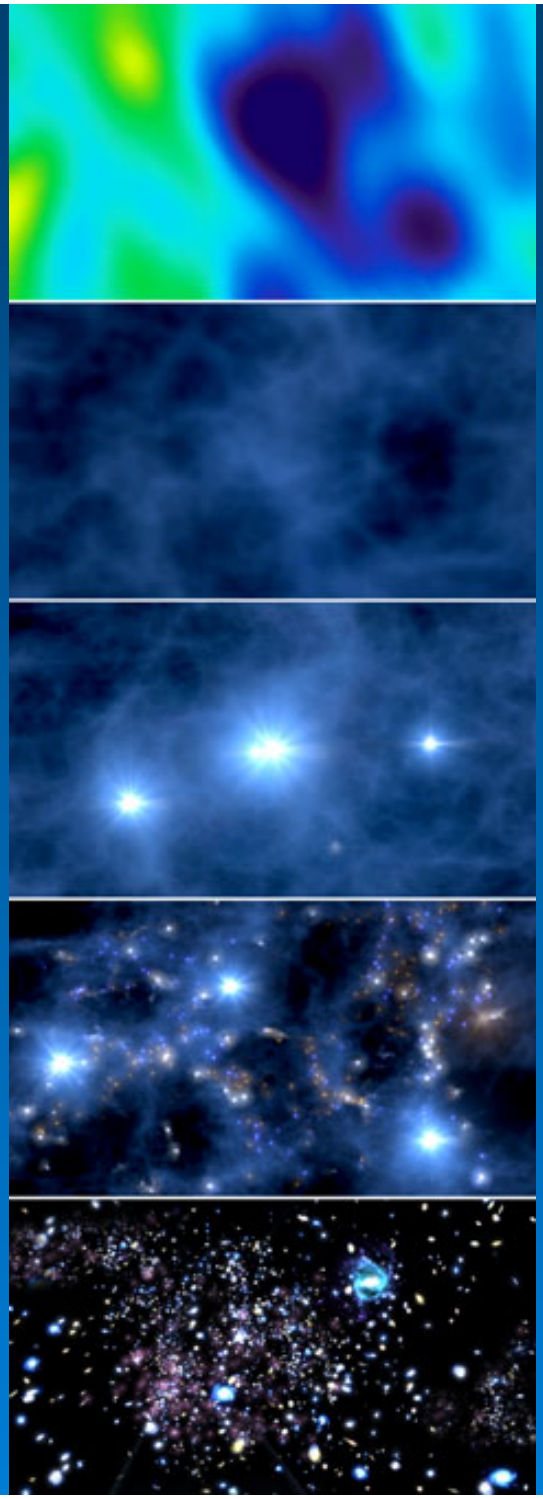
OPEN

FLAT

CLOSED

Formación de Estructura a Gran Escala





$z \approx 1100$ Anisotropías CMB

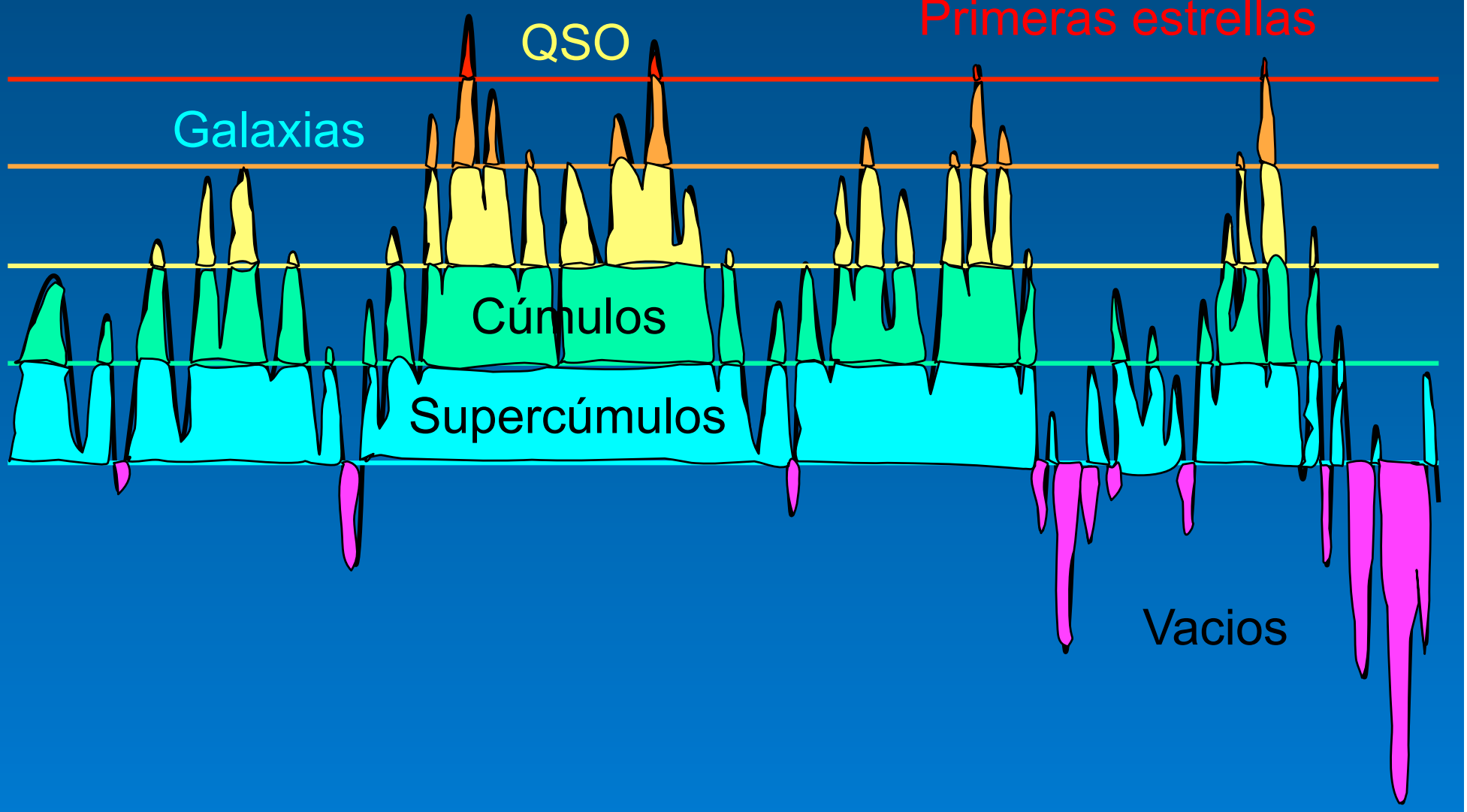
$z \approx 100$ Epoca oscura

$z \approx 20$ Primeras estrellas

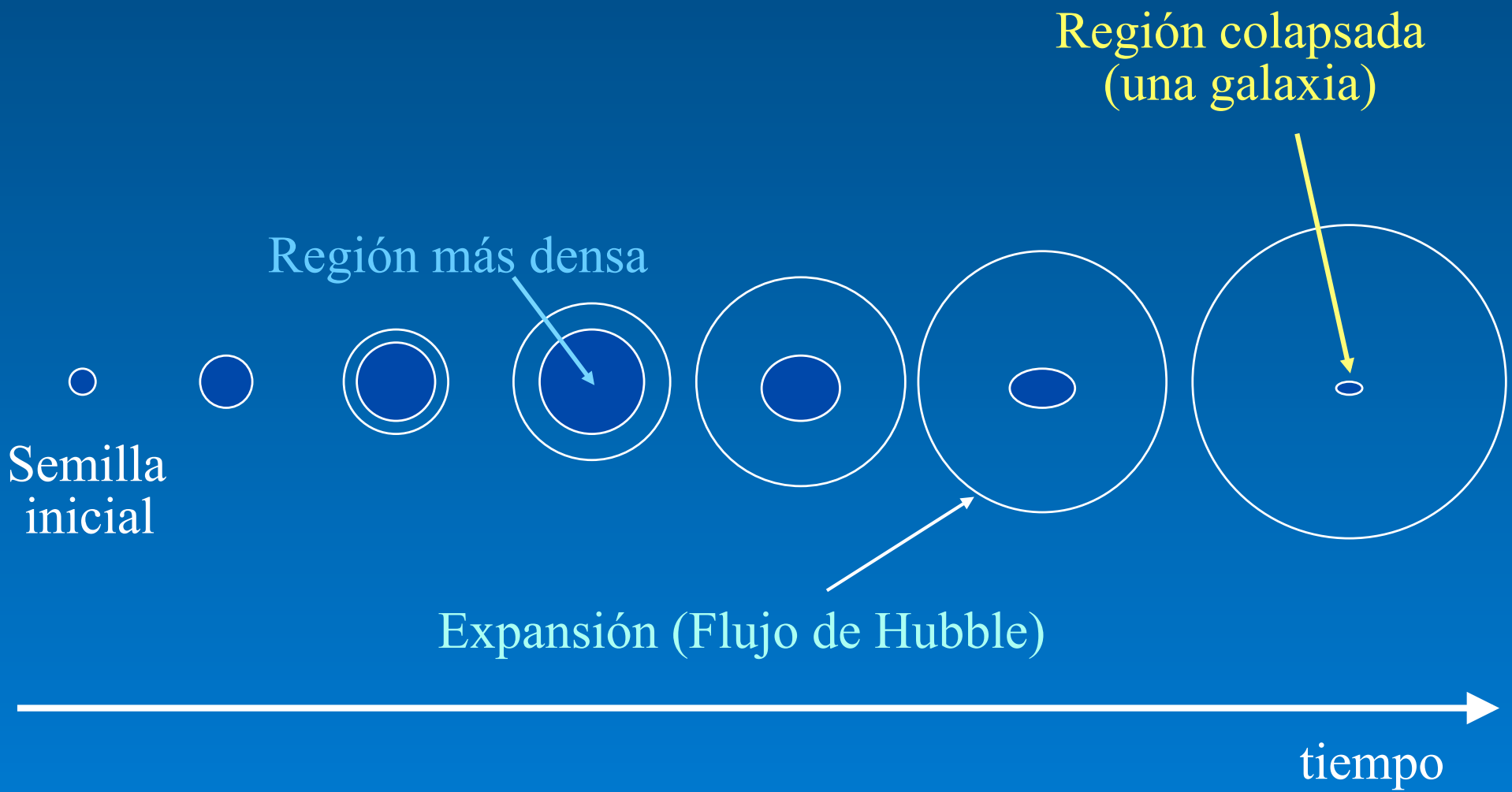
$z \approx 10$ Galaxias & Quásares

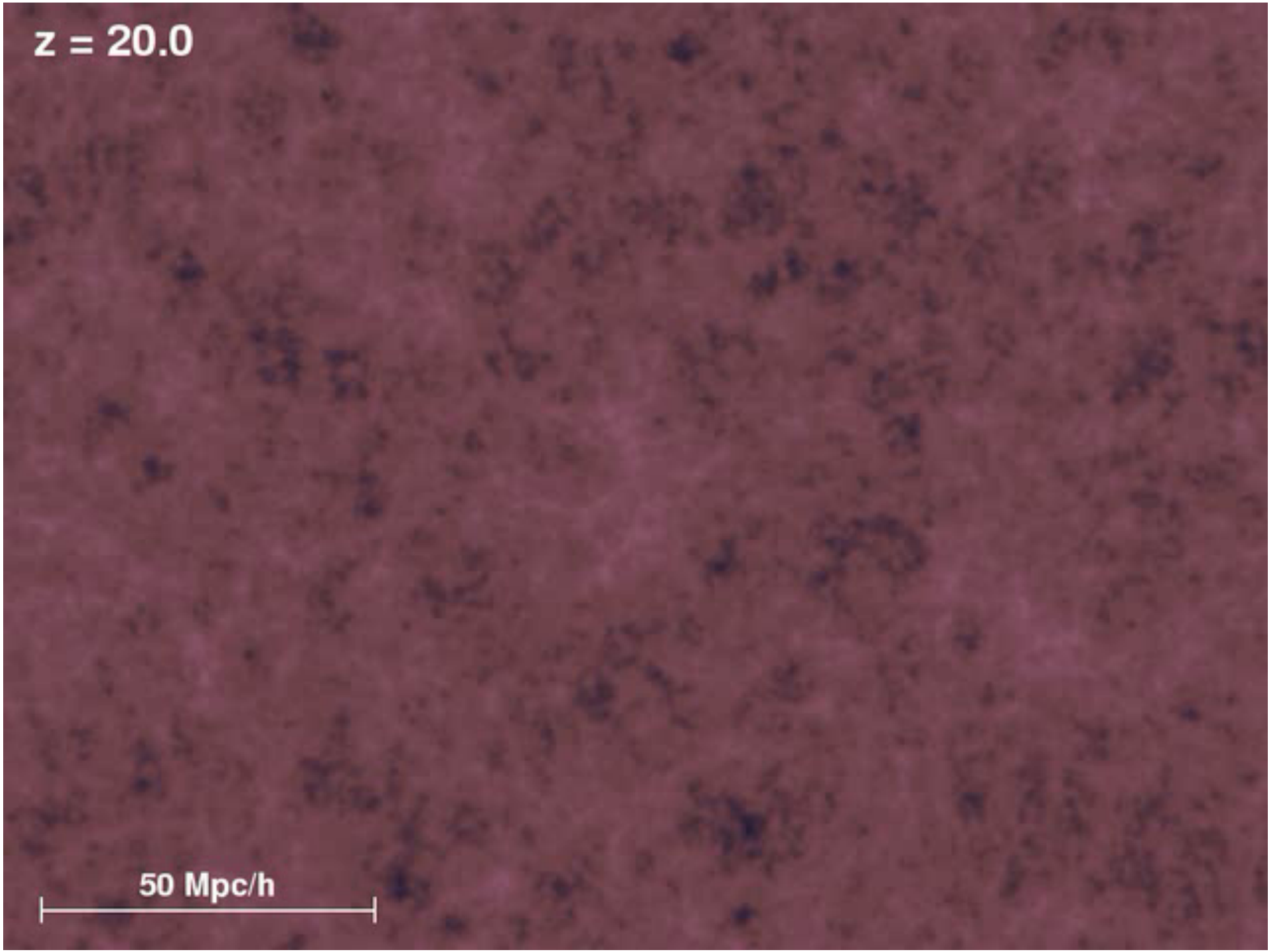
$z \approx 1$ Cúmulos & Supercúmulos

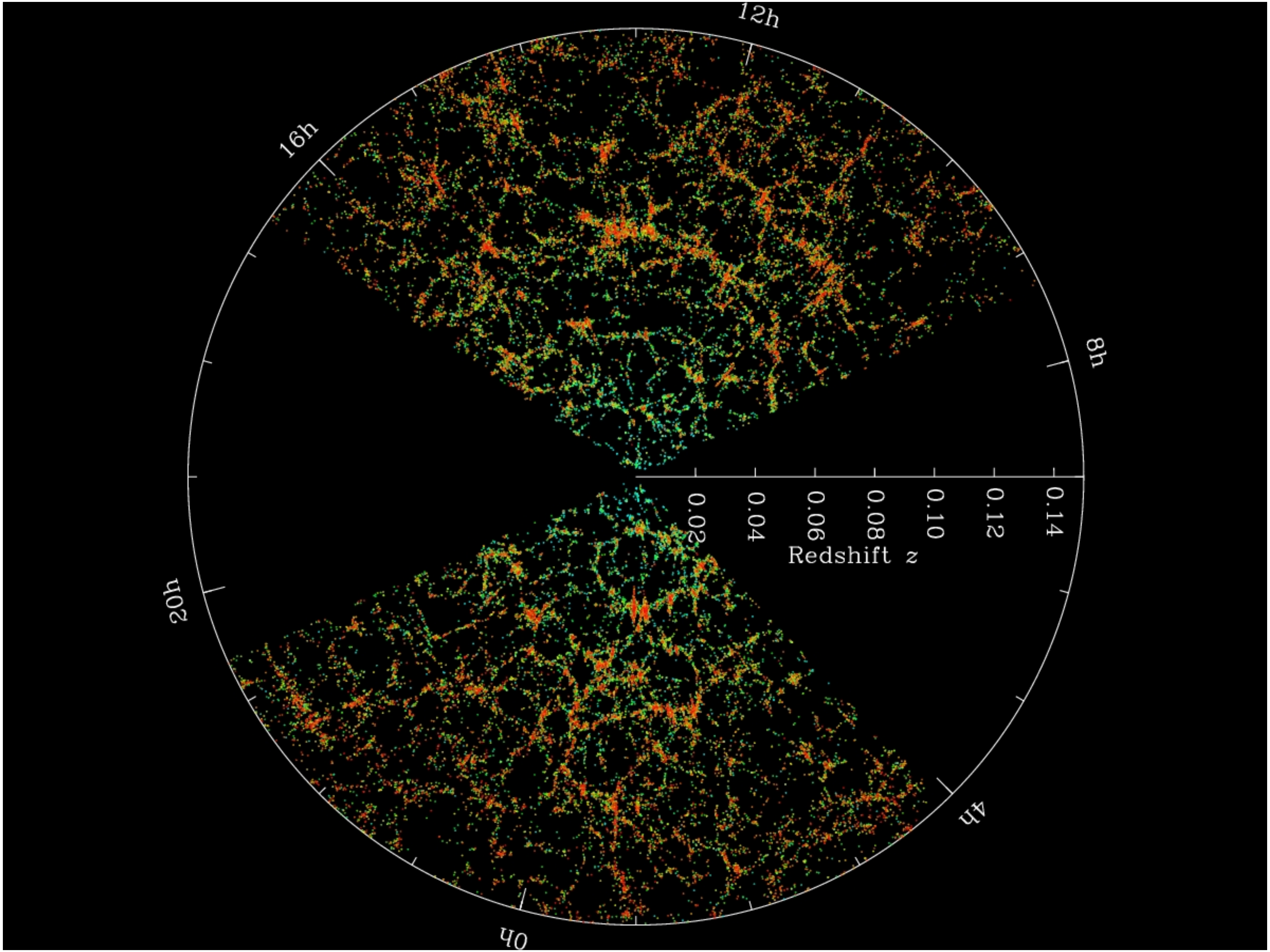
Umbrales de contraste de densidad

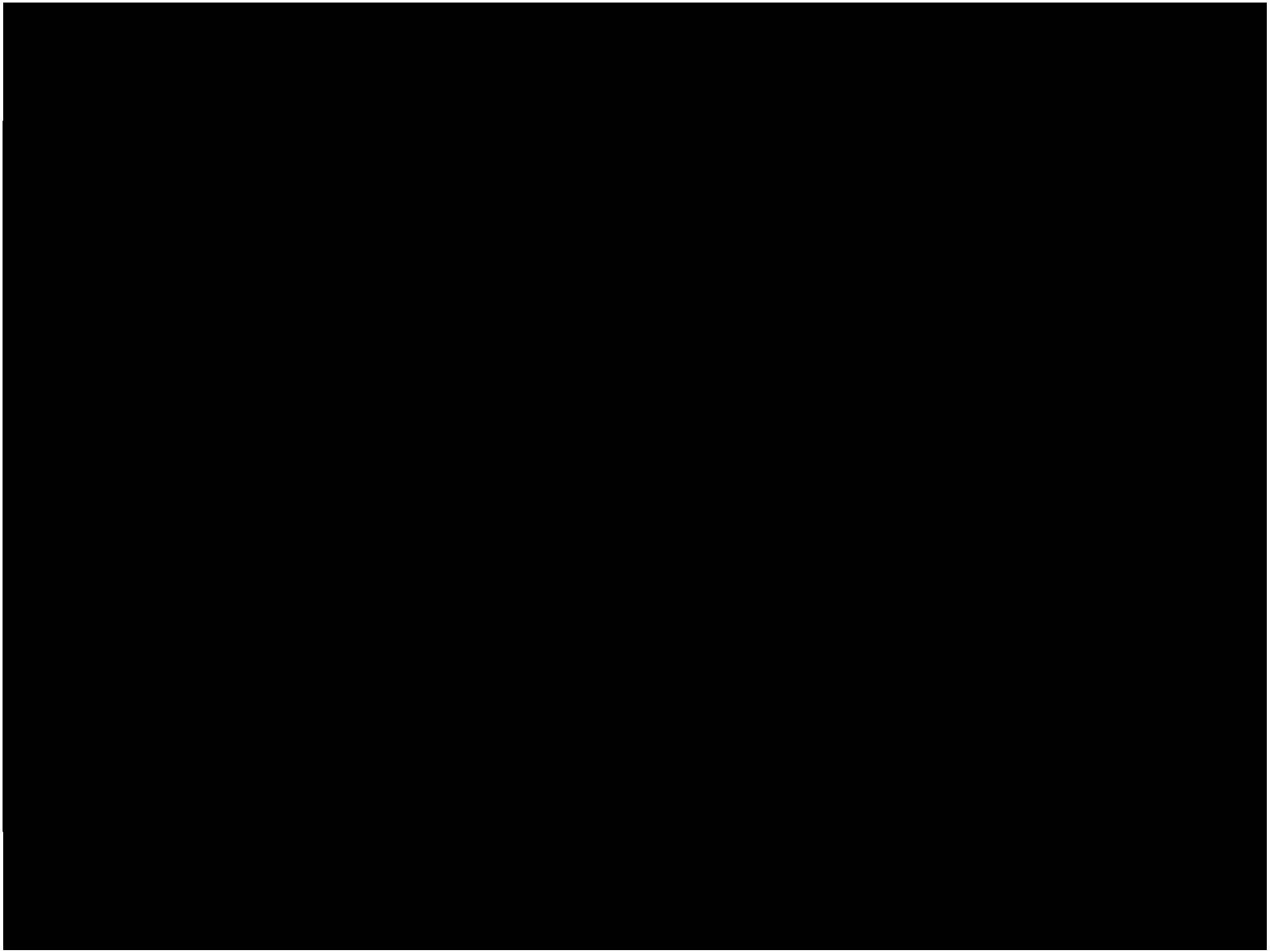


Colapso Gravitacional




z = 20.0
50 Mpc/h


12h
16h
8h
20h
4h
0h
0.02
0.04
0.06
0.08
0.10
0.12
0.14
Redshift z



El Universo acelerado: Energía Oscura

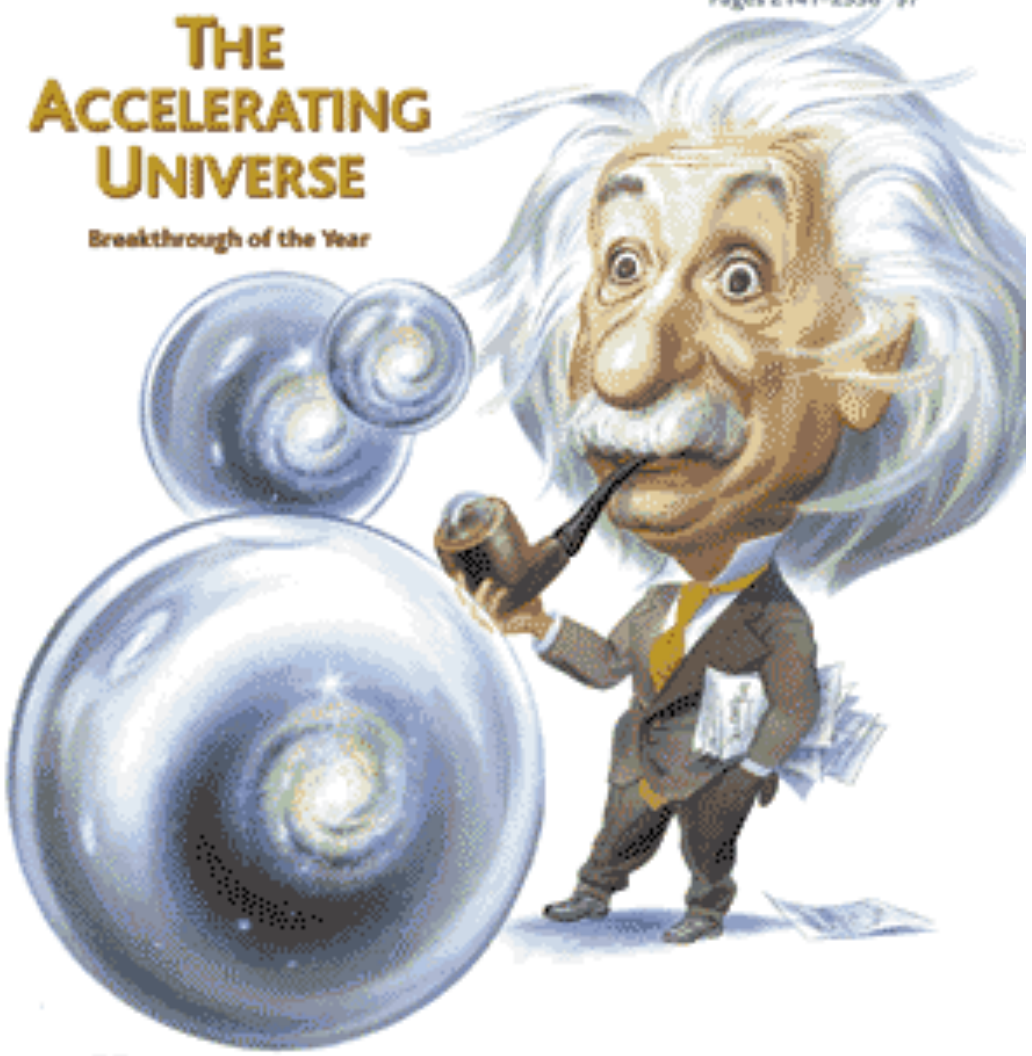
18 December 1998

Science

Vol. 282 No. 5397
Pages 2141–2336 $7

THE ACCELERATING UNIVERSE

Breakthrough of the Year



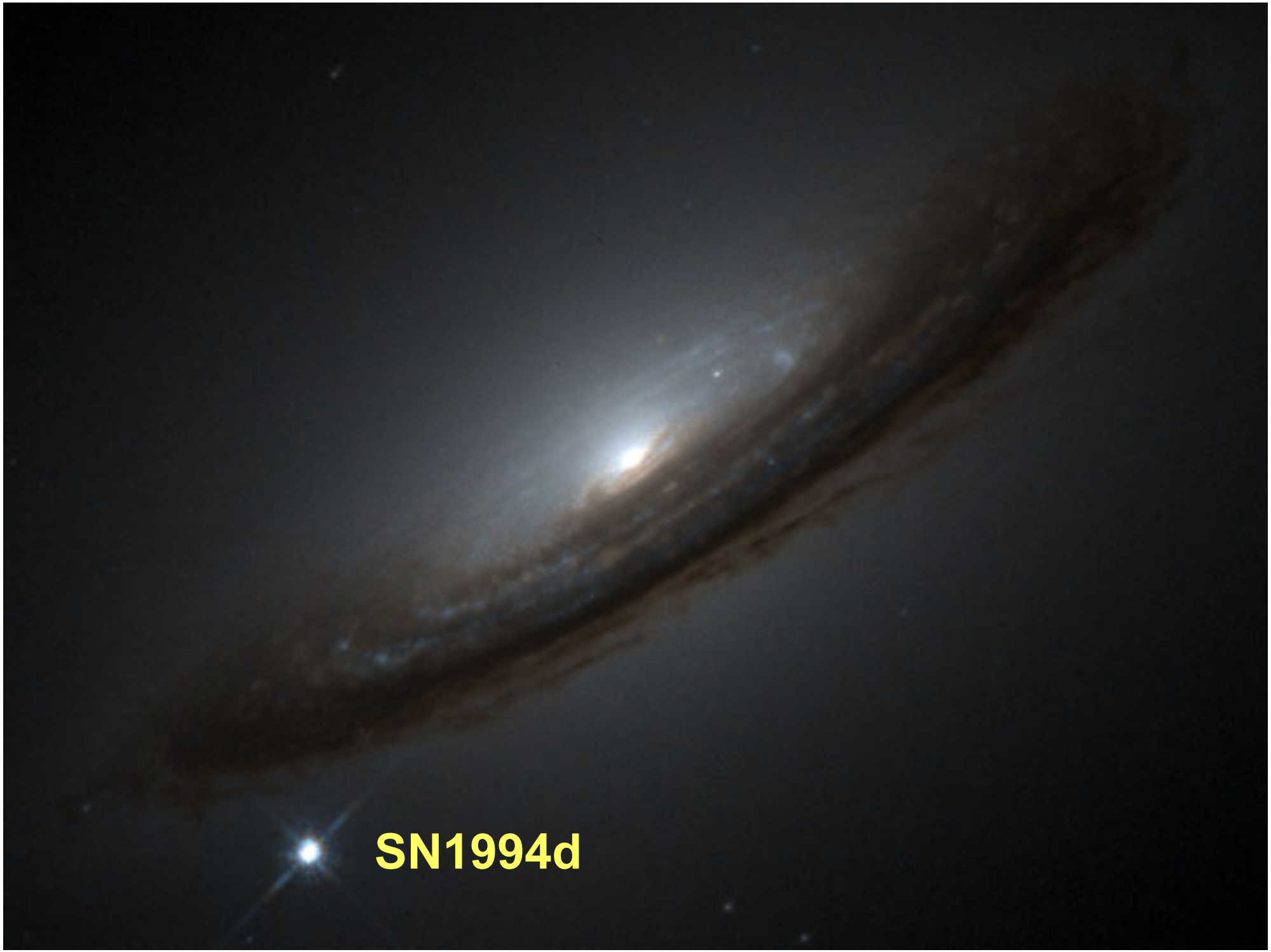
AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

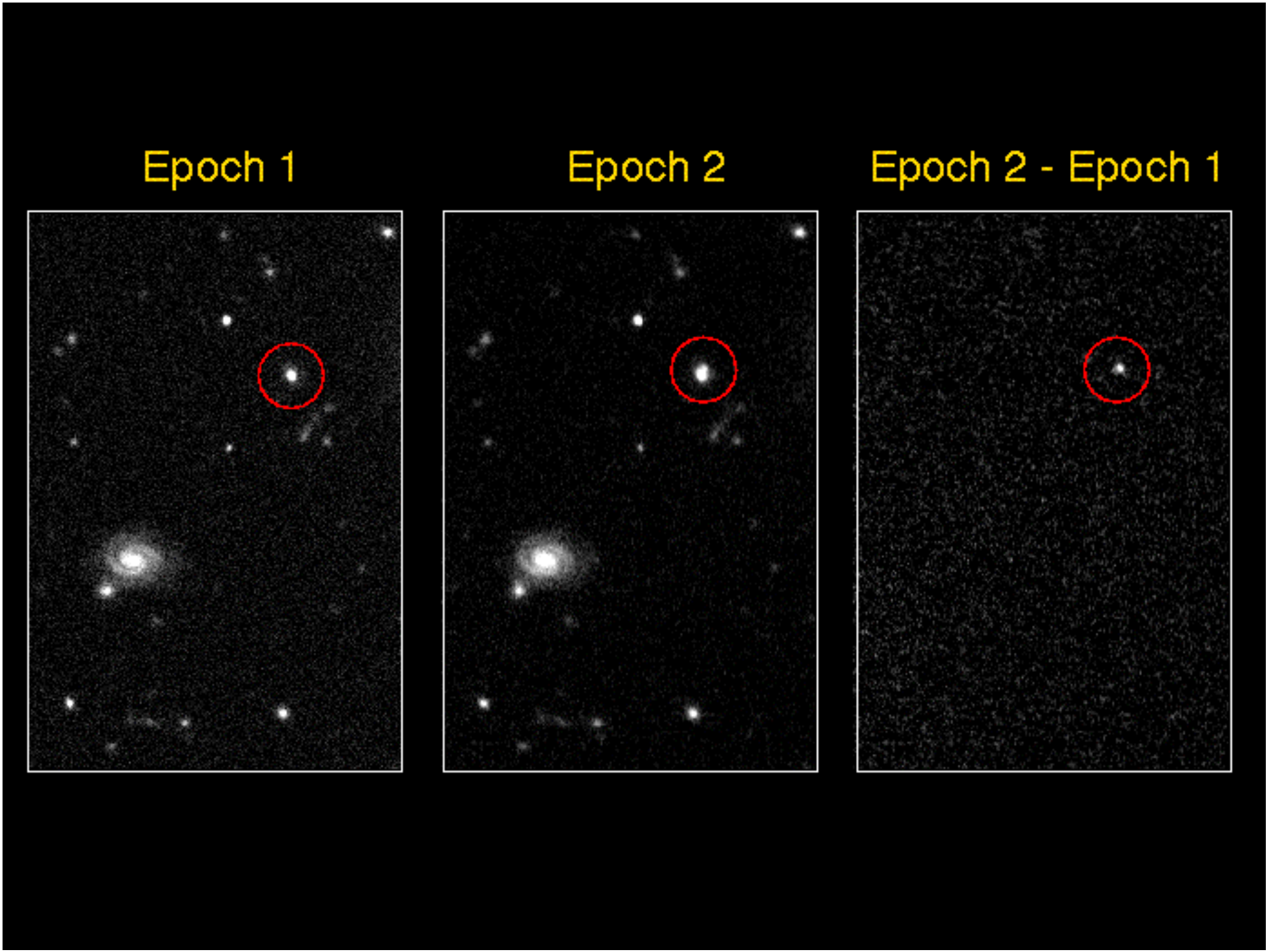
The Nobel Prize in Physics 2011

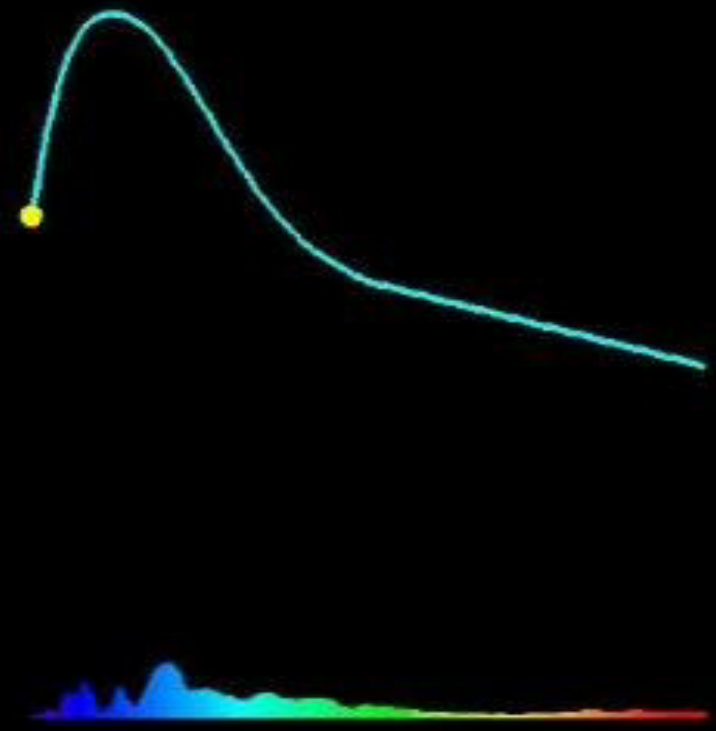
"for the discovery of the accelerating expansion of the Universe through observations of distant supernovae"



Saul Perlmutter Brian P. Schmidt Adam G. Riess


SN1994d

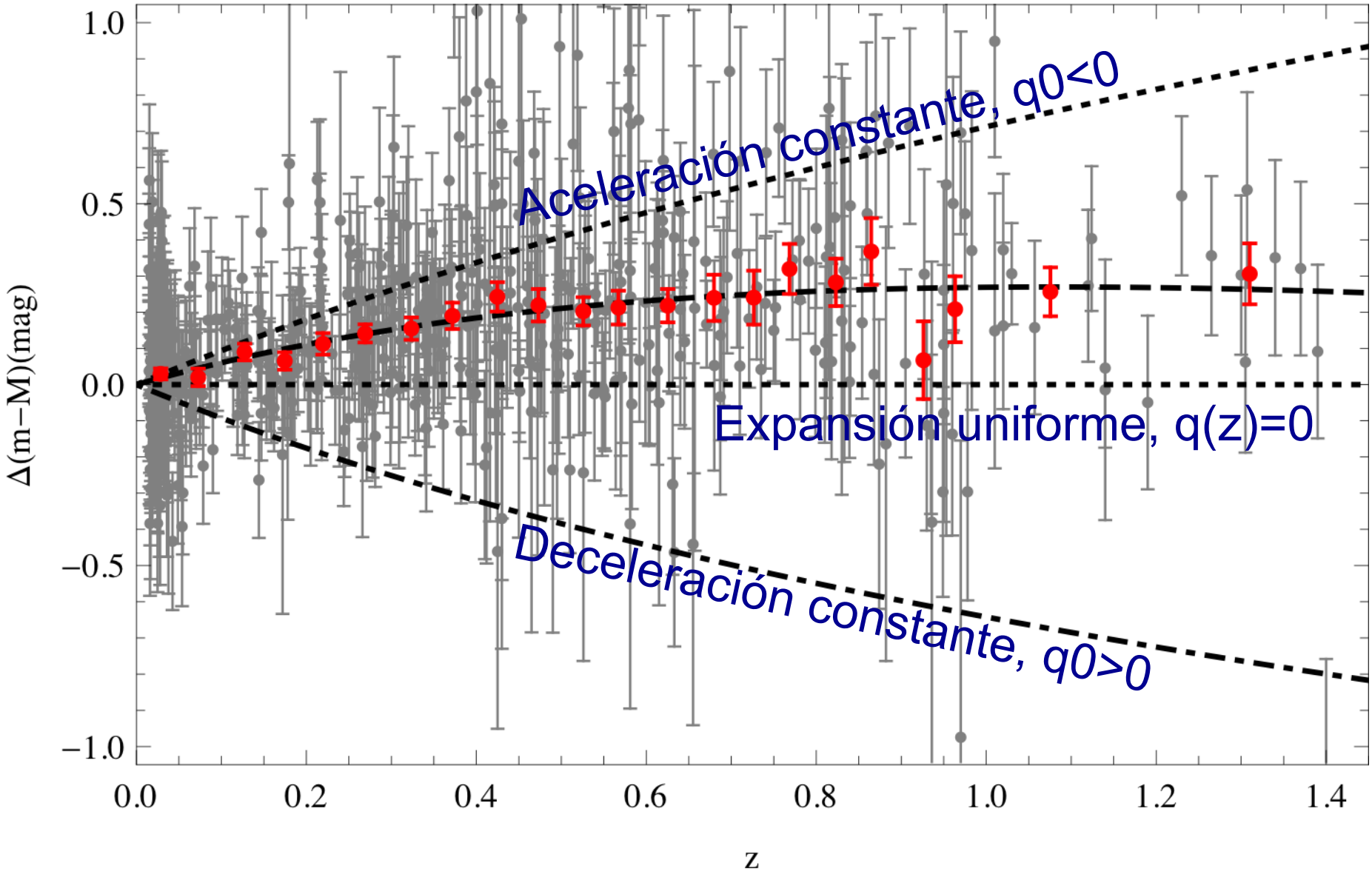

Epoch 1
Epoch 2
Epoch 2 - Epoch 1

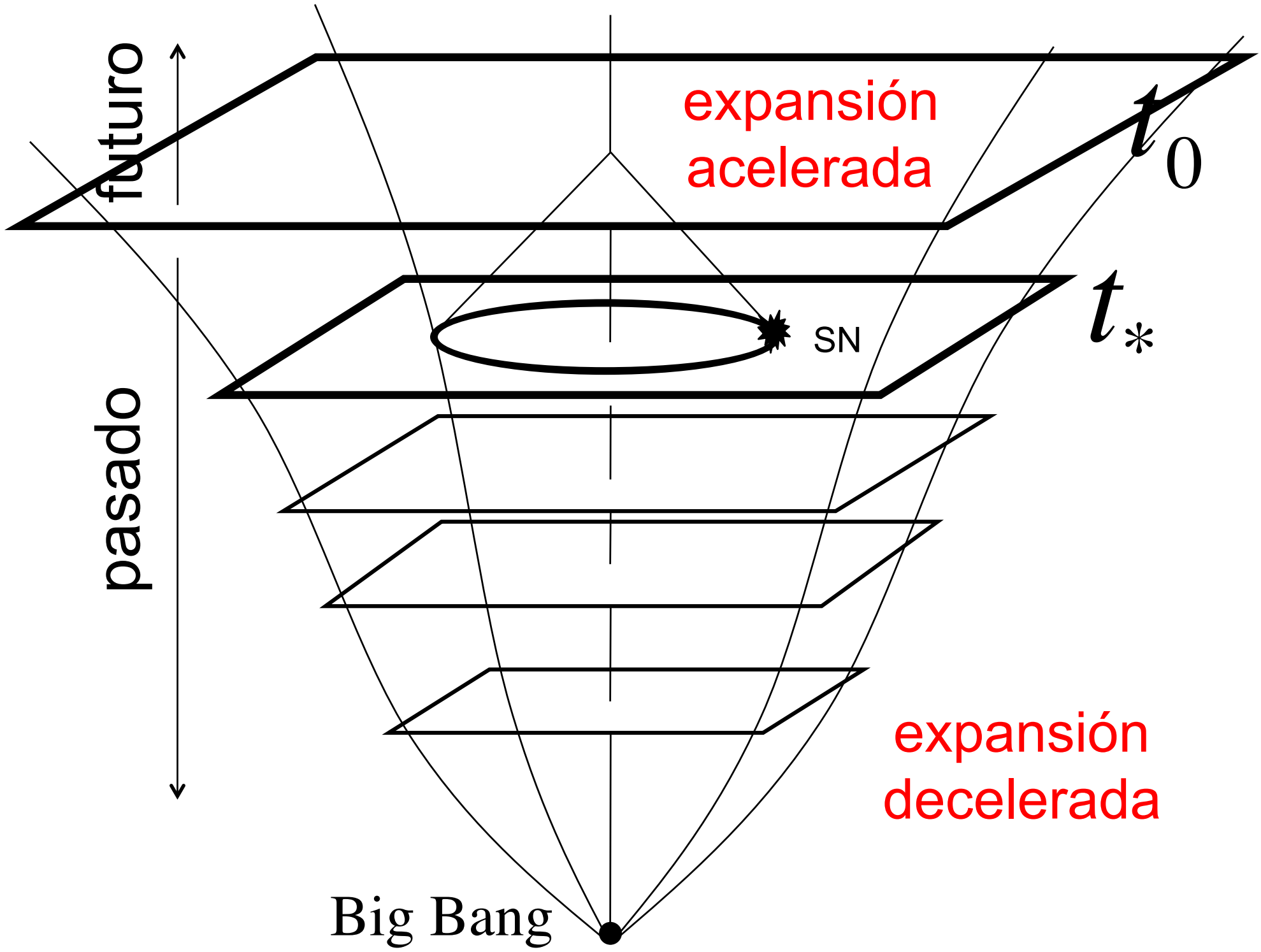


Hubble Space Telescope

Union-2 SNe Ia

Amanullah et al. (2012)




futuro
pasado
expansión
acelerada
t_0
t_*
SN
expansión
decelerada
Big Bang

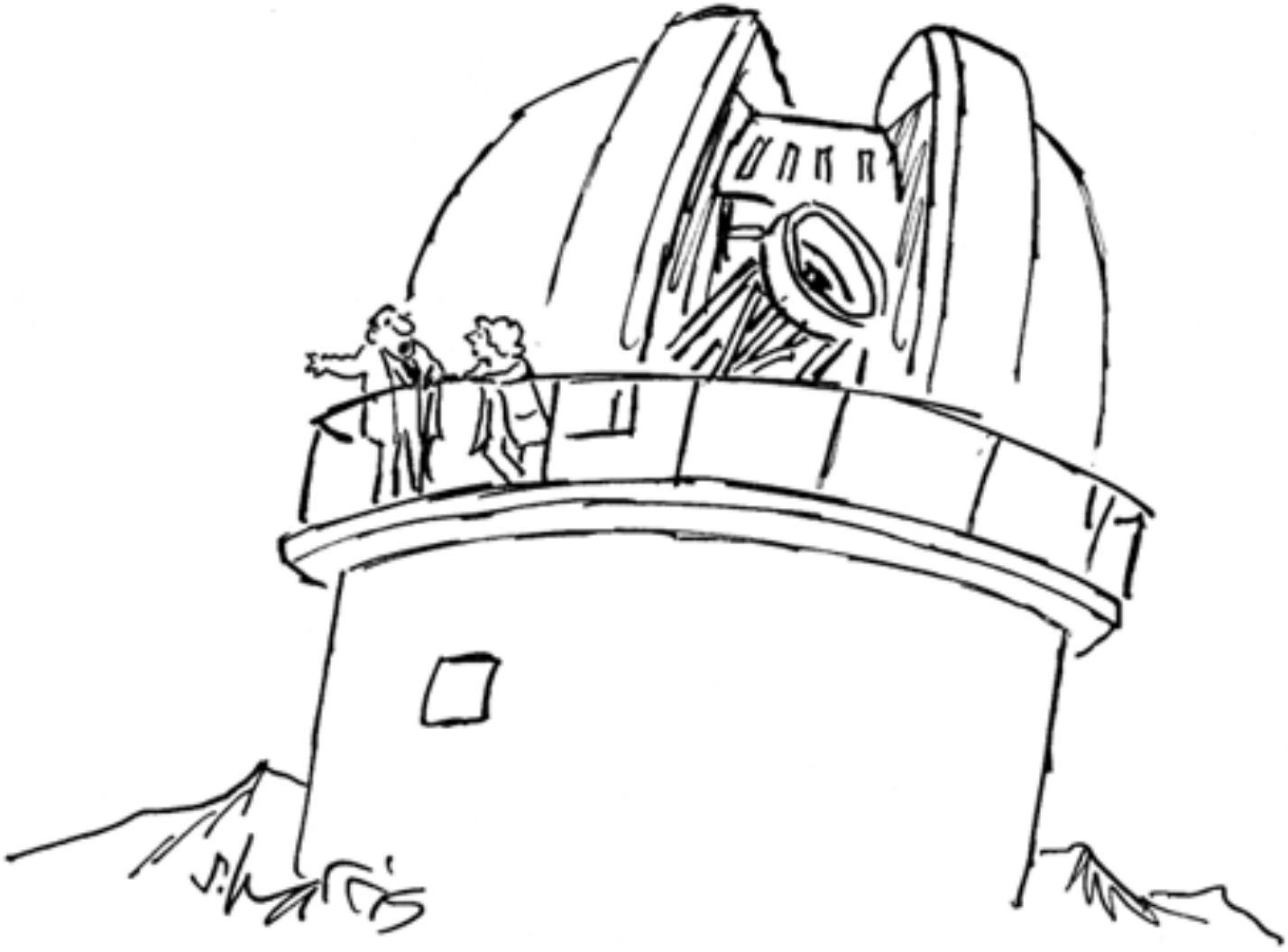
¿Cuál es la aceleración del Universo hoy?

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

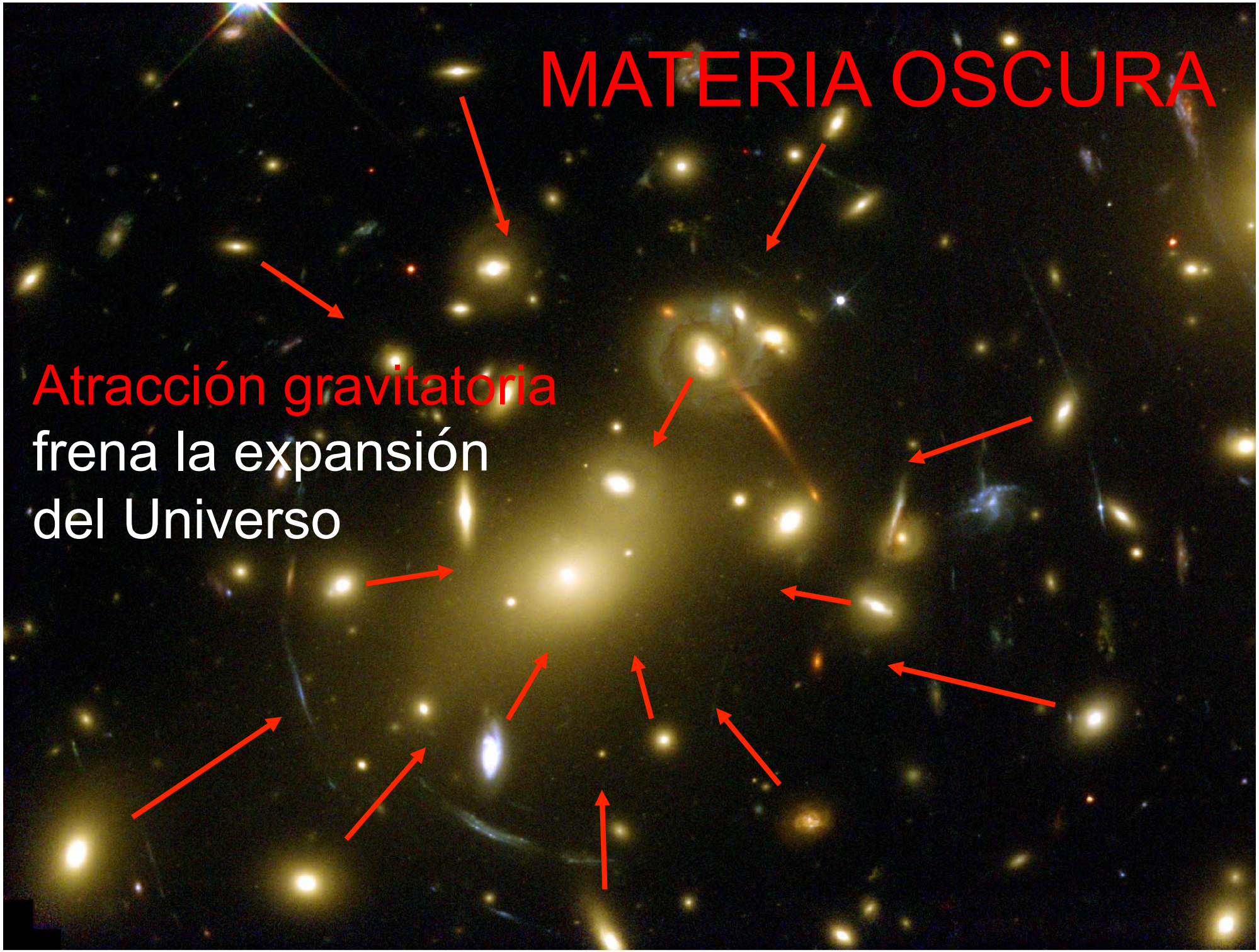
$$\ddot{a}_0 = \left(-\frac{\Omega_M}{2} + \Omega_\Lambda\right) a_0 H_0^2$$

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

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

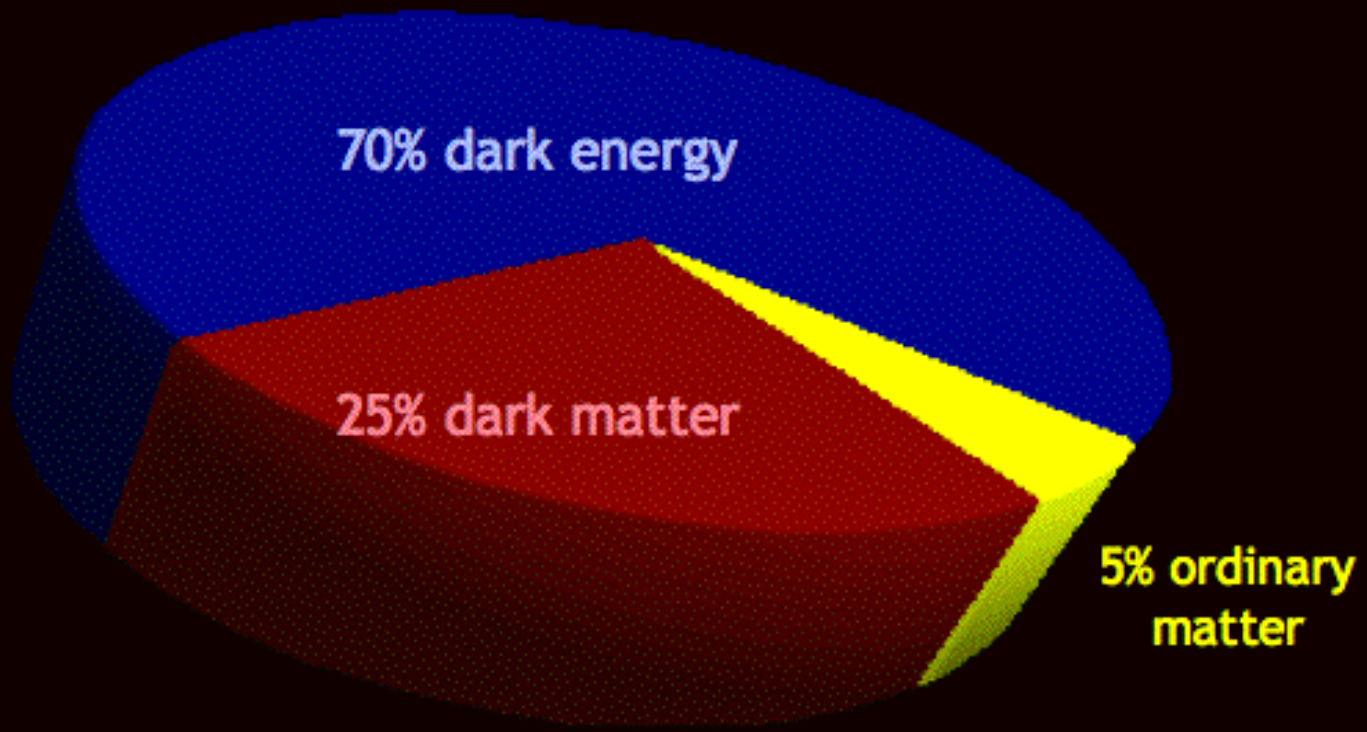


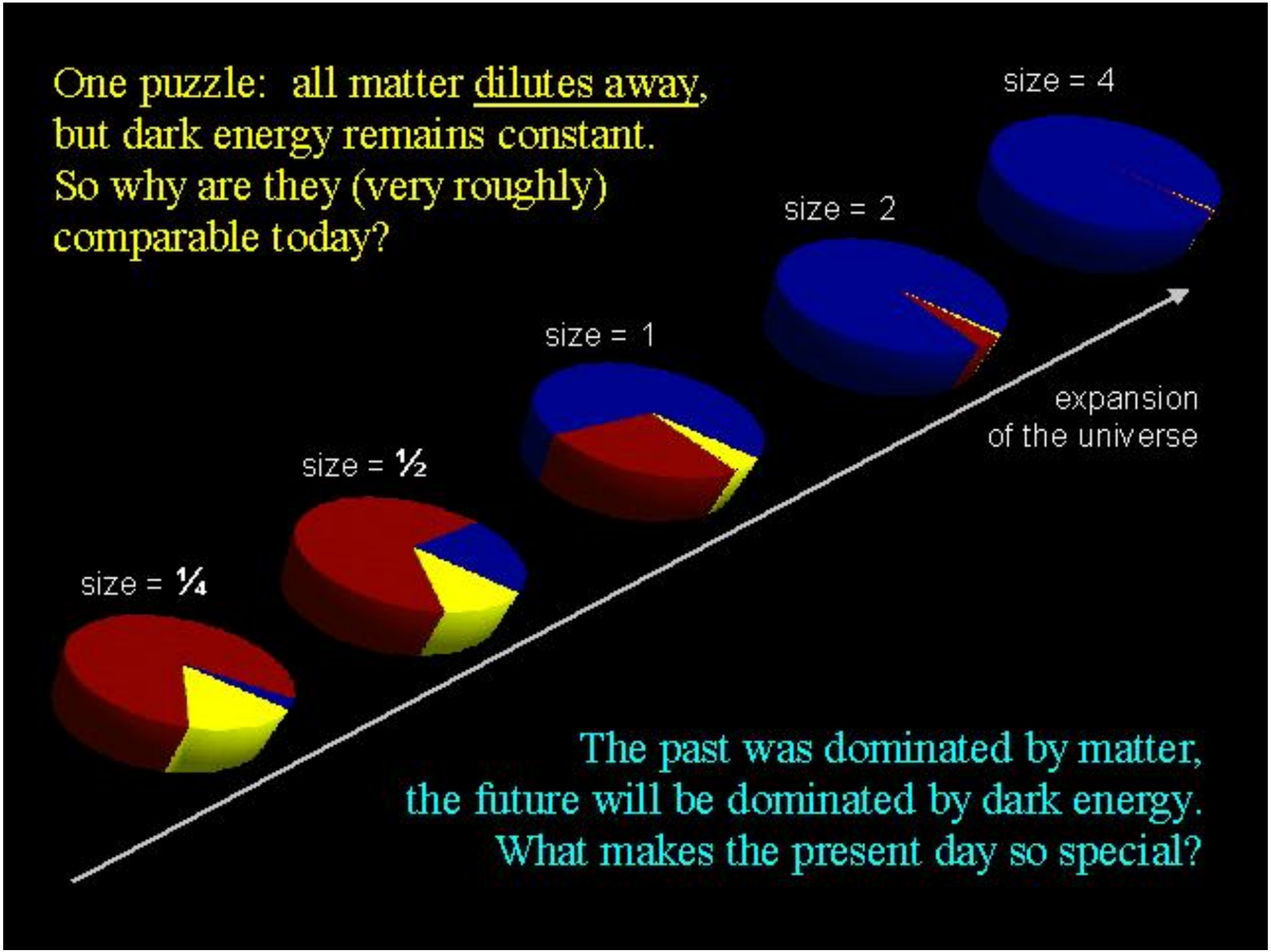
"THE UNIVERSE IS EXPANDING FASTER THAN EVER, AND I DON'T EVEN FEEL A BREEZE."


MATERIA OSCURA
Atracción gravitatoria
frena la expansión
del Universo


Algo hace que las galaxias
se alejen unas de otras
ENERGIA OSCURA

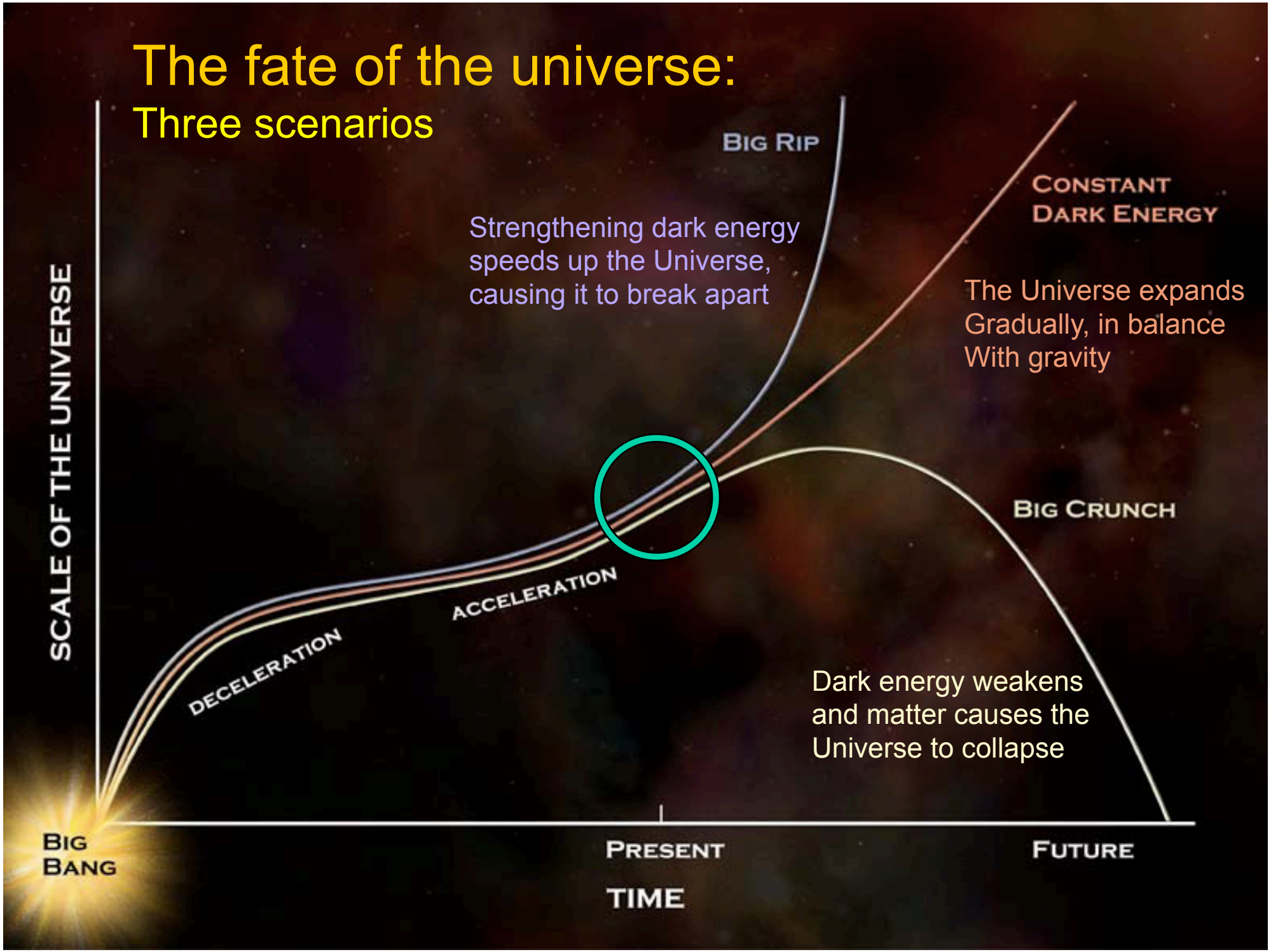
We have a complete inventory of the universe.

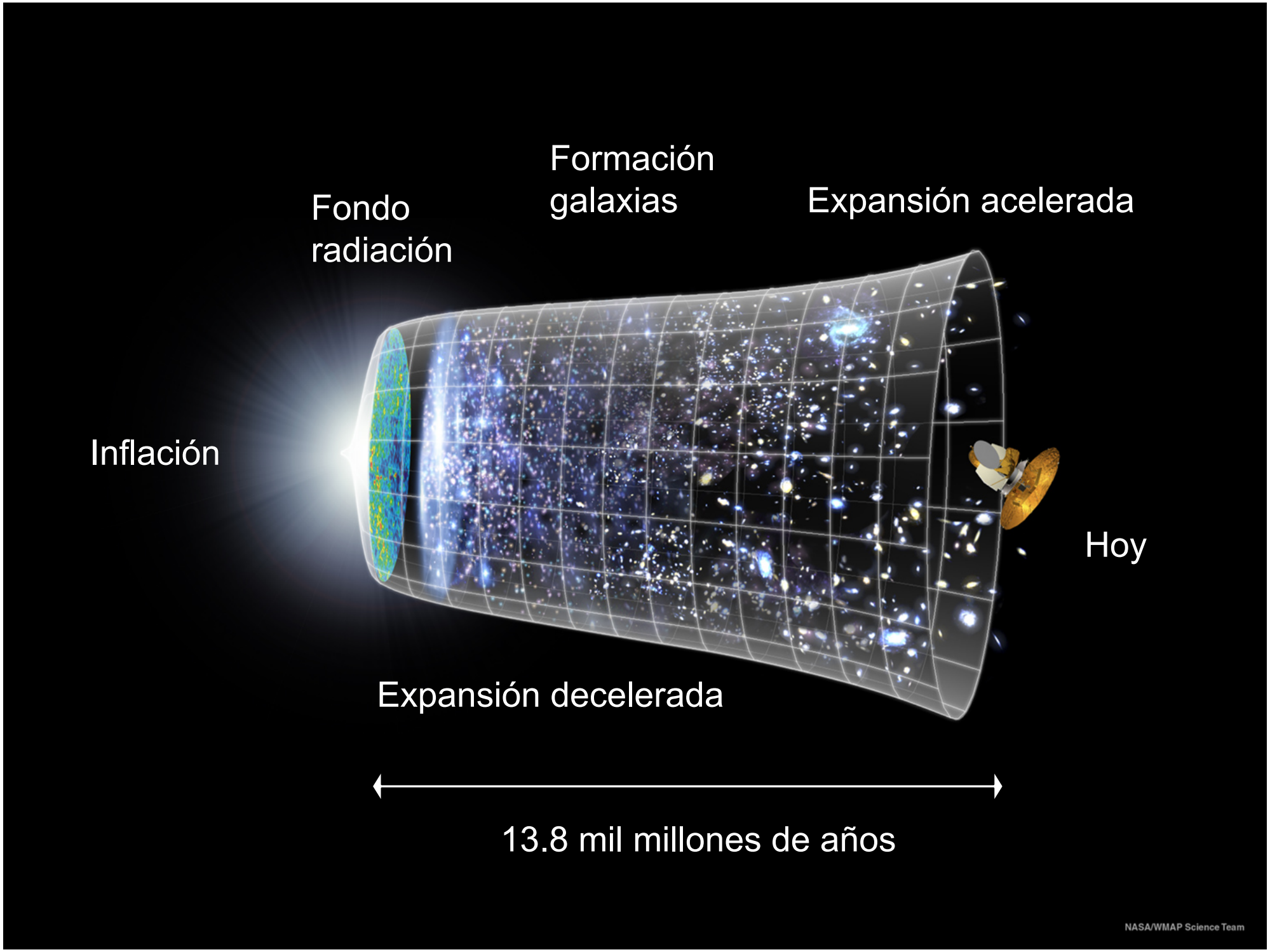



One puzzle: all matter dilutes away,
but dark energy remains constant.
So why are they (very roughly)
comparable today?
size = 4
size = 2
size = 1
size = ½
size = ¼
expansion
of the universe
The past was dominated by matter,
the future will be dominated by dark energy.
What makes the present day so special?

The fate of the universe:

Three scenarios




Formación
galaxias
Fondo
radiación
Expansión acelerada
Inflación
Hoy
Expansión decelerada
13.8 mil millones de años
NASA/WMAP Science Team

Blog : Investigación y Ciencia

INVESTIGACIÓN Y CIENCIA
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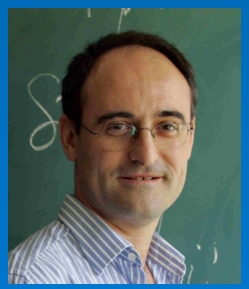
SciLogs

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

Cosmología de precisión



Juan García-Bellido Capdevila