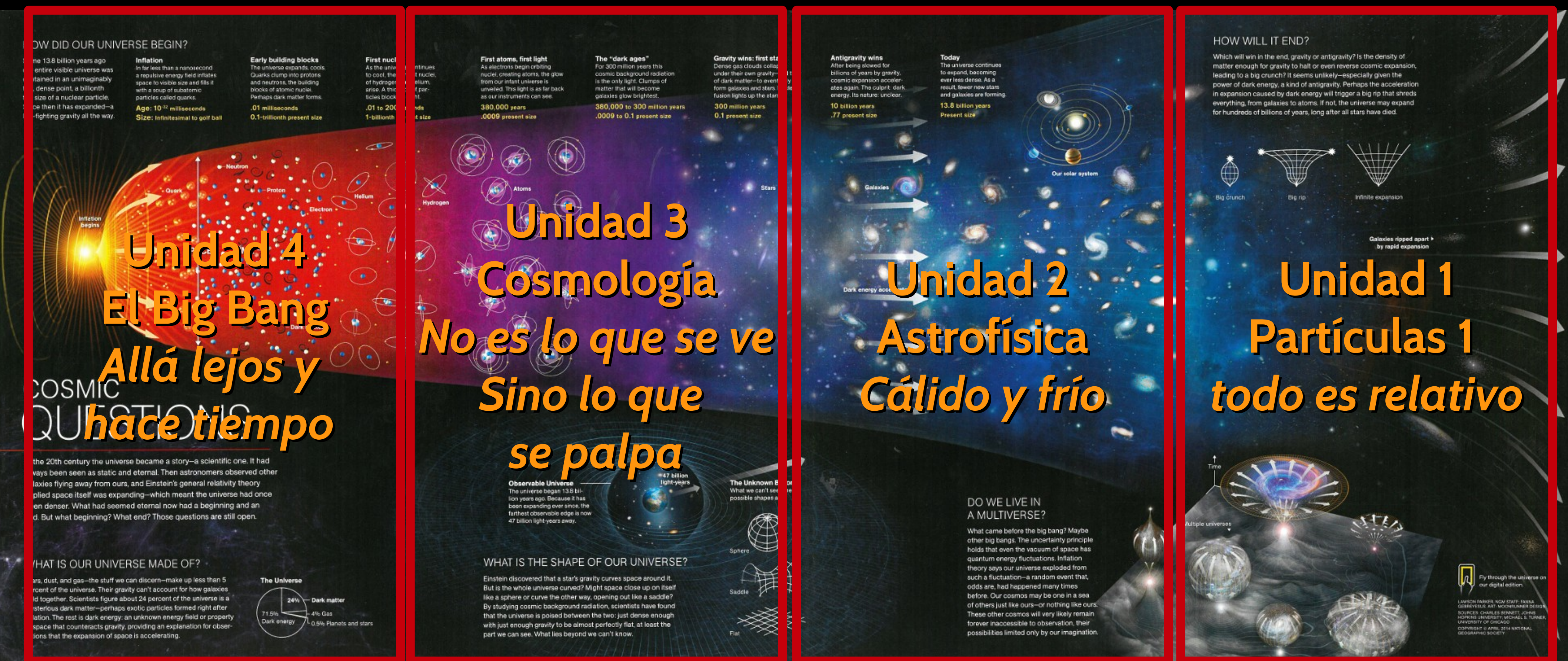
Universidad Nacional de Río Negro
Int. Partículas, Astrofísica & Cosmología - 2018

- **Unidad** 04 – El Big Bang
- **Clase** U04 C03
- **Fecha** 24 Nov 2018
- **Cont** Relatividad General, 2da parte
- **Cátedra** Asorey
- **Web** https://asoreyh.github.io/unrn-ipac/
- **Youtube** https://goo.gl/UZJzLk

RIO NEGRO

Contenidos: un viaje en el tiempo



Unidad 4
El Big Bang
Allá lejos y hace tiempo

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

Unidad 2
Astrofísica
Cálido y frío

Unidad 1
Partículas 1
todo es relativo

Pero si el Universo está en expansión....

- … siempre lo estuvo?

- Estado estacionario
  - Creación contínua de materia (hidrógeno)

$$1\frac{M_\odot}{Mpc^3}$$

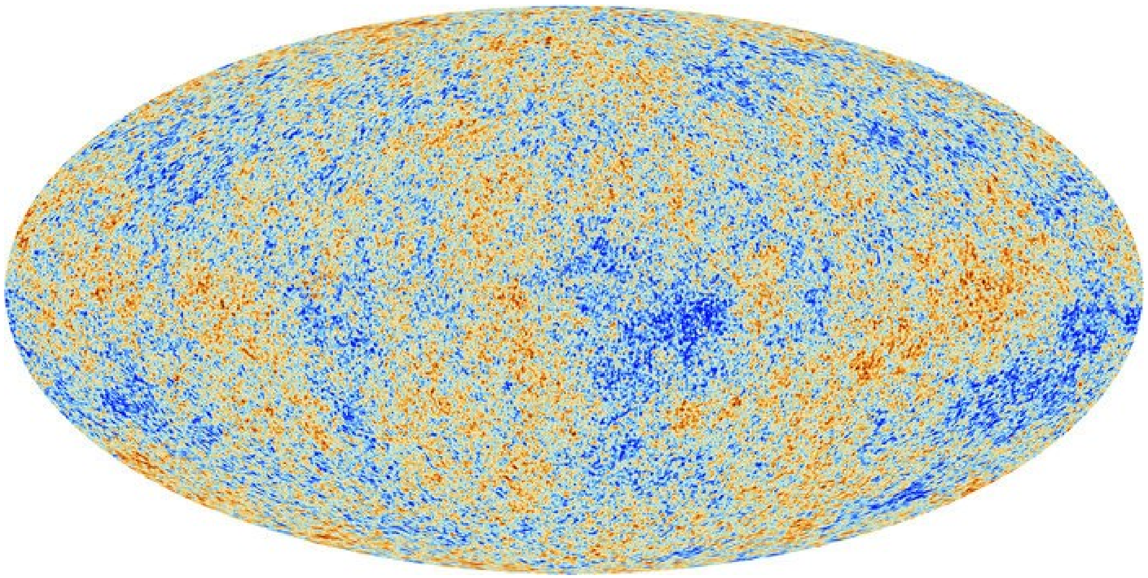
  - Universo homogeneo e isótropo

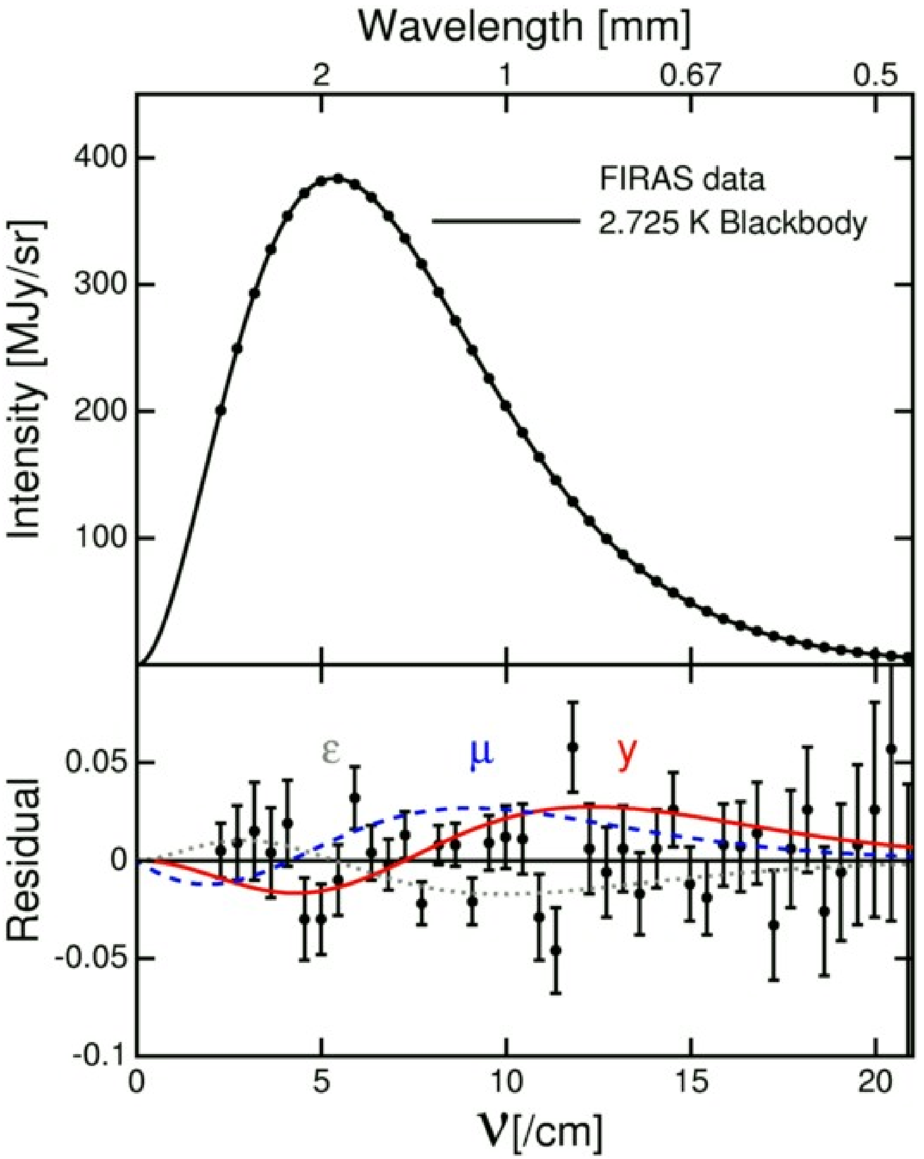
- generación inicial
  - Principio cosmológico: las propiedades del Universo son las mismas para todos los observadores
  - Altas temperaturas y densidades
  - Expansión y enfriamiento

Radiación de fondo de microondas

- Radiación de cuerpo negro:

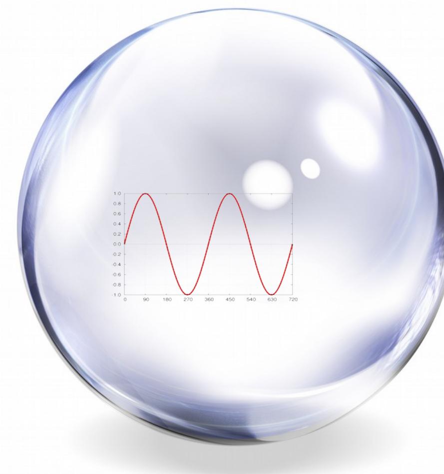
$$T = (2.726 \pm 0.0013)\,K$$
$$n_\gamma = 430\ \text{fotones}/\text{cm}^3$$
$$\langle E_\gamma / V \rangle = 0.25\,\text{eV}/\text{cm}^3$$





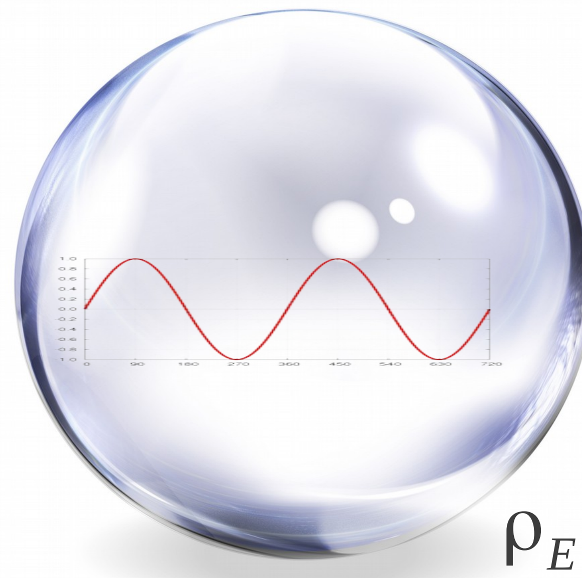
Materia y energía en la expansión

$$E = m c^2$$

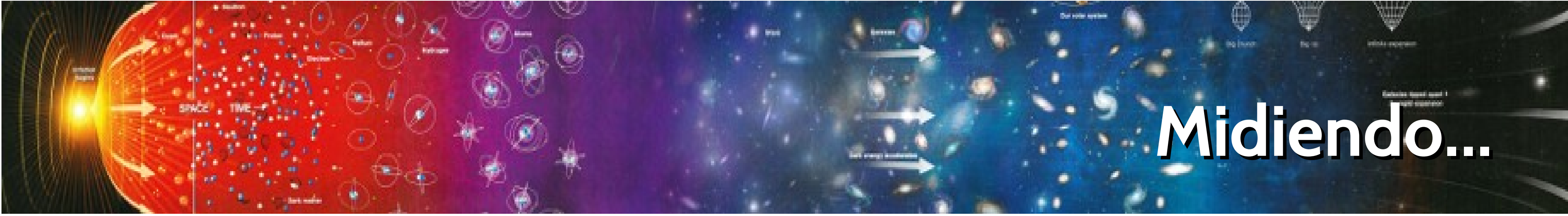


$$E = \frac{hc}{\lambda}$$

$$\rho_M \sim 1/R^3$$



$$\rho_E \sim \left(1/R^4\right)$$



Midiendo...

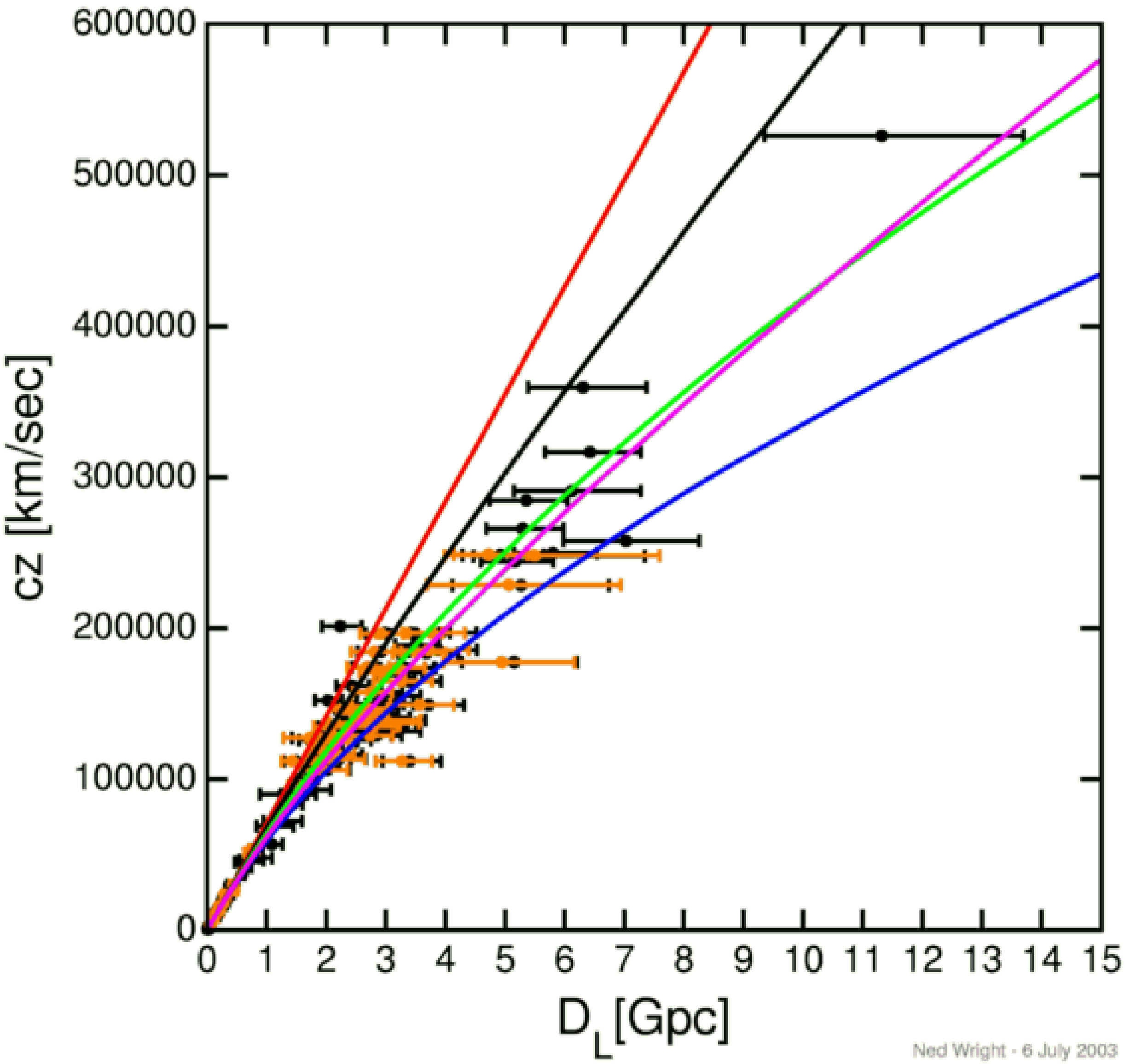
- Defino: $\Omega = \rho / \rho_c$
- Ahora mido el contenido de materia del Universo, y obtengo:

$$\Omega = 1.00 \;\; +/- \;0.01$$

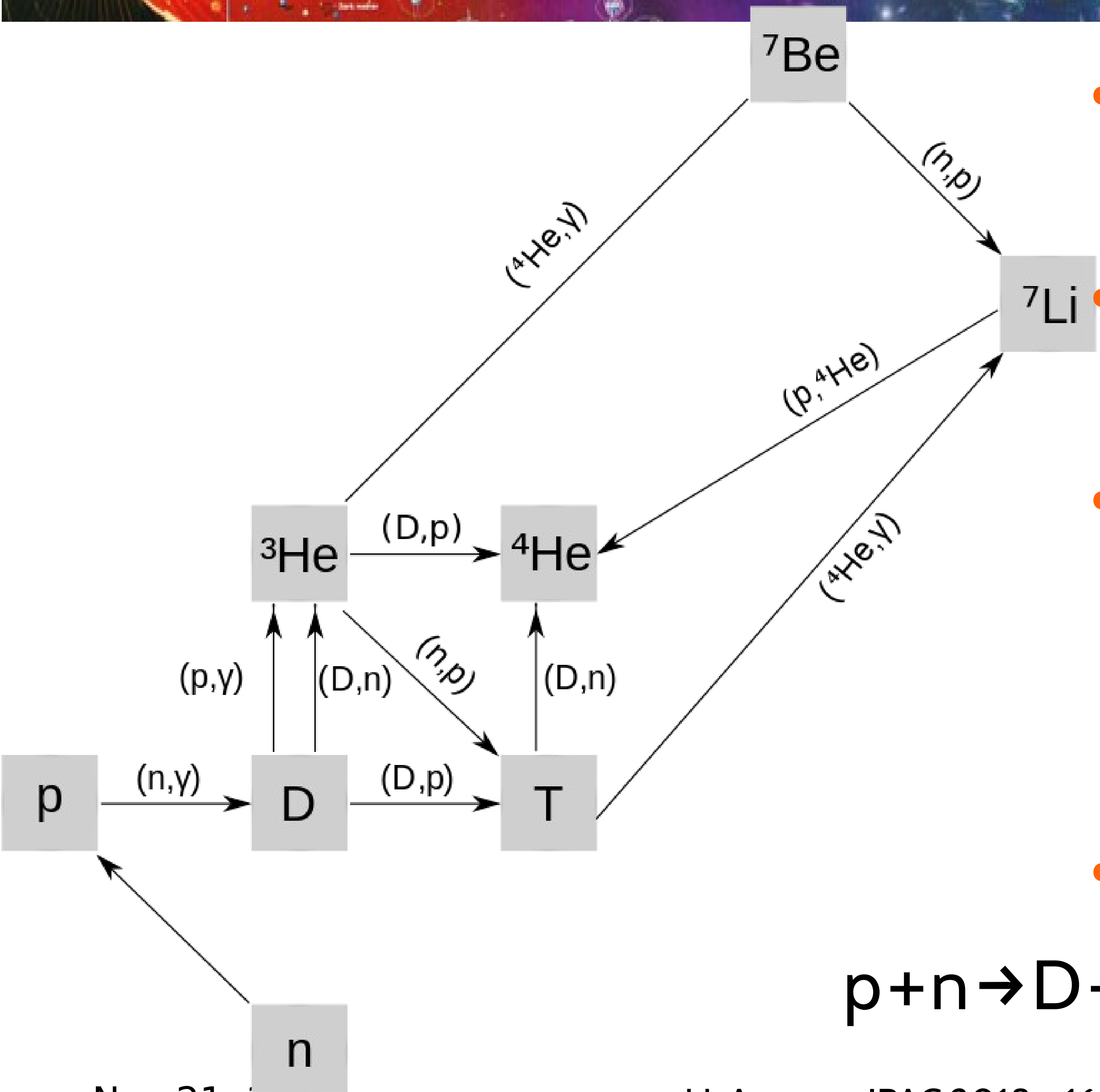
Contenido de materia energía del Universo

- Cómo se compone:
  - Ωk = 0.001%
  - $\Omega \gamma$ = 0.2%
  - Ωm = 4%
  - ΩM = 23%
  - ΩE = 73%

El nuevo diagrama de Hubble



Nucleosíntesis en el big-bang



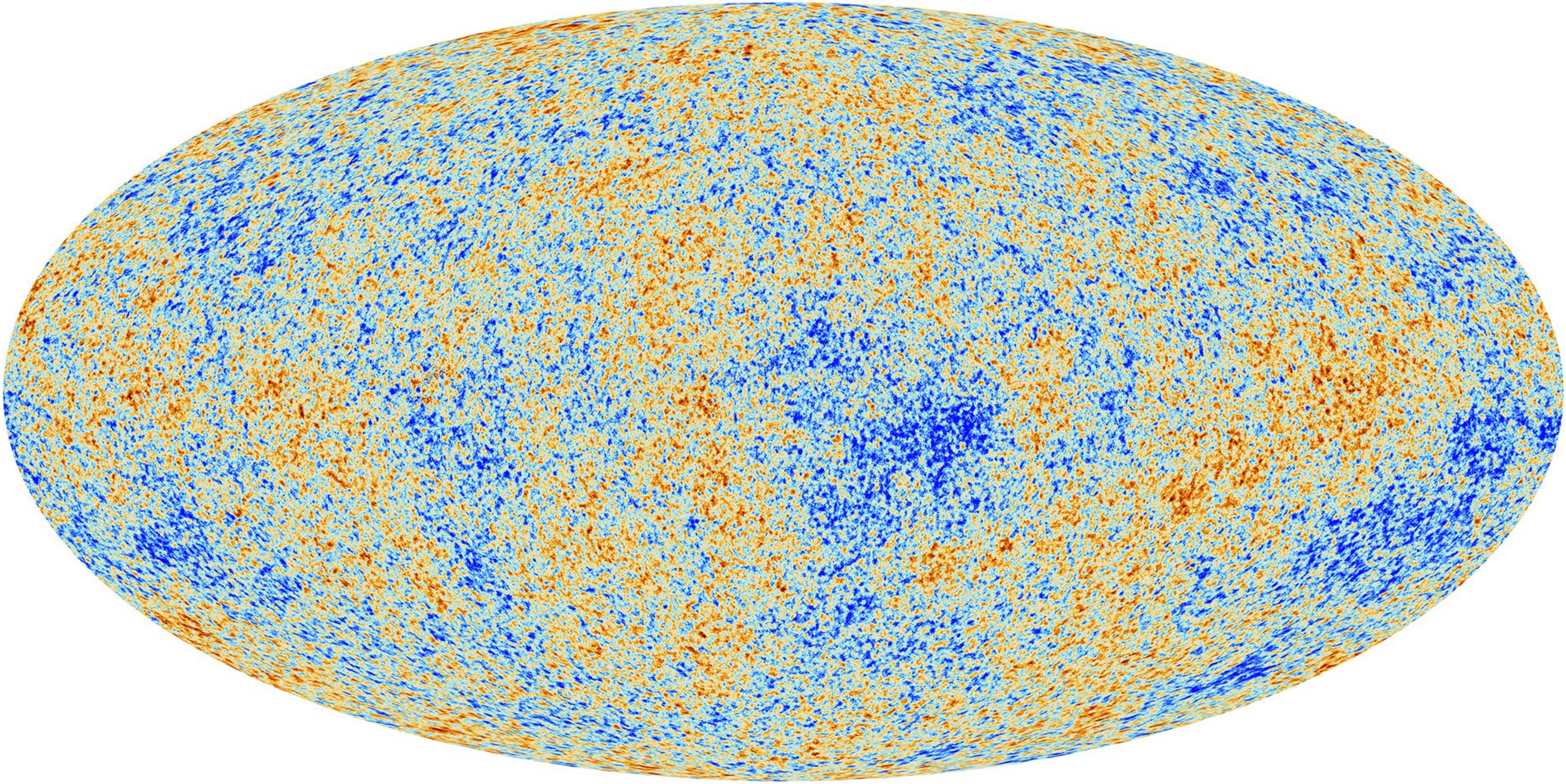
- Formación de átomos simples
- Principal fuente de hidrógeno y helio
- Los átomos pesados se forman en la nucleosíntesis estelar (supernovas)
- Notación:

$$p+n \rightarrow D+\gamma \text{, se escribe } p(n,\gamma)D$$

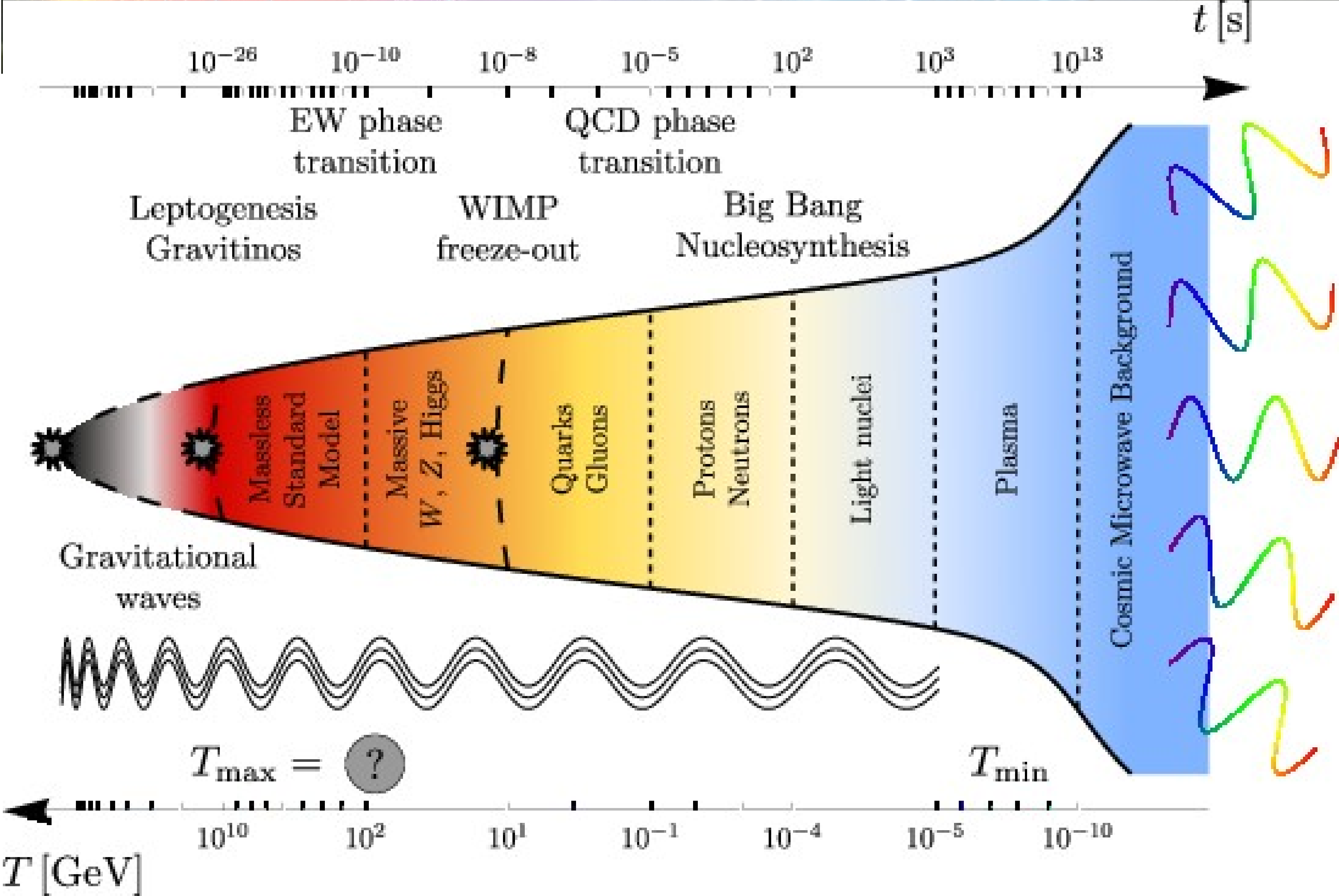
Muy poco después de la recombinación

- Los electrones formaron átomos, y la densidad de electrones cae abruptamente
- La disminución de electrones disminuye la tasa de interacción Compton, y además el Universo se está expandiendo
- El Universo se vuelve transparente, los fotones continúan propagándose hasta hoy, perdiendo energía por la expansión (redshift!)

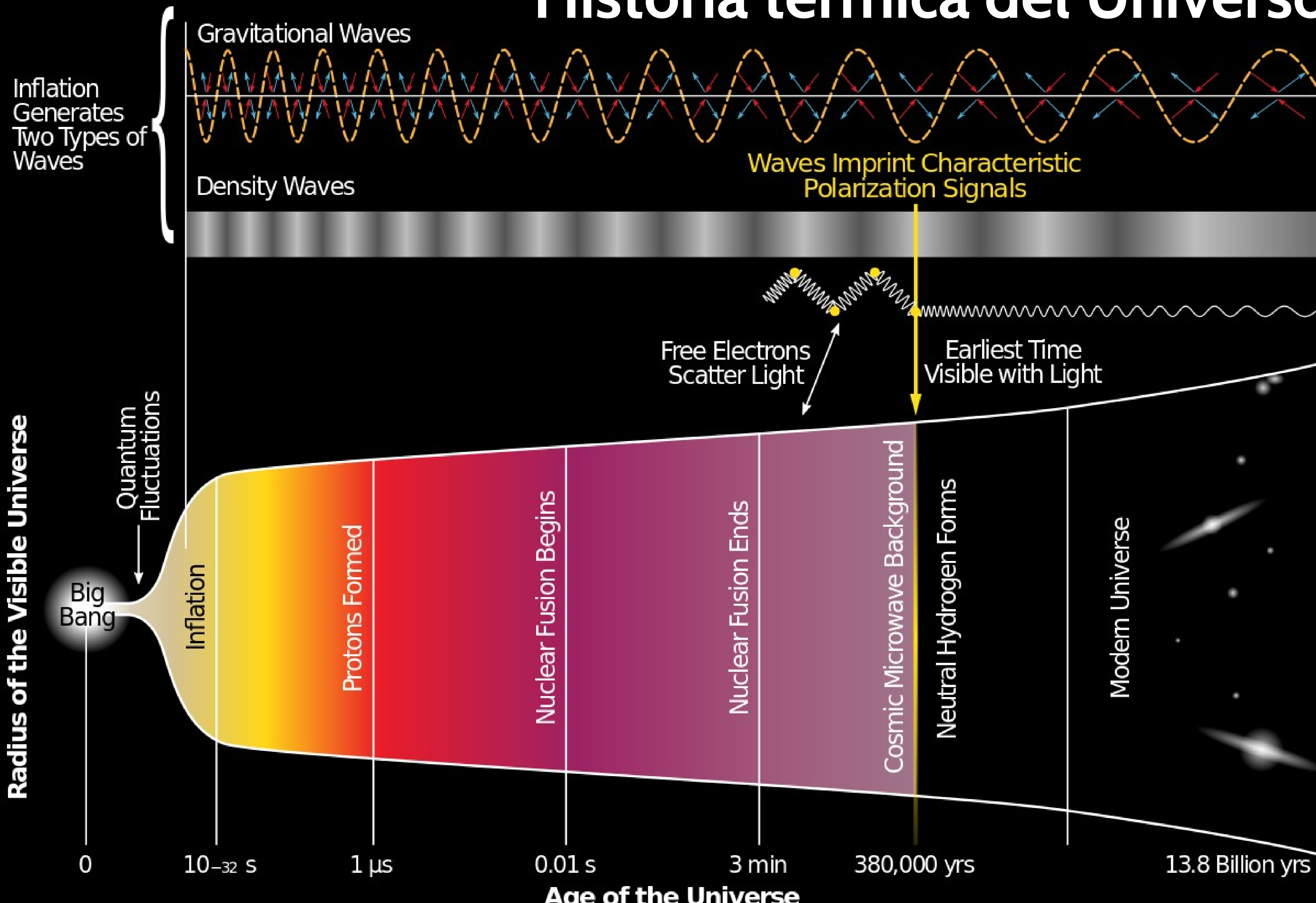
Una foto del Universo a z=1100



Historia térmica del Universo

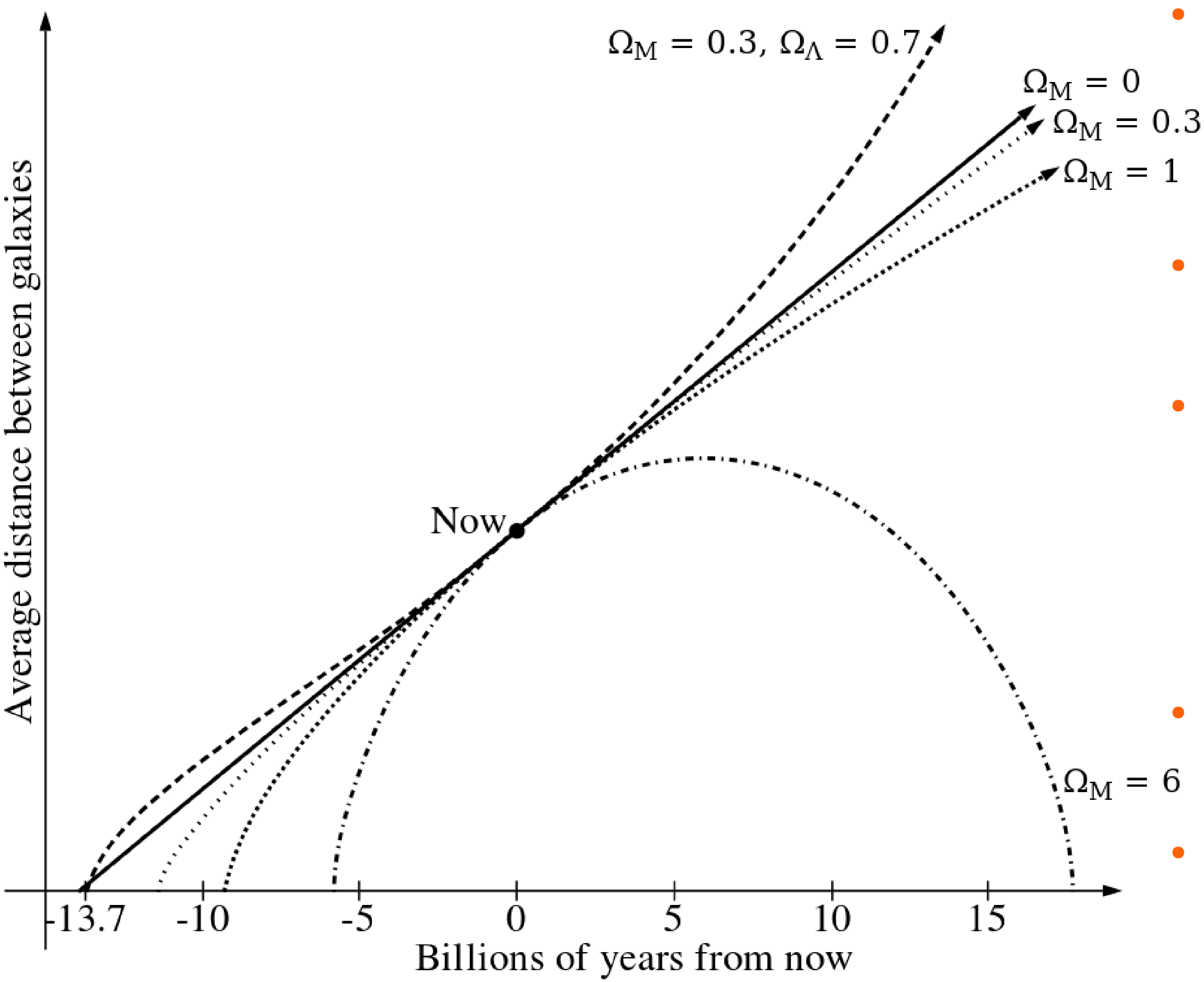


Historia térmica del Universo



https://en.wikipedia.org/wiki/Chronology_of_the_universe#Summary

Historia térmica del Universo
El futuro



- **Big crunch (Ω>1)**: la gravedad eventualmente domina la expansión hasta el colapso gravitatorio
- **Big Bounce:** big bang luego del big crunch
- **Big Rip:** si la densidad de la energía oscura aumenta, entonces la aceleración es cada vez mayor → ruptura del espacio tiempo
- **Abierto (Ω<1)**: la expansión continúa para siempre
- **Plano (Ω=1)**: la expansión continúa para siempre, pero en forma desacelerada (v=0 a t=inf)
-

Relatividad general, continuación

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.

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 far less than a nanosecond a repulsive energy field inflates space to visible size and fills it with a soup of subatomic particles called quarks.
Age: 10^{-32} milliseconds
Size: Infinitesimal to golf ball

Early building blocks
The universe expands, cools. Quarks clump into protons and neutrons, the building blocks of atomic nuclei. Perhaps dark matter forms.
.01 milliseconds
0.1-trillionth 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.
.01 to 200 seconds
1-billionth present size

First atoms, first light
As electrons begin orbiting nuclei, creating atoms, the glow from our infant universe is unveiled. This light is as far back as our instruments can see.
380,000 years
.0009 present size

The "dark ages"
For 300 million years this cosmic background radiation is the only light. Clumps of matter that will become galaxies glow brightest.
380,000 to 300 million years
.0009 to 0.1 present size

Gravity wins: first stars
Dense gas clouds collapse under their own gravity—and that of dark matter—to eventually form galaxies and stars. Nuclear fusion lights up the stars.
300 million years
0.1 present size

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

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

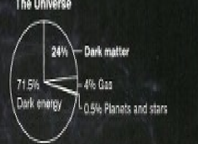
HOW WILL IT END?

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.

WHAT IS OUR UNIVERSE MADE OF?

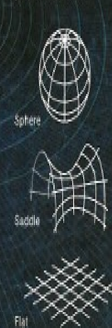
Stars, dust, and gas—the stuff we can discern—make up less than 5 percent of the universe. Their gravity can't account for how galaxies hold together. Scientists figure about 24 percent of the universe is a mysterious dark matter—perhaps exotic particles formed right after inflation. The rest is dark energy: an unknown energy field or property of space that counteracts gravity, providing an explanation for observations that the expansion of space is accelerating.

The Universe



Observable Universe
The universe began 13.8 billion years ago. Because it has been expanding ever since, the farthest observable edge is now 47 billion light-years away.

The Unknown Beyond
What we can't see. The possible shapes are:



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 says our universe 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.

LAWSON PARKER, NGM STAFF; FANNA GEBREYESUS. ART: MOONRUNNER DESIGN
SOURCES: CHARLES BENNETT, JOHNS HOPKINS UNIVERSITY; MICHAEL S. TURNER, UNIVERSITY OF CHICAGO

Muchas gracias