

Universidad Nacional de Río Negro

Int. Partículas, Astrofísica & Cosmología - 2018

- **Unidad** 04 – El Big Bang
- **Clase** U04 C02
- **Fecha** 21 Nov 2018
- **Cont** Expansión y relatividad general
- **Cátedra** Asorey
- **Web** <https://asoreyh.github.io/unrn-ipac/>
- **Youtube** <https://goo.gl/UZJzLk>



HOW DID OUR UNIVERSE BEGIN?

The 13.8 billion years ago entire visible universe was contained in an unimaginably dense point, a billionth the size of a nuclear particle. Then it expanded—defying 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.

First nuclei
As the universe cools, the first nuclei of hydrogen and helium form.

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.

The "dark ages"
For 300 million years this cosmic background radiation is the only light. Clumps of matter that will become galaxies glow brightest.

Gravity wins: first stars
Dense gas clouds come under their own gravity of dark matter—to event form galaxies and stars. Fusion lights up the stars.

Antigravity wins
After being slowed for billions of years by gravity, cosmic expansion accelerates again. The output of dark energy, its nature unclear.

Today
The universe continues to expand, becoming ever less dense. As a result, newer stars and galaxies are forming.

10 billion years
.77 present size

13.8 billion years
Present size

Our solar system

Galaxies

Dark energy accelerates

Stars

Hydrogen

Atoms

Quark

Neutron

Proton

Electron

Helium

Unidad 3 Cosmología

No es lo que se ve

Sino lo que se palpa

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

The Unknown Edge
What we can't see possible shapes a sphere, a saddle, or flat.

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.

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 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

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

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.

Unidad 2 Astrofísica

Cálido y frío

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

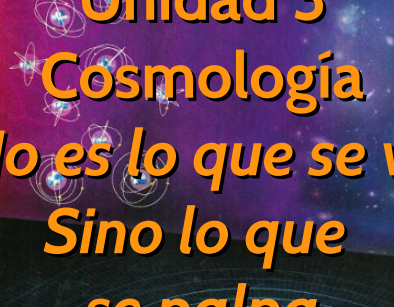
Unidad 1 Partículas

todo es relativo

Multiple universes

Fly through the universe on our digital edition.

UNIVERSITY OF CHICAGO
COSMOS: A DIGITAL NATIONAL GEOGRAPHIC SOCIETY



Hydrogen

Unidad 3

Cosmología

No es lo que se ve
Sino lo que
se palpa

#47 billion

Unidad 2

Astrofísica

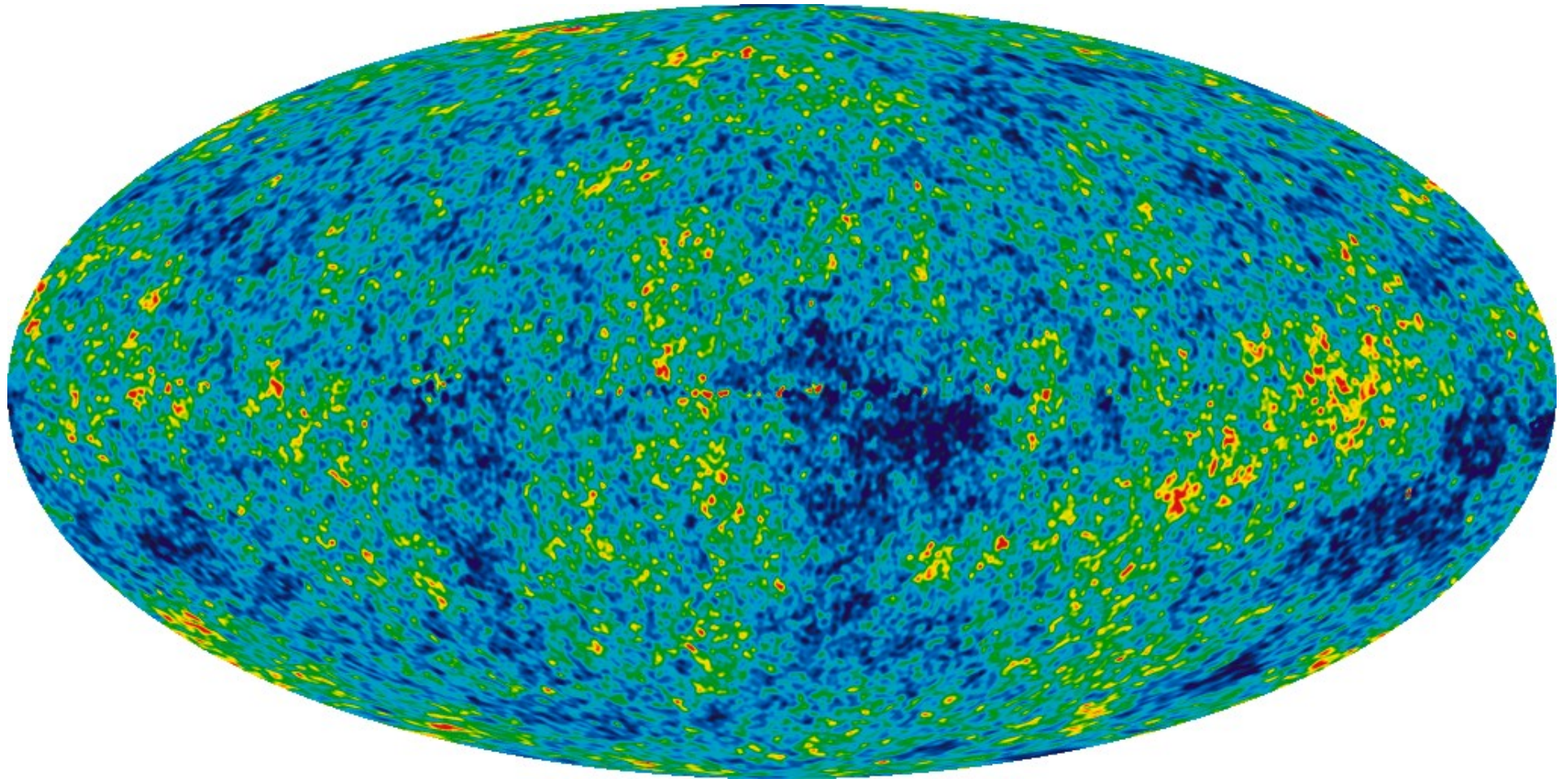
Cálido y frío

Unidad 1

Partículas 1

todo es relativo

A las escalas más grandes...

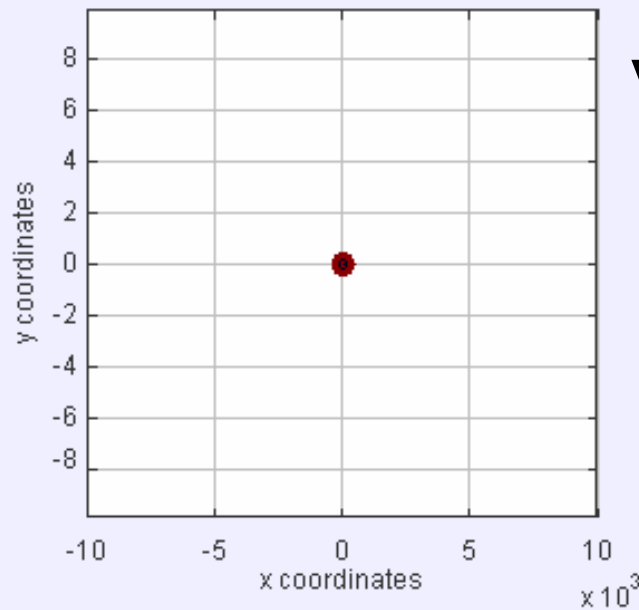


“Es el cambio aparente en la frecuencia de una onda causado por el movimiento relativo entre la fuente de la ondas y el observador”

Dr. Sheldon Cooper

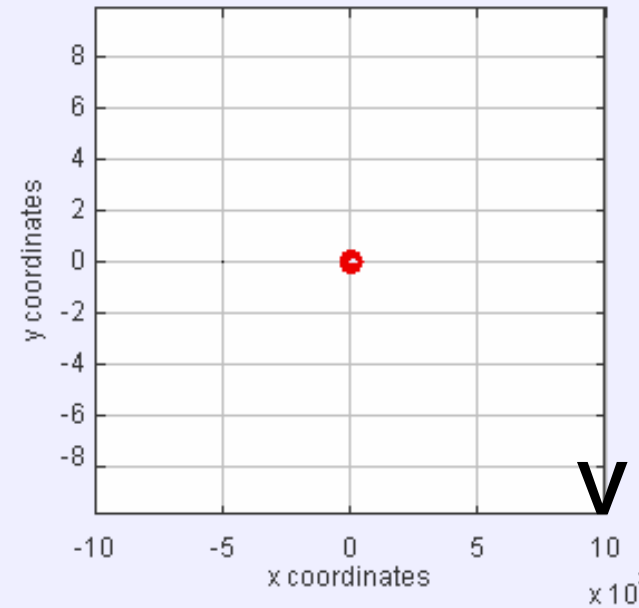
Efecto Doppler

$\times 10^3$ Doppler Effect Model in 1 Doppler Effect



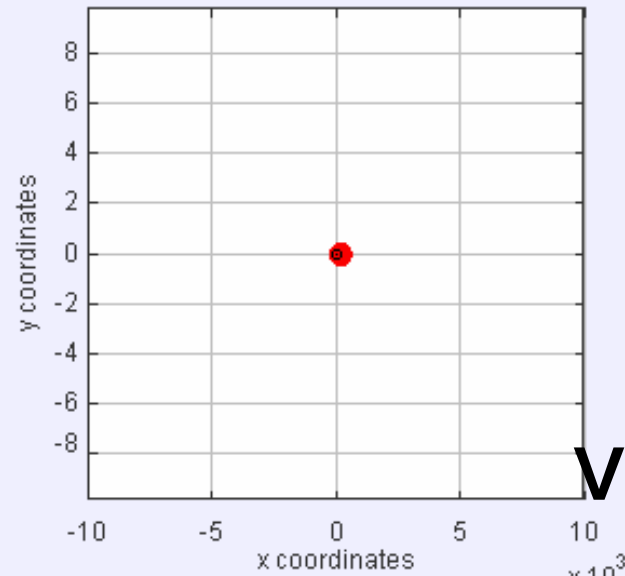
$$v = 0$$

$\times 10^3$ Doppler Effect Model in 1 Doppler Effect



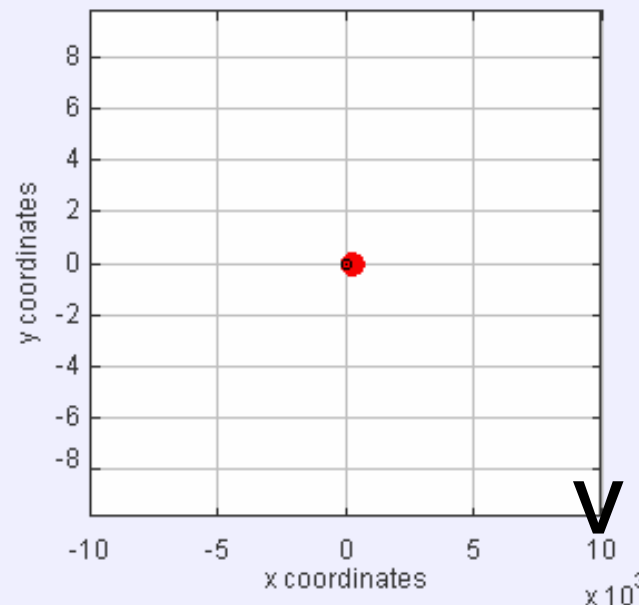
$$v = 0,7 v_s$$

$\times 10^3$ Doppler Effect Model Breaking the sound barrier

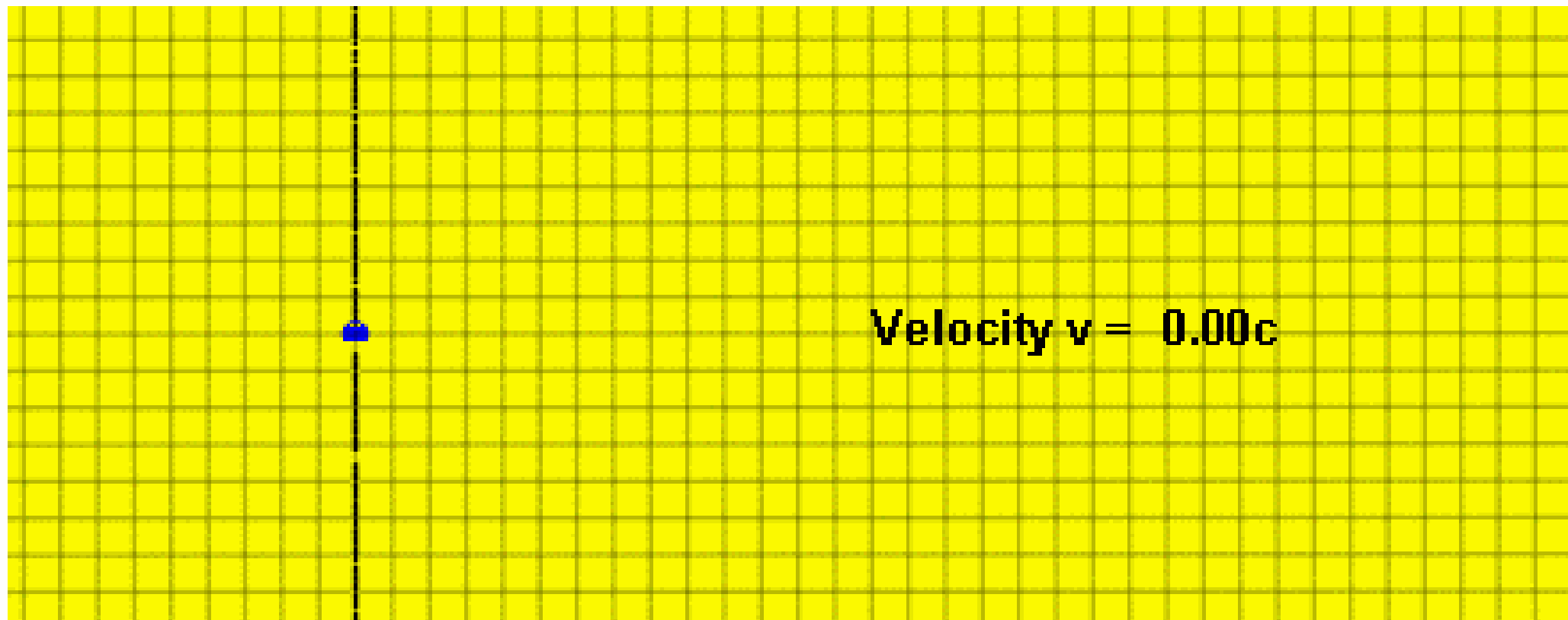
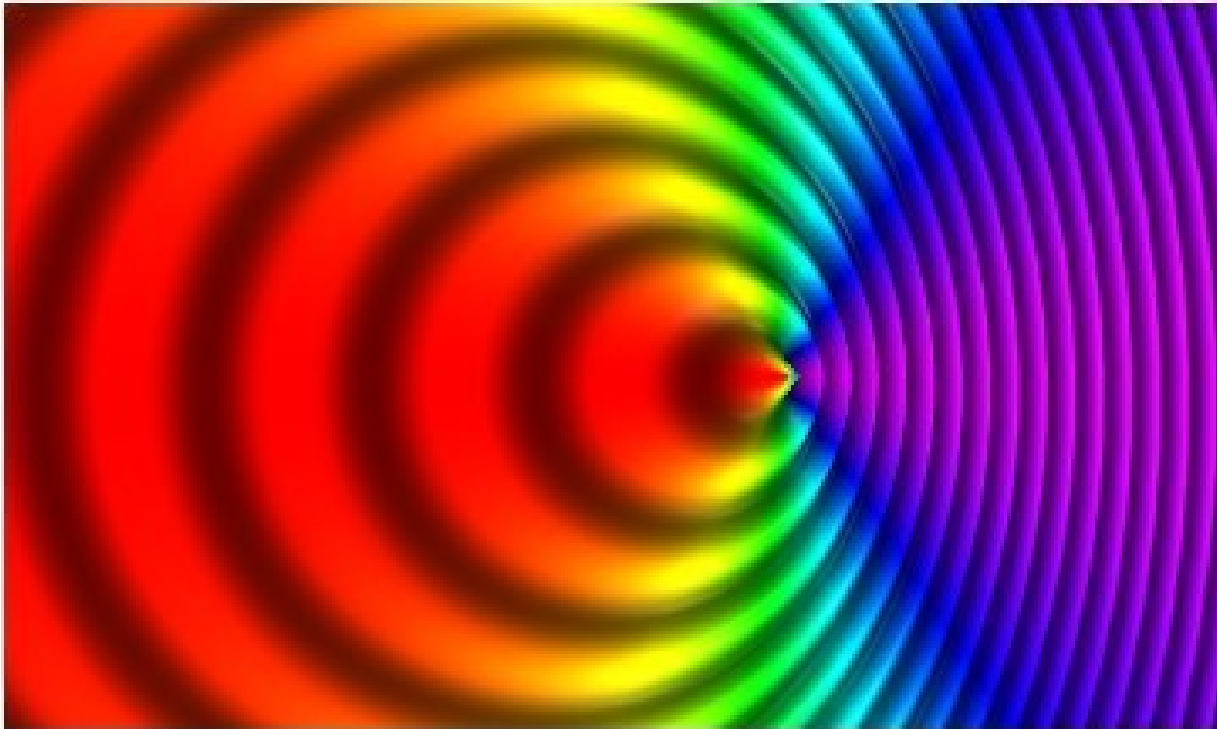


$$v = 1 v_s$$

$\times 10^3$ Doppler Effect Model in 1 Di Supersonic



$$v = 1,4 v_s$$





Corrimiento al rojo

$$\frac{f_o}{f_e} = \sqrt{\frac{1-\beta}{1+\beta}} < 1 \rightarrow f_o < f_e, \text{ y } f\lambda = c \Rightarrow f_o = \frac{c}{\lambda_o}, \text{ y lo mismo para } \lambda_e$$

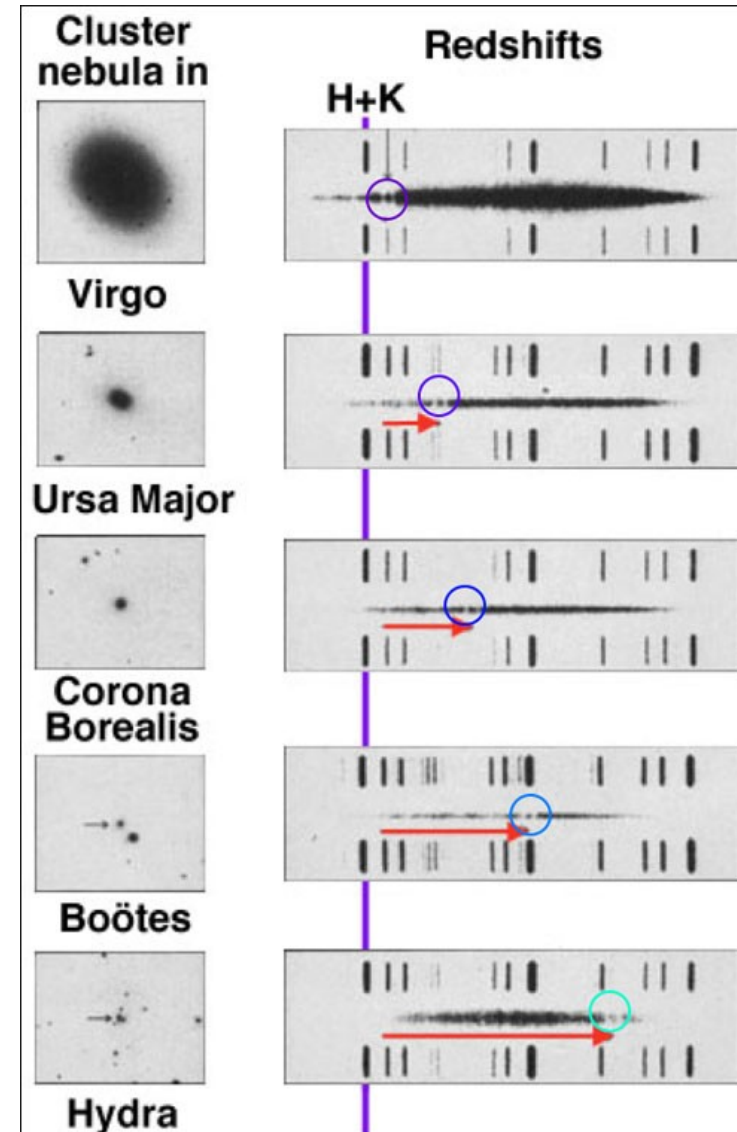
$$\frac{\lambda_o}{\lambda_e} = \sqrt{\frac{1+\beta}{1-\beta}} > 1 \rightarrow \lambda_o > \lambda_e$$

$$\text{Def. } z \equiv \frac{\lambda_o - \lambda_e}{\lambda_e} \Rightarrow 1+z = \frac{\lambda_o}{\lambda_e} = \sqrt{\frac{1+\beta}{1-\beta}}$$

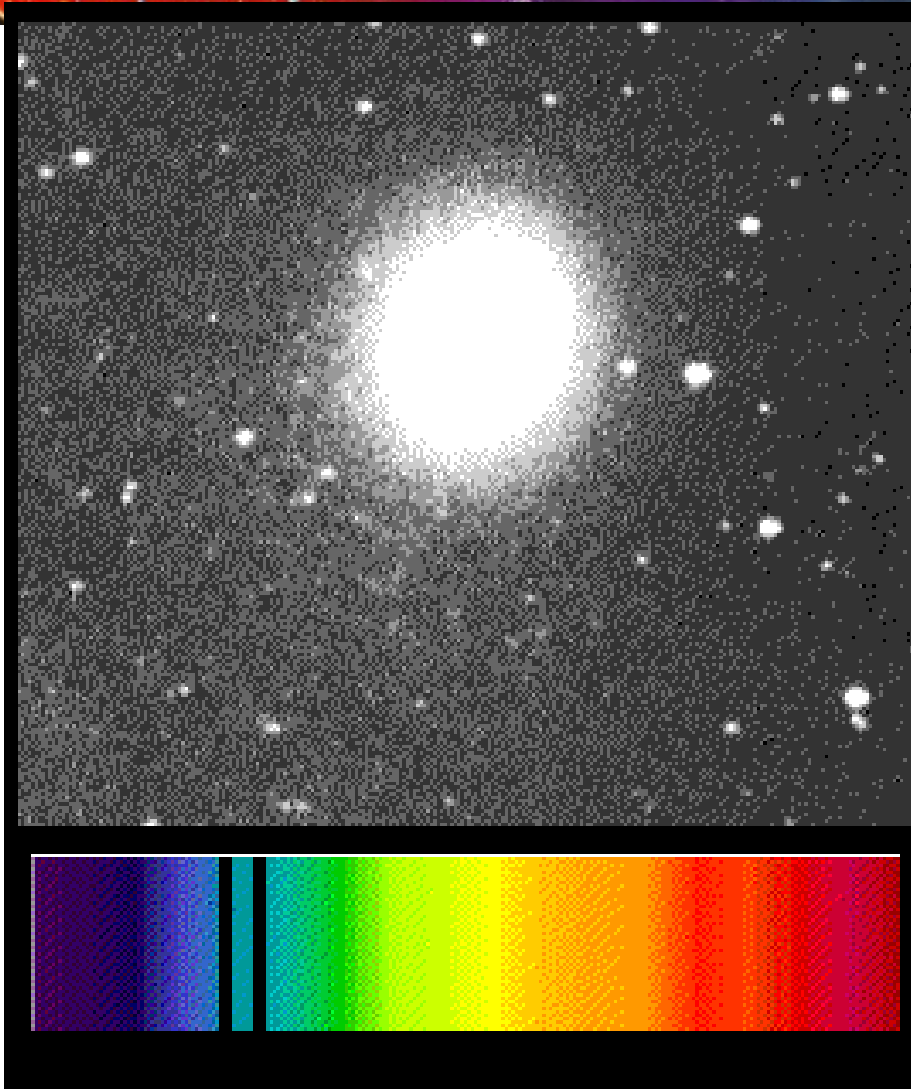
z es el corrimiento al rojo.

Se puede probar que si $v \ll c$

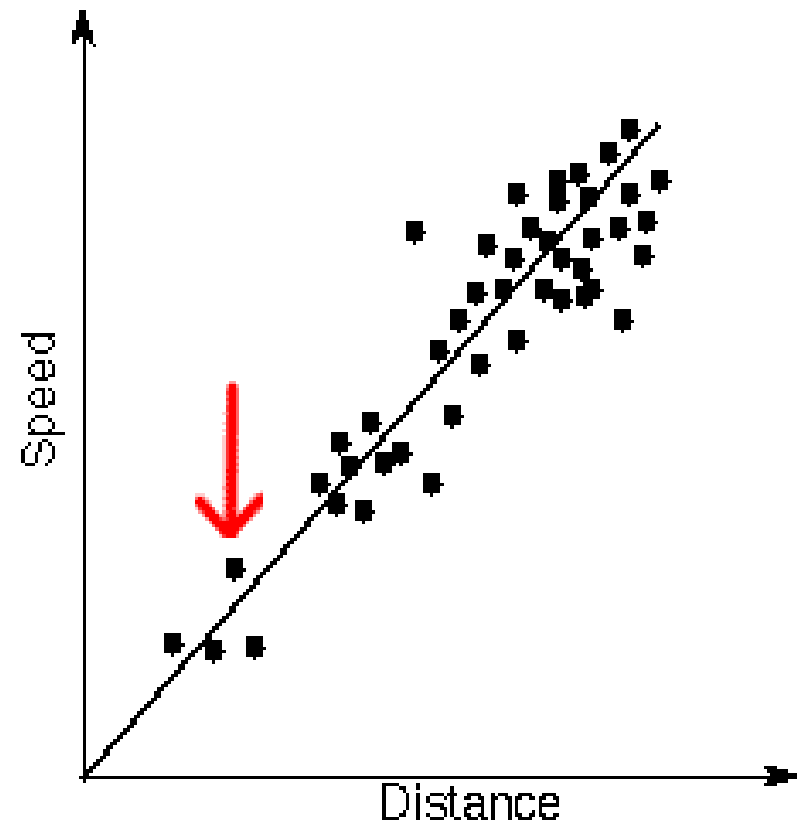
$$z \simeq \beta$$



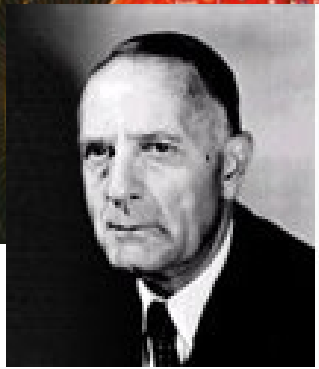
El Universo se expande



Hubble Law
 recession speed = $H_0 \times \text{distance}$

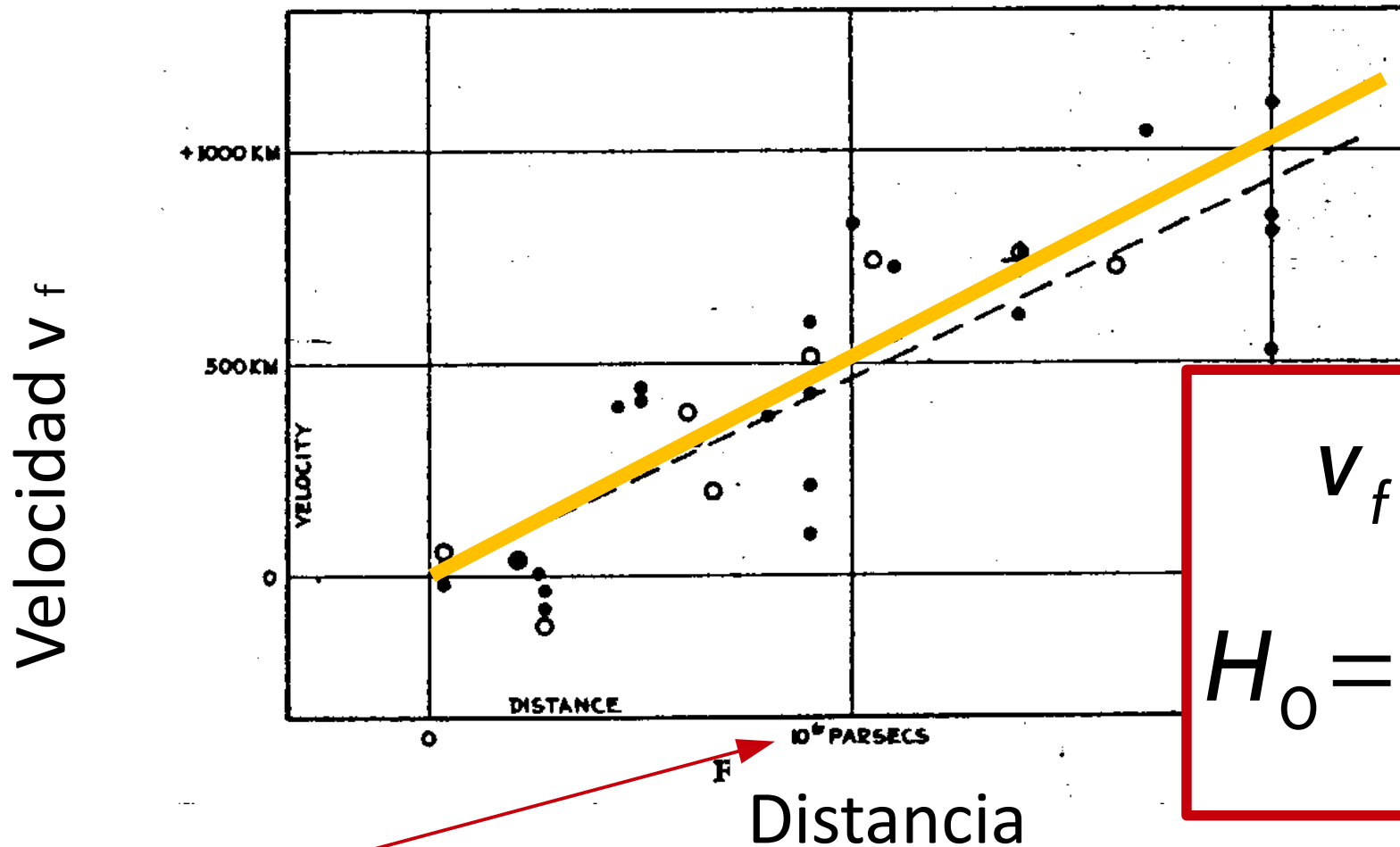


Nov 21, $1+z = \frac{\lambda_o}{\lambda_e} = \sqrt{\frac{1+\beta}{1-\beta}}; \quad v = H_0 d; \quad H_0 = 67 \text{ km s}^{-1} \text{ Mpc}_3$



Ley de Hubble: el Universe se expande

Un objeto situado a 1 Mpc de la Tierra se aleja a una velocidad de 67 km/s



$$v_f = H_0 d$$
$$H_0 = 67 \frac{\text{km}}{\text{s Mpc}}$$

10^6 parsecs = 1 Mpc (megaparsec) = 3.085×10^{22} m



¿De qué manera?



Una torta de chips de chocolate



- La velocidad depende de la distancia entre los chips
- Cada uno piensa que es el “centro del Universo”
- Pero ninguno lo es

A horizontal banner image illustrating the expansion of the universe. The left side shows a bright yellow sun-like object with concentric circles representing light waves, labeled 'SPACE' and 'TIME'. The middle section is a red field filled with small blue dots representing particles, with labels for 'Protons', 'Neutrons', 'Electrons', 'Hydrogen', 'Helium', and 'Dark matter'. The right side is a blue field with galaxies and arrows pointing away from a central point, labeled 'Dark energy acceleration'.

Horizontes en el Universo

- Radio de Hubble: distancia a la cual la velocidad de expansión es igual a c

$$r_H(t) = \frac{c}{H(t)}$$

- Horizonte cosmológico: la distancia que se propagó la luz desde el inicio del Universo. Como el universo se expande, esto no es “simplemente” 13.8×10^9 años luz

Hoy es $14.4 \text{ Gpc} = 46.9 \text{ Gal}$

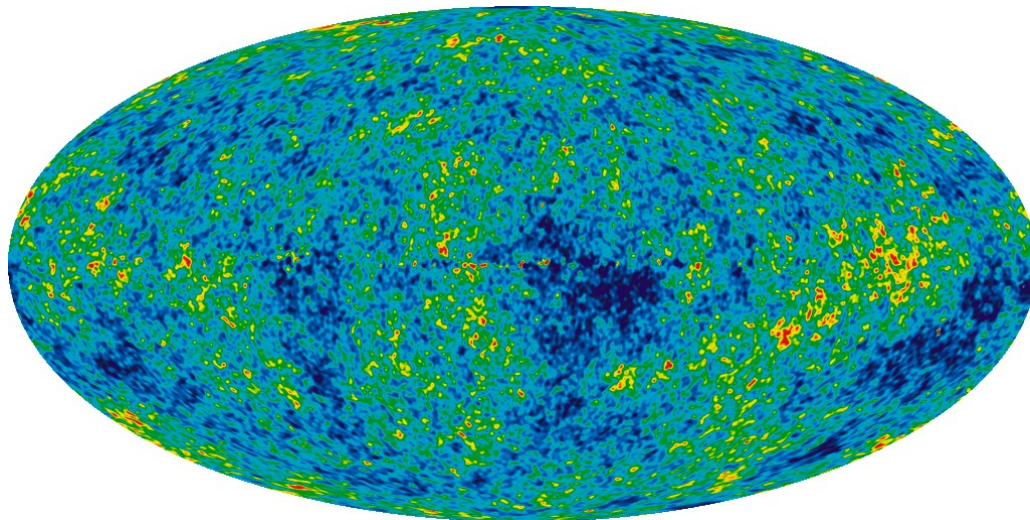
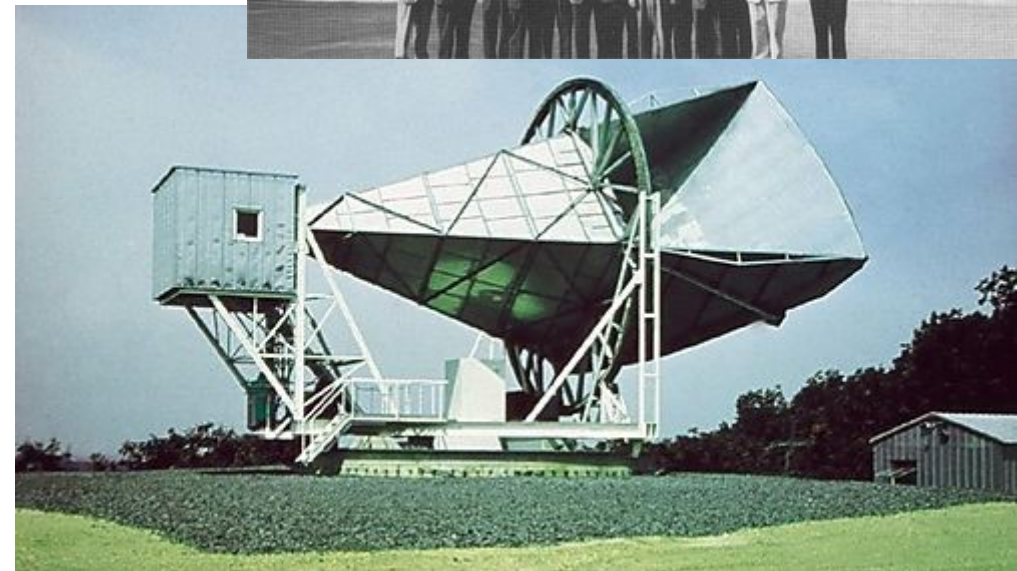
A composite image showing the expansion of the universe. On the left, a red sphere with arrows pointing outwards is labeled 'SPACE' and 'TIME'. In the center, a diagram shows the evolution of matter from a singularity through various stages (quarks, protons, neutrons, atoms) to the formation of galaxies. On the right, a blue background shows distant galaxies with arrows indicating their recession from a central point.

Pero si el Universo está en expansión....

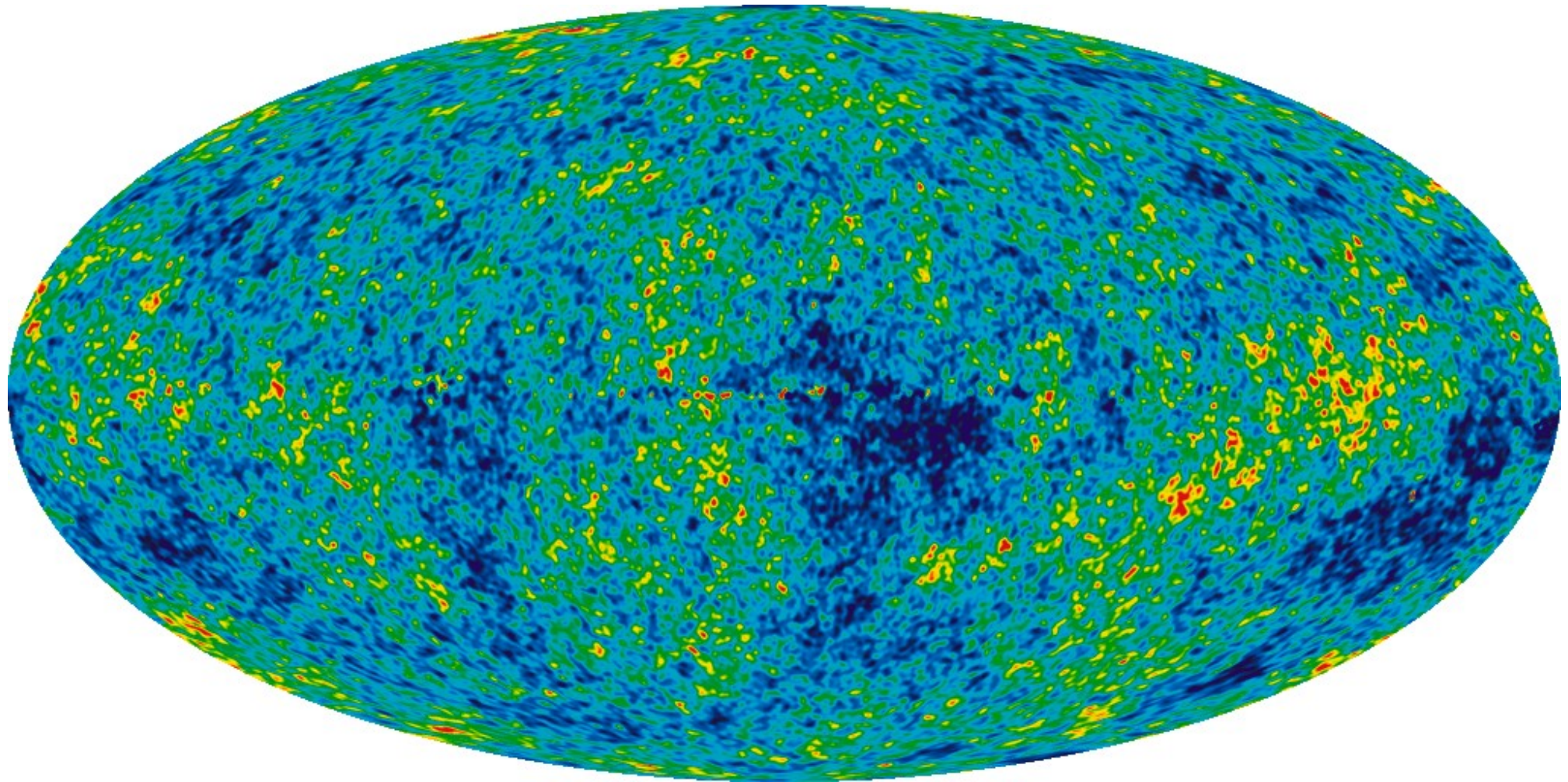
- ... siempre lo estuvo?
- Estado estacionario
 - Creación continua de materia (hidrógeno)
$$1 \frac{M_{\odot}}{Mpc^3}$$
 - Universo homogéneo e isótropo
- generación inicial
 - Principio cosmológico: las propiedades del Universo son las mismas para todos los observadores
 - Altas temperaturas y densidades
 - Expansión y enfriamiento

The Big Bang Theory

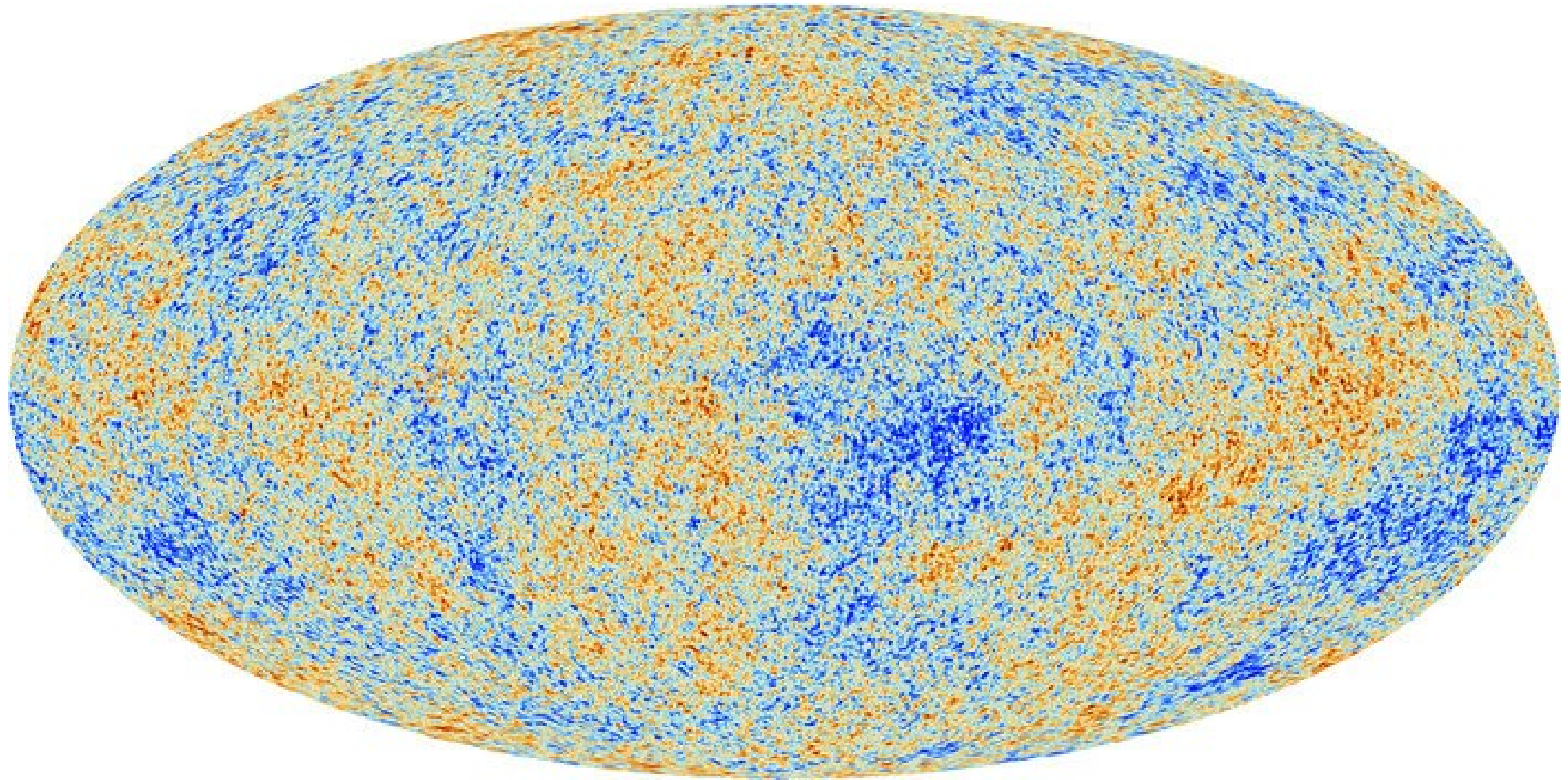
- Alpher & (Bethe) & Gamow → Paper alfabético
- Penzias & Wilson (1965)
- $\lambda = 7.35 \text{ cm}$
- ¿Energía? ¿Temperatura?



Radiación de fondo de microondas

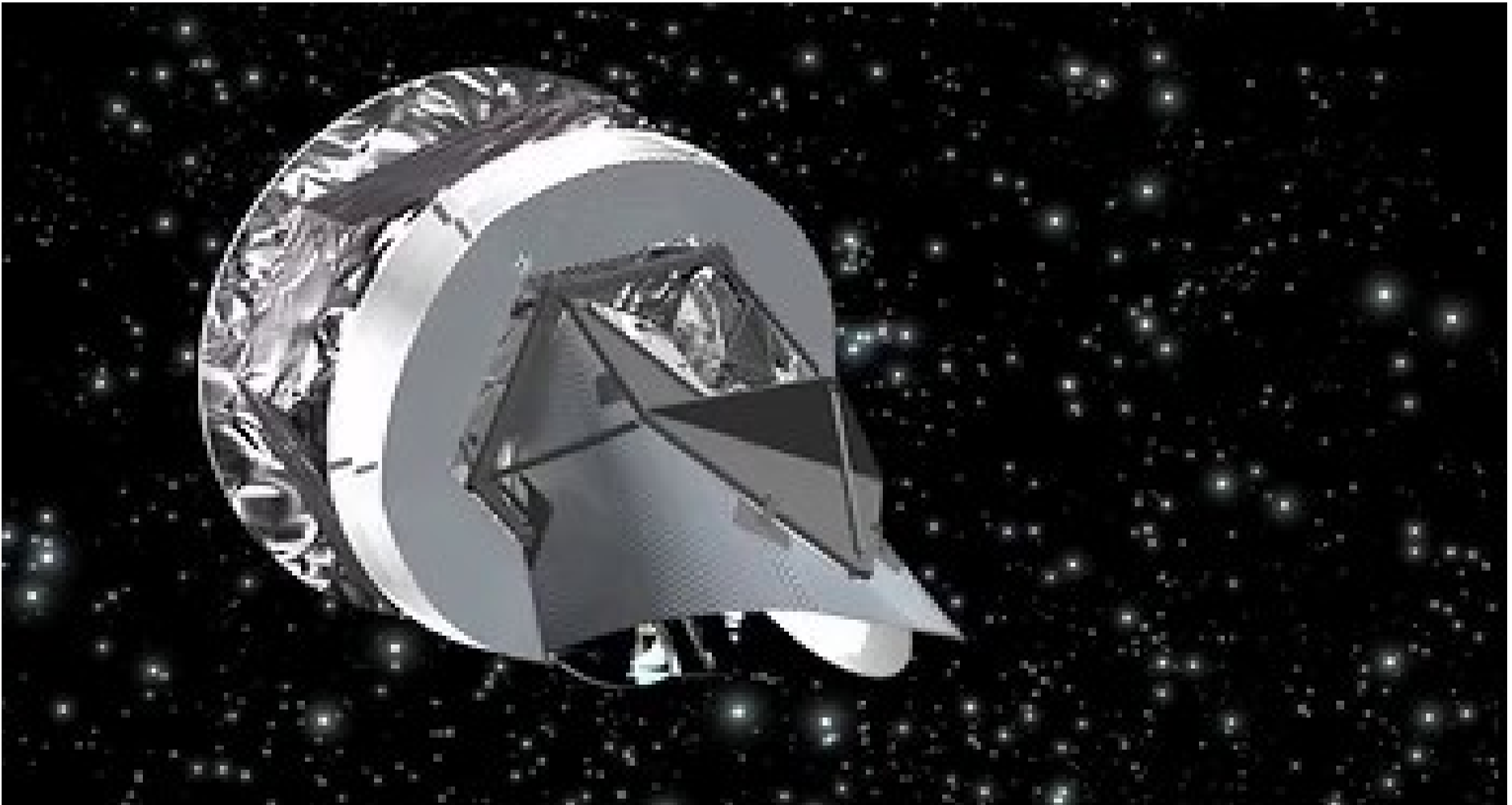


Radiación de fondo de microondas





Asi se construye



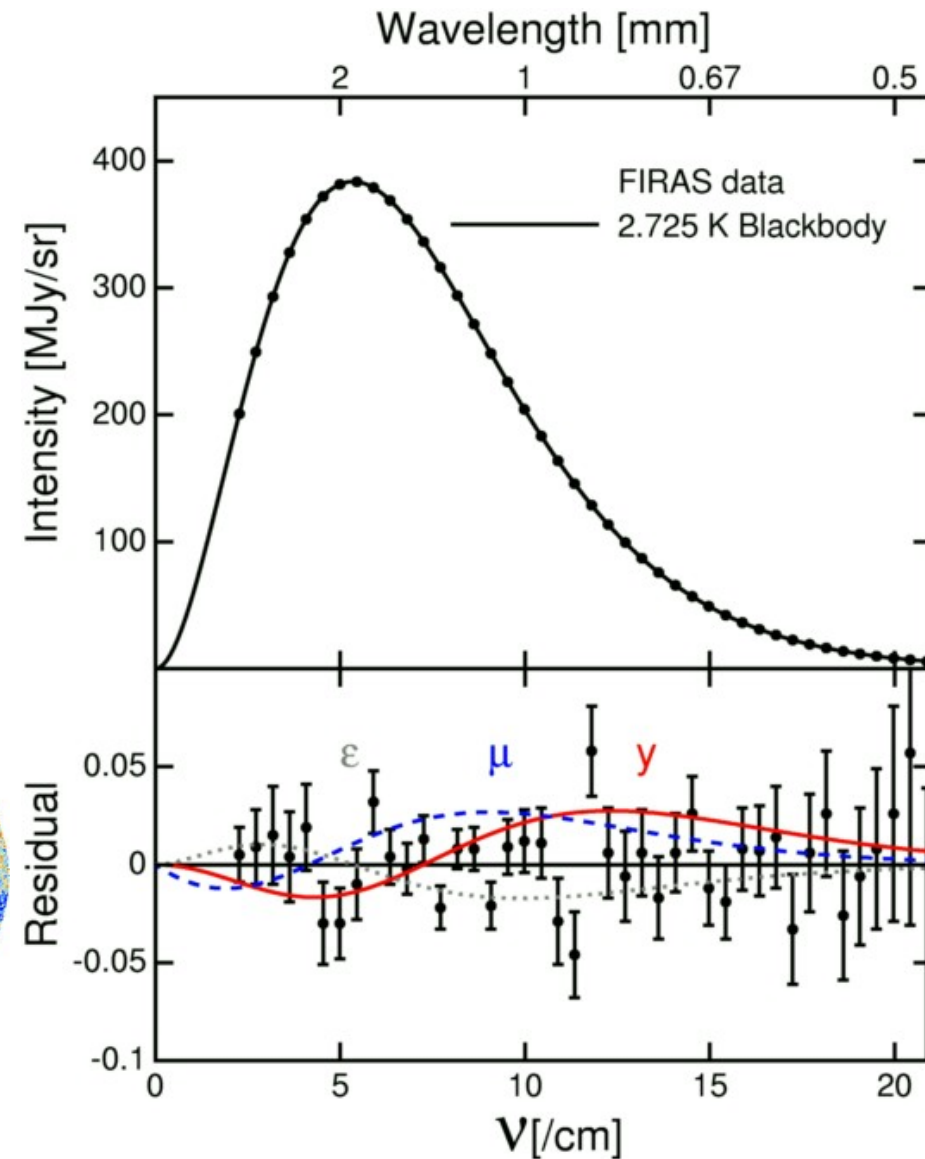
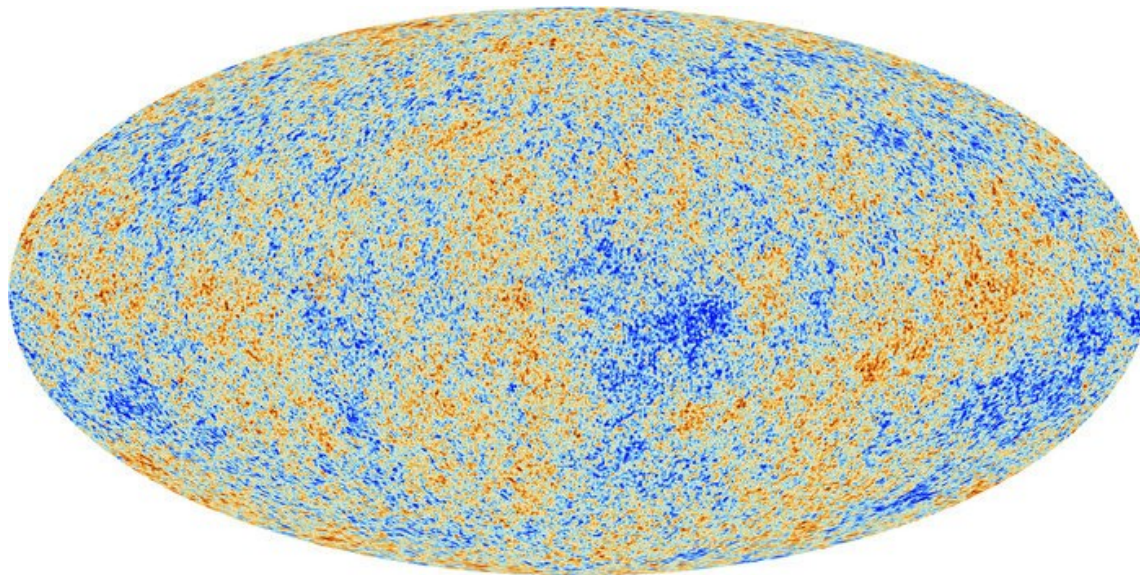
Radiación de fondo de microondas

- Radiación de cuerpo negro:

$$T = (2.726 \pm 0.0013) \text{ K}$$

$$n_\gamma = 430 \text{ fotones/cm}^3$$

$$\langle E_\gamma/V \rangle = 0.25 \text{ eV/cm}^3$$

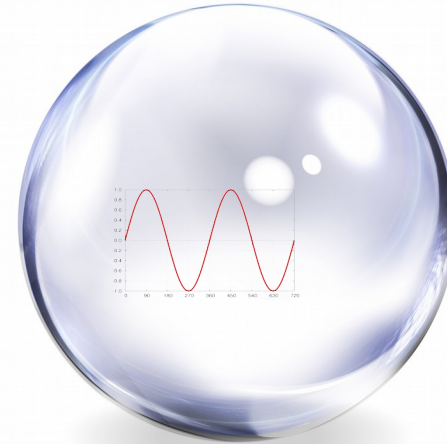


Materia y energía en la expansión

$$E = mc^2$$



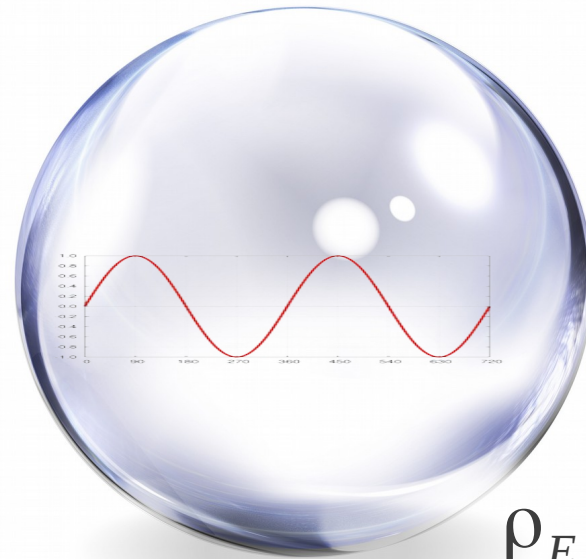
$$E = \frac{hc}{\lambda}$$



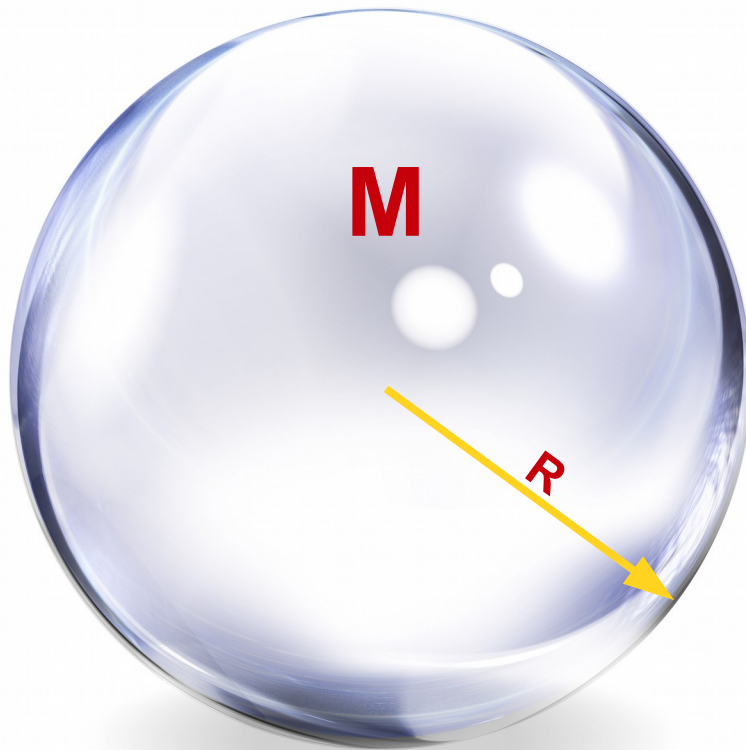
$$\rho_M \sim 1/R^3$$



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



¿La gravedad podrá compensar la expansión?



$$\frac{\rho_c}{m_p} = 6 \text{ protones}/m^3$$

- Densidad crítica:
Densidad para la cual la gravedad detendrá la expansión del Universo
- ¿Cómo podemos calcularla?

$$\rho_c = \frac{3 H_0^2}{8 \pi G}$$

$$\Omega_i \equiv \frac{\rho_i}{\rho_c}$$

Densidad crítica

La velocidad de expansión para un objeto en d es

$$v = H_0 d$$

Sea una esfera de radio R . Luego la superficie se aleja del centro con velocidad $v = H_0 R$

¿Podrá escapar de la atracción de la materia del interior?

$$v_E = \sqrt{\frac{2GM}{R}}$$

Si la esfera tiene densidad ρ y volumen $V \Rightarrow \rho = M/V \Rightarrow$

$$M = \rho \frac{4}{3} \pi R^3 \Rightarrow v_E^2 = \frac{2G}{R} \rho \frac{4}{3} \pi R^3 \Rightarrow \rho = \frac{3 v_E^2}{8\pi G R^2}$$

reemplazando $v_E^2 = H_0^2 R^2 \Rightarrow$

$$\rho_c = \frac{3 H_0^2 R^2}{8\pi G R^2} \Rightarrow$$

$$\rho_c = \frac{3 H_0^2}{8\pi G}$$

Densidad
crítica



Midiendo...

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

$$\Omega = 1.00 \pm 0.01$$





Alto, ¿cómo lo medimos...?

- La distribución de materia y energía del Universo, ¿es uniforme?
- ¿Cuánta materia y cuanta energía?
- ¿Qué otros factores debemos tener en cuenta?

A composite image showing the cosmic microwave background (CMB) on the left, a diagram of the universe's expansion from a singularity in the center, and various celestial objects like galaxies and nebulae on the right. The title 'Contenido de materia energía del Universo' is overlaid in large white text.

Contenido de materia energía del Universo

- Cómo se compone:
 - $\Omega_k = 10^{-5}$
 - $\Omega_\gamma = 0.002$
 - $\Omega_m = 0.04$
- Total esperado: $\Omega = 0.0421$
- Total medido: $\Omega = 1 \rightarrow$ problemas



Contenido de materia energía del Universo

- Cómo se compone:

- $\Omega_k = 0.001\%$

- $\Omega_\gamma = 0.2\%$

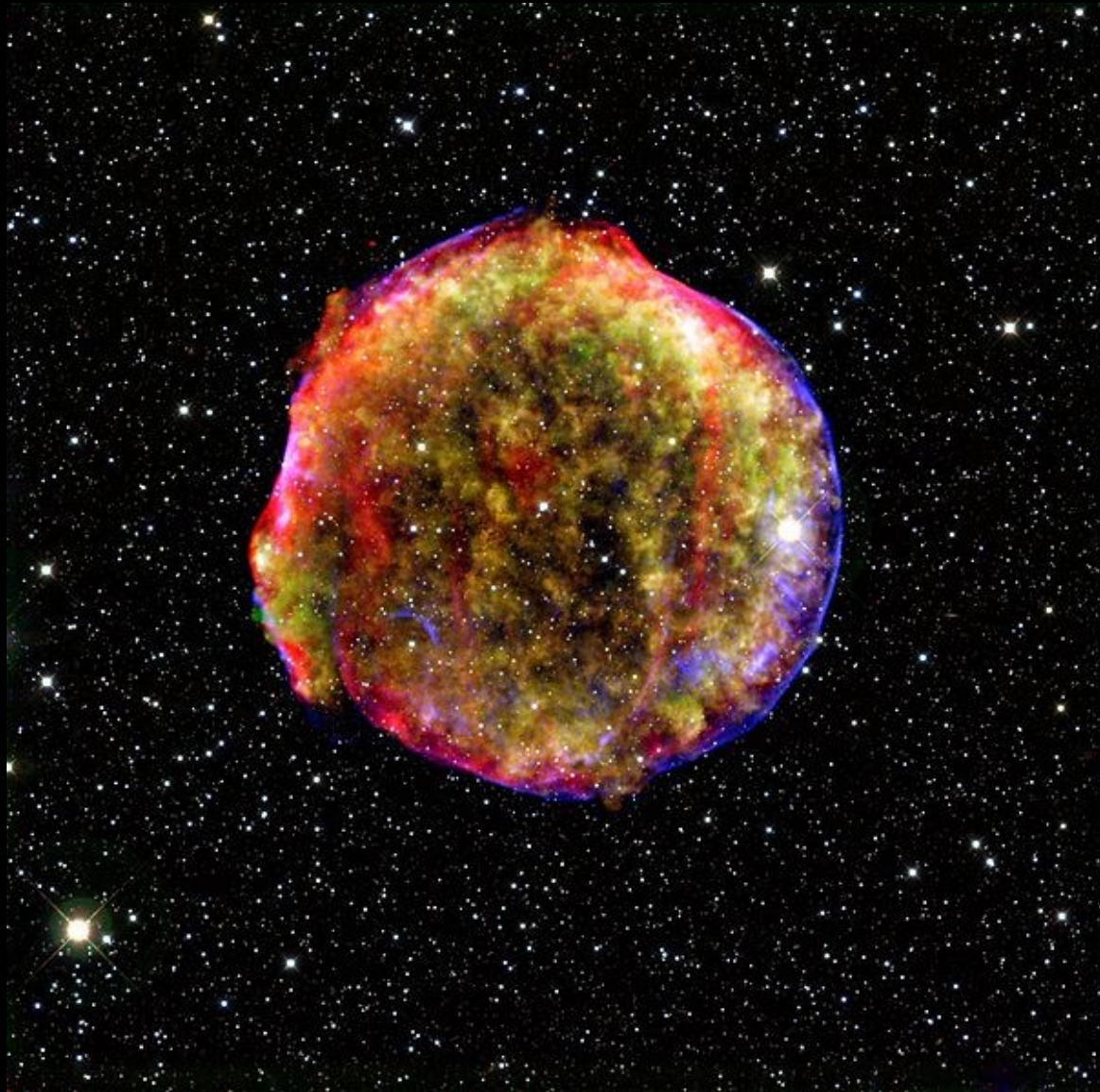
- $\Omega_m = 4\%$

- $\Omega_M = 23\%$

- $\Omega_E = 73\%$



Supernovas Ia



The progenitor of a Type Ia supernova

"Velas estándares"



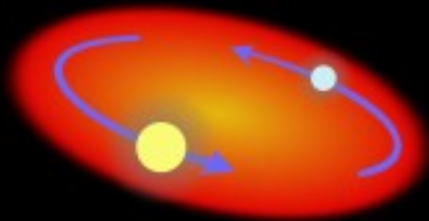
Two normal stars are in a binary pair.



The more massive star becomes a giant...



...which spills gas onto the secondary star, causing it to expand and become engulfed.



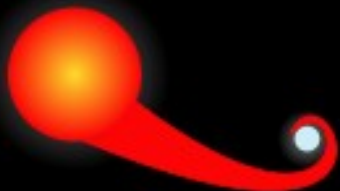
The secondary, lighter star and the core of the giant star spiral toward within a common envelope.



The common envelope is ejected, while the separation between the core and the secondary star decreases.



The remaining core of the giant collapses and becomes a white dwarf.



The aging companion star starts swelling, spilling gas onto the white dwarf.

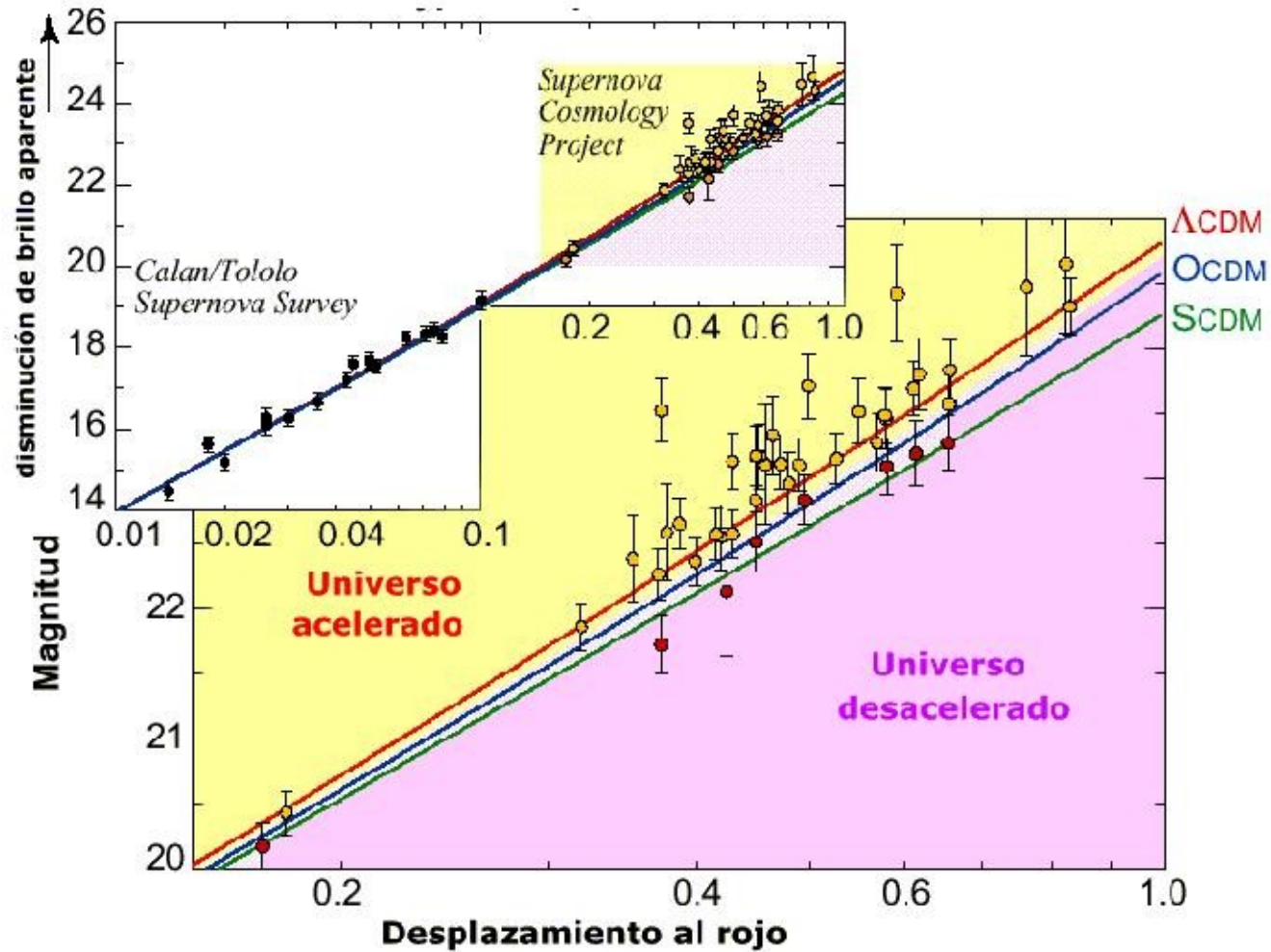


The white dwarf's mass increases until it reaches a critical mass and explodes...

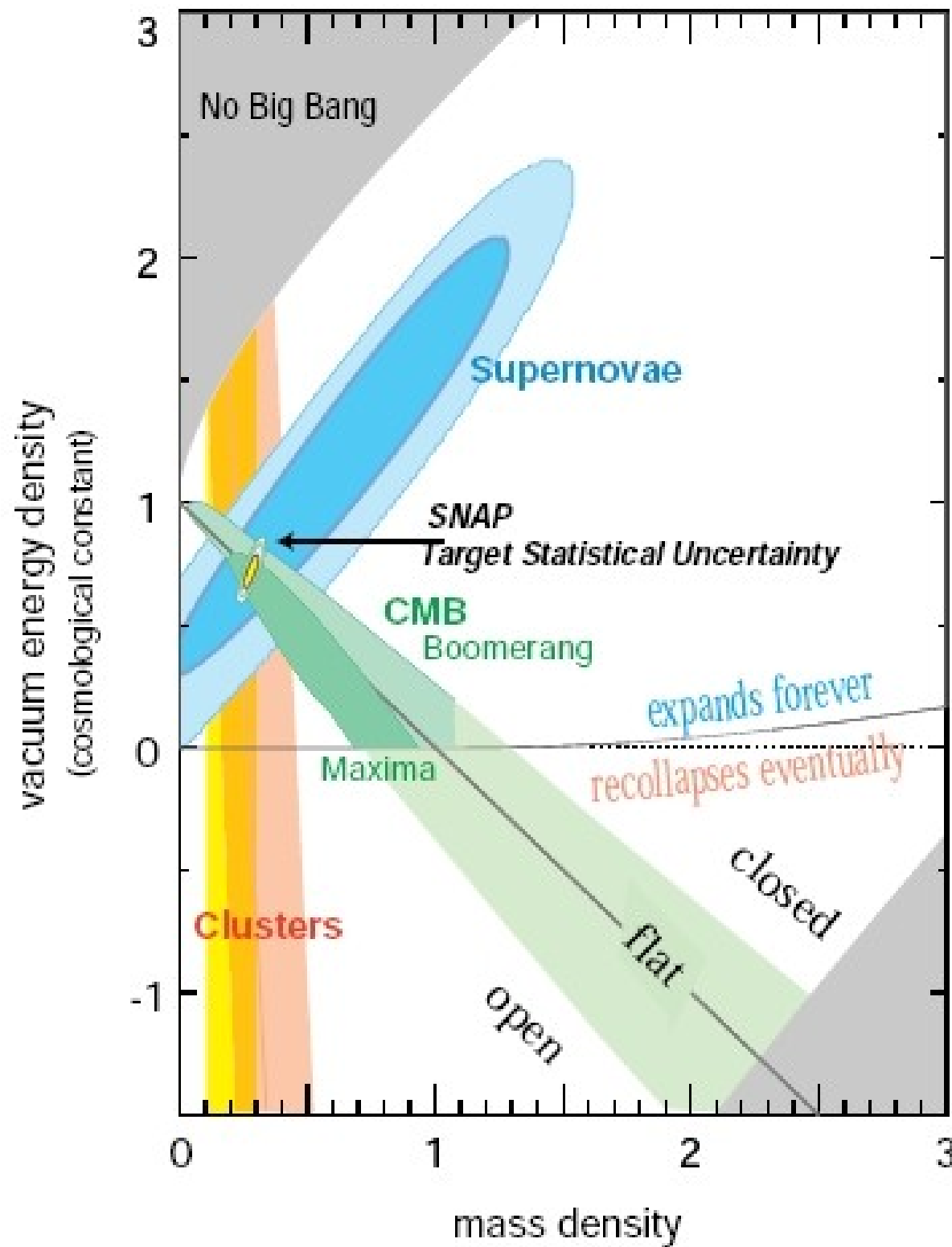


...causing the companion star to be ejected away.

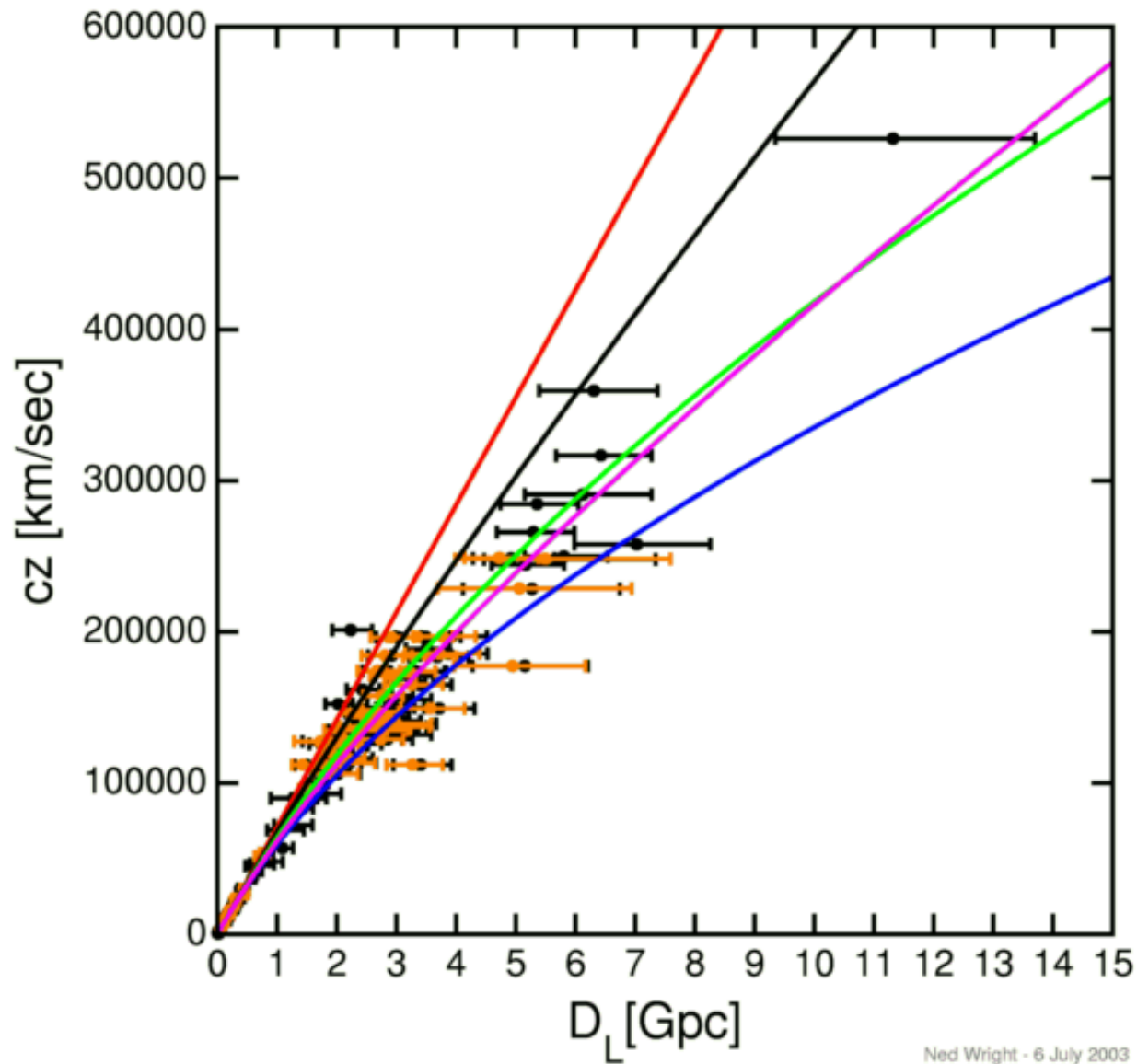
Expansión acelerada



elo cosmológico



El nuevo diagrama de Hubble





¿Como se explica el universo en expansión?

- Relatividad general