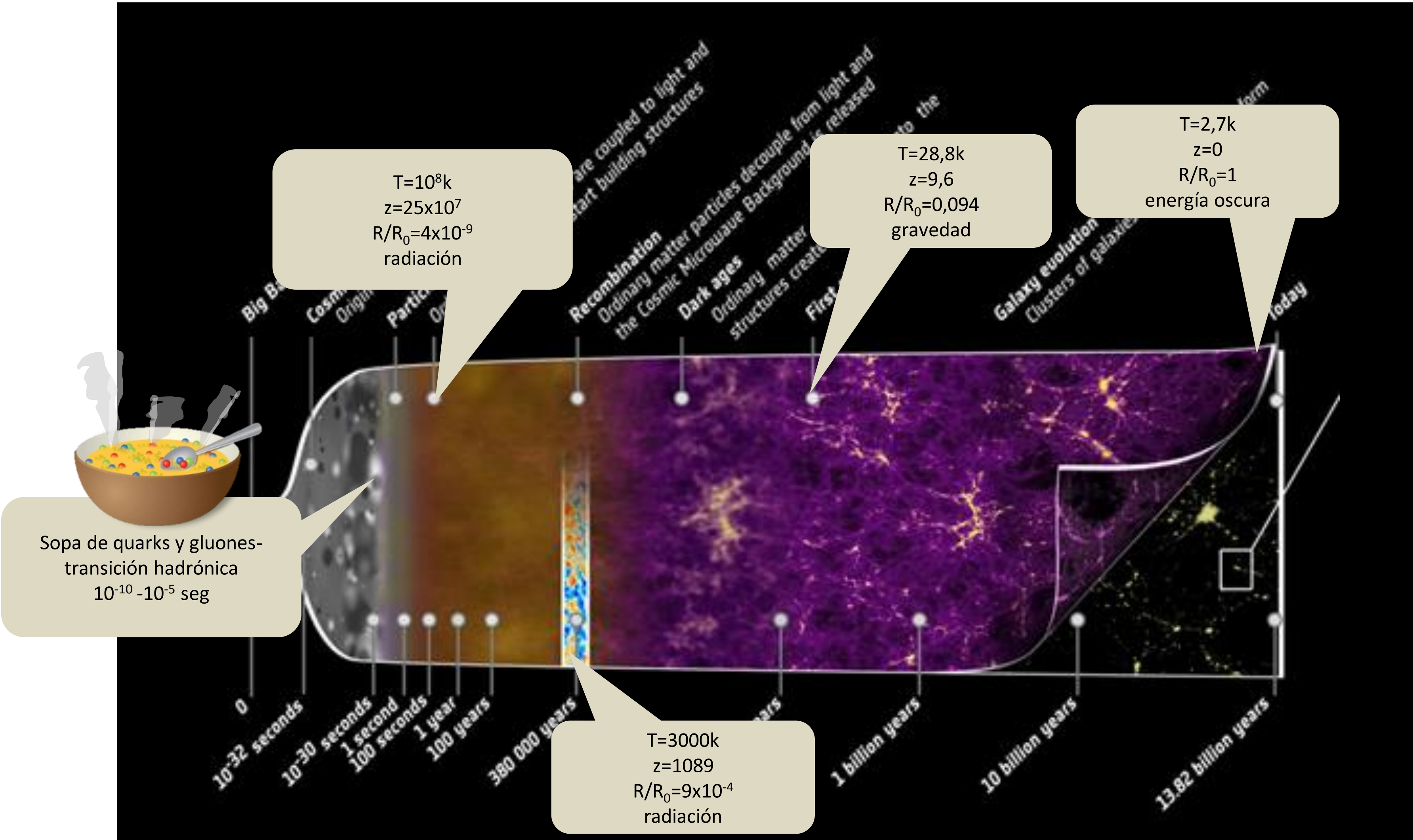
Mecánica Estadística

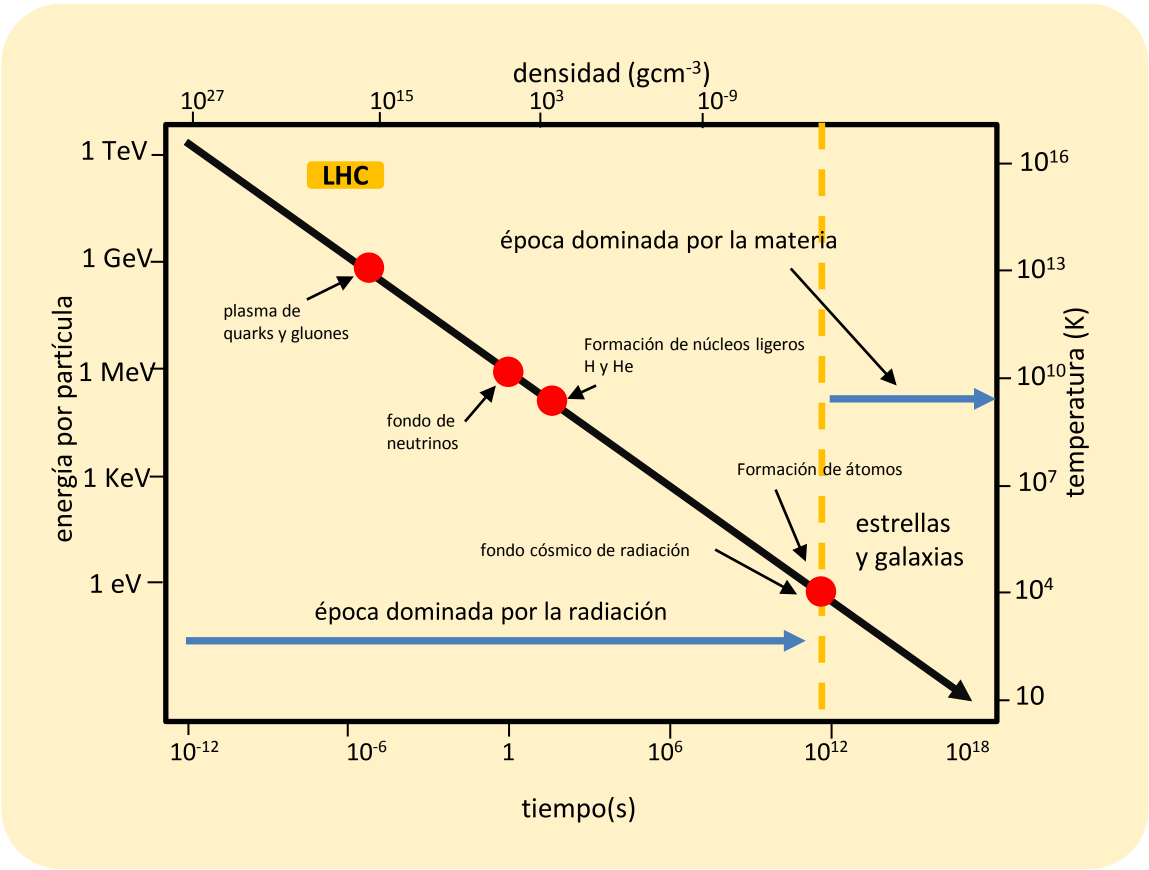
2015

Charla 2: cuchara Cosmología

Sopa de quarks y gluones

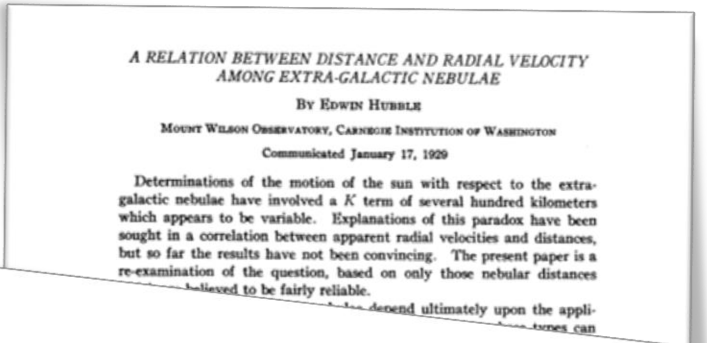


Sopa de quarks y gluones



J. Letessier, J. Rafelski. Hadrons quarks-gluon plasma (2004)

Ley de Hubble-1929



A RELATION BETWEEN DISTANCE AND RADIAL VELOCITY AMONG EXTRA-GALACTIC NEBULAE

By Edwin Hubble

Mount Wilson Observatory, Carnegie Institution of Washington

Communicated January 17, 1929

Determinations of the motion of the sun with respect to the extra-galactic nebulae have involved a K term of several hundred kilometers which appears to be variable. Explanations of this paradox have been sought in a correlation between apparent radial velocities and distances, but so far the results have not been convincing. The present paper is a re-examination of the question, based on only those nebular distances ... believed to be fairly reliable.

... depend ultimately upon the appli- ... types can

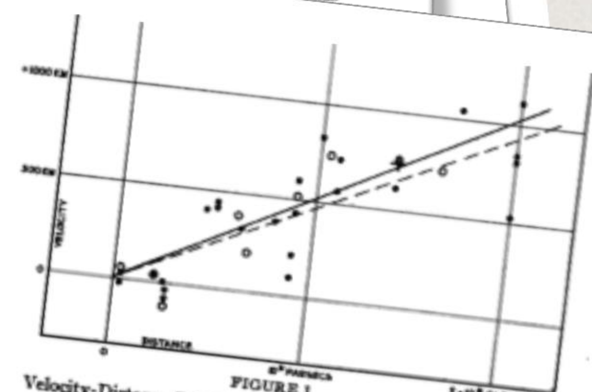
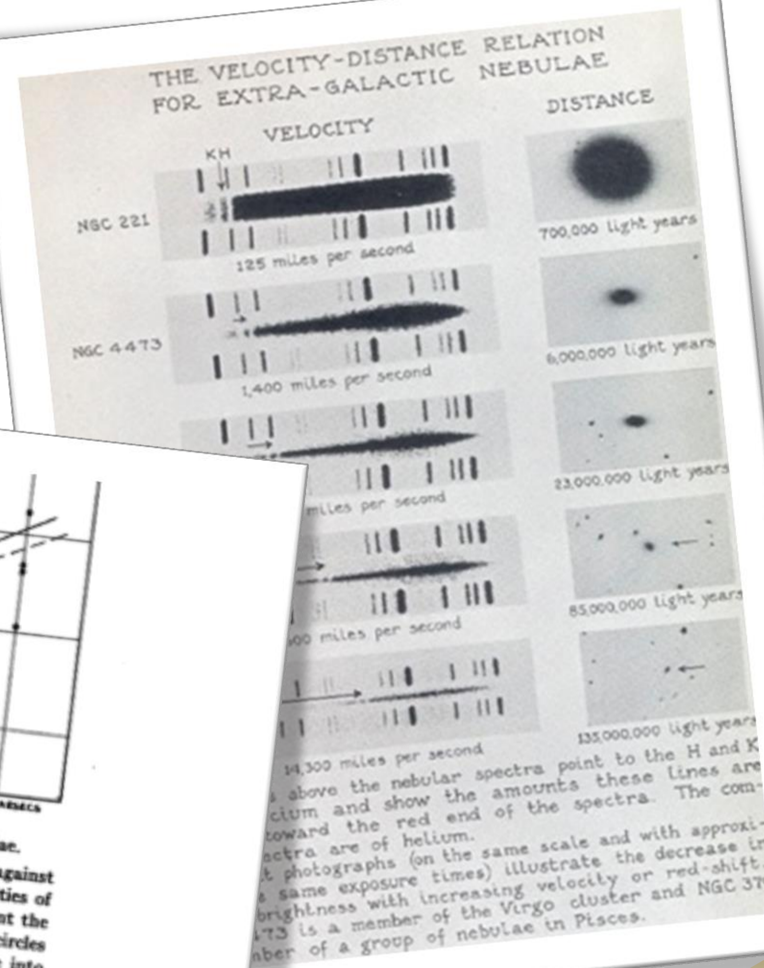


FIGURE 1

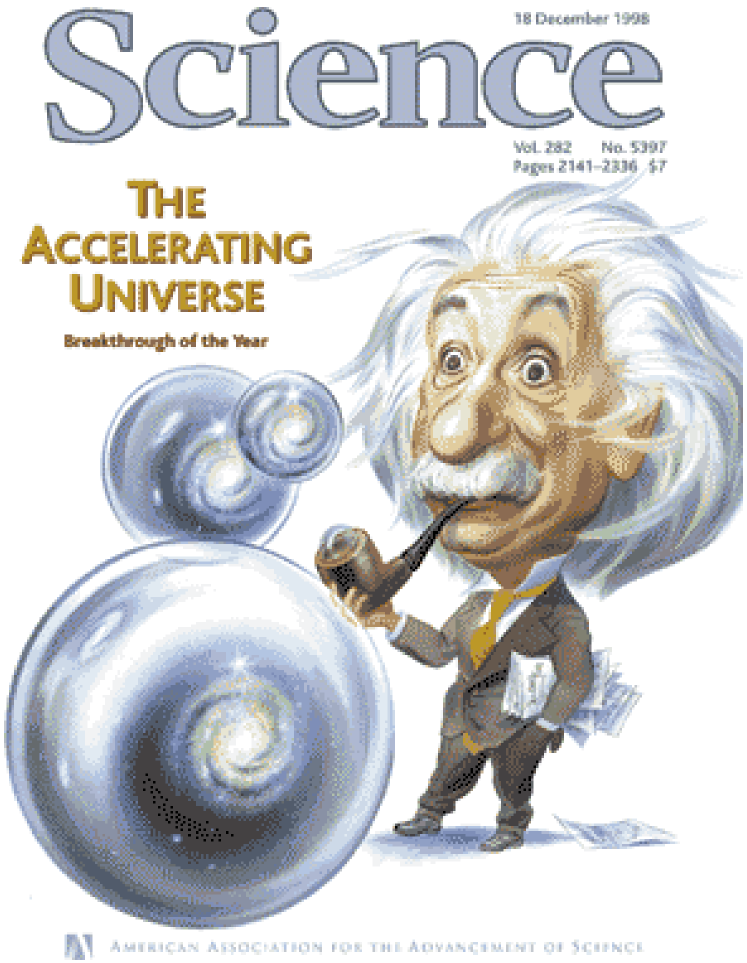
Velocity-Distance Relation among Extra-Galactic Nebulae.

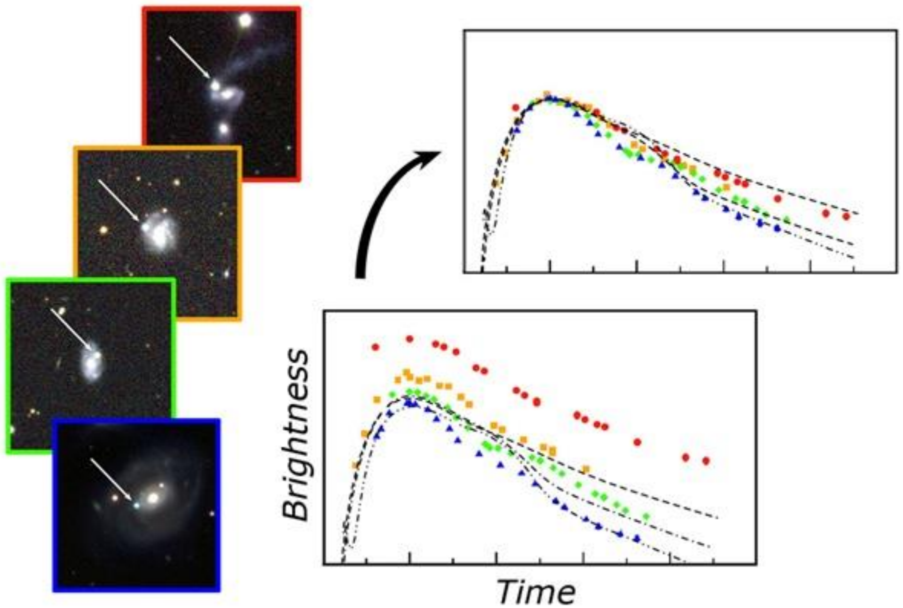
Radial velocities, corrected for solar motion, are plotted against distances estimated from involved stars and mean luminosities of nebulae in a cluster. The black discs and full line represent the solution for solar motion using the nebulae individually; the circles and broken line represent the solution combining the nebulae into groups; the cross represents the mean velocity corresponding to the mean distance of 22 nebulae whose distances could not be estimated individually.



Hubble, E. (1929). "A relation between distance and radial velocity among extra-galactic nebulae". Proceedings of the National Academy of Sciences 15 (3): 168–73.

Supernovas tipo Ia-1998





Hamuy, M., Phillips, M.M., Suntzeff, N.B., Schommer, R.A., Maza, J., & Aviles, R. The Hubble diagram of the Calan/Tololo Type Ia supernovae and the value of Ho. AJ, 112, 2398 (1996).
J. Glanz. Astronomy: cosmic motion revealed. Science Vol. 282 no. 5397 pp. 2156-2157 (1998)

Abundancia relativa de elementos

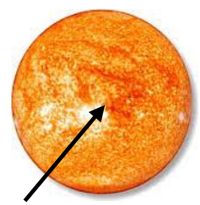
3min después del Big Bang

$T=10^8 k$

$z=25x10^7$

$R/R_0=4x10^{-9}$

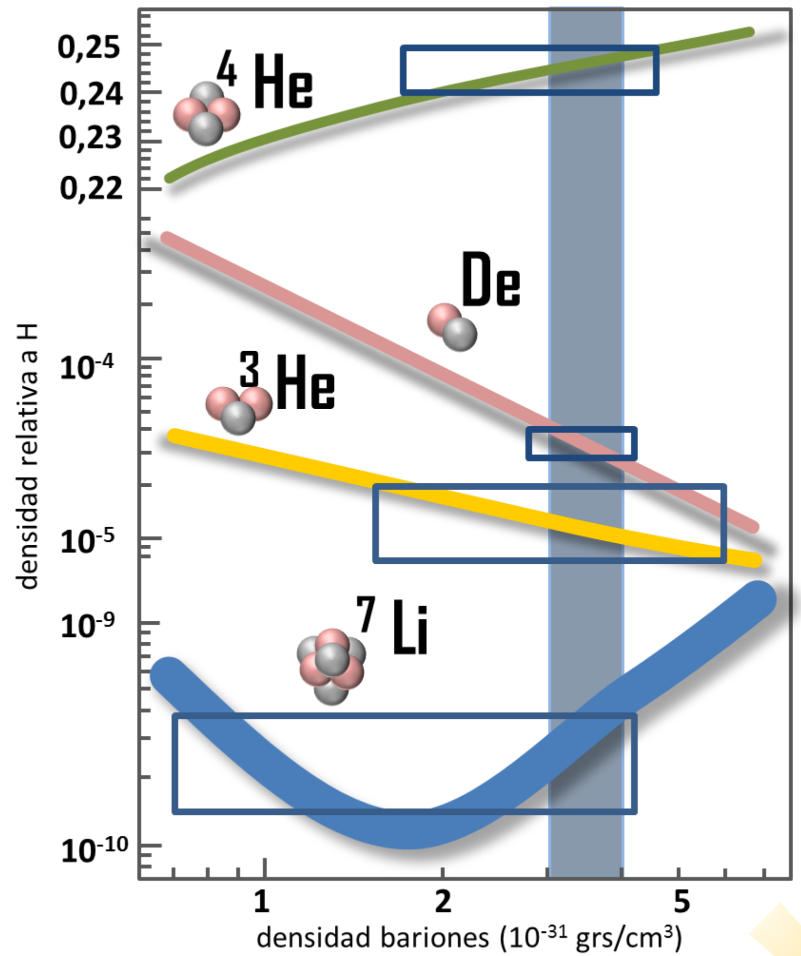
radiación



$T_{centro\ del\ sol} = 11x10^6 K$

76% protones libres

- 24% ^4He
- $4x10^{-5}$ D
- 10^{-5} ^3He
- 10^{-9} ^7Be
- 10^{-10} ^7Li



B Scott Burles, Kenneth M. Nollett and Michael S. Turner. BIG BANG NUCLEOSYNTHESIS PREDICTIONS FOR PRECISION COSMOLOGY. The Astrophysical Journal, 552:L1–L5, 2001 May 1

Fondo cósmico de microondas

- 300.000 años después del Big Bang

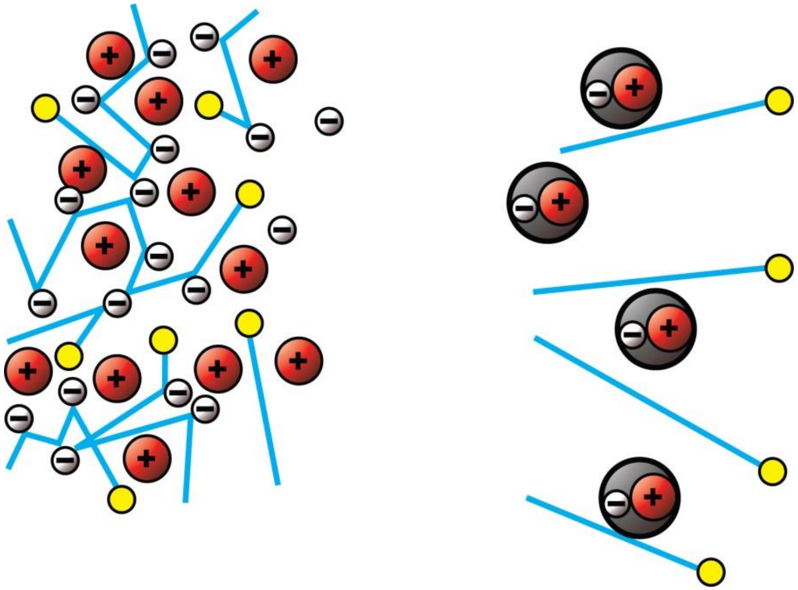
T=3000k

z=1089

$R/R_0=9x10^{-4}$

radiación

$T_{superficie\ del\ sol} = 6x10^3 K$

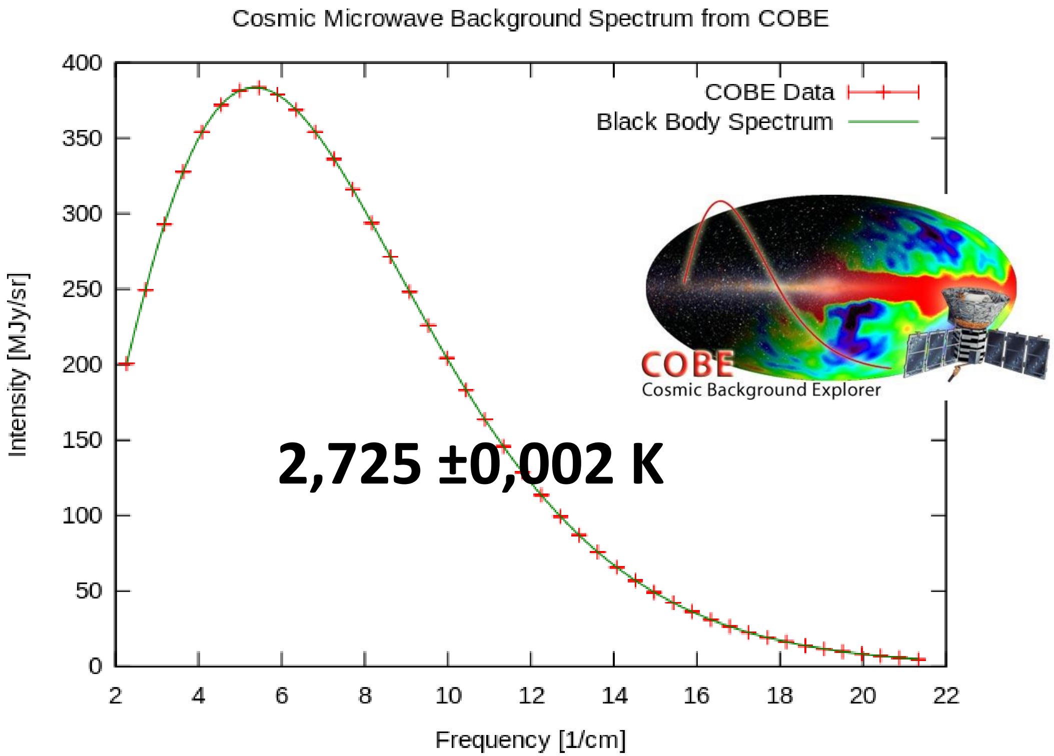


Fondo cósmico de microondas-1964

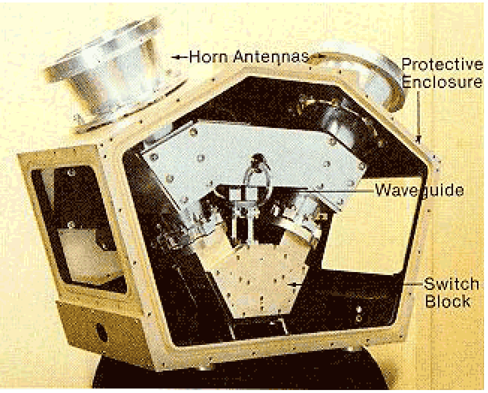
cuchara

Penzias, A. A.; Wilson, R. W. A Measurement of Excess Antenna Temperature at 4080 Mc/s. Astrophysical Journal, vol. 142, p.419-421.1965

Cosmic Background Explorer-1989



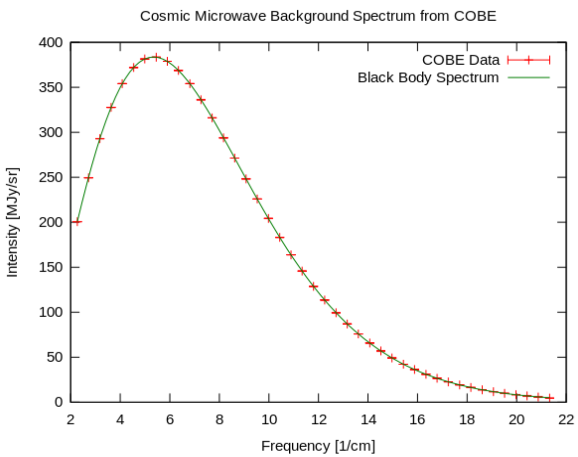
2,725 ±0,002 K



The 9.6 mm DMR receiver partially assembled. Corrugated cones are antennas.

J.C. Mather, E.S. Cheng, R.E. Eplee, Jr., R.B. Isaacman. A PRELIMINARY MEASUREMENT OF THE COSMIC MICROWAVE BACKGROUND SPECTRUM BY THE COSMIC BACKGROUND EXPLORER (COBE) SATELLITE Preprint No. 90-01 Astrophysical Journal, 354, L37 (1990)

Fondo cósmico de microondas



$$I(T) = \frac{2h}{c^2}\frac{\nu^3}{e^{h\nu/kT} - 1}$$ Ley de Planck

$$\lambda_{max} = \frac{2{,}9x10^{-3}mK^{-1}}{T}$$ Ley de Wien

➡ $\mathrm{T} = 2{,}725 \ \pm 0{,}002\ K$

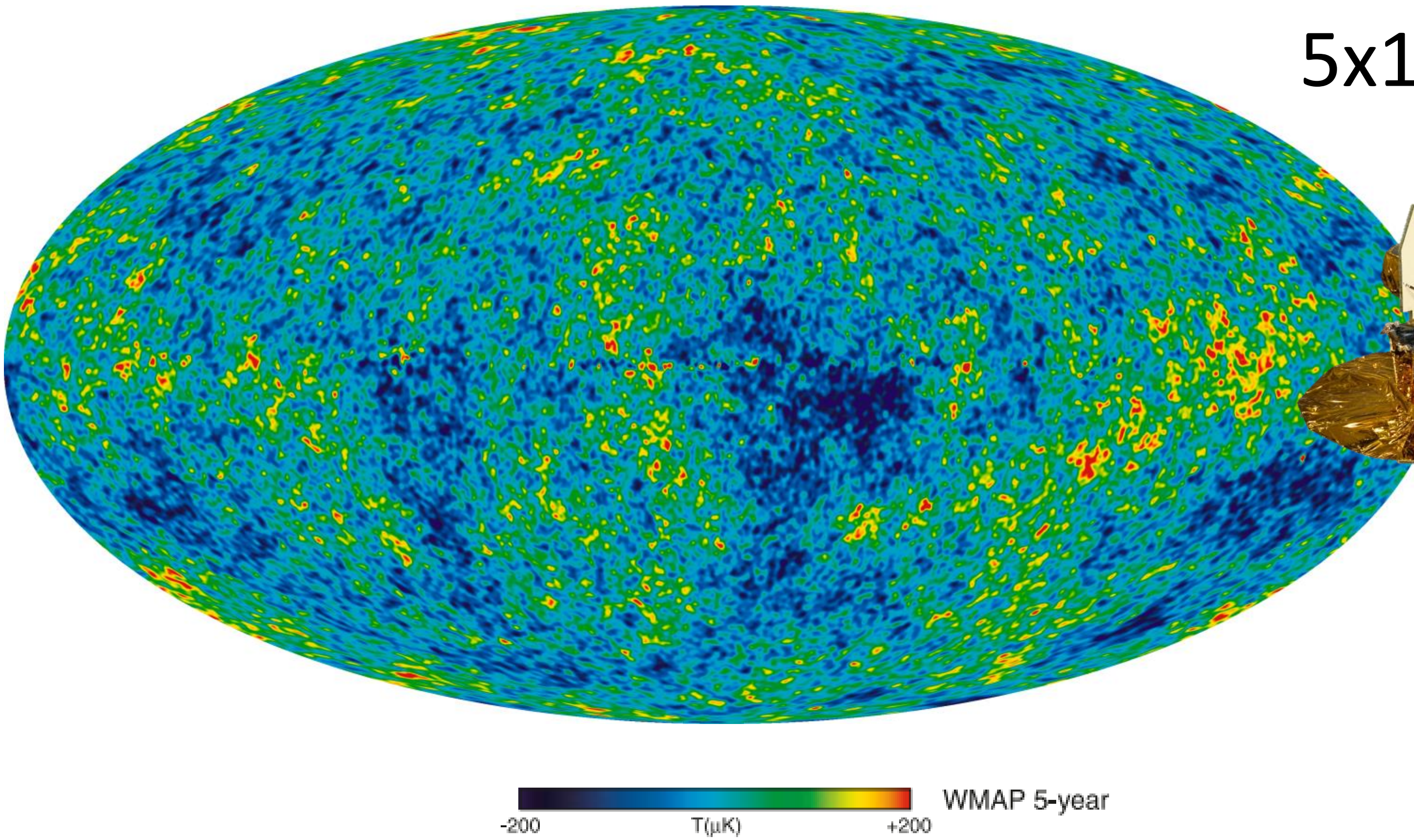
$$n_\gamma = \frac{N}{V} = \beta T^3 = \frac{2{,}404k^3}{\pi^2\hbar^3c^3} = (\frac{2{,}03x10^7}{m^3K^3})T^3 = \frac{4{,}11x10^8}{m^3}$$

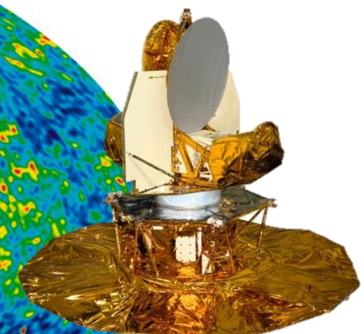
$$\eta = \frac{n_{bar}}{n_\gamma} = \frac{0{,}22m^{-3}}{4{,}11x10^8m^{-3}} = 5{,}5x10^{-10}$$

$$\lambda_{max} \cong 1mm$$

Wilkinson Microwave Anisotropy Probe-2001

$5x10^{-5}K$

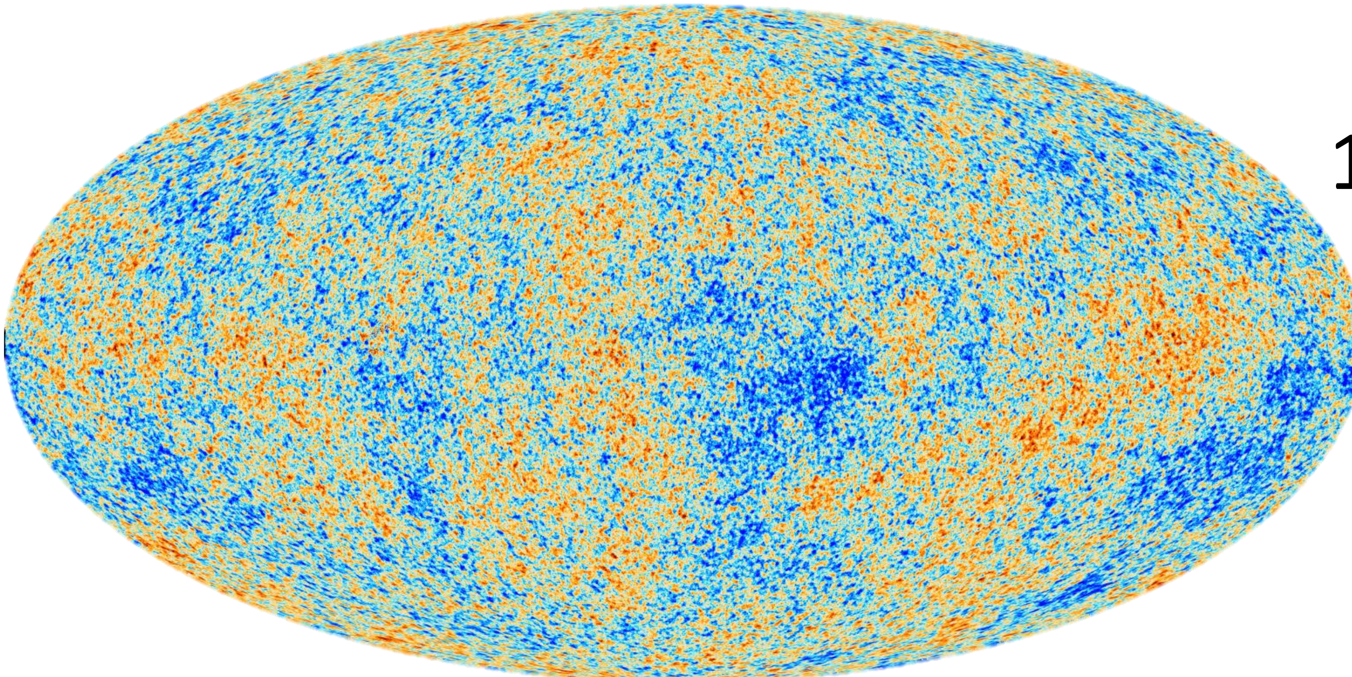




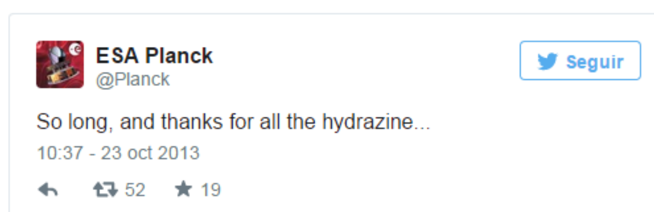
Bennett, C.L., et.al., Nine-Year Wilkinson Microwave Anisotropy Probe (WMAP) Observations: Final Maps and Results . ApJS., 208, 20B (2013).

Planck-2009

planck



$1x10^{-6}K$



http://www.cosmos.esa.int/web/planck/publications

Anisotropías del fondo cósmico de microondas

$$C(\theta) = \left\langle \frac{\delta T}{T}(n)\frac{\delta T}{T}(n')\right\rangle_{n.n'=\cos(\theta)}$$

$$C(\theta) = \frac{1}{4\pi}\sum_{l=0}^{\infty}(2l+1)C_l P_l(\cos(\theta))$$

$$(\Delta T)^2 = \left(\frac{l(l+1)}{2\pi}C_l\right)\langle T\rangle^2$$

potencia angular

$$\theta = \frac{180}{l}$$

ángulo

multipolo

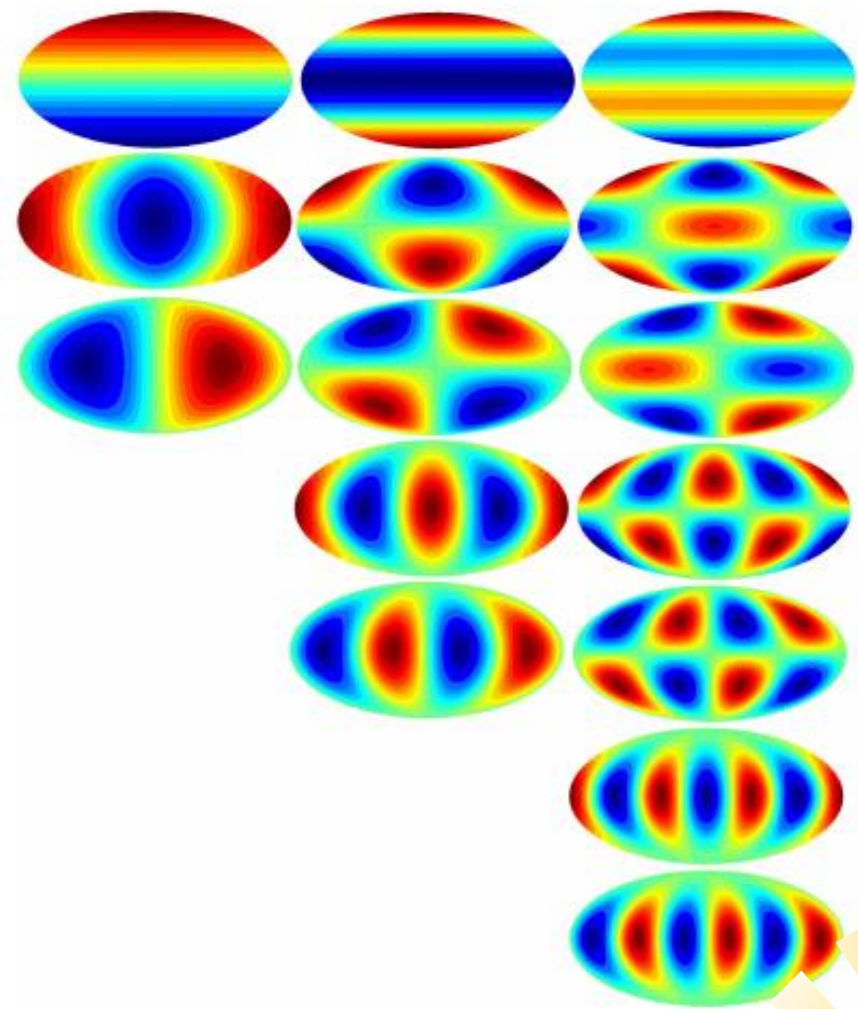
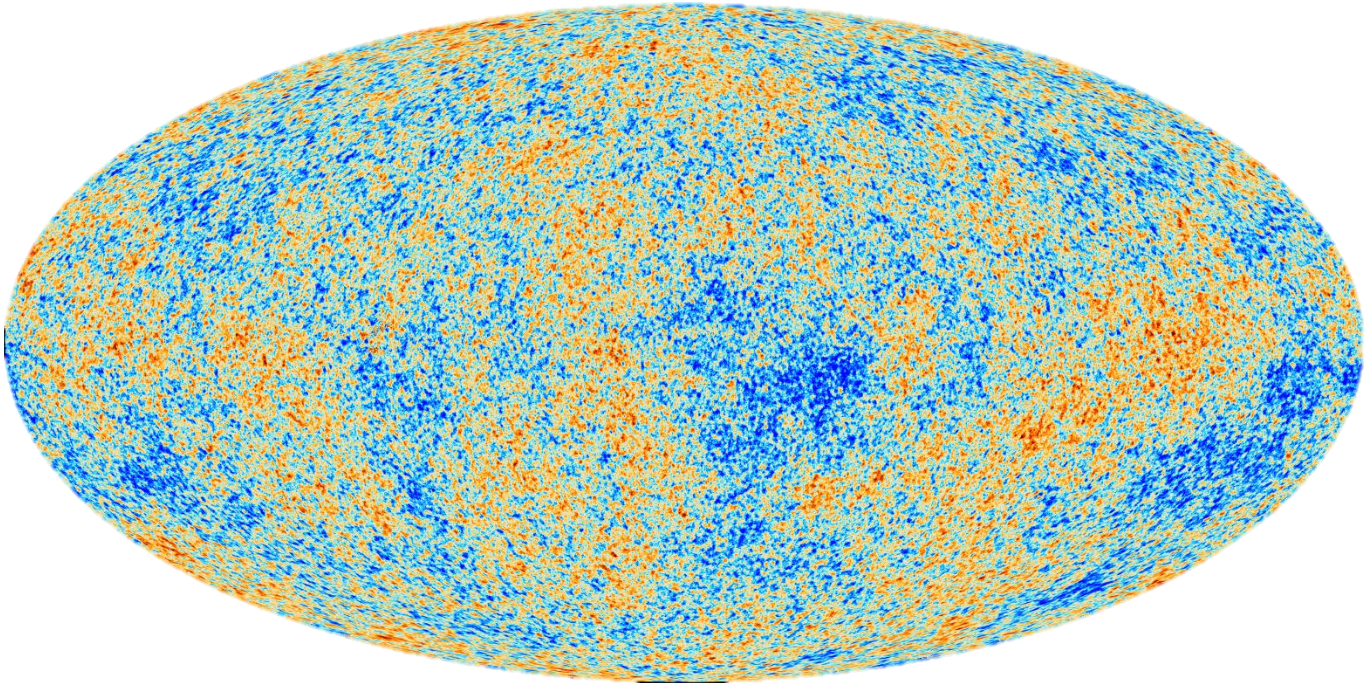
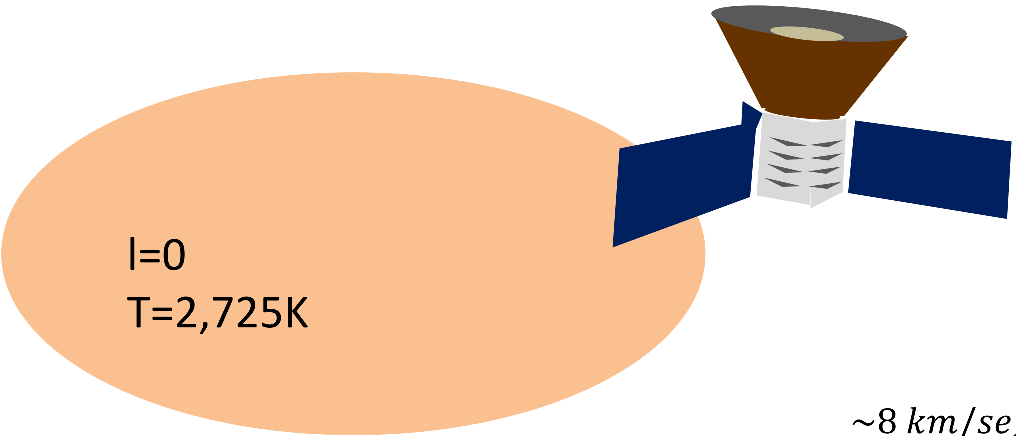


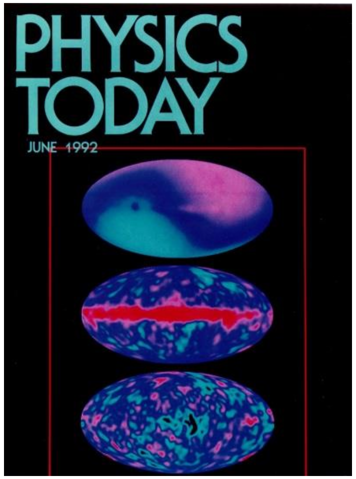
Figure 4: The three lowest multipoles $\ell = 1, 2, 3$ of spherical harmonics. Left ... : Y_{10}, $\mathrm{Re}\,Y_{11}$, $\mathrm{Im}\,Y_{11}$. Middle column: Y_{20}, $\mathrm{Re}\,Y_{21}$, $\mathrm{Im}\,Y_{21}$, $\mathrm{Re}\,Y_{22}$, $\mathrm{Im}\,Y_{22}$. Right colum... $\mathrm{Re}\,Y_{31}$, $\mathrm{Im}\,Y_{31}$, $\mathrm{Re}\,Y_{32}$, $\mathrm{Im}\,Y_{32}$, $\mathrm{Re}\,Y_{33}$, $\mathrm{Im}\,Y_{33}$. Figure by Ville Heikkilä.

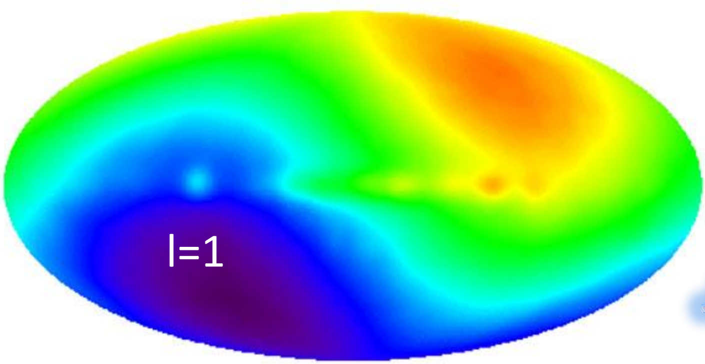
Anisotropías del fondo cósmico de microondas



Anisotropías del fondo cósmico de microondas

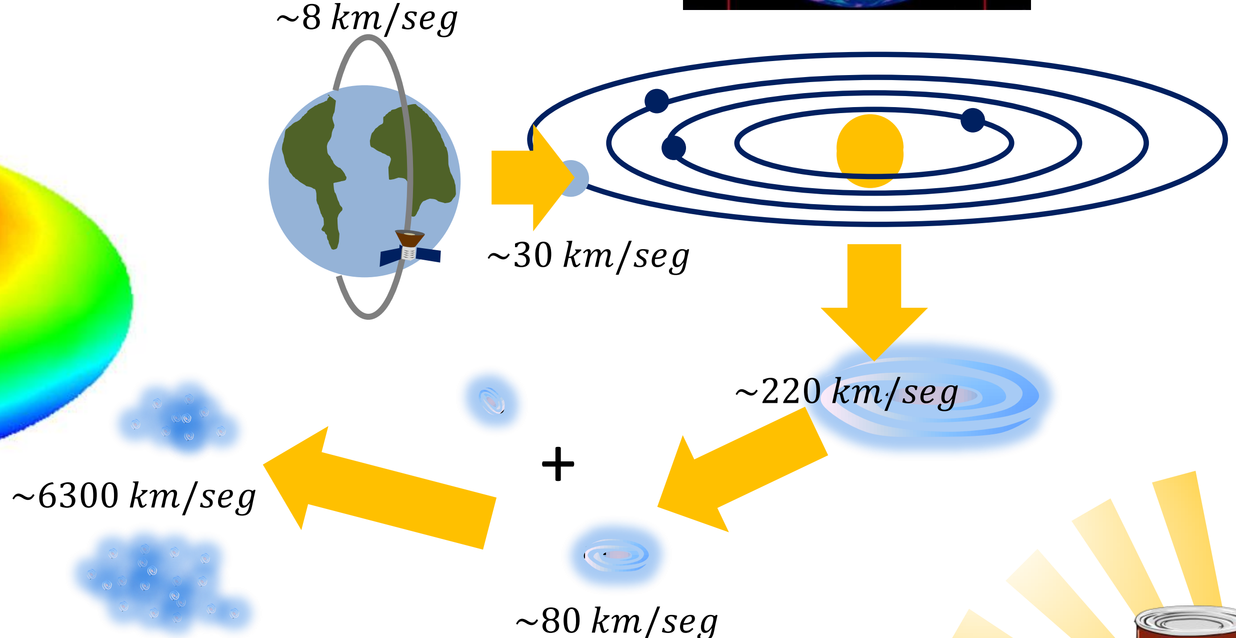




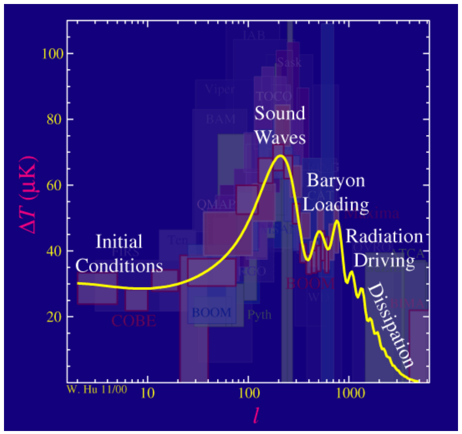


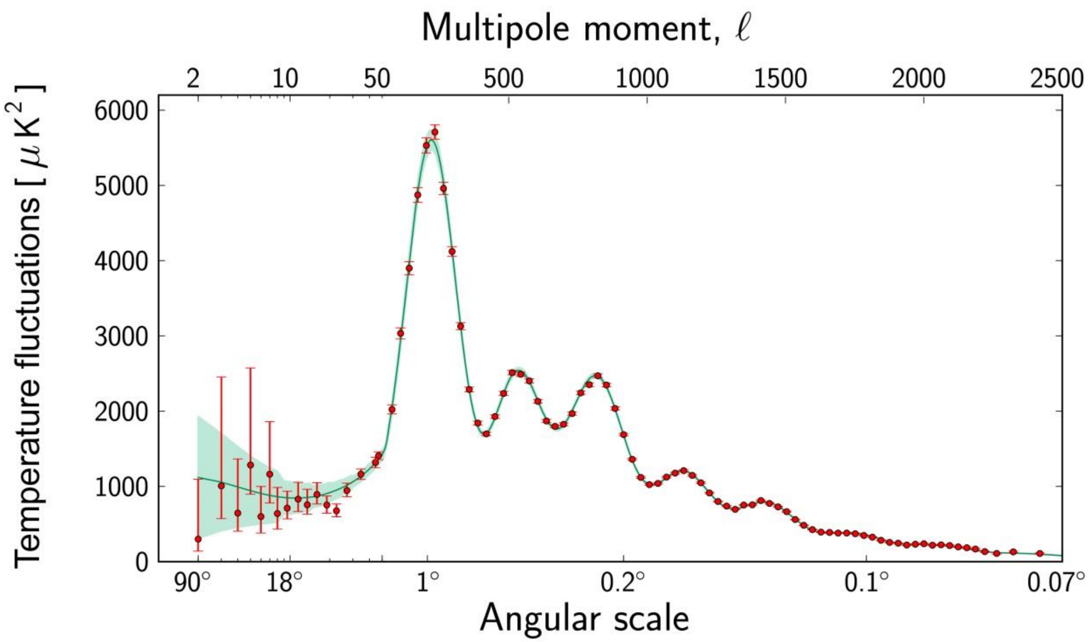
dipolo

$\Delta T = 3{,}35 mK$



Anisotropías del fondo cósmico de microondas





➡ pico principal

$$l = 200$$

$$\theta = 1^0$$

$\theta > 1^0$ fluctuaciones primordiales de densidad
regiones no conectadas causalmente

$\theta < 1^0$ fluctuaciones del plasma de bariones y fotones
horizonte acústico zonas conectadas causalmente
por ondas de presión

Anisotropías del fondo cósmico de microondas

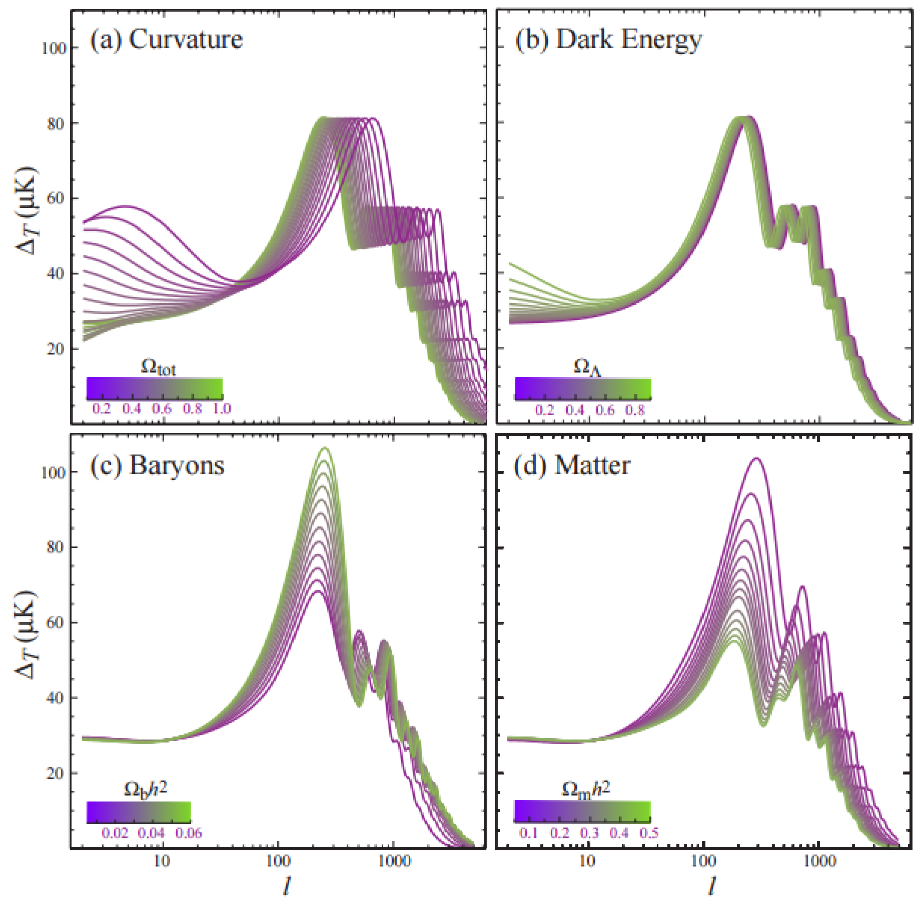


Plate 4: Sensitivity of the acoustic temperature spectrum to four fundamental cosmological parameters (a) the curvature as quantified by Ω_{tot} (b) the dark energy as quantified by the cosmological constant Ω_Λ ($w_\Lambda = -1$) (c) the physical baryon density $\Omega_b h^2$ (d) the physical matter density $\Omega_m h^2$, all varied around a fiducial model of $\Omega_{tot} = 1$, $\Omega_\Lambda = 0.65$, $\Omega_b h^2 = 0.02$, $\Omega_m h^2 = 0.147$, $n = 1$, $z_{ri} = 0$, $E_i = 0$.

W Hu and S Dodelson. Cosmic Microwave Background Anisotropies. Annu. Rev. Astron. and Astrophys. (2002).

Sopa de quarks

- kT~150MeV

$$\gamma + \gamma \leftrightarrow q + \bar{q}$$

$$q + \bar{q} \rightarrow \gamma + \gamma$$

$$\delta_q = \frac{n_q - n_{\bar{q}}}{n_q + n_{\bar{q}}} \ll 1$$

$$n_\gamma \approx n_q + n_{\bar{q}}$$

$$n_{bar} = \frac{1}{3}(n_q - n_{\bar{q}})$$

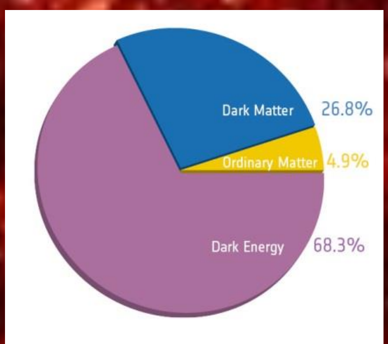
$$\delta_q = \frac{n_q - n_{\bar{q}}}{n_q + n_{\bar{q}}} = \frac{3n_{bar}}{n_\gamma} = 3\eta \approx 3x5{,}5x10^{-10}$$

Sopa de quarks

1.000.000.000 quarks

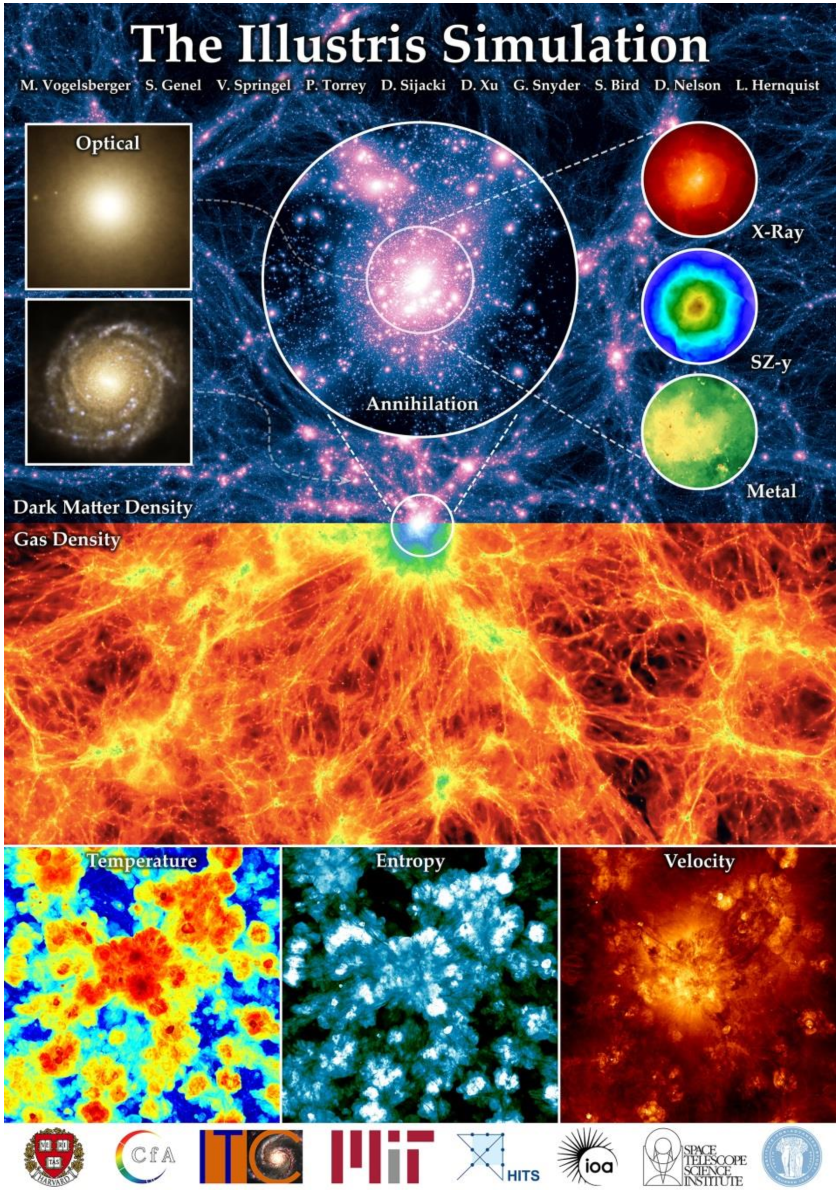
999.999.998 antiquarks

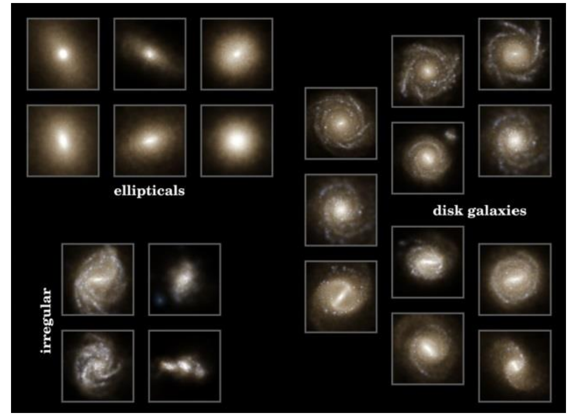
Modelo Lambda-CDM

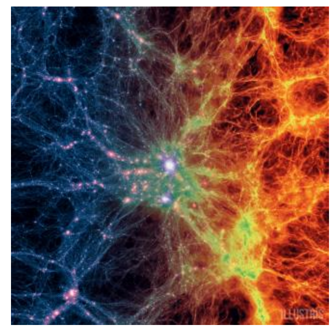


parámetro	valor	Descripción
parámetros básicos		
H_0	73,2±2 km $s^{-1}Mpc^{-1}$	parámetro de Hubble
Ω_b	0,0444±0,0004	densidad bariónica
Ω_m	0,266±0,02	densidad total de materia (bariónica +oscura)
T	0,079±0,03	camino óptico
A_s	0,813±0,04	amplitud de fluctuación escalar
n_s	0,948±0,01	índice espectral escalar

Illustris







12 millones de años-presente.
12 billones de elementos.
16 millones de horas de CPU con 8192 núcleos MPI-racks.
3 millones de horas CPU análisis de datos

M. Vogelsberger,et. al. Properties of galaxies reproduced by a hydrodynamic simulation. Nature 509, 177–182 (2014).