Ecuación
de estado
del universo


Parte 3:
The
end

Expansión

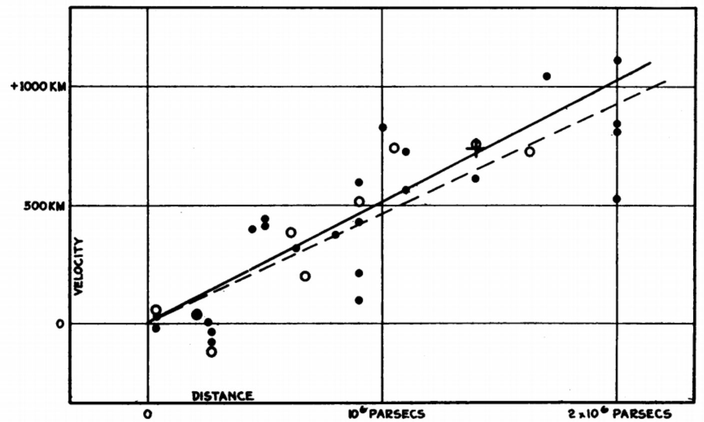
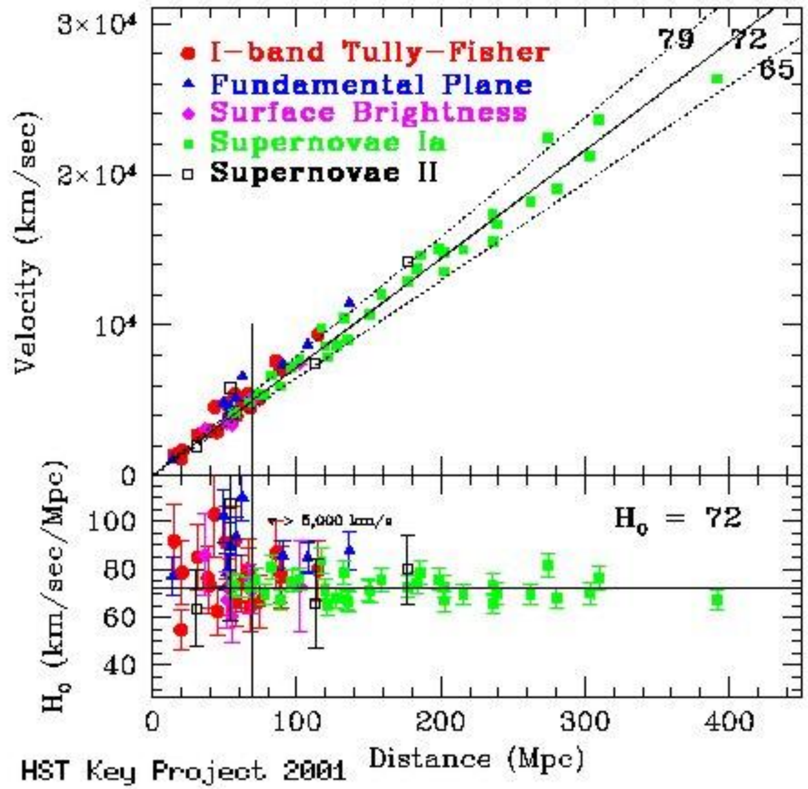


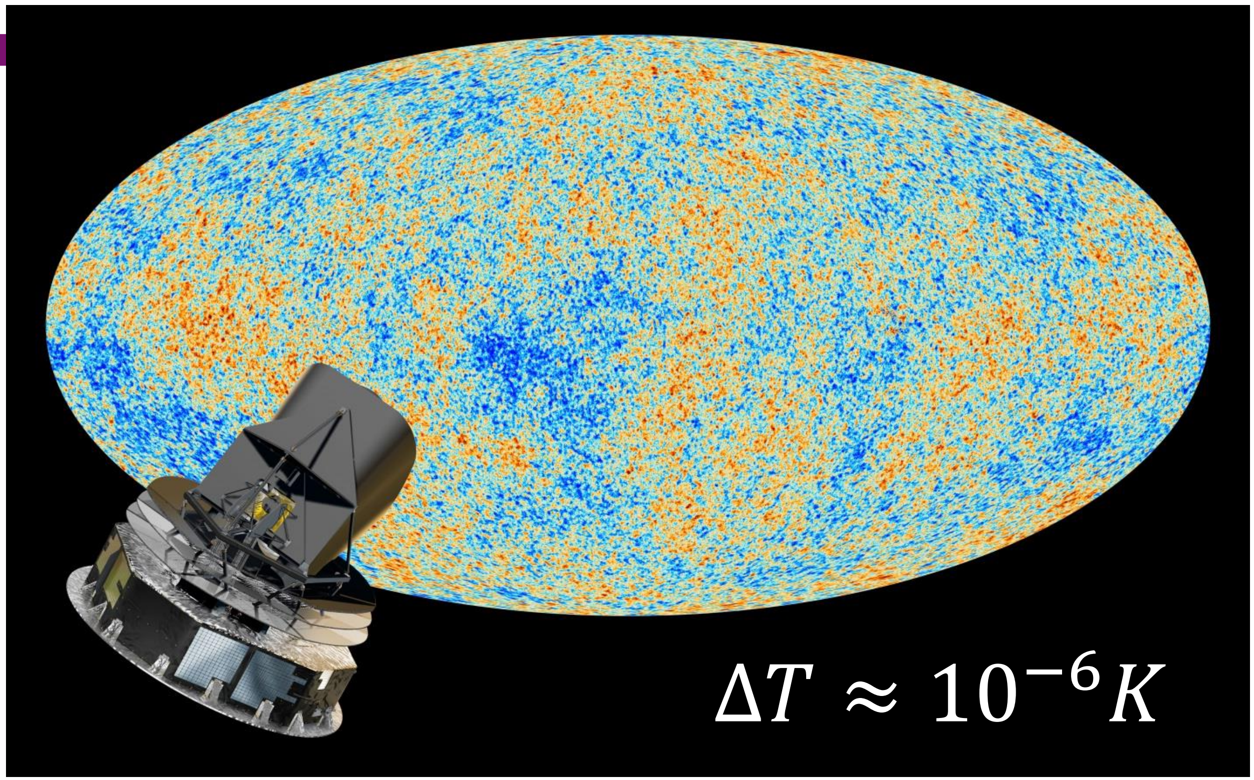
FIGURE 1

10^6 *mediciones*



Freedman, W. L., Madore, B. F., Gibson, B. K., Ferrarese, L., Kelson, D. D., Sakai, S., ... & Huchra, J. P. (2001). Final Results from the Hubble Space Telescope Key Project to Measure the Hubble ConstantBased on observations with the NASA/ESA Hubble Space Telescope, obtained at the Space Telescope Science Institute, which is operated by AURA, Inc., under NASA contract NAS5-26555. The Astrophysical Journal, 553(1), 47.

Isótropo y homogéneo



planck

COBE 7°

Boomerang 10´

WMAP 10´

Planck 5´

Ade, P. A. R., Aghanim, N., Akrami, Y., Aluri, P. K., Arnaud, M., Ashdown, M., ... & Bartolo, N. (2015). Planck 2015 results. XVI. Isotropy and statistics of the CMB. arXiv preprint arXiv:1506.07135.

Big Freeze-Big Rip-Big Crunch

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3c^2}\varepsilon(t) - \frac{kc^2}{{R_0}^2 a(t)^2}$$

$$H(t) = \frac{\dot{a}}{a}$$ ¨cte¨ de Hubble

$$H(t)^2 = \frac{8\pi G}{3c^2}\varepsilon(t) - \frac{kc^2}{{R_0}^2 a(t)^2}$$

$$H_0 = H(t_o) = \left.\frac{\dot{a}}{a}\right|_{t=t_o} = 70 \pm 7 kms^{-1}Mpc^{-1}$$

$$ {H_o}^2 = \frac{8\pi G}{3c^2}\varepsilon_o - \frac{kc^2}{{R_0}^2} \qquad a(t_o)^2 = 1$$

E. Kolb and M. Turner. The Early Universe. 1999

Big Freeze-Big Rip-Big Crunch

k=0

$$H(t)^2 = \frac{8\pi G}{3c^2}\varepsilon(t) \rightarrow \varepsilon_c = \frac{3c^2\, H(t)^2}{8\pi G}$$

energía crítica

en t=0 (presente) $\varepsilon(t_o) = \varepsilon_{c,o} = \frac{3c^2\, {H_o}^2}{8\pi G}$

Podemos reescribir la ecuación de Friedmann

$$1 - \Omega(t) = -\frac{kc^2}{{R_0}^2 a(t)^2 H(t)^2}$$

$$\Omega(t) = \frac{\varepsilon(t)}{\varepsilon_c(t)}$$

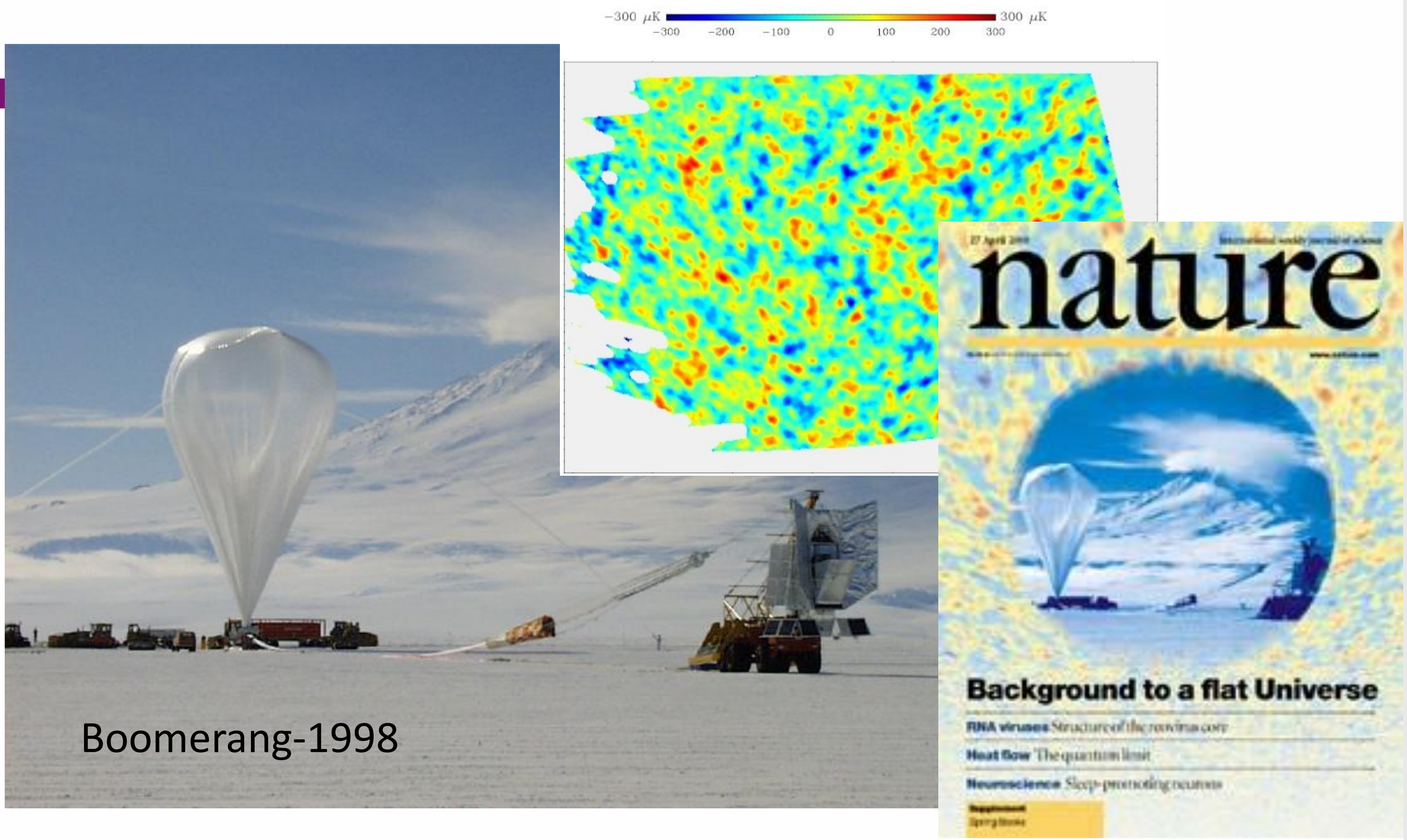
$\Omega < 1\ en\ algún\ tiempo\ \forall t\ k > 0$

$\Omega = 0\ en\ algún\ tiempo\ \forall t\ k = 0$

$\Omega < 0\ en\ algún\ tiempo\ \forall t\ k < 0$

E. Kolb and M. Turner. The Early Universe. 1999

Universo plano

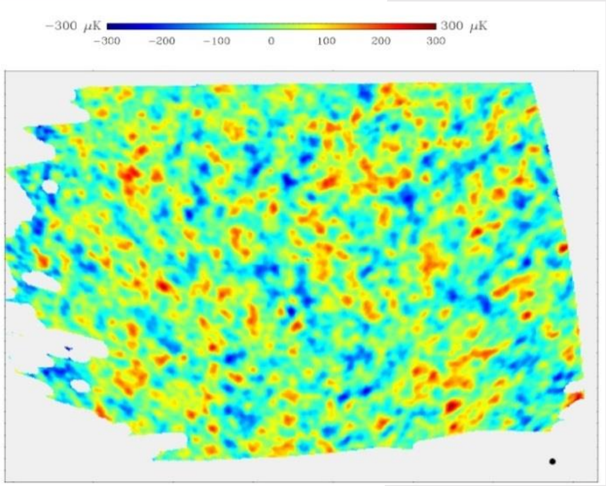


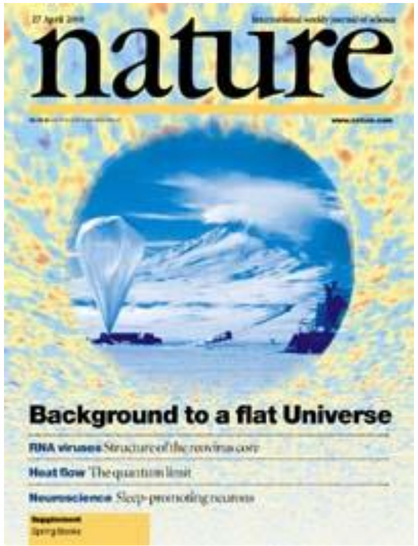
de Bernardis, P., Ade, P. A., Bock, J. J., Bond, J. R., Borrill, J., Boscaleri, A., ... & Ferreira, P. G. (2000). A flat Universe from high-resolution maps of the cosmic microwave background radiation. Nature, 404(6781), 955-959.

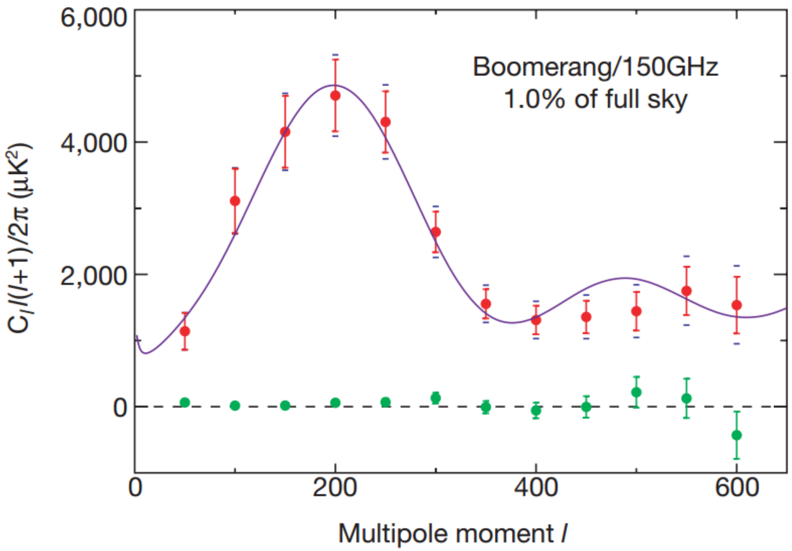
Universo plano

t=0

$$1-\Omega_o=-\frac{kc^2}{R_0{}^2H_o{}^2}\rightarrow-\frac{k}{R_0{}^2}=\frac{H_o{}^2}{c^2}(\Omega_o-1)$$







$$l\approx\frac{200}{\Omega_o{}^{1/2}}$$

de Bernardis, P., Ade, P. A., Bock, J. J., Bond, J. R., Borrill, J., Boscaleri, A., ... & Ferreira, P. G. (2000). A flat Universe from high-resolution maps of the cosmic microwave background radiation. Nature, 404(6781), 955-959.

Planitud-Inflación

$$1 - \Omega_o = -\frac{kc^2}{{R_o}^2 {H_o}^2}$$

$$\Omega_o \approx 1 \;\; ????$$

$$1 - \Omega(t) = -\frac{{H_o}^2(1 - \Omega_o)}{H(t)^2 a(t)^2}$$

materia=radiación t=10^4 años

$$|1 - \Omega_{mat-rad}| \leq 2.10^{-4}$$

nucleosíntesis t=100seg

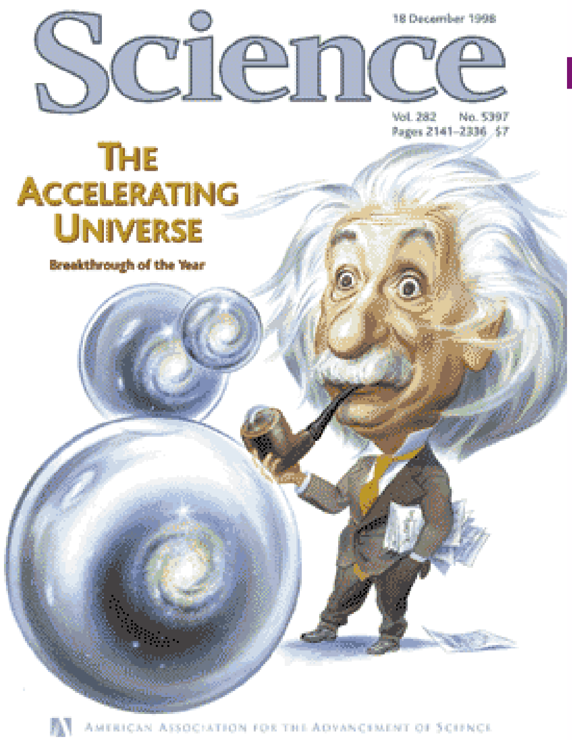
$$|1 - \Omega_{nuc}| \leq 3.10^{-14}$$

Planck t=10^{-44}seg

$$|1 - \Omega_{Planck}| \leq 1.10^{-60}$$

E. Kolb and M. Turner. The Early Universe. 1999

Universo acelerado

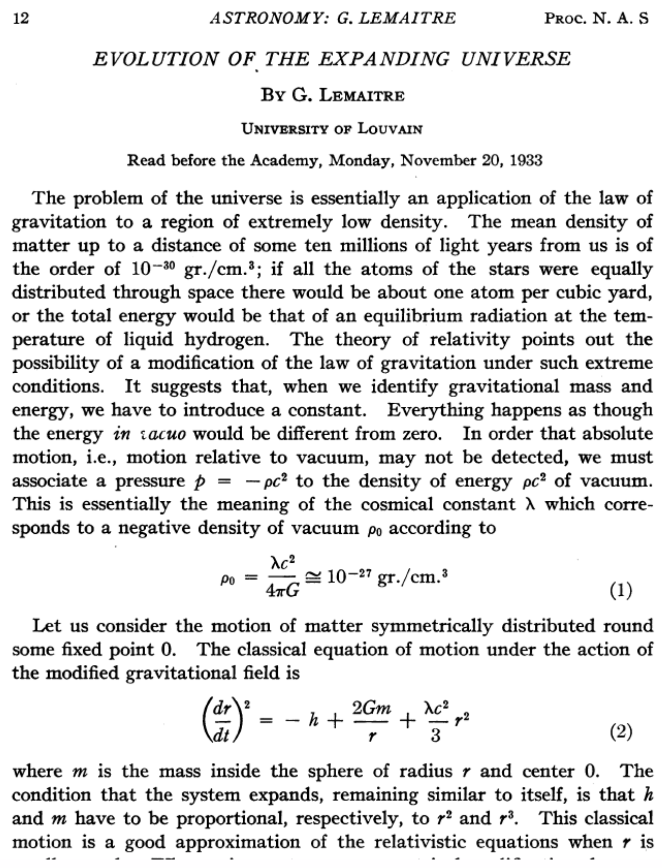


$$d_l \approx \frac{c}{H_0} z \left[1 + \left(\frac{1 - q_0}{2} \right) z \right]$$

supernova tipo la

Riess, A. G., Filippenko, A. V., Challis, P., Clocchiatti, A., Diercks, A., Garnavich, P. M., ... & Leibundgut, B. R. U. N. O. (1998). Observational evidence from supernovae for an accelerating universe and a cosmological constant. The Astronomical Journal, 116(3), 1009.

Cte. cosmológica



EVOLUTION OF THE EXPANDING UNIVERSE

By G. Lemaitre

University of Louvain

Read before the Academy, Monday, November 20, 1933

The problem of the universe is essentially an application of the law of gravitation to a region of extremely low density. The mean density of matter up to a distance of some ten millions of light years from us is of the order of 10^{-30} gr./cm.^{3}; if all the atoms of the stars were equally distributed through space there would be about one atom per cubic yard, or the total energy would be that of an equilibrium radiation at the temperature of liquid hydrogen. The theory of relativity points out the possibility of a modification of the law of gravitation under such extreme conditions. It suggests that, when we identify gravitational mass and energy, we have to introduce a constant. Everything happens as though the energy *in vacuo* would be different from zero. In order that absolute motion, i.e., motion relative to vacuum, may not be detected, we must associate a pressure $p = -\rho c^2$ to the density of energy ρc^2 of vacuum. This is essentially the meaning of the cosmical constant λ which corresponds to a negative density of vacuum ρ_0 according to

$$\rho_0 = \frac{\lambda c^2}{4\pi G} \cong 10^{-27} \text{ gr./cm.}^3 \qquad (1)$$

Let us consider the motion of matter symmetrically distributed round some fixed point 0. The classical equation of motion under the action of the modified gravitational field is

$$\left(\frac{dr}{dt}\right)^2 = -h + \frac{2Gm}{r} + \frac{\lambda c^2}{3} r^2 \qquad (2)$$

where m is the mass inside the sphere of radius r and center 0. The condition that the system expands, remaining similar to itself, is that h and m have to be proportional, respectively, to r^2 and r^3. This classical motion is a good approximation of the relativistic equations when r is

física de partículas

$$10^{23}$$

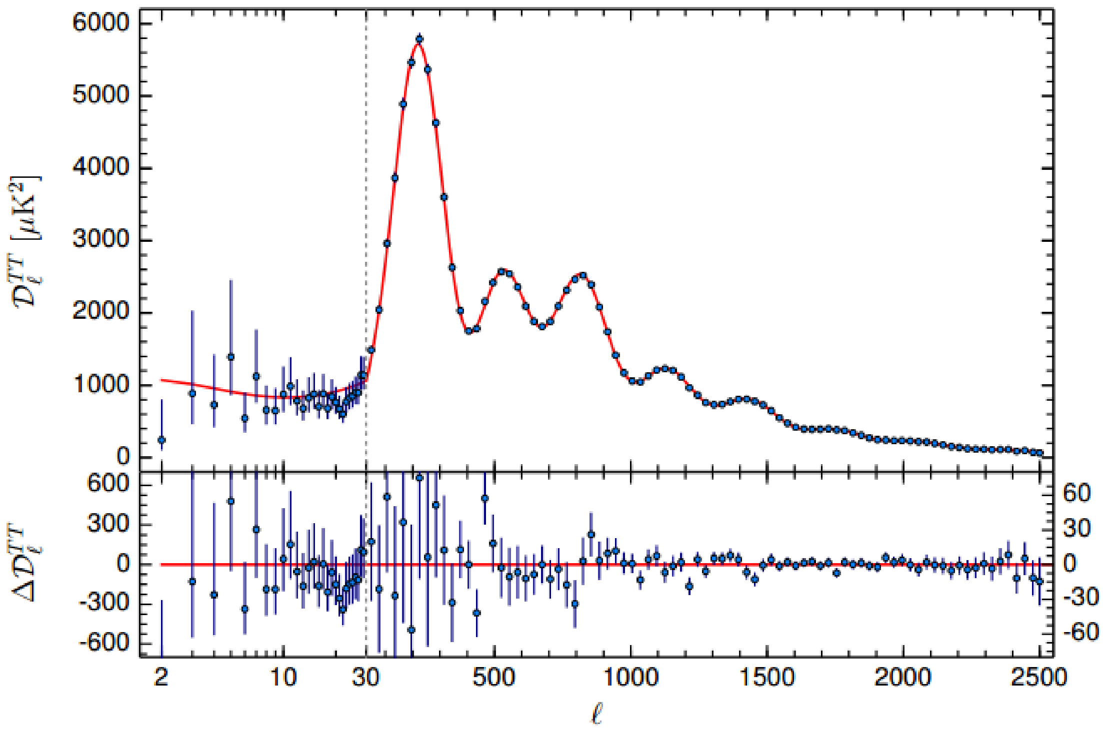
Steven Weinberg

(Los primeros tres minutos del universo)

¨el peor fracaso en la estimación de un orden de magnitud en toda la historia de la ciencia¨

Lemaitre Lemaître, G. (1934). Evolution of the expanding universe. Proceedings of the National Academy of Sciences, 20(1), 12-17.

Planck



energía oscura

68,3%

materia oscura

26,8%

materia bariónica

4,9%

Collaboration, P. (2015). Planck 2015 results. xiii. cosmological parameters. arXiv preprint. arXiv, 1502.

Big Freeze-Big Rip-Big Crunch

$$\frac{H^2}{{H_o}^2} = \frac{\Omega_{R,o}}{a^4} + \frac{\Omega_{M,o}}{a^3} + \Omega_{\Lambda,o} + \frac{1-\Omega_o}{a^2}$$

$$\frac{\dot{a}}{H_o} = \left[\frac{\Omega_{R,o}}{a^2} + \frac{\Omega_{M,o}}{a} + \Omega_{\Lambda,o}a^2 + (1-\Omega_0)\right]^{1/2}$$

$$H_o t = \int_0^a \frac{da}{\left[\frac{\Omega_{R,o}}{a^2} + \frac{\Omega_{M,o}}{a} + \Omega_{\Lambda,o}a^2 + (1-\Omega_0)\right]^{1/2}}$$

E. Kolb and M. Turner. The Early Universe. 1999

Big Freeze-Big Rip-Big Crunch

et donc

$$\kappa\rho = \frac{\alpha}{R^3} + \frac{3\beta}{R^4} \tag{9}$$

Substituant dans (2), nous avons à intégrer

$$\frac{R'^2}{R^2} = \frac{\lambda}{3} - \frac{1}{R^2} + \frac{\kappa\rho}{3} = \frac{\lambda}{3} - \frac{1}{R^2} + \frac{\alpha}{3R^3} + \frac{\beta}{R^4} \tag{10}$$

ou

$$t = \int \frac{dR}{\sqrt{\frac{\lambda R^2}{3} - 1 + \frac{\alpha}{3R} + \frac{\beta}{R^2}}} \tag{11}$$

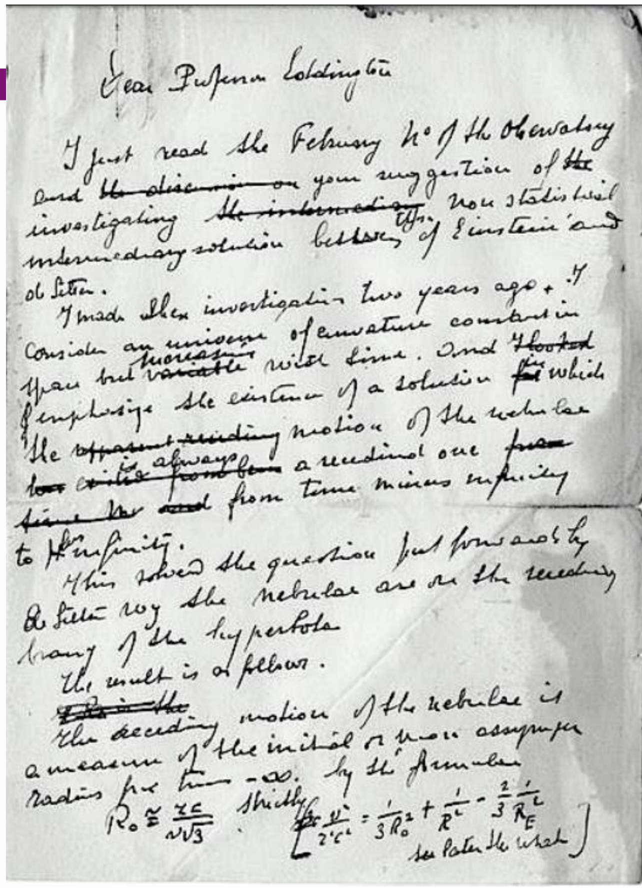
Pour α et β égaux à zéro, nous trouvons la solution de de Sitter ([1])

$$R = \sqrt{\frac{3}{\lambda}} \cosh \sqrt{\frac{\lambda}{3}} (t - t_0) \tag{12}$$

La solution d'Einstein s'obtient en posant $\beta = 0$ et R constant. Posant

Lemaitre, A. G. (1931). A homogeneous universe of constant mass and increasing radius accounting for the radial velocity
of extra-galactic nebulae. Monthly Notices of the Royal Astronomical Society, 91(5), 483-490.

Big Freeze-Big Rip-Big Crunch



Dear Professor Eddington

I just read the February No of the Observatory and ~~the discussion~~ on your suggestion of ~~the~~ investigating ~~the intermediary~~ non statistical intermediary solution between those of Einstein and de Sitter.

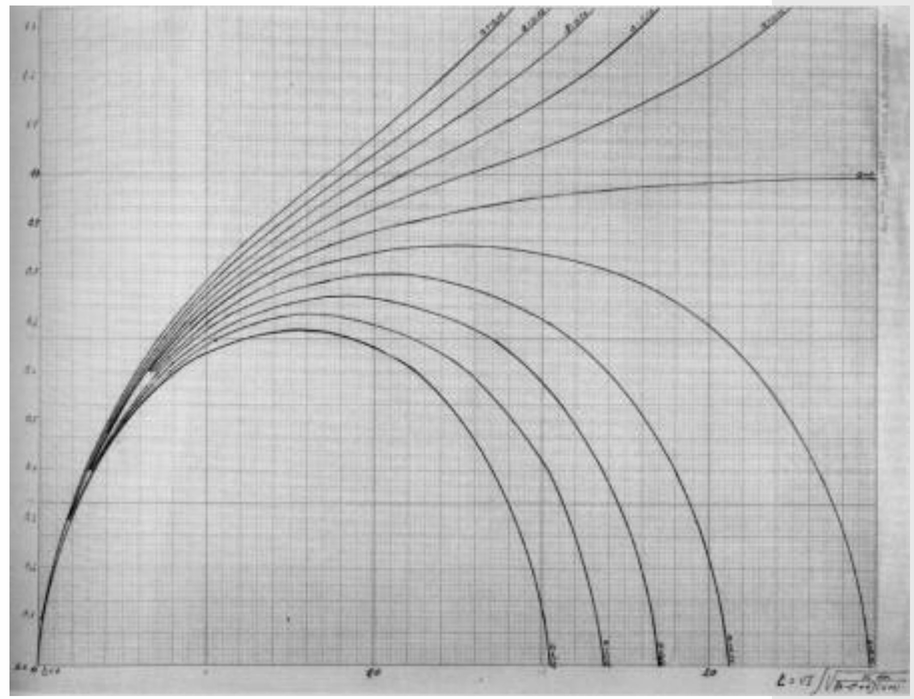
I made these investigations two years ago. I consider an ~~universe~~ of curvature constant in space but ~~variable~~ increasing with time. And ~~I looked~~ for which I emphasize the existence of a solution ~~for~~ which the ~~apparent receding~~ motion of the nebulae ~~is always from~~ a receding one ~~from~~ ~~for ever from time~~ ~~and~~ from time minus infinity to +infinity.

This solved the question put forward by de Sitter by the hyperbola theory of the nebulae are in the receding

The result is as follows.

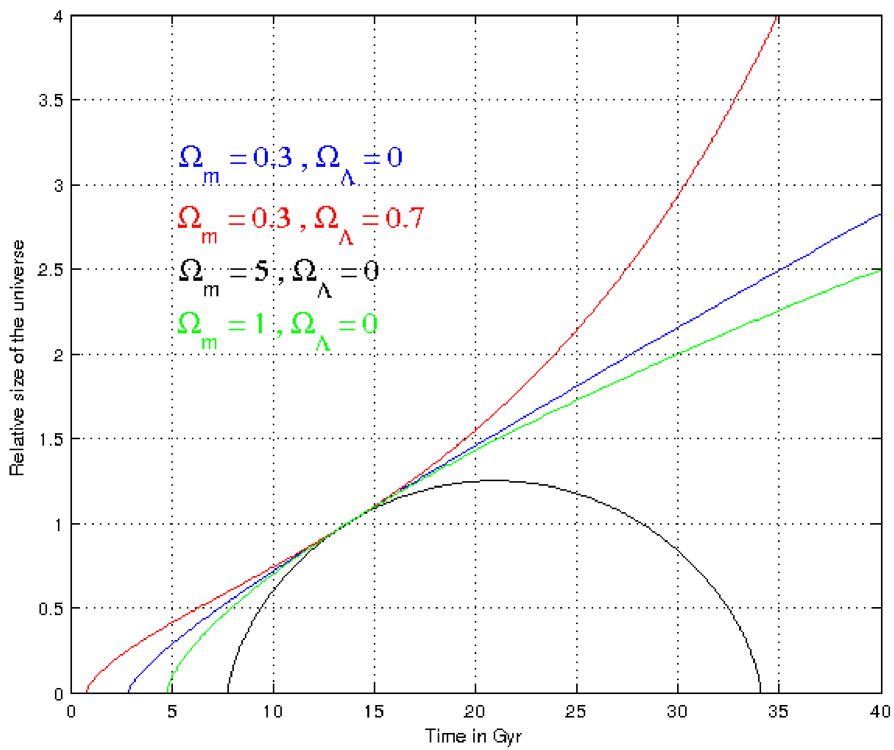
~~This is the~~ The receding motion of the nebulae is a measure of the initial or non asymptotic radius for time $-\infty$. by the formula

$R_0 \cong \frac{\pi c}{v\sqrt{3}}$ strictly $\left[\frac{\dot{v}^2}{2c^2} = \frac{1}{3R_0^2} + \frac{1}{R^2} - \frac{2}{3}\frac{1}{R_E^2}\right.$ see later the what $\left.\right]$



Archives Lemaître at Universilté de Louvain

ΛCDM



- Big Crunch k=1
- Einstein de Sitter, k=0 expansión eterna (desacelerada)
- k=-1, expansión eterna (desacelerada)
- Big Rip, k=0, expansión eterna (acelerada)

https://dournac.org/info/friedmann

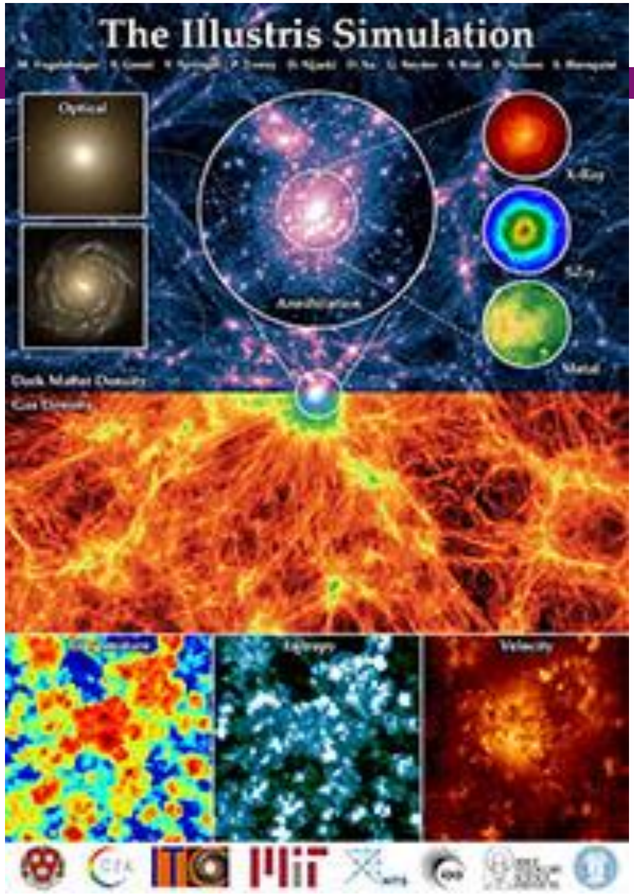
ΛCDM

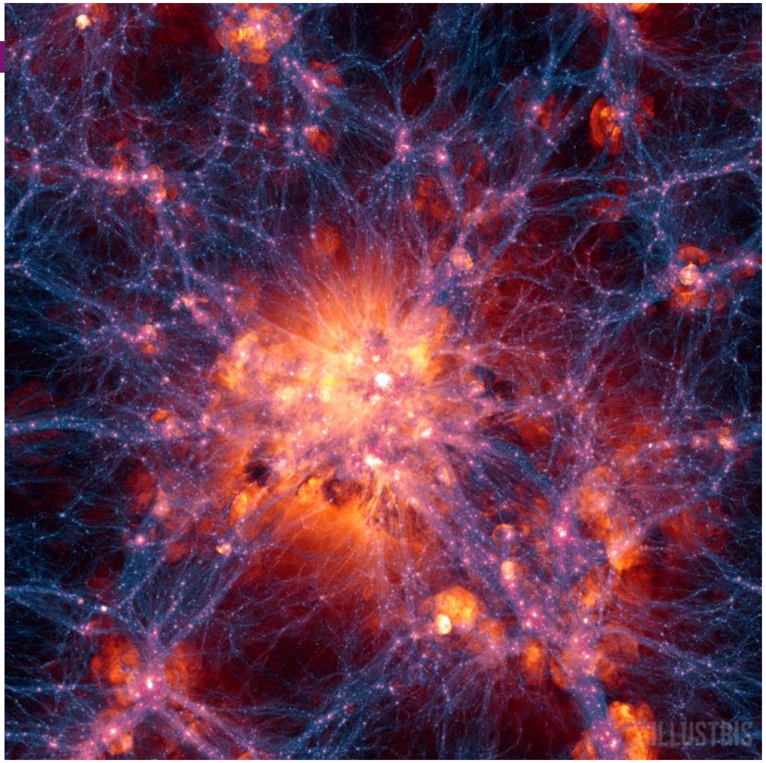
Planck best fit ΛCDM model.

	Planck		*Planck*+WP	
Parameter	Best fit	68% limits	Best fit	68% limits
$\Omega_b h^2$	0.022068	0.02207 ± 0.00033	0.022032	0.02205 ± 0.00028
$\Omega_c h^2$	0.12029	0.1196 ± 0.0031	0.12038	0.1199 ± 0.0027
$100\theta_{MC}$	1.04122	1.04132 ± 0.00068	1.04119	1.04131 ± 0.00063
τ	0.0925	0.097 ± 0.038	0.0925	$0.089^{+0.012}_{-0.014}$
n_s	0.9624	0.9616 ± 0.0094	0.9619	0.9603 ± 0.0073
$\ln(10^{10} A_s)$	3.098	3.103 ± 0.072	3.0980	$3.089^{+0.024}_{-0.027}$
Ω_Λ	0.6825	0.686 ± 0.020	0.6817	$0.685^{+0.018}_{-0.016}$
Ω_m	0.3175	0.314 ± 0.020	0.3183	$0.315^{+0.016}_{-0.018}$
σ_8	0.8344	0.834 ± 0.027	0.8347	0.829 ± 0.012
z_{re}	11.35	$11.4^{+4.0}_{-2.8}$	11.37	11.1 ± 1.1
H_0	67.11	67.4 ± 1.4	67.04	67.3 ± 1.2
$10^9 A_s$	2.215	2.23 ± 0.16	2.215	$2.196^{+0.051}_{-0.060}$
$\Omega_m h^2$	0.14300	0.1423 ± 0.0029	0.14305	0.1426 ± 0.0025
Age/Gyr	13.819	13.813 ± 0.058	13.8242	13.817 ± 0.048
z_*	1090.43	1090.37 ± 0.65	1090.48	1090.43 ± 0.54
$100\theta_*$	1.04139	1.04148 ± 0.00066	1.04136	1.04147 ± 0.00062
z_{eq}	3402	3386 ± 69	3403	3391 ± 60

Collaboration, P. (2015). Planck 2015 results. xiii. cosmological parameters. arXiv preprint. arXi
1502.

ΛCDM-illustris





Boylan-Kolchin, M. (2014). Cosmology: A virtual universe. Nature, 509(7499), 170-171.

muchas gracias