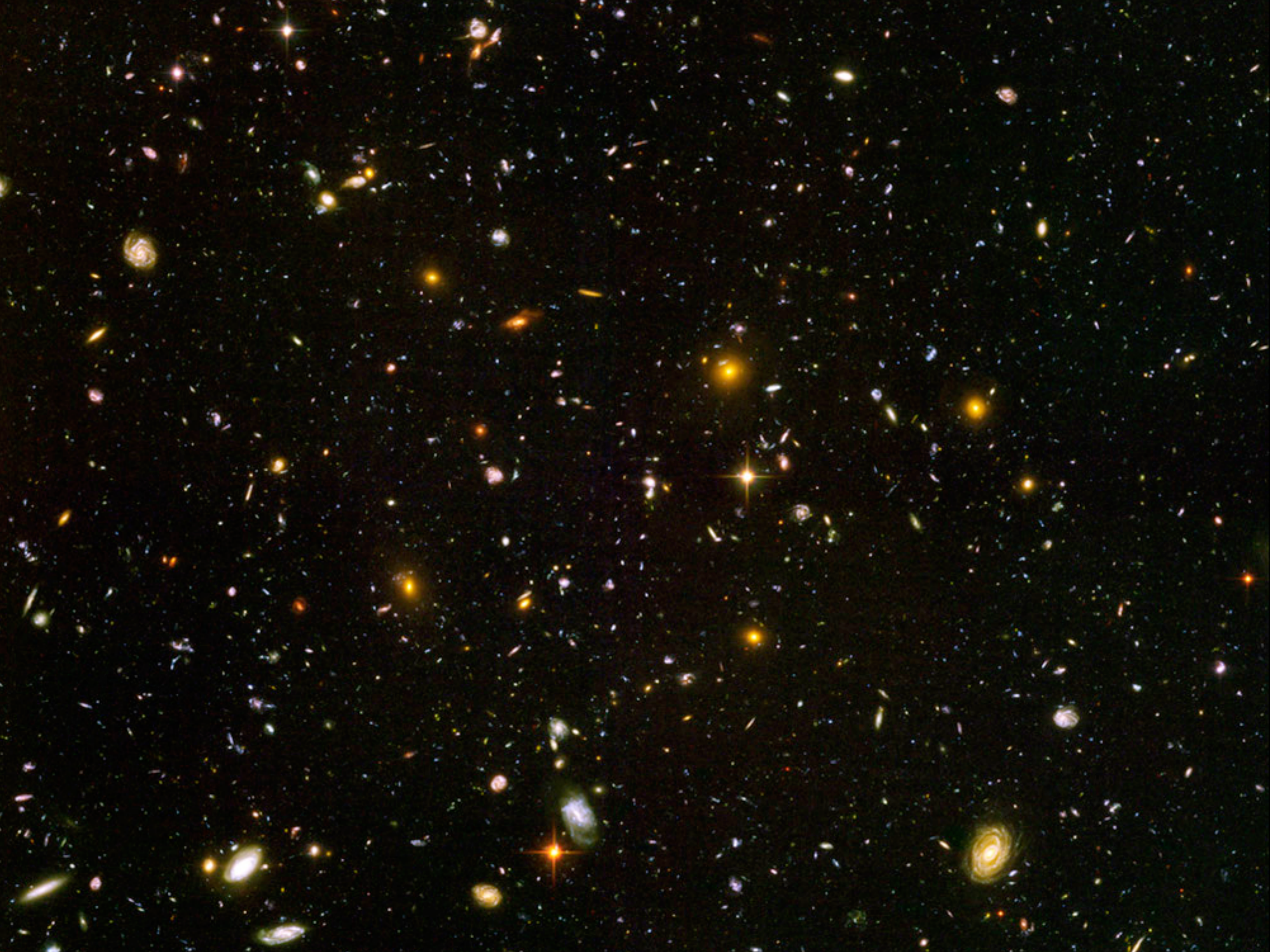
JRJC 2018

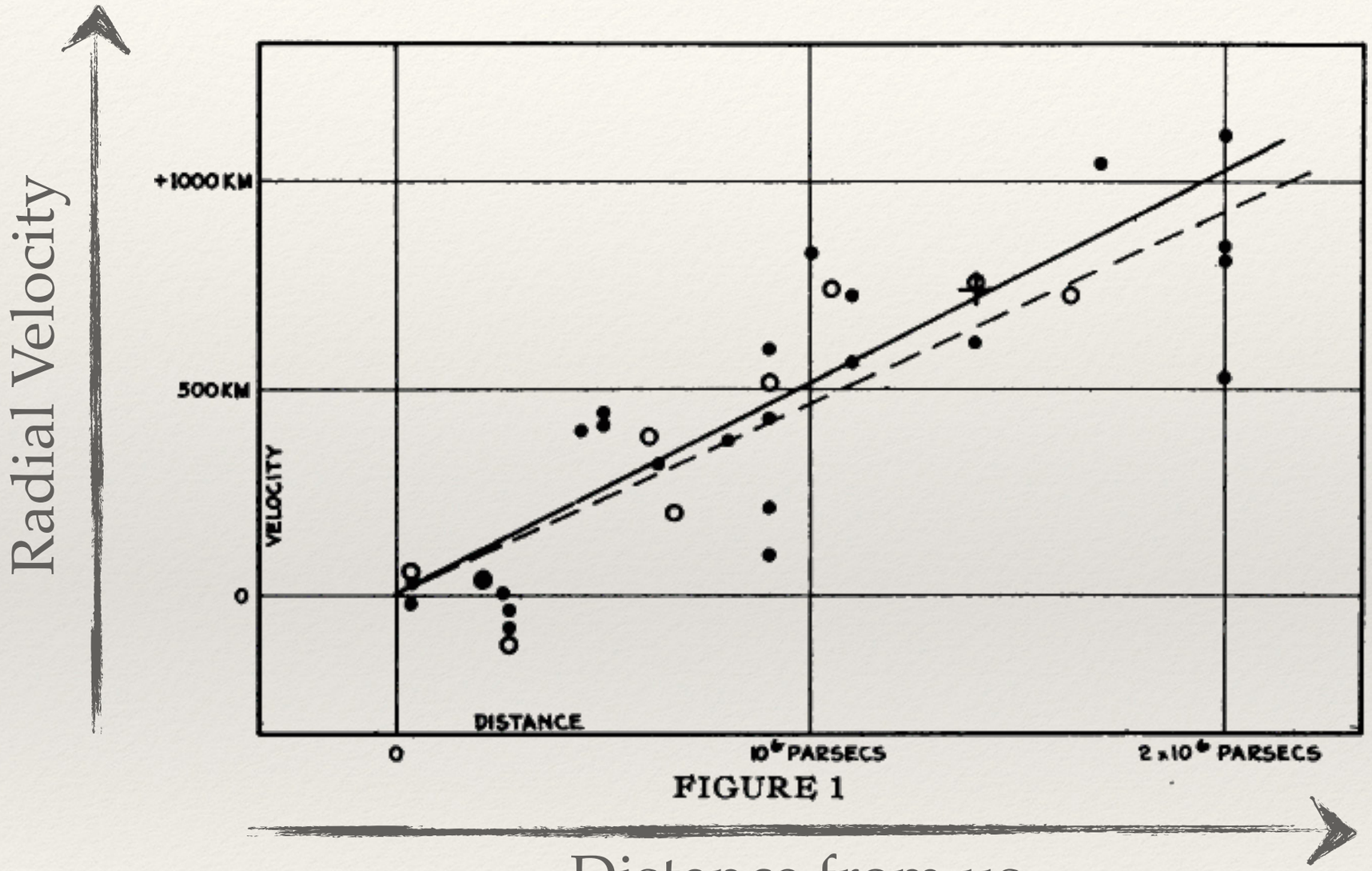
Cosmology

Mickael RIGAULT

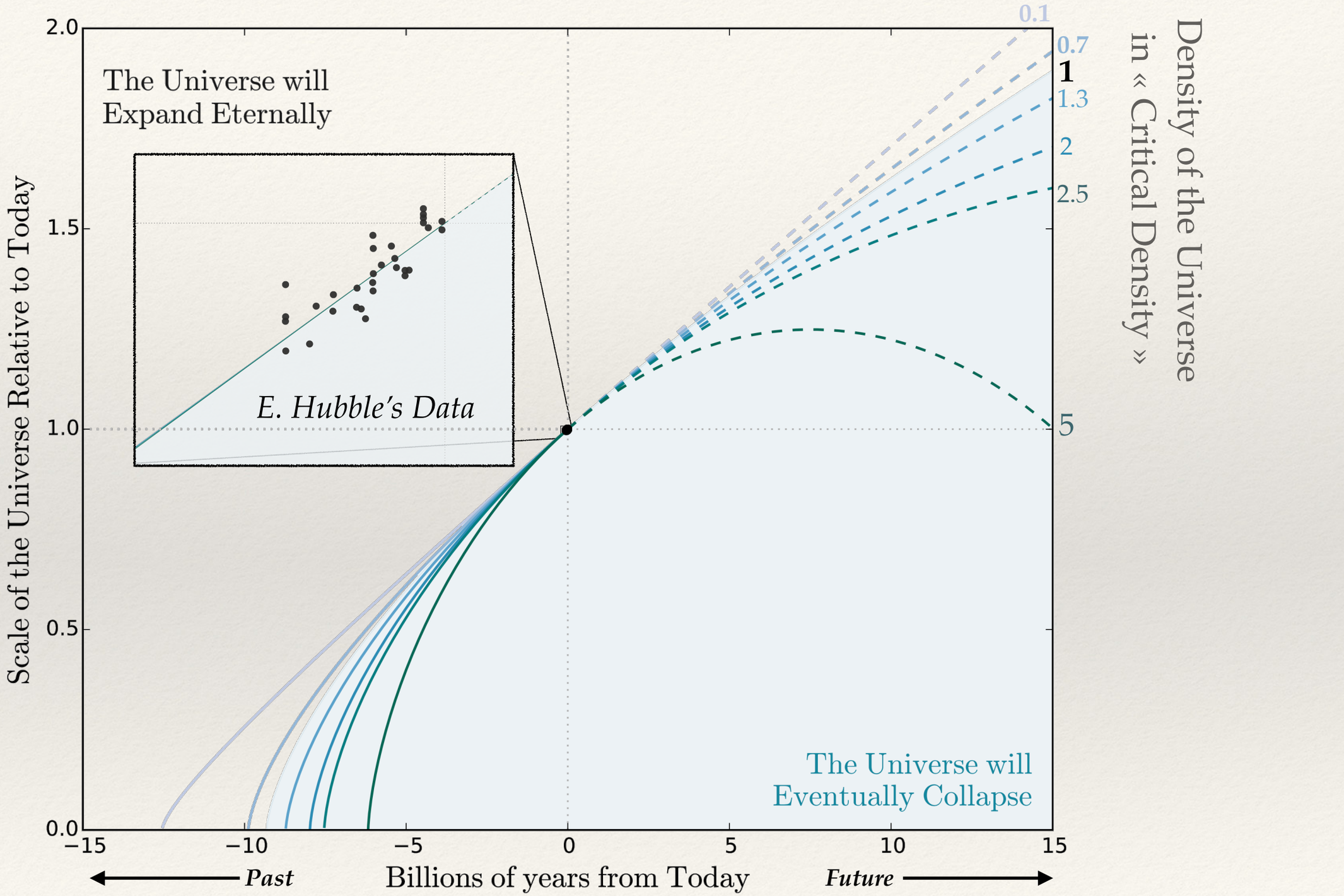


The Universe is Expanding !

Edwin HUBBLE, 1929



Measuring the Fate of the Universe



Evolution of the densities

Expansion rate of the Universe

$$H^2(z) = \frac{8\pi G}{3}\rho_m + \frac{8\pi G}{3}\rho_r - \frac{kc^2}{a^2}$$

Matter (non-relativistics)
baryons / dark matter

Radiation (relativistics)
photons / neutrinos

Curvature of the Universe

$\rho_M \propto a^{-3}$

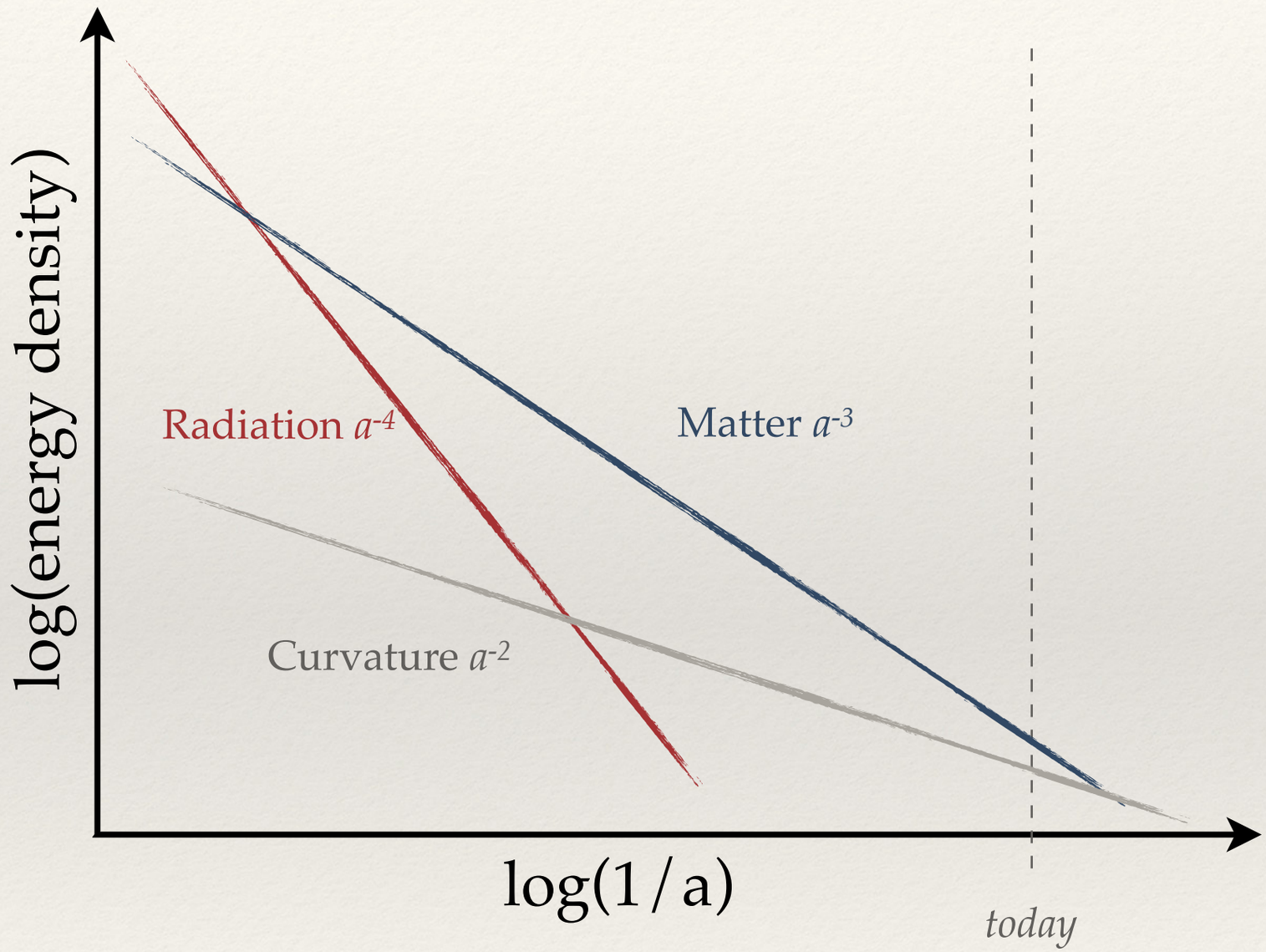
Pure dilution (N/V)

$\rho_R \propto a^{-4}$

dilution of particles (N/V)
& of energy ($E=h\nu$)

$\propto a^{-2}$

Evolution of Densities in an expanding Universe



Cosmological Parameters

$$H^2(z) = \frac{8\pi G}{3}\rho_m^0 a^{-3} + \frac{8\pi G}{3}\rho_r^0 a^{-4} - kc^2 a^{-2}$$

Let's define the Hubble Constant:

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

Density in a flat Universe such that the current expansion rate is H_0
(~ 6 proton / m^3)

$$\frac{H^2(z)}{H_0^2} = \frac{\rho_m^0}{\rho_c}a^{-3} + \frac{\rho_r^0}{\rho_c}a^{-4} - \frac{3kc^2}{8\pi G\rho_c}a^{-2}$$

Ω_m Ω_r Ω_k

Cosmological Parameters

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Let's define the Hubble Constant:

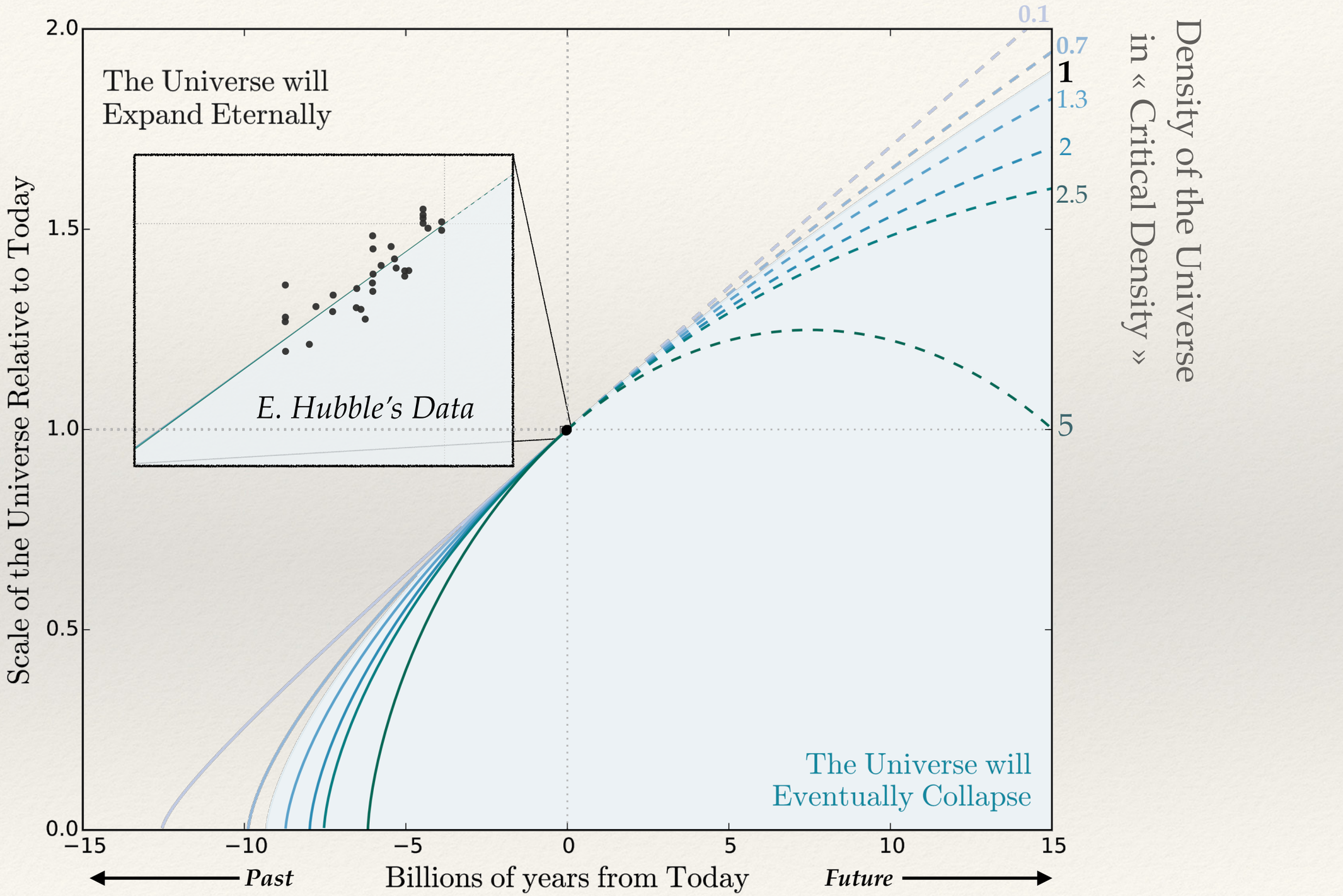
$$H_0^2 = \frac{8\pi G}{3}\rho_c$$

Density in a flat Universe such that the current expansion rate is H_0
(~ 6 proton / m^3)

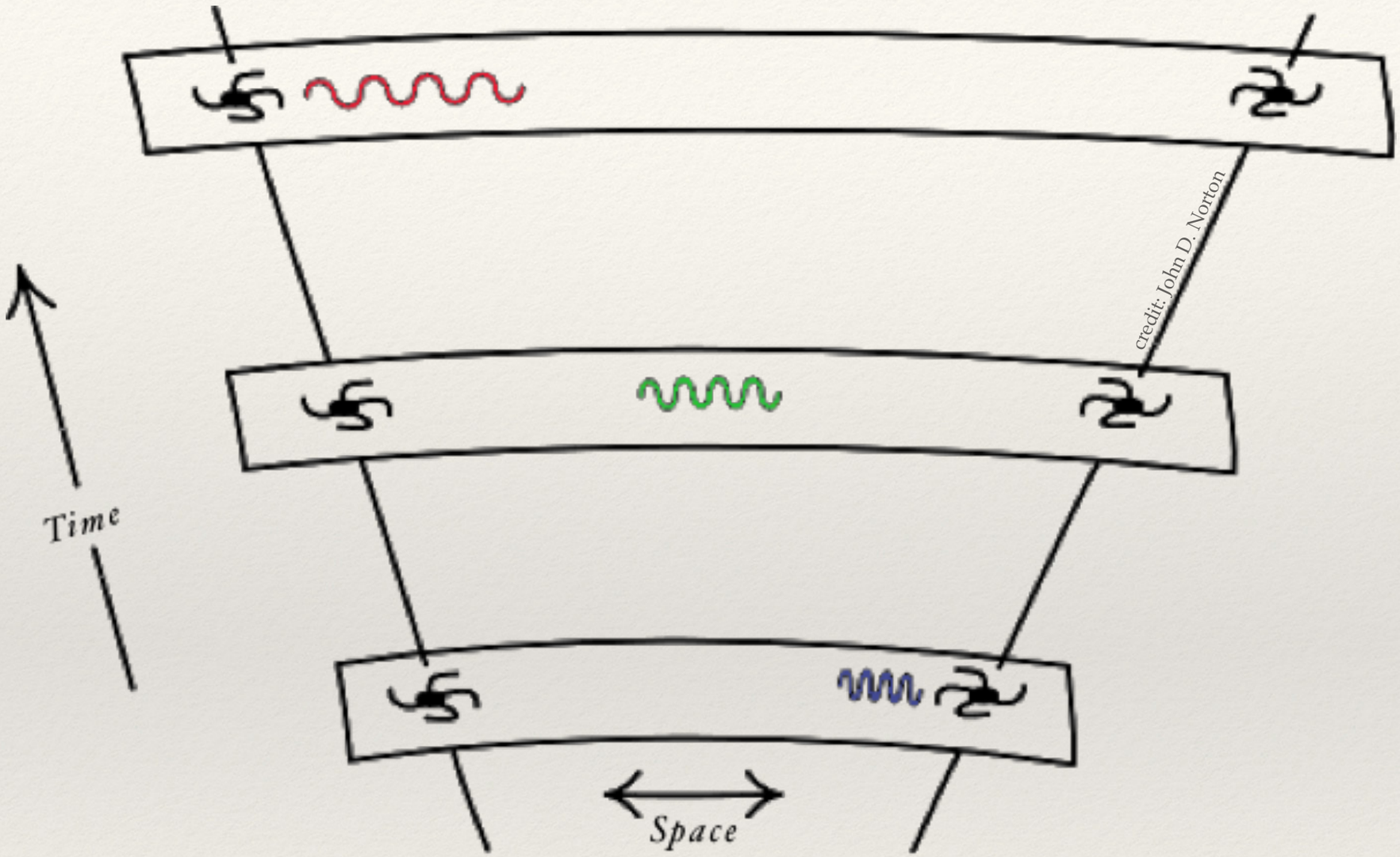
$$H^2(z) = H_0^2\left(\Omega_m^0 a^{-3} + \Omega_r^0 a^{-4} + \Omega_k^0 a^{-2}\right)$$

$$1 = \Omega_m^0 + \Omega_r^0 + \Omega_k^0 \quad or, \quad \Omega_m^0 + \Omega_r^0 = 1 - \Omega_k^0$$

Weighting the Universe



The Redshift as an Expansion Tracer



The expansion of the Universe stretchs the photon's wavelength

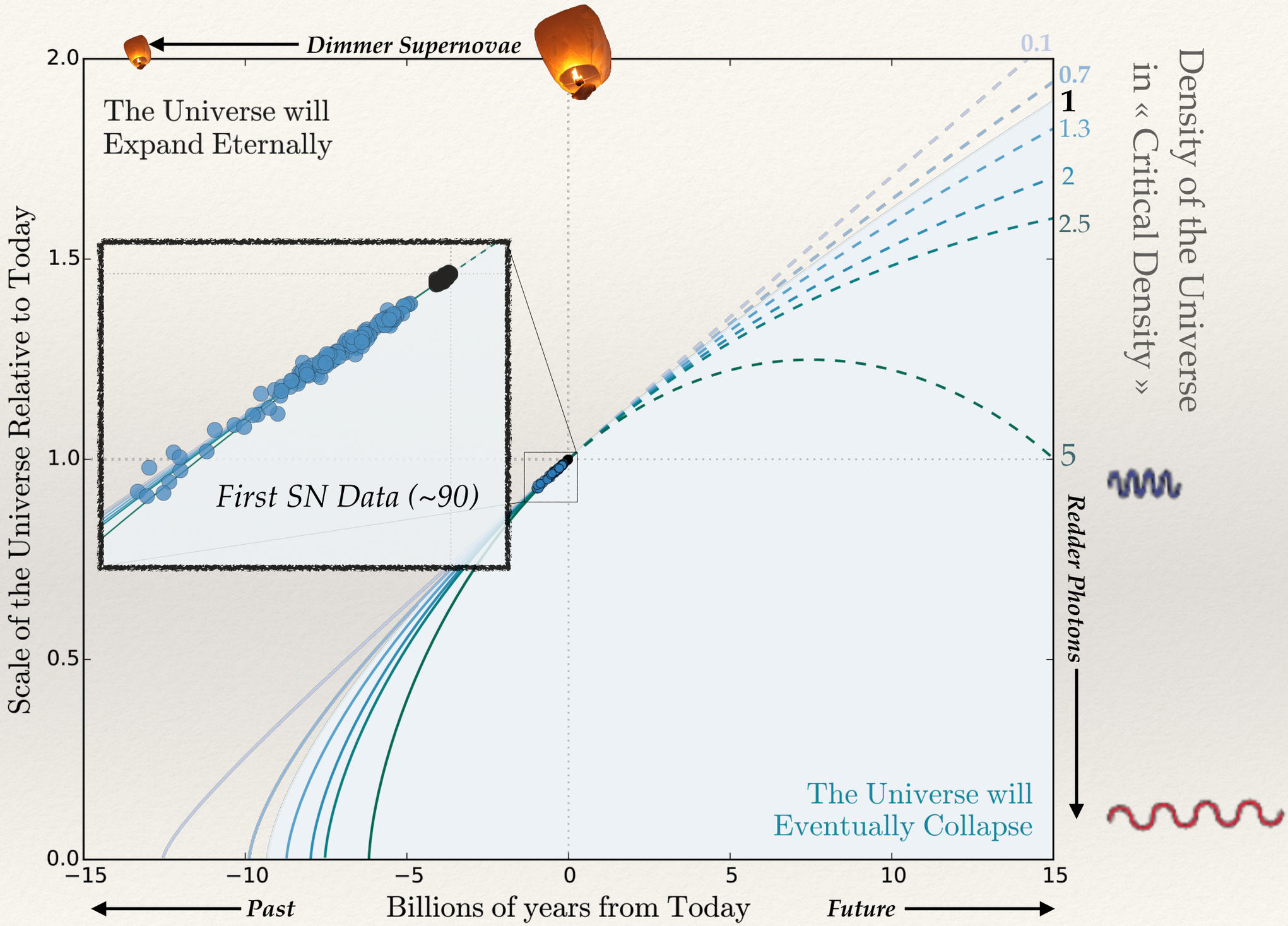
Type Ia Supernovae: Standard Candles

Flux ⇔ Distance

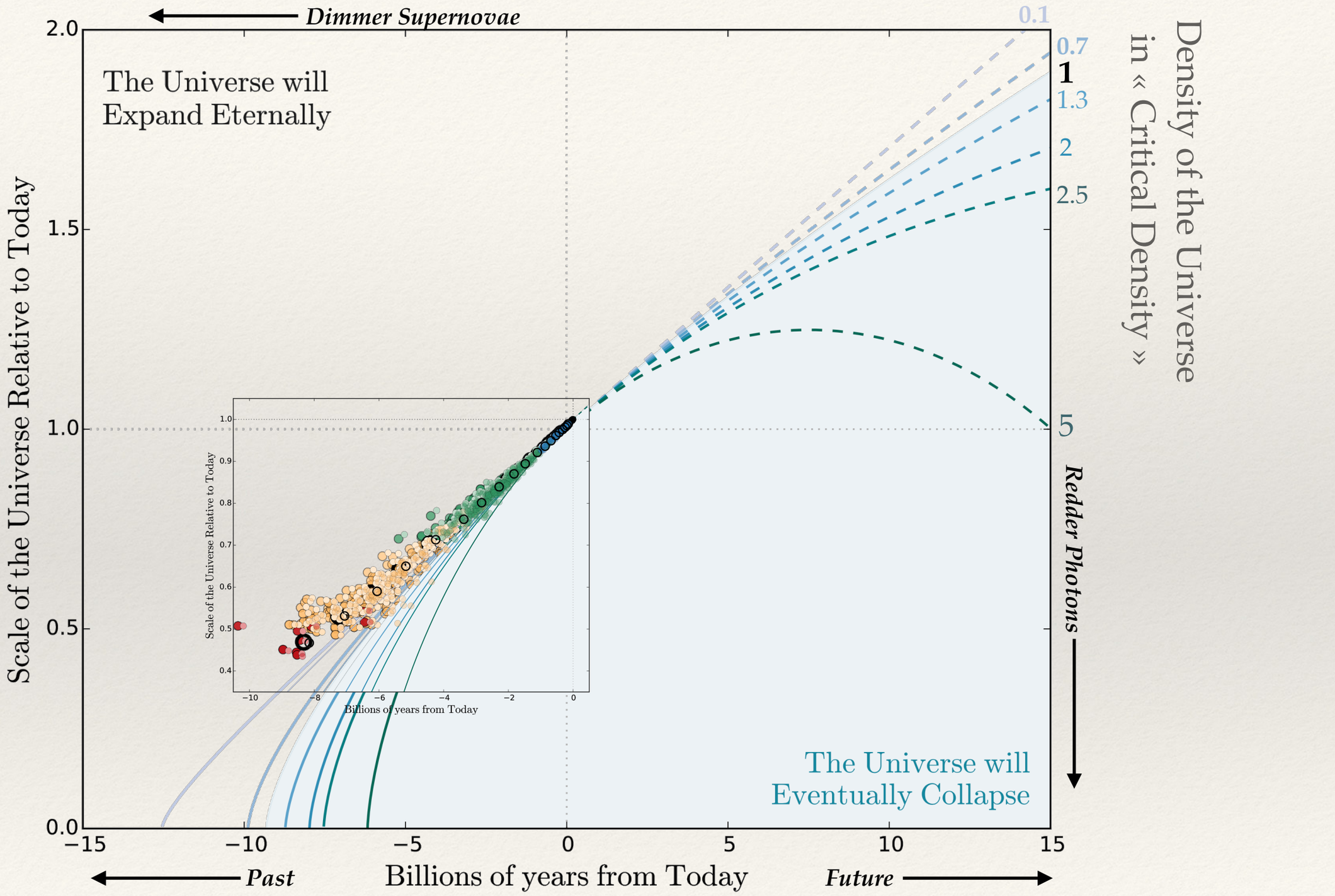
As bright as a galaxy for few days

Artist's Concept

Measuring the Fate of the Universe



Data do not match the predictions



Einstein's equation

Einstein's equation

$$R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} = \frac{8\pi G}{c^4}T_{\mu\nu}$$

Einstein's equation

the divergence of $g_{\mu\nu}$ is also null : $\dfrac{\partial g_{\mu\nu}}{\partial x^{\mu}} = 0$

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

Which is equivalent to: $R_{\mu\nu} - \dfrac{1}{2} R g_{\mu\nu} = \dfrac{8\pi G}{c^4} T_{\mu\nu} - \Lambda g_{\mu\nu}$

Einstein's equation

the divergence of $g_{\mu\nu}$ is also null : $\dfrac{\partial g_{\mu\nu}}{\partial x^{\mu}} = 0$

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

This works, but it affects the Newtonian limit:

$$\vec{F_g} = -\frac{GM}{r^2}\vec{u_r} + \frac{\Lambda c^2 r}{3}\vec{u_r}$$

Repulsive force increasing with distance
never observed in Newtonian gravitation

Evolution of the densities

Expansion rate of the Universe

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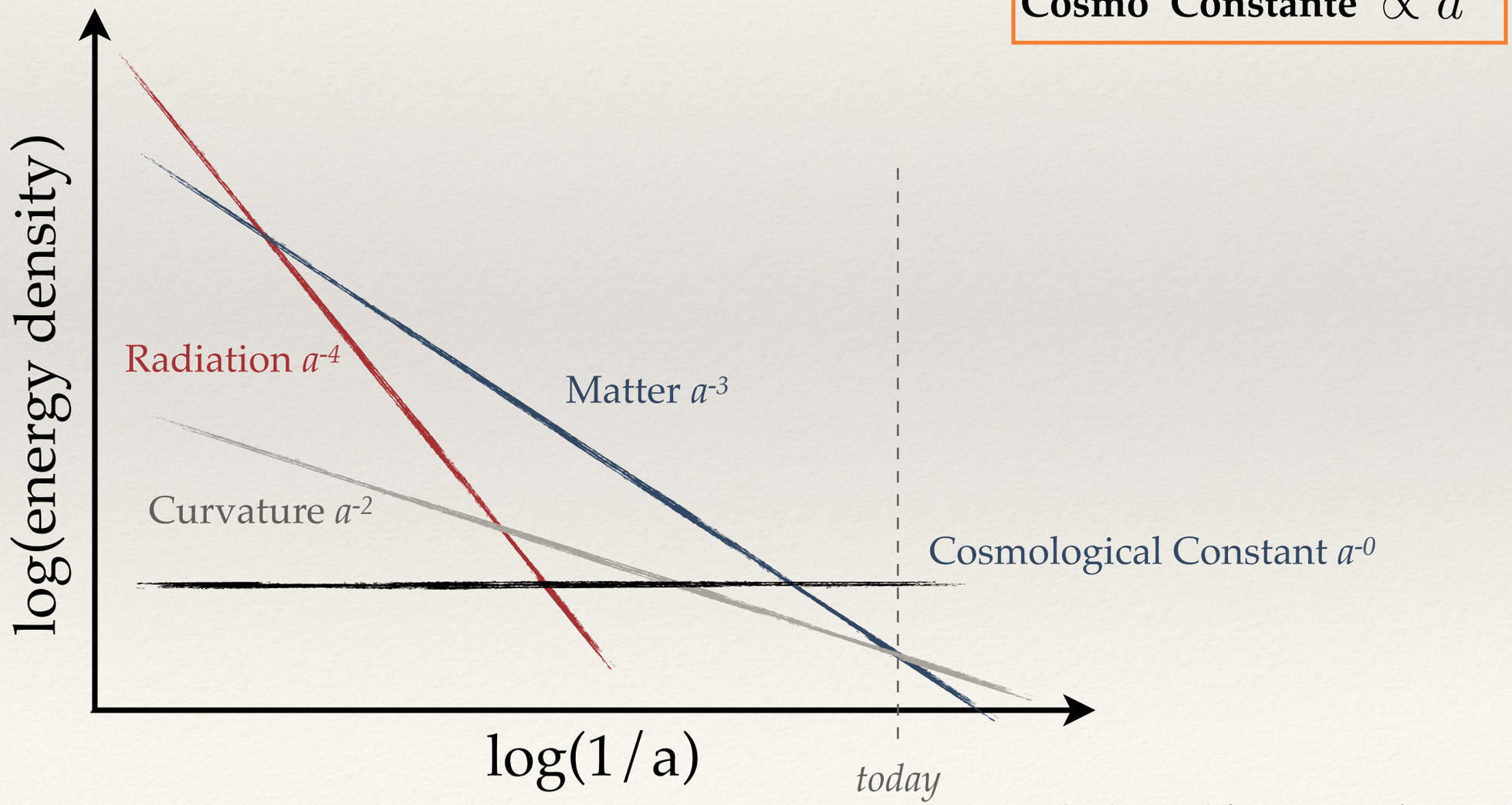
$\rho_M \propto a^{-3}$ $\rho_R \propto a^{-4}$ $\propto a^{-2}$

Cosmo Constante $\propto a^0$



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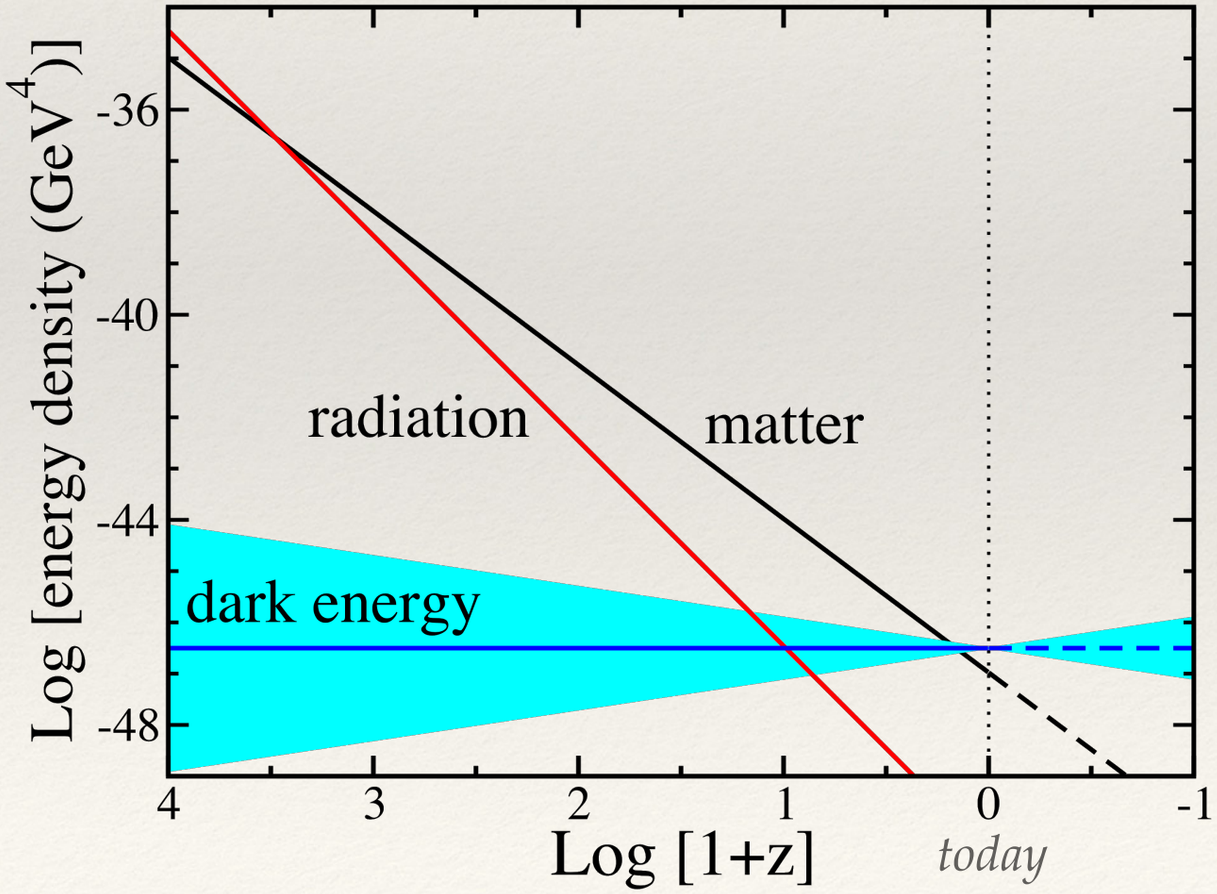
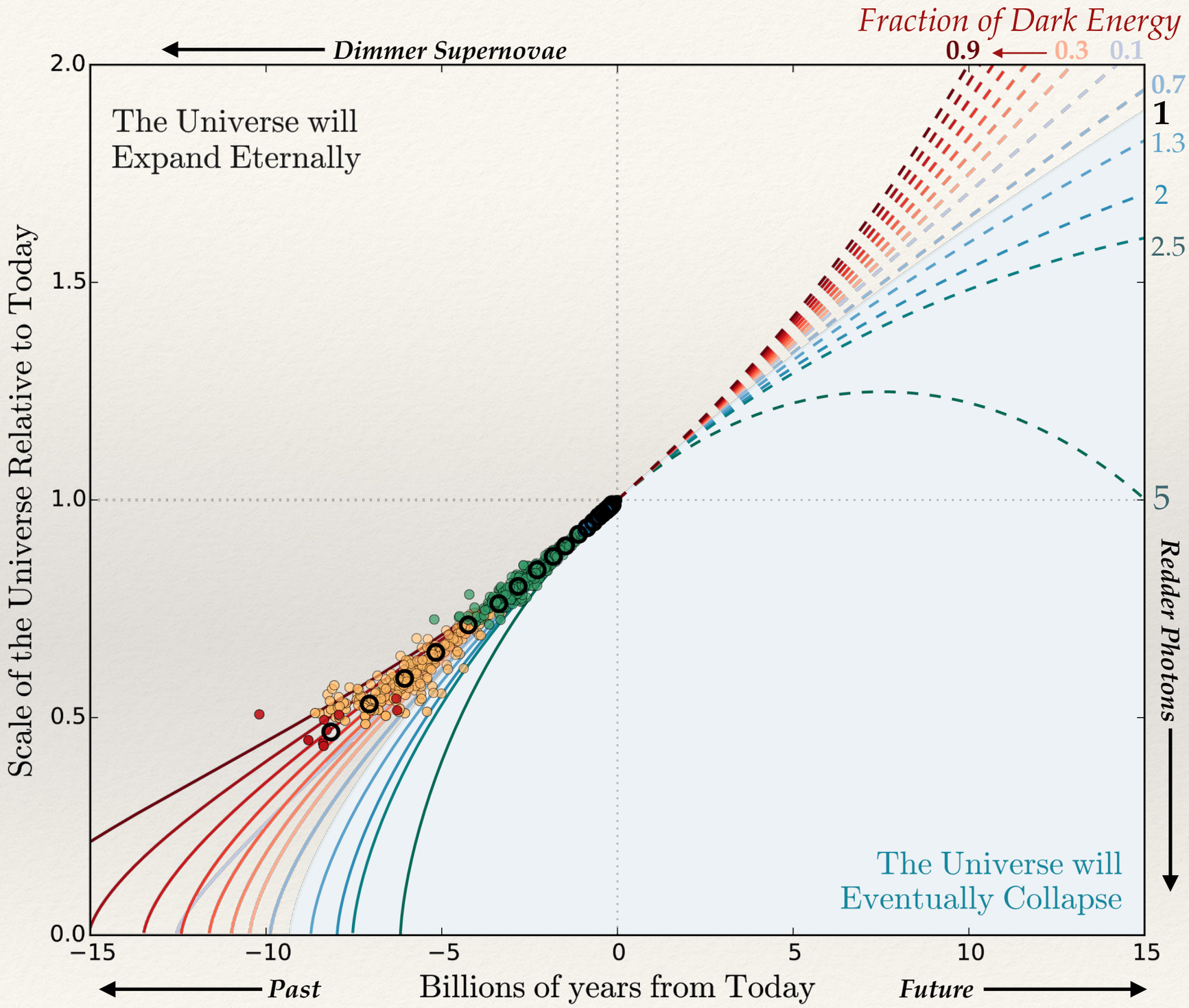
$\rho_M \propto a^{-3}$ $\rho_R \propto a^{-4}$ $\propto a^{-2}$

Dark Energy $\propto a^{3(1+w)}$



The Universe's Expansion is Accelerating !



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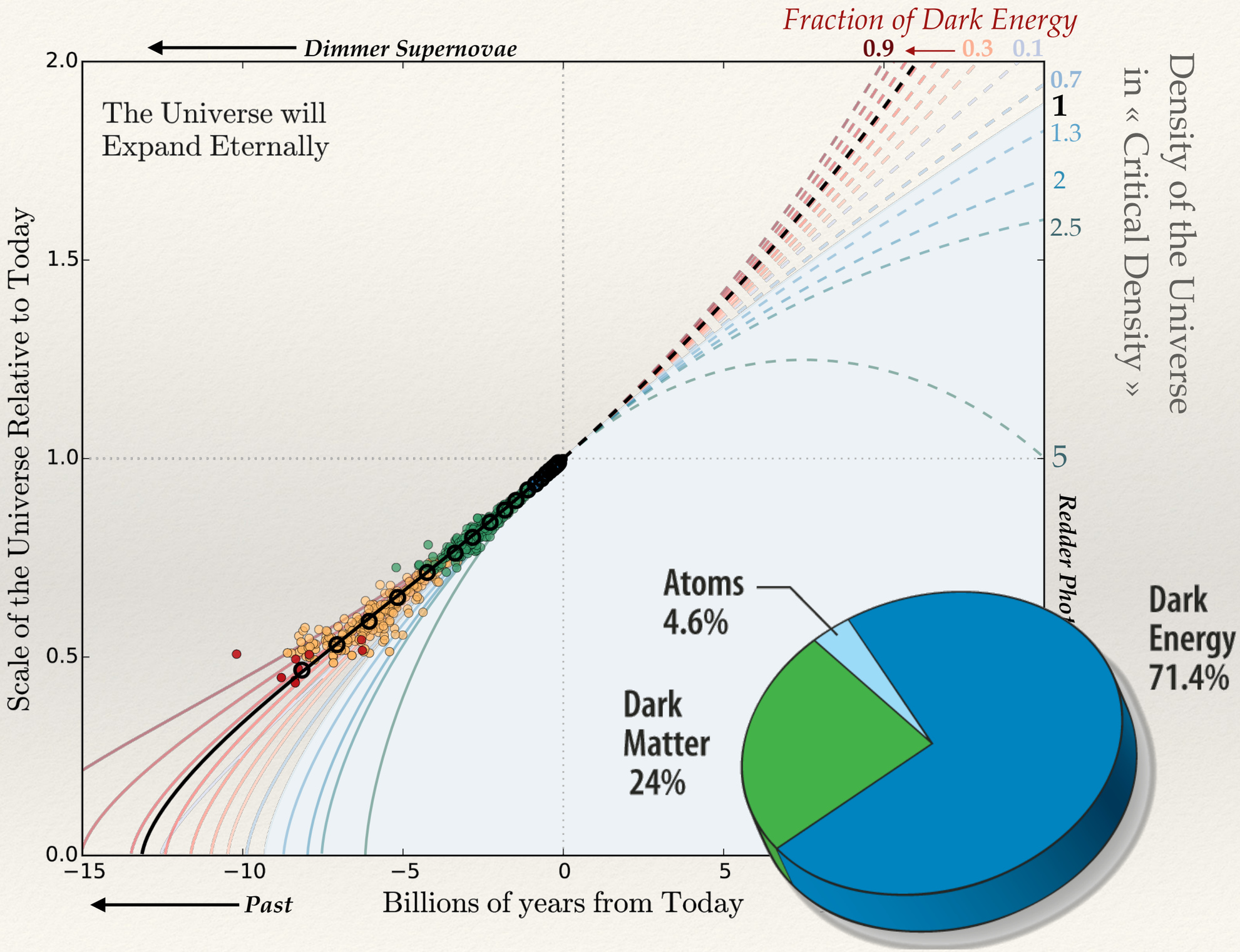
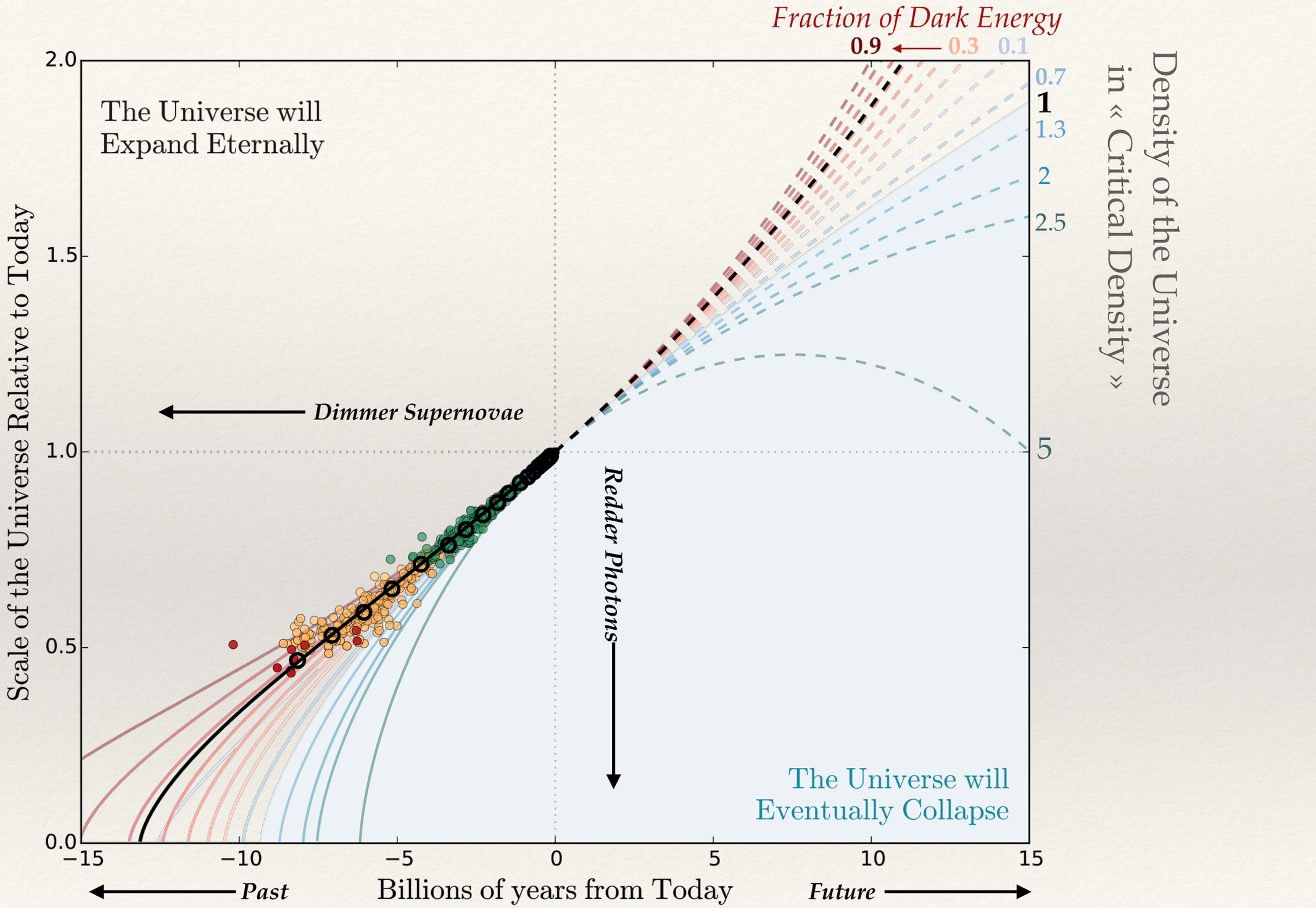
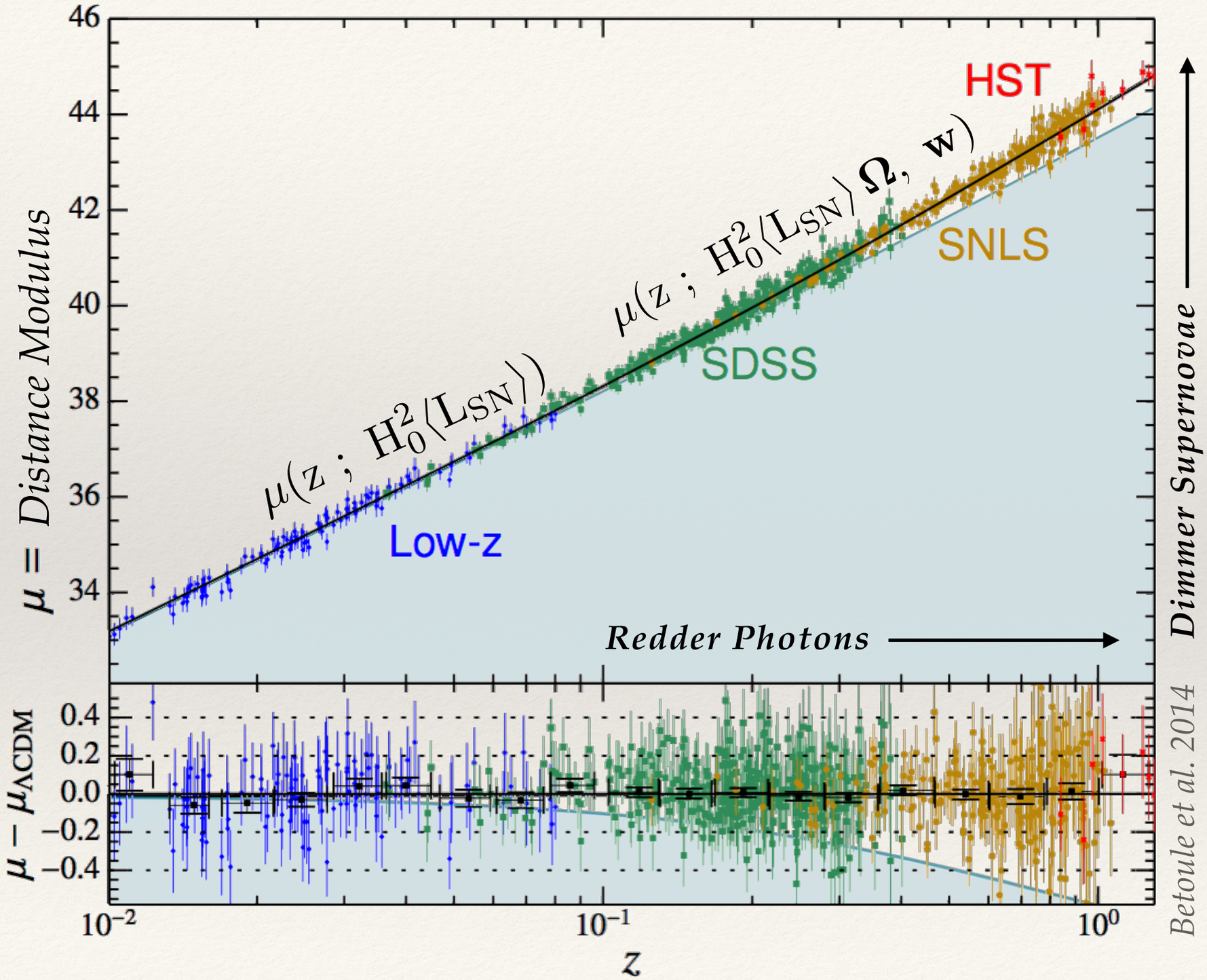


Study the Acceleration



Type Ia Supernovae Cosmology

See Florient's & Martin's Talks



Type Ia Supernova Cosmology

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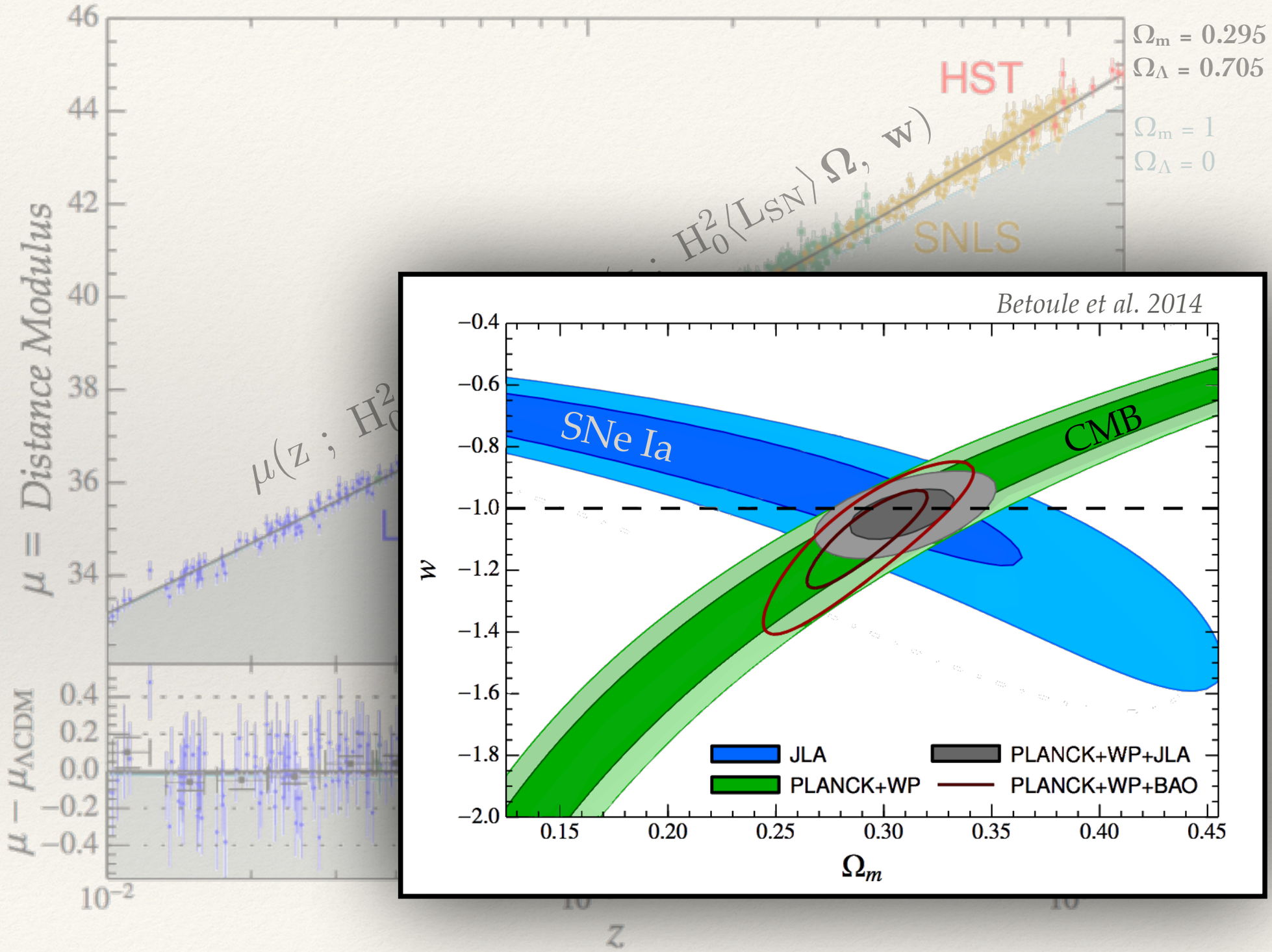
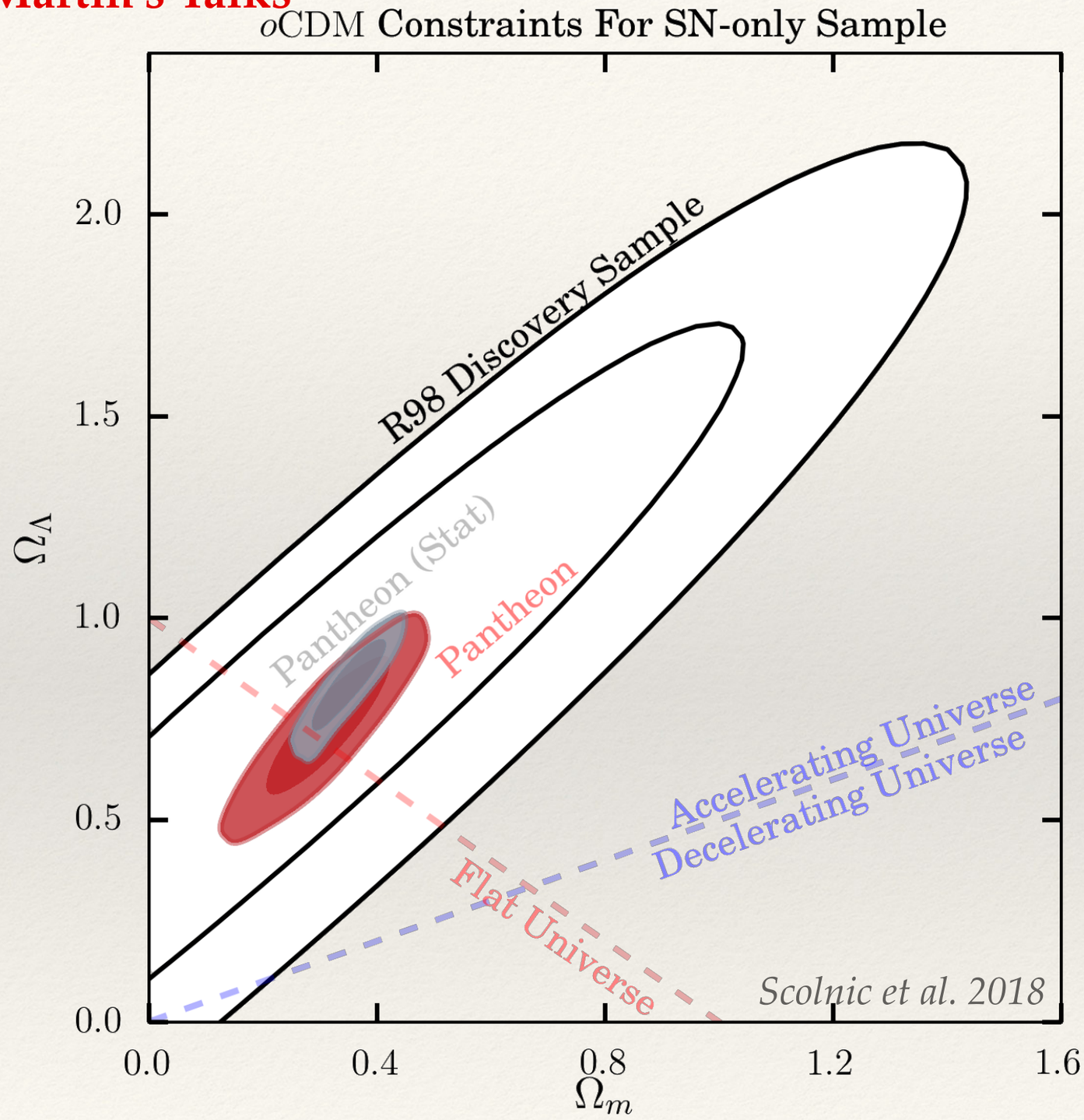
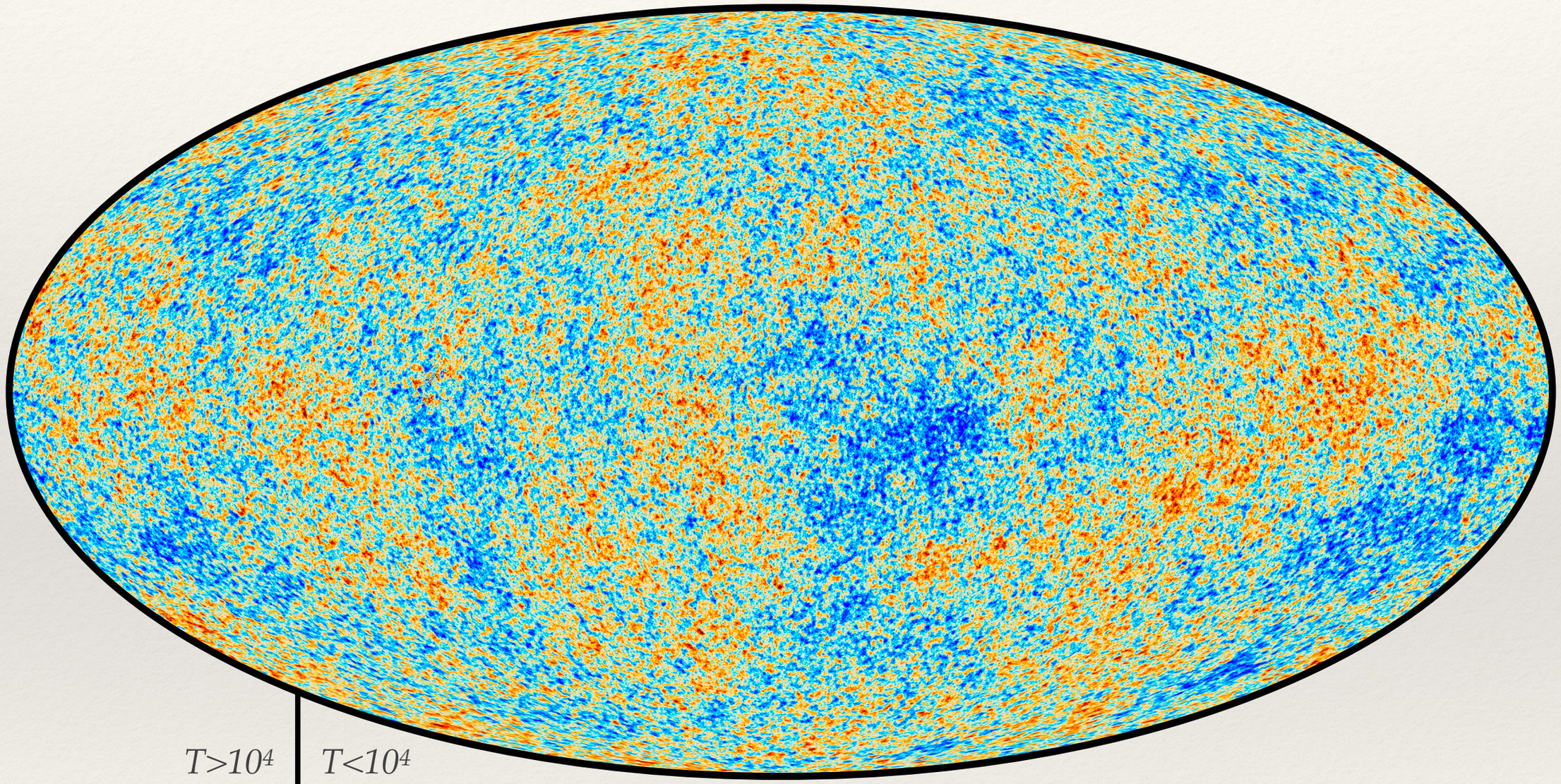


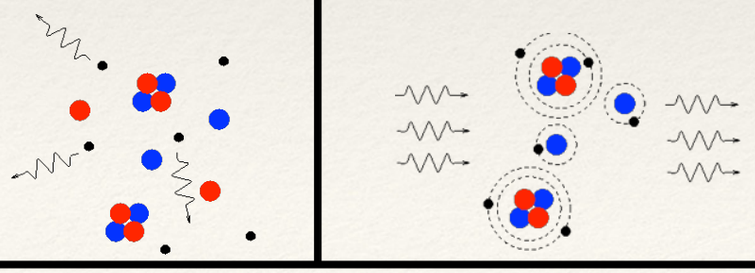
Only 20 years !

See Florient's & Martin's Talks



Cosmic Microwave Background





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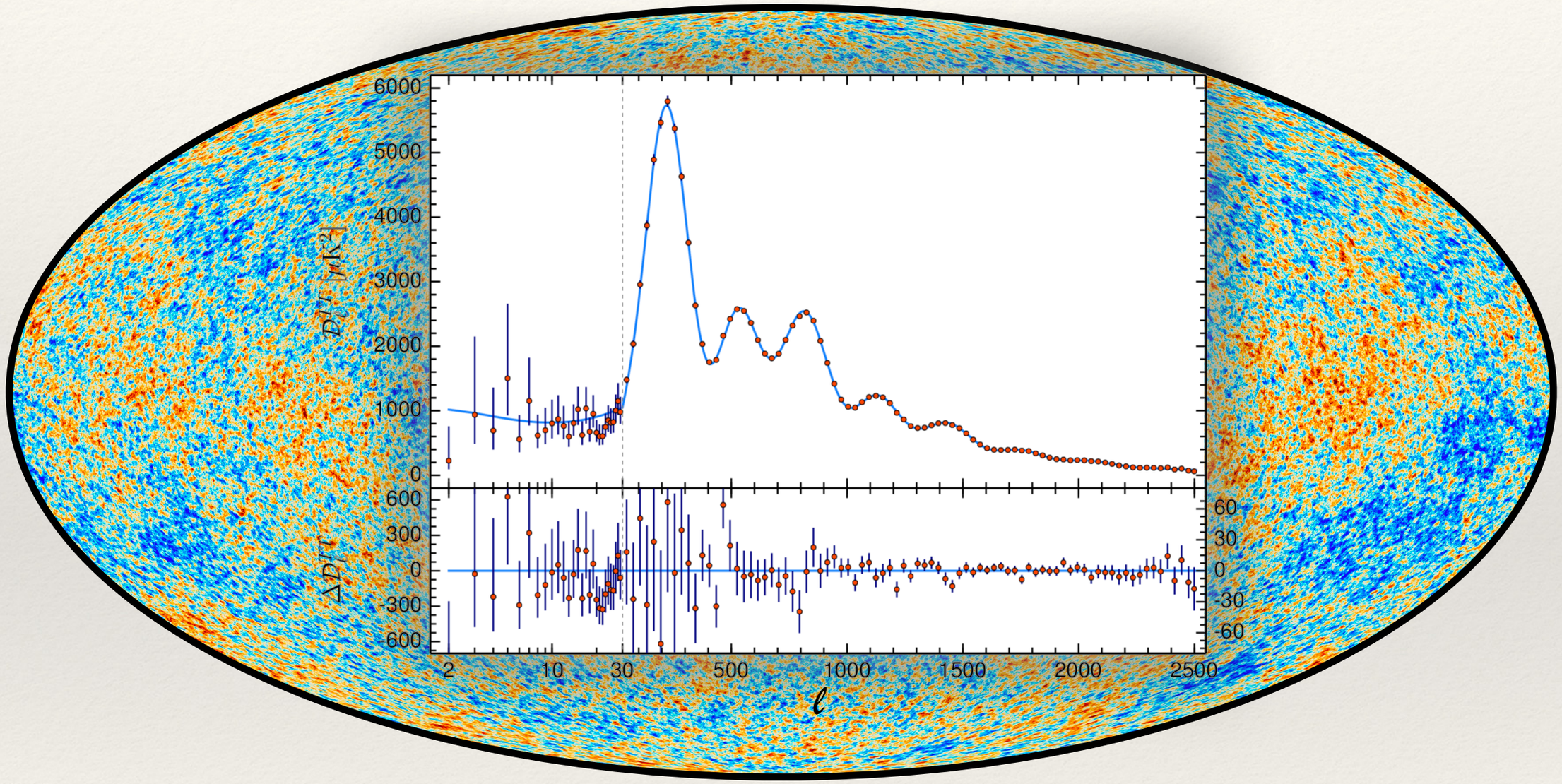
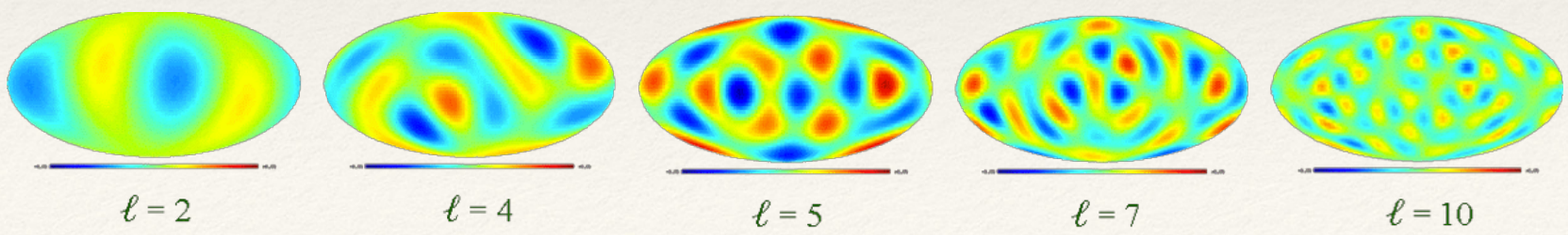
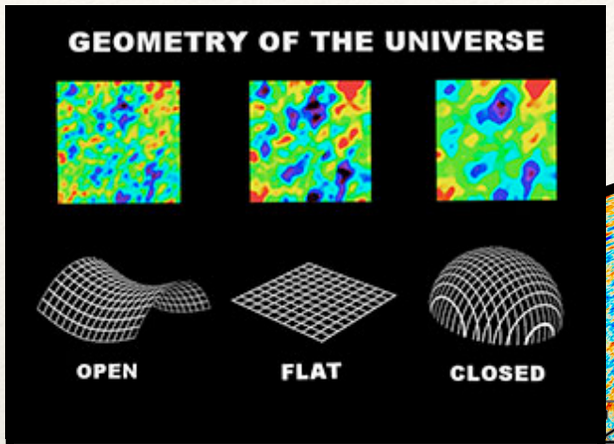
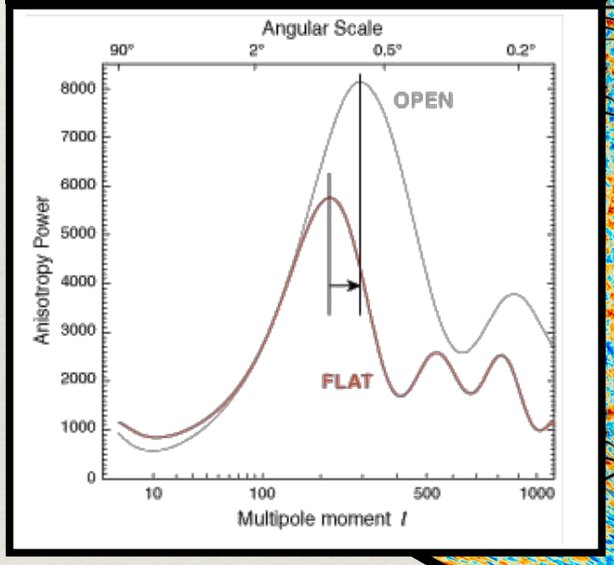
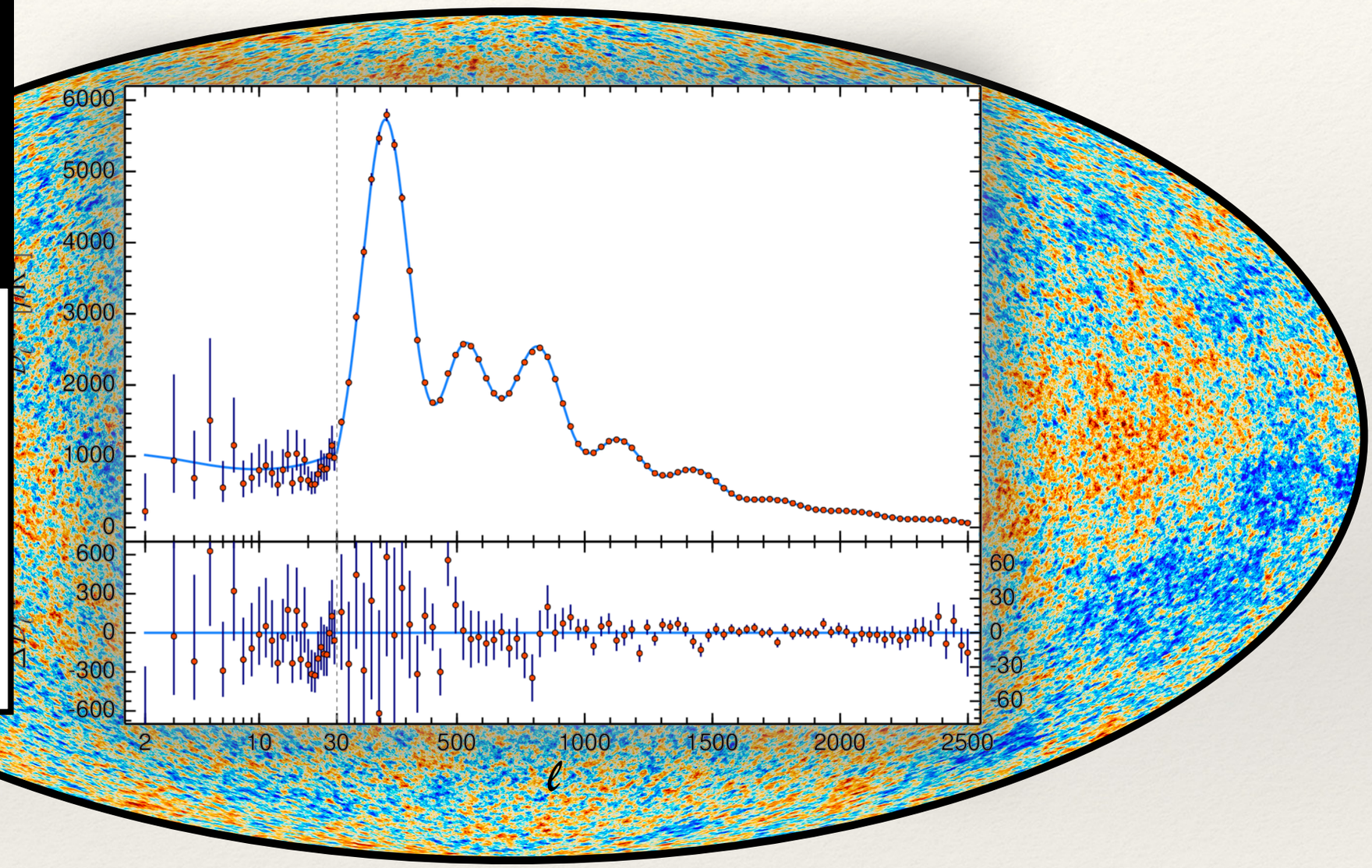


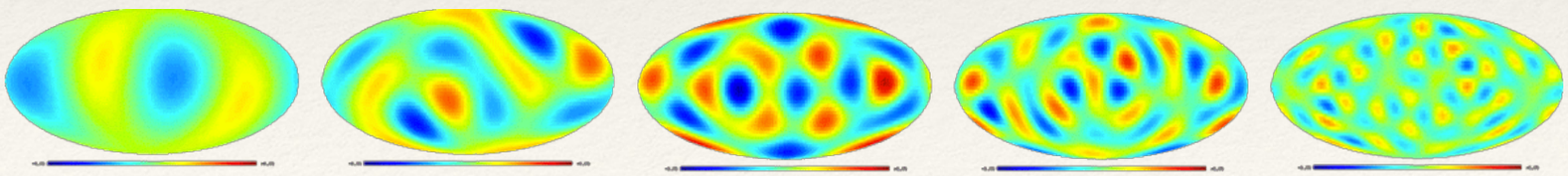


Cosmic Microwave Background









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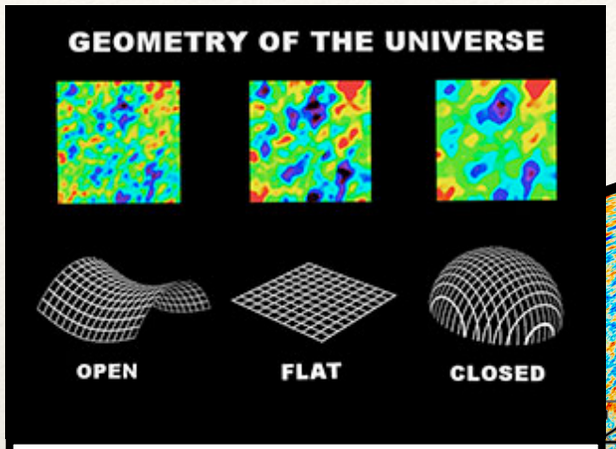
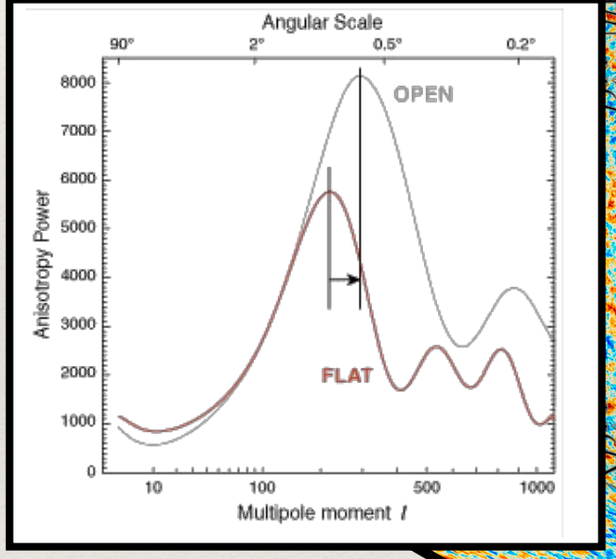
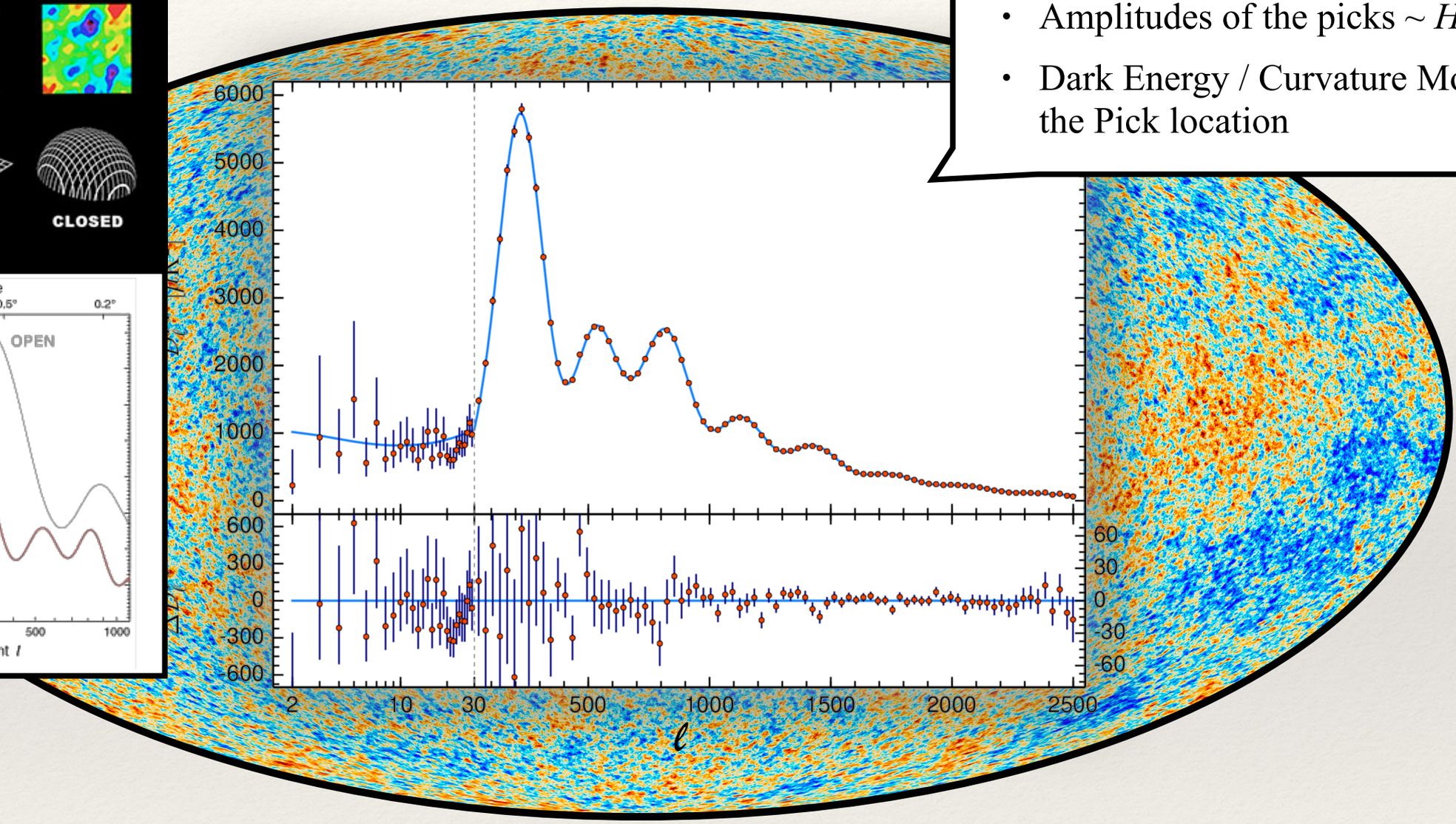
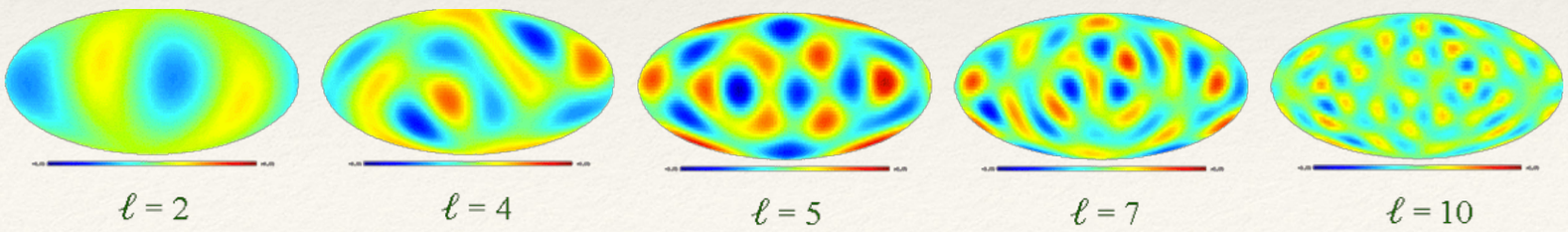




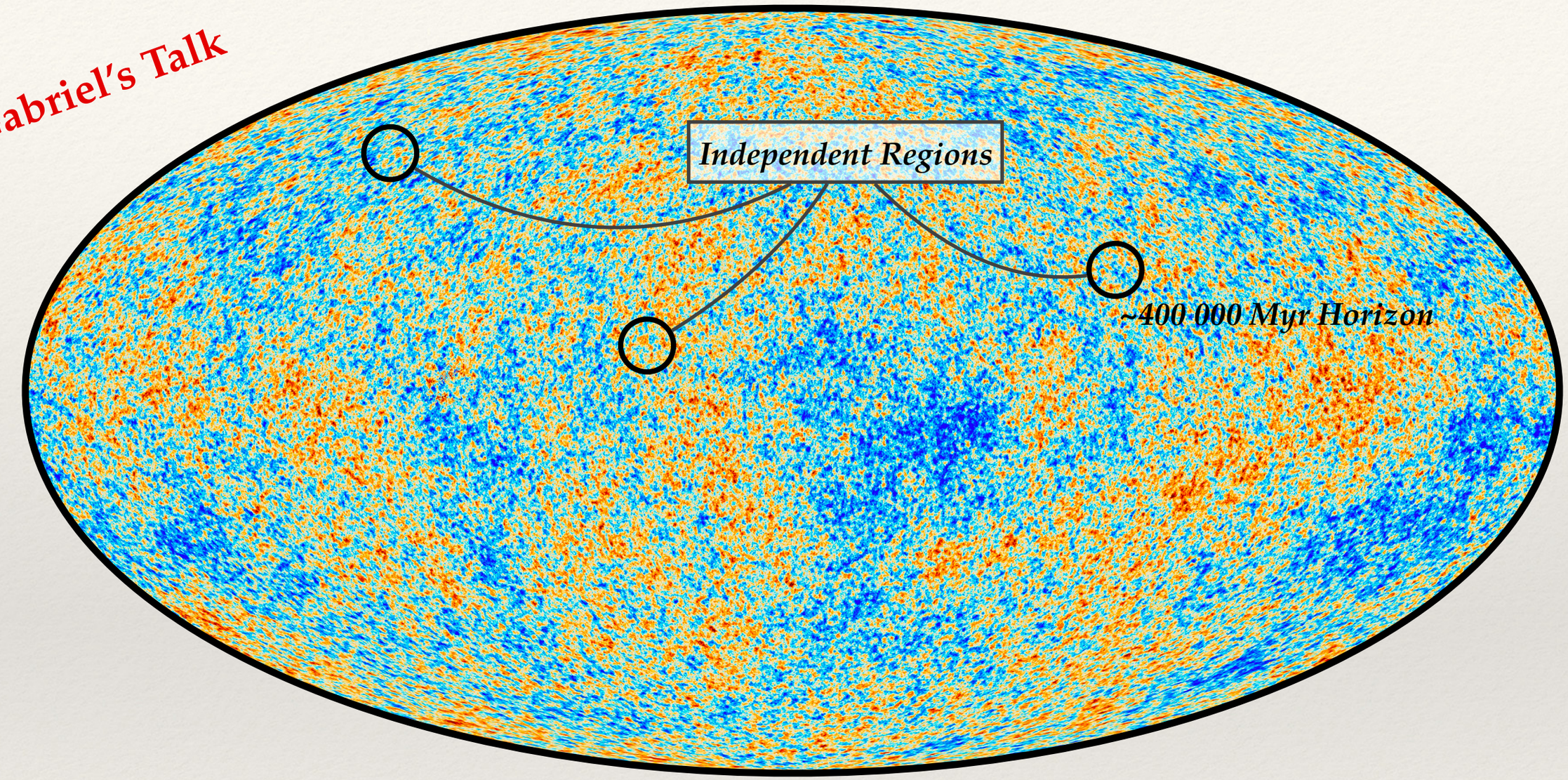
- 1st to 2nd pick ratio = ratio CDM/ Matter
- Amplitudes of the picks ~ H_0
- Dark Energy / Curvature Moves the Pick location



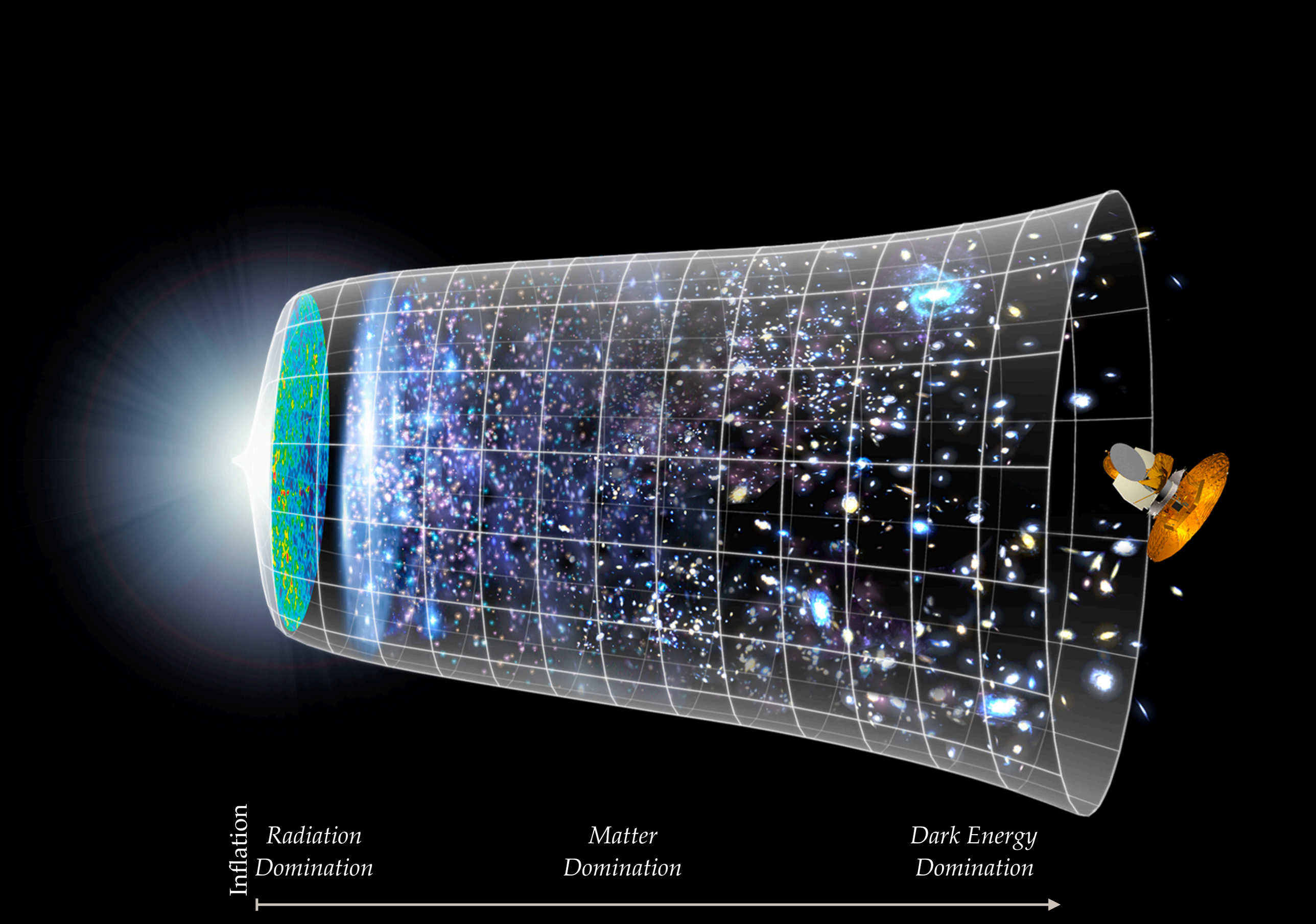


Cosmic Microwave Background | *Two Issues*

Gabriel's Talk



1. **Looks the same everywhere even though things are too far to ever have been causally connected |**
   How come they have the same initial conditions ?
2. **Why is the curvature so close to 0 (or 0) ?**



NASA/WMAP Science Team