Cosmology and String Theory

The very large and the very small

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Overview

- Things in perspective

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- Things in perspective
- The expanding Universe

  Cosmic Microwave Background Radiation (CMBR)

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- Friedman-Robertson-Walker model

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- Problems with the Standard Model of Cosmology
- Inflationary paradigm
- Uses of string theory

From Planck to PLANCK

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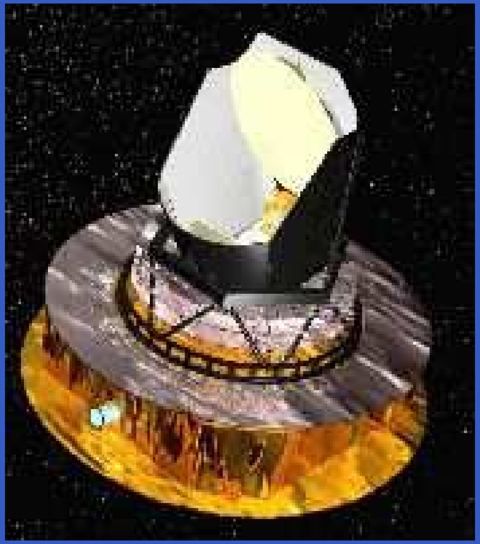

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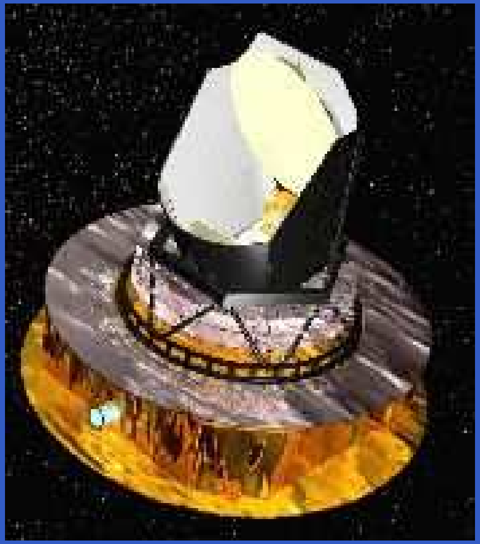

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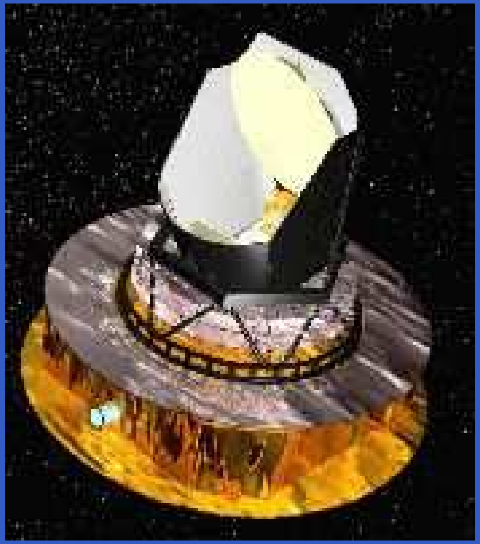

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Size of the Universe $\sim 5 \times 10^{30}$ cm

Our neighbourhood

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1 pc = 3.26 *ly* = 3.09×10^{18} cm

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The next galaxy is 50kpc $\simeq 1.7 \times 10^5$ *ly* away.

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Quasars are the farthest structures seen in the Universe $\sim$ 12–14 Gpc away.

Distribution of galaxies

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Density of matter $\rho_{\text{matter}} \sim 10^{-31}$ gm/cm^3

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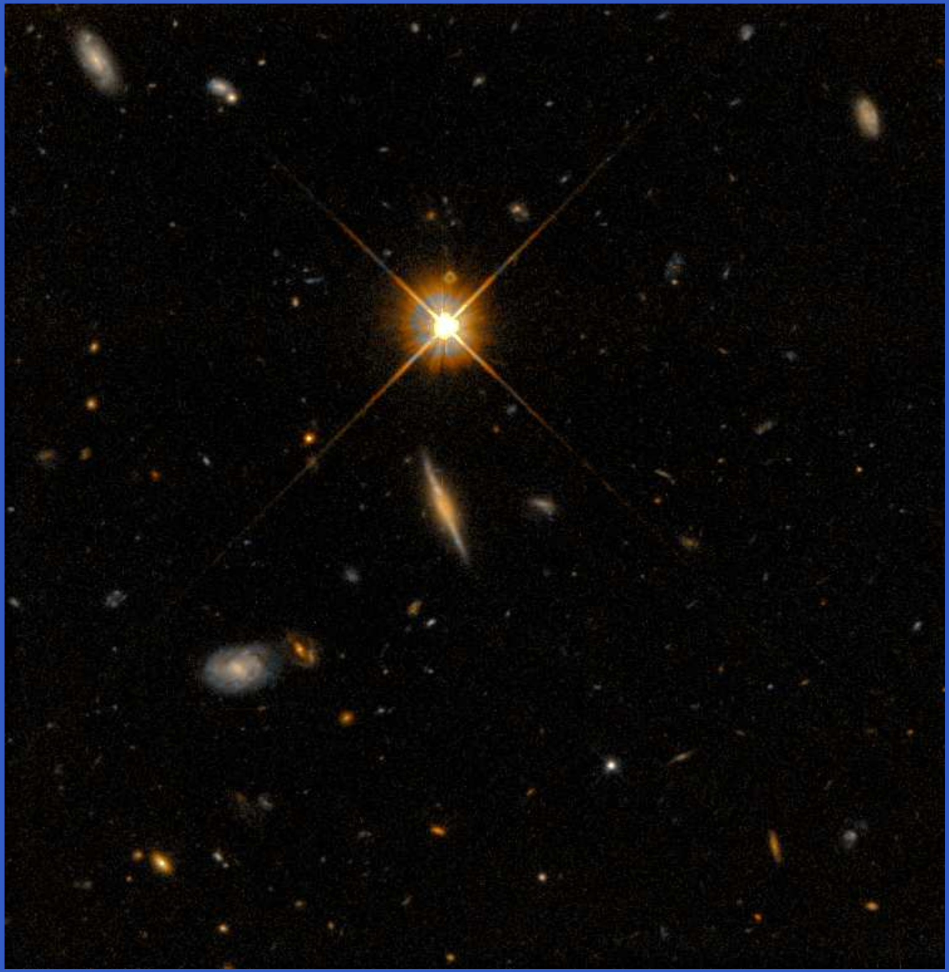

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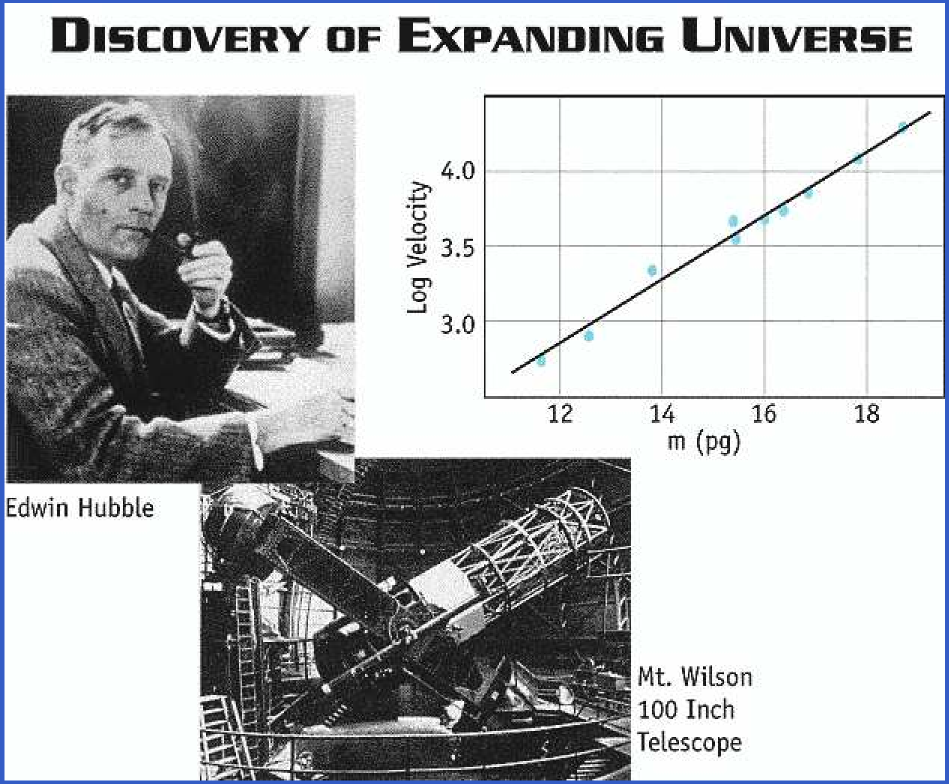
Ours is an expanding Universe. Galaxies are moving away from each other.

Hubble's observation



Hubble's observation

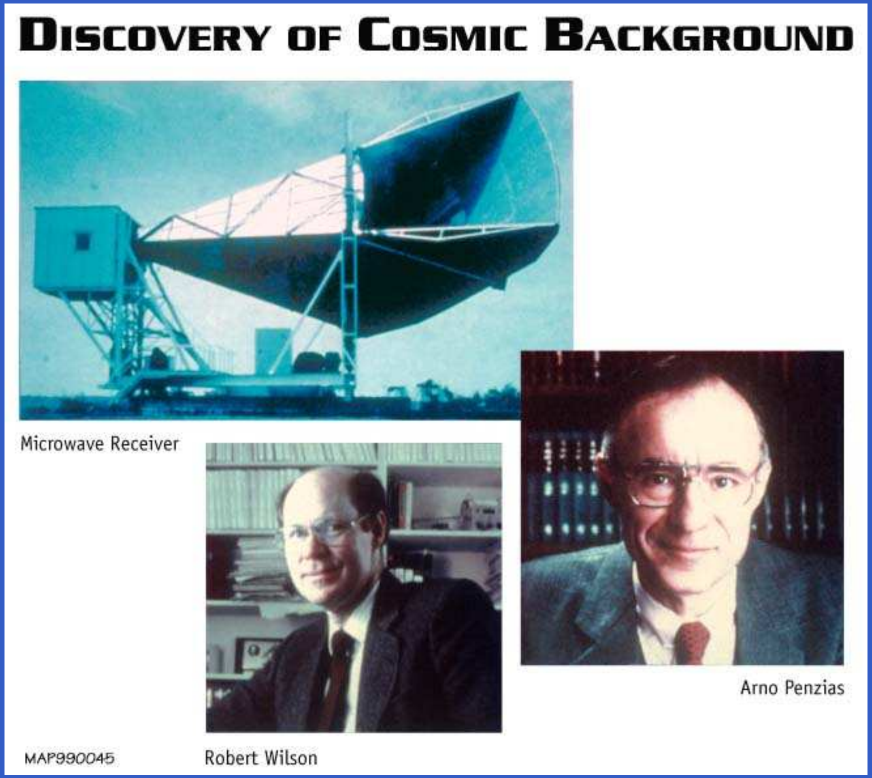
Hubble's law:

The velocity of recession v of a galaxy at a distance d is a linearly increasing function of d.

$$v = H_0 d$$

$H_0 = 72 \pm 7$ (km/s)/Mpc is the Hubble's constant.

Cosmic microwave radiation



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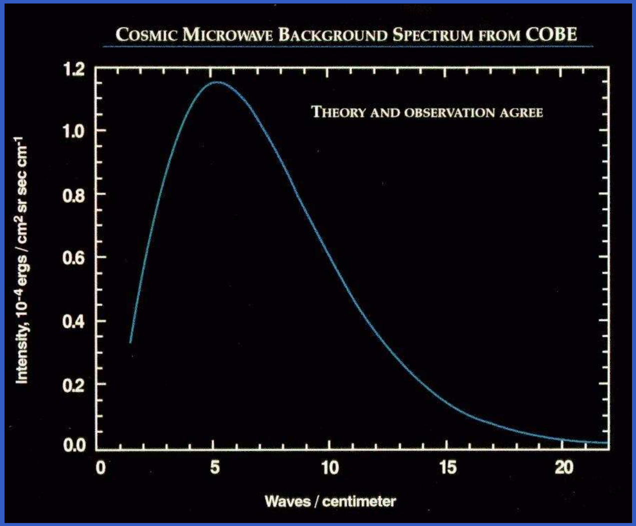

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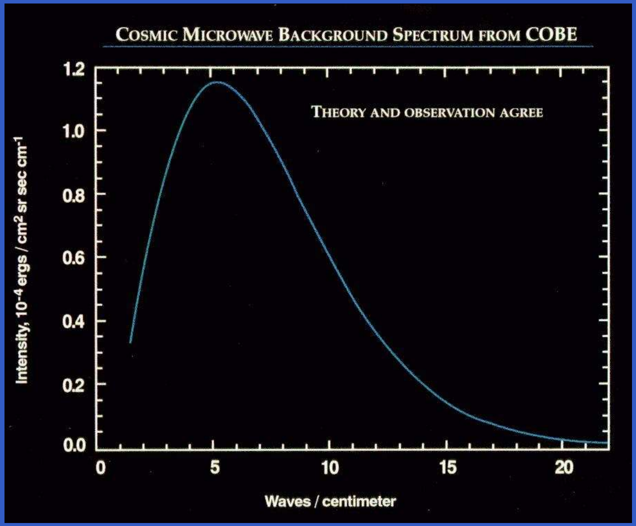

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[animated] TV noise

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This is easy to observe.

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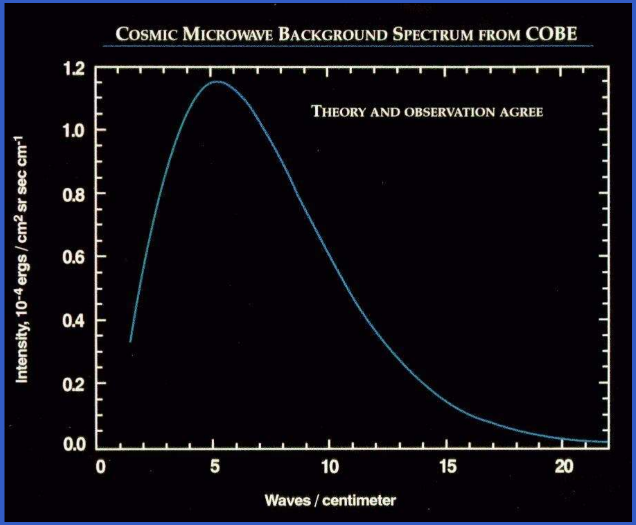

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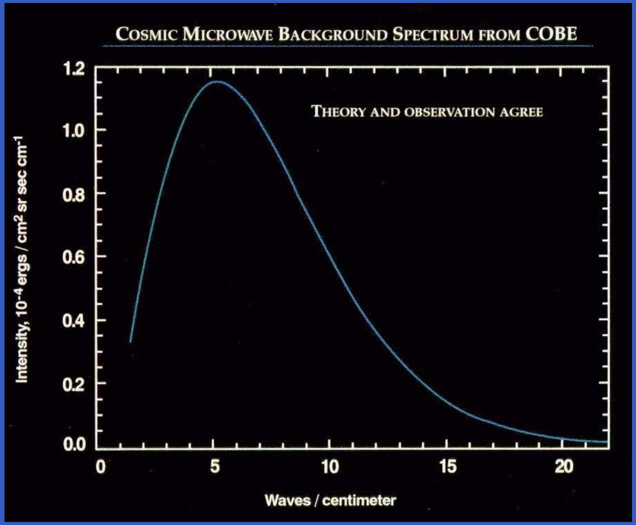

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A candidate is vacuum energy.

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physical distance = $a(t)$ coordinate distance

(x, y, z) are called comoving coordinates.

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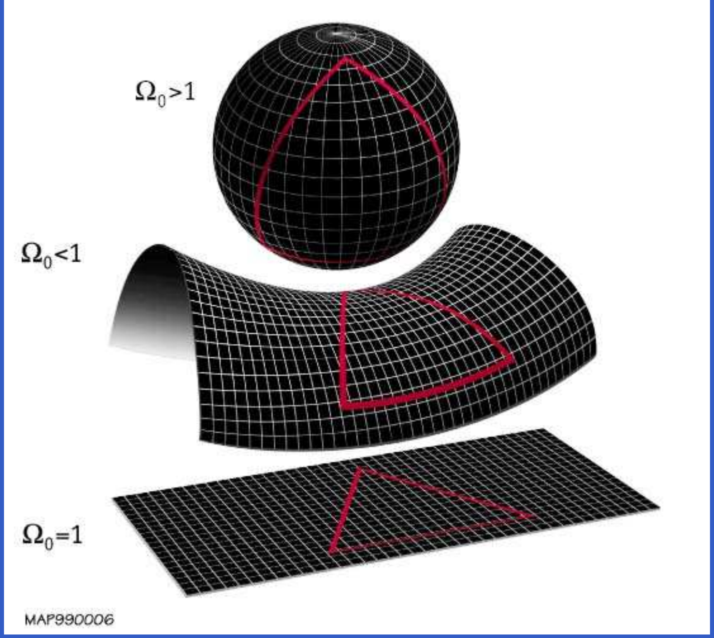

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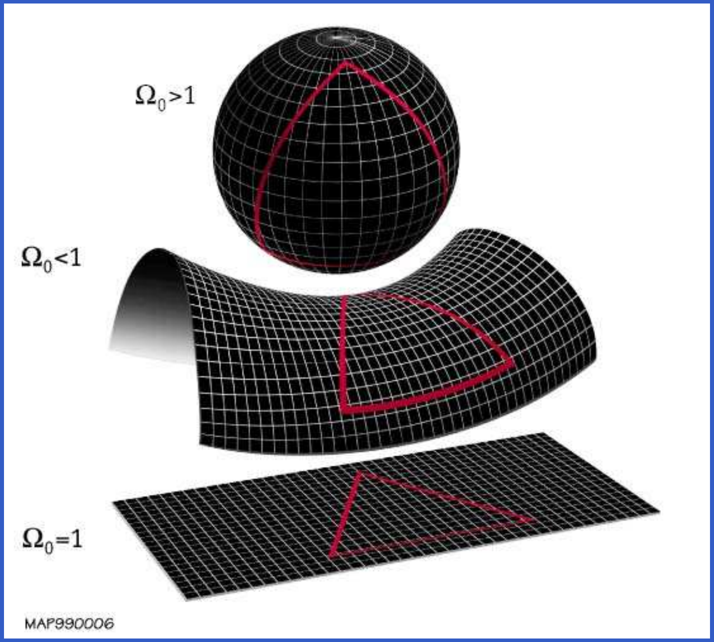

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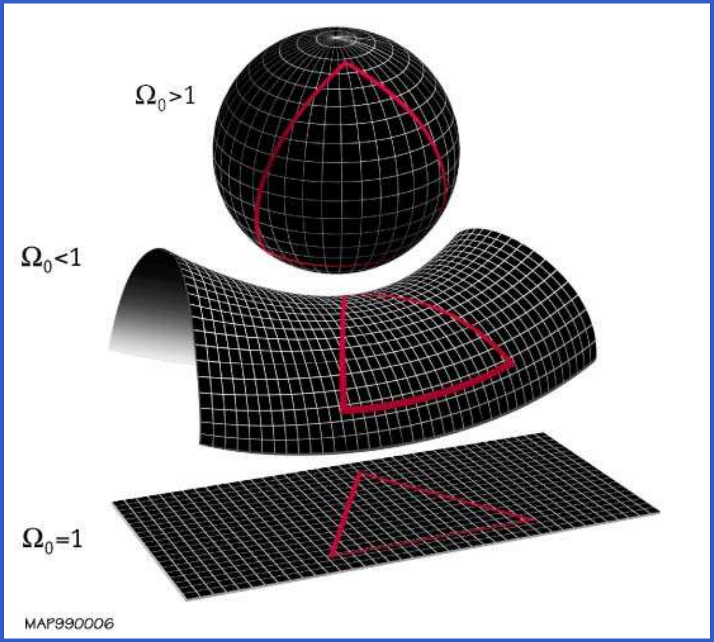

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Is the expansion uniform, accelerated or decelerated?

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$z = \Delta\lambda/\lambda$ is also a measure of distance. Quasars have $z \sim 6.6$.

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From the equation of state

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$\rho_m(\text{now}) \sim 10^{-30}\text{g/cm}^3$ Visible matter is $\sim$ 10% of this.

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$\rho_r(\text{now}) \sim 10^{-34}\text{g/cm}^3 < \rho_m(\text{now})$. Matter dominates over radiation at present.

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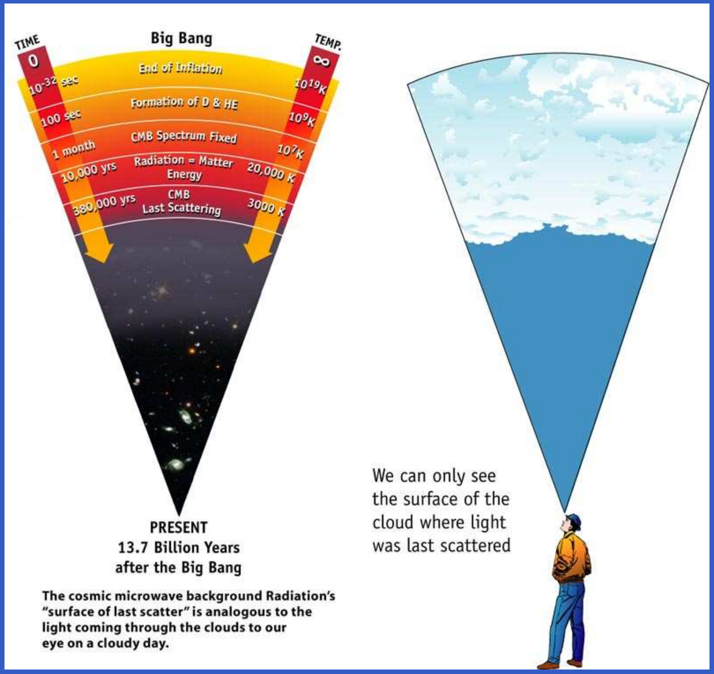

The Universe cooled as it expanded and the density of matter and radiation decreased. $t = 10^9$yrs, $T = 15°$K: Star and [animated] galaxy formation begins. $t = 3 \times 10^5$yrs, $T = 3000°$K: Matter radiation decoupling. Last scattering surface — CMBR originates. Protons and electrons combine to form Hydrogen and Helium atoms shortly afterwards.

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$t = 10^{-43}$s, $T = 10^{31\circ}$K: Quantum gravity era

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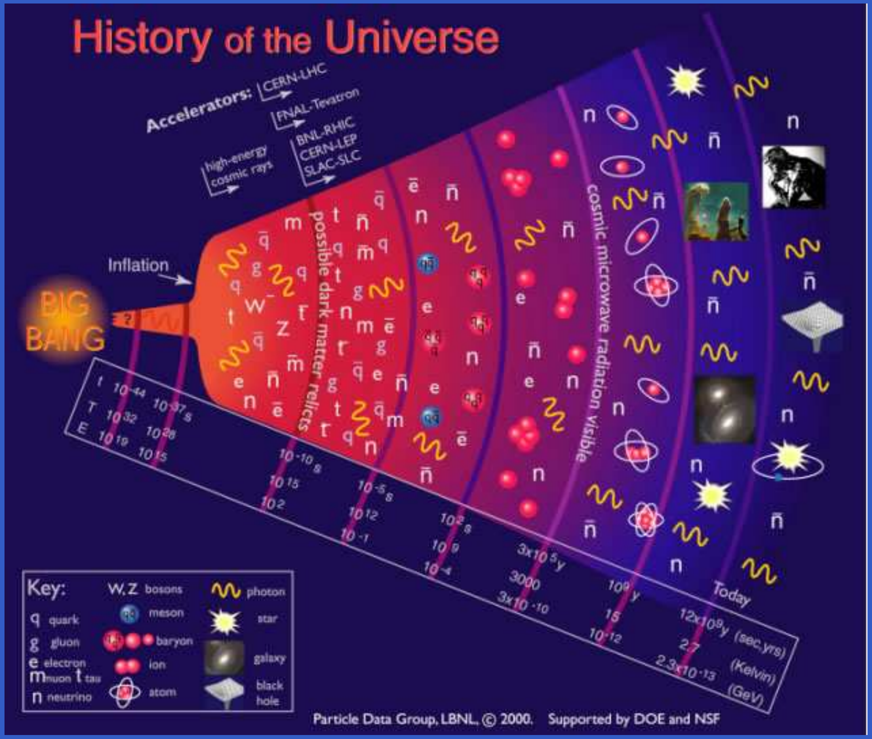

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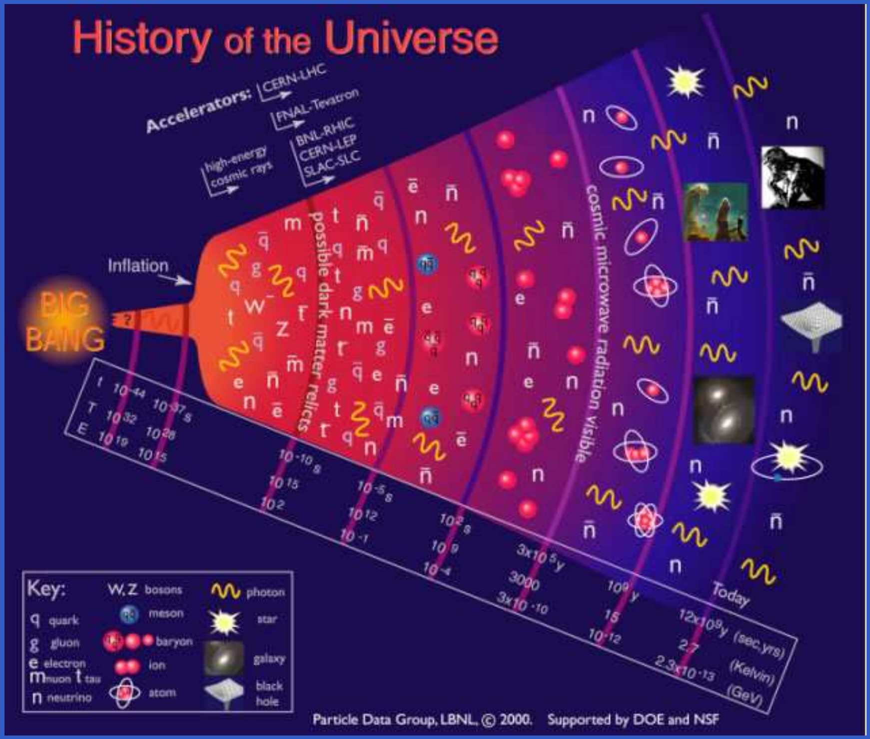

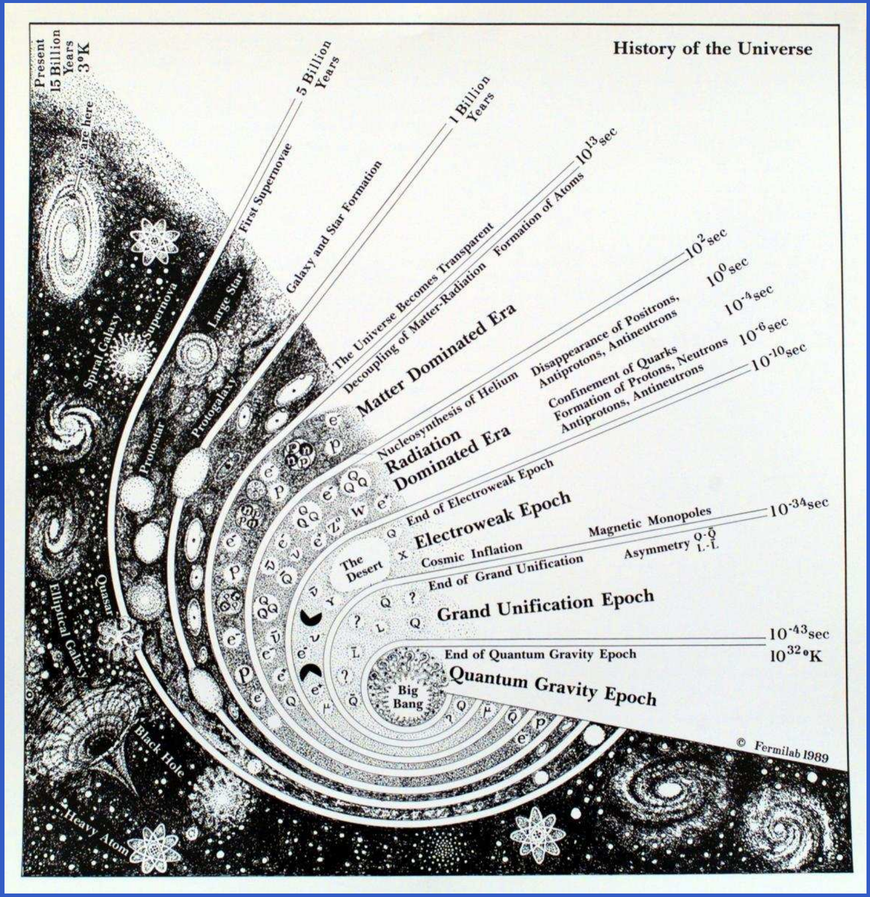

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Observation favours a positive value of cosmological constant but just barely above zero. From equation of state: $p = -\rho$: negative pressure.

Einstein equations

Just one equation: $\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G_N}{3}\,\rho_{\text{tot}}$ Friedman equation.

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$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G_N}{3}\,\rho_{\text{tot}} - \frac{k}{a^2}$$

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$$\rho_{cr} = \frac{3H_0^2}{8\pi G_N} = 10^{-29}\text{g/cm}^3$$

the critical density.

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the critical density. Dimensionless densities:

$$\Omega_m = \rho_{m,0}/\rho_{cr}\,, \quad \Omega_r = \rho_{r,0}/\rho_{cr}\,, \quad \Omega_\Lambda = \rho_{v,0}/\rho_{cr}$$

$(\Omega_m + \Omega_r + \Omega_\Lambda = 1)$.

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Using eqns of state

$$-\frac{1}{2}\left(a^2\Omega_\Lambda + \frac{\Omega_m}{a} + \frac{\Omega_r}{a^2}\right) \equiv V_{\text{eff}}(a)$$

$$\frac{1}{2H_0^2}\,\dot{a}^2 + V_{\text{eff}}(a) = 0$$

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$$
\begin{aligned}
-\frac{1}{2}\left(a^2\Omega_\Lambda + \frac{\Omega_m}{a} + \frac{\Omega_r}{a^2}\right) &\equiv V_{\text{eff}}(a) \\
\frac{1}{2H_0^2}\,\dot{a}^2 + V_{\text{eff}}(a) &= 0
\end{aligned}
$$

Energy condition for a (NR) particle in a potential.

Evolution of scale factor

Scale factor $a(t)$ grows as

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Big Bang Singularity

CMBR and COBE

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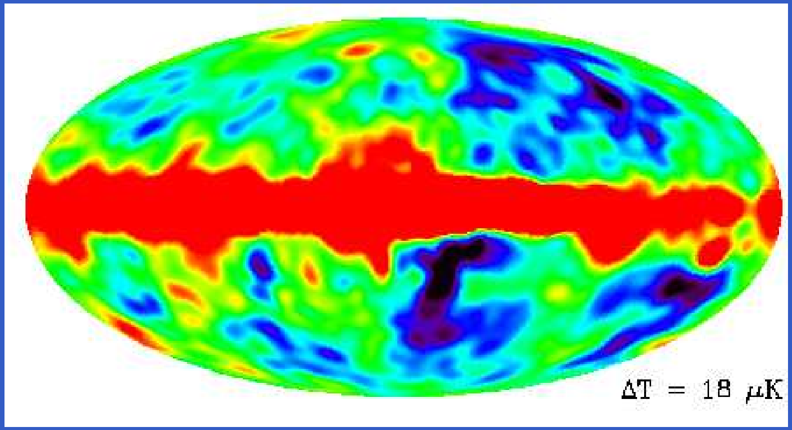

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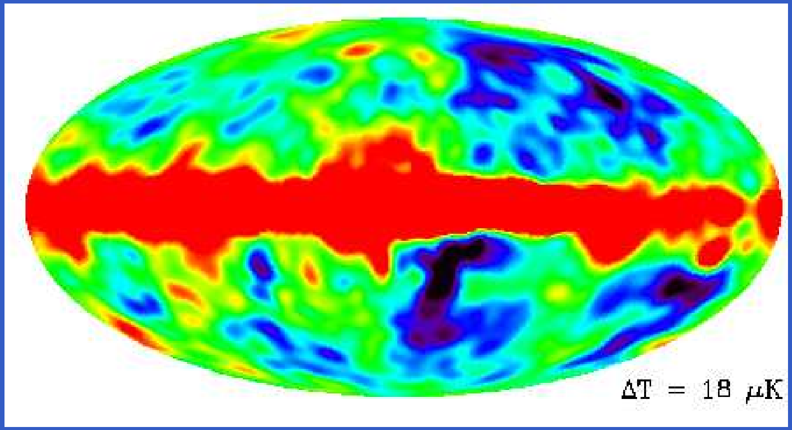

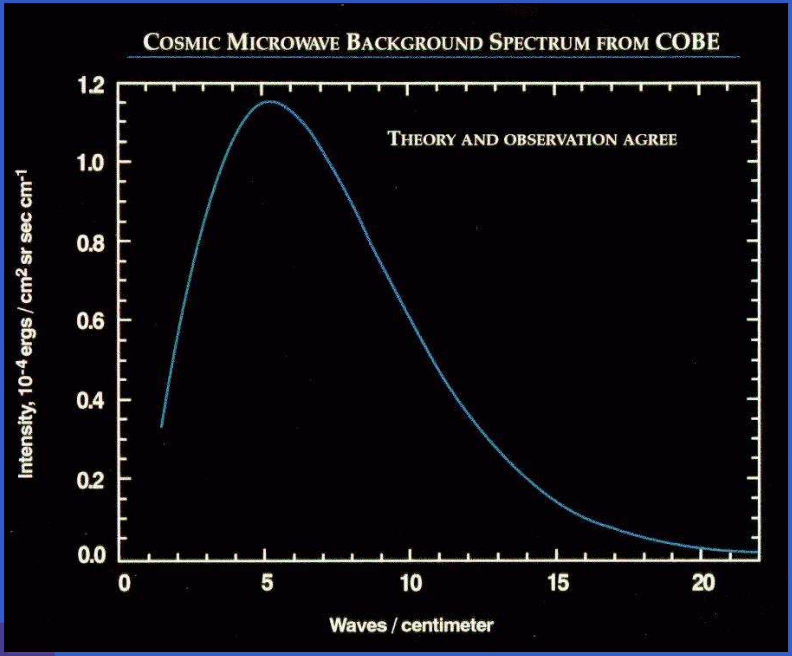

WMAPping CMBR

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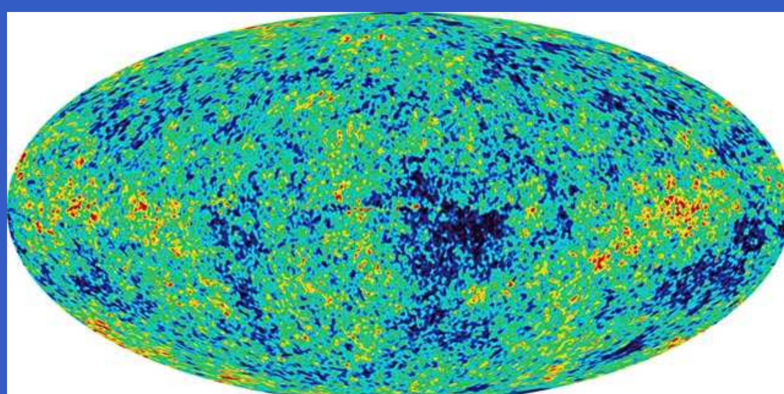
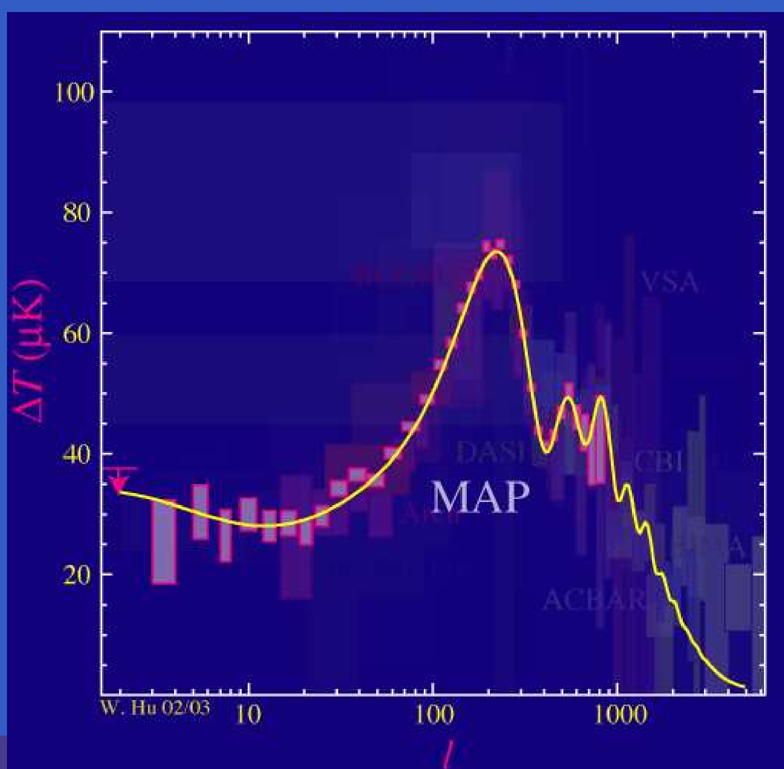


Fluctuations: 1 part in 10^5

WMAPping CMBR



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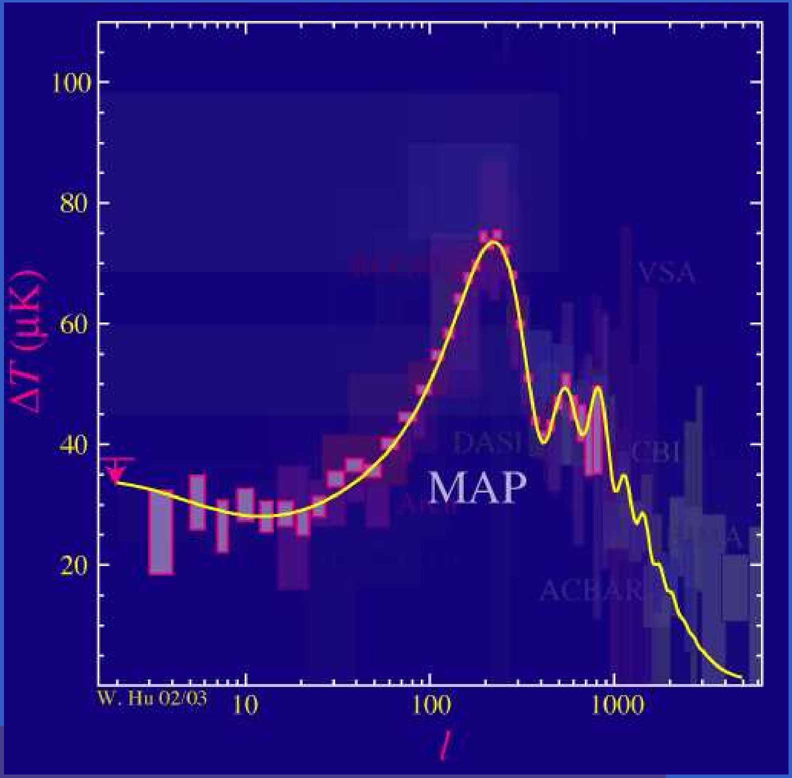

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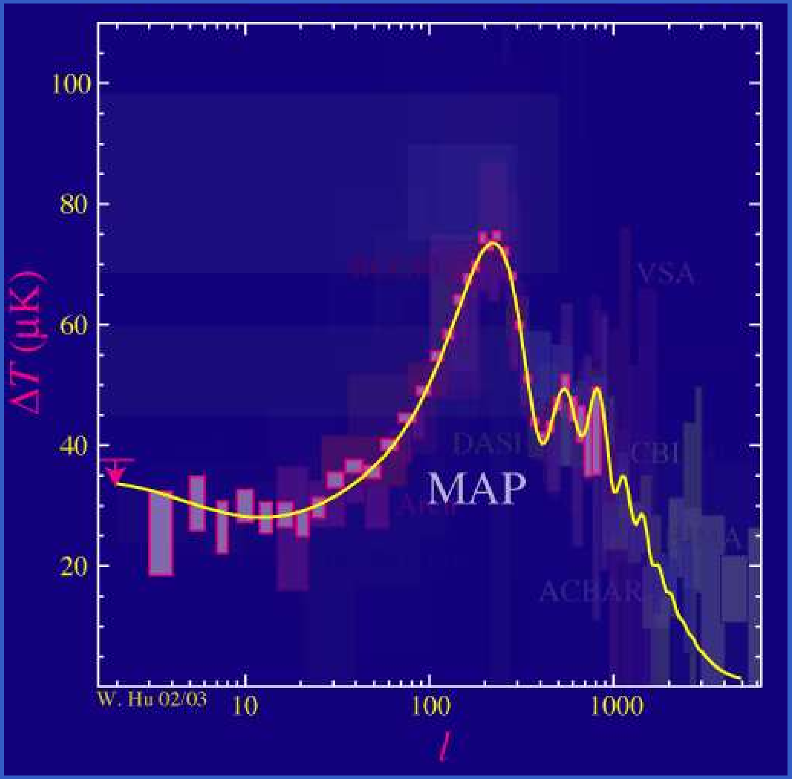

Angular correlation of temperature fluctuations in μK.

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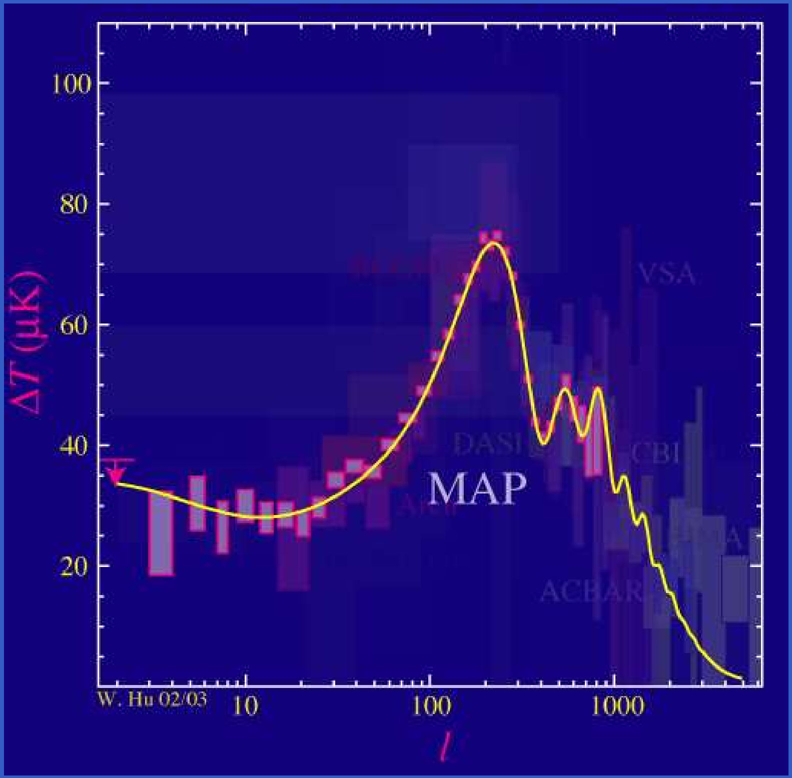

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Music from the primordial universe

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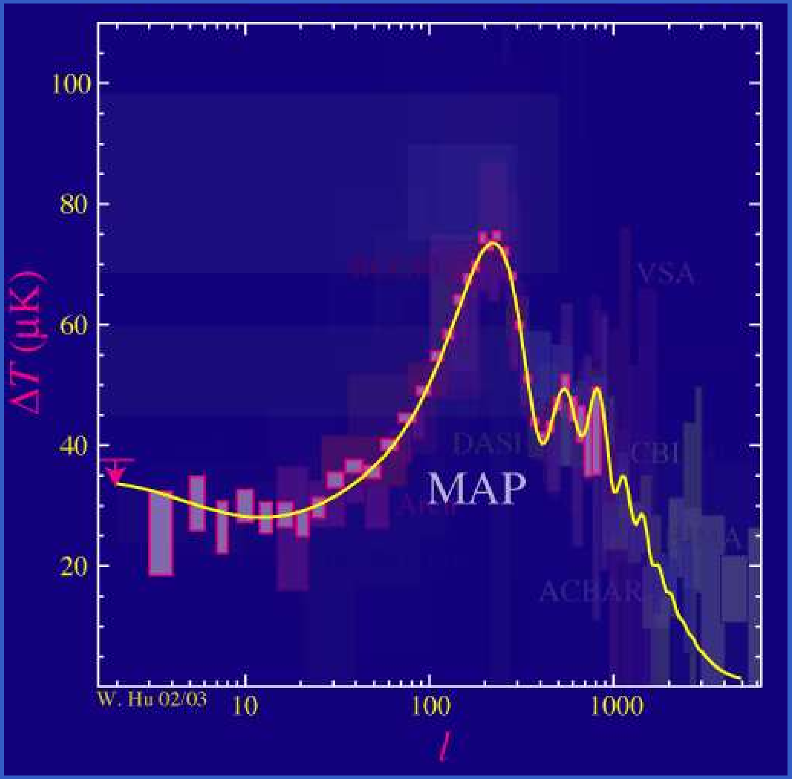

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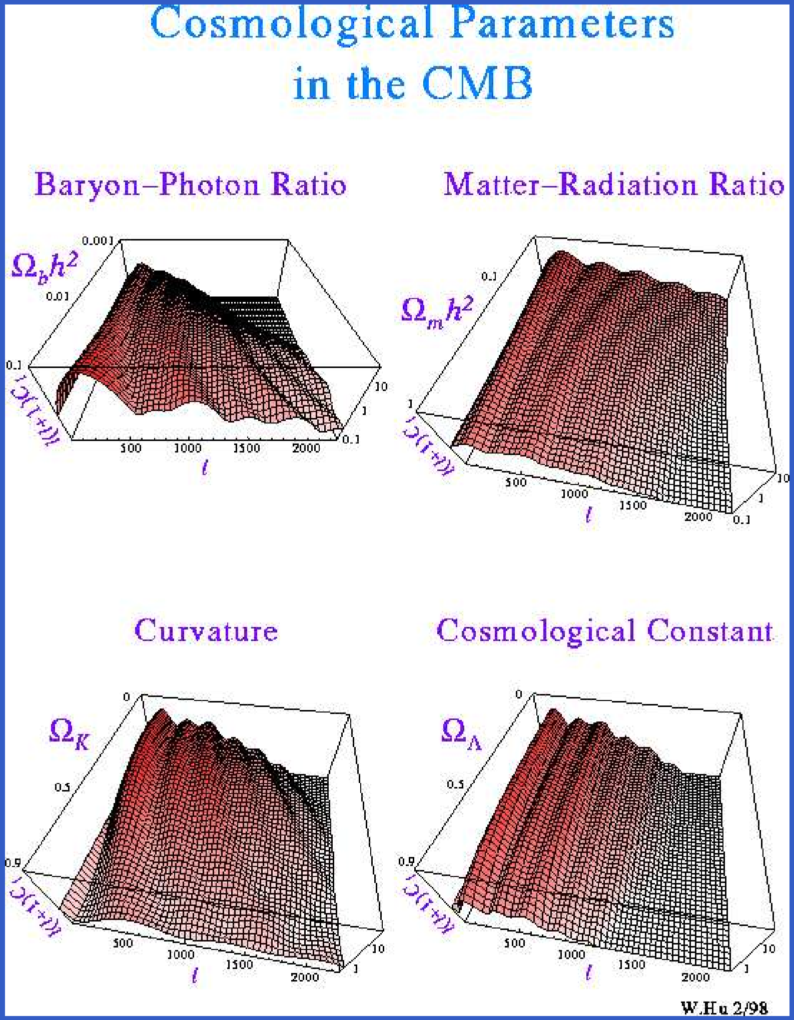

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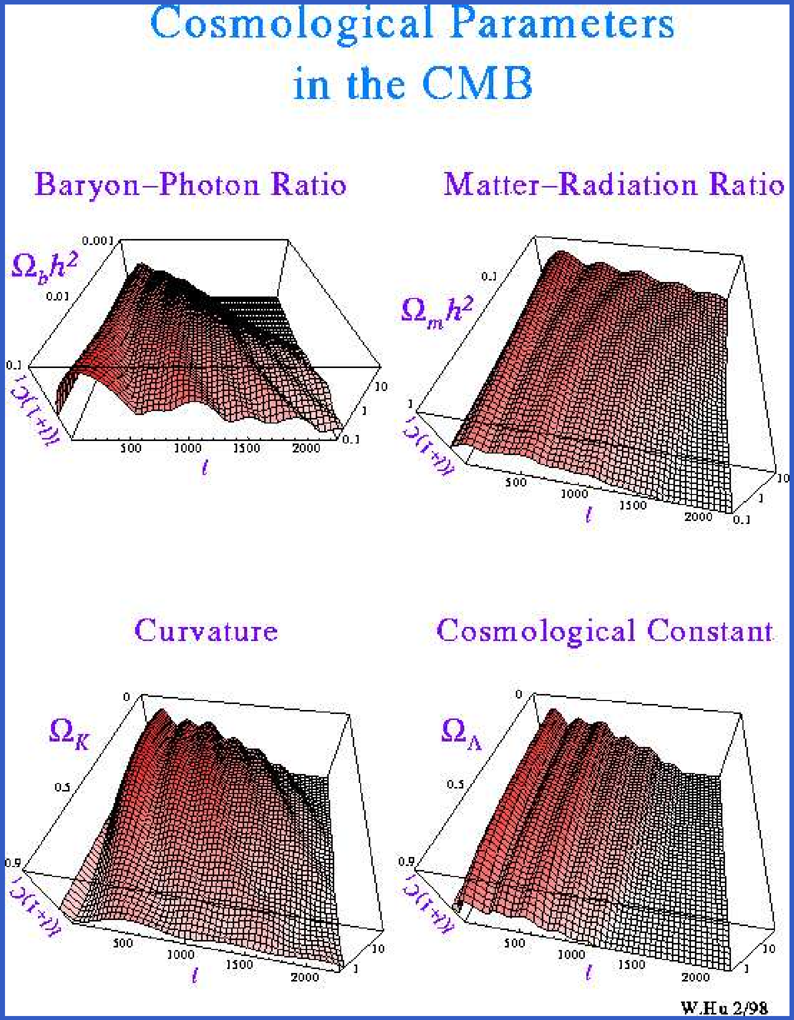

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But . . .

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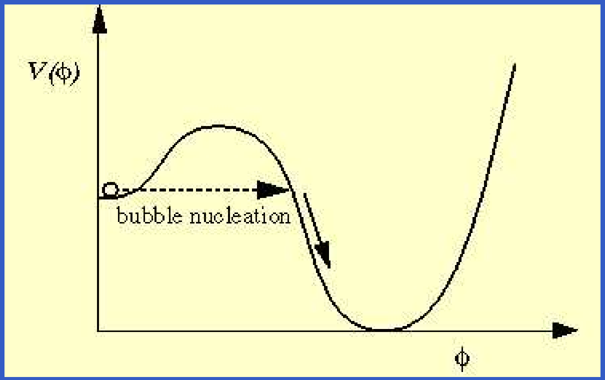

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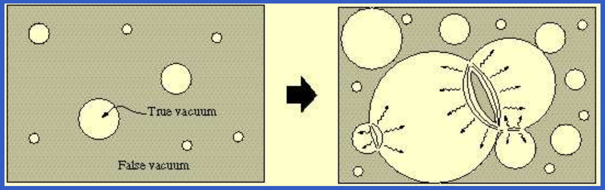

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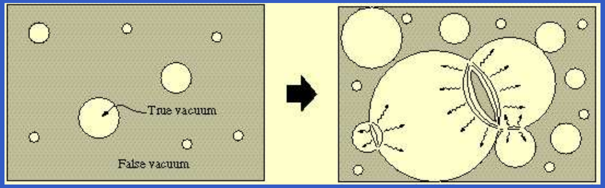

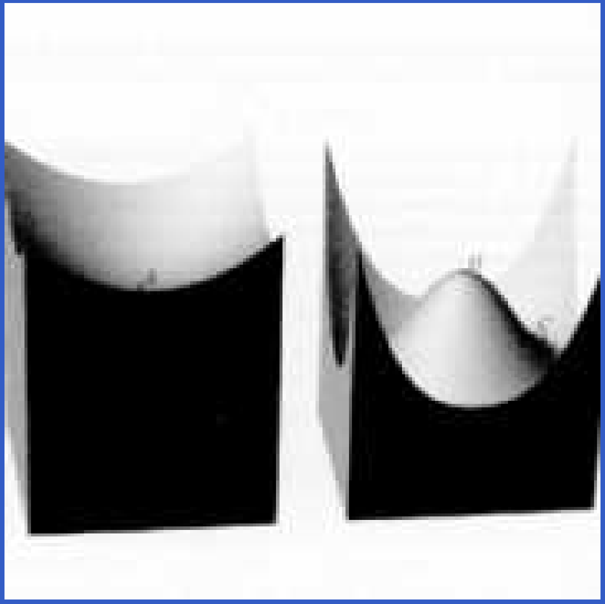

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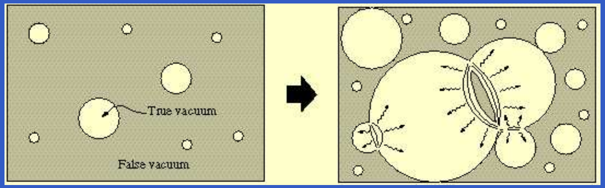

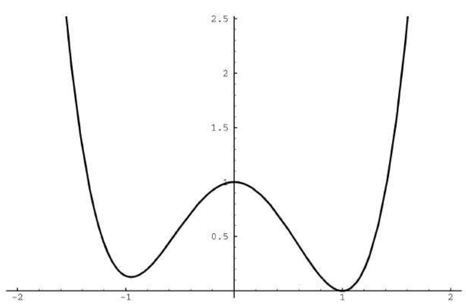

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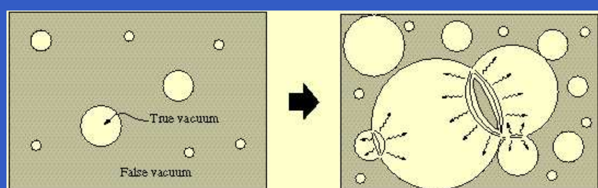

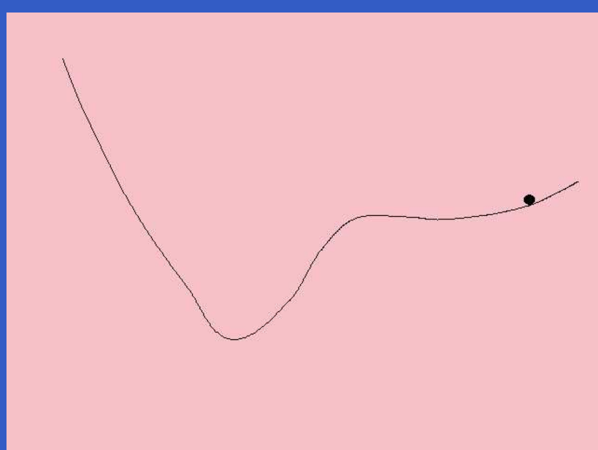

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Inflation. . . (ii)

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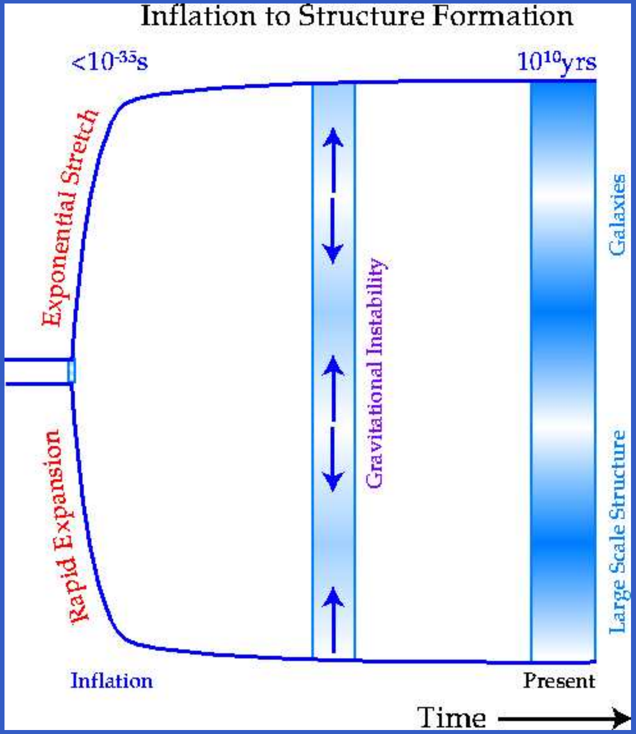

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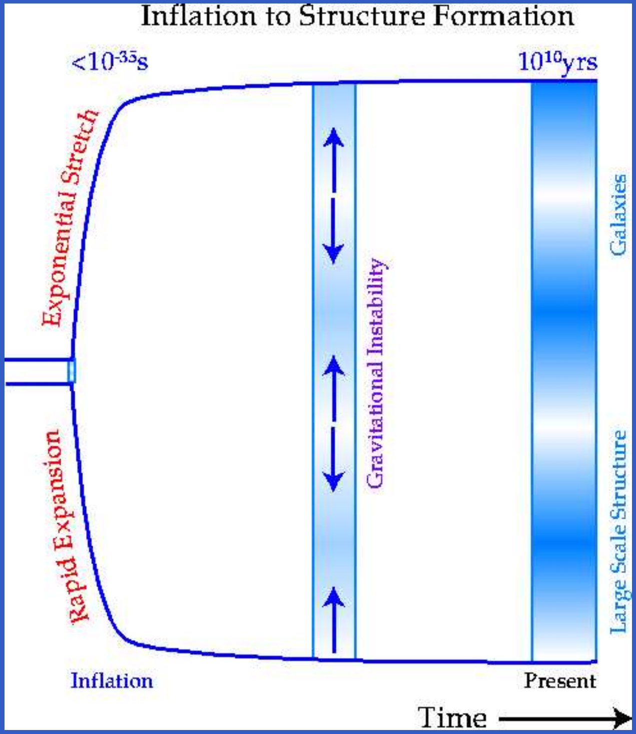

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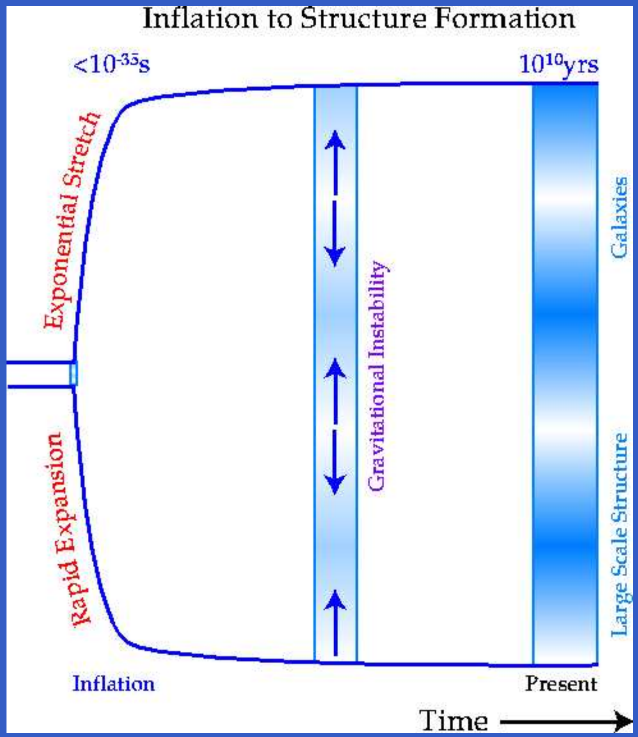

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Which model?
Is semiclassical treatment enough?

Role of string theory

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Tachyon field on unstable D-brane or brane-antibrane pair. **Tachyon inflation** Tachyon behaves like pressureless dust at late times.

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A combination of moduli and tachyon:

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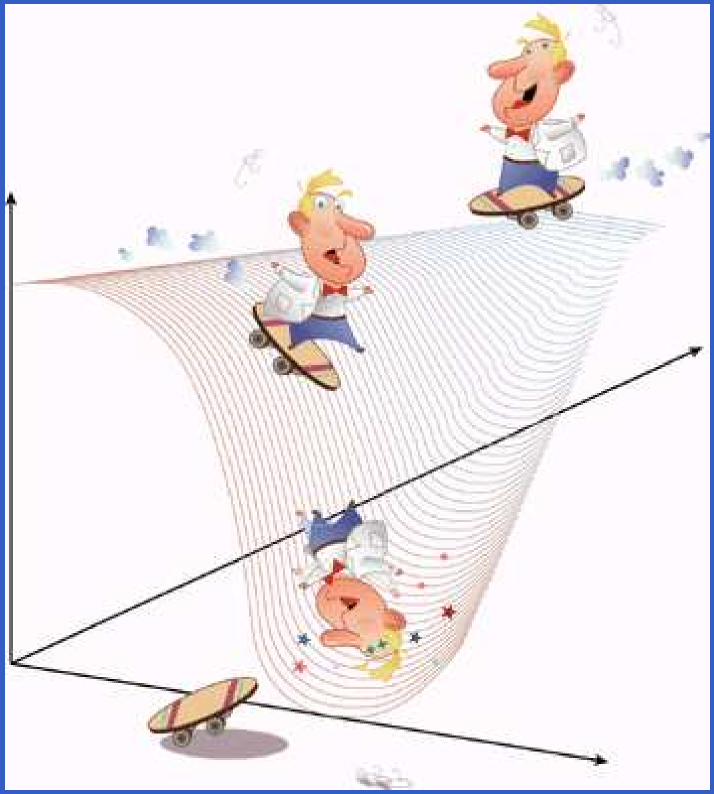

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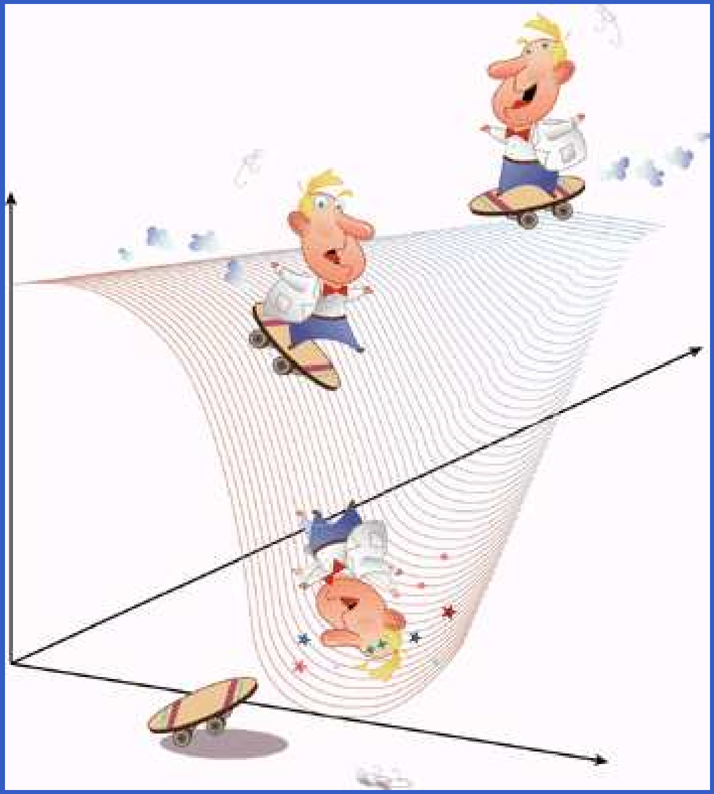

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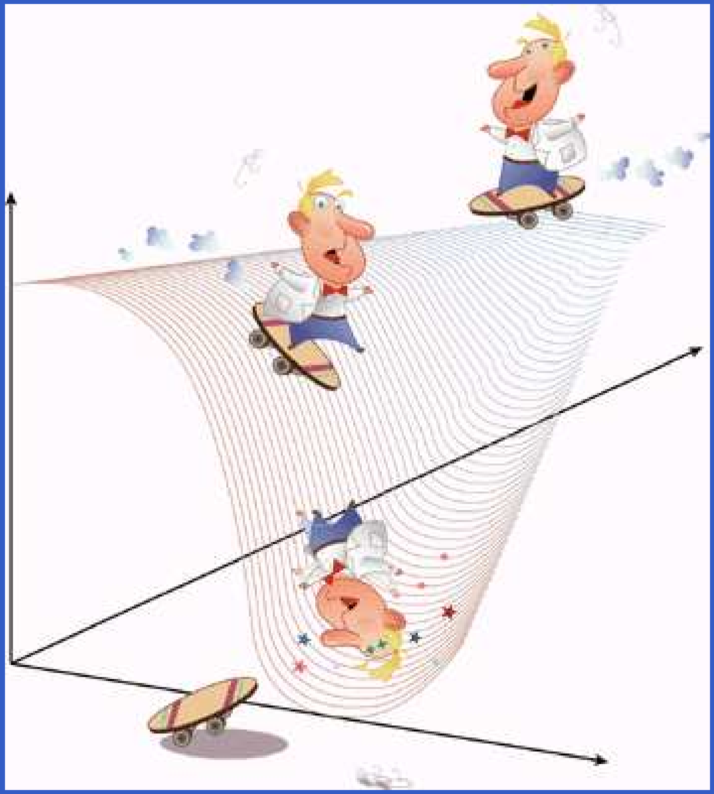

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Many other models. . .

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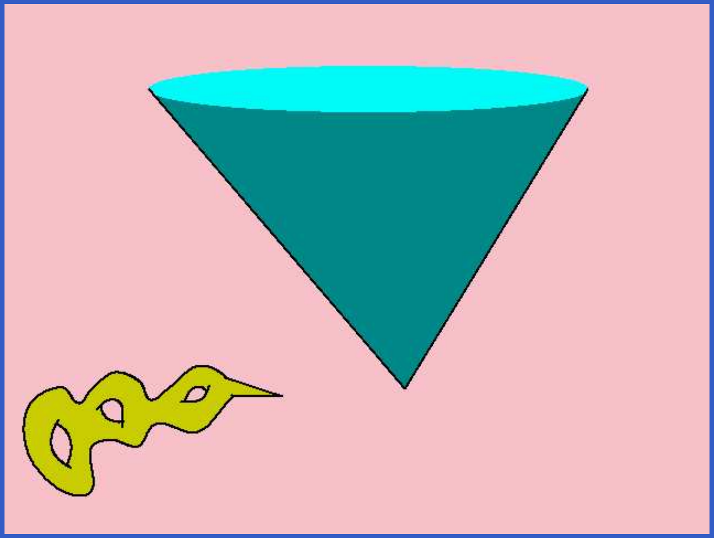

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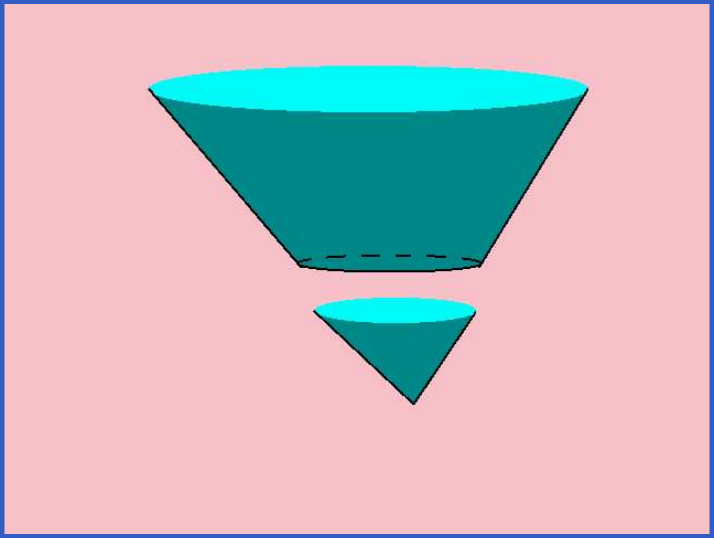

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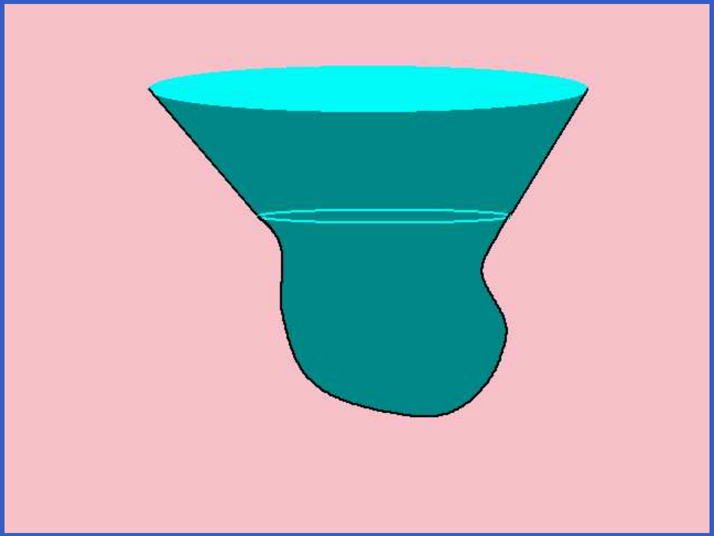

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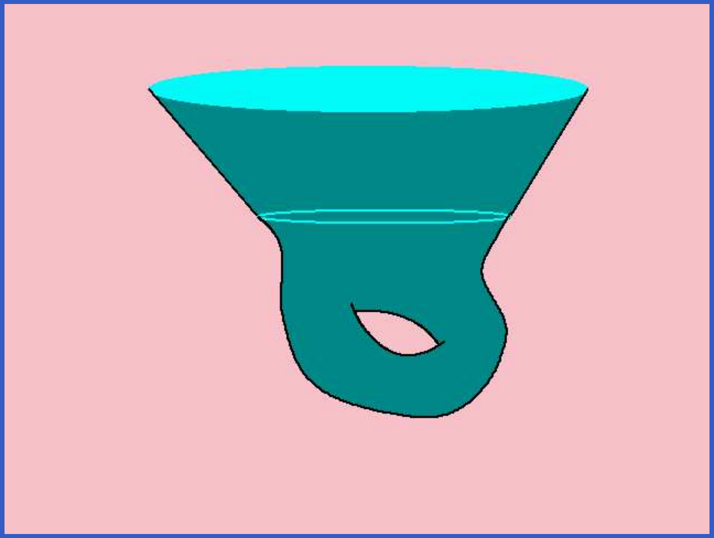

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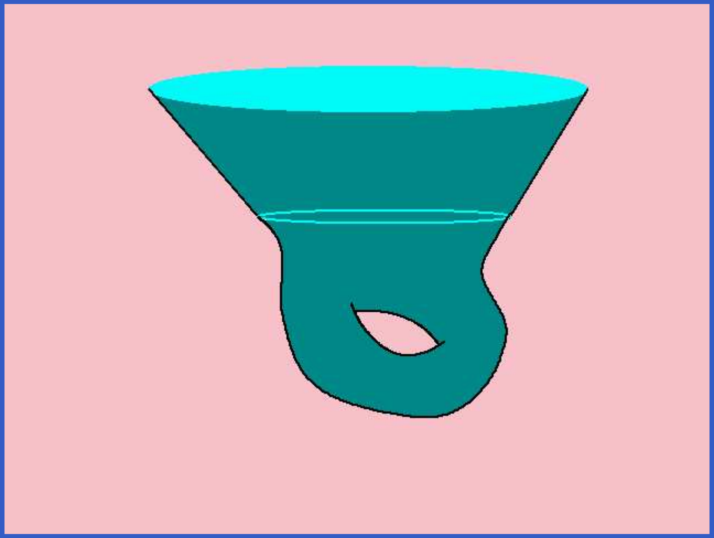

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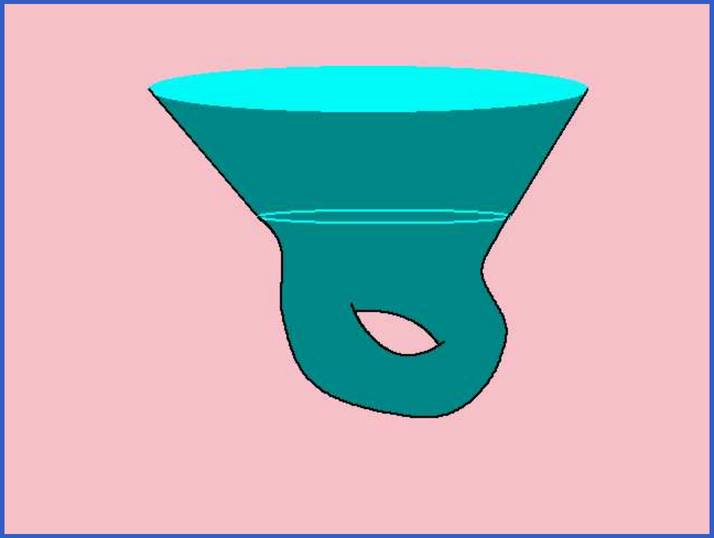

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Can string theory resolve the space-time singularity in Big Bang?

Can it explain four dimensions?

Whether string, whither string

If string theory describes nature, the confirmation may well come from the sky.

Acnowledgement

Wayne Hu's cosmology page:
background.uchicago.edu/~whu/
NASA homepage
Cambridge Relativity Group:
www.damtp.cam.ac.uk/user/gr/public/index.html

and many others via google.