Non-Inflationary Geometrical Solution of Horizon Problem

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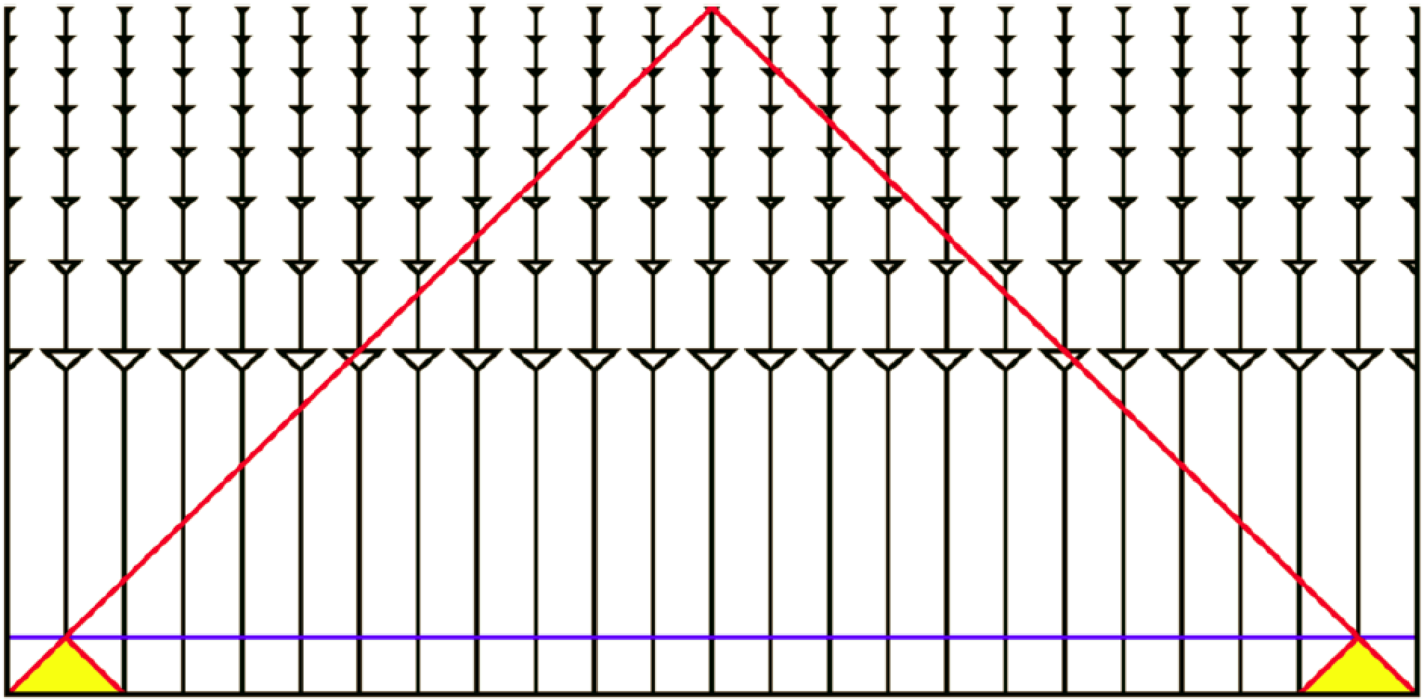
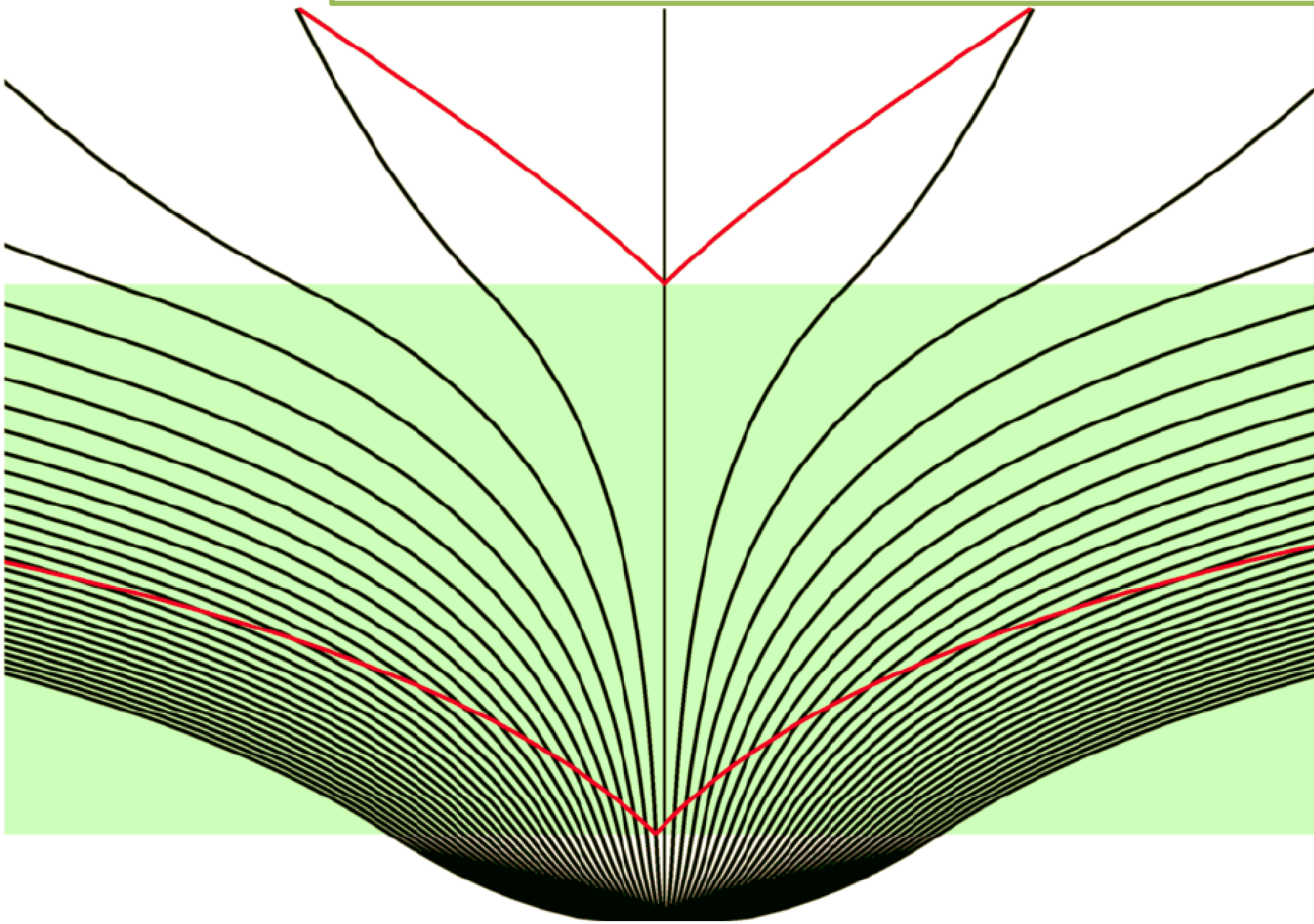
Horizon Problem

Regions seen on left and right of sky can only be influenced by the yellow areas in their past lightcones. These are disjoint, so why is the CMB T the same in both?



Inflation: The same parts of the early universe



After the time when inflation ended to the moment of the last recombination densities changed from

10^{38} kg/m^3 to 10^{-17} kg/m^3

CMB isotropy indicates that any density variations from one region of space to another at the time of decoupling must have been small, at most a few parts in 10^{-5}

This requires that changes in density at any part of the universe is the same to the 60 orders of magnitude

It is statistically unlikely that the CMB will have observed uniformity. This is similar to the horizon problem, but after inflation, inflation does not help to solve it.

M.A. Amin, M.P. Hertzberg, D.I. Kaiser and J. Karouby, Nonperturbative Dynamics Of Reheating After Inflation: A Review, Int. J. Mod. Phys. D 24 (2015) 1530003; arXiv:1410.3808 [hep-ph]

"our understanding of the state of the universe between the end of inflation and big bang nucleosynthesis is incomplete"

$E \sim 10^{16}\,GeV,\ t \sim 10^{-38}\,s$ $\qquad\qquad$ $E \sim 10^{-3}\,GeV,\ t \sim 1\,s$

$$\text{inflaton} \xrightarrow{\hspace{2em}} \text{Standard Model fields}$$

reheating; thermalization

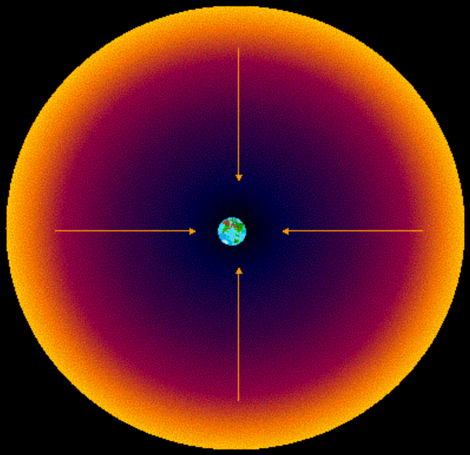
"…it is crucial to understand how the universe transitioned from the supercooled conditions during inflation to the hot, thermalized, radiation-dominated state required for nucleosynthesis…"

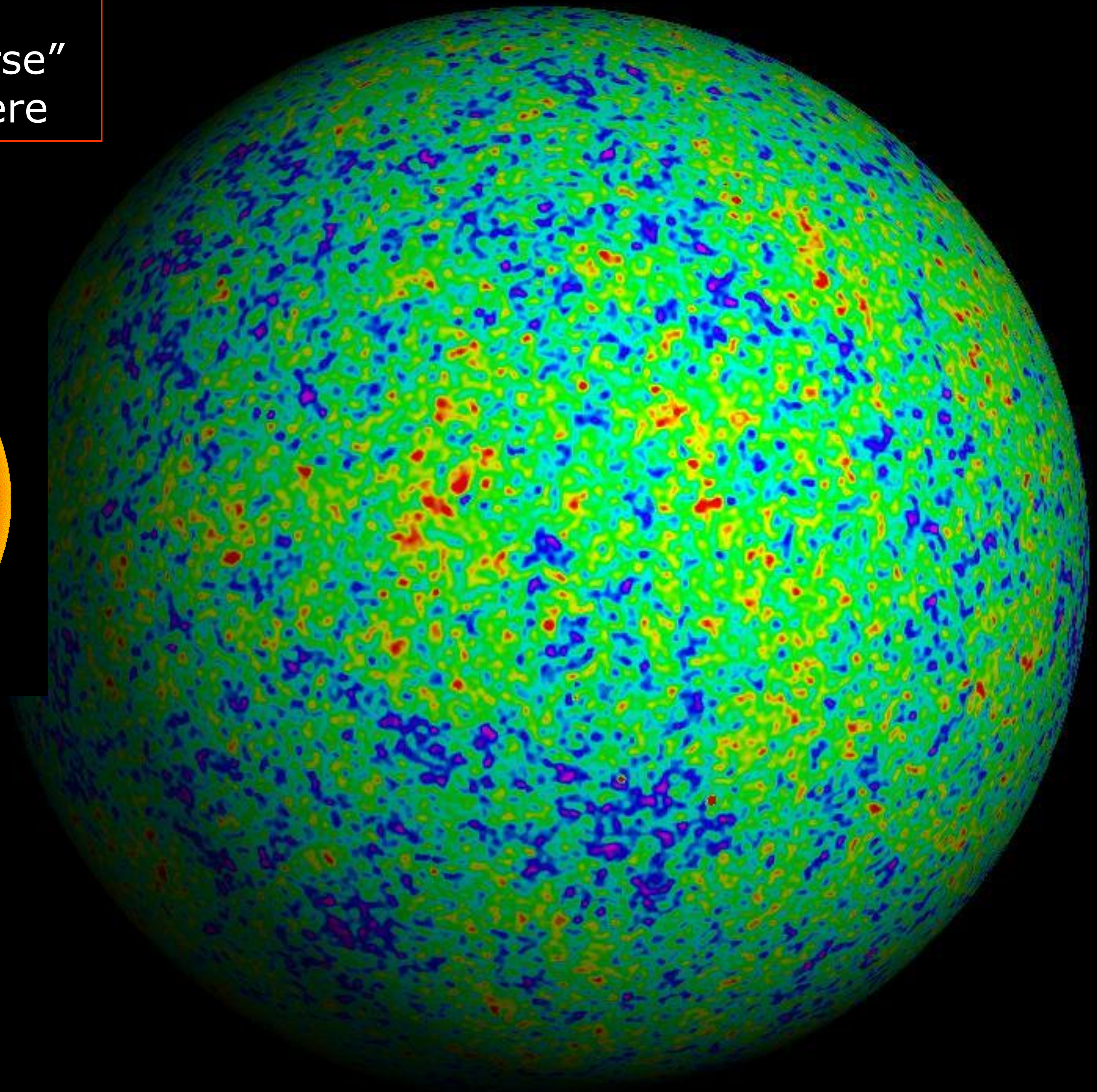
"…the energy transfer at the end of inflation could involve highly nonperturbative resonances, as the inflaton field oscillated around the minimum of its potential…"

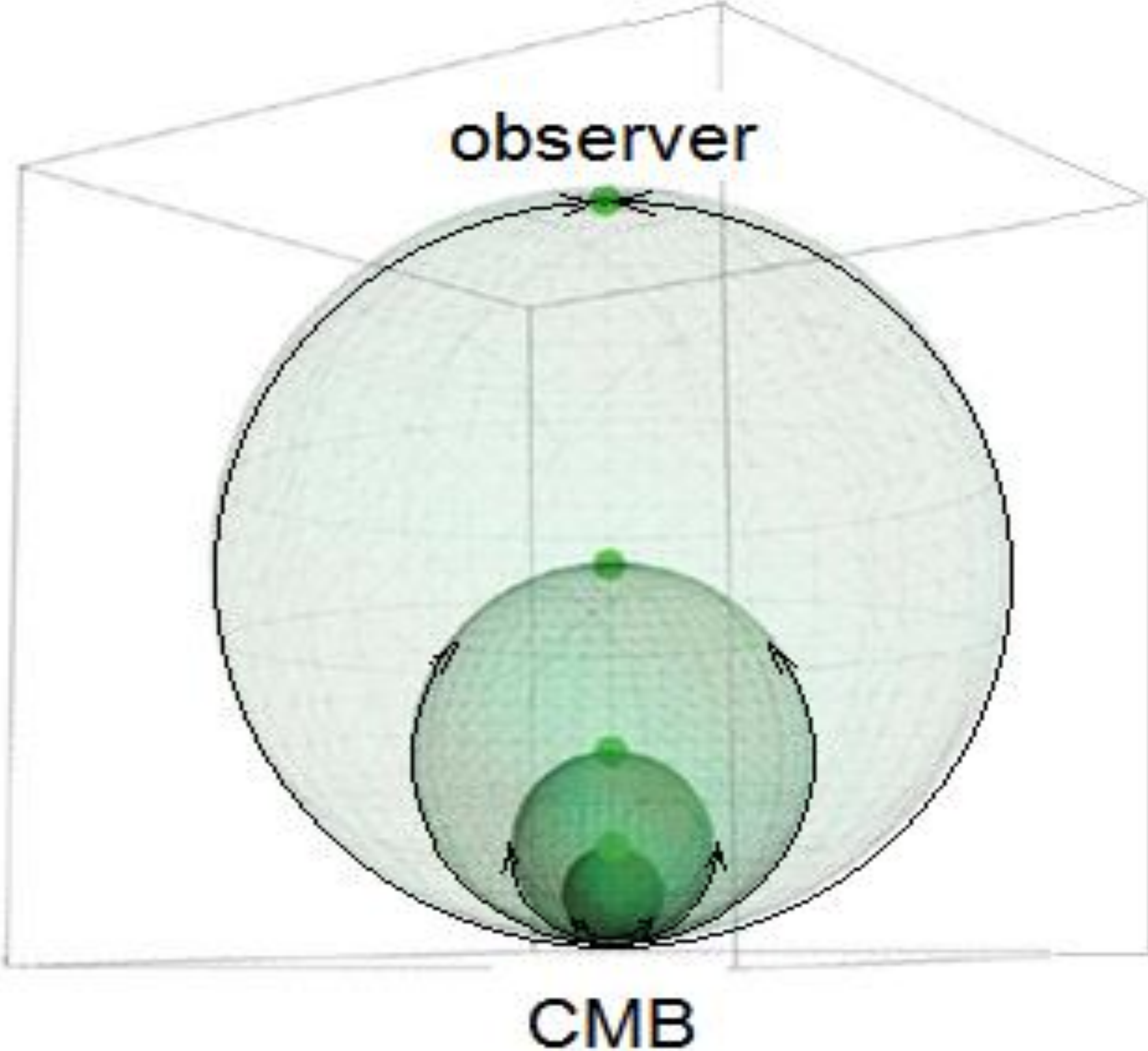
"…in a large class of models the homogenous oscillations of the inflaton(s) lead to rapid growth of spatially varying perturbations via parametric or tachyonic resonance…"

--- soliton-like configurations known as "oscillons" and nontopological solitons called Q-balls could play an important role in baryogenesis, generate high-frequency gravitational waves, change the expansion history or delay thermalization

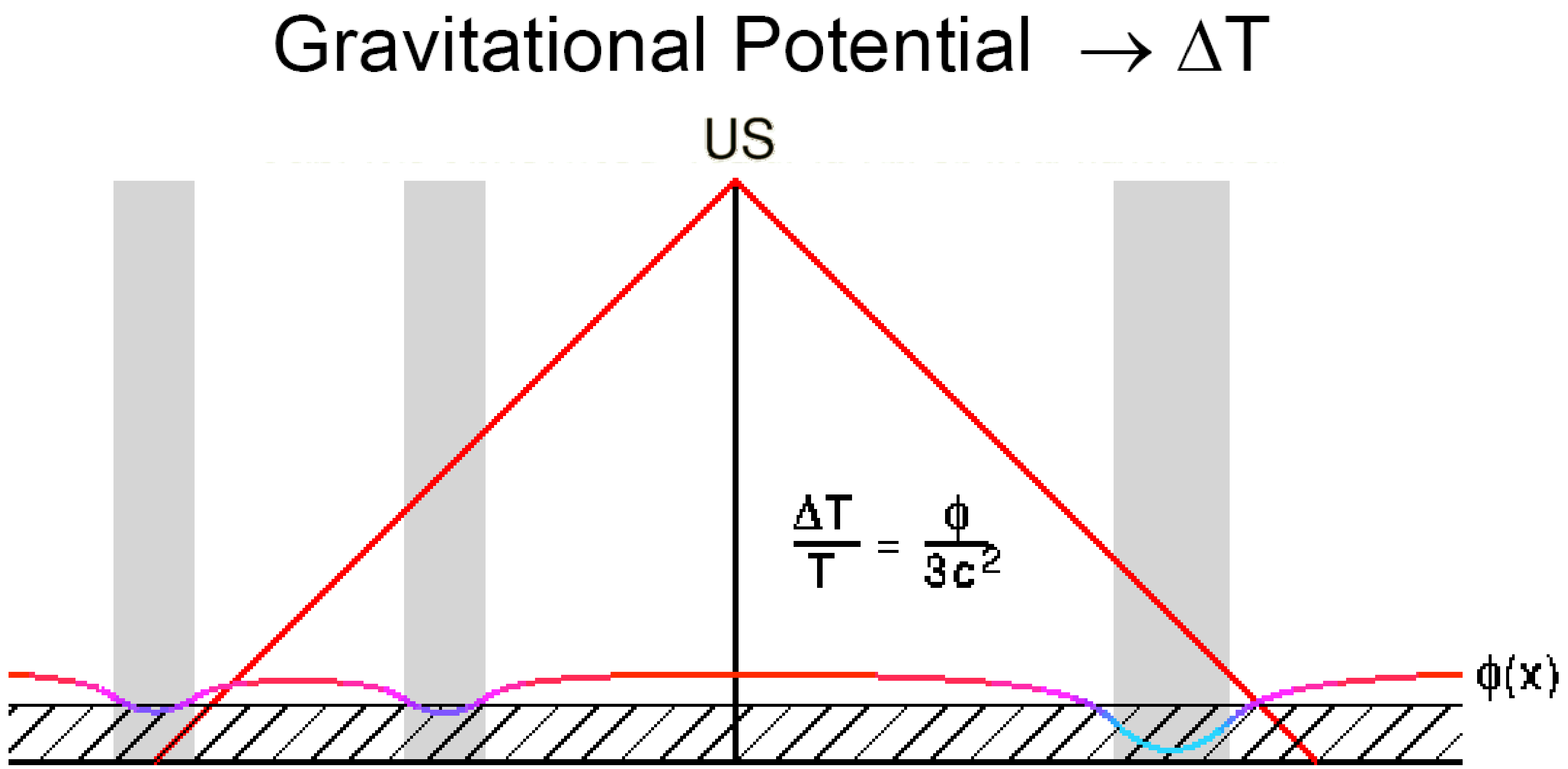
WMAP map of the
“edge of the
observable universe”
plotted as a sphere






observer
CMB

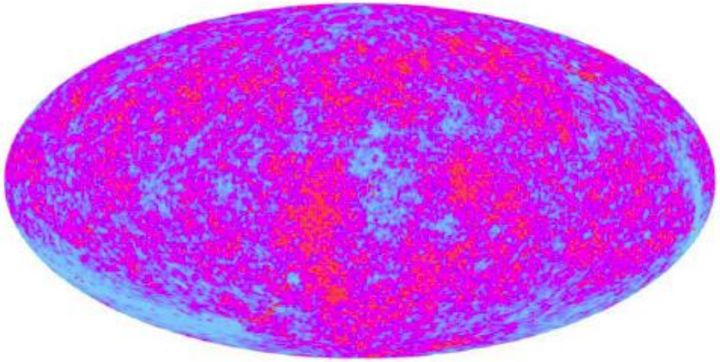
The observed fluctuations in the CMB are created by the integrated Sachs-Wolfe effect

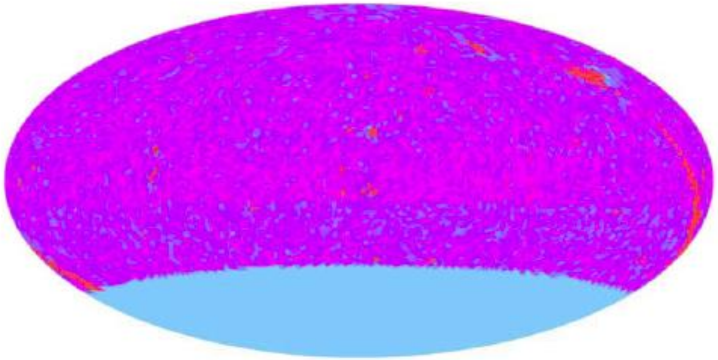


This potential also leads to large scale structure formation.

Structure CMB & IR maps

- This late Integrated Sachs-Wolfe effect occurs on our past light cone so the CMB ΔT we see is due to structures we also see.
- Correlation between WMAP and large-scale structure seen by:
  - Boughn & Crittenden at 99.7% confidence with hard X-ray background
  - Nolta at 98% confidence with the NRAO VLA Sky Survey
  - Ashfordi at 99.4% with the 2MASS 2 micron all sky survey





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Is there a possibility from the mathematical point of view that the last scattering surface is approximately point-like in the closed FLRW Universe?

$$ds^2 = c^2 dt^2 - a^2(t)\left[d\chi^2 + \sin^2\chi\left(d\theta^2 + \sin^2\theta d\psi^2\right)\right]$$

Hyperspherical coordinates:

$$\chi \in [0,\pi]; \quad \theta \in [0,\pi]; \quad \psi \in [0,2\pi)$$

I. The pure ΛCDM model

$$H^2 = \left(\frac{\dot{a}}{a}\right)^2 = \frac{\kappa\bar{\rho}c^4}{3a^3} + \frac{\Lambda c^2}{3} - \frac{c^2}{a^2} = H_0^2\left(\Omega_M \frac{a_0^3}{a^3} + \Omega_\Lambda + \Omega_K \frac{a_0^2}{a^2}\right)$$

$$\Omega_M = \frac{\kappa\bar{\rho}c^4}{3H_0^2 a_0^3}, \quad \Omega_\Lambda = \frac{\Lambda c^2}{3H_0^2}, \quad \Omega_K = -\frac{c^2}{a_0^2 H_0^2}, \quad \kappa = \frac{8\pi G_N}{c^4}$$

$\downarrow$ **0.31** $\quad$ $\downarrow$ **0.69** $\quad$ $\downarrow$ **–0.001** $\quad$ **[~ PLANCK]**

0.535

The deceleration parameter

$$-q = \frac{1}{aH^2}\frac{d^2a}{dt^2} = \left(\frac{H_0}{H}\right)^2 \left\{-\frac{\Omega_M}{2}\left(\frac{a_0}{a}\right)^3 + \Omega_\Lambda\right\}$$

Dimensionless quantities:

$$\tilde{a} = \frac{a}{a_0}, \quad \tilde{t} = H_0 t, \quad \tilde{a}(0) = 1, \quad \tilde{a}(-\tilde{t}_0) = 0$$

The age of the Universe:

$$\tilde{t}_0 = \int_0^1 \frac{\sqrt{\tilde{a}}\, d\tilde{a}}{\sqrt{\Omega_M + \Omega_K \tilde{a} + \Omega_\Lambda \tilde{a}^3}}$$

$\downarrow$

0.96 $\longrightarrow$ **13.9 billions of years**

$$H_0 \approx 2.2 \times 10^{-18}\, \mathrm{s}^{-1}$$

The approximate condition of light traveling between the antipodal points during the age of the Universe

$$\int_{-t_0}^{0} \frac{c\,dt}{a(t)} = \pi$$

$$\sqrt{-\Omega_K}\int_0^1 \frac{d\tilde{a}}{\sqrt{\Omega_M \tilde{a} + \Omega_K \tilde{a}^2 + \Omega_\Lambda \tilde{a}^4}} \approx 0.1 \neq \pi$$

Thus, this condition is not satisfied in the standard cosmological model.

II. ΛCDM + Quintessence with w = -1/3

$$H^2 = \left(\frac{\dot{a}}{a}\right)^2 = H_0^2\left(\Omega_M \frac{a_0^3}{a^3} + \Omega_\Lambda + \Omega_Q \frac{a_0^2}{a^2} + \Omega_K \frac{a_0^2}{a^2}\right)$$

$$\begin{cases} \Omega_M + \Omega_\Lambda + \Omega_Q + \Omega_K = 1 \\ -\dfrac{\Omega_M}{2} + \Omega_\Lambda = -q = 0.535 \end{cases}$$

$$\underline{\Omega_M} = \frac{2}{3}\left(1 - \Omega_Q - \Omega_K + q\right) \qquad \underline{\Omega_\Lambda} = \frac{2}{3}\left(\frac{1}{2} - \frac{\Omega_Q}{2} - \frac{\Omega_K}{2} - q\right)$$

$$\sqrt{-\Omega_K}\int_0^1 \frac{d\tilde{a}}{\sqrt{\Omega_M \tilde{a} + \Omega_Q \tilde{a}^2 + \Omega_K \tilde{a}^2 + \Omega_\Lambda \tilde{a}^4}} = \pi$$

A) Exact compensation

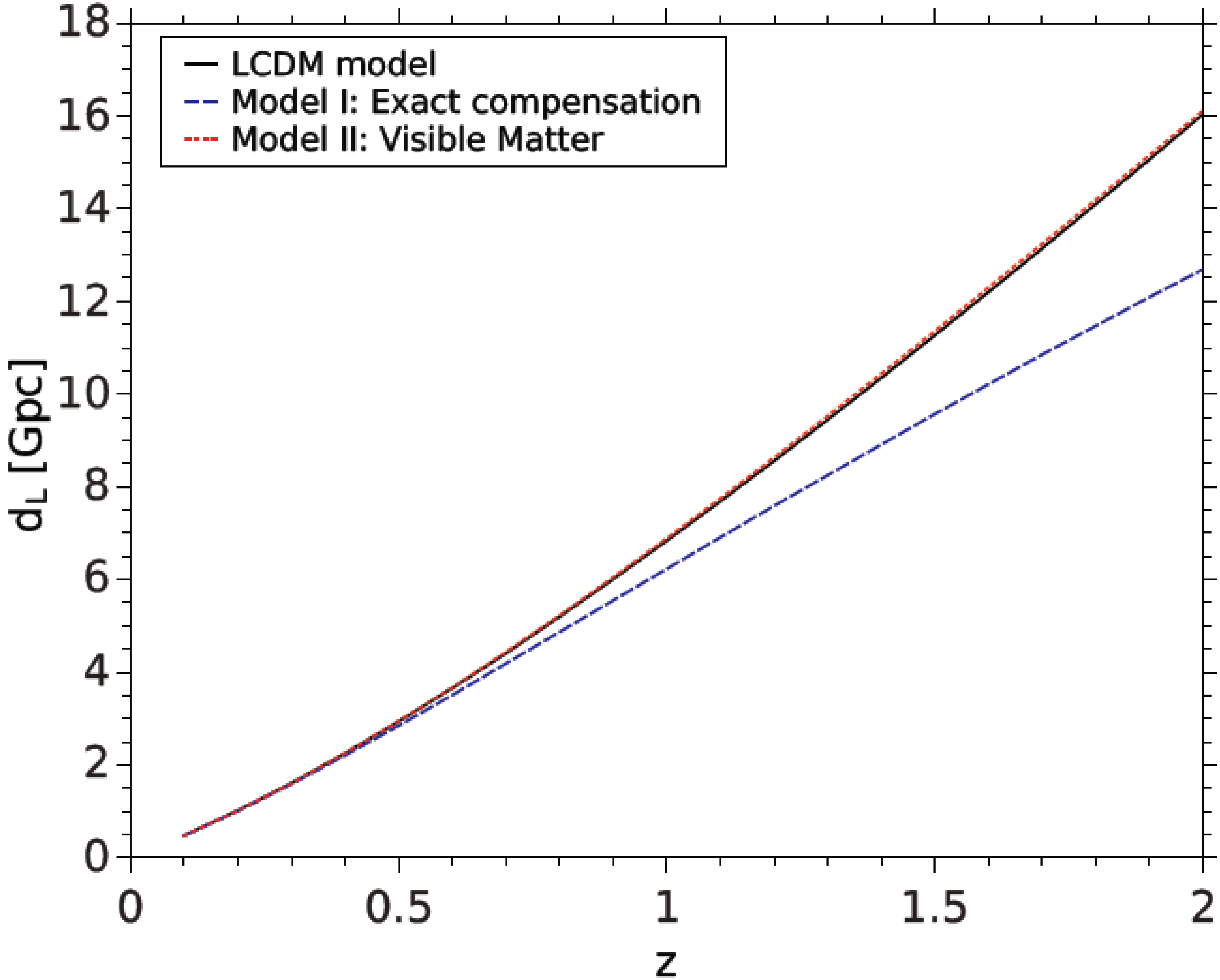
z	a/a_0	$-t$, Gyr	$-ct$, Gpc	d_L, Gpc	$d_{L(\Lambda CDM)}$, Gpc
0.1	0.91	1.34	0.41	0.48	0.48
0.5	0.67	5.17	1.59	2.85	2.94
1.0	0.50	7.99	2.45	6.23	6.84
1.5	0.40	9.58	2.94	9.57	11.27
2.0	0.33	10.63	3.26	12.69	16.04
1000	0.001	13.89	4.26	489.4	14046

$-\Omega_K = \Omega_Q = 0.93$ $\Omega_M = 0.31, \quad \Omega_\Lambda = 0.69$

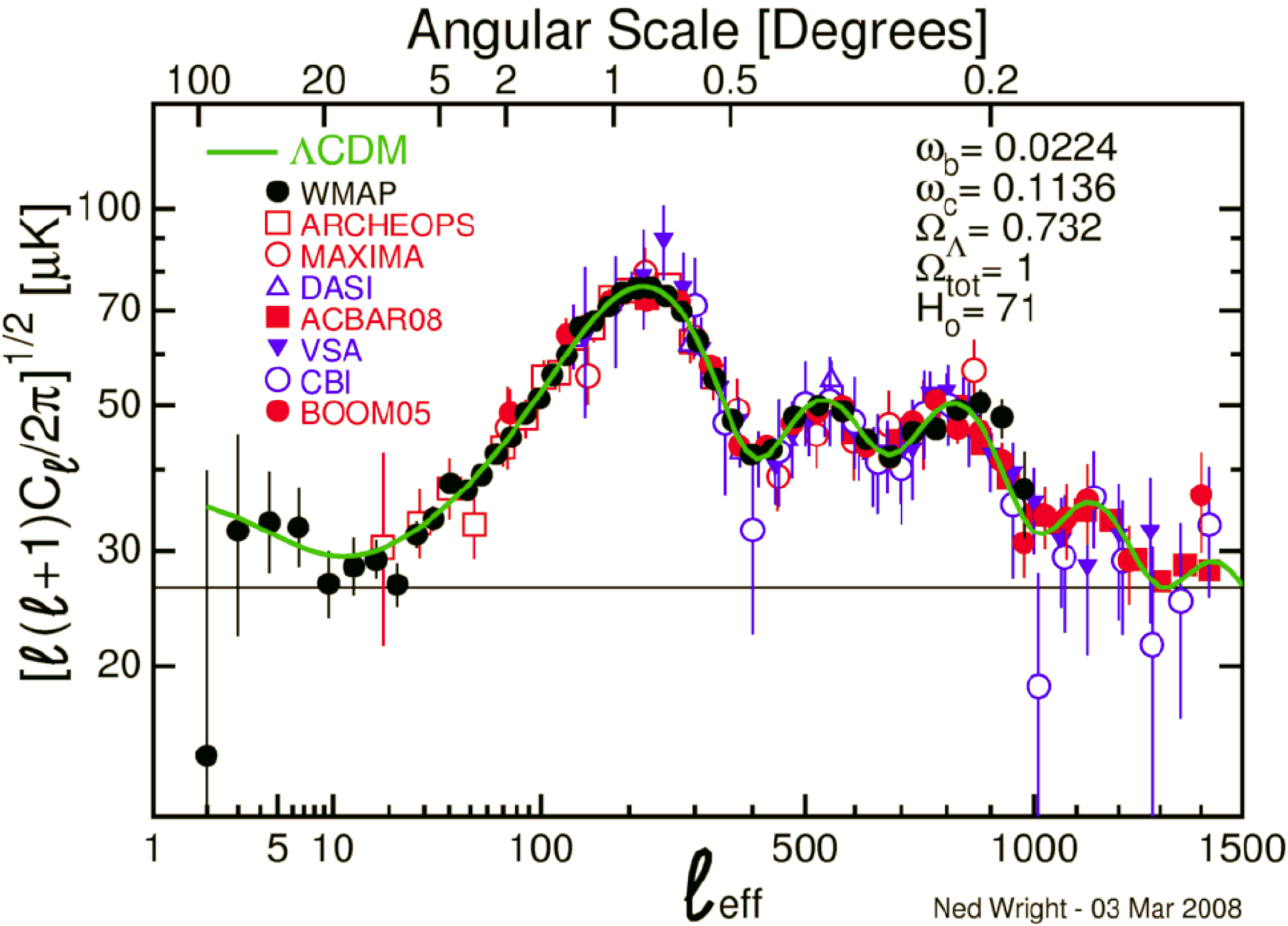
B) Visible matter

z	a/a_0	-t, Gyr	-ct, Gpc	d_L, Gpc	$d_{L(\Lambda CDM)}$, Gpc
0.1	0.91	1.34	0.41	0.48	0.48
0.5	0.67	5.23	1.61	2.95	2.94
1.0	0.50	8.26	2.54	6.89	6.84
1.5	0.40	10.13	3.11	11.36	11.27
2.0	0.33	11.45	3.51	16.11	16.04
1000	0.001	16.86	5.17	1385.7	14046

$\Omega_Q = 0.721, \quad \Omega_K = -0.316 \qquad \Omega_M = 0.040, \quad \Omega_\Lambda = 0.555$



LCDM model
Model I: Exact compensation
Model II: Visible Matter
d_L [Gpc]
z
0
2
4
6
8
10
12
14
16
18
0.5
1
1.5


Angular Scale [Degrees]
100
20
5
2
1
0.5
0.2
ΛCDM
WMAP
ARCHEOPS
MAXIMA
DASI
ACBAR08
VSA
CBI
BOOM05
$\omega_b = 0.0224$
$\omega_c = 0.1136$
$\Omega_\Lambda = 0.732$
$\Omega_{tot} = 1$
$H_o = 71$
$[\ell(\ell+1)C_\ell/2\pi]^{1/2}$ [μK]
100
70
50
30
20
1
5
10
100
500
1000
1500
ℓ_{eff}
Ned Wright - 03 Mar 2008

CMB: estimation of location of the first acoustic peak

The acoustic scale

$$\theta_* = \frac{r_s}{D_A} = \frac{\text{comoving size of sound horizon at time of recombination}}{\text{angular diameter distance}}$$

Requirement: $$\frac{\theta_*}{\theta_{*(\Lambda CDM)}} \sim 1 \quad \Rightarrow \quad \frac{r_s}{r_{s(\Lambda CDM)}} \sim \frac{D_A}{D_{A(\Lambda CDM)}} \sim 0.1$$

(the visible matter case)

way out: change the initial power spectrum

$$k^3 P(k) \sim (k t_0)^{n-1} \quad \rightarrow \quad \tilde{P}(k) = \left(\frac{\chi(t_0)}{t_0}\right)^3 P\left(k \frac{\chi(t_0)}{t_0}\right)$$

$$k^3 \tilde{P}(k) = \left(k \frac{\chi(t_0)}{t_0}\right)^3 P\left(k \frac{\chi(t_0)}{t_0}\right) \sim \left(k \frac{\chi(t_0)}{t_0} t_0\right)^{n-1} = \left[k \chi(t_0)\right]^{n-1}$$

difference between the angular diameter distance and the comoving distance for curved geometry is absorbed in the amplitude of the primordial power spectrum

$$\frac{\tilde{P}(k)}{P(k)} = \left(\frac{\chi(t_0)}{t_0}\right)^{n-1} = \frac{\tilde{A}_s(k_*)}{A_s(k_*)} = (0.1)^{n-1} \overset{n=0.96}{\Longrightarrow} 1.096$$

In the framework of the ΛCDM model supplemented in the spherical space with quintessence there is an elegant solution of the horizon problem without inflation: under the proper choice of the parameters light travels between the antipodal points during the age of the Universe. Consequently, one may suppose that the observed CMB radiation originates from a very limited space region, which explains its uniformity.

There are certain difficulties when one tries to adjust the proposed concept to the CMB anisotropy arriving at the necessity to change the amplitude of initial power spectrum. However, the changes that should be done may be well inside experimentally allowed constrains.

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