Λ-CDM Model and Inflation

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Structure of the talk

1. Λ-CDM Model

2. Drawbacks of the Λ-CDM Model

3. Inflation

Λ-CDM MODEL

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Assumptions

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1. Einstein field equations

Λ-CDM MODEL

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$$G_{\mu\nu}^{(\Lambda)} = R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R + \Lambda g_{\mu\nu} = \kappa \, T_{\mu\nu}$$

Λ-CDM MODEL

Assumptions

1. Einstein field equations

$$G_{\mu\nu}^{(\Lambda)} = R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R + \Lambda g_{\mu\nu} = \kappa T_{\mu\nu}$$

$R_{\mu\nu}$ — Ricci tensor

$g_{\mu\nu}$ — metric tensor

Λ — cosmological constant

$T_{\mu\nu}$ — stress-energy tensor

$$\kappa = \frac{8\pi G_N}{c^4}$$

Λ-CDM MODEL

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→ Ideal fluid description

$$T_{\mu\nu} = (\rho + P)u_\mu u_\nu - P\,\eta_{\mu\nu}$$

$\rho = \rho(\tau)$ – energy density

$P = P(\tau)$ – isotropic pressure

$\eta_{\mu\nu} = diag(1, -1, -1, -1)$

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+ Equations of state

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$$P = P(\rho)$$

Λ-CDM MODEL

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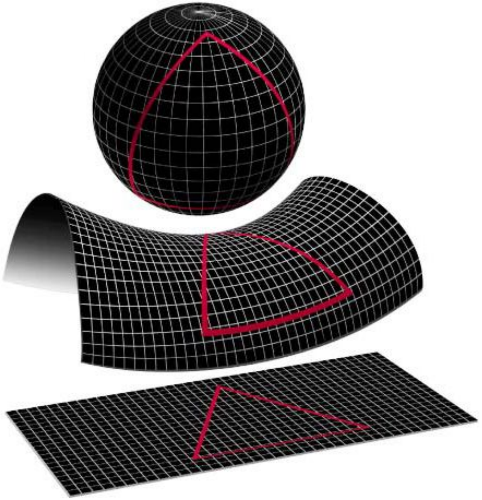

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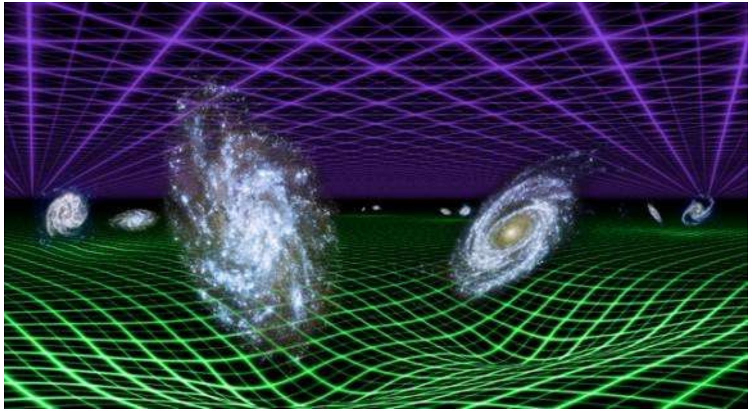

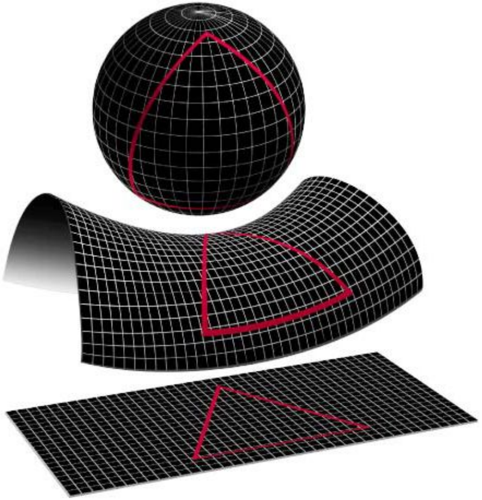

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3. Universe expands $\dot{a} > 0$

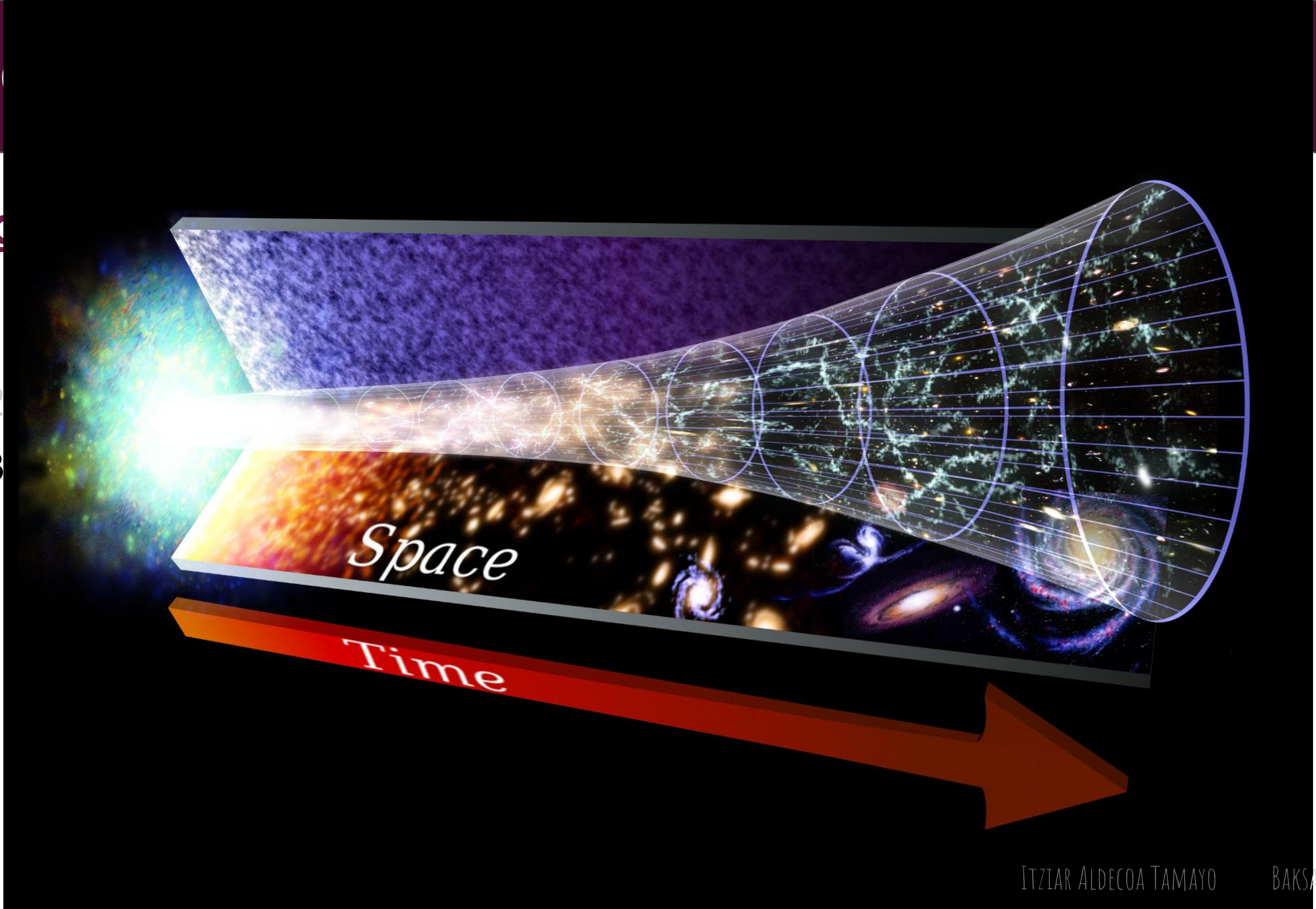
Λ-

Co

1

2

3



Λ-C

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1

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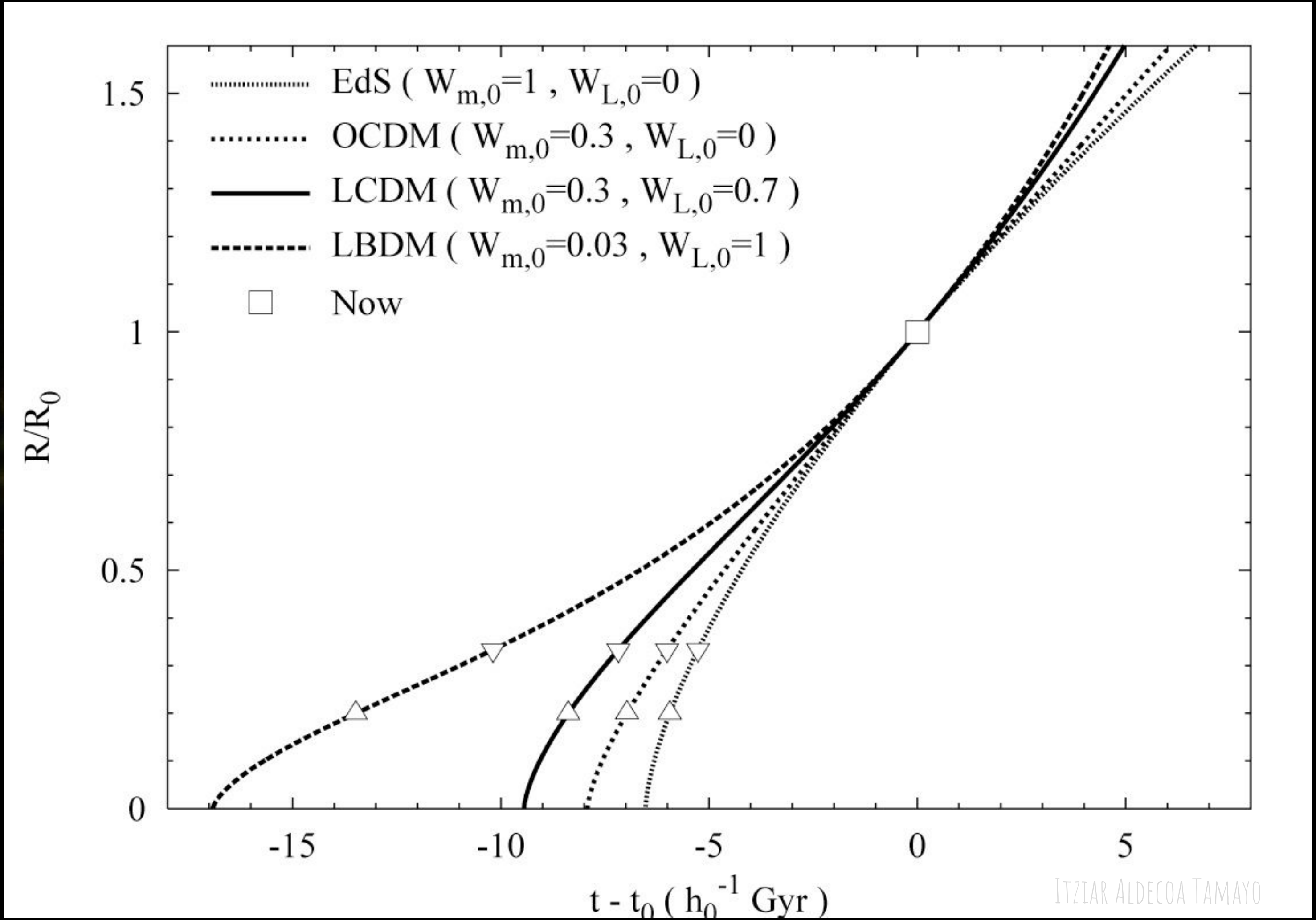
EdS ($W_{m,0}$=1 , $W_{L,0}$=0)
OCDM ($W_{m,0}$=0.3 , $W_{L,0}$=0)
LCDM ($W_{m,0}$=0.3 , $W_{L,0}$=0.7)
LBDM ($W_{m,0}$=0.03 , $W_{L,0}$=1)
Now
R/R_0
$t - t_0$ (h_0^{-1} Gyr)
1.5
1
0.5
0
-15
-10
-5
0
5

Λ-CDM MODEL

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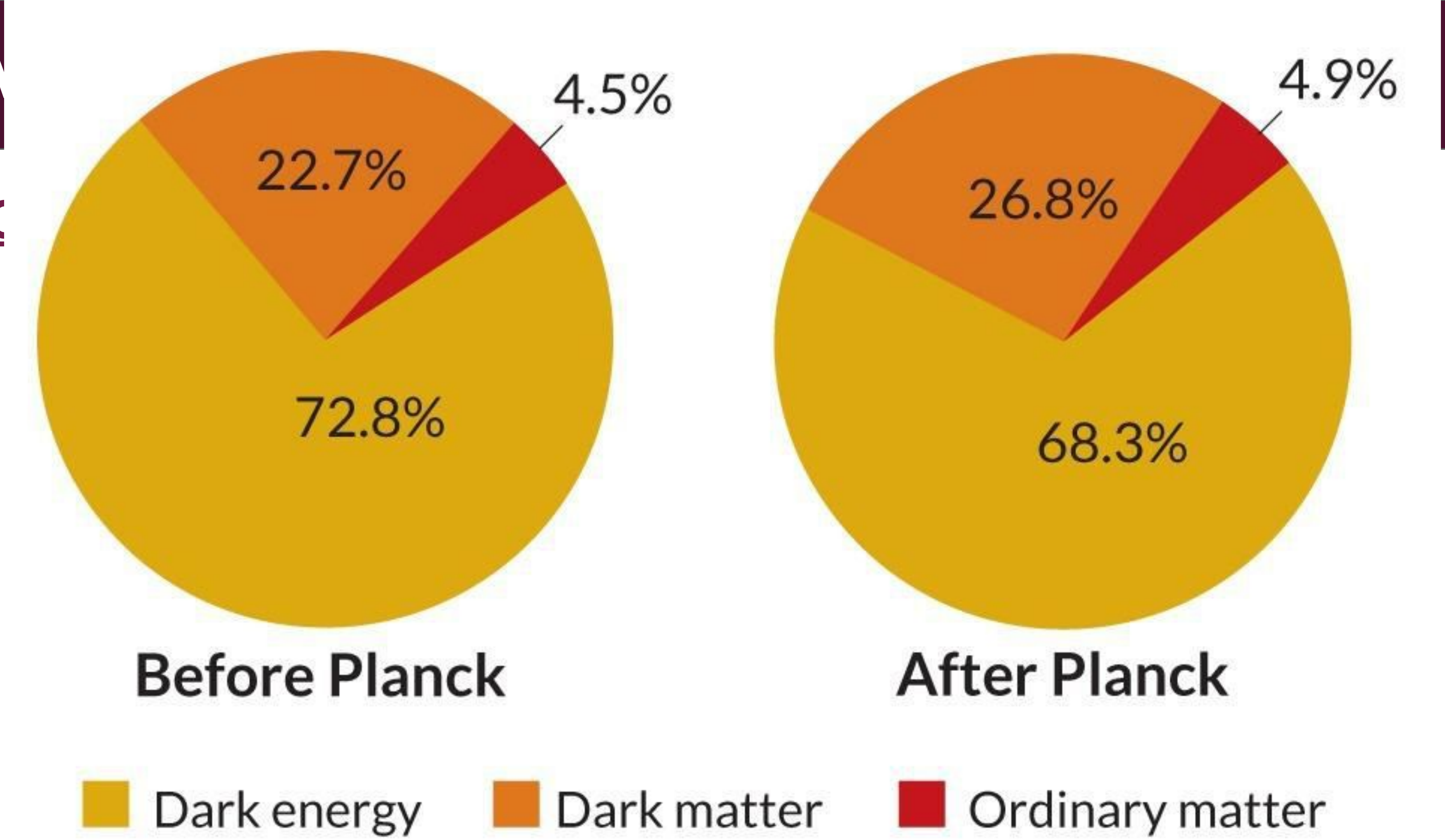
4.5%
22.7%
72.8%
Before Planck
4.9%
26.8%
68.3%
After Planck
Dark energy
Dark matter
Ordinary matter

Λ-CDM MODEL

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Λ-CDM MODEL

Conservation laws:

$$H^2 \propto \rho$$

$$\begin{aligned} \text{MD}: \quad & \rho \propto a^{-3} \\ \text{RD}: \quad & \rho \propto a^{-4} \end{aligned}$$

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

$$T \propto a^{-1}$$

DRAWBACKS OF THE MODEL

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1. Flatness problem
2. Horizon problem
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$$\Omega - 1 = \frac{k}{H^2 a^2}$$

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$k = +1$	→	$\Omega > 1$	CLOSED UNIVERSE
$k = 0$	→	$\Omega = 1$	FLAT UNIVERSE
$k = -1$	→	$\Omega < 1$	OPEN UNIVERSE

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$$\Omega - 1 = \frac{k}{H^2 a^2}$$

Radiation dominated:

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FLATNESS PROBLEM

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$$\frac{|\Omega - 1|_{\tau=\tau_{Pl}}}{|\Omega - 1|_{\tau=\tau_0}} \approx \mathcal{O}(10^{-64})$$

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Today $\Omega \sim 1$

FLATNESS PROBLEM

Flatness problem = fine-tuning problem

HORIZON PROBLEM

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CMB → Uniform to $\frac{\Delta T}{T} \sim 10^{-6}$

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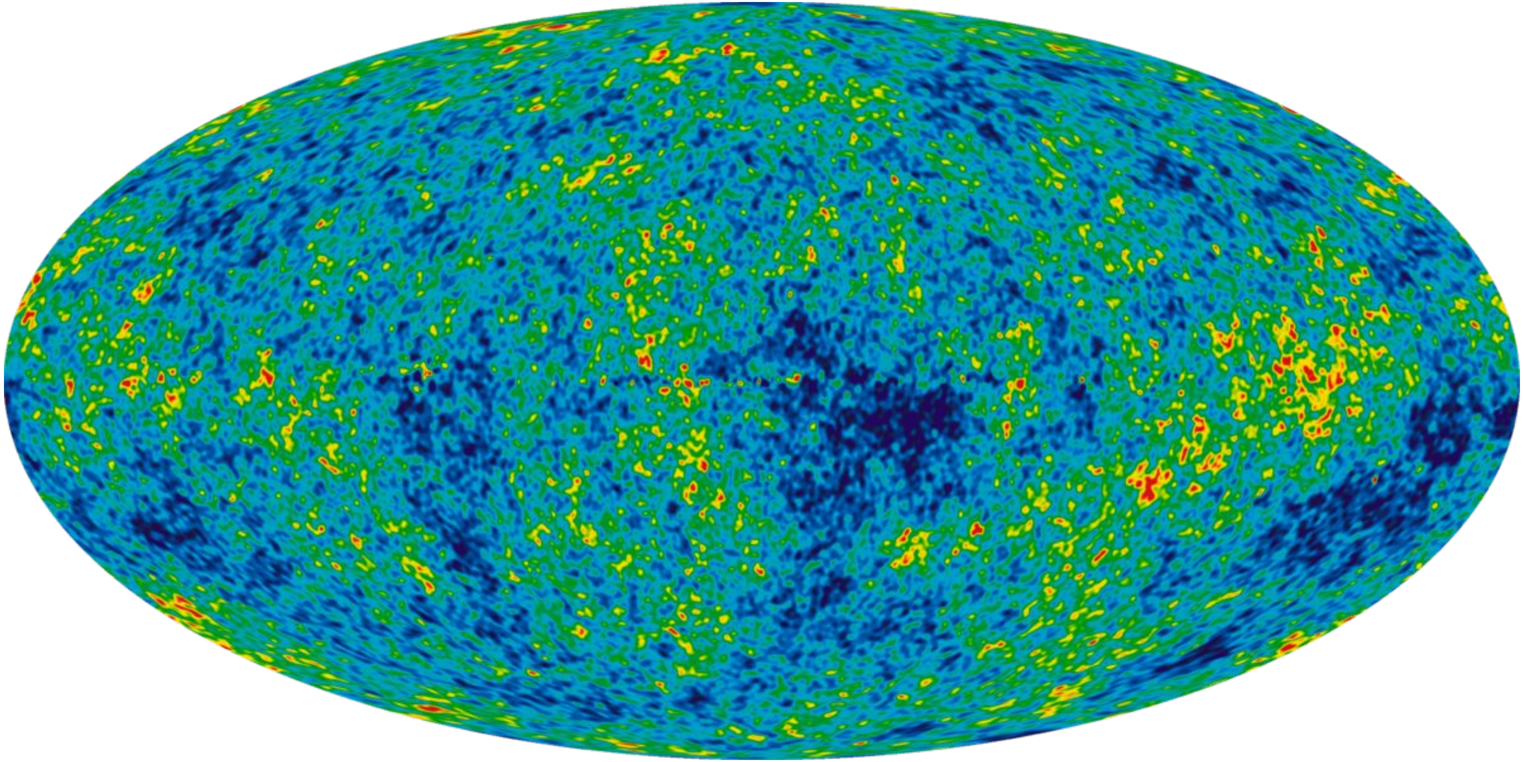
CMB → Uniform to $\frac{\Delta T}{T} \sim 10^{-6}$

Causally disconnected $\sim 2^{\circ}$

HORIZON PROBLEM



INFLATION

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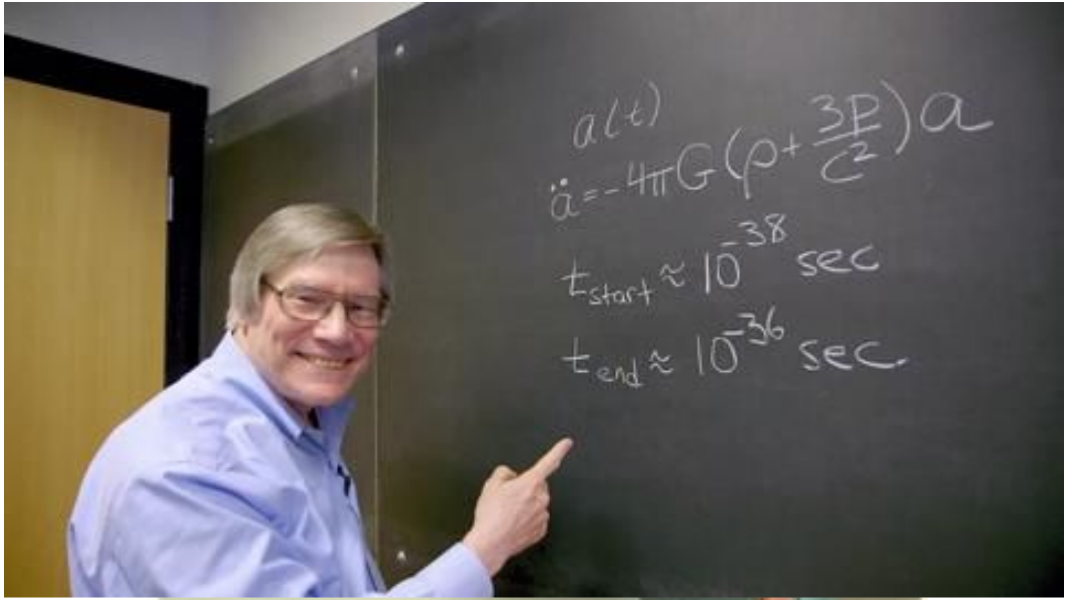
Alan Guth (1979)

INFLATION



Alan Guth (2004)

INFLATION

INFLATION

What is it? Exponential expansion of space in the early universe

When did it happen? Sometime between 10^{-36}s to 10^{-32}s after singularity

How much did it last? 10^{-35}s

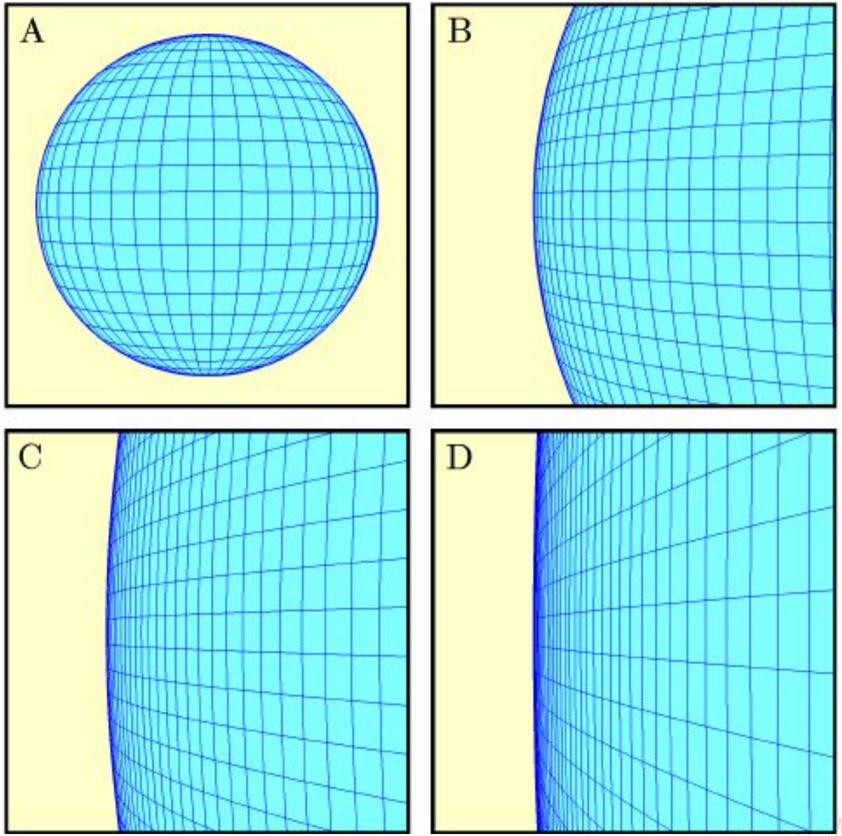
Size of the universe before inflation: one hundred billion times smaller than the size of a proton (10^{-26}m)

Size of the universe after inflation: size of a grapefruit (0,1 m)

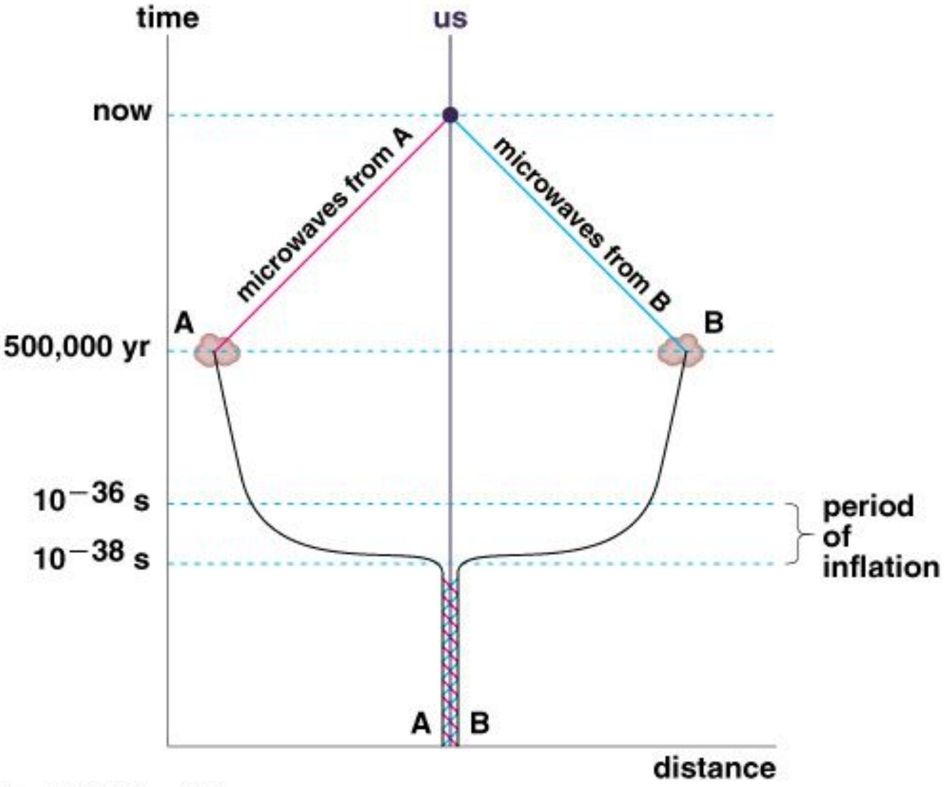
INFLATION

How does this solve the flatness and the horizon problem?

FLATNESS



HORIZON



time
us
now
microwaves from A
microwaves from B
A
B
500,000 yr
10^{-36} s
10^{-38} s
period of inflation
A
B
distance

INFLATION

Many models!

For the curious…

arXiv:1312.3529v3 [astro-ph.CO] 3 Jun 2014

Thank you for your attention!

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