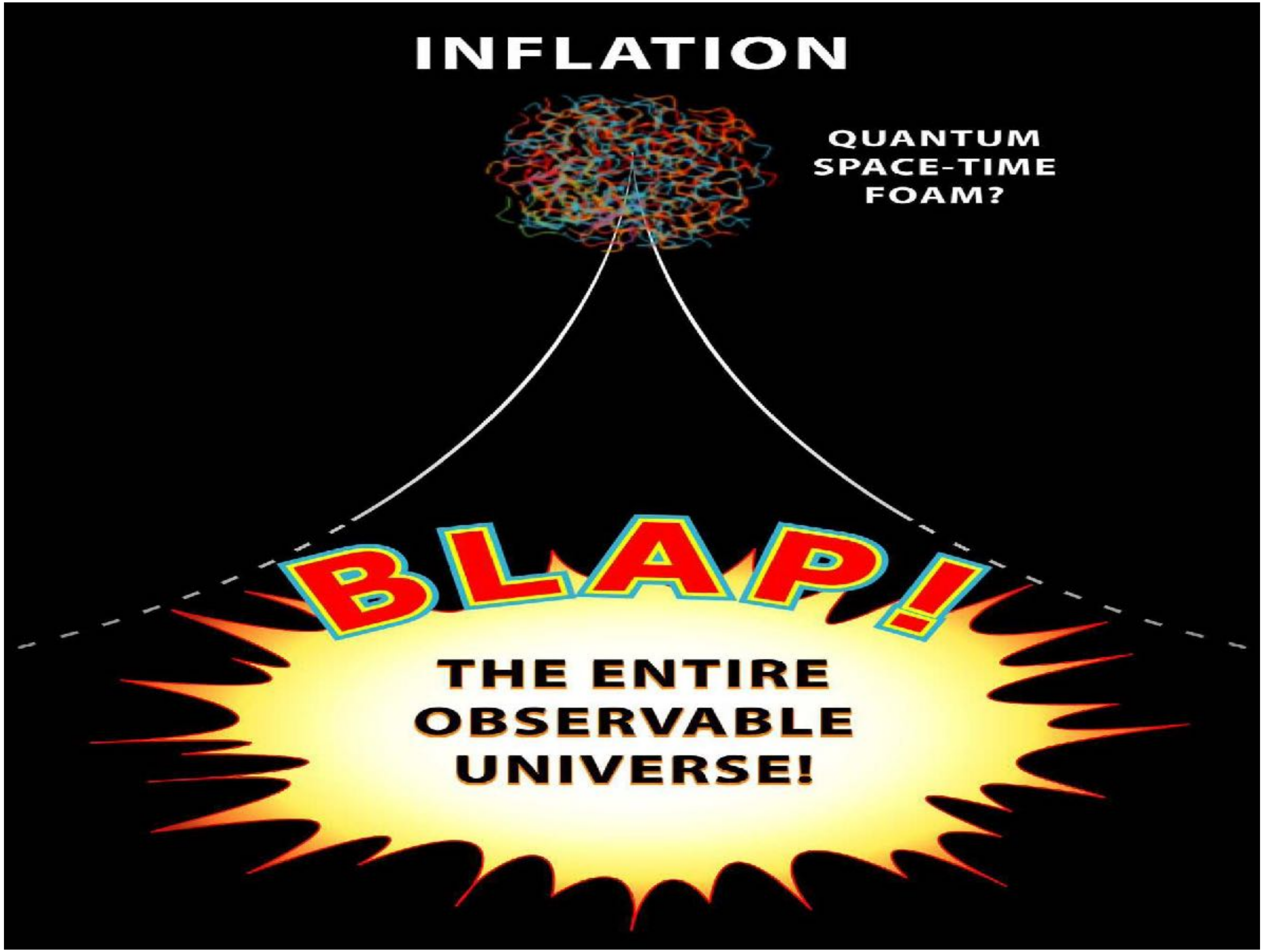
Inflation

ASTR/PHYS 4080:
Intro to Cosmology
Week 9



Successes of the Hot Big Bang Model

Consists of:

- General relativity
- Cosmological principle
- Known atomic/nuclear/particle physics

Explains:

- dark night sky
- Hubble expansion
- age of the universe
- CMB (existence + blackbody spectrum)
- light element abundances
- … much more!

- successful theory supported by observation
- clear understanding of what happened from $t \sim 1$s to $t \sim 13.7$Gyr $\sim 4 \times 10^{17}$s
- may speculate what happened as early as Planck time ($t \sim 10^{-43}$s) based on known physics

“Problems” with the Hot Big Bang Model

Unable to explain

- baryon asymmetry (Extension of particle physics)
- horizon problem (Why so homogeneous)
- flatness problem (Why so flat)
- monopole problem (Why so rare)
- small scale inhomogeneities (What gives rise to it? the origin of irregularities)
- … probably so more stuff

Lack a Complete Theory: these are clues…

The problems and the need for extension

- NOT a demonstrable failure to fit observation by standard model
- BUT its incomplete explanatory power
  - or perhaps unsatisfying

Analogy - particle standard model

- successful, but unable to explain particle mass spectrum, dark matter, dark energy, ...
- extension(s): SUSY, String Theory, TOE, ...

Extension to standard big bang model:
INFLATION

Flatness Problem

(Why is the curvature so fine-tuned?)

Observed: $|1 - \Omega_0| \leq 0.005$

Friedmann Equation:

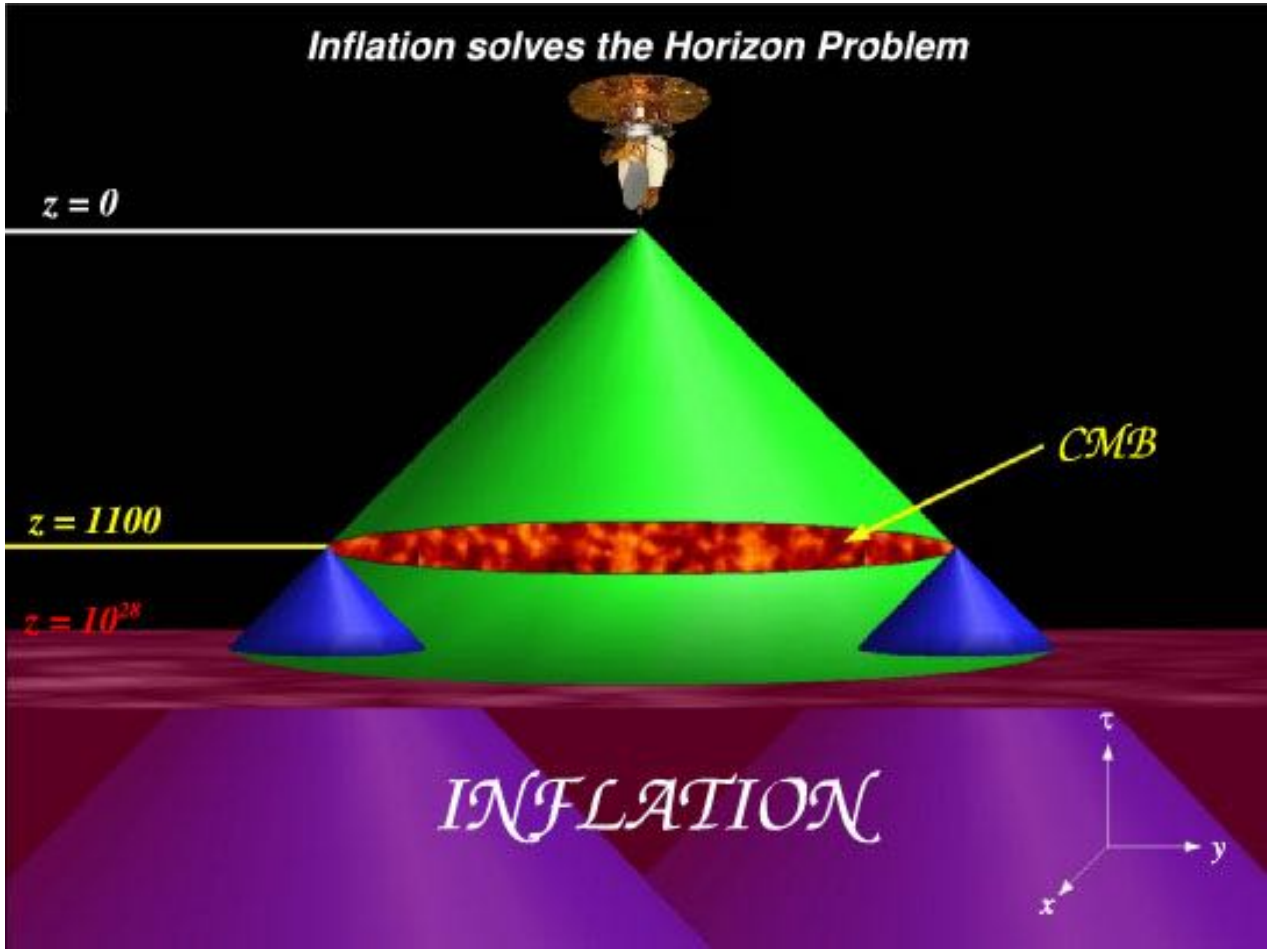
$$1 - \Omega(t) = -\kappa \left(\frac{c/H(t)}{a(t) R_0} \right)^2$$

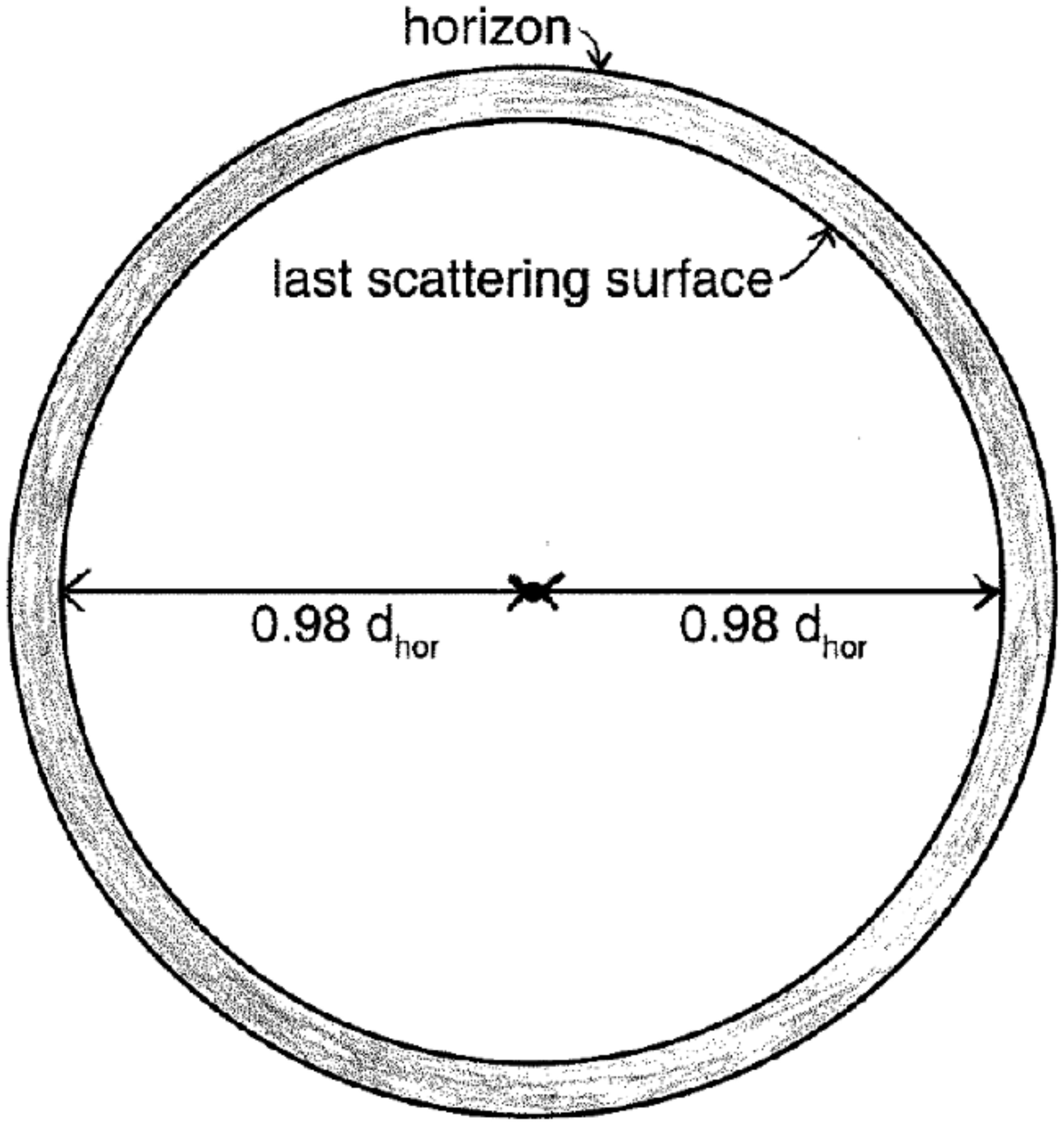
$$1 - \Omega_0 = -\kappa \left(\frac{c/H_0}{R_0} \right)^2$$

$$1 - \Omega(t) = \frac{H_0^2 (1 - \Omega_0)}{H(t)^2 a(t)^2}$$

Horizon Problem

(How can the universe be homogeneous and isotropic on the largest scales?)

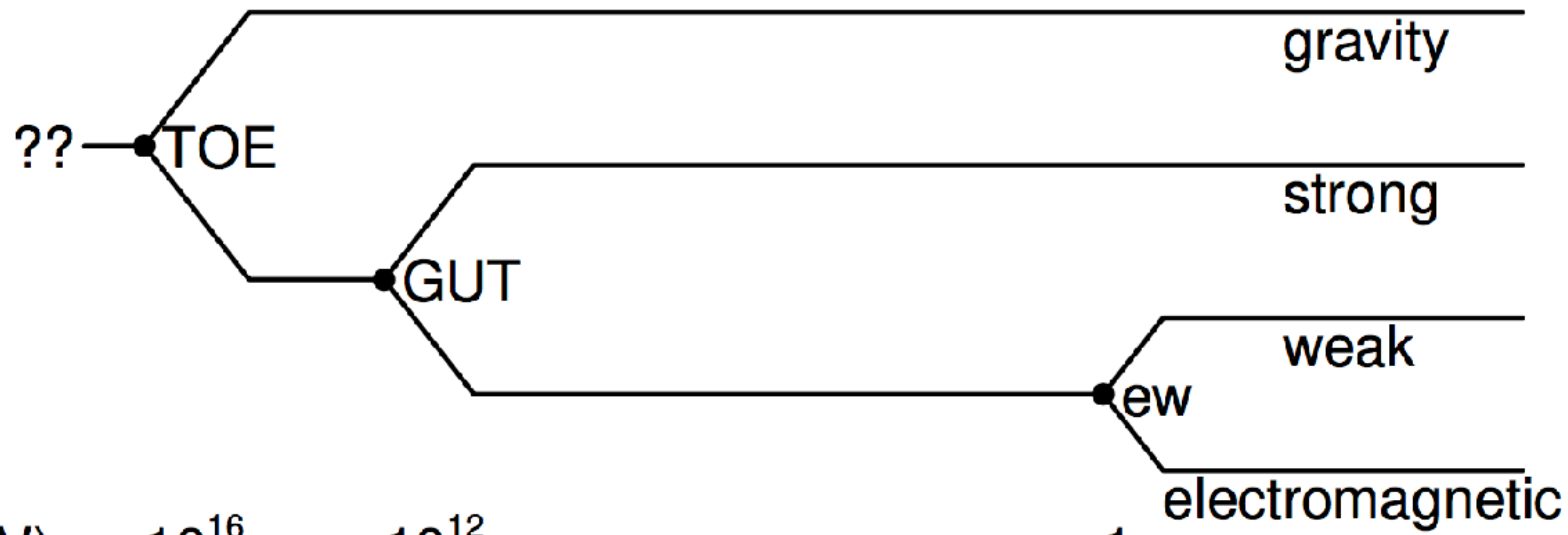




Monopole Problem

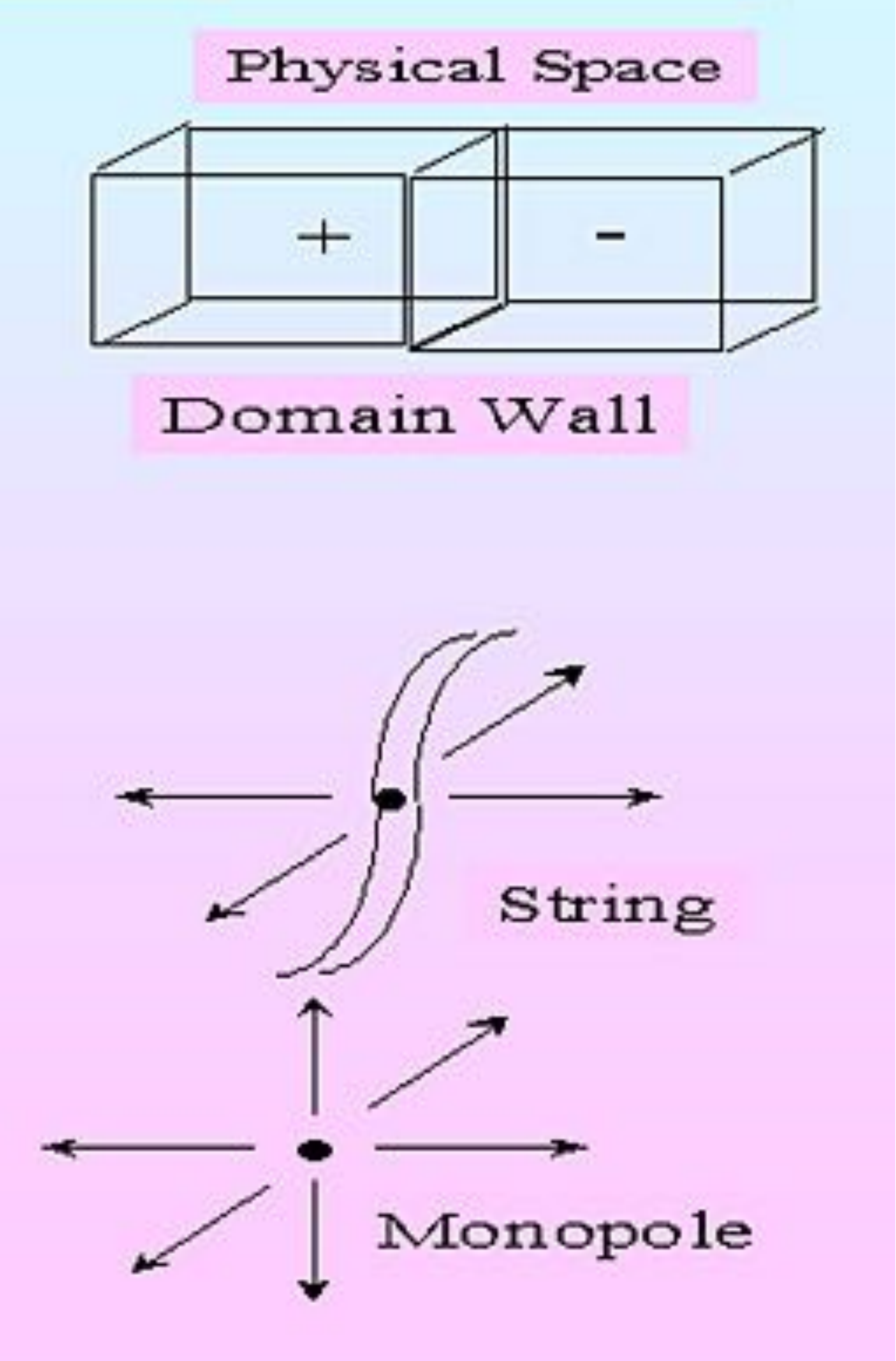
(Where are all the topological defects, like magnetic monopoles and cosmic strings?)

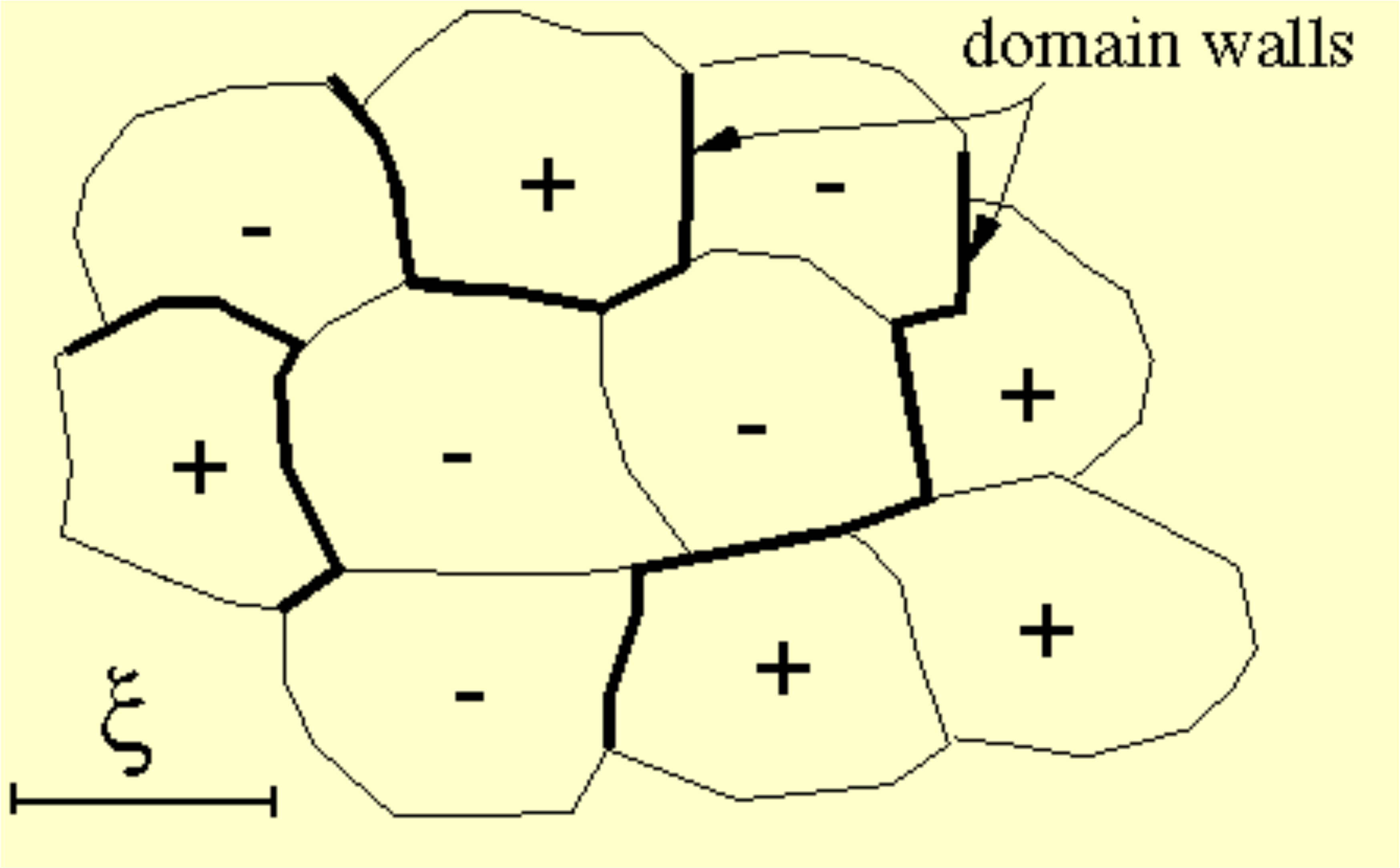
At larger energies, “fundamental” forces unify
or equivalently, as energy decreases a phase transition occurs causing a break in symmetry



E (TeV)	10^{16}	10^{12}	1
T (K)	10^{32}	10^{28}	10^{16}
t (sec)	10^{-43}	10^{-36}	10^{-12}

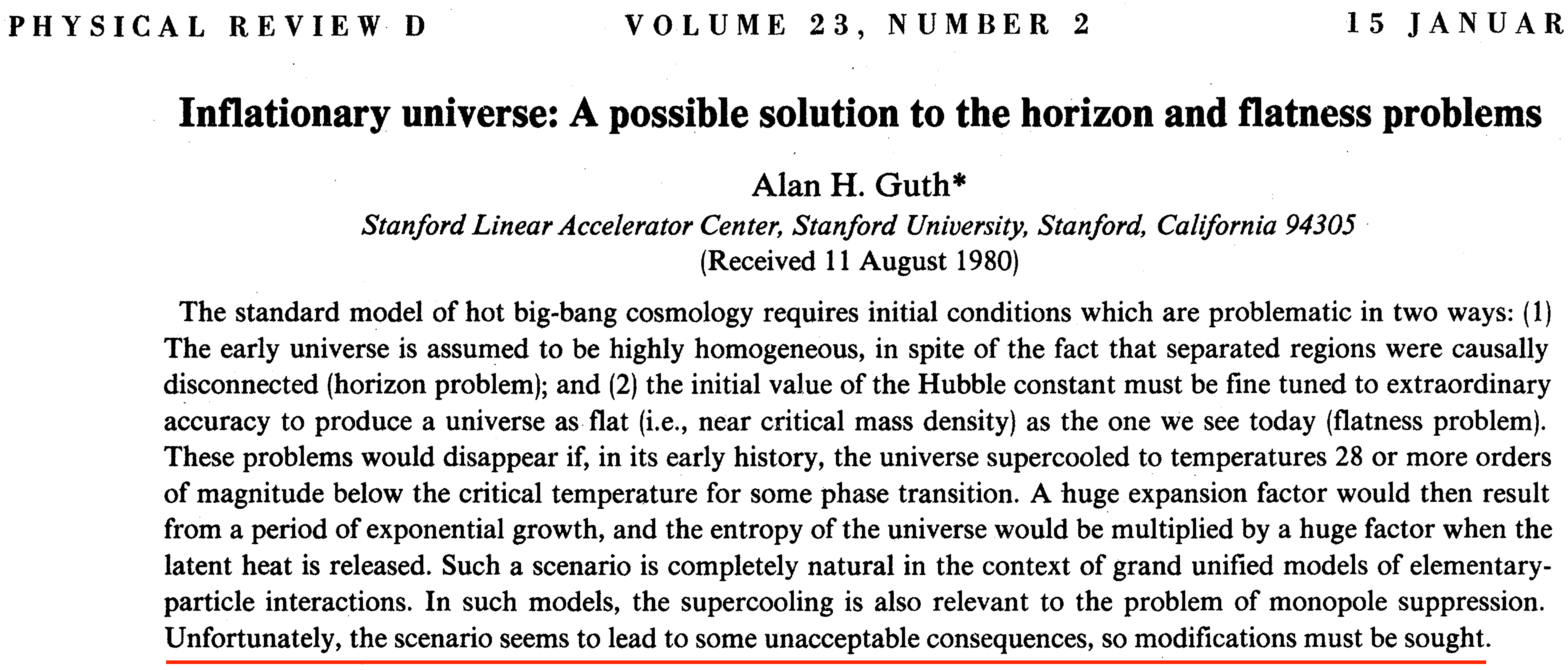
Topological Defects





Monopoles are predicted by GUTs, expect 1 per horizon zone (causally-connected volumes when the phase transition occurred)

Inflation to the Rescue!



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Inflationary universe: A possible solution to the horizon and flatness problems

Alan H. Guth*

Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305

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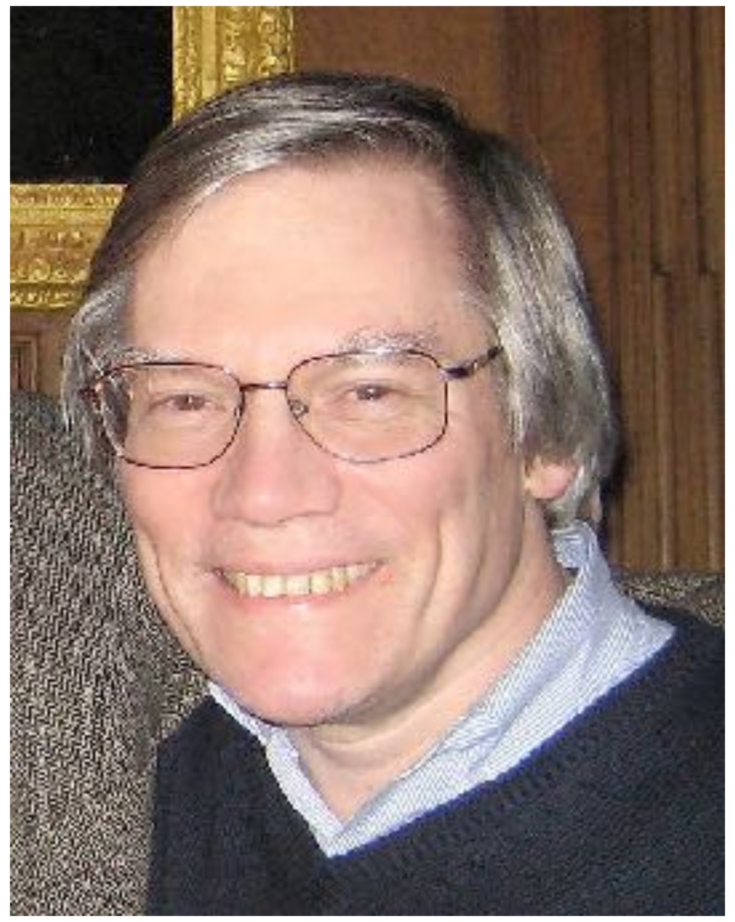
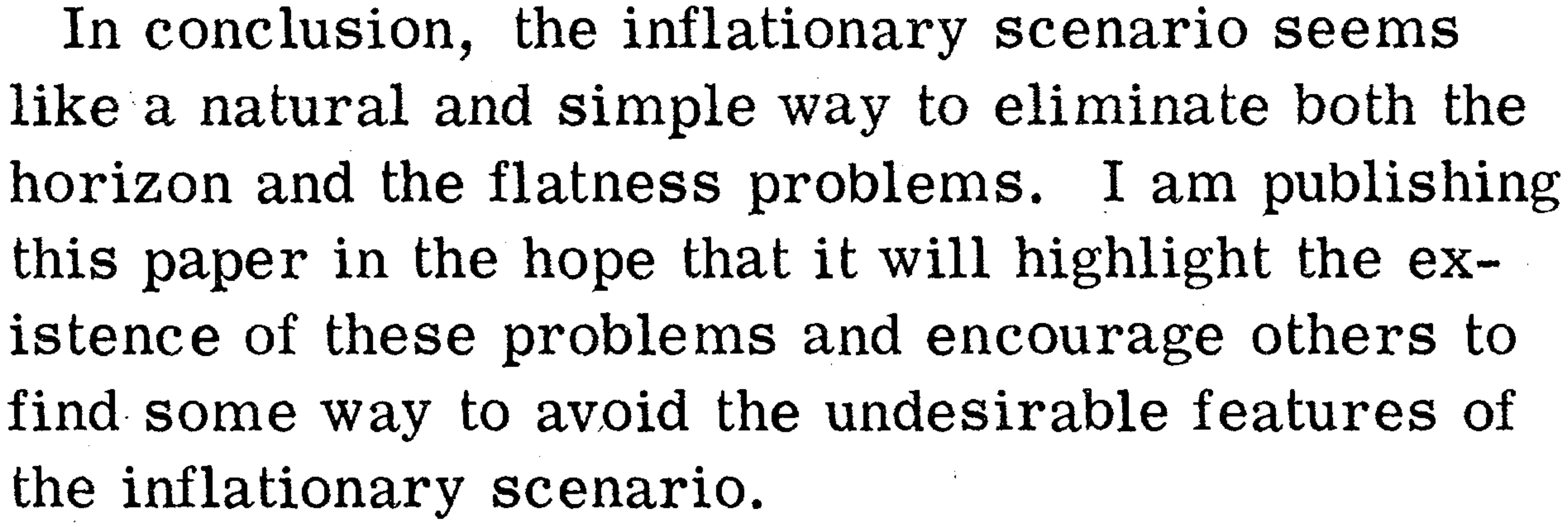
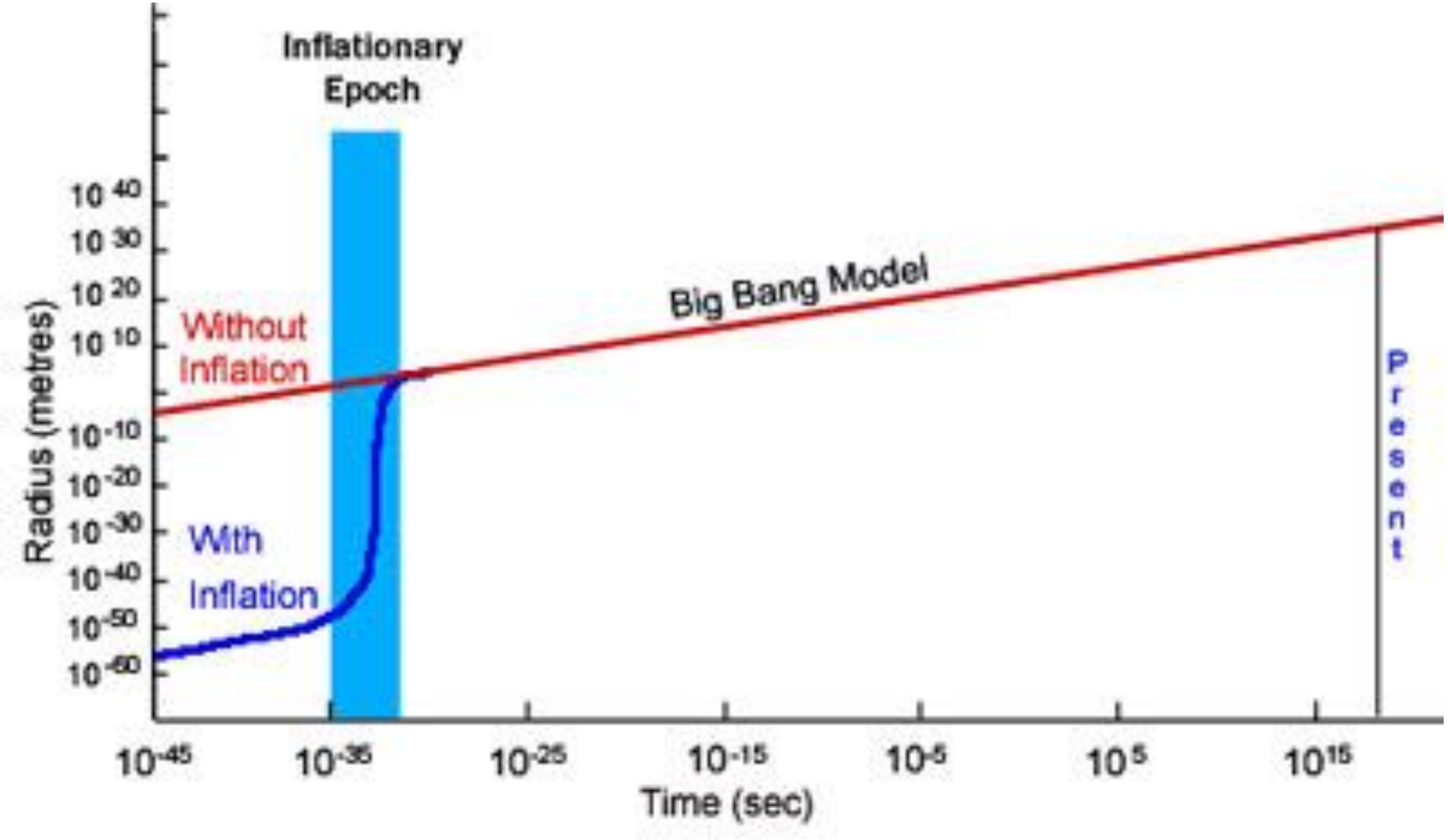
The standard model of hot big-bang cosmology requires initial conditions which are problematic in two ways: (1) The early universe is assumed to be highly homogeneous, in spite of the fact that separated regions were causally disconnected (horizon problem); and (2) the initial value of the Hubble constant must be fine tuned to extraordinary accuracy to produce a universe as flat (i.e., near critical mass density) as the one we see today (flatness problem). These problems would disappear if, in its early history, the universe supercooled to temperatures 28 or more orders of magnitude below the critical temperature for some phase transition. A huge expansion factor would then result from a period of exponential growth, and the entropy of the universe would be multiplied by a huge factor when the latent heat is released. Such a scenario is completely natural in the context of grand unified models of elementary-particle interactions. In such models, the supercooling is also relevant to the problem of monopole suppression. Unfortunately, the scenario seems to lead to some unacceptable consequences, so modifications must be sought.



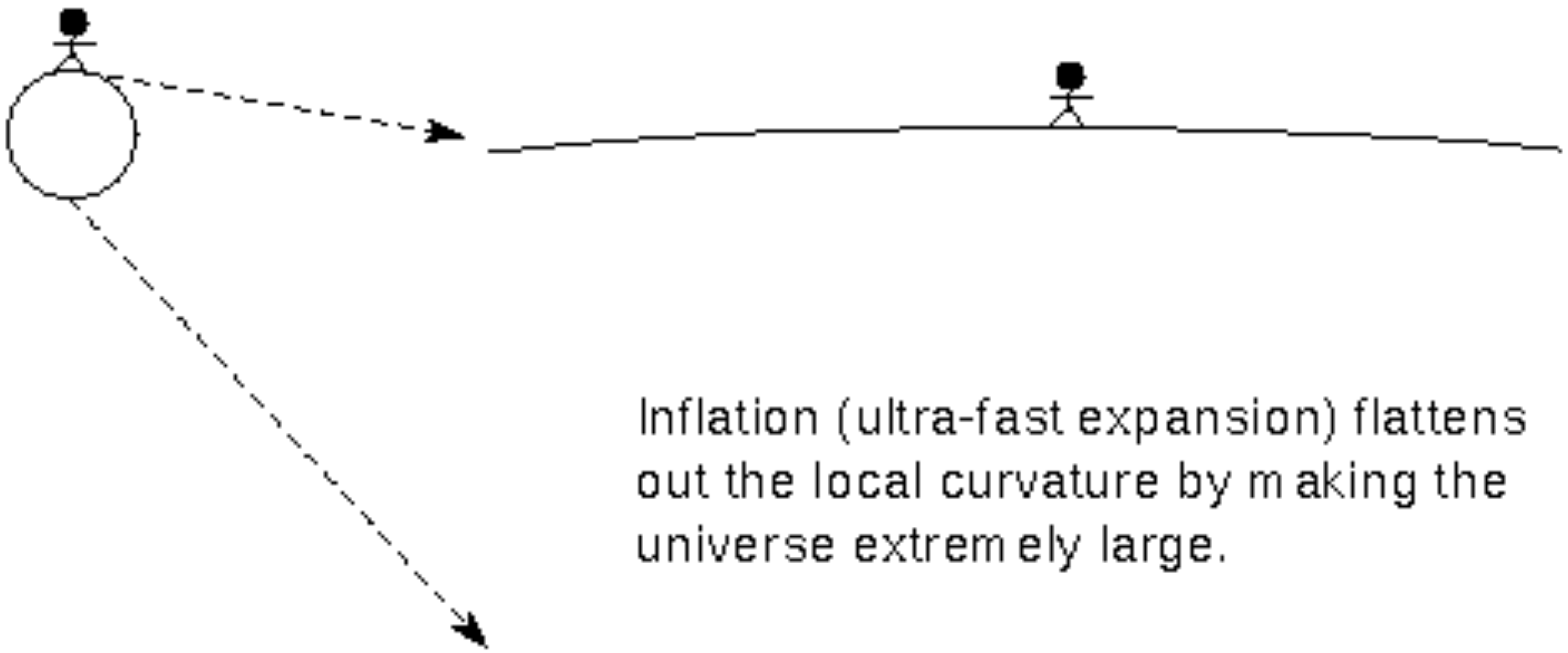


In conclusion, the inflationary scenario seems like a natural and simple way to eliminate both the horizon and the flatness problems. I am publishing this paper in the hope that it will highlight the existence of these problems and encourage others to find some way to avoid the undesirable features of the inflationary scenario.

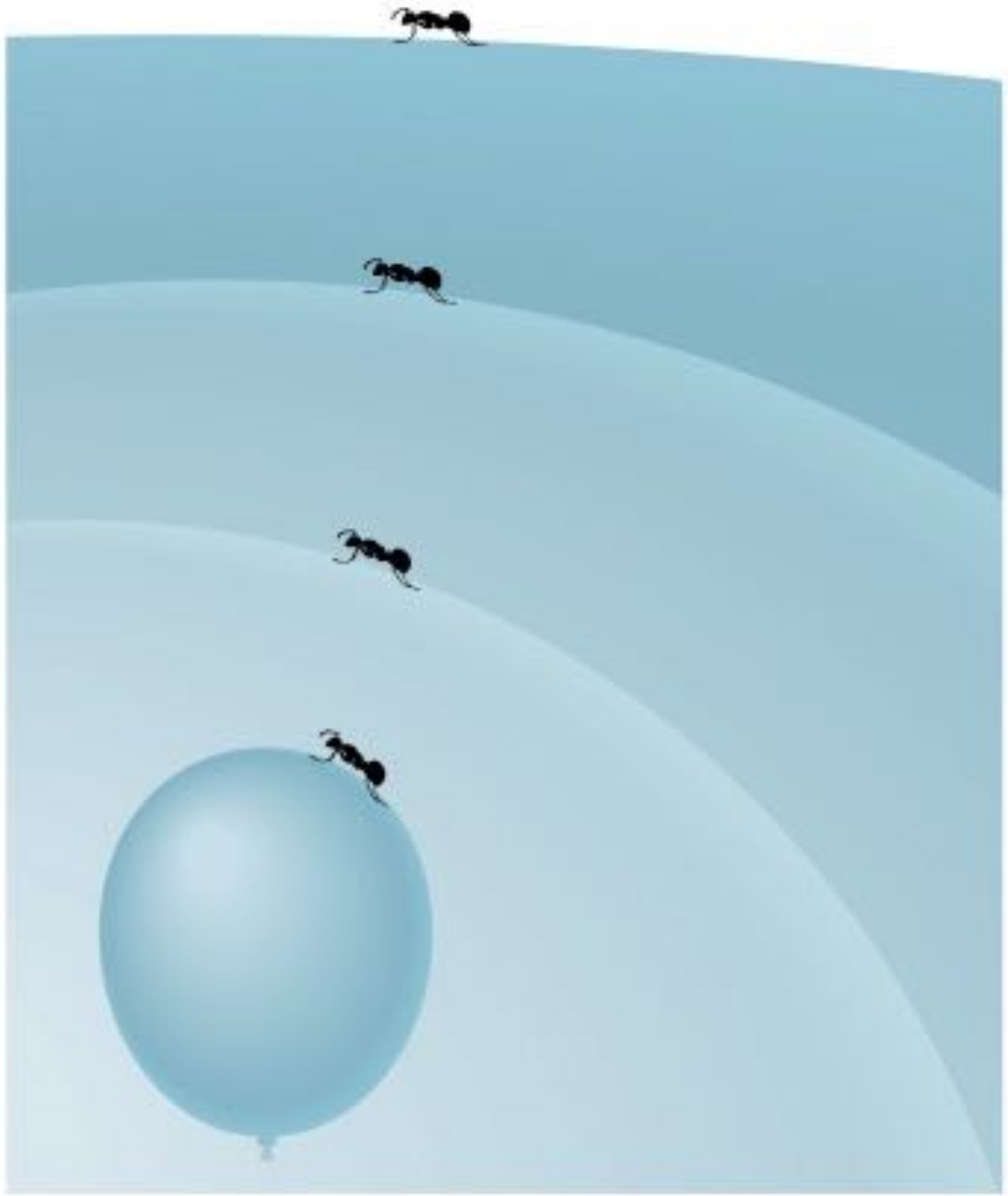
A period of exponential expansion *BEFORE* the Big Bang



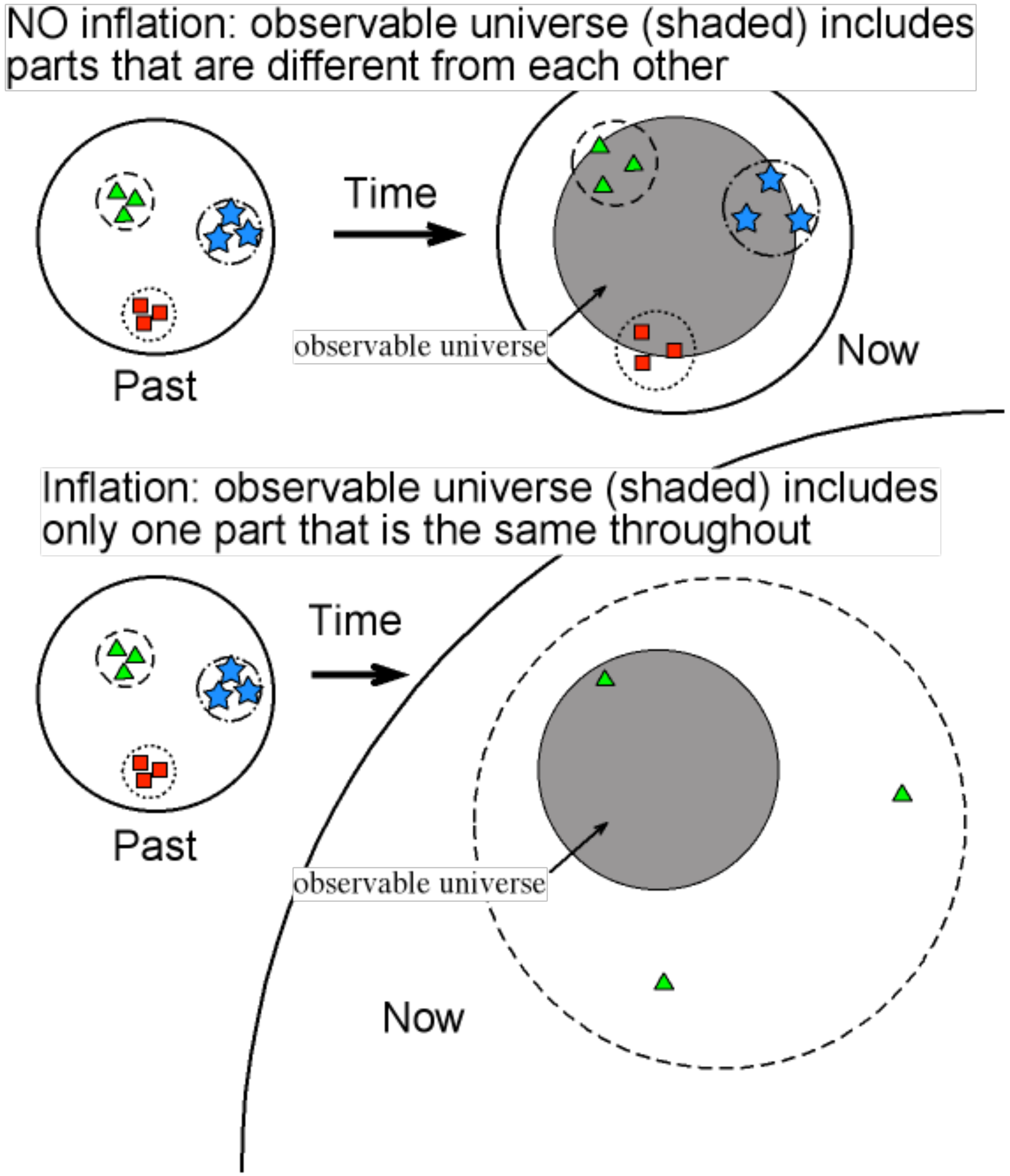
Solves the Flatness Problem



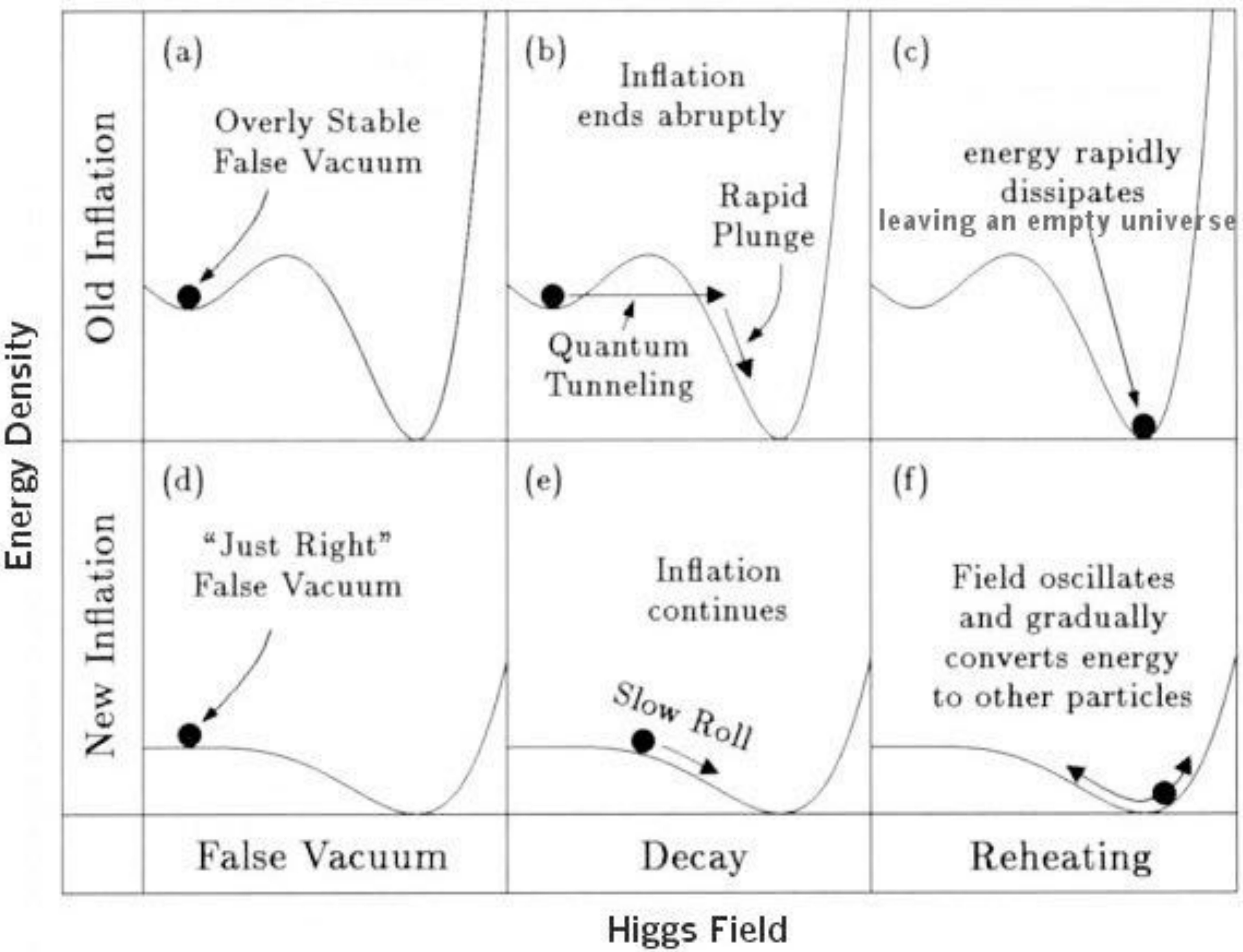
Inflation (ultra-fast expansion) flattens out the local curvature by making the universe extremely large.



Solves the Horizon and Monopole Problems

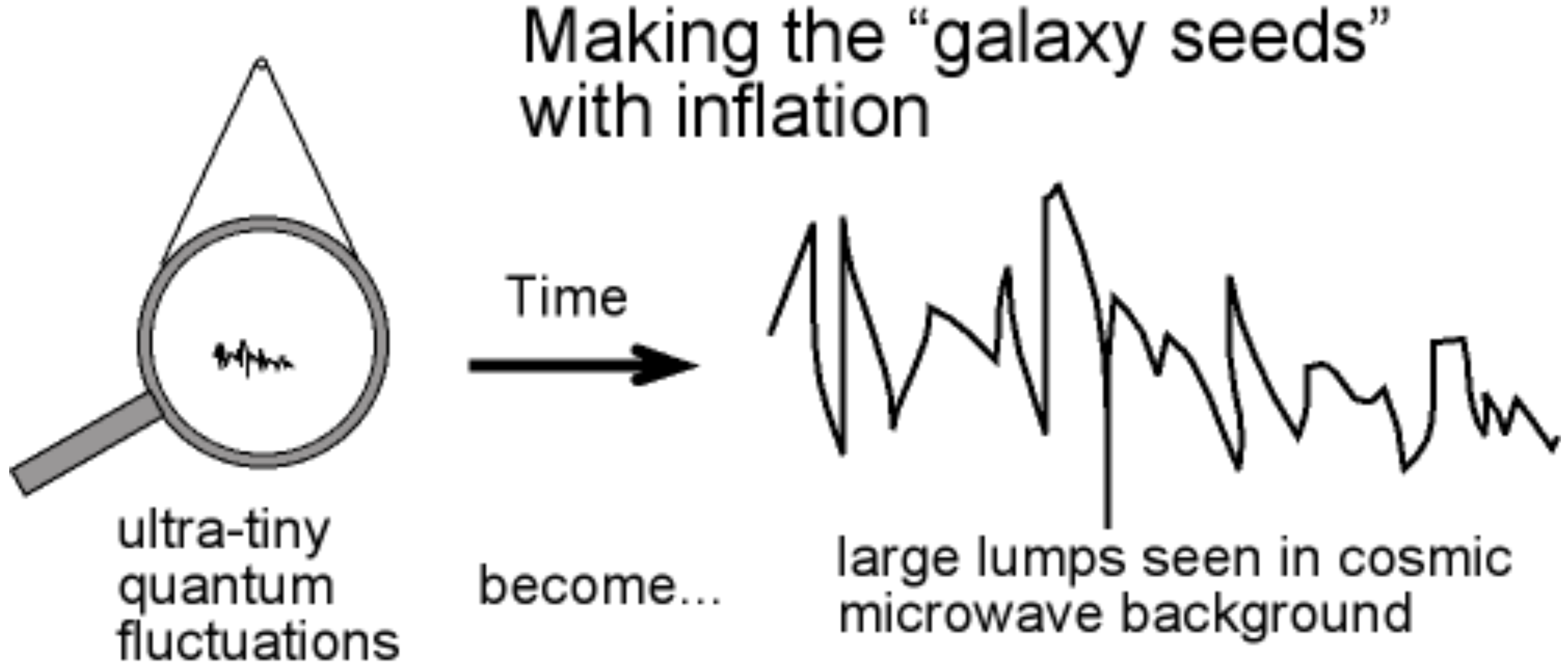


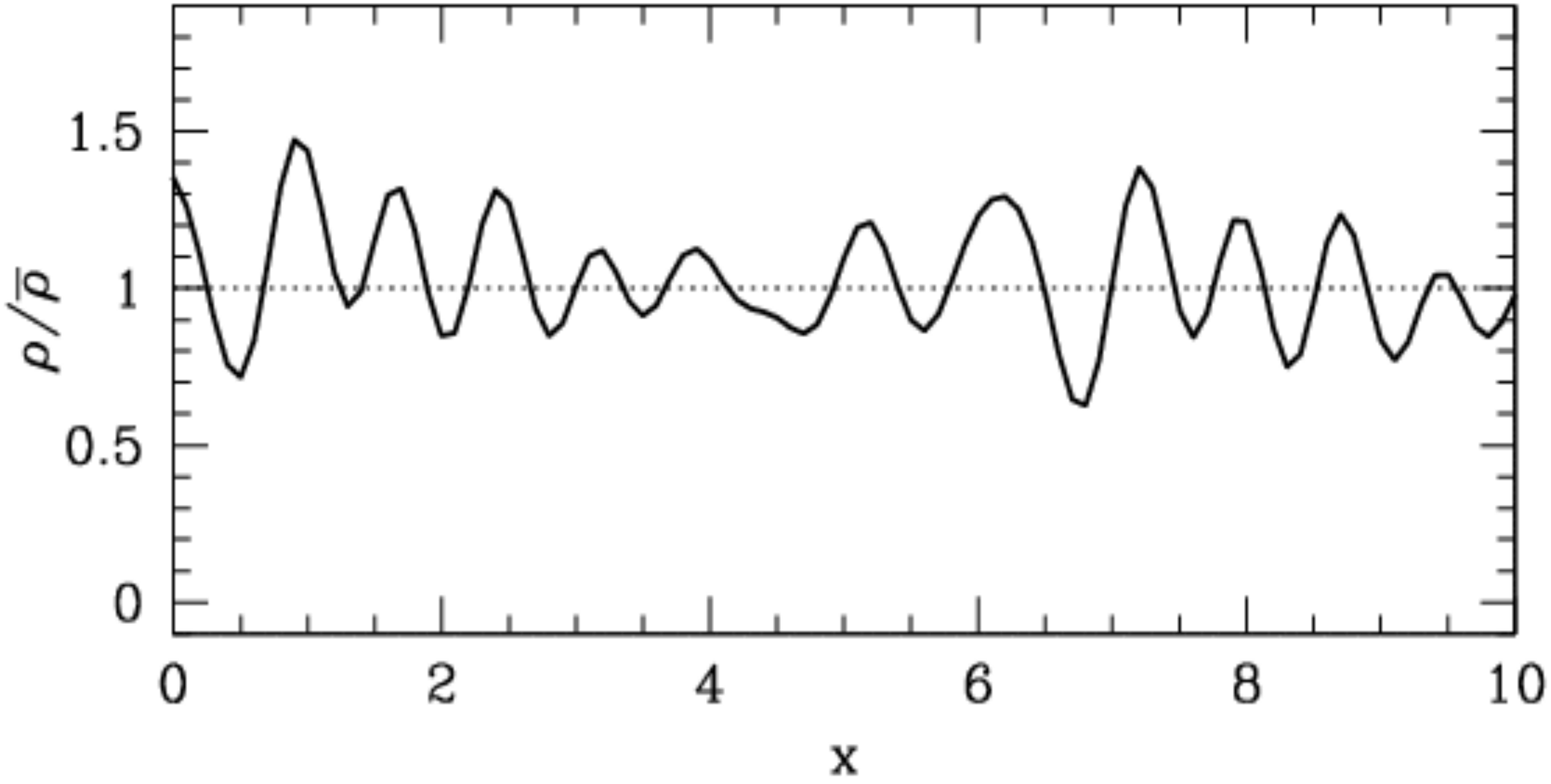
Inflation needs finely-tuned properties to work



Primordial Density Fluctuations from Inflation

- isentropic/adiabatic fluctuation, equal fluctuation in all forms of energy (photons, neutrinos, DM, baryons)
  ⇒ perturbation to spacetime curvature
- quantum fluctuation (of a weakly coupled field)
  ⇒ Gaussian fluctuation
  - distribution of fluctuation in space P(δ), Gaussian
  - joint distribution $P(\delta_1, \delta_2, \ldots, \delta_n)$ at points $\mathbf{x}_1, \mathbf{x}_2, \ldots, \mathbf{x}_n$, multi-variate Gaussian





Inflation:
Extension to the Standard Big Bang Theory

- solved horizon, flatness, monopole problems
- predicted flat space (observation✓)
- predicted nearly scale-invariant spectrum of adiabatic Gaussian primordial fluctuations (observation✓)

- V(ϕ) fine-tuned? alternative models (e.g., cyclic model)
- further tests to differentiate models
  - non-gaussianity
  - primordial gravitational waves (effect on CMB polarization)

fluctuation power spectrum - V(ϕ) shape
primordial gravitational waves - V(ϕ) amplitude