Reconstructing the Physics of Inflation

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Introduction - Kavli Prize

The theory of inflation represents the paradigm of modern cosmology: generates solutions for some observational problems.

Introduction -The Big Bang Model

The standard Big Bang model explains important features of our Universe...

- The Hubble expansion
- The existence and the thermal nature of CMB
- The abundances of light elements (D,He-4)

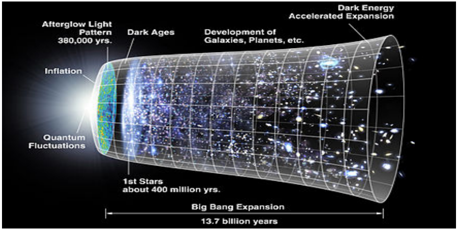
Nevertheless the Universe presents some peculiarities to much fine tuned:

- The flatness problem:
  - Why the early universe appears so flat?
- Horizon problem
  - Why the universe on large scales appears so homogeneous and isotropic (in mean)?
- The monopoles problems:
  - Where are the magnetic monopoles?

Physical mechanism able to prepare the initial Friedman's conditions?

The Big Bang puzzles are solved introducing an accelareted expansion in early times: $\ddot{a} > 0$

$$a(t) \sim e^N, \quad N \sim H\Delta t \quad \text{number of e-foldings}$$

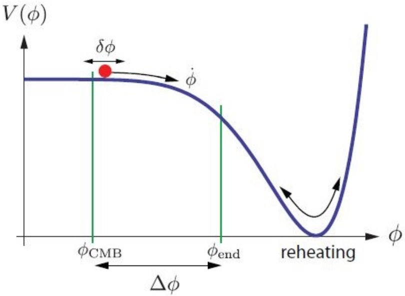


In this way:

- a streching of the hypersurfaces
- a particle horizon larger then the previous one d_p
- a dilution of the monopoles on large scales

Inflationary Universe II

The simplest way to obtain inflation is considerer a scalar field.



- $S = \int d^4x\sqrt{-g}\left\{\frac{1}{2}M_p^2 R - \frac{1}{2}\partial_\mu\phi\partial^\mu\phi - V(\phi)\right\}$
- $V(\phi)$ presents an initial platau and subsequent minimum
- Inflation is codified by: $\epsilon_V = \frac{1}{2}M_p^2\left(\frac{V'}{V}\right)^2, \quad \eta_V = M_p^2\frac{V''}{V}$
- Inflation ends when inflaton approaches the minimum: reheating

Cosmological Fluctuations I

Inflation and QFT explain in natural way the density fluctuations that lead to LSS and $\Delta T/T$ on CMB. The field is not completely homogeneaus but admits a fluctuation:

$$\phi(t) \rightarrow \phi(x,t) = \phi(t) + \delta\phi(x,t) \text{ dove } <0|\hat{\phi}(x,t)|0>=\phi(t)$$

This implies

- Flactutions on Stress-Energy tensor and consequently on Einstein tensor
- The wavelenghts are streched above the Hubble's horizon $\rightarrow$ classical perturbation
- Flutctuations re-enter because the growthing of R_H is faster then the horizon ones d_p
- Finally are shared by barions and photons $\rightarrow$ LSS e $\Delta T/T$

Power spectrum, tilt, tensor-to-scalar ratio

By the Einstein field equation is possible to derive equation for the scalar and tensor flactuations and the relative observable quantities:

- Scalar sector:

$$u_k''(\tau) + \left[k^2 - \frac{1}{\tau^2}\left(\nu^2 - \frac{1}{4}\right)\right] u_k(\tau) = 0 \quad \nu \approx \frac{3}{2} + 2\epsilon - \eta$$

with:

$$P_S(k) = \frac{1}{8\pi^2 M_p^2}\frac{H^2}{\epsilon}|_{k=aH} \quad \text{e} \quad n_S - 1 = -4\epsilon + 2\eta$$

- Tensor sector:

$$v_k''(\tau) + \left[k^2 - \frac{1}{\tau^2}\left(\nu^2 - \frac{1}{4}\right)\right] v_k(\tau) = 0 \quad \nu \simeq \frac{3}{2} + \epsilon$$

with:

$$P_T(k) = \frac{2}{\pi^2}\frac{H^2}{M_p^2}|_{k=aH} \quad \text{e} \quad n_T = -2\epsilon$$

- Tensor-to-scalar ratio: $r = P_T/P_S = 16\epsilon$

Potential Reconstruction I

The usual method to probe the inflationary dyanamics consist to write a model,extract predictions and compare with the data:

$$\mathcal{M}_\phi \leftrightarrow V(\phi) \Rightarrow \text{ slow roll } \beta_i \Rightarrow \text{ predictions } \mathcal{P}_i \Longleftrightarrow \text{ data } \mathcal{O}_i$$

This is not the unique way. In principle is possible to use directly the data to constrain the potential:

$$\text{data } \mathcal{O}_i \Rightarrow V(\phi)$$

Indeed:

- The observable modes corresponds to $N \simeq 50 - 60$
- The variation of the field during inflation is small: $\phi \simeq \phi_0$

Then:

$$V(\phi) \simeq V(\phi_0) + V'(\phi)|_{\phi=\phi_0}(\phi-\phi_0) + \frac{1}{2}V''(\phi)|_{\phi=\phi_0}(\phi-\phi_0)^2 + \ldots \quad (1)$$

and connect the coefficents to slow roll parameters $\beta_i(\phi)$ and to observables $\mathcal{O}_i$.

Potential Reconstruction II

The coefficents of the expansion are derived from the Hamilton-Jacobi equation for the inflationary dynamics:

$$V(\phi) = 3M_p^2 H^2(\phi) - 2M_p^2 \dot{H}^2(\phi) \quad (2)$$

Using a little algebra and the general form of the slow roll parameters, at lowest order one has:

$$V(\phi_0) = \frac{3}{2}\pi^2 M_p^4 P_S(k) r|_{\phi_0}$$

$$V'(\phi_0) = \frac{3}{4\sqrt{2}}\pi^2 M_p^3 P_s(k) r^{\frac{3}{2}}|_{\phi_0}$$

$$V''(\phi_0) = \frac{1}{2}\pi^2 M_p^2 P_S(k) r \left[9\left(\frac{r}{16}\right) - \frac{3}{2}(1-n_S)\right]|_{\phi_0} \quad (3)$$

Now is possible to sampling the potential k times, using

- Gaussian sampling on n_s with $n_s = 0.968$, $\sigma_n = 0.006$
- Uniform distribution on r with $r < 0.09$

consistently with latest Planck release.

Potential Reconstruction III

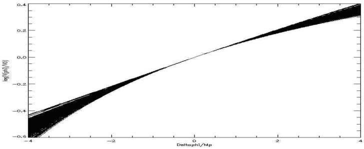


Figura: Sampling ns, $k = 500$

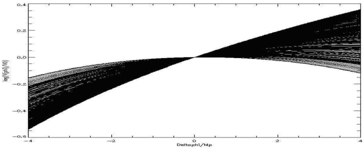


Figura: Sampling r, $k = 500$

Potential Reconstruction IV

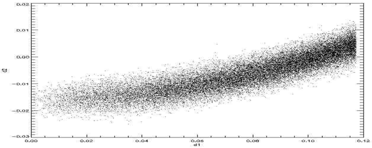


Figura: Ratio d2/d1, $k = 10^4$

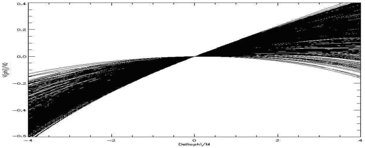


Figura: Sampling both ns and r, $k = 500$

Conclusions and Future

This communication represents a first approach to the local reconstruction of the inflaton potential.
These preliminary results show how:

- An improvement of the current measures of n_s and r reduces the permitted region.
- The first order expansion in the inflationary parameters for the coefficents represents a limitation.

So is understandable extend the study considering

- A different sampling for r (e.g gaussian) simulating what will happen,hopefully, in the future.
- A correlation between n_s and r.
- An expansion up to second order in the inflationary parameters for the coefficents of the potential, repeating the previous steps.
- Estimations of the slow roll parameters.