XXIII DAE-BRNS Symposium, December 10 -14, 2018

Constraining the parameters of Warm Inflationary models

Based on: JCAP02(2018)043,

arXiv: 1812.03107

Richa Arya

In collaboration with: Prof. Raghavan Rangarajan

Physical Research Laboratory

11 December 2018

Outline

1. Standard Cold Inflation
2. Warm Inflation
3. Evolution equations in warm inflation
4. Models of Warm Inflation
5. Results

Standard Cold Inflation

Phase of accelerated expansion in the early Universe for a brief duration.

- Inflation starts when energy density of inflaton ρ_ϕ dominates
- The Universe undergoes a nearly exponential expansion.
- The number density of all species dilute away and the Universe supercools.
- There is a *reheating* phase during which the particles are created by the inflaton decay.
- The Universe attains temperature during reheating.

Warm Inflation [1]

- An alternate description of inflation.
- In this scenario also, the condition of inflation is $\rho_\phi > \rho_r$.
- The difference is that inflaton coupling to other fields relevant both *during and after* the inflationary phase.
- The inflaton dissipates into particles during inflation as well.
- As radiation is created during the inflation, the Universe has a temperature T, and hence *warm*.

[1] A. Berera and L. Z. Fang, Phys. Rev. Lett. **74**, 1912 (1995), A. Berera, Phys. Rev. Lett. **75**, 3218 (1995).

Evolution equations in warm inflation

Equation of motion for the inflaton field ϕ is given as

$$\ddot{\phi} + (3H + \Upsilon)\dot{\phi} + V'(\phi) = 0 \tag{1}$$

- $\Upsilon\dot{\phi}$ is a dissipative term due to inflaton interactions with other fields.

Defining a **dissipation parameter** $Q \equiv \frac{\Upsilon}{3H}$, we obtain

$$\boxed{\ddot{\phi} + 3H(1 + Q)\dot{\phi} + V'(\phi) = 0} \tag{2}$$

$Q > 1 \rightarrow$ **strong dissipative WI** $Q < 1 \rightarrow$ **weak dissipative WI**

The **radiation energy density**, ρ_r evolves as

$$\boxed{\dot{\rho}_r + 4H\rho_r = \Upsilon\dot{\phi}^2 \ .} \tag{3}$$

In the **slow roll approximation**,

we approximate $\ddot{\phi} \approx 0$, which gives

$$\boxed{\dot{\phi} \approx \frac{-V'(\phi)}{3H(1+Q)}}$$

and $\dot{\rho}_r \approx 0$, which gives

$$\boxed{\rho_r \approx \frac{\Upsilon}{4H}\dot{\phi}^2 = \frac{3}{4}Q\dot{\phi}^2}$$

What do we observe today?

Cosmic Microwave Background (CMB) Radiation

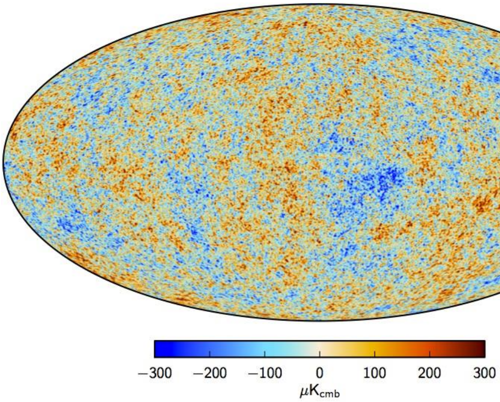

Figure : CMB seen by Planck. Temperature anisotropies: 1 part in 10^5.

Source:www.esa.int

Observables

- Two point correlation function of density fluctuations generated during inflation - **Primordial power spectrum**, $P_{\mathcal{R}}(k)$. It has an amplitude A_s.
- **Spectral index** is a measure of the tilt of power spectrum at a fiducial scale, pivot scale.

$$n_s - 1|_{k=k_P} = \left. \frac{d \ln P_{\mathcal{R}}(k)}{d \ln(k/k_P)} \right|_{k=k_P} .$$

- Two point correlation function of tensor fluctuations, $P_T(k)$ has an amplitude A_T.
- **Tensor-to-scalar ratio**,

$$r = \frac{A_T}{A_s}$$

Primordial power spectrum in warm inflation

The primordial power spectrum for warm inflation in the weak dissipative regime is given as[2]

$$P_{\mathcal{R}}(k) = \left(\frac{H_k^2}{2\pi\dot{\phi}_k}\right)^2 \left[coth\left(\frac{H_k}{T_k}\right) + \left(\frac{T_k}{H_k}\right)\frac{2\sqrt{3}\pi Q_k}{\sqrt{3+4\pi Q_k}}\right]$$

It has contributions because of temperature T and the dissipation Q.

[2] S. Bartrum, M. Bastero-Gil, A. Berera, R. Cerezo, R. O. Ramos and J. G. Rosa, Phys. Lett. B **732**, 116 (2014).

Motivation of this work

- The *Planck* measurements of temperature anisotropies in the CMB have put tight constraints on cosmological parameters (n_s, r).
- The inflationary potentials $V(\phi) = \lambda\phi^4$, $\lambda\phi^6$ are ruled out to be viable models in the standard cold inflation.
- We are estimating the range of parameters for which these are viable models of inflation in the context of *Warm Inflation.*
- This is significant because these these allowed range of parameters are important for constructing inflation from first principles.

Warm Inflation Models considered

- $V(\phi) = \lambda\phi^4$, with dissipation coefficient $\Upsilon = C_\phi \frac{T^3}{\phi^2}$.
- $V(\phi) = \lambda\phi^4$, with dissipation coefficient $\Upsilon = C_T T$.
- $V(\phi) = \frac{\lambda}{M_{Pl}^2}\phi^6$, with dissipation coefficient $\Upsilon = C_\phi \frac{T^3}{\phi^2}$.
- $V(\phi) = \frac{\lambda}{M_{Pl}^2}\phi^6$, with dissipation coefficient $\Upsilon = C_T T$.

The different forms of dissipation coefficient Υ, arises from many mechanisms in which inflaton decay [3].

[3] I. G. Moss and C. Xiong, hep-ph/0603266.

Model I: [4]: $V(\phi) = \lambda\phi^4$, with $\Upsilon = C_\phi \frac{T^3}{\phi^2}$

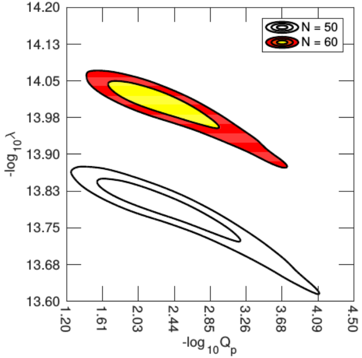

Figure : Joint probability of $-\log_{10}\lambda$ and $-\log_{10} Q_P$ in the weak dissipative regime.

For $N_P = 50$,

Mean value of $\lambda = 1.66 \times 10^{-14}$

Mean value of $Q_P = 3.7 \times 10^{-3}$

$n_s = 0.9660$

$r = 0.0275$

For $N_P = 60$,

Mean value of $\lambda = 1.0 \times 10^{-14}$

Mean value of $Q_P = 4.4 \times 10^{-3}$

$n_s = 0.9712$,

$r = 0.0222$

[4] R. Arya, A. Dasgupta, G. Goswami, J. Prasad, R. Rangarajan, JCAP02 (2018) 043

Model II: $V(\phi) = \lambda\phi^4$ with $\Upsilon = C_T T$

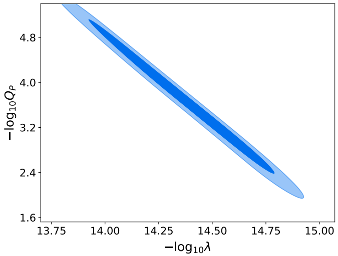

Figure : Joint probability in the weak dissipative regime for $N_P = 60$.

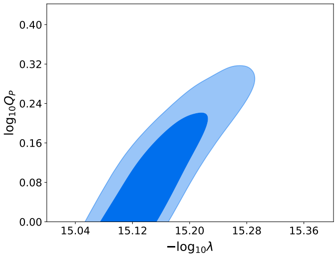

Figure : Joint probability in the strong dissipative regime for $N_P = 60$.

Mean value of $\lambda = 4.07 \times 10^{-15}$

Mean value of $Q_P = 2.29 \times 10^{-4}$

$n_s = 0.967$

$r = 0.0330$

Mean value of $\lambda = 6.82 \times 10^{-16}$

Upper limit of $Q_P = 1.43$

$n_s = 0.973$

$r = 0.000214$

Model III: $V(\phi) = \frac{\lambda}{M_{Pl}^2}\phi^6$ with $\Upsilon = C_\phi \frac{T^3}{\phi^2}$

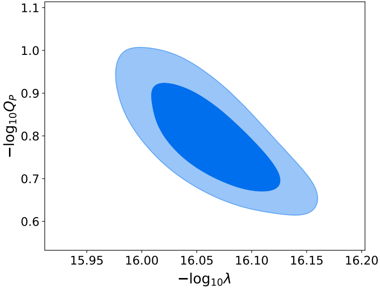

Figure : Joint probability of $-\log_{10}\lambda$ and $-\log_{10} Q_P$ in the weak dissipative regime.

For $N_P = 60$,

Mean value of $\lambda = 8.63 \times 10^{-17}$

Mean value of $Q_P = 0.1588$

$n_s = 0.969$

$r = 0.00480$

Model IV: $V(\phi) = \frac{\lambda}{M_{Pl}^2}\phi^6$, with $\Upsilon = C_T T$

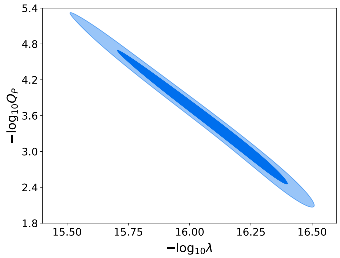

Figure : Joint probability in the weak dissipative regime for $N_P = 60$.

Mean value of $\lambda = 8.51 \times 10^{-17}$

Mean value of $Q_P = 2.88 \times 10^{-4}$

$n_s = 0.956$

$r = 0.0451$

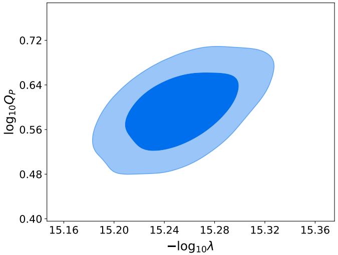

Figure : Joint probability in the strong dissipative regime for $N_P = 60$.

Mean value of $\lambda = 5.59 \times 10^{-16}$

Mean value of $Q_P = 3.94$

$n_s = 0.970$

$r = 0.0000426$

Conclusion

- In warm inflation, radiation production takes place during the inflationary phase also and therefore the Universe has temperature.
- We studied $\lambda\phi^4$ and $\lambda\phi^6$ models of inflation with two types of dissipation coefficient.
- We obtained the joint and marginalised distribution for the model parameters, λ and Q_P. This is crucial for model building.
- For the mean values of parameters, we calculated the n_s and r, and found them to be consistent with the *Planck* observations.

Thank you