Different aspects of primordial Anisotropies: Theoretical and Observational signatures

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Outline

- Brief review of Inflation as a solution to the Big-Bang problems,
- Motivation of the primordial anisotropy from the CMB observation,
- Anisotropic Inflation from the Charged Scalar field,
- Anisotropic corrections in the curvature power-spectrum,
- Anisotropic corrections in the tensor power-spectrum,
- Anisotropic corrections in the CMB.
- Clustering Fossil From Anisotropic Inflation

Inflaionary universe

Big-Bang Puzzles

As it is well-known, there exists two puzzles in the standard model of cosmology, namely the Horizon as well as the Flatness problems.

★ Inflation is (one of) the best scenarios to solve the Big-Bang puzzles.

A first look at Inflation

Inflation is an accelerated phase of the expansion when the strong energy condition has been violated.

★ It can very easily solve the big bang puzzles, such as the horizon as well as the flatness problems.

♦ And It Is Very Easy To Generate Inflation!!!

Inflationary universe

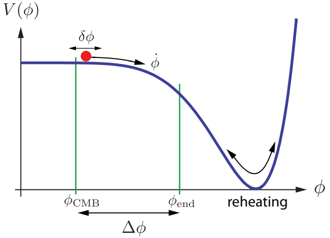
♦ Scalar Driven Slow-roll inflation,

$$S = \int d^4x\sqrt{-g}\left[\frac{M_P^2}{2}R + \frac{1}{2}g^{\mu\nu}\partial_\mu\varphi\partial_\nu\varphi - V(\varphi)\right] = S_{EH} + S_\varphi$$

◊ The acceleration of the universe is given by,

$$\frac{\ddot{a}}{a} = -\frac{1}{6M^P}\left(\rho_\varphi + 3p_\varphi\right) = H^2\left(1-\epsilon\right) \quad , \quad \epsilon = \frac{1}{2}\frac{\dot{\varphi}^2}{H^2}$$

♦ So inflationary phase corresponds to $\epsilon \ll 1$, slow-roll condition,



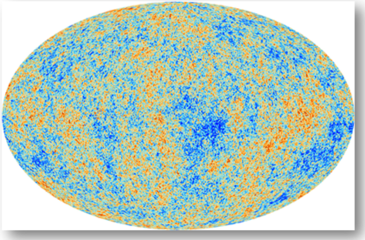
◊ One may add another scalar or higher spin fields, e.g. vector fields, in the system as well. This leads to a huge number of inflationary models!!!

Inflationary Universe

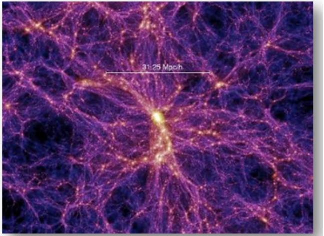
Connection to observation

★ There are two different experimental labs to examine the physics during inflation.

★ One is the CMB map and the other is Large Scale Surveys.



CMB



LSS

◊ One may either try to explain the new observations with the new models or look for the specific predictions that these models would have for the futuristic observations.

Inflationary universe

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perturbation
Scalar
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CMB
Clustering

The aim of this talk

★ In this talk, we consider a very specific category of inflationary models, i.e. Anisotropic Inflation.
★ At first, we talk about the motivation of considering higher spin fields, like the vectors, during inflation.
★ Then we will discuss about its unique futuristic predictions for the CMB as well as Large Scale surveys.

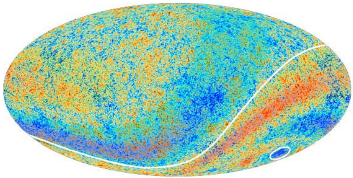
♦ This is based on the following publications:

JCAP 1102 (2011) 005, JCAP 1310 (2013) 041,
JCAP 1408 (2014) 027, JCAP 1510 (2015) 043

Anisotropic Inflation from observations

The story of CMB Anomalies

The observational data provided by Planck satellite indicates some deviations from the statistical isotropy. There are different explanations in the literature about them. They can be from the early universe or they can be arised from the secondary events.



In this talk, we will concentrate to the former explanation in which these anomalies have been produced during inflation.

The correction of the primordial power spectrum due to these anomalies

$$P(k) = P_0(k)\left(1 + g_*(n.k)^2\right) \quad , \quad |g_*| < 0.01$$

Anisotropy at the background

Action:

$$S = \int d^4x\sqrt{-g}\left[\frac{M_P^2}{2}R - \frac{1}{2}D_\mu\varphi\,\overline{D^\mu\varphi} - \frac{f^2(\varphi)}{4}F_{\mu\nu}F^{\mu\nu} - V(\varphi,\overline{\varphi})\right]$$

Covariant derivative is given by,

$$D_\mu\varphi = \partial_\mu\varphi + ie\,\varphi\,A_\mu$$

Decomposing the inflaton field into radial and axial parts as $\varphi(x) = \phi(x)\,e^{i\theta(x)}$ the action will be,

$$\begin{aligned} S \quad = \quad & \int d^4x\sqrt{-g}\Big(\frac{M_P^2}{2}R - \frac{1}{2}\partial_\mu\phi\partial^\mu\phi - \frac{\phi^2}{2}\left(\partial_\mu\theta + eA_\mu\right)\left(\partial^\mu\theta + eA^\mu\right) \\ & -\frac{f^2(\phi)}{4}F_{\mu\nu}F^{\mu\nu} - V(\phi)\Big) \end{aligned}$$

Anisotropy at the background

- Choose Bianchi I metric as the background ,

$$ds^2 = -dt^2 + e^{2\alpha(t)}(e^{-4\sigma(t)}dx^2 + e^{2\sigma(t)}(dy^2 + dz^2)) .$$

  - $\dot{\alpha}$: Isotropic Hubble expansion rate,
  - $\dot{\sigma}$: Anisotropic expansion rate.
  - For a universe with small anisotropies, $\delta \equiv |\dot{\sigma}/\dot{\alpha}| \ll 1$
- Take the background gauge field as $A_\mu = (0, A(t), 0, 0)$
- Choose unitary gauge ,($\theta = 0$), which is equivalent to Coulomb-radiation gauge ,($A_0 = \partial_i A^i = 0$), at background level.

The equation for the acceleration of universe:

$$\ddot{\alpha} + \dot{\alpha}^2 = -2\dot{\sigma}^2 - \frac{1}{3M_P^2}\dot{\phi}^2 + \frac{1}{3M_P^2}\left[V - \frac{1}{2}f^2(\phi)\dot{A}^2 e^{-2\alpha+4\sigma}\right] .$$

Inflation happens if V is dominant over the gauge field kinetic energy.

Anisotropy at the background

The background equations of motion :

$$\begin{aligned}
\partial_t\left(f^2(\phi)e^{\alpha+4\sigma}\dot{A}\right) &= -e^2\phi^2 e^{\alpha+4\sigma}A \\
\ddot{\phi}+3\dot{\alpha}\dot{\phi}+V_\phi+\left(-f(\phi)f_\phi(\phi)\dot{A}^2+e^2\phi A^2\right)e^{-2\alpha+4\sigma} &= 0 \\
\frac{1}{2}\dot{\phi}^2+V(\phi)+\left(\frac{1}{2}f^2(\phi)\dot{A}^2+\frac{e^2\phi^2}{2}A^2\right)e^{-2\alpha+4\sigma} &= 3M_P^2\left(\dot{\alpha}^2-\dot{\sigma}^2\right) \\
V(\phi)+\left(\frac{1}{6}f^2(\phi)\dot{A}^2+\frac{e^2\phi^2}{3}A^2\right)e^{-2\alpha+4\sigma} &= M_P^2\left(\ddot{\alpha}+3\dot{\alpha}^2\right) \\
\left(\frac{1}{3}f^2(\phi)\dot{A}^2-\frac{e^2\phi^2}{3}A^2\right)e^{-2\alpha+4\sigma} &= M_P^2\left(3\dot{\alpha}\dot{\sigma}+\ddot{\sigma}\right) .
\end{aligned}$$

If anisotropy converges to a value $\Rightarrow \quad \delta \simeq \frac{2}{3}(R_1-R_2)$

$$R_1 \equiv \frac{\dot{A}^2 f(\phi)^2 e^{-2\alpha}}{2V} \quad , \quad R_2 \equiv \frac{e^2\phi^2\, A^2 e^{-2\alpha}}{2V}$$

During inflation $(R_1 \gg R_2) \quad \Longrightarrow \quad R_1$ has to be almost constant

Anisotropy at the background

♦ Maxwell equation:

$$\dot{A} = f(\phi)^{-2} e^{-\alpha(t) - 4\sigma(t)} p_A$$

R_1 grows slowly and becomes a constant if,

$$f \propto \exp\left[2c \int d\phi \frac{V}{M_P^2 V_\phi}\right]$$

The behavior of the system depends on the value of c.
★ $c - 1 \ll O(1)$ In this case, the contribution of the vector in the evolution of the inflaton field remains subleading during the whole of the Inflation .
R_1 is almost constant and at the background level, we are left with the usual nearly isotropic phase.

Anisotropy at the background

★ $c-1 \gtrsim O(1)$ In this case, there is an attractor in the system where the contribution of the gauge field in the evolution of the inflaton field is not negligible at the background level.

- First phase :

$$M_P^{-2}\frac{d\phi}{d\alpha} \simeq -(\frac{V_\phi}{V}) \qquad , \qquad R_1 \sim e^{4(c-1)\alpha} \ll \epsilon_H$$

- Second phase (attractor solution) :

$$M_P^{-2}\frac{d\phi}{d\alpha} \simeq -\frac{V_\phi}{V} + \frac{c-1}{c}\frac{V_\phi}{V} \qquad , \qquad R_1 = \frac{c-1}{2c}\epsilon_H \equiv \frac{I}{2}\epsilon_H$$

- Third phase (for the gauge field) :

$$A \sim e^{\frac{3\alpha}{2}} J_{3/4}\left(\frac{\sqrt{\beta}}{2}e^{2\alpha}\right) \qquad , \qquad \beta \equiv 24e^2(\frac{c-1}{c^2})(\frac{M_P^4}{P_A^2})$$

Anisotropy at the background

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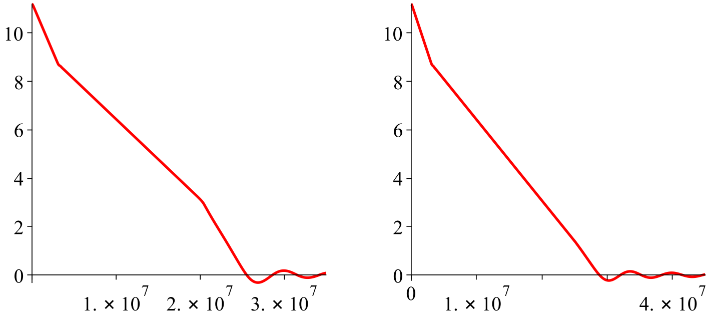
★ The attractor behavior of the system for the chaotic potential.



The evolution of the inflaton field for $e = 0.1$ (left) and for the $e = 0$ (right). The first kink is where the gauge kinetic coupling would be important while the second kink refers to the moment where the charge coupling is important.

Generalized Perturbations in Bianchi 1 universe

★ There are two ways of considering the perturbations in this anisotropic setup

In-In formalism

In order to use this method, we should first calculate the interaction Hamiltonian between the fields and then evaluate the correction to the n-point functions. It is more or less similar to the FRW case, but with a reduced amount of the symmetries. We will discuss it in detail below

δN *formalism*

It is required to generalize the well-known δN formalism for the Bianchi 1 universe. A way to do this is to prove that the background field equations are locally hold inside each an every homogenized patch.

★ We use the first method in what follows

Generating anisotropic seeds during inflation

Background level :

$$ds^2 = a(\eta)^2(-d\eta^2 + dx^2) + b(\eta)^2(dy^2 + dz^2)$$

It has been proven that at the leading order, $a \simeq b$.
Perturbations level :
Metric Perturbation: Most generic perturbations for the Bianchi 1 universe is given by,

$$\delta g_{\alpha\beta} = \begin{pmatrix} -2a^2 A & a^2 \partial_x \beta & a\, b\, (\partial_i B + B_i) \\ & -2a^2 \bar{\psi} & ab\, \partial_x\, (\partial_i \gamma + \Gamma_i) \\ & & b^2\, (-2\psi\delta_{ij} + 2E_{,ij} + E_{i,j} + E_{j,i}) \end{pmatrix}$$

It has been proven that the leading corrections does come from the matter content and it is thus safe to use the following line element,

$$ds^2 = a(\eta)^2 \left(-d\eta^2 + [\delta_{ij} + h_{ij}]\, dx^i dx^j\right) .$$

Where h_{ij} denotes the tensor perturbation.

Generating anisotropic seeds during inflation

Matter perturbations :

As we discussed, the action is given by,

$$S = \int d^4x\sqrt{-g}\left[\frac{M_P^2}{2}R - \frac{1}{2}D_\mu\varphi\,\overline{D^\mu\varphi} - \frac{f^2(\varphi)}{4}F_{\mu\nu}F^{\mu\nu} - V(\varphi,\overline{\varphi})\right]$$

also,

- Potential : $V = \frac{1}{2}m^2|\varphi|^2 = \frac{1}{2}m^2\phi^2$
- Gauge kinetic coupling : $f = \left(\frac{\eta}{\eta_e}\right)^{2c}$

♦ Curvature perturbations :

$$\zeta = -\frac{H}{\dot{\phi}}\delta\phi = \frac{\delta\phi}{M_P\sqrt{2\epsilon_H}}$$

ζ is nearly massless scalar field,

$$\zeta_k(\eta) = \frac{iH\eta}{M_P\sqrt{2\epsilon_H k}}\left(1 - \frac{i}{k\eta}\right)e^{-ik\eta}$$

♦ Choose unitary gauge:

$$\theta(x) = 0$$

Generating anisotropic seeds during inflation

♦ Gauge field fluctuations:
In the unitary gauge, there are two transverse and one longitudinal mode,

$$\delta A_\mu^{(S)} = (\delta A_0, \delta A_1, \partial_y M, 0) \qquad , \qquad \delta A_\mu^{(V)} = (0, 0, 0, D) \, .$$

$A_\mu^{(V)}$: Transverse polarizations.
$A_\mu^{(S)}$: Two polarizations in the scalar sector.
$A_\mu^{(S)}$ can be decomposed into one transverse and one longitudinal polarizations,

$$\begin{aligned} D_1 &\equiv \delta A_1 - ik\cos\theta M \\ D_2 &\equiv \cos\theta \delta A_1 + ik\sin^2\theta M \, . \end{aligned}$$

Where we have, $\vec{k} = (k_x, k_y, 0) = k\,(\cos\theta, \sin\theta, 0)$.
D_1: Transverse polarization AND D_2: Longitudinal polarization
It has been demonstrated that in (arXiv:1301.1219) that longitudinal mode are exponentially suppressed during inflation and thus are negligible.
Both of D_{1k} and D_k are nearly massless,

$$\sin\theta D_{1k}(\eta) = D_k(\eta) = \frac{i}{f\sqrt{2k}} \left(1 - \frac{i}{k\eta}\right) e^{-ik\eta} \, .$$

Generating anisotropic seeds during inflation

Leading Interaction Hamiltonian for the curvature perturbation is given by,

$$H_{\zeta D_1} \quad = \quad 4M_P\sqrt{3I\epsilon_H}\sin^2\theta\left(\frac{af}{\eta}\right)\zeta D_1' + 4e^2M_P^3\sqrt{\frac{I\epsilon_H}{3}}\sin^2\theta\left(\frac{a^3}{f}\right)\zeta D_1$$

So the corrected curvature power spectrum would be,

$$P_\zeta = P_\zeta^{(0)}\left(1 + 24IN^2F(\beta)\sin^2\theta\right) \quad , \quad P_\zeta^{(0)} = \frac{H^2}{8\pi^2\epsilon_H M_P^2}$$

where we have defined

$$\beta \equiv \frac{e^2}{42N}\left(\frac{M_P}{H}\right)^2 \quad , \quad F(\beta) \equiv 1 - \beta + \frac{9}{22}\beta^2$$

Comparison with the simulations $P(k) = P_0(k)\left(1 + g_*(n.k)^2\right)$

$$g_* = -24IN^2F(\beta)$$

- The correction is proportional to I.
- Demanding that $|g_*| < 0.01$ gives, $IF(\beta) < 10^{-6}$

Anisotorpic Corrections in the Tensor perturbations:

- **Tensor perturbations:** Decomposing h_{ij} into $h_\times$ and h_+, we would have,

$$h_{ij}(\mathbf{k}) = \frac{1}{\sqrt{2}} \begin{pmatrix} h_+ \sin^2\theta & -h_+ \sin\theta\cos\theta & -ih_\times \sin\theta \\ -h_+ \sin\theta\cos\theta & h_+ \cos^2\theta & ih_\times \cos\theta \\ -ih_\times \sin\theta & ih_\times \cos\theta & -h_+ \end{pmatrix} .$$

Where the tensor modes are nearly massless,

$$h_s(k,\eta) = \frac{2iH\eta}{M_P\sqrt{2k}} \left(1 - \frac{i}{k\eta}\right) e^{-ik\eta} \quad , \quad (s = +, \times)$$

Leading Interaction Hamiltonian for the tensor perturbation is given by,

$$\begin{aligned} L_{\zeta h_+} &= -\frac{3\sqrt{2}}{2\eta^2} I\epsilon_H M_P^2 \sin^2\theta a^2 \zeta h_+ + \frac{e^2\sqrt{2}}{6} I\epsilon_H M_P^4 \sin^2\theta \left(\frac{a^4}{f^2}\right) \zeta h_+ \\ L_{h_+ D_1} &= \frac{M_P}{2}\sqrt{\frac{3I\epsilon_H}{2}} \sin^2\theta \left(\frac{fa}{\eta}\right) D_1' h_+ + \sqrt{\frac{I}{6\epsilon_H}} e^2 M_P^3 \sin^2\theta \left(\frac{a^3}{f}\right) D_1 h_+ \\ L_{h_\times D} &= \frac{M_P}{2}\sqrt{\frac{3I\epsilon_H}{2}} \sin\theta \left(\frac{fa}{\eta}\right) D' h_\times + \sqrt{\frac{I}{6\epsilon_H}} e^2 M_P^3 \sin\theta \left(\frac{a^3}{f}\right) D h_\times \end{aligned}$$

Anisotorpic Corrections in the Tensor perturbations:

★ Corrected Tensor power spectrum is given by:

$$P_h = P_h^{(0)} \left(1 + 6I\epsilon_H N^2 F(\hat{\beta}) \sin^2\theta\right) \quad , \quad P_h^{(0)} = \frac{2H^2}{\pi^2 M_P^2} = 16\epsilon_H P_\zeta^{(0)}$$

Where $\hat{\beta} \equiv \frac{2\beta}{\epsilon_H}$. $\Rightarrow$ $\hat{\beta}$ is enhanced compared to β by the factor $1/\epsilon_H$. Indeed, $\hat{\beta}$ can be as large as 100 for $\epsilon_H \sim 0.01$. This means that the anisotropy in Tensor power spectrum becomes very strong for large e so there will be upper bound on e and $\hat{\beta}$.

★ $\langle \zeta h \rangle$ Cross-correlation is given by:

$$\begin{aligned} P_{\zeta h} &= \frac{k^3}{2\pi^2}\left\langle \zeta_{\mathbf{k}}(\eta_e) h_{+\mathbf{k}^*}(\eta_e) \right\rangle \\ &= -24\sqrt{2} I N^2 \epsilon_H P_\zeta^{(0)} G(\beta) \sin^2\theta \end{aligned}$$

where we hae defined $G(\beta)$ as,

$$G(\beta) \equiv 1 - \frac{\beta}{\epsilon_H} + \frac{9}{11}\frac{\beta^2}{\epsilon_H}$$

As a result, the enhancement in the cross-correlation of the ζh is less than the enhancement in the tensor power spectrum.

From the primordial fluctuations to the CMB

♦ The correlators of CMB observables is given by:

$$\langle a^{X_1}_{l_1,m_1} a^{X_2}_{l_2,m_2}\rangle = 4\pi \int \frac{dk}{k}\Delta^{i_1 X_1}_{l_1}(k)\Delta^{i_2 X_2}_{l_2}(k)\int d\Omega\ [{}_{i_1}Y^*_{l_1 m_1}(\theta,\phi)][{}_{i_2}Y_{l_2 m_2}(\theta,\phi)] \times P^{i_1,i_2}(k,\theta,\phi)$$

Where ${}_iY^*_{lm}(\theta,\phi)$ is the spin-i-weighted spherical harmonics.
X^i can be the temperature anisotropy, T, the E-mode, E, and B-mode, B.
★ Important points:

- There is no ϕ-dependence for the power spectrum. So the momentum along the ϕ-rotation is conserved and thus $\langle a^{X_1}_{l_1,m_1} a^{X_2}_{l_1,m_1}\rangle$ is non-vanishing only when $m_1 = m_2$.
- The rotational symmetry on the θ direction is broken. As a result, the correlation $\langle a^{X_1}_{l_1,m_1} a^{X_2}_{l_1,m_1}\rangle$ is not restricted to $l_1 = l_2$ and we also have $l_1 = l_2 \pm 1$ for TB and EB, and $l_1 = l_2 \pm 2$ for TT, TE, EE and BB respectively.

From the primordial fluctuations to the CMB

♦ In this basis $P^{i_1,i_2}(\sin^2\theta)$ takes the form

$$P^{0,0} = P^{\zeta\zeta}\ , \quad P^{0,\pm2} = P^{\pm2,0} = \frac{1}{\sqrt{2}}P^{0,+}$$
$$P^{\pm2,\pm2} = \frac{1}{2}\left(P^{++} + P^{\times\times}\right)\ , \quad P^{\pm2,\mp2} = \frac{1}{2}\left(P^{++} - P^{\times\times}\right)$$

♦ The transfer function part encodes very complicated late time physics. Since this part does not have angular dependence, one can use the standard Boltzmann code for the calculation.

♦ We have also neglected the vector part, i.e. $i = 1$, since they have a decaying transfer function and thus are not important.

♦ We would also do not take any average over the m, since the tensor-scalar cross-correlation would be averaged out. Instead, for the numerical analysis, we just restrict ourselves to $m = l$.

From the primordial fluctuations to the CMB

★ Three sets of parameters are examined numerically:

- Case I: Real Inflaton field: In this class of models, we put $I = 10^{-7}$ and $e = 0$. Case I is shown in blue color.
- Case II: Balanced: In this class of models, we put $I = 10^{-7}$ and $e = 10^{-3}$. so g_* is not improved a lot while the gravitational sector is largely modified. On the plots, Case II is shown in black color.
- Case III: Charge coupling dominated: In this class of models, we put $I = 10^{-11}$ and $e = 0.025$. So g_* is smaller than Cases I and II while the charge contribution is large in the tensor sector. On the plots, Case III is shown in red color.

From the primordial fluctuations to the CMB

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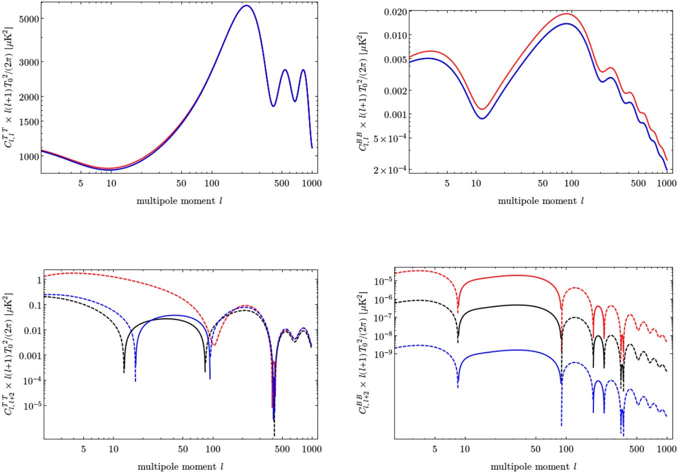
★ The TT (left) and BB (right) modes with $l_1 = l_2$ and $l_1 = l_2 + 2$:



From the primordial fluctuations to the CMB

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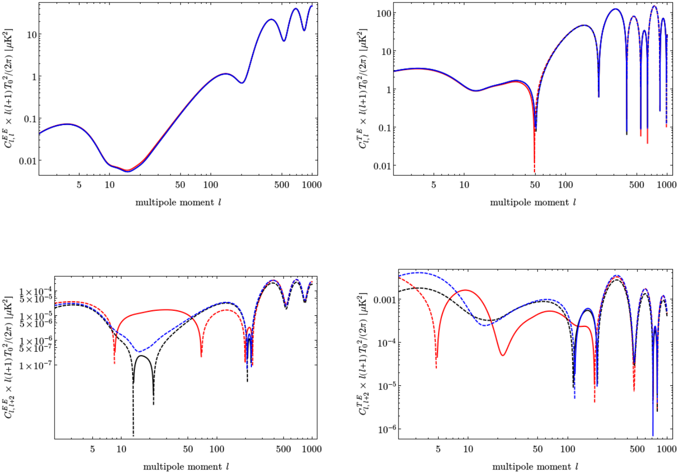
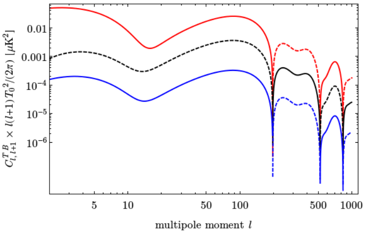
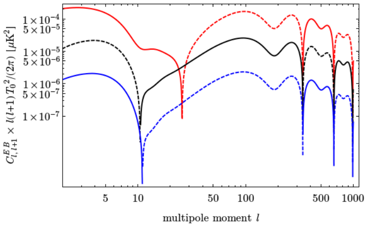
★ The EE (left) and TE (right) modes with $l_1 = l_2$ and $l_1 = l_2 + 2$:



From the primordial fluctuations to the CMB

★ TB (left) and EB (right) correlations with $l_1 = l_2 \pm 1$:





◇ we emphasis here that TB and EB cross-correlation is absent in the usual isotropic inflationary modes.

Clustering Fossil from GW in Anisotorpic Inflation

★ While the CMB experiments are near to their completion, it is required to search for another experimental lab for the cosmology. It turns out that the galaxy Surveys can be a good new candidate for extracting information about the early Universe.

★ The main purpose of the galaxy Surveys are the two-point function. According to the Null hypothesis, this correlation function is diagonal in the Fourier Space.

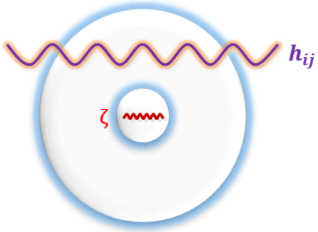
★ However, in the presence of a new field, Fossil field, different Fourier modes do couple to each other. So any non-zero elements of this correlation function would give us information about new elements during the early universe.

★ However, since the galaxy surveys are sensitive to the two point correlation function, the Fossil Field, must have larger wavelength as compared to the typical scales fo the galaxies.

★ Here we consider the case of the Tensor Fossil. It turns out that in this case, there would be a Quadrupole Asymmetry in the density two point correlation function.

Clustering Fossil from GW in Anisotorpic Inflation

★ Here is the general picture of the setup. we Have a large Wavelength Tensor mode on the top of the small scale structures. This long wavelength mode can be either inside or outside the horizon at any times.



★ There would be a mixing between this mode and the small scale modes. This mixing has three different parts. One coming from the Inflationary Phase, in a model dependent way, Second does come from the Non-linear mode coupling during the radiation and matter dominance. Third, comes from the Projection effects. Here we focus on the First effect and investigate how different Inflationary Models lead to distinguishable effects.

Clustering Fossil from GW in Anisotorpic Inflation

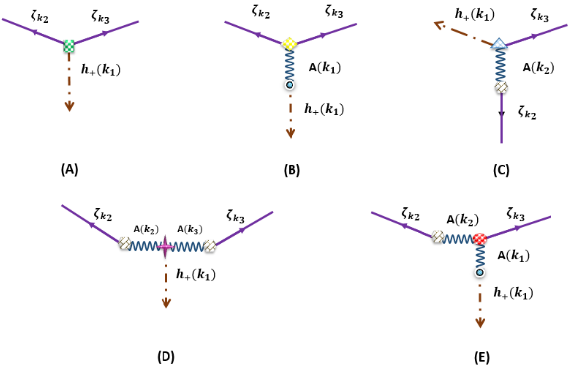
★ It has been proven that in the single field inflation there is a cancellation between the above effects and the remaining Quadrupole Asymmetry is very small. This cancellation does not exit in the Multiple Field Inflation though.
★ However the shape of this Quadrupole asymmetry is the same for any Scalar Driven Inflation.

$$P_\zeta(\mathbf{k_s})\Big|_{h_{(\lambda)}(\mathbf{k_L})} = P_\zeta(k_s) k_s^i k_s^j h_{ij}^{(\lambda)}(\mathbf{k_L}) \, ,$$

Question: What will happen for the models with one or more non-zero spins?
Answer: As we see models containing non-zero spins would lead to different deviation from the statistical Anisotropies.
In the following, we consider how this may happen.

Clustering Fossil from GW in Anisotorpic Inflation

★ For this purpose, we should calculate the Tensor-Scalar-Scalar three point function in the squeezed limit.



★ Among the above five diagrams, the main contribution does come from the diagram (E).

Clustering Fossil from GW in Anisotorpic Inflation

★ Finally the corrected Power-Spectrum is given by,

$$P_\zeta(\mathbf{K_S})\Big|_{h_{(\lambda)}(\mathbf{K_L})} = P_\zeta(k_S)\Delta^{ij} h^{(\lambda)}_{ij}(\mathbf{K_L}),$$

where Δ_{ij} is given by,

$$\Delta^{ij} = -\left(\frac{144 R N_e^3}{\epsilon_H}\right)\left(\hat{\mathbf{x}}^i\hat{\mathbf{x}}^j - (\hat{\mathbf{K}}_\mathbf{S}\cdot\hat{\mathbf{x}})(\hat{\mathbf{x}}^i\hat{\mathbf{K}}^j_\mathbf{S})\right)$$
$$= 3 g_* N_e\left(\hat{\mathbf{x}}^i\hat{\mathbf{x}}^j - (\hat{\mathbf{K}}_\mathbf{S}\cdot\hat{\mathbf{x}})(\hat{\mathbf{x}}^i\hat{\mathbf{K}}^j_\mathbf{S})\right)$$

★ As we see the shape of this Quadrupole Asymmetry is different than what we got from the scalar only Inflationary models and thus can be thought as a unique signatures for distinguishing this model from the rest of the other models in the market.
★ At the end, we can use this setup to determine the required size of the galaxy survey for detecting this tensor mode.

$$k_{max}/k_{min} = 12800(g_* N_e)^{(-2/3)}.$$

For $g_* N_e \sim 8 \Rightarrow k_{max}/k_{min} \sim 3876$ which can be detected by the Euclid and/or the 21cm surveys.

Conclusion

- Inspired by the CMB observations of the anomaly in the sky, we considered a primordial realization of the Anisotropic Universe where inflaton field is charged under the U(1) gauge field.
- We then, studied how this may affect the curvature power-spectrum as well as the gravitational waves.
- Finally, we tried to connect this primordial anisotropies to what we observe in the CMB.
- We checked explicitly that this leads to the non-diagonal correlations for the a_{lm} as well as non-zero values for the TB and EB.
- Finally we considered the Clustering Fossil as a completion of the CMB experiments to extract information about the GW as well as the Primordial Anisotropies.