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Inhomogeneities in anisotropic universe

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- MOTIVATION
- VECTOR FIELD – BASIC PICTURE
- EVOLUTION OF AN ANISOTROPIC UNIVERSE
- PERTURBATIONS IN THE CURVATON SCENARIO

- NO SCALAR FIELDS IN MODERN EXPERIMENTS
- AXIS OF EVIL
- POSSIBLE SOURCE OF INFLATION
- SOURCE OF PRIMORDIAL GRAVITATIONAL WAVES AND VECTOR PERTURBATIONS

LET US CONSIDER $g_{\mu\nu} = Diag(1, -a^2, -a^2, -b^2)$, THEN

$$G^0{}_0 = H^2 + 2H\mathcal{H} \qquad G^3{}_3 = 2\dot{H} + 3H^2$$

$$G^1{}_1 = G^2{}_2 = \dot{\mathcal{H}} + \dot{H} + H^2 + \mathcal{H}^2 + \mathcal{H}H$$

$$\mathcal{H} = \frac{\dot{b}}{b}$$

$$H = \frac{\dot{a}}{a}$$

WE WILL ANALYSE THE EVOLUTION OF $\mathcal{H} - H = \lambda$

LET US INTRODUCE THE VECTOR FIELD IN THE ANIOSOTROPIC UNIVERSE

$$V_\mu = (0,0,0,V) \qquad \delta V_\mu = (\delta V_t, \delta\vec{V}) \qquad \rho_V = \frac{1}{2b^2}\left(\dot{V}^2 + m^2 V^2\right) \qquad \vec{V} = b\vec{U}$$

EQUATION OF MOTION

$$\ddot{\vec{V}} + (2H - \mathcal{H})\dot{\vec{V}} + m^2\vec{V} = 0$$

$$\ddot{\vec{U}} + (2H + \mathcal{H})\dot{\vec{U}} + (m^2 + 2H\mathcal{H} + \dot{\mathcal{H}})\vec{U} = 0$$

STRANGE MASS TERM FOR INFLATION!

$$m^2 \approx -2H\mathcal{H} \approx -2H^2$$

FOR THE VECTOR FIELD + PERFECT FLUID ONE OBTAINS

$$T^1_{\ 1} = T^2_{\ 2} = -p_V - p_f \qquad T^3_{\ 3} = +p_V - p_f$$

THEN $\dot{\lambda} + 3\mathcal{H}\lambda + 2\lambda^2 = 2p_V$, WHICH GIVES

- SMALL ANISOTROPY LIMIT $\quad \lambda \ll \mathcal{H} \Rightarrow \lambda = \frac{2}{b^3}\int b^3 p_V \, dt$
- LACK OF THE VECTOR FIELD $\quad p_V = 0 \Rightarrow \lambda \propto \frac{1}{b^3}$

FOR THE QUASI DE SITTER UNIVERSE WE OBTAIN

$$\mathcal{H}, p_V = const \Rightarrow \lambda = \frac{2p_V}{3\mathcal{H}}$$

MORE REALISTIC MODELS GIVES THE SAME RESULT!

NUMBER OF E-FOLDS

$$N_z = \int \mathcal{H} dt \qquad N_x = \int H dt$$

THIS CAN GIVE SOME INFORMATION ABOUT ALLOWED ENERGY DENSITY OF THE VECTOR FIELD

$$\Delta N = \int \lambda \, dt = \frac{2p_V}{3\mathcal{H}} t \Rightarrow \frac{\Delta N}{N_z} = \frac{2p_V}{3\mathcal{H}^2} \propto \frac{p_V}{\rho} \propto U^2$$

DECREASING, WHILE $\vec{U}$ IS GLUTTED TO THE WALL OF ITS POTENTIAL $mt \ll 1$

$$p_V \approx H\dot{U}U + \frac{1}{2}\mathrm{H}^2\mathrm{U}^2 \qquad 3\mathrm{H}\dot{\mathrm{U}} \approx -\mathrm{m}^2\mathrm{U}$$

$$\lambda \approx HU_o^2(1 - 2.5\, m^2 t^2)$$

DECREASING FOR THE OSCILLATION PHASE $mt \gg 1$

$$p_V \propto \cos{(2mt)} \Rightarrow < p_V >= 0$$

WHEN $\vec{U}$ OSCILLATES IT EVOLVES LIKE A SCALAR FIELD

$$mU = \sqrt{6}Hcos(mt) \qquad \dot{U} = -\sqrt{6}Hsin(mt)$$

THEN

$$H \approx \frac{2}{3t}\left(1 + \frac{\sin(2mt)}{6mt}\right) \approx \frac{2}{3t}$$

SO $\omega \approx 0 \quad \Rightarrow$ NO PRESSURE! λ DECREASE LIKE a^{-3}

EXISTENCE OF THE VECTOR FIELD BREAKS ISOTROPY AT THE PERTURBATIONS LEVEL

$$\delta g_{\alpha\beta} = \begin{pmatrix} 2\Phi & -aB_{,i} & -b\chi_{,z} \\ & 2a^2(\Psi\delta^i{}_j + E_{,ij}) & -abC_{,zi} \\ & & 2b^2\Sigma \end{pmatrix}$$

GAUGE FIXING: $\Rightarrow E = C = \Psi = 0$

VANISHING OF NON DIAGONAL COMPONENTS

$$\delta T^i{}_j = 0 \Rightarrow \Sigma = \Phi + a\dot{B} + a(H + \mathcal{H})B \quad i \neq j$$

THE LIQUID INDEPENDENT EQUATION OF MOTION

$$2\ddot{\Sigma} + 2(\mathrm{H} + 2\mathcal{H})\dot{\Sigma} + 2(\mathcal{H} - H)\dot{\Phi} + (\mathcal{H}H + \mathcal{H}^2 - 2\mathrm{H}^2 + \dot{\mathcal{H}} - \dot{\mathrm{H}})\Phi = 4\delta p_V \cong 0$$

FOR $\mathcal{H} \cong H$ WE OBTAIN

$$\ddot{\Sigma} + 3\mathrm{H}\dot{\Sigma} = 0 \Rightarrow \Sigma = \Sigma_* = \mathrm{const}$$

FROM THE EINSTEINS EQUATION WE HAVE

$$\mathrm{H}\left(\dot{\Phi} + 3\mathrm{H}c_s^2\Phi\right) = \tau\delta S \qquad 3\mathrm{H}^2\Phi = -\frac{1}{2}\delta\rho$$

FOR THE VECTOR + RADIATION SCENARIO ONE OBTAINS

$$c_s^2 = \frac{\beta}{a} \Rightarrow \Phi = \Phi_* e^{3\beta/a} \rightarrow \Phi_*$$

THEN

$$\Phi_* = \Psi_* \Rightarrow \mathrm{B} \propto \mathrm{t}^{-4/3}$$

WE RECONSTRUCT THE STANDARD FRW PERTURBATION POWER SPECTRUM!

ONLY Φ IS CHANGED BY THE ENTROPY!

$$\Phi_* \to \Phi_f \quad \Rightarrow \quad \Phi_f \neq \Sigma_f$$

THE ENTROPY PERTURBATION BREAKS THE INITIAL SYMMETRY!

IT DOES NOT NEED TO BE DANGEROUS. WE SIMPLY NEED SMALL INITIAL ENTROPY PERTURBATION

IT MEANS, THAT INITIALLY WE NEED

$$\frac{\delta U_*}{U_*} \ll \Phi_*$$

- THE SUBDOMINANT VECTOR FIELD SHALL NOT PRODUCE HUGE BACKGROUND ANISOTROPIES

- GOOD CURVATON CANDIDATE

- FUTURE PROBLEMS WITH THE VECTOR PERTURBATIONS POSSIBLE