Stirring Up The Primordial Soup

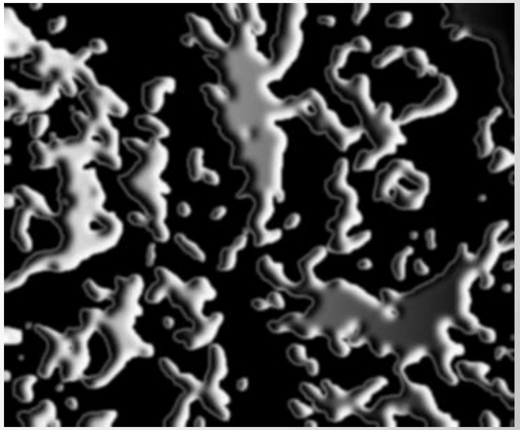
Based on:
JN & Joao Magueijo, Non-adiabatic primordial fluctuations, arXiv: 0911.1907

Johannes Noller, IberiCos 2010, 29/03/2010

Structure Formation

Homogeneous background

+ small irregularities



Growth of structure via gravitational instability

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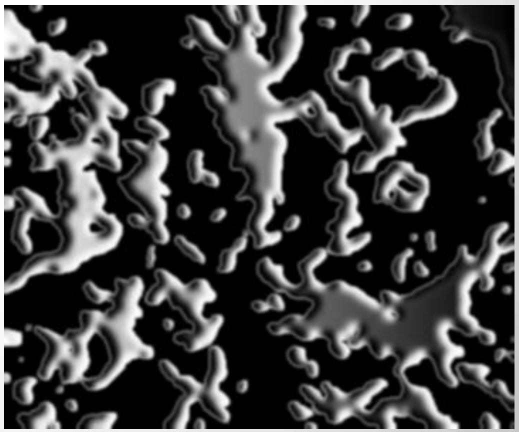
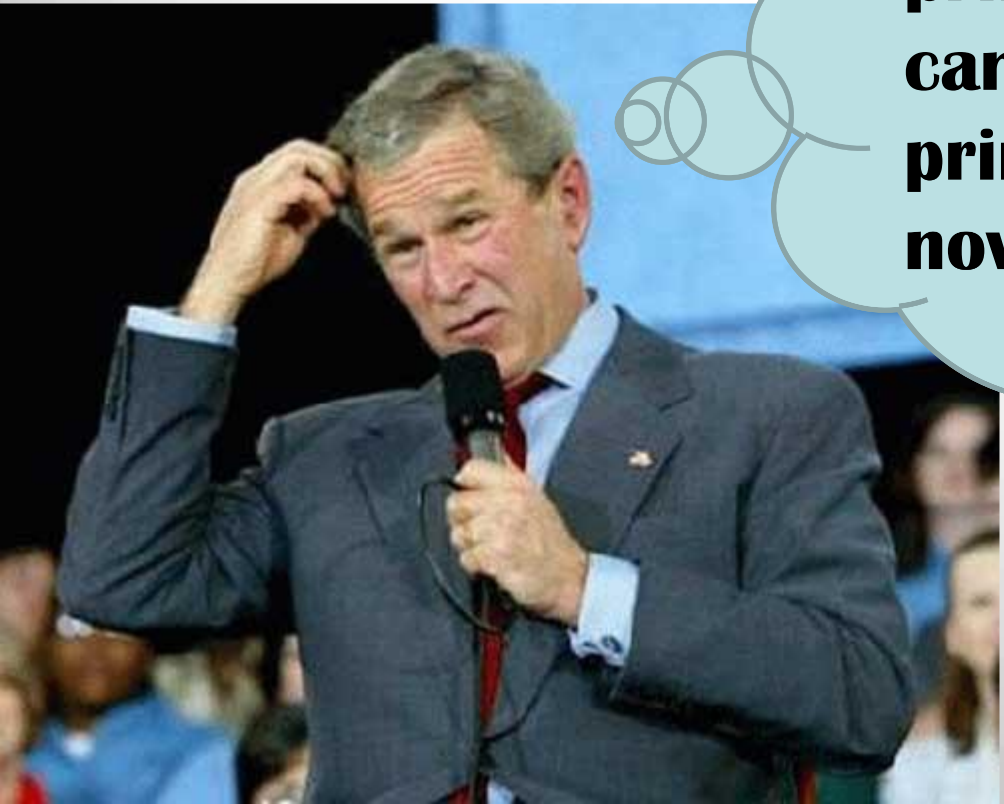


Growth of structure via gravitational instability

Device a formalism describing primordial fluctuations independently of the precise nature of primordial matter

Philosophy

Dunno much about primordial matter. What can I say about primordial perturbations now then…..???



Entropic perturbations

$$\delta p = \left.\frac{\partial p}{\partial \varepsilon}\right|_S \delta\varepsilon + \left.\frac{\partial p}{\partial S}\right|_\varepsilon \delta S$$

$$= c_s{}^2 \delta\varepsilon + \delta p_{na}$$

Adiabatic

Entropic

Entropic perturbations

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Adiabatic — Entropic

For arbitrary mixtures of modes introduce an "effective" sound speed

$$c_{es}^2 \equiv \frac{\delta p}{\delta \varepsilon}$$

A single scalar field

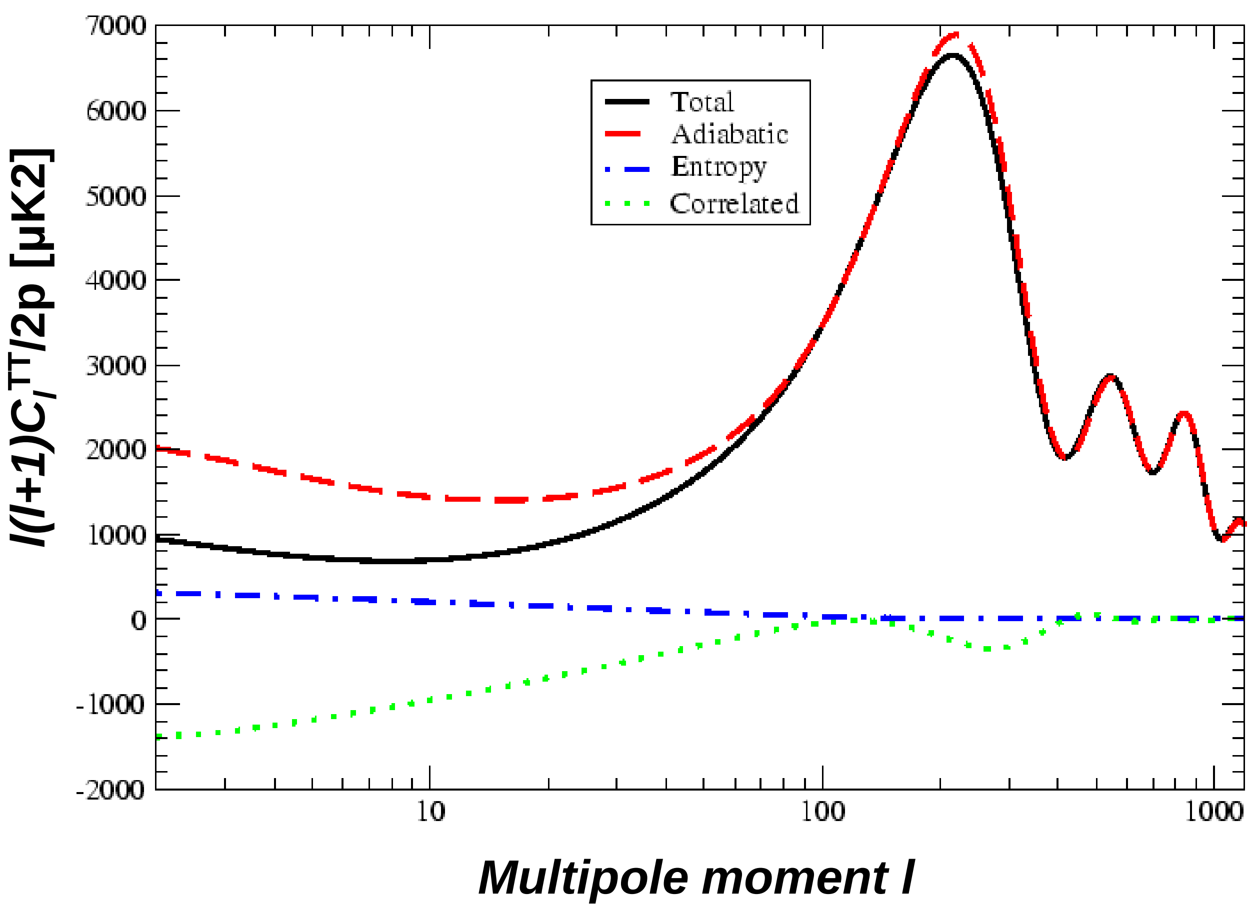
$$\mathcal{L} = P(X, \phi)$$

$$\begin{aligned} \delta p_{na} &= \left[P_{,\phi}\left(1 + {c_s}^2\right) - 2{c_s}^2 X P_{,X\phi}\right]\delta\phi \\ &+ \left[P_{,X}\left(1 - {c_s}^2\right) - 2{c_s}^2 X P_{,XX}\right]\delta X \\ &= 0 \end{aligned}$$

in the super-horizon limit

Christopherson & Malik, arXiv:0809.3518

Power Spectra



Ingredients

$$\delta G_{\mu\nu} = \frac{8\pi G}{c^4}\delta T_{\mu\nu}$$

$$T^{\alpha}{}_{\beta} = (\varepsilon + p)u^{\alpha}u_{\beta} - p\delta^{\alpha}{}_{\beta}$$

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$$= T_1{}^{\alpha}{}_{\beta} + T_2{}^{\alpha}{}_{\beta} + \ldots$$

So we consider primordial perturbations with arbitrary mixtures of adiabatic and entropy modes and allow for varying equation of state w and speed of sound c_s

The "v"-equation

$$v'' + (c_{es}^2 k^2 - \frac{z''}{z})v = 0$$

$$z^2 \propto \frac{(\mathcal{H}^2 - \mathcal{H}')a^2}{\mathcal{H}^2} \frac{1}{f c_{es}^2 \mu^2}$$

$$v \equiv z\theta = z(\mu f \zeta_{ad} - \nu \xi_{ad})$$

Non-adiabatic factors

$$\frac{f'}{f} \equiv \frac{p'}{\varepsilon+p} + 3c_{es}^2\mathcal{H}$$

Null-measure of adiabaticity, can introduce exponential tilts into perturbation power spectrum.

$$\mu' = \frac{(\mathcal{H}^2-\mathcal{H}')a^2}{\mathcal{H}^2 f}\nu$$

Relative weight of ζ_{ad} to ν.

$$\nu' = \frac{\mathcal{H}f'}{a^2}\mu$$

Relative weight of ξ_{ad} to ν. So ratio of μ and ν gives a measure of the departure from adiabaticity in terms of ν .

Features & Phenomenology

Power spectrum of curvature perturbation

$$P_\theta(k) \propto \frac{z''}{z^3 {c_{es}}^3}$$

Horizon crossing modes

$$c_{es}^2 k^2 = \frac{z''}{z}$$

Growing & decaying modes

$$z \;\; vs. \;\; z \int \frac{d\eta}{z^2}$$

A Conserved super-horizon charge

$$\theta$$

A conserved super-horizon charge

$$\theta \equiv \mu f \zeta_{ad} - \nu \xi_{ad}$$

$$\Downarrow$$

$$\zeta_{ad}^{'} = \frac{(\nu \xi_{ad})^{'}}{f \mu} - \left(\frac{\mu^{'}}{\mu} + \frac{f^{'}}{f} \right) \zeta_{ad}$$

Awesome!! Now gimme a specific model…

A Chaplygin gas-like example

Effectively have a two parameter model

$$w \propto \varepsilon^{2\beta} \qquad c_{es}^2 \propto \varepsilon^{2\alpha}$$

Where adiabaticity corresponds to $\alpha = \beta$

and non-adiabaticity correspondingly to $\alpha \neq \beta$

Constraints & Classification

$$w \propto \varepsilon^{2\beta} \qquad\qquad c_{es}^2 \propto \varepsilon^{2\alpha}$$

	Structure	Horizon Problem
Adiabatic	$P_\theta \propto t^{\frac{2\beta-2}{1+4\beta}}$	$(k^2)' \propto (\mathcal{H}^2)' < 0$
Non-adiabatic	$P_\theta \propto t^{\frac{2\alpha}{1+4\beta}}$	$(k^2)' \propto (t^{-2})' < 0$

Solutions

We obtain two scale-invariant solutions

Adiabatic : $w \propto \varepsilon^2$

Non-adiabatic : $\beta > 0$ $\quad {c_s}^2 \propto 1$

Both have to be implemented in a contracting phase in order resolve the horizon problem.

Summary

- ***Formalism*** **for non-adiabatic perfect fluid perturbations**
- **A generalised** ***conserved super-horizon quantity***
- **A specific model implementation, which gives rise to** ***two new contracting, scale-invariant solutions***