The curvaton model for the origin of the primordial perturbation

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1. The model
2. The spectral index ($n = 1.00$?)
3. Non-gaussianity ($f_{\rm NL} \gg 1$?)
4. Primordial isocurvature perturbations

Curvaton model papers

Mollerach (1990) [isocurvature $\rightarrow$ curvature]

Linde & Mukhanov (1997) [non-gaussianity]

Lyth & Wands (2001) [the hard sell]

Moroi & Takahashi (2001) [curvaton = modulus?]

Bartolo & Liddle (2001) [quadratic potentials]

Moroi & Takahashi (2002) [CDM and B isocurvature]

Lyth, Wands & Ungarelli (2002) and in preparation [CDM, B & L isocurvature]

In preparation

Dimopoulos & Lyth [liberated inflation models]

Dimopoulos, Lazarides, Lyth & Ruiz de Austri [curvaton evolution and particle physics, 2 papers]

Malik, Wands & Ungarelli [gradual decay]

The curvaton model

Basic idea

The inflaton field gives a negligible primordial density perturbation, say $< 1\%$ of observed value, requiring

$$V^{\frac{1}{4}} < 2 \times 10^{15}\,\mathrm{GeV}$$

hence negligible gravitational waves. Some other field the curvaton does the job.

What happens

1. Cosmological scales leave horizon during almost exponential 4-D inflation.

2. Curvaton field σ has $|V_{\sigma\sigma}| \ll H^2$ during inflation.

3. After inflation, curvaton oscillates, $\rho_\sigma \propto a^{-3}$.

4. Curvaton decays after reheating when

$$r \equiv (\rho_\sigma/\rho)_{\mathrm{decay}} > 10^{-5}$$

5. After curvaton decay everything thermalizes (except maybe CDM).

The curvature perturbation ζ

At curvaton decay,

$$\zeta = r\frac{\delta\rho_\sigma}{\rho_\sigma} \simeq 2r\frac{\delta\sigma}{\sigma}$$

$$\equiv 2qr\left(\frac{\delta\sigma}{\sigma}\right)_*$$

Spectrum

$$\mathcal{P}_\zeta^{\frac{1}{2}} = \frac{qr}{\pi}\left(\frac{H}{\sigma}\right)_*$$

Spectral index

$$n = 1 + 2\eta_{\sigma\sigma} - 2\epsilon$$

Non-gaussianity from $\rho_\sigma \propto \sigma^2$,

$$f_{\rm NL} = \frac{5}{4}\frac{1}{r}$$

Present bound:	$r > 0.0006$
MAP: detection or	$r > 0.06$
PLANCK: detection or	$r > 0.2$

Isocurvature perturbations

Definition of the primordial perturbations

Note: The ‘primordial’ epoch is $T \sim$ keV, when the smallest cosmological scale approaches the horizon.

$$S_{\rm CDM} \equiv \frac{\delta\rho_{\rm CDM}}{\rho_{\rm CDM}} - \frac{3}{4}\frac{\delta\rho_\gamma}{\rho_\gamma}$$

$$S_B \equiv \frac{\delta\rho_B}{\rho_B} - \frac{3}{4}\frac{\delta\rho_\gamma}{\rho_\gamma}$$

$$S_L \equiv \frac{\delta n_L}{n_L} - \frac{3}{4}\frac{\delta\rho_\gamma}{\rho_\gamma}$$

$$S_\nu \equiv \frac{3}{4}\frac{\delta\rho_\nu}{\rho_\nu} - \frac{3}{4}\frac{\delta\rho_\gamma}{\rho_\gamma}$$

$$S_\nu = 10.5\left(\frac{n_L}{n_\gamma}\right)^2 S_L$$

Residual isocurvature perturbations

'Residual' means they are a side-effect of the curvaton density perturbation.

At creation, density of CDM/B/L depends only on local values of ρ_σ and ρ_r.

Residual perturbations are fully correlated:

$$S_i(\mathbf{x}) = X_i \zeta(\mathbf{x})$$

with $i =$CDM, B or L.

One, two or all three of X_i may be nonzero (see next overhead)

Observation must bound

$$\left\{ X_{\rm CDM},\ X_B,\ (n_L/n_\gamma)^2 X_L \right\}$$

One- two- or three-parameter space (seven cases)

Note: For massive neutrinos, evolution equations not yet worked out.

The predicted residual isocurvature perturbations

1. Creation of CDM/B/L is after curvaton decay

$$X_i = 0$$

2. CDM/B/L is created by the curvaton decay

$$X_i = 3\frac{1-r}{r}$$

Observational constraints
(Amendola, Gordon, Wands & Sasaki; Amendola)
CDM (alone): $r > 0.9$
B (alone): $r > 0.6$

Note: For L we can have $r \ll 1$ giving correlation with the non-gaussianity parameter $f_{\rm NL} = 5/4r$.

3. CDM/B/L created before curvaton decay and with $\rho_\sigma \ll \rho$

$$X_i = -3$$

Observational constraints (Amendola et. al.)
CDM: Forbidden. Rules out eg. Wimpzillas
B: Marginally allowed

4. CDM/B/L created before curvaton decay with $\rho_\sigma \simeq \rho$

Need dependence of CDM/B/L density (at creation) on ρ_σ and ρ

Examples

Production by particle decay Occurs when local age of Universe equals lifetime.

Production by field oscillation Axion CDM or Affleck-Dine baryogenesis. Occurs when local expansion rate equals frequency.

CDM from freezout Neutralino CDM.

Results to be reported soon.

Summary

Theory of early Universe

Rich new possibilities. No time in this talk.
Work with Lazarides, Dimopoulos & Ruiz de Austri..

The primordial perturbation

Significant gravitational waves impossible.

Significant departure from $n = 1$ ‘unlikely’

Non-gaussianity and fully correlated isocurvature perturbations generic. Their detection would be a smoking gun for the model. Non-detection would constrain early-Universe physics.