Multiple field inflation

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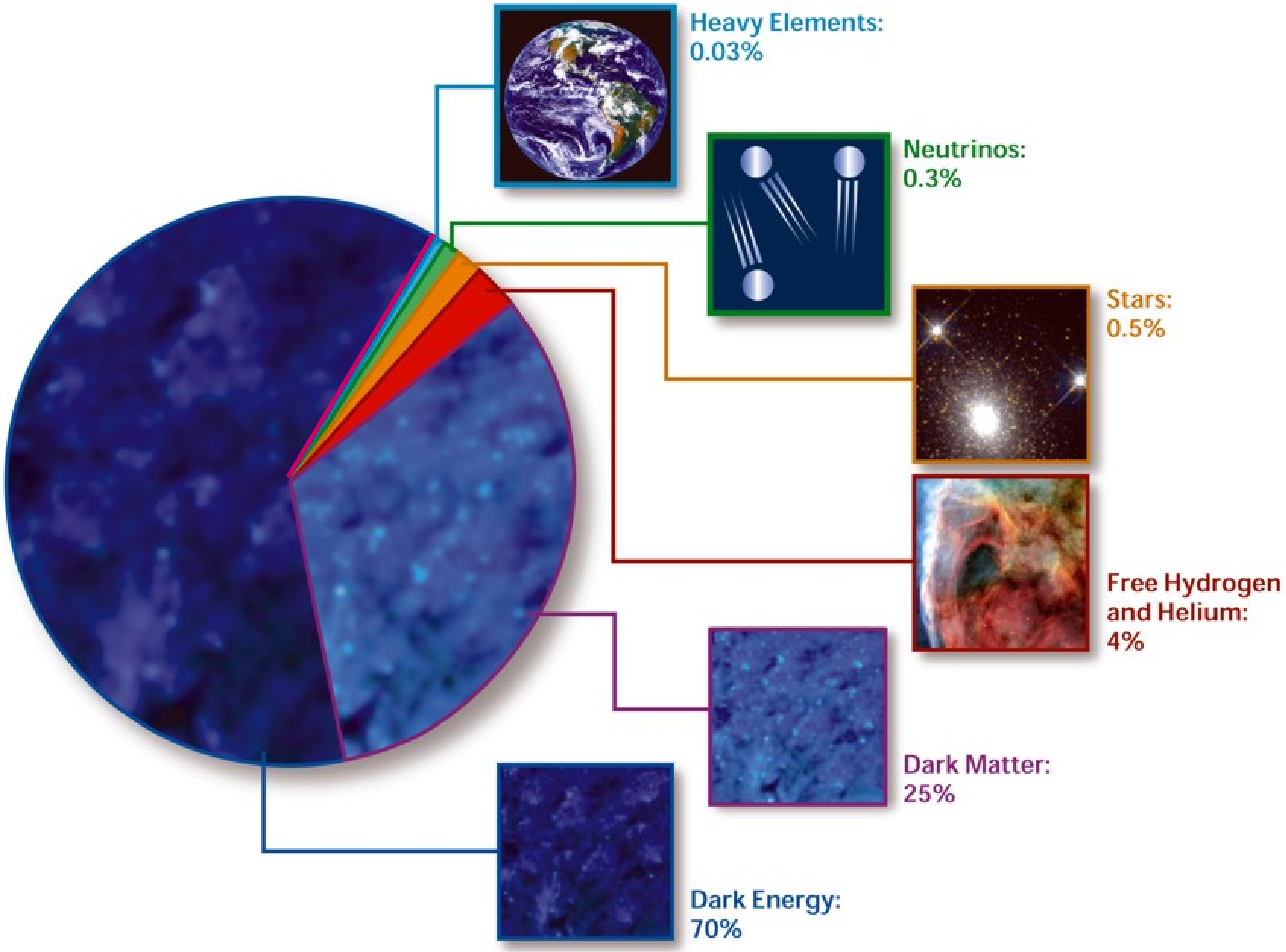
the non-minimal cosmos

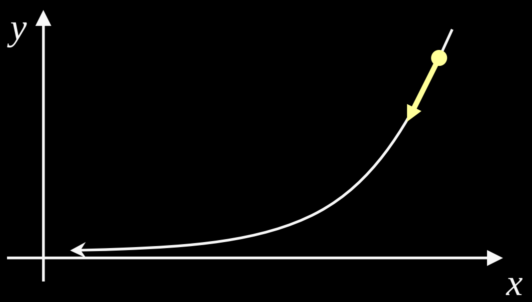


Large-scale perturbations with multiple components

- **adiabatic perturbations**
  - *perturb along the classical background trajectory*

$$R = H\frac{\delta x}{\dot{x}} = H\frac{\delta y}{\dot{y}} = H\delta t$$

  - ***adiabatic perturbations stay adiabatic***

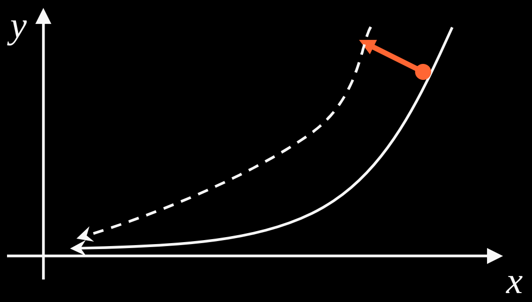


- **entropy perturbations**
  - *perturb off the background trajectory*

$$H\frac{\delta x}{\dot{x}} \neq H\frac{\delta y}{\dot{y}}$$

  - *e.g., baryon-photon **isocurvature** perturbation:*

$$S_B = \frac{\delta n_B}{n_B} - \frac{\delta n_\gamma}{n_\gamma} = 3H\left(\frac{\delta n_\gamma}{\dot{n}_\gamma} - \frac{\delta n_B}{\dot{n}_B}\right)$$



non-adiabatic perturbations during inflation with multiple fields

- ***quantum fluctuations in light scalar fields (m<H) become frozen-in on super-Hubble scales***

- ***can generate primordial isocurvature density perturbations***
  - *necessary, not sufficient to produce primordial isocurvature*
  - *equilibrium attractor can lead to decay of non-adiabatic modes*

- ***additional source for primordial adiabatic density perturbations***
  - *change in the local equation of state*
  - *can produce **local non-Gaussianity***

distinctive observational predictions vs single-field models

entropy fluctuations can perturb the primordial radiation density after inflation

- ***coupled fields during slow-roll during inflation***

  Starobinski & Yokoyama; Sasaki & Stewart; Mukhanov & Steinhardt; Linde, Garcia-Bellido & Wands…. (1995)

- ***inhomogeneous end of inflation***

  Bernardeau & Uzan (2002); Lyth; Salem (2005)

- ***inhomogeneous / modulated reheating***

  inflaton decay-rate modulated by another light field

  Dvali, Gruzinov & Zaldariaga; Kofman (2003); Kolb, Riotto & Vallinotto (2004)

- ***curvaton decay after inflation***

  weakly-coupled, late-decaying scalar field

  Linde & Mukhanov (1997);

  Enqvist & Sloth; Lyth & Wands; Moroi & Takahashi (2001)

linear perturbations

parameterise physics by transfer matrix

$$\begin{pmatrix} R \\ S \end{pmatrix}_{\text{primordial}} = \begin{pmatrix} 1 & \tau_{RS} \\ 0 & \tau_{SS} \end{pmatrix} \begin{pmatrix} R_* \\ S_* \end{pmatrix}_{\text{inflation}}$$

-> observable **curvature** and **isocurvature perturbations**

correlation angle quantifies how much the non-adiabatic modes during inflation contribute to the primordial curvature perturbation

$$\cos\Theta = \frac{\langle RS \rangle}{\langle R^2 \rangle^{1/2} \langle S^2 \rangle^{1/2}} \propto \tau_{RS}$$

two-field consistency relation:

Wands, Bartolo, Matarrse & Riotto (2002)

if can reconstruct from observations the curvature at horizon-exit

$$\left\langle R_*^{\,2} \right\rangle = \sin^2\Theta \left\langle R^2 \right\rangle$$

obtain generalised consistency relation

$$r \equiv \frac{\left\langle T^2 \right\rangle}{\left\langle R^2 \right\rangle} = \frac{\left\langle T_*^{\,2} \right\rangle}{\left\langle R_*^{\,2} \right\rangle} \sin^2\Theta = -8\, n_T \sin^2\Theta$$

=> can have large (negative) tensor tilt in multiple field inflation

beyond linear order

Lyth & Rodriguez (2005)

- identify curvature perturbation with perturbed expansion

$$\mathcal{R} = \delta N = N - \bar{N}$$

- local function of local field values during inflation

$$\mathcal{R} = \sum \frac{dN}{d\varphi_I}\delta\varphi_I + \frac{1}{2}\sum \frac{d^2N}{d\varphi_I d\varphi_J}\delta\varphi_I\delta\varphi_J + \ldots$$

- local form of non-Gaussianity

$$\mathcal{R} = \mathcal{R}_1 + \frac{3}{5} f_{NL} \mathcal{R}_1^2 \ldots$$

  - Single field: $f_{NL} = 5N''/6N'^2 = 5(\eta - 2\varepsilon)/6 \ll 1$
  - Multi-field: N'' and hence f_{NL} not constrained by slow-roll

local non-Gaussianity from curvaton decay

Lyth, Ungarelli & Wands '02

for massive scalar field $$\rho_\chi = \frac{1}{2} m^2 (\chi + \delta\chi)^2$$

decays into radiation
$$R \approx \Omega_{\chi,\mathrm{decay}} \left(\frac{\delta\rho_\chi}{\rho_\chi} \right) \approx \Omega_{\chi,\mathrm{decay}} \left(\frac{\delta\chi}{\chi} + \left(\frac{\delta\chi}{\chi} \right)^2 \right)$$

precisely of local form
$$R = R_1 + \frac{3}{5} f_{NL} R_1^2 \quad \text{where} \quad f_{NL} \approx \frac{1}{\Omega_{\chi,\mathrm{decay}}}$$

constraints on f_{NL} from WMAP $f_{NL} < 100$

hence $\Omega_{\chi,\mathrm{decay}} > 0.01$ and $10^{-5} < \delta\chi/\chi < 10^{-3}$

"minimal curvaton model" $r = (f_{NL}/522)^4$ Huang (2008) and now

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