Paris Centre for Cosmological Physics

Probing inflation with cosmological observables

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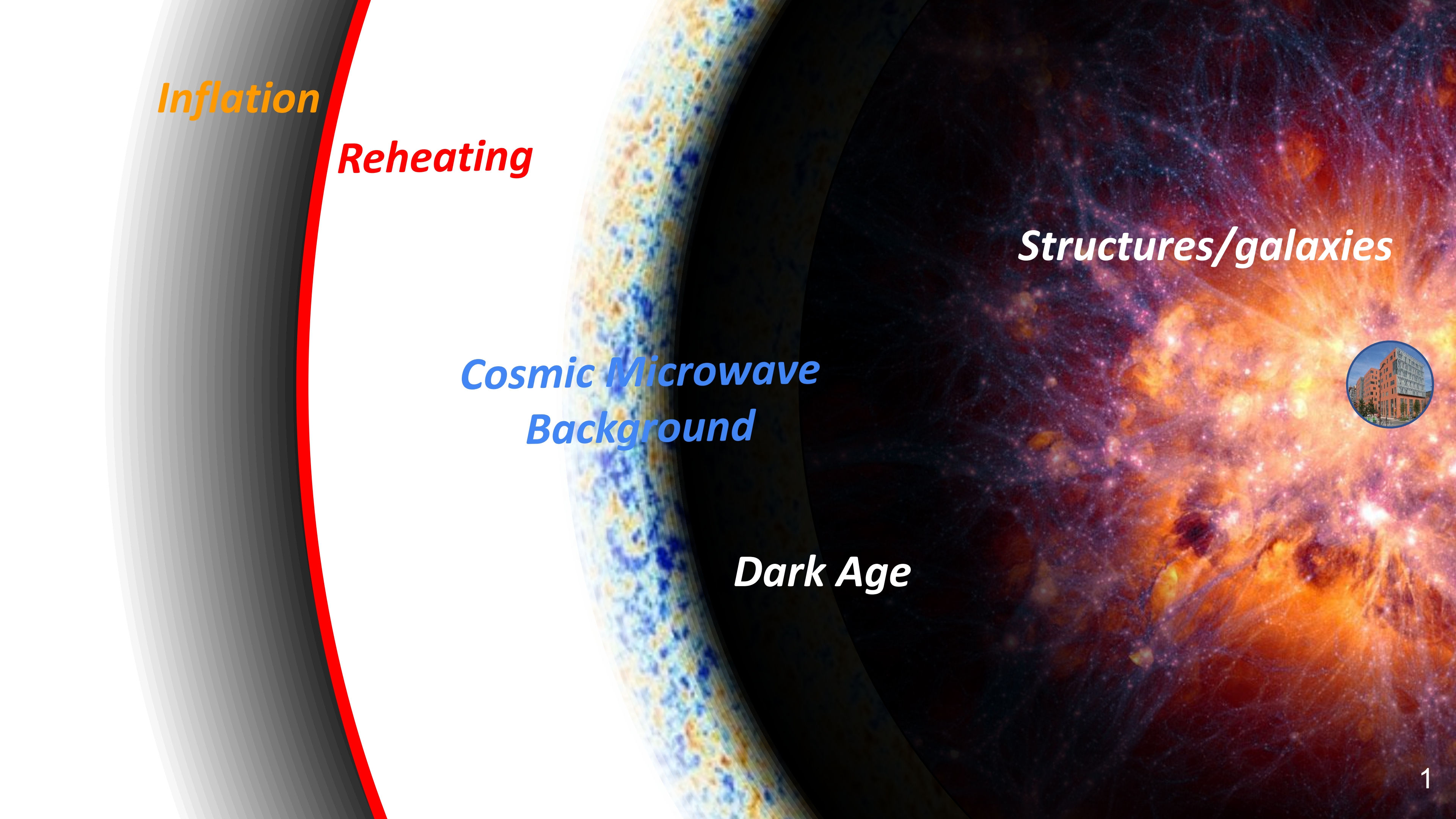
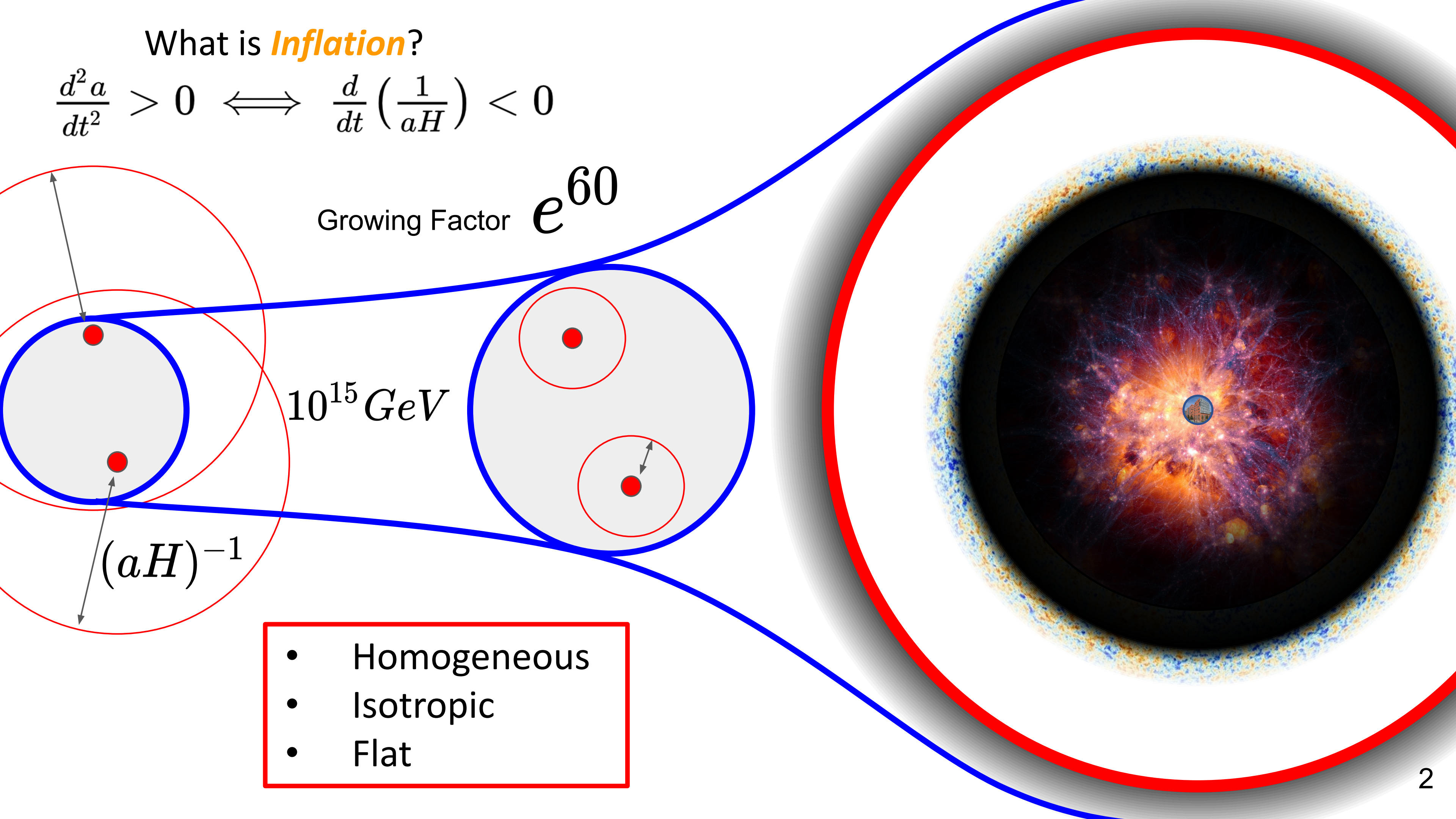

Inflation
Reheating
Structures/galaxies
Cosmic Microwave Background
Dark Age

What is *Inflation*?

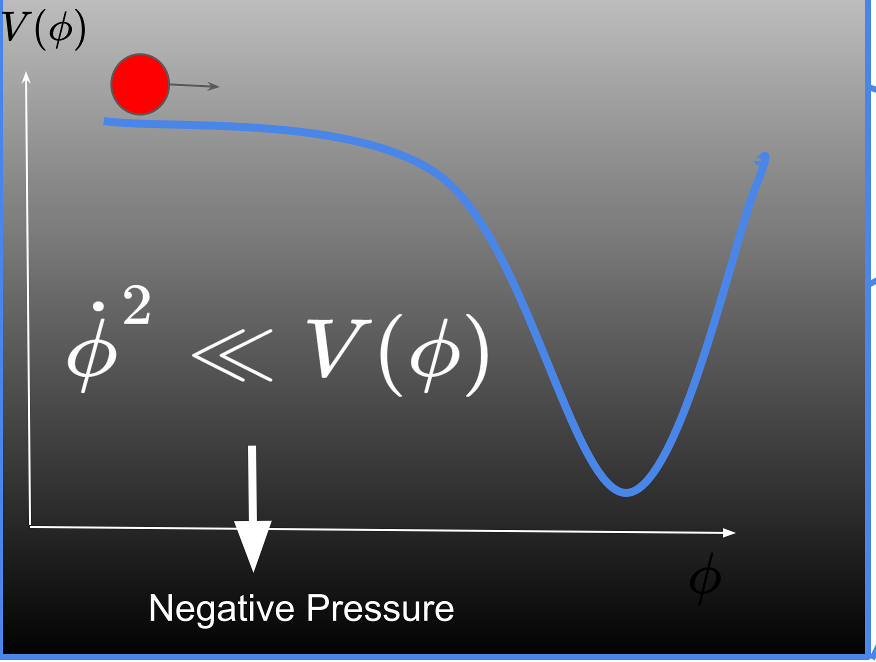
$$\frac{d^2a}{dt^2} > 0 \iff \frac{d}{dt}\left(\frac{1}{aH}\right) < 0$$

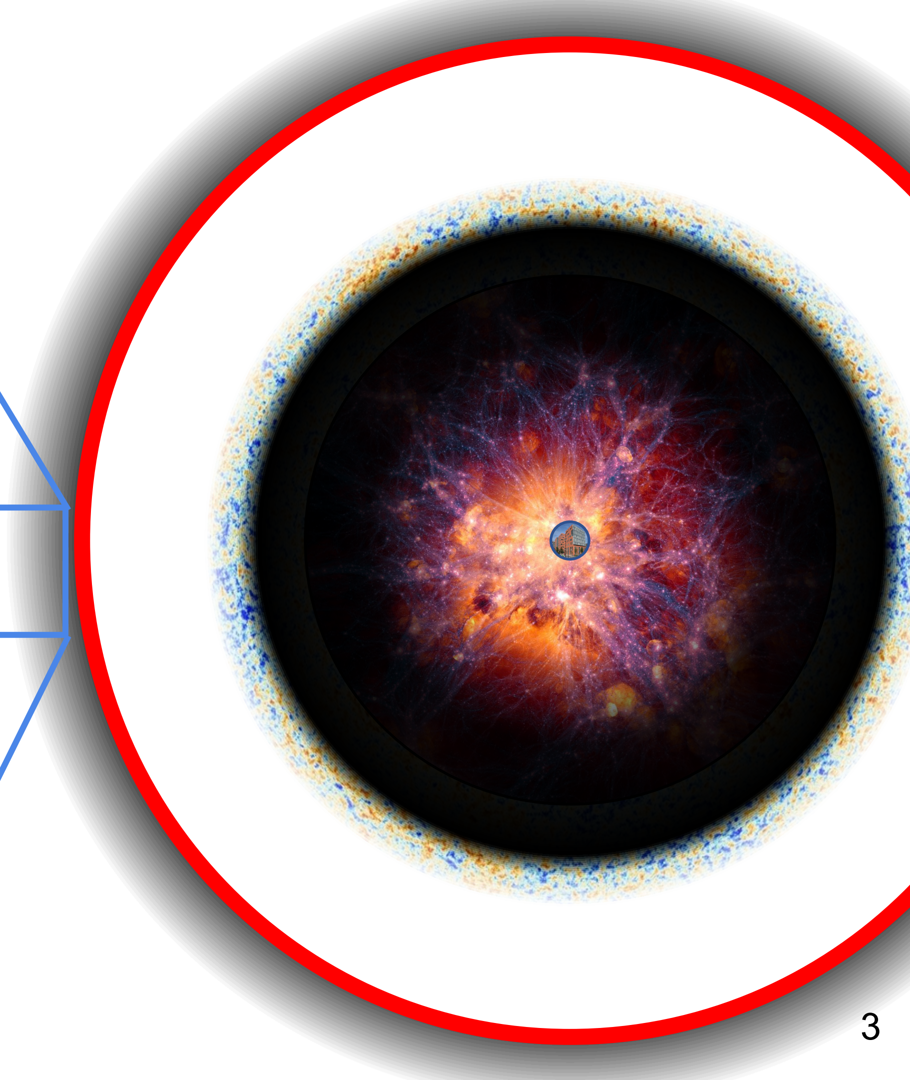


- Homogeneous
- Isotropic
- Flat

How ***Inflation?***

- One scalar field ϕ
- slow-roll
- Negative pressure





How does *Inflation* end ***?***

At the end of inflation:

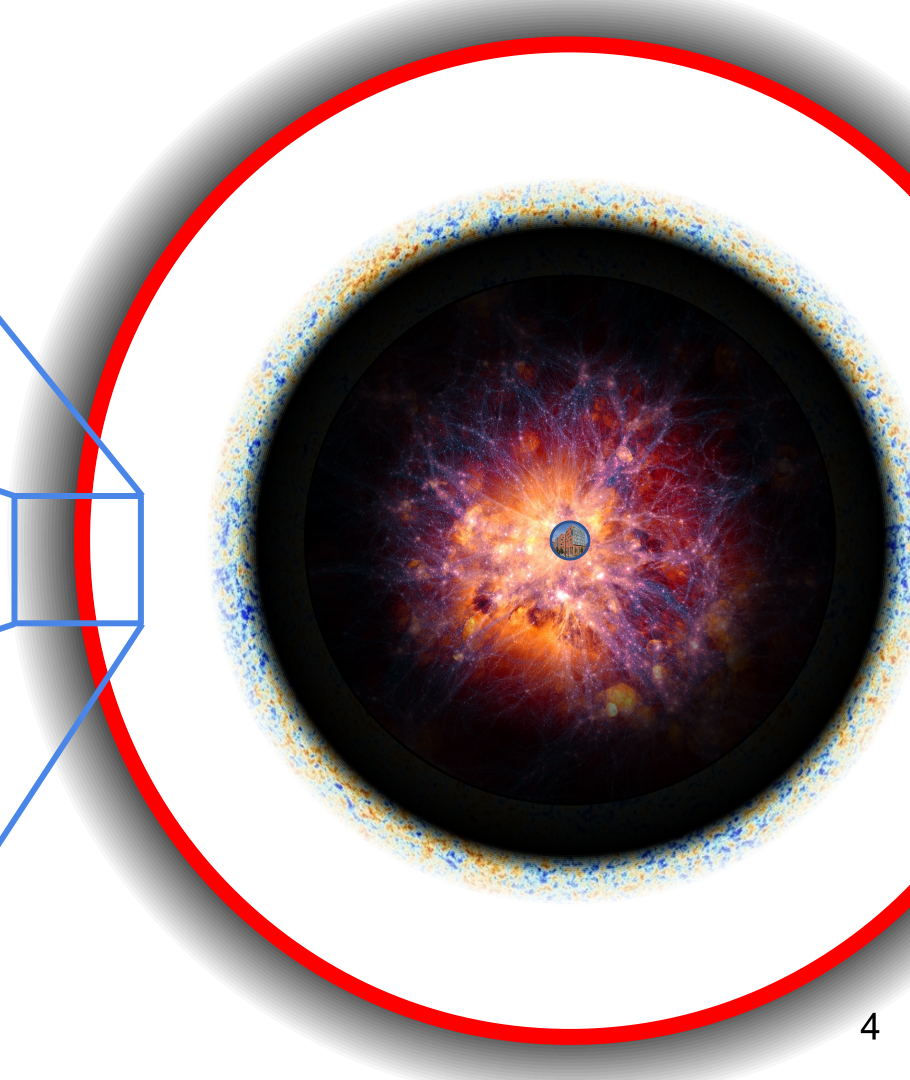
- Homogeneous
- isotropic
- flat
- But… Empty !

$$\phi$$

Reheating

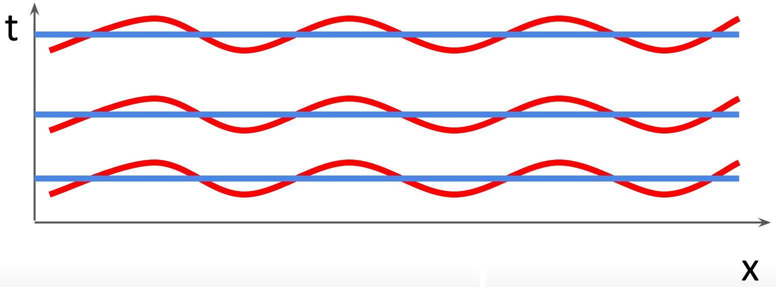
??????

$$CDM + b + \nu + \gamma$$



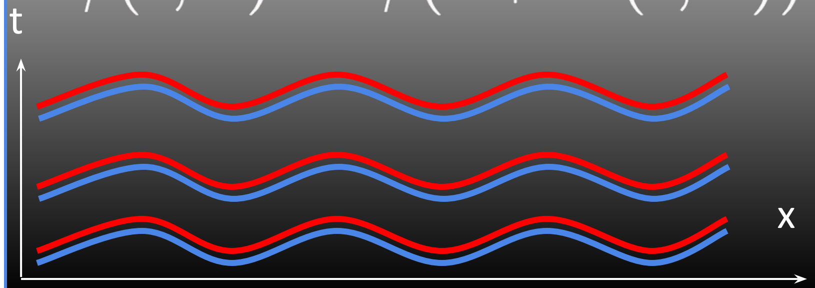
Inflaton is not necessarily a fundamental field

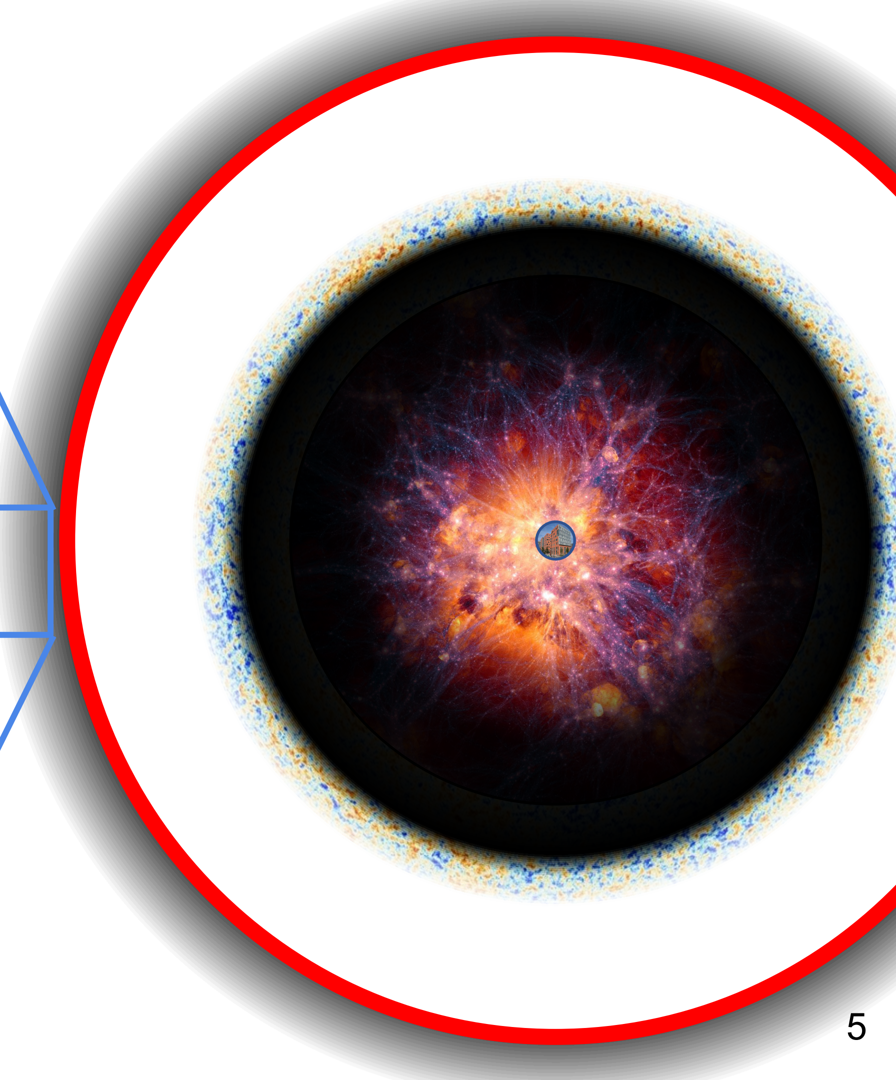
$$\phi(t, \mathbf{x}) = \bar{\phi}(t)(1 + \delta(t, \mathbf{x}))$$



$$t \to t + \delta t(t, \mathbf{x})$$

$$\phi(t, \mathbf{x}) = \bar{\phi}(t + \delta t(t, \mathbf{x}))$$



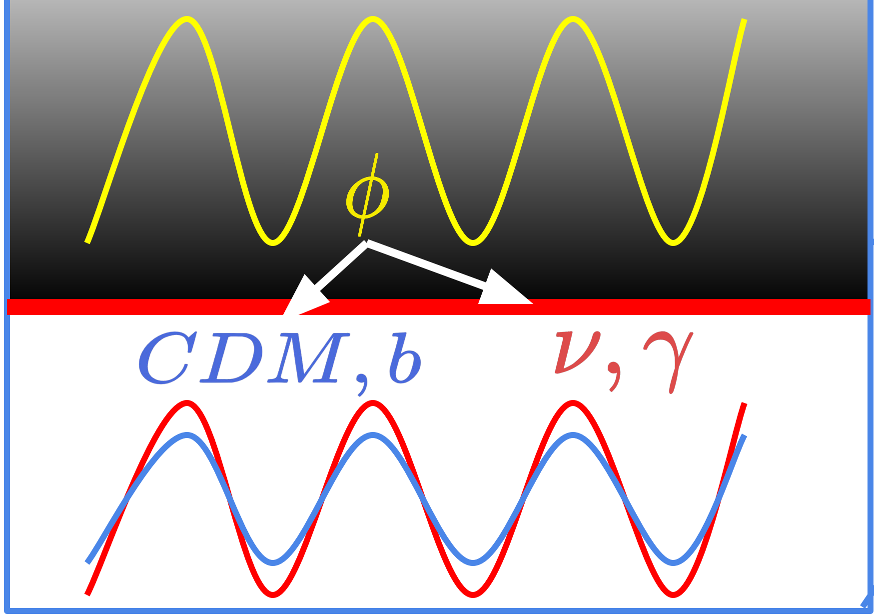


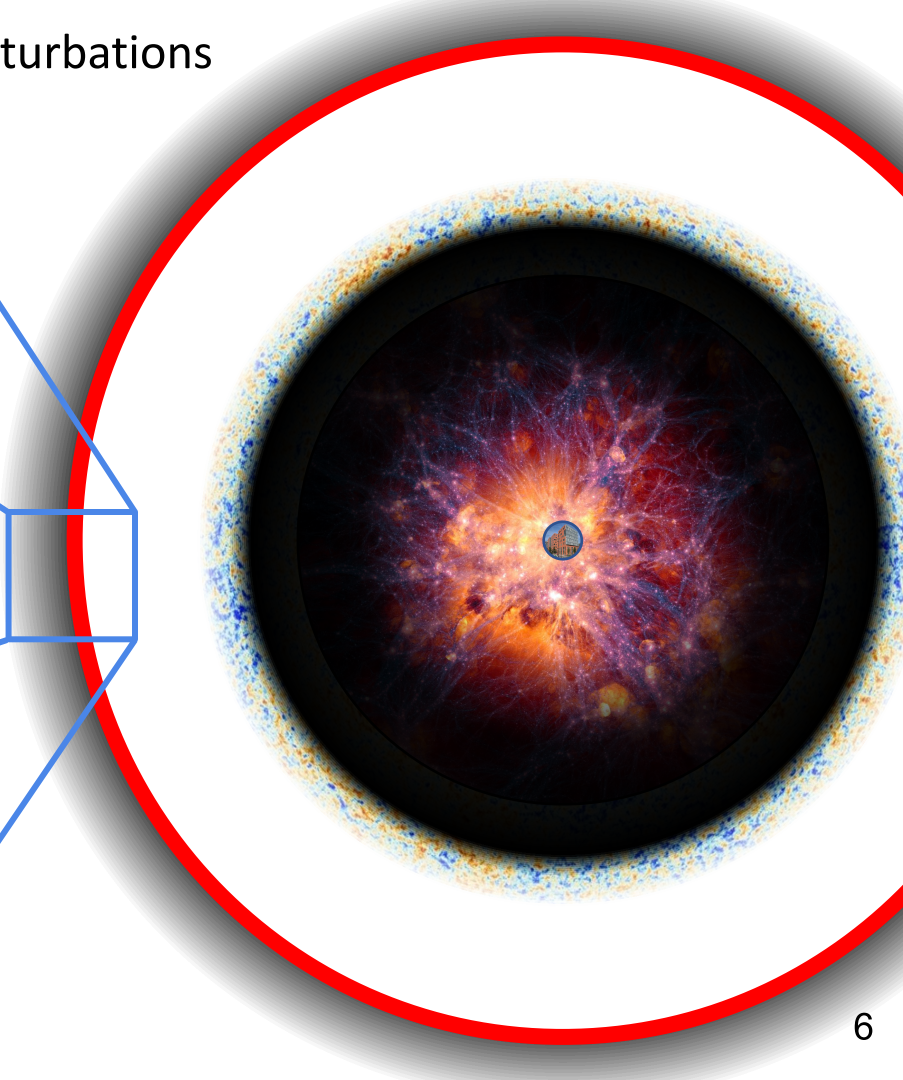
One field *Inflation* can generates Adiabatic perturbations

$$\rho_i(t,\mathbf{x}) = \bar{\rho}_i(t+\delta t(t,\mathbf{x}))$$

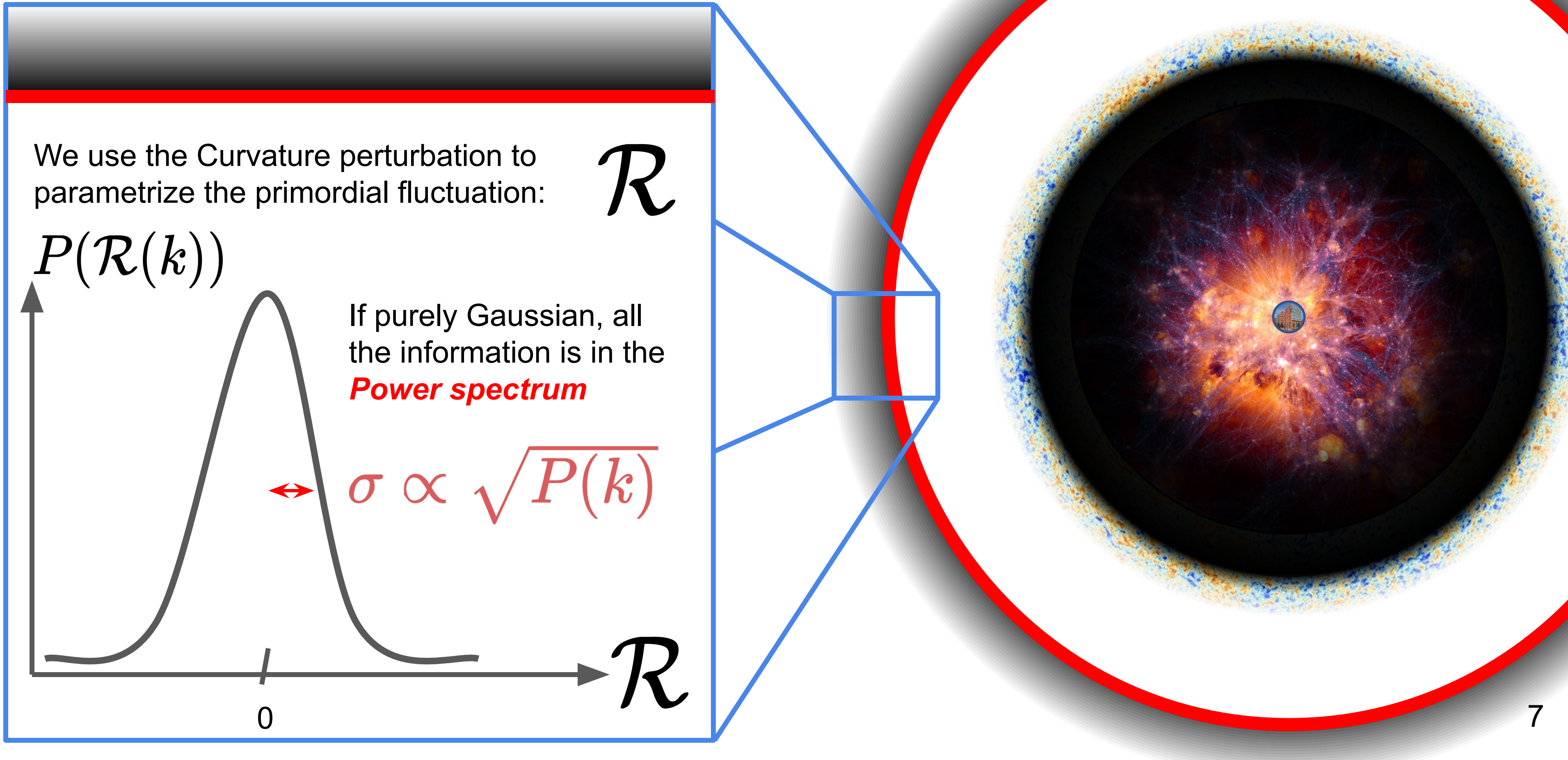
$$\rightarrow \delta_{CDM} = \delta_b = \frac{3}{4}\delta_\nu = \frac{3}{4}\delta_\gamma$$

$$v_i = 0$$



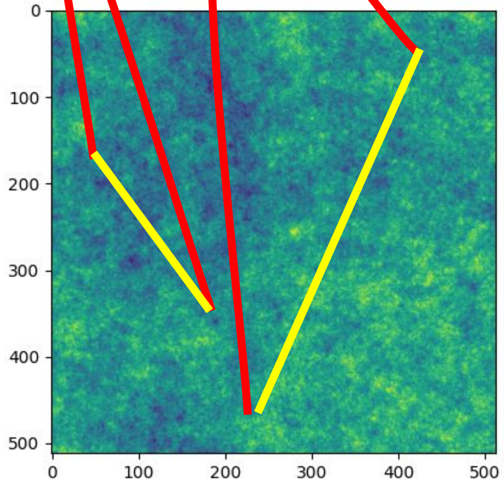


One field *Inflation* generates nearly-Gaussian Adiabatic perturbations



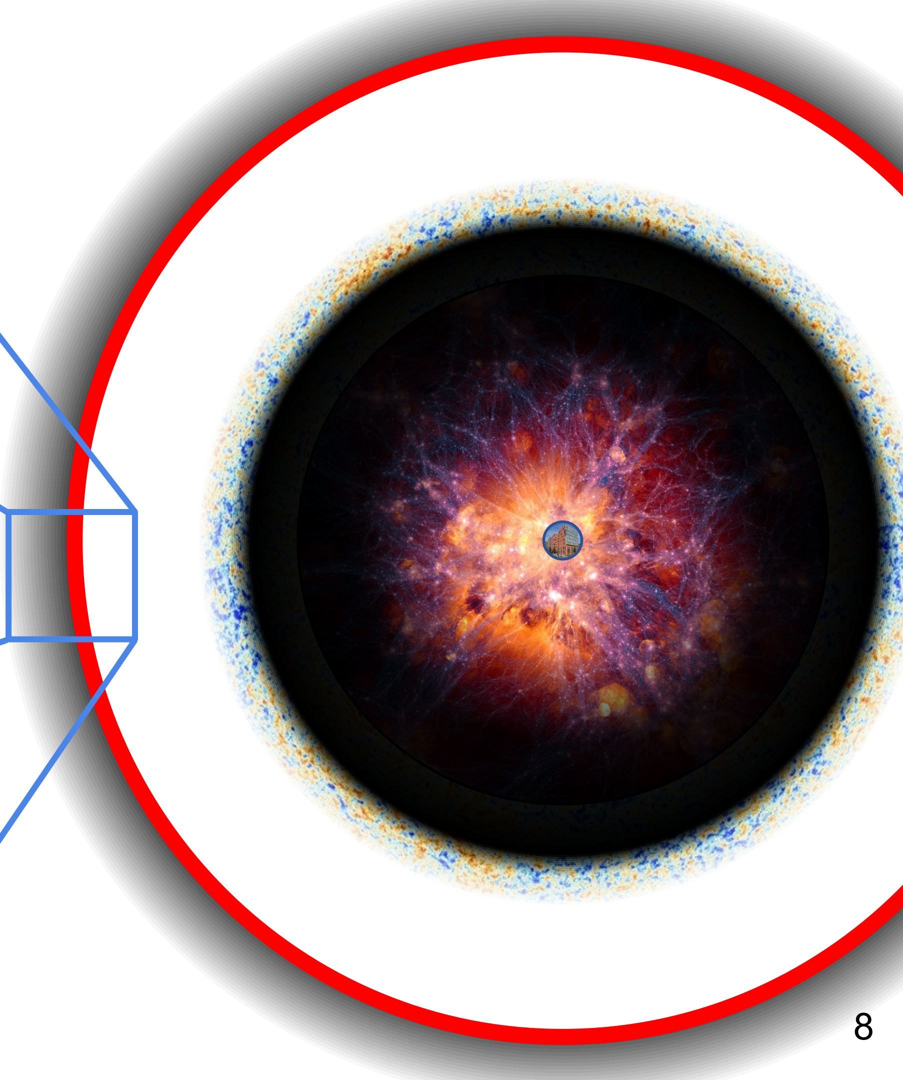
Inflation generates nearly-Gaussian Adiabatic and nearly-scale invariant perturbations

$$\langle \phi(\mathbf{k}_1)\phi(\mathbf{k}_2)\rangle = \delta(\mathbf{k}_1+\mathbf{k}_2)P^{\phi}(k_1)$$



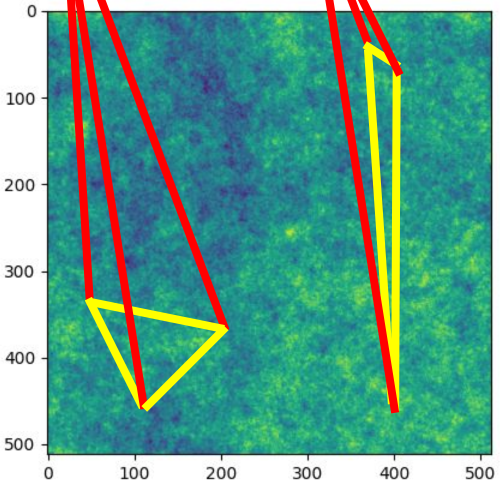
$$\langle \mathcal{R}(\mathbf{k}_1)\mathcal{R}(\mathbf{k}_2)\rangle = \delta(\mathbf{k}_1+\mathbf{k}_2)P(k_1)$$

scale invariant: $k^3 P(k) \sim k^{n_s-1}$



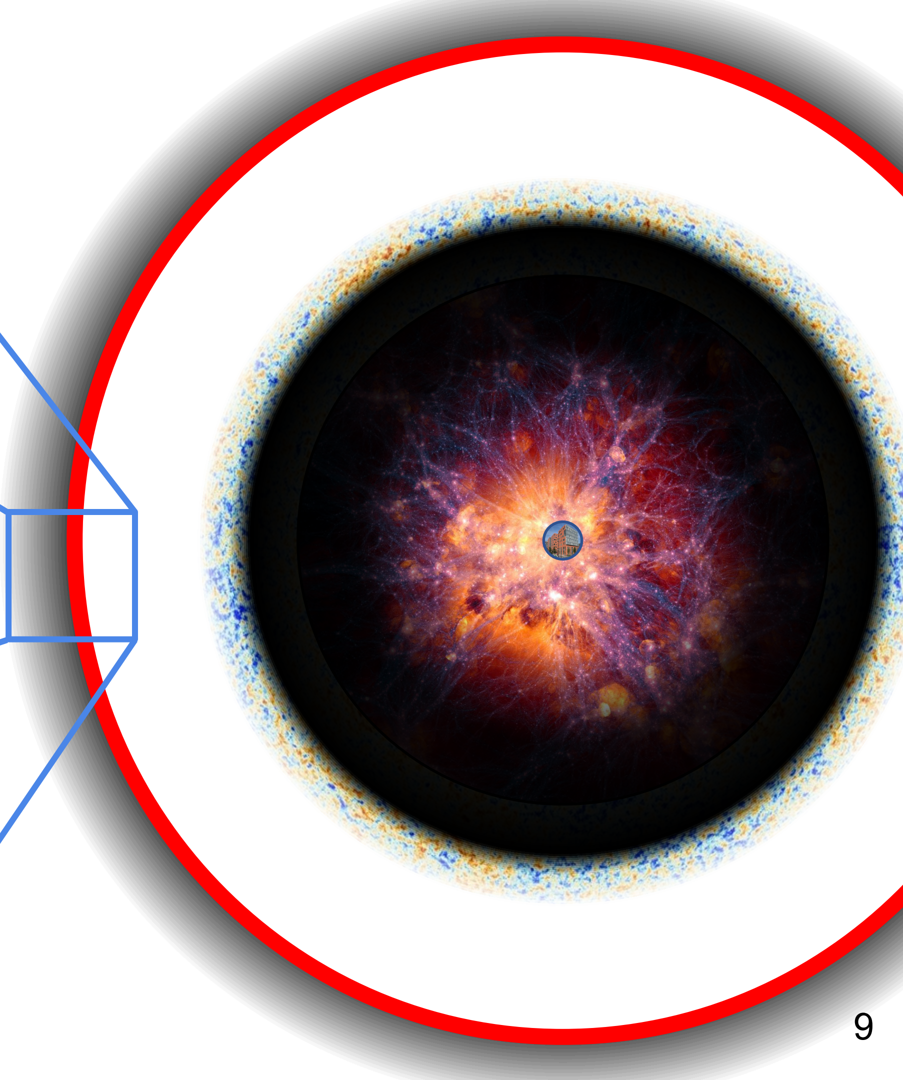
Inflation generates nearly-Gaussian Adiabatic and nearly-scale invariant perturbations

$$\langle \phi(\mathbf{k}_1)\phi(\mathbf{k}_2)\phi(\mathbf{k}_3)\rangle = \delta(\mathbf{k}_1+\mathbf{k}_2+\mathbf{k}_3)B^{\phi\phi\phi}(k_1,k_2,k_3)$$



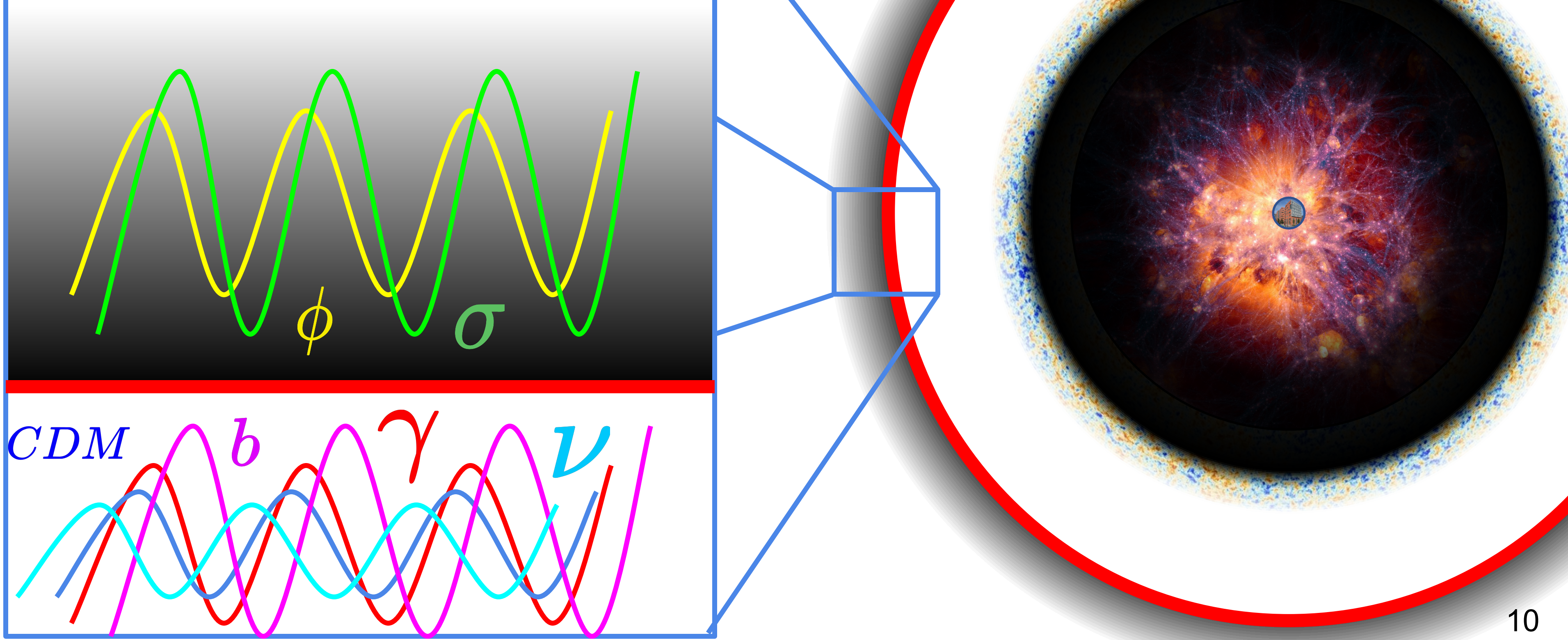
$$\langle \mathcal{R}(\mathbf{k}_1)\mathcal{R}(\mathbf{k}_2)\mathcal{R}(\mathbf{k}_3)\rangle = \delta(\mathbf{k}_1+\mathbf{k}_2+\mathbf{k}_3)B(k_1+k_2+k_3)$$

$$f_{NL} \sim \left(\frac{B(k_1,k_2,k_3)}{P(k_1)P(k_2)}\right)_{k_3\to 0} = n_s - 1$$

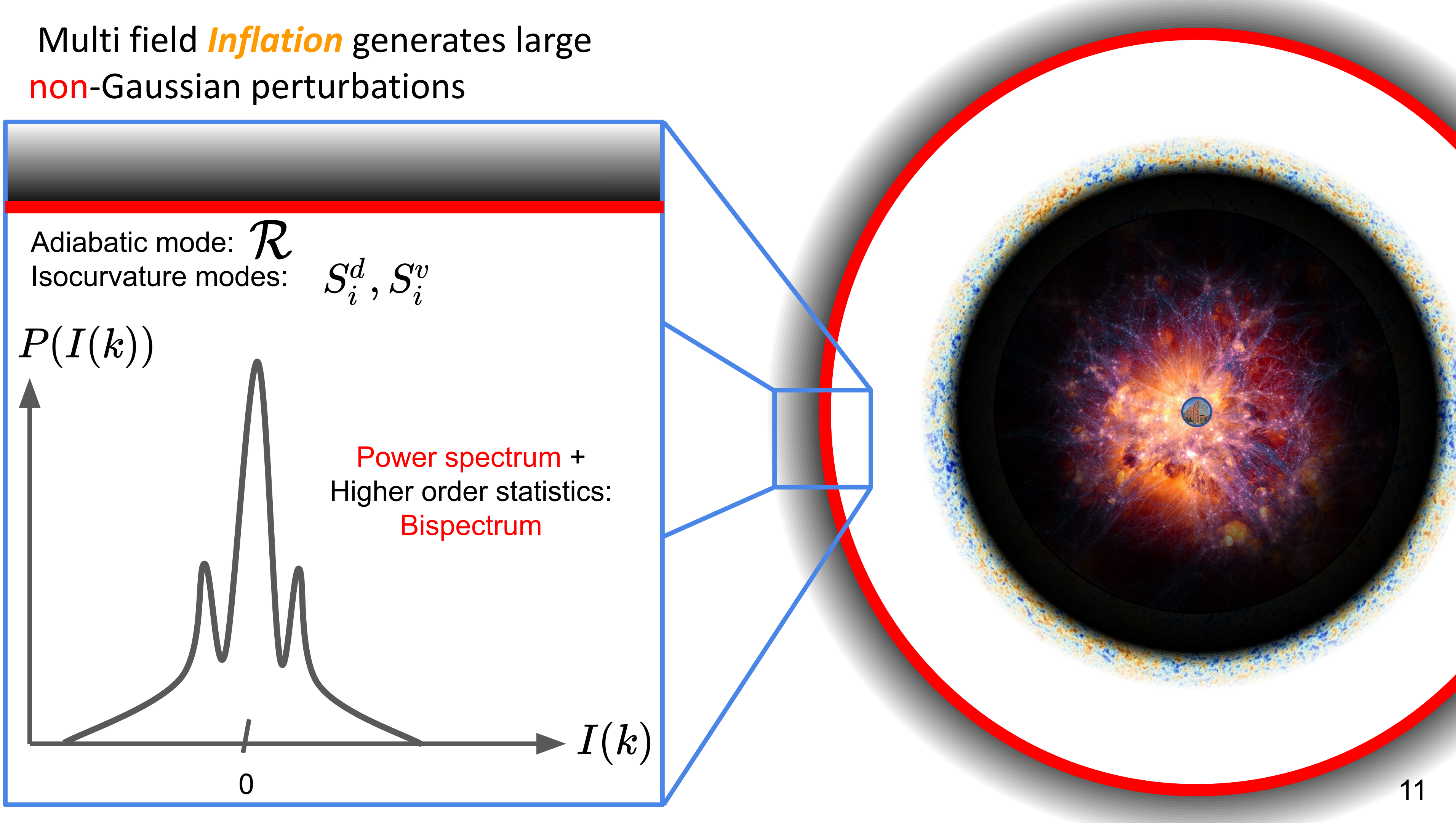


Multi field *Inflation* generates Adiabatic and density isocurvature perturbations

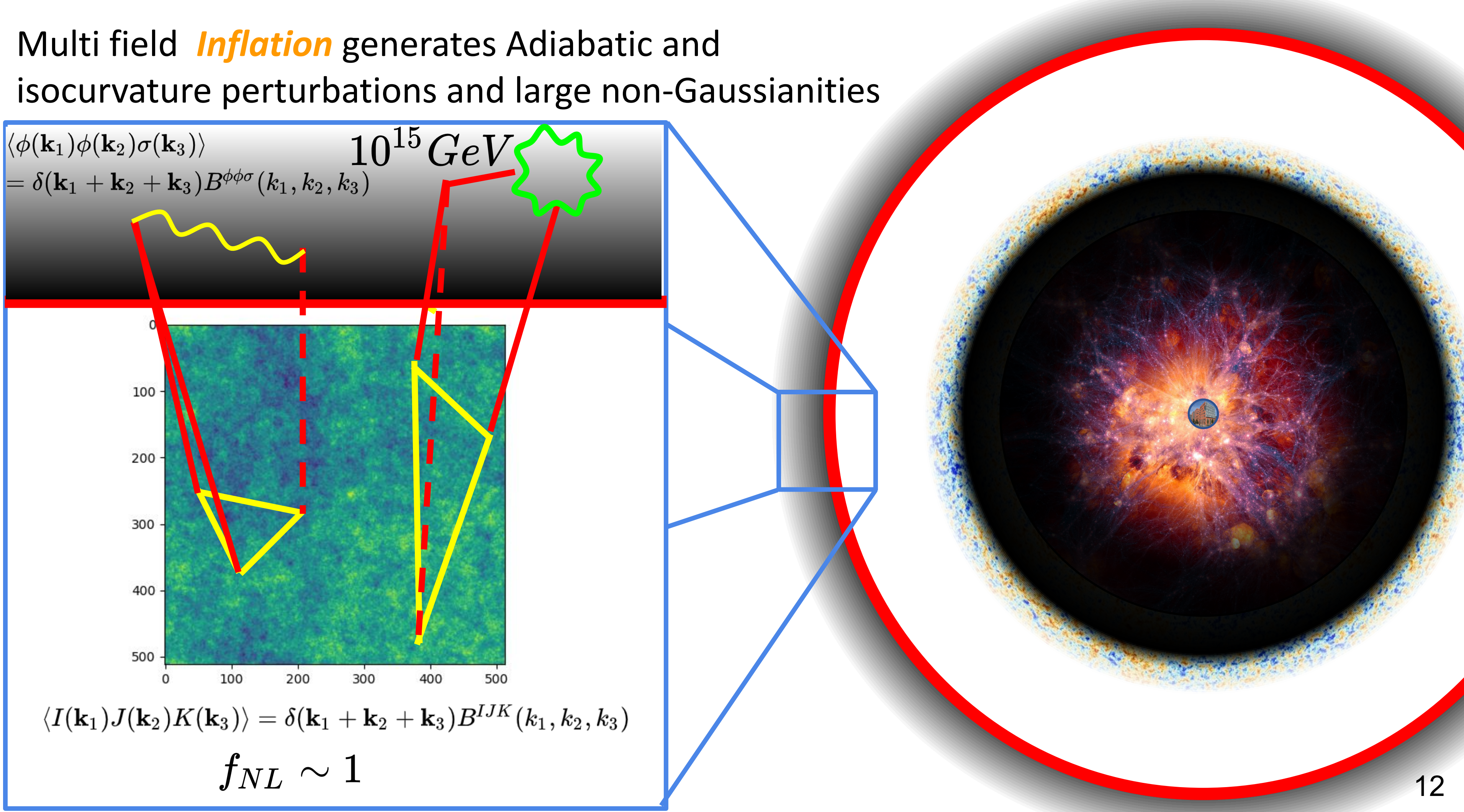
$$S_d^i = \frac{1}{1+\omega_i}\delta_i - \frac{3}{4}\delta_\gamma$$



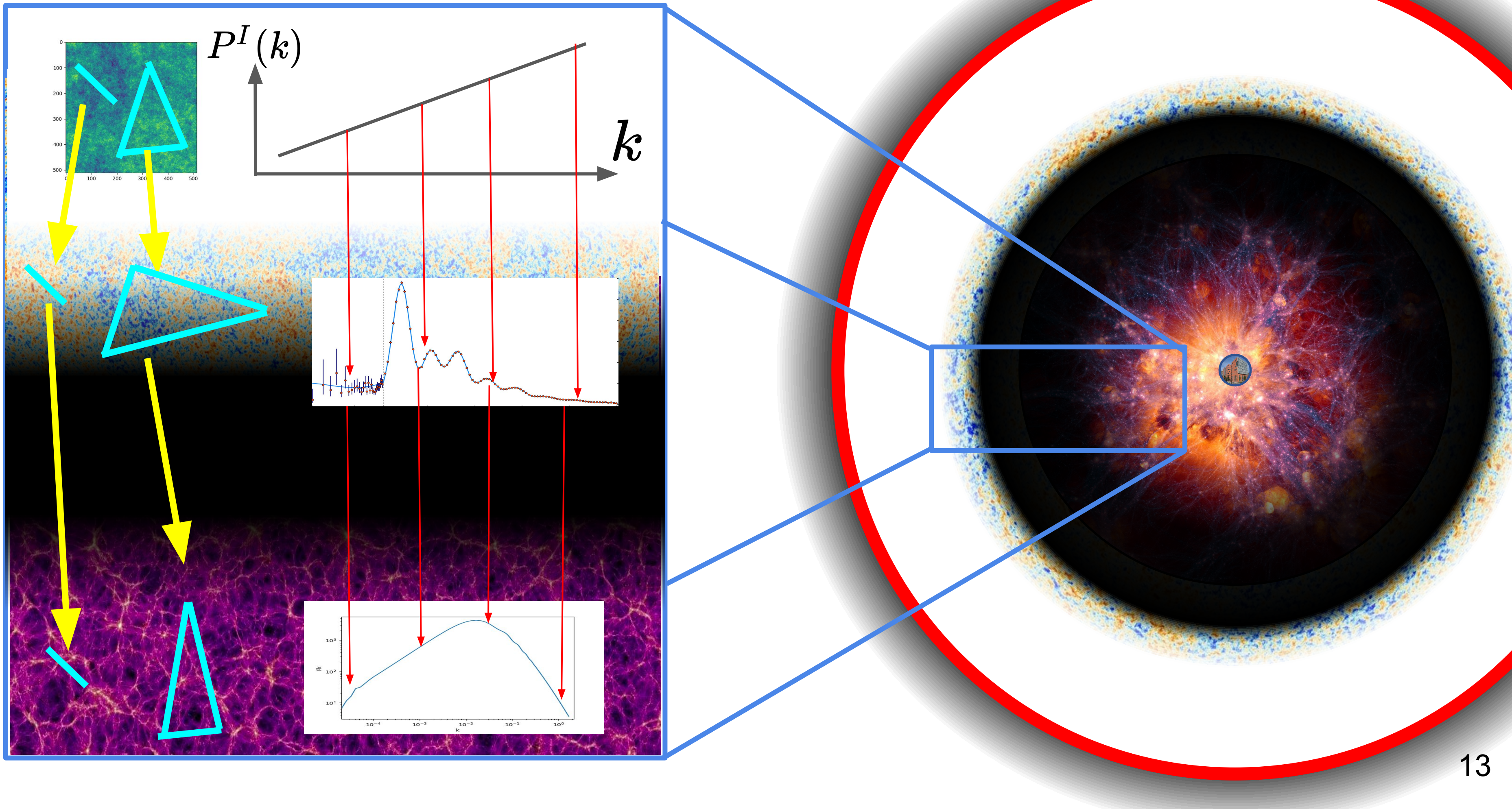
Multi field *Inflation* generates large non-Gaussian perturbations



Multi field *Inflation* generates Adiabatic and isocurvature perturbations and large non-Gaussianities



Perturbations in the CMB

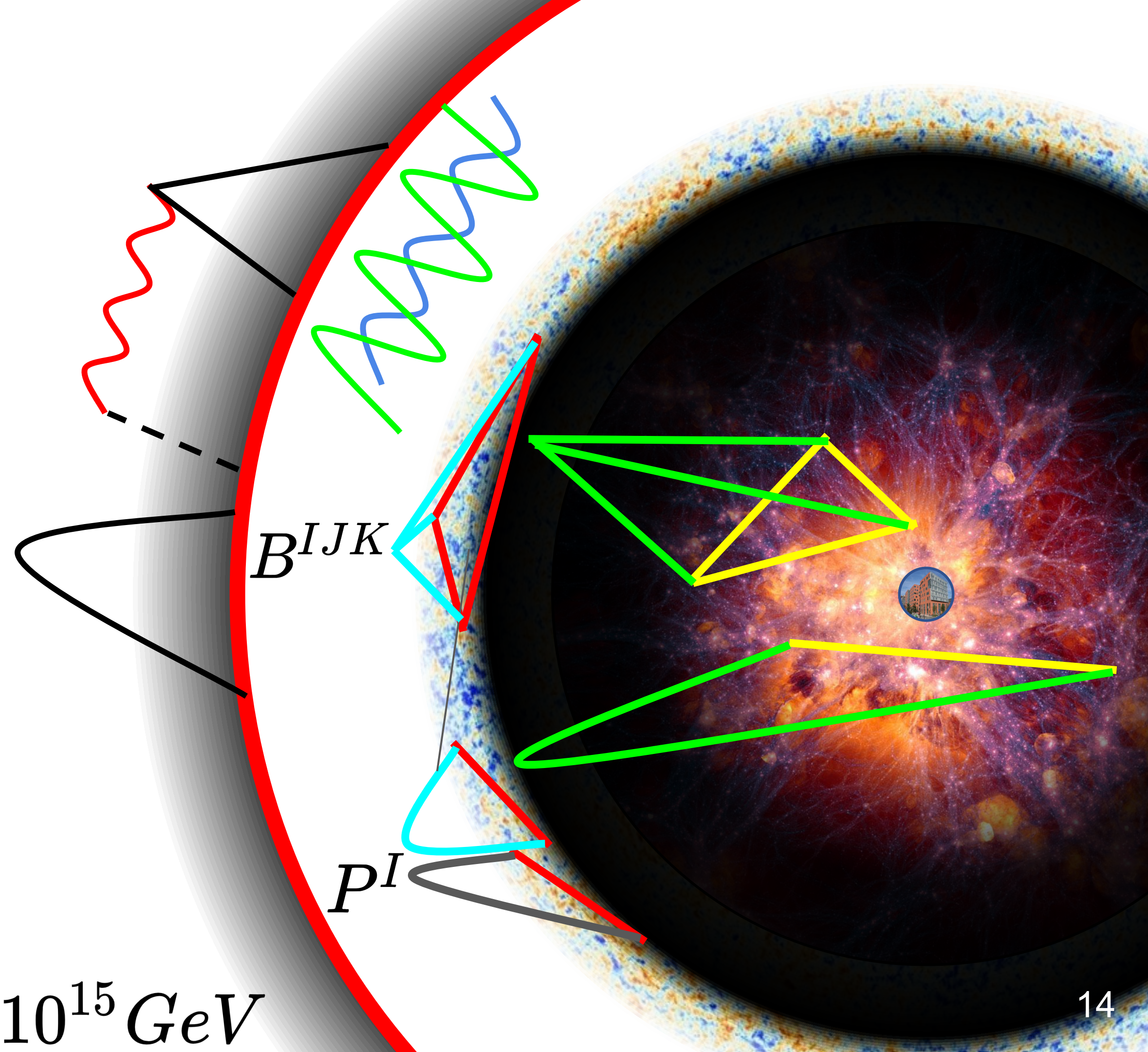


Conclusion

- Inflation predicts many features of our universe:
  - Single field inflation predicts Gaussian and Adiabatic initial conditions
  - Multi fields can generates Isocurvature modes and large non-Gaussianities

- The primordial fluctuation can be propagated through the universe history. We can measure the primordial power spectrum in
  - the CMB temperature fluctuations
  - the LSS distributions

The study of these correlations, especially the non-Gaussianities and the isocurvature modes, gives us access to the physics of the largest energy scale we could have access to: $10^{15}\,GeV$

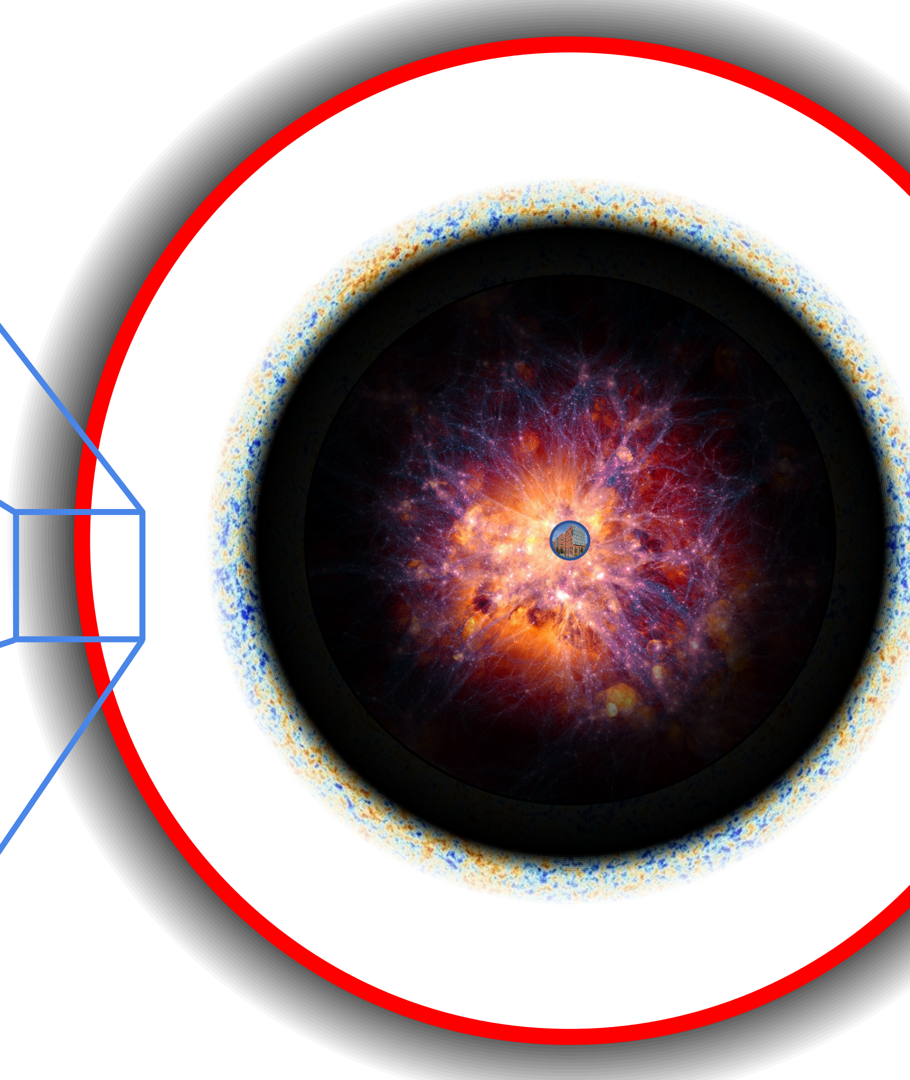


One field *Inflation*

$$P_{\mathcal{R}}(k)k^3 \propto A_s\left(\frac{k}{k_p}\right)^{n_s-1}$$

$$f_{NL} \sim \left(\frac{B(k_1,k_2,k_3)}{P(k_1)P(k_2)}\right)_{k_3\to 0} = n_s - 1$$

- Adiabatic
- quasi Gaussian
- quasi scale invariant

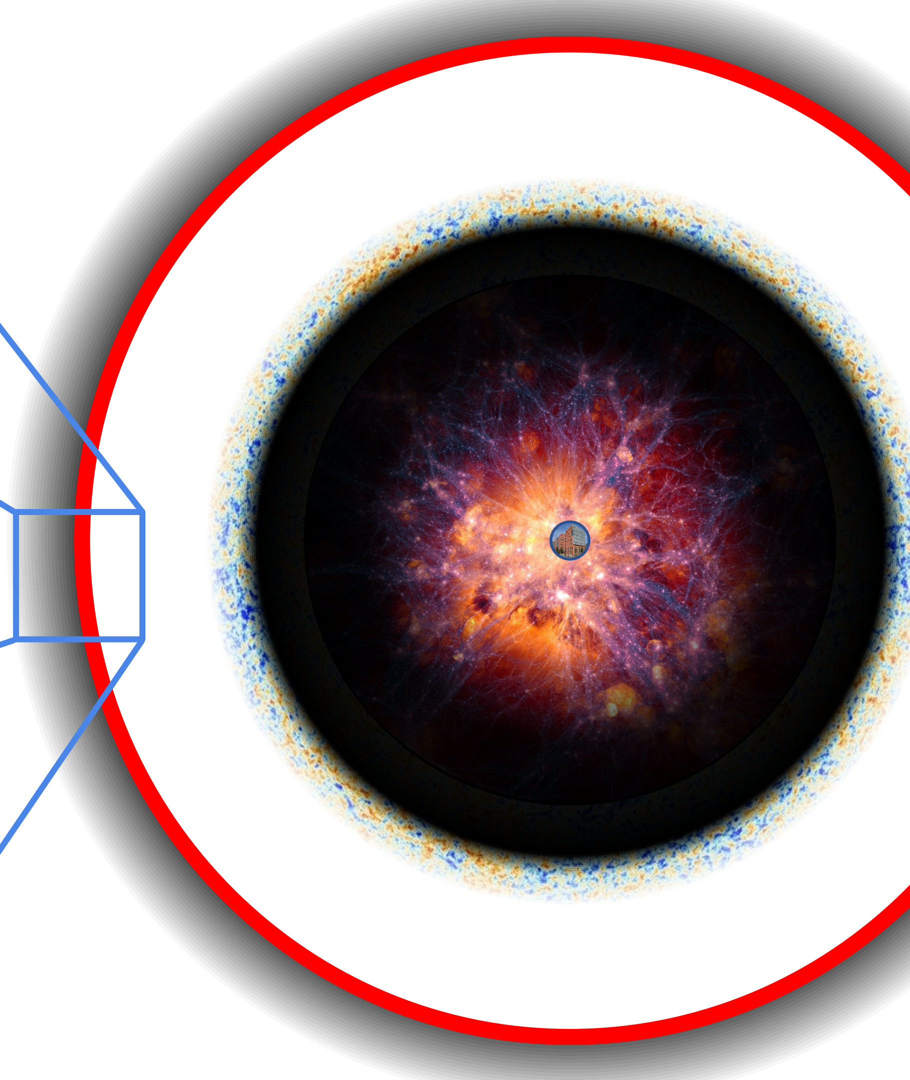


Multi-field *Inflation*

$$P_I(k)k^3 = A_s^I\left(\frac{k}{k_p}\right)^{n_s^I-1}$$

$$B(k_1,k_2,k_3) = f_{NL}(P(k_1)P(k_2) + perm)$$

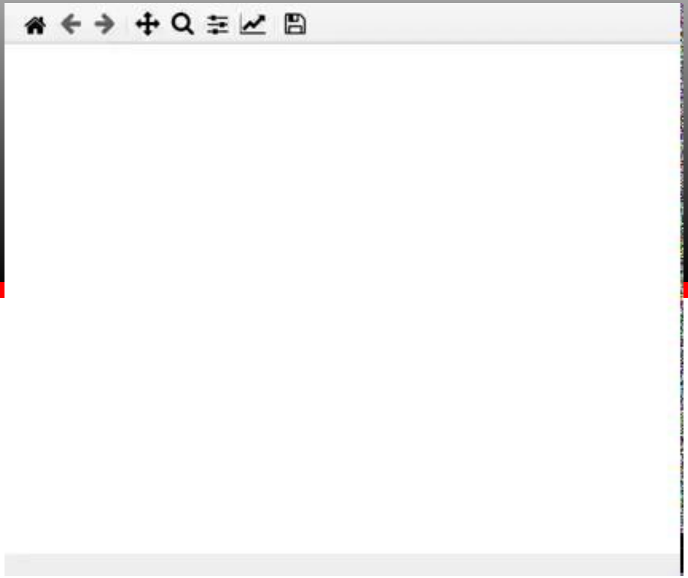
- Adiabatic/Isocurvature
- large non-Gaussianities
- quasi scale invariant

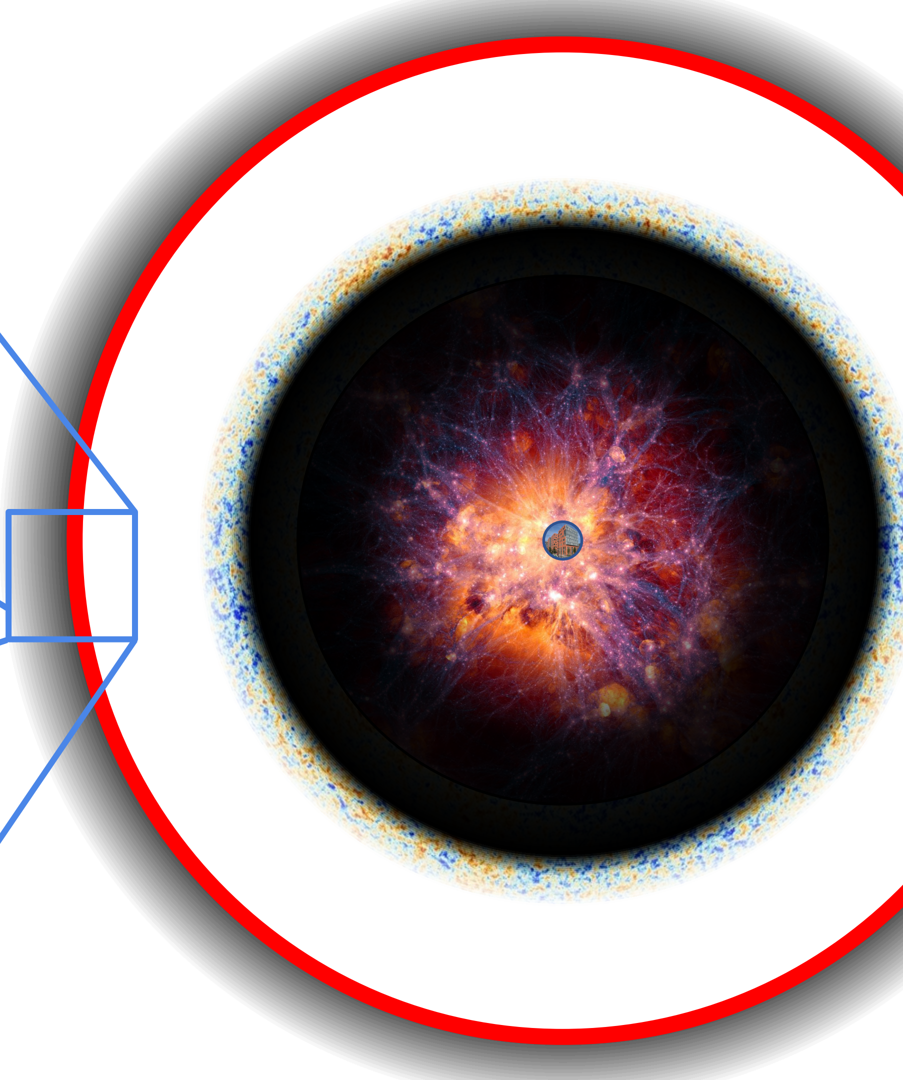


Multi field *Inflation* generates Adiabatic and density and velocity isocurvature perturbations

$$S_v^i = \frac{1}{1-f_\nu}(v_i - v_\gamma)$$

$$v = \frac{\delta H}{H}$$





Perturbations evolution

$$\delta_i(t,\vec{k}) = T_{\delta,i}(t,k)\mathcal{R}(\vec{k})$$

Transfer function,
deterministic

Primordial perturbation,
Stochastic