Reconstructing the inflationary landscape

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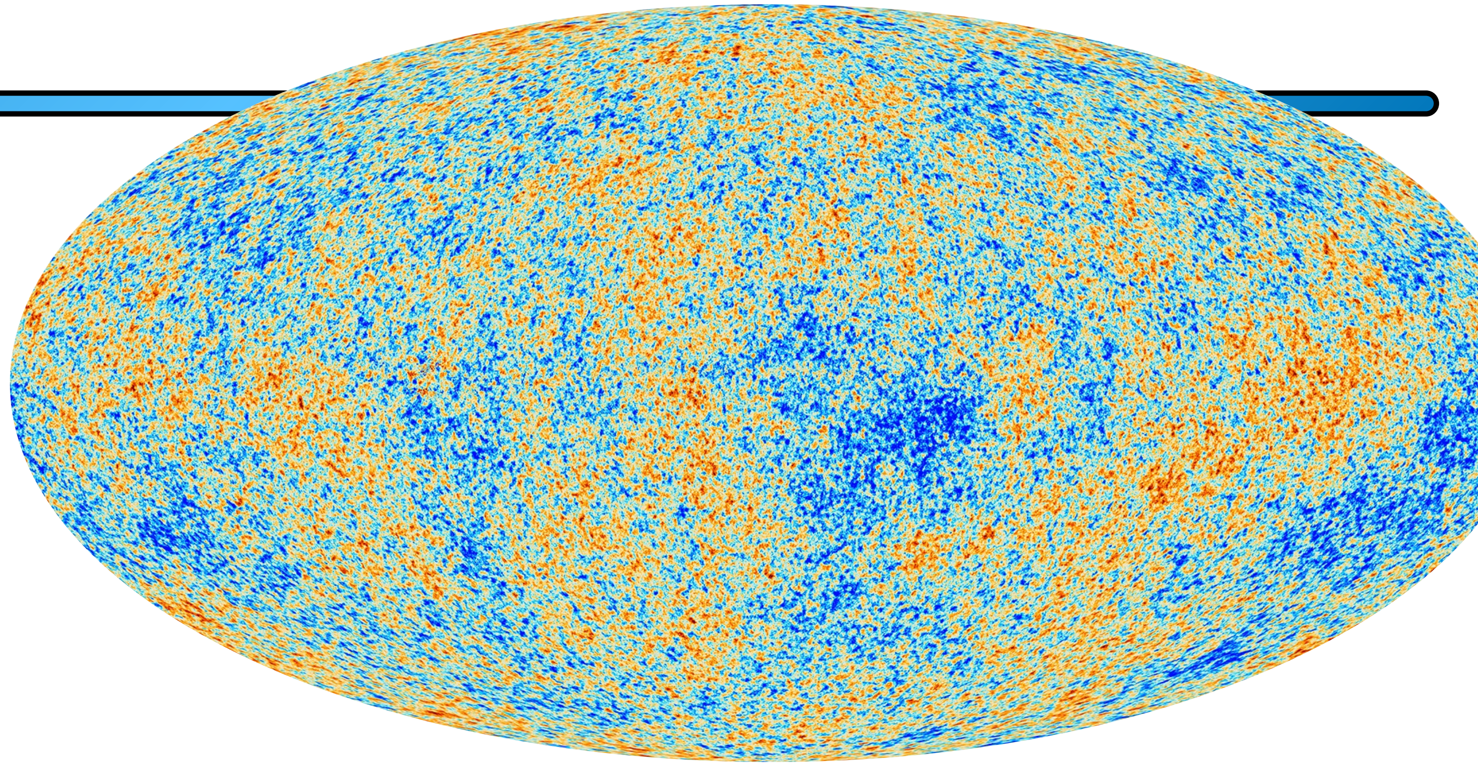
Based on 1804.07315 & 1806.05202

Work with Xingang Chen (Harvard)
Walter Riquelme, Bruno Scheihing & Spyros Sypsas (UCH)

COSMO18

Preamble



Inflation:

- An early stage of accelerated expansion
- It explains the origin of the primordial fluctuations that seeded the CMB
- The simplest models of inflation predict a scale invariant and nearly Gaussian distribution of primordial fluctuations

Inflation and primordial fluctuations 1

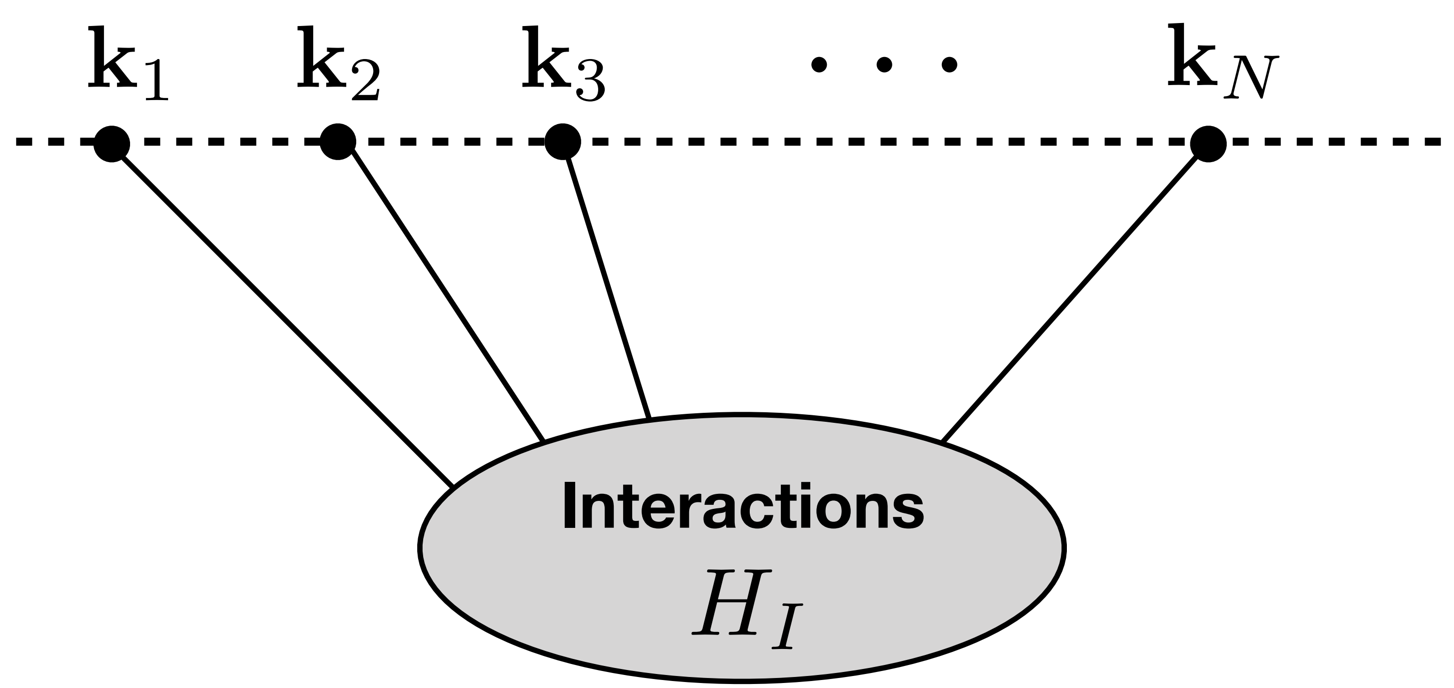
In inflation we are interested in predicting correlation functions:

$$ds^2 = -dt^2 + a^2(t)e^{2\zeta(t,\mathbf{x})}d\mathbf{x}^2 \qquad\qquad \zeta = -\frac{H}{\dot{\phi}_0}\delta\phi$$

To compute them we use the in-in formalism:

$$H_I(t) = \mathcal{O}(\zeta_I^3) + \mathcal{O}(\zeta_I^4) + \cdots$$

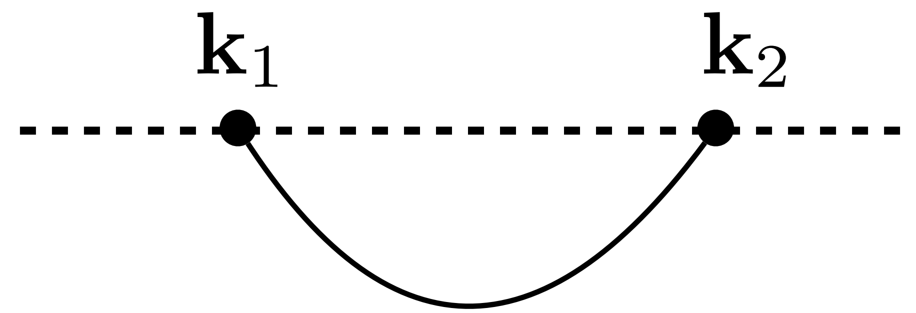
$$\langle \zeta_{\mathbf{k}_1}(t) \cdots \zeta_{\mathbf{k}_N}(t) \rangle =$$



Inflation and primordial fluctuations

Power spectrum

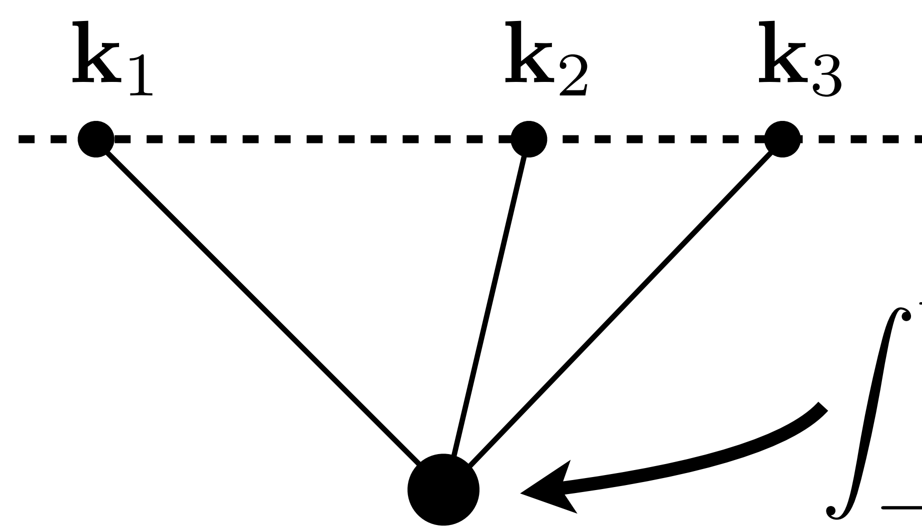
$$\langle \zeta_{\mathbf{k}_1} \zeta_{\mathbf{k}_2} \rangle =$$



$$= (2\pi)^3 \delta(\mathbf{k}_1 + \mathbf{k}_2) \frac{2\pi^2}{k^3} \mathcal{P}_\zeta(k)$$

Bi-spectrum

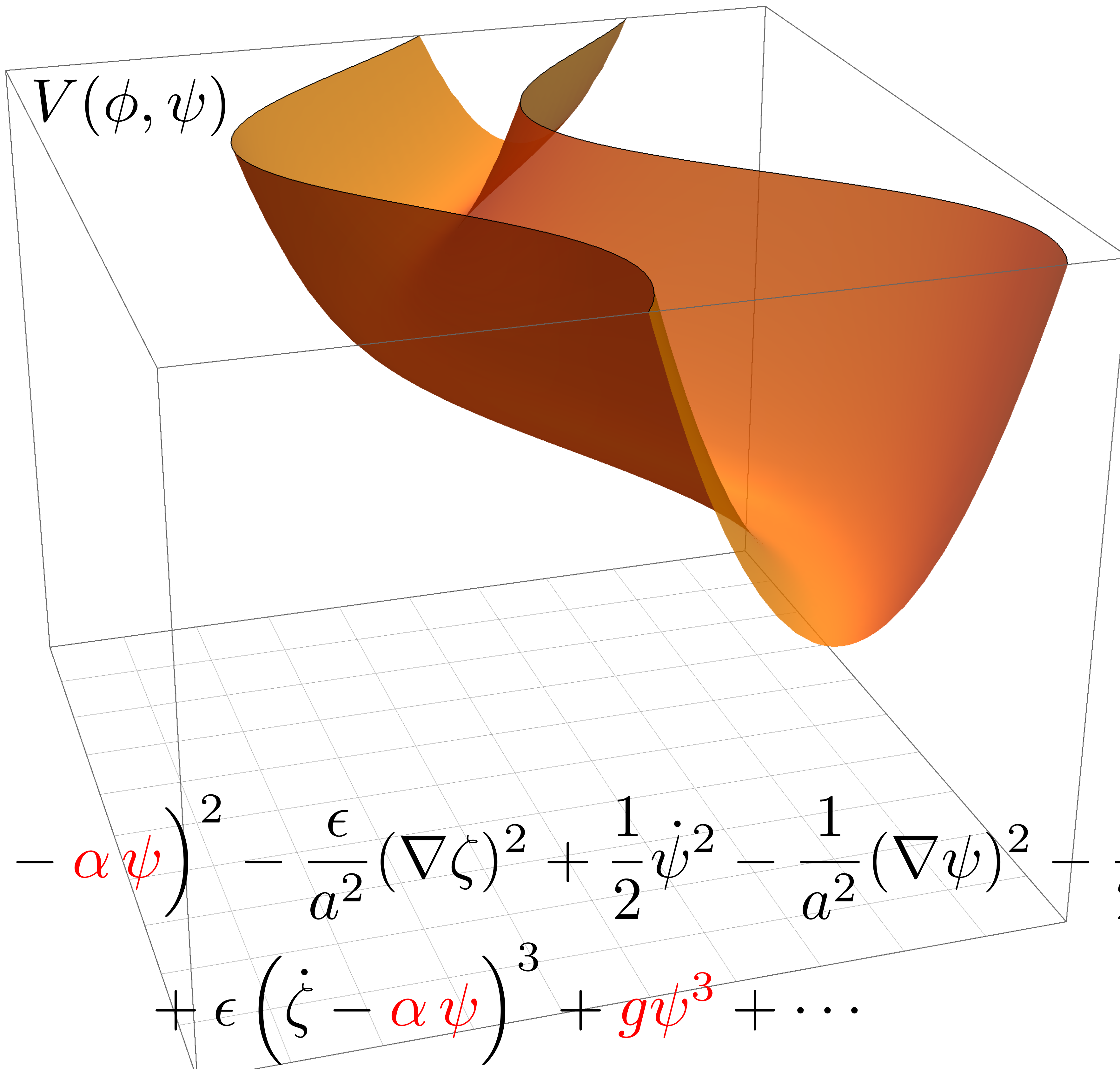
$$\langle \zeta_{\mathbf{k}_1} \zeta_{\mathbf{k}_2} \zeta_{\mathbf{k}_3} \rangle =$$



$$\int_{-\infty}^{t} dt' \ H_I^{(3)}(t') = \mathcal{O}(\zeta_I^3)$$

$$= (2\pi)^3 \delta(\mathbf{k}_1 + \mathbf{k}_2 + \mathbf{k}_3) B(\mathbf{k}_1, \mathbf{k}_2, \mathbf{k}_3)$$

Non-Gaussianity



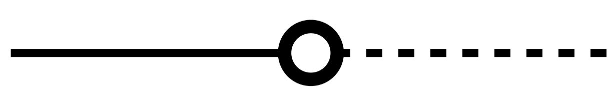
$$\mathcal{L} = \epsilon\left(\dot{\zeta} - \alpha\,\psi\right)^2 - \frac{\epsilon}{a^2}(\nabla\zeta)^2 + \frac{1}{2}\dot{\psi}^2 - \frac{1}{a^2}(\nabla\psi)^2 - \frac{1}{2}\mu^2\psi^2$$

$$+\,\epsilon\left(\dot{\zeta} - \alpha\,\psi\right)^3 + g\psi^3 + \cdots$$

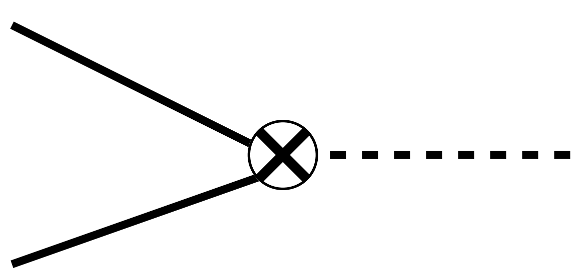
Non-Gaussianity

$$\mathcal{L} = \epsilon\left(\dot{\zeta} - \alpha\,\psi\right)^2 - \frac{\epsilon}{a^2}(\nabla\zeta)^2 + \frac{1}{2}\dot{\psi}^2 - \frac{1}{a^2}(\nabla\psi)^2 - \frac{1}{2}\mu^2\psi^2$$
$$+\,\epsilon\left(\dot{\zeta} - \alpha\,\psi\right)^3 + g\psi^3 + \cdots$$

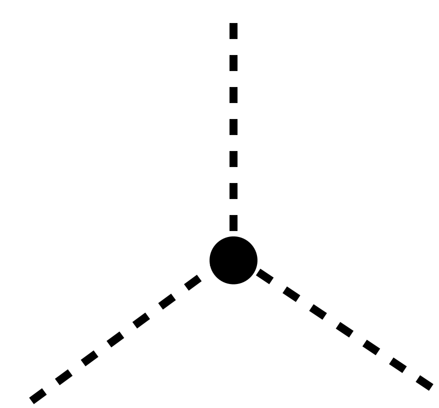
$\sim \alpha\dot{\zeta}\psi$:



$\sim \alpha\dot{\zeta}^2\psi$:



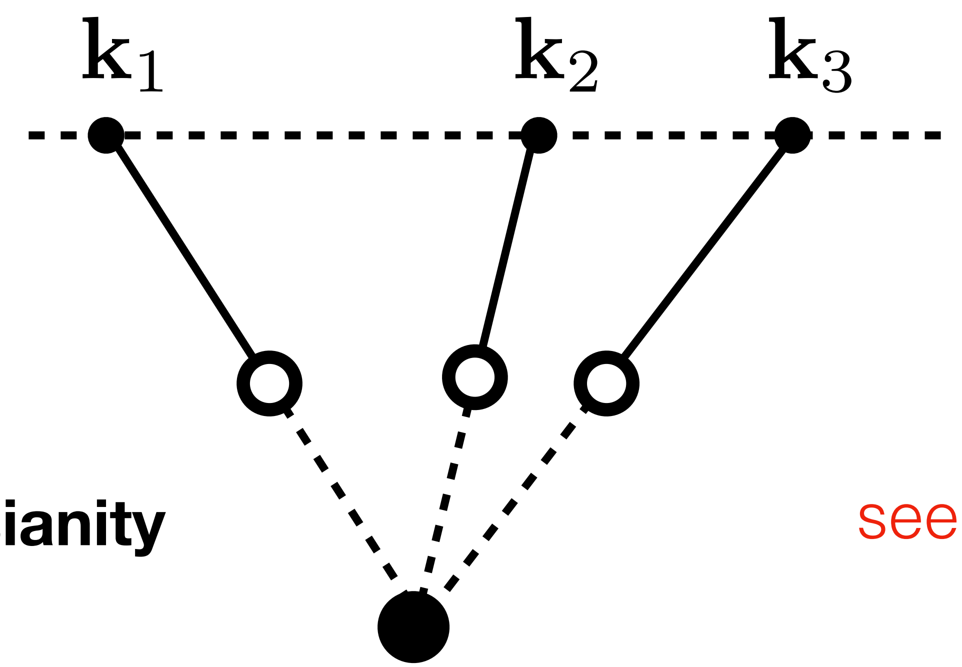
$g\psi^3$:



Non-Gaussianity

Quasi-single field:

$$\langle \zeta_{\mathbf{k}_1} \zeta_{\mathbf{k}_2} \zeta_{\mathbf{k}_3} \rangle =$$

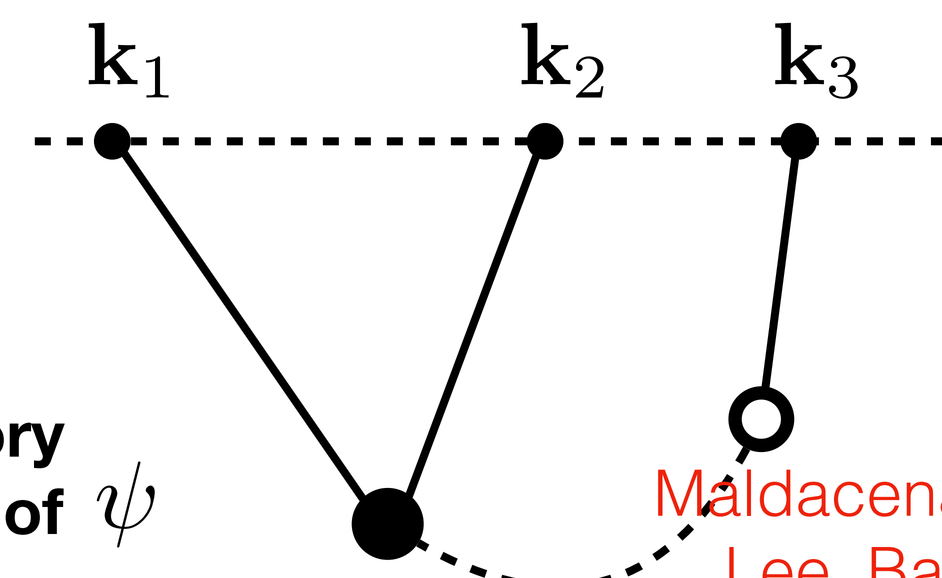


Enhances local non Gaussianity

Chen & Wang (2012)
see also Assassi et al. (2013)

Cosmological colliders:

$$\langle \zeta_{\mathbf{k}_1} \zeta_{\mathbf{k}_2} \zeta_{\mathbf{k}_3} \rangle =$$



Bispectrum with oscillatory patterns set by the mass of ψ

Maldacena & Arkani-Hamed (2016)
Lee, Baumann & Pimentel (2016)

Tomographic non-Gaussianity

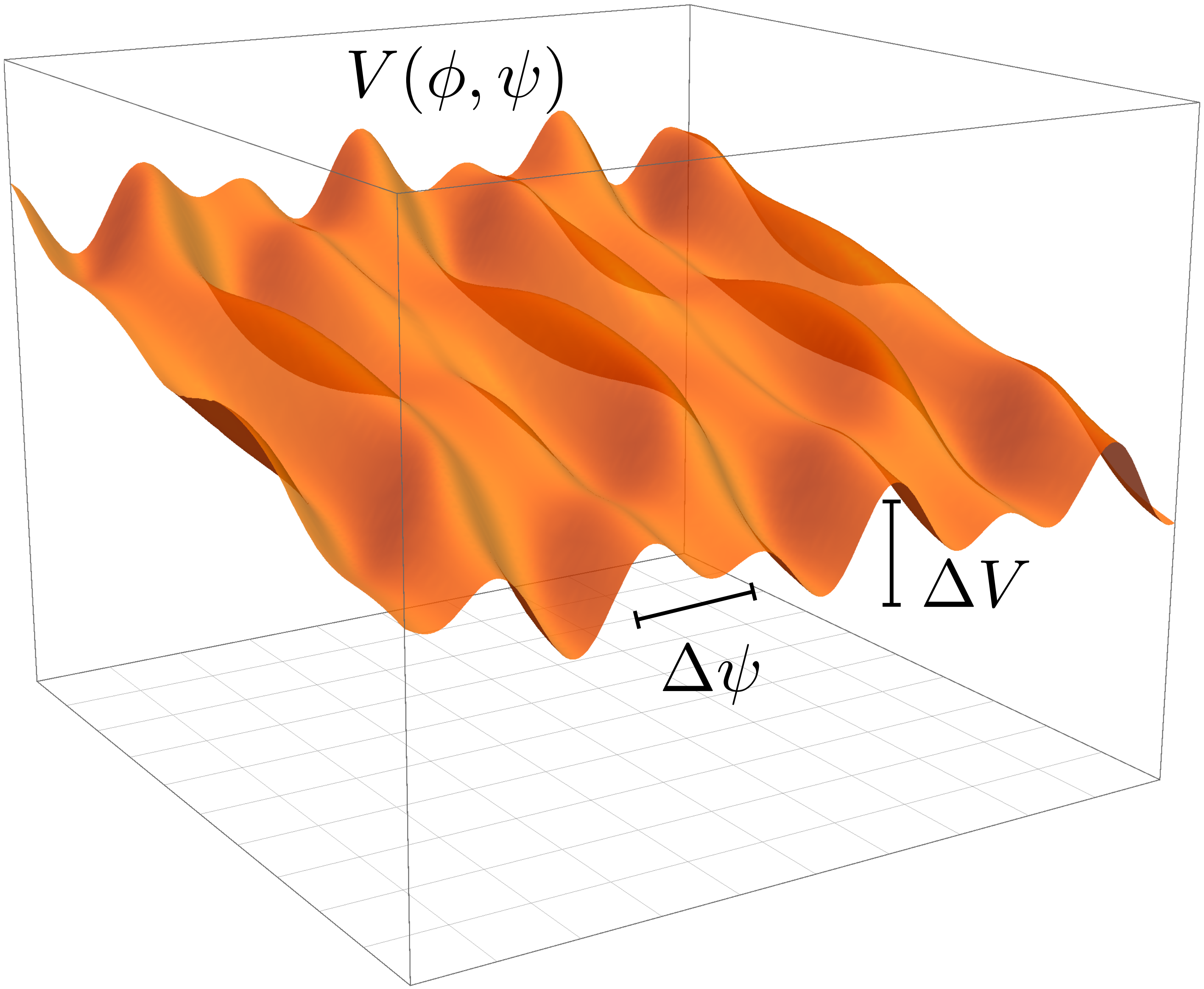
$$\mathcal{L} = \epsilon\left(\dot{\zeta} - \alpha\,\psi\right)^2 - \frac{\epsilon}{a^2}(\nabla\zeta)^2 + \frac{1}{2}\dot{\psi}^2 - \frac{1}{a^2}(\nabla\psi)^2 - \frac{1}{2}\mu^2\psi^2 + g\psi^3 + \cdots$$

What about a more general situation:

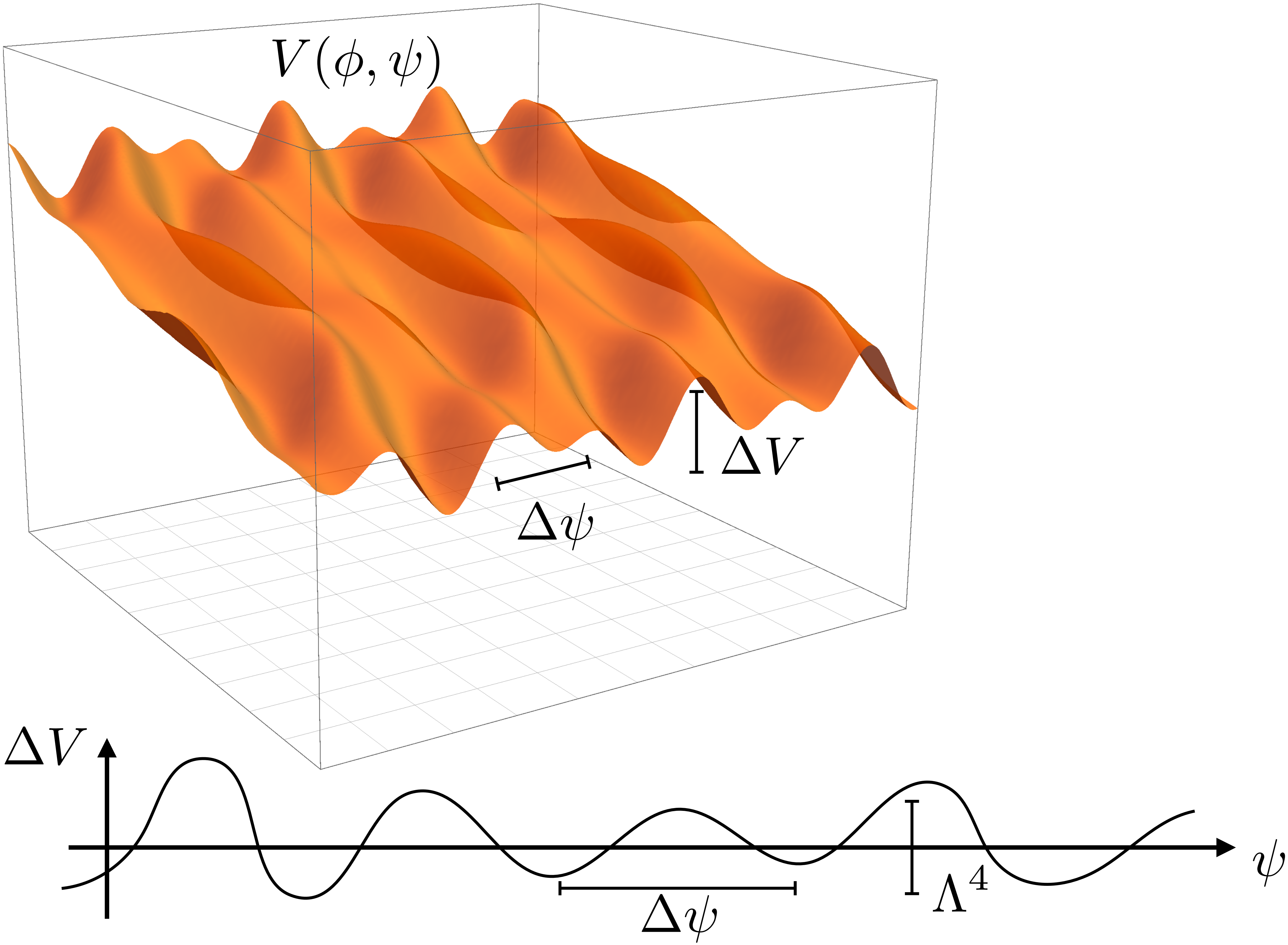
$$\mathcal{L} = \epsilon\left(\dot{\zeta} - \alpha\,\psi\right)^2 - \frac{\epsilon}{a^2}(\nabla\zeta)^2 + \frac{1}{2}\dot{\psi}^2 - \frac{1}{a^2}(\nabla\psi)^2 - \frac{1}{2}\mu^2\psi^2 + \Delta V(\psi) + \cdots$$

X. Chen, GAP, B. Scheihing, S. Sypsas (2018)

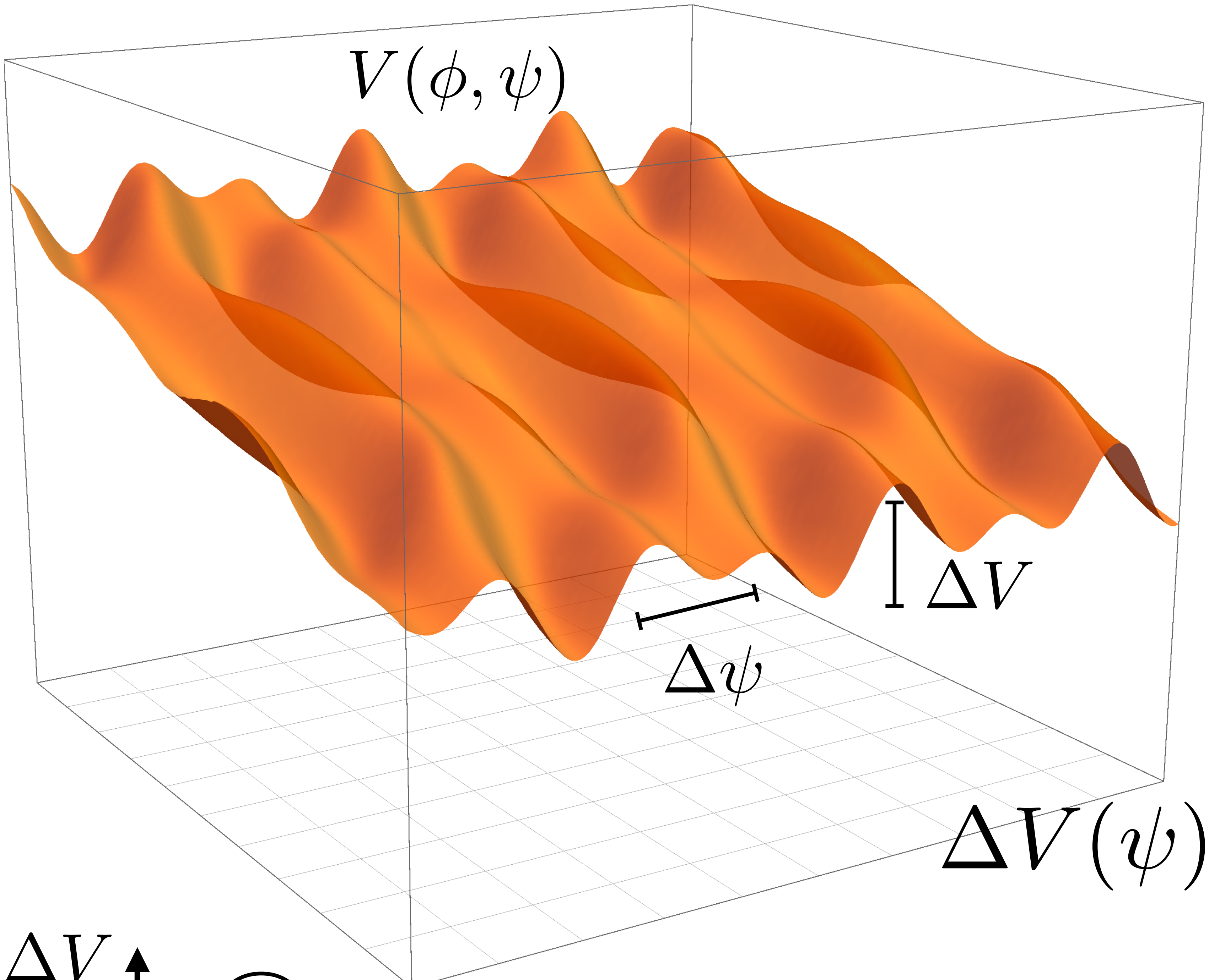
Tomographic non-Gaussianity



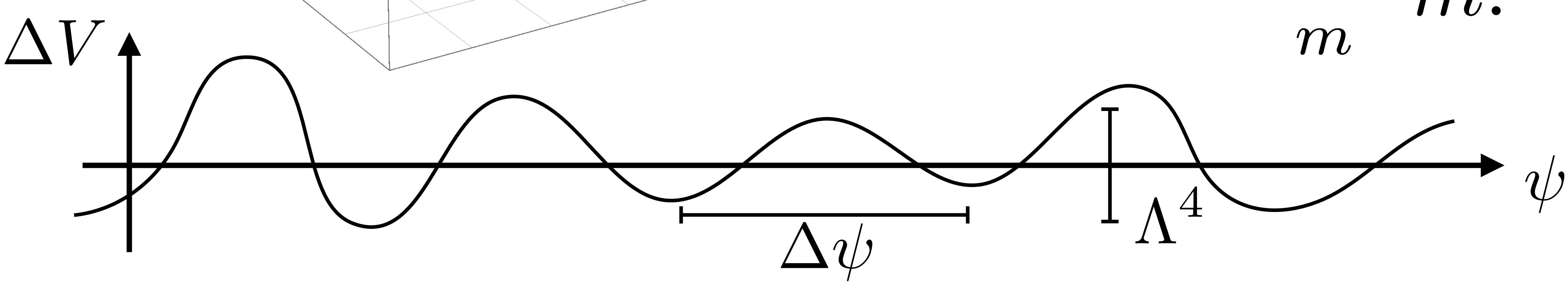
Tomographic non-Gaussianity



Tomographic non-Gaussianity



$$\Delta V(\psi) = \sum_m \frac{c_m}{m!}\psi^m$$



n-point correlation functions

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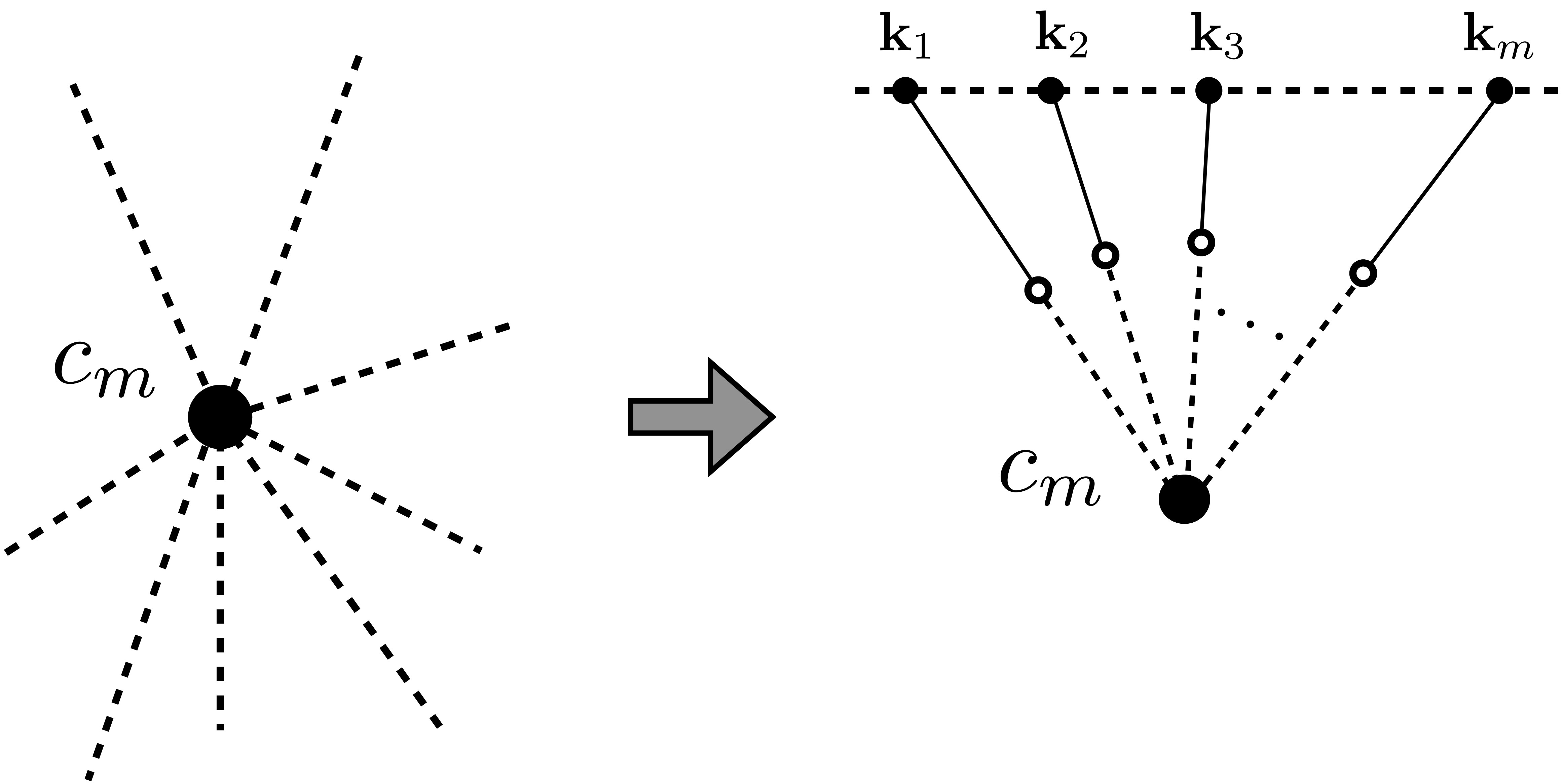

Recall Spyros Sypsas' talk

n-point correlation functions

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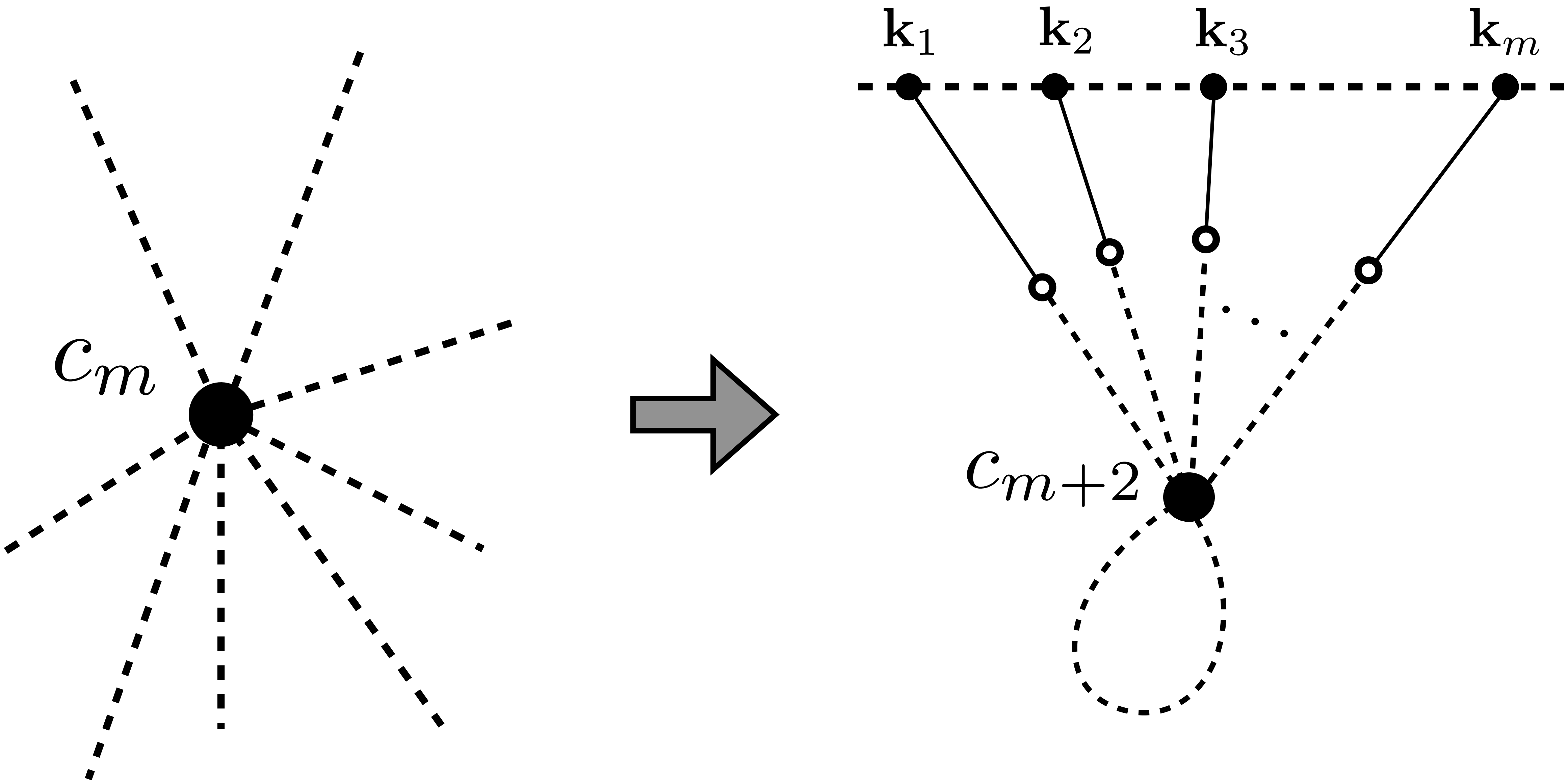

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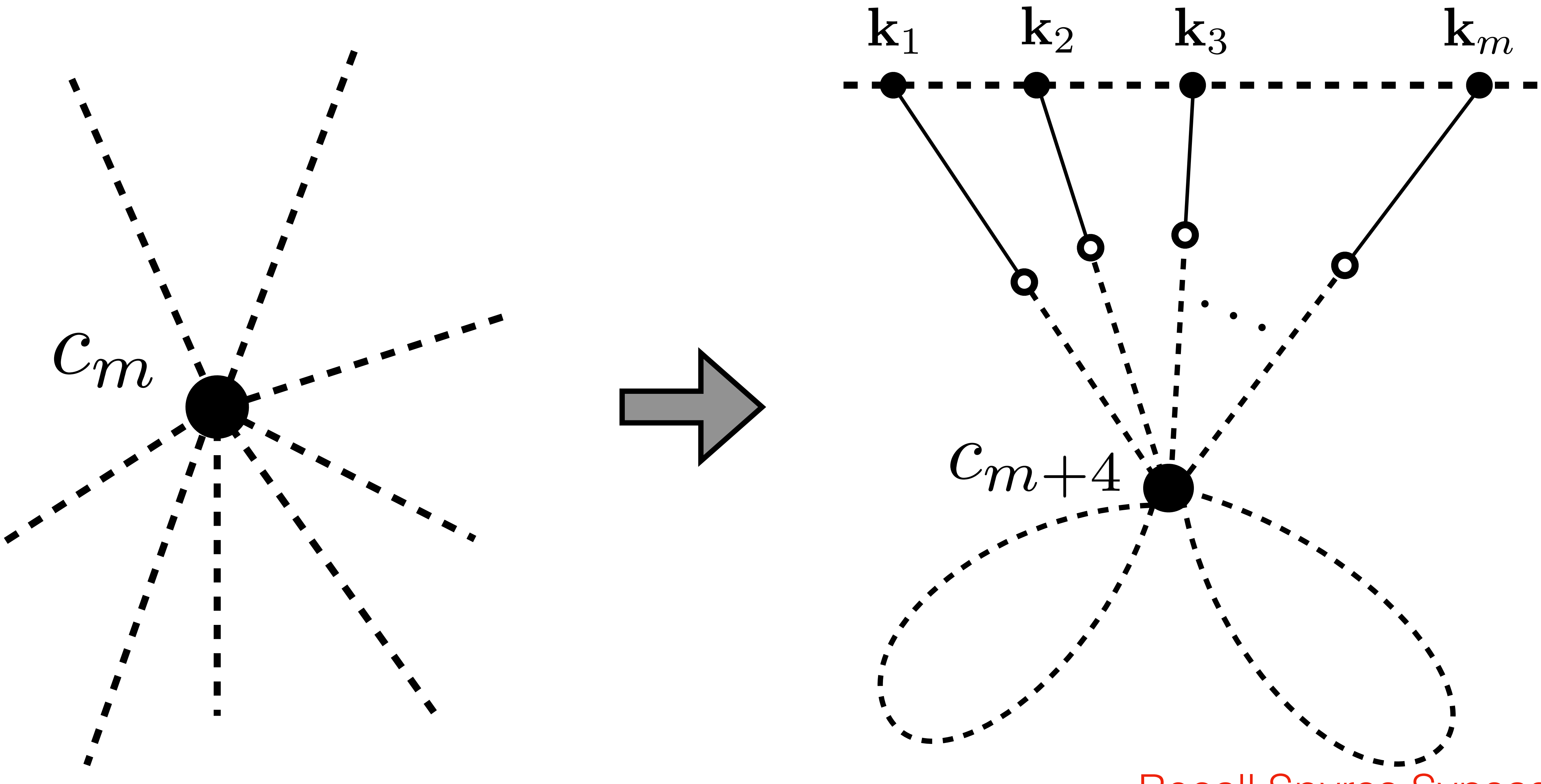

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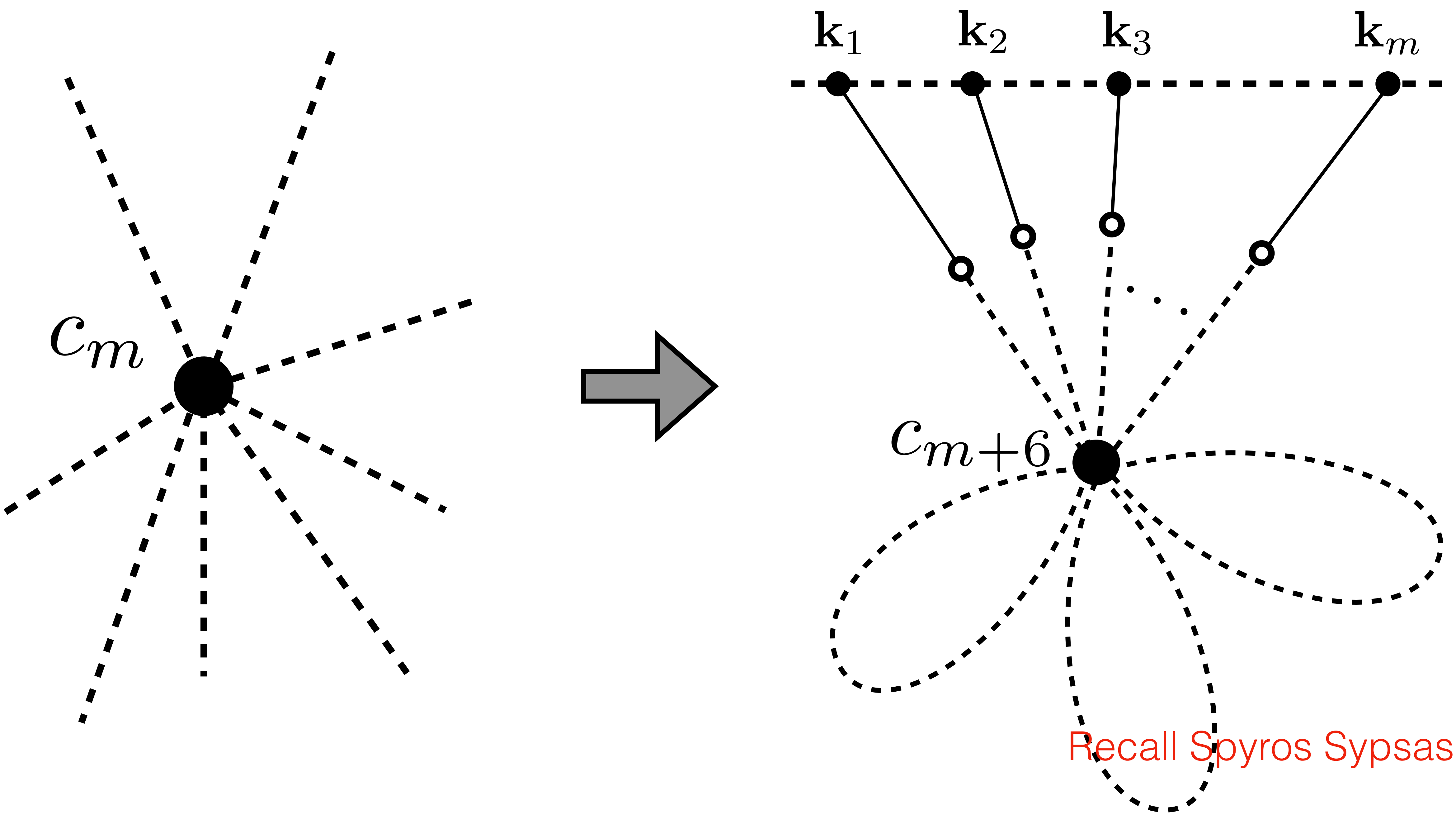

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n-point correlation functions

One finds:

$$\langle \zeta_{\mathbf{k}_1}(t) \cdots \zeta_{\mathbf{k}_N}(t) \rangle = (2\pi)^3 \, h_n \, \delta^3(\sum \mathbf{k}) \frac{k_1^3 + \cdots + k_N^3}{k_1^3 \cdots k_N^3}$$

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$$h_n = \frac{1}{n} \left(\frac{\alpha H \Delta N}{2\sigma_L} \right)^n \frac{\Delta N}{3H^4} \int d\psi \, \frac{e^{-\frac{\psi^2}{2\sigma_L^2}}}{\sqrt{2\pi}\sigma_L} \mathrm{He}_n\left(\psi/\sigma_L\right) \times \left(\sigma_L^2 \frac{\partial^2}{\partial \psi^2} - \psi \frac{\partial}{\partial \psi} \right) \Delta V_{\mathrm{ren}}(\psi),$$

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Probability distribution function

The reconstructed PDF is found to be

$$\rho(\zeta) = \frac{1}{\sqrt{2\pi}\sigma_\zeta} e^{-\frac{\zeta^2}{2\sigma_\zeta^2}} \left[1 + \Delta(\zeta)\right]$$

$$\Delta(\zeta) \equiv \int_0^\infty \frac{dx}{x} \mathcal{K}(x) \int_{-\infty}^\infty d\bar{\zeta} \; \frac{\exp\left[-\frac{\left(\bar{\zeta}-\zeta(x)\right)^2}{2\sigma_\zeta^2(x)}\right]}{\sqrt{2\pi}\sigma_\zeta(x)} \times \frac{\Delta N}{3H^4} \left(\sigma_\zeta^2 \frac{\partial^2}{\partial\bar{\zeta}^2} - \bar{\zeta}\frac{\partial}{\partial\bar{\zeta}}\right) \Delta V_{\mathrm{ren}}\left(\psi_{\bar{\zeta}}\right)$$

It looks complicated, but in fact it has some simple characteristics

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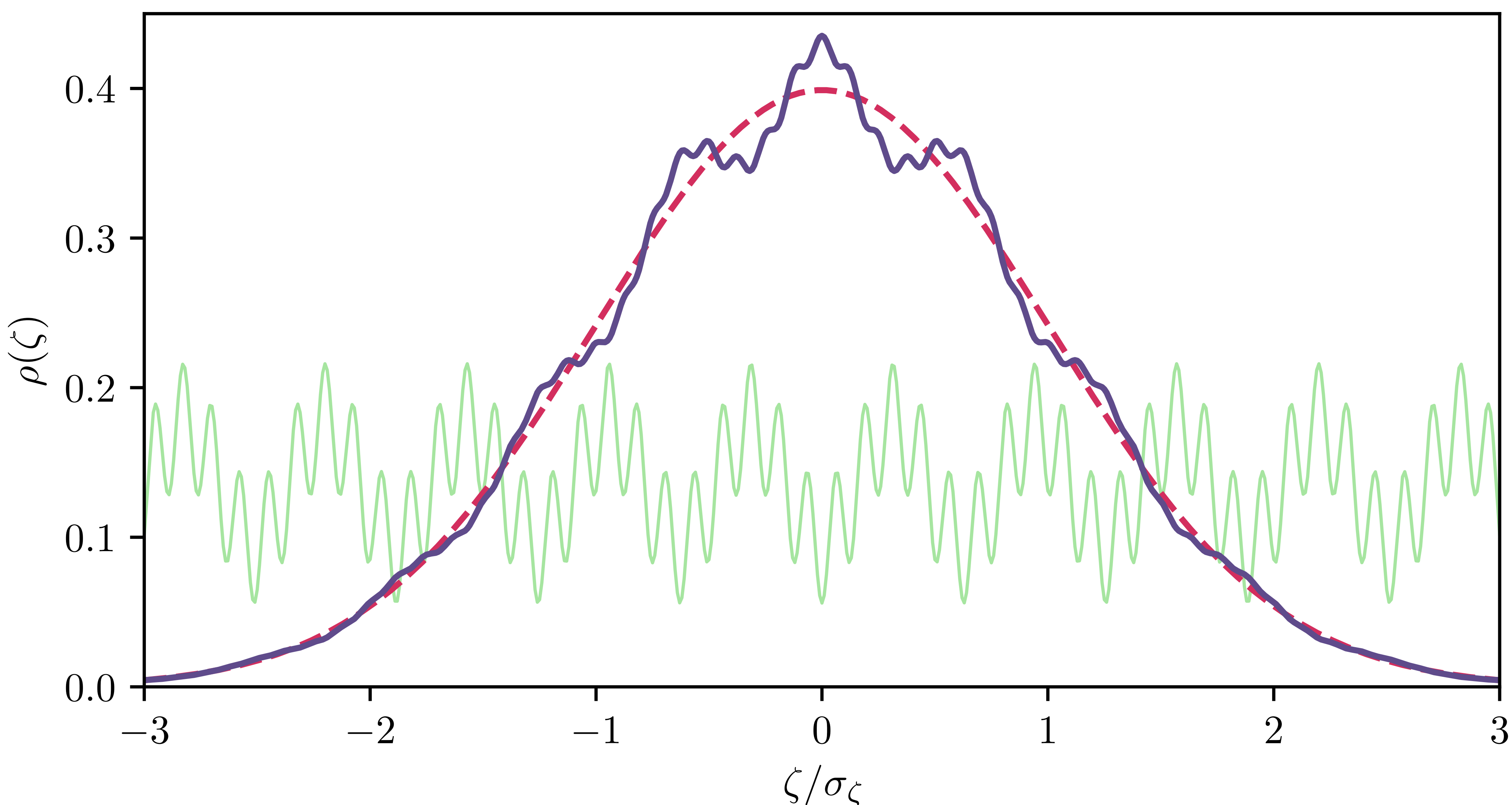
$$\times \frac{\Delta N}{3H^4} \left(\sigma_\zeta^2 \frac{\partial^2}{\partial \bar{\zeta}^2} - \bar{\zeta} \frac{\partial}{\partial \bar{\zeta}}\right) \Delta V_{\rm ren}\left(\psi_{\bar{\zeta}}\right)$$

It looks complicated, but in fact it has some simple characteristics

Probability distribution function

Example:

$$\Delta V(\psi) \propto [1 - \cos(\psi/f_1)] + [1 - \cos(\psi/f_2)]$$



Recall Spyros Sypsas' talk

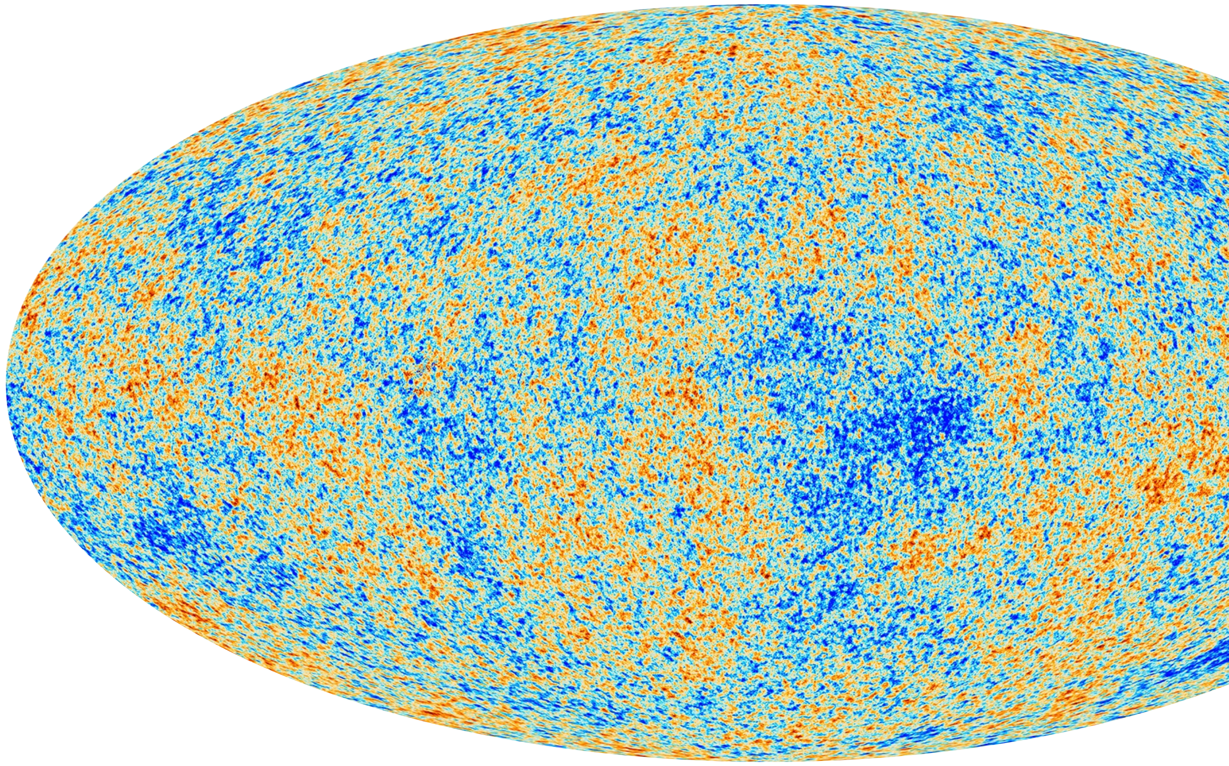
Primordial fluctuations and the CMB

We can compute: N-point functions at the end of inflation

$$\langle \zeta(\mathbf{x}_1, t)\zeta(\mathbf{x}_2, t)\cdots\zeta(\mathbf{x}_N, t)\rangle_{t=t_{\mathrm{end}}}$$

On Earth we observe: One realization of temperature fluctuations

$$\Theta(\hat{n}) \equiv \frac{\Delta T(\hat{n})}{T_0} = \frac{T(\hat{n}) - T_0}{T_0}$$



$$\Theta_{\mathbf{k}}(\hat{n}) = \mathcal{T}(k, \mu)\zeta_{\mathbf{k}}(t_{\mathrm{end}})$$

$$\mu \equiv \mathbf{k} \cdot \hat{n}$$

We may asses non-Gaussianity in a different way: Let us introduce a probability distribution function (PDF)

$$\rho(\zeta) \longrightarrow \rho(\Theta)$$

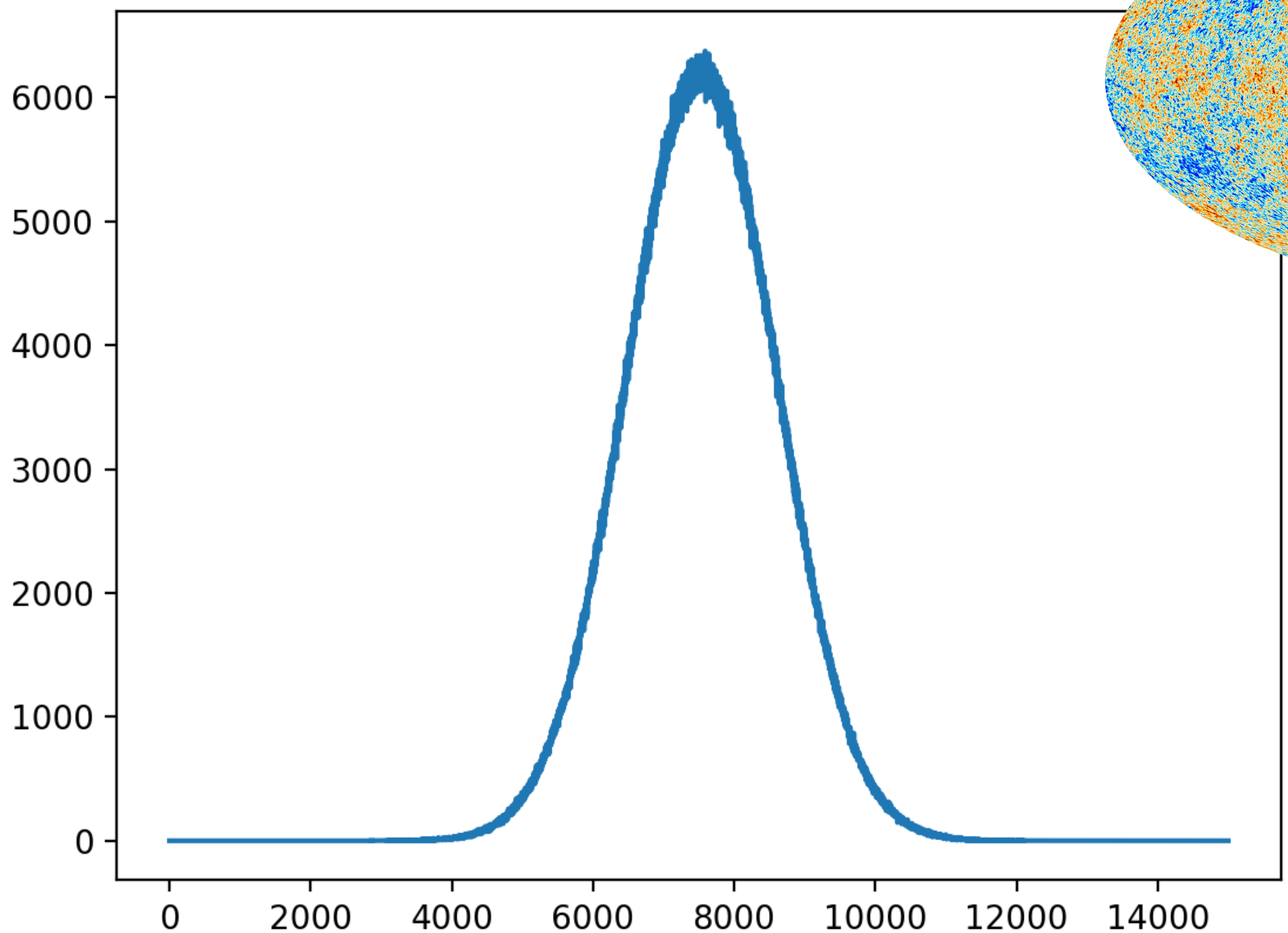
Such that $$\langle \Theta^n \rangle = \int d\Theta \; \rho(\Theta) \; \Theta^n$$

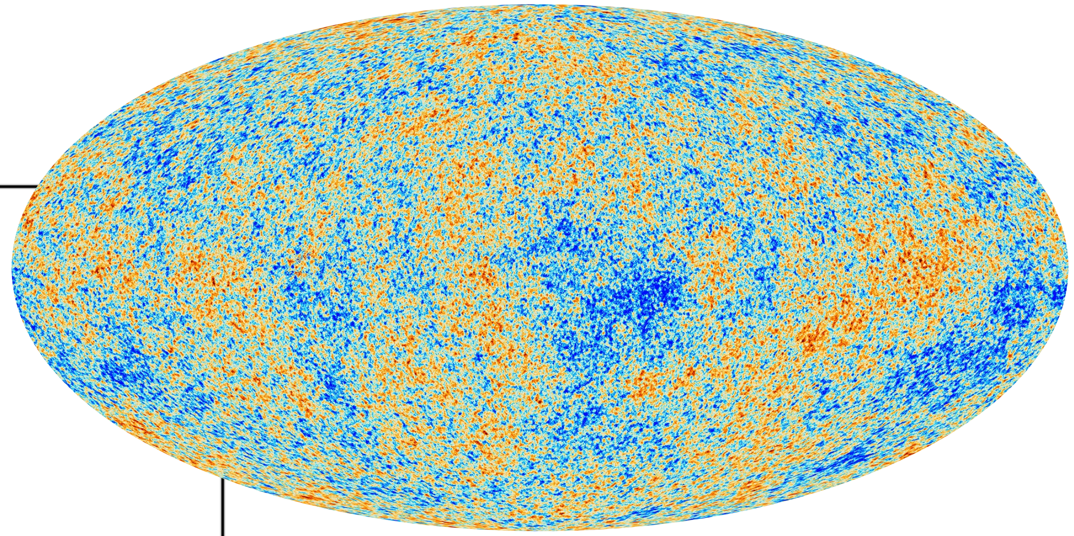
The variance of $\rho(\Theta)$ is found to be given by:

$$\sigma_\Theta^2 \equiv \langle \Theta(\hat{n}) \Theta(\hat{n}) \rangle = \int d\Theta \, \rho(\Theta) \, \Theta^2$$

$$\sigma_\Theta^2 = \frac{1}{4\pi} \sum_\ell (2\ell + 1) C_\ell$$

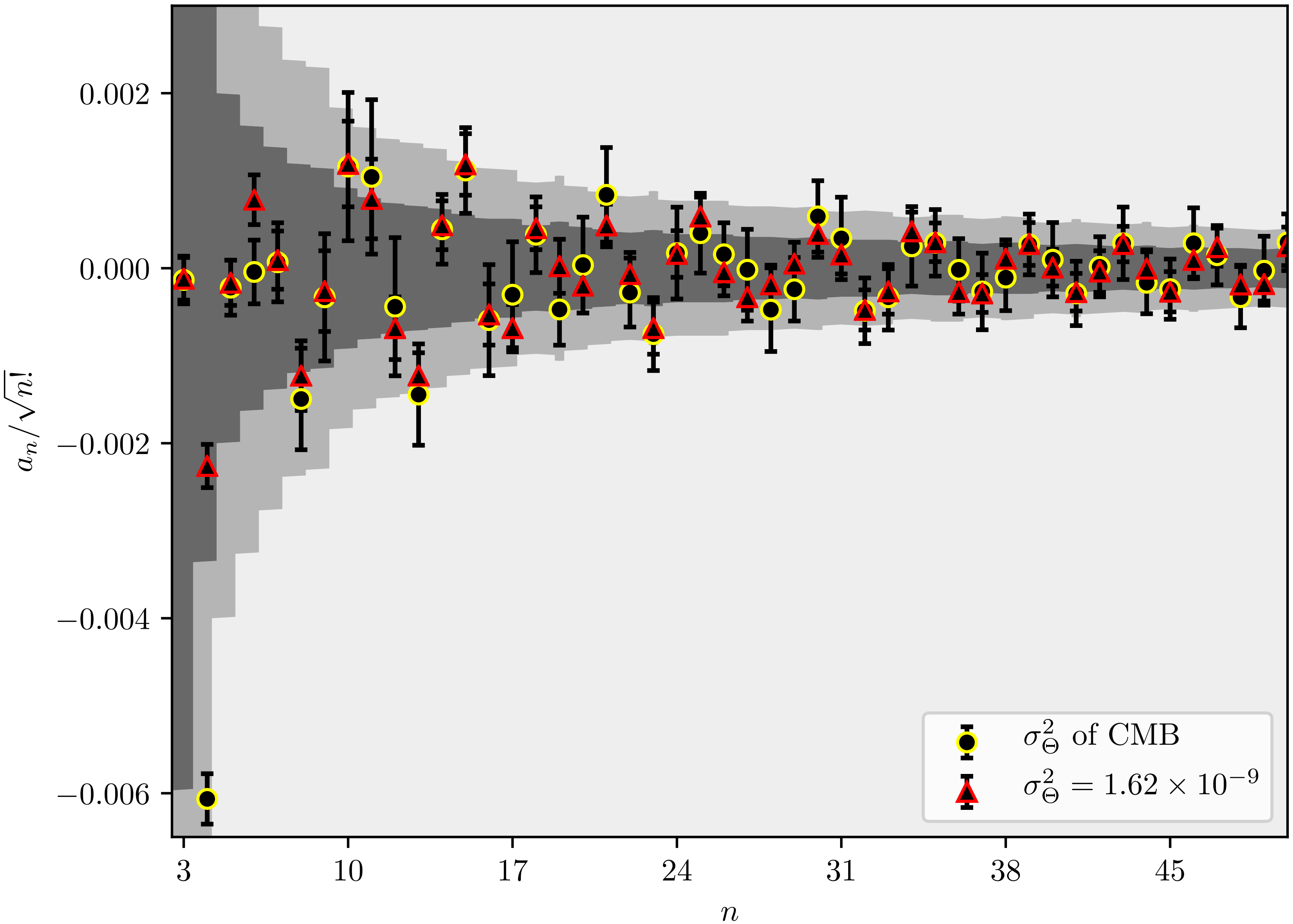
The reconstructed PDF from CMB data is





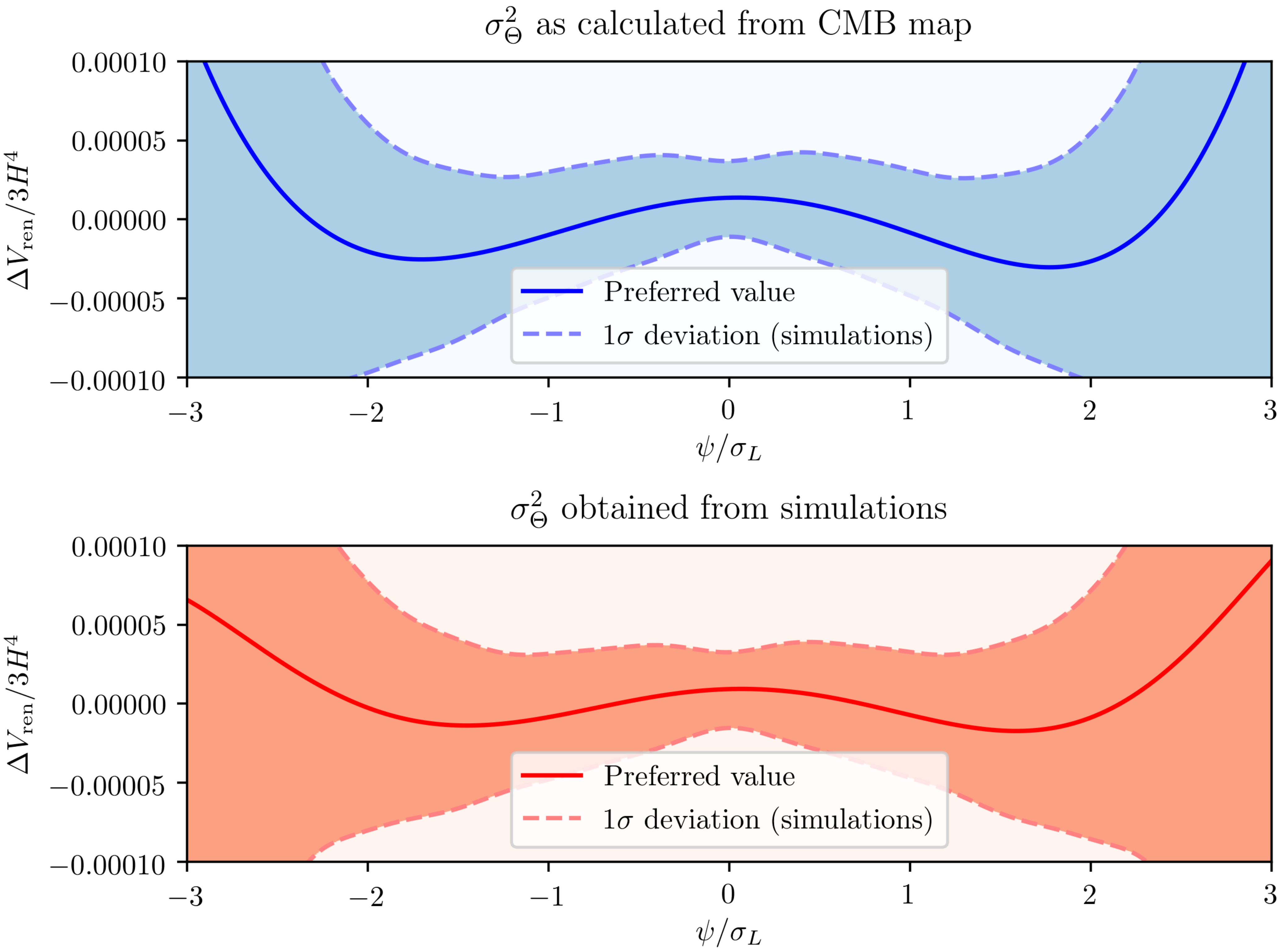
$$a_n \equiv \int d\Theta \, \rho(\Theta) He_n(\Theta/\sigma_\Theta)$$

Reconstructing the landscape



$$a_n \equiv \int d\Theta\, \rho(\Theta) He_n(\Theta/\sigma_\Theta) \longrightarrow \Delta V(\psi)$$

Reconstructing the landscape



Conclusions

- We have unveiled a novel class of NG that requires a description with many n-point functions

- Possibly, an effect only achievable with multi-field inflation

- Although not significant, current Planck data contains some level of tomographic NG

- Future CMB and LSS surveys will shed some light

Conclusions

Thanks!