(NonGaussian) Curvature Perturbations from Entropy Generation on Cosmic Trajectories

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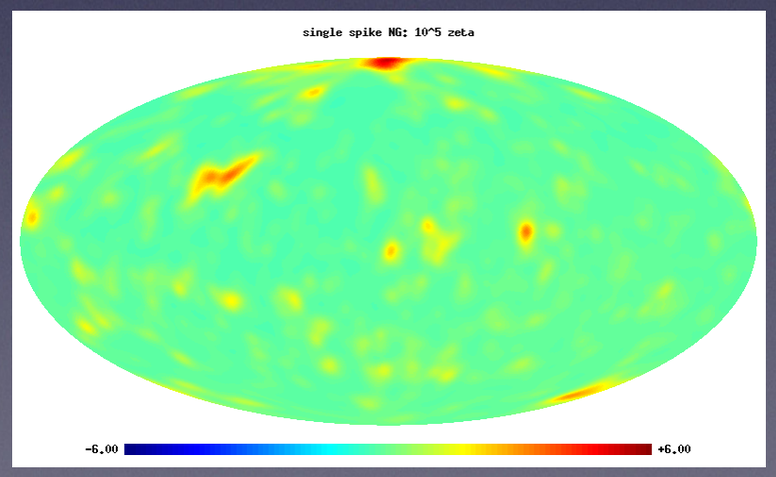


Work with

Dick Bond, *Andrei Frolov*,

Zhiqi Huang, Thomas Morrison,

Jibran Haidar, Jaafar Chakrani

Particle Physics Meets Inflationary Reheating

ζ and Entropy [JB and Bond, in progress]

$$\frac{d\zeta}{dt} = \frac{1}{3(1+w)}\frac{d\ln\rho}{dt} + \frac{d\ln a}{dt}$$
$$= \frac{T}{3V(\rho+P)}\frac{dS}{dt}$$

Entropy Production → ζ Production

Entropy Production Mechanisms

- Potential features during inflation [JB, Bond, Morrison]
  - Nonlinear superhorizon evolution
  - Particle production during inflation
- End-of-inflation dynamics [JB, Bond, Frolov, Huang]
- Initial Conditions [JB, Johnson, Peiris, Aguirre]

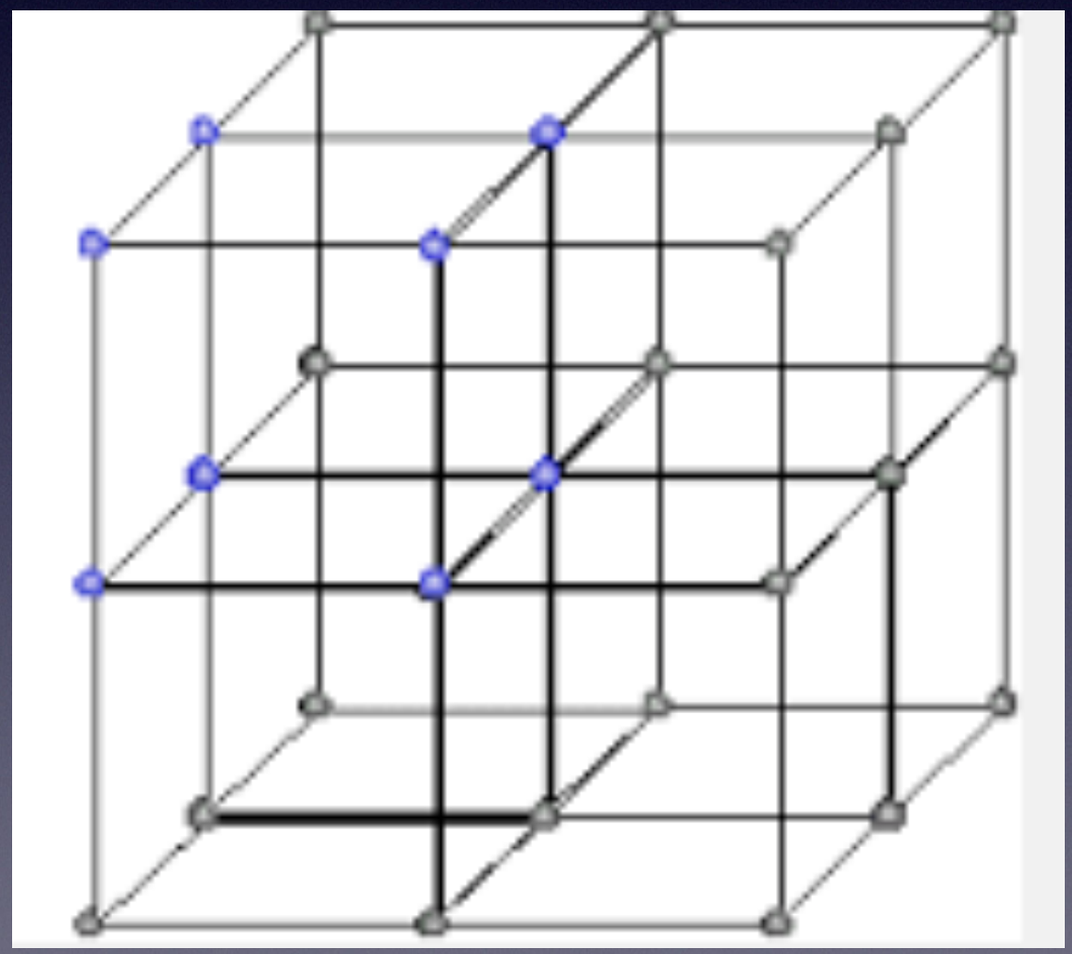
Lattice Simulations

[Braden]

$$\frac{\mathcal{L}}{\sqrt{|g|}} = -\frac{1}{2}G_{IJ}(\phi)\partial_\mu\phi^I\partial^\mu\phi^J - V(\phi) + \frac{M_P^2}{2}f(\phi)R_{\rm FRW}$$

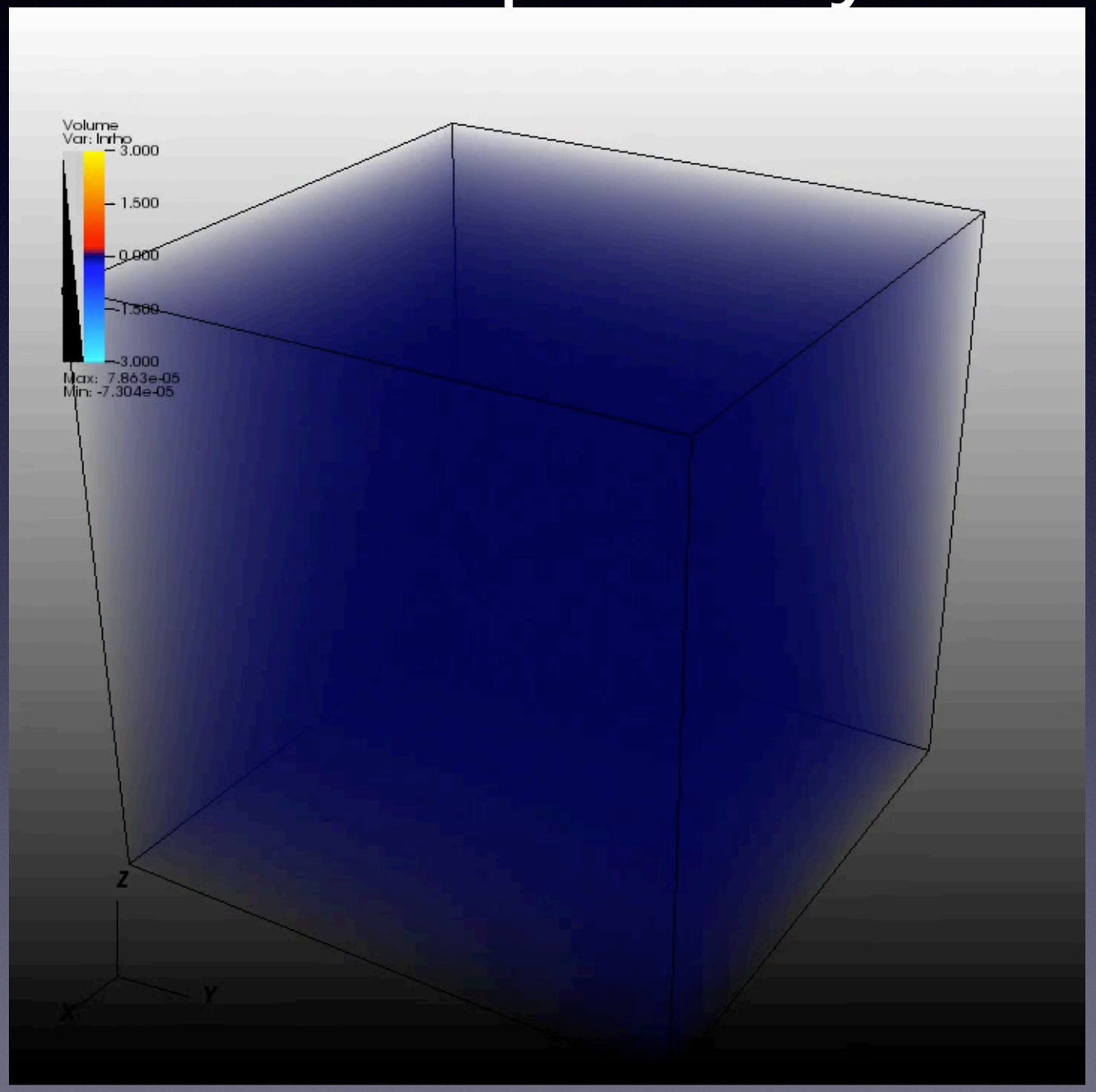
$$ds^2 = -dt^2 + a^2(t)d\mathbf{x}^2$$

- Finite-difference or pseudospectral
- 10th order Gauss-Legendre (general) or 8th order Yoshida (nonlinear sigma model)
- Quantum fluctuations → random field realization
- Scales to (at least) 2048^3 sites



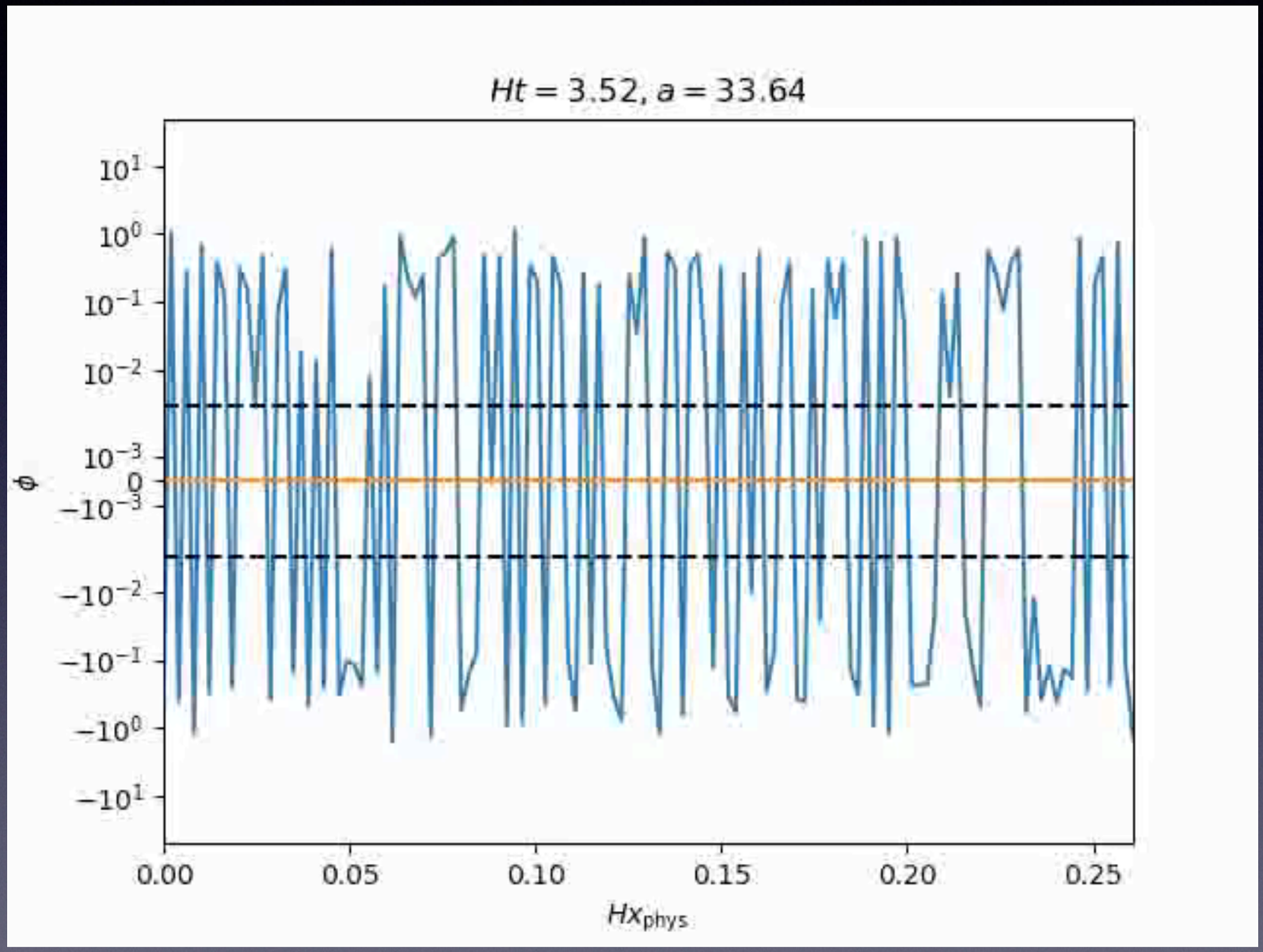
$\mathcal{O}(10^{-15})$ convergence

Nonlinearity Leads to Complexity



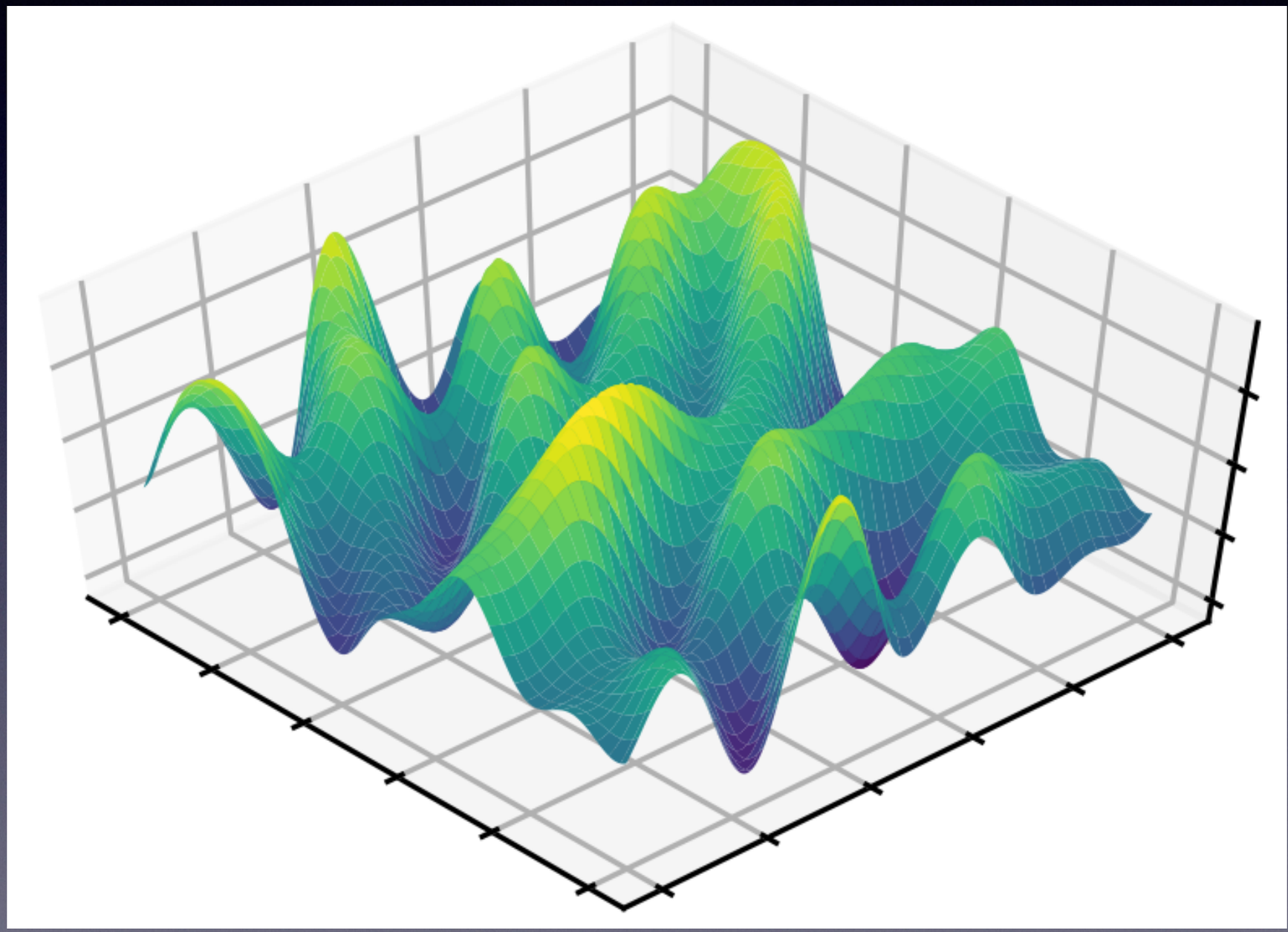
$$\ln \frac{\rho}{\langle \rho \rangle}$$

Superhorizon Complexity



Time evolution of large scale condensate

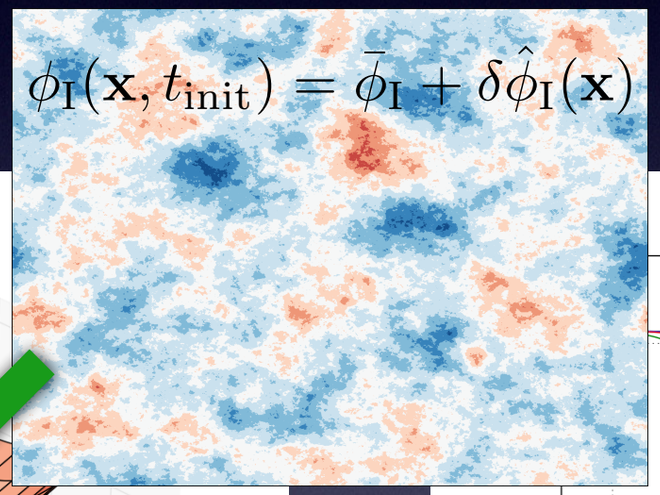
Inflation may have been complex

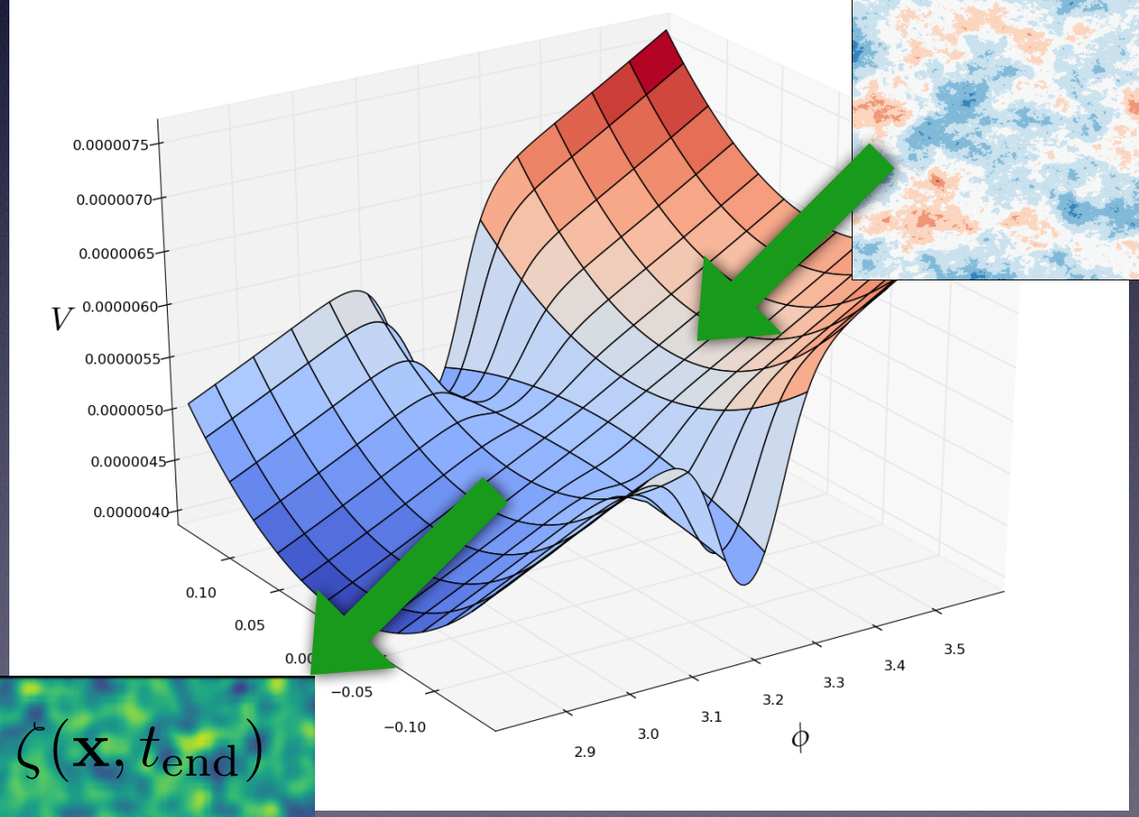


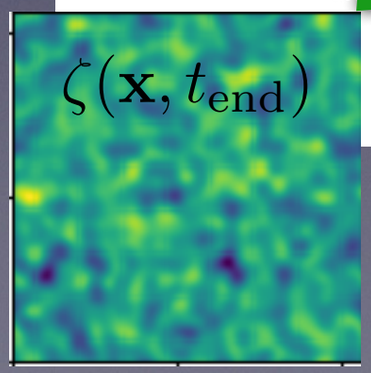
Tachyonic Features

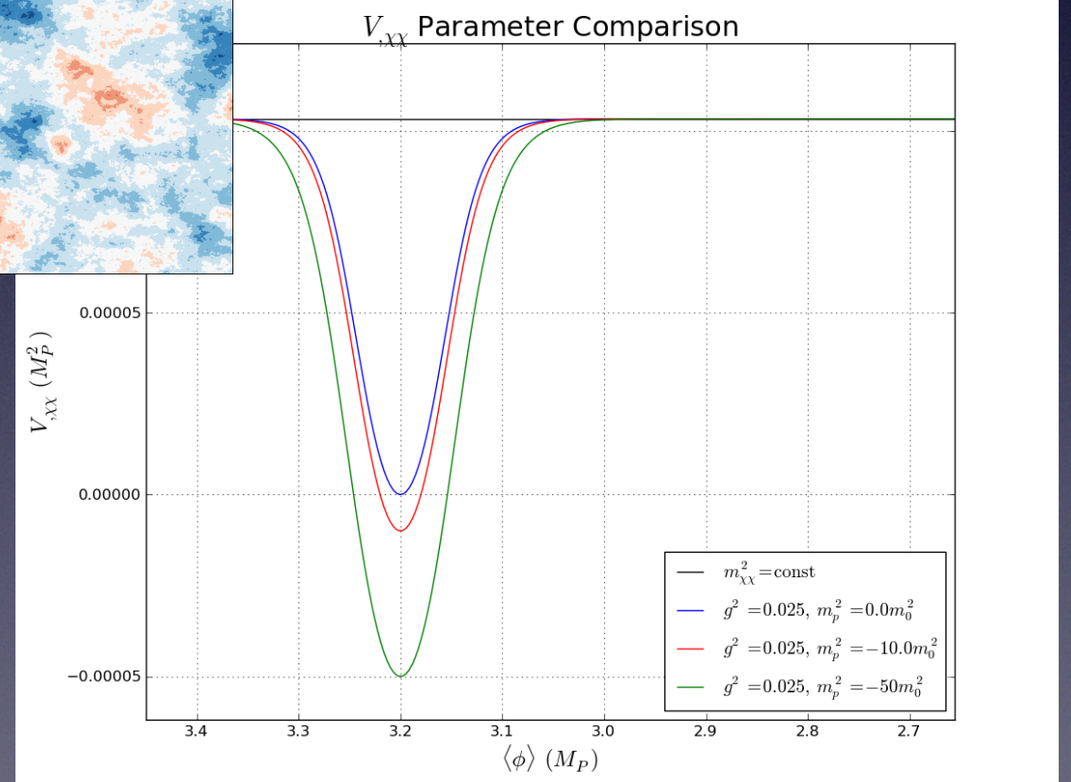
[Bond, JB, Thomas Morrison]

$$V(\phi) = V_{\rm inf} + \frac{m^2(\phi)}{2}\chi^2 + V_{\rm stabilise}(\chi)$$

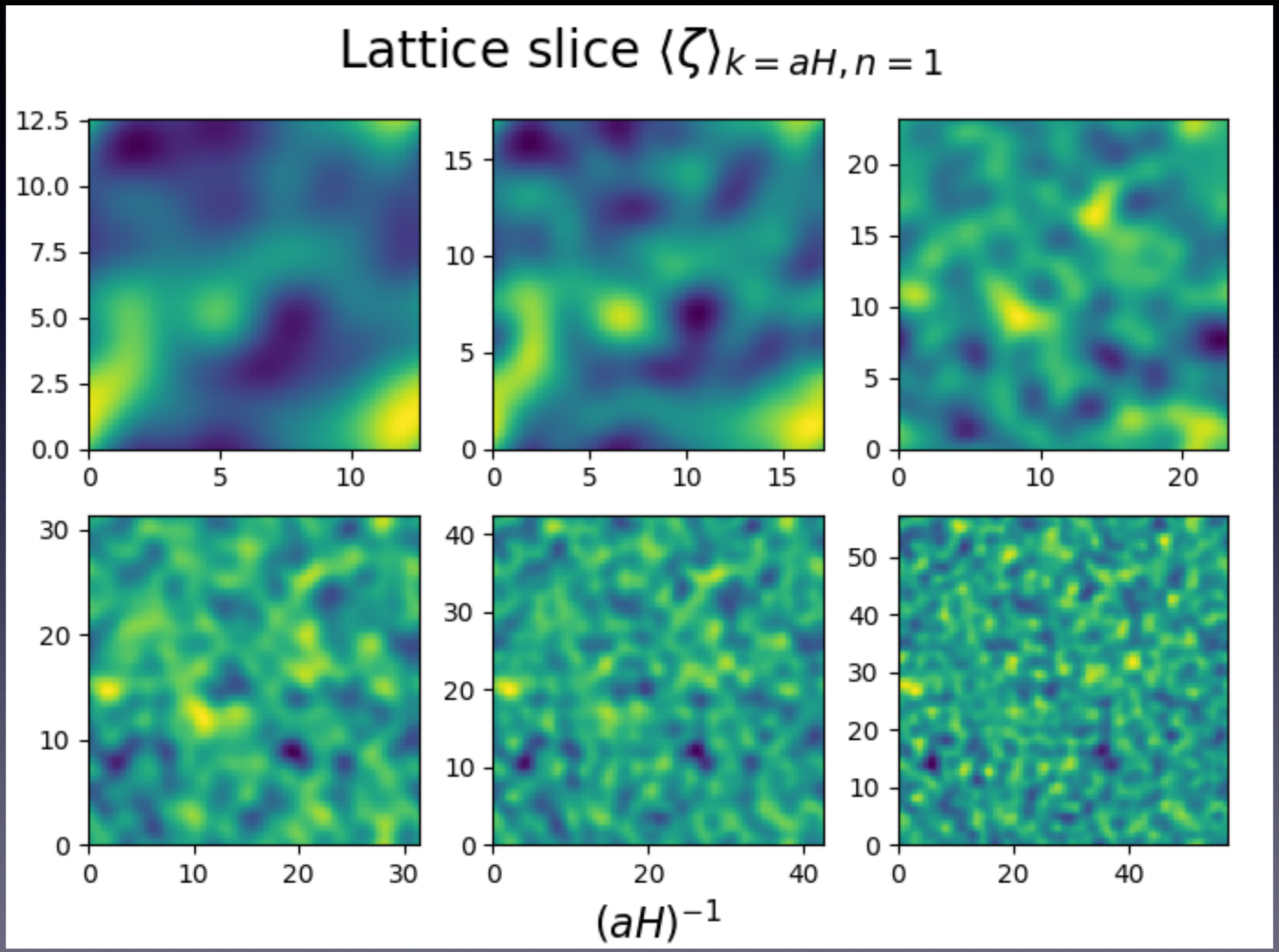






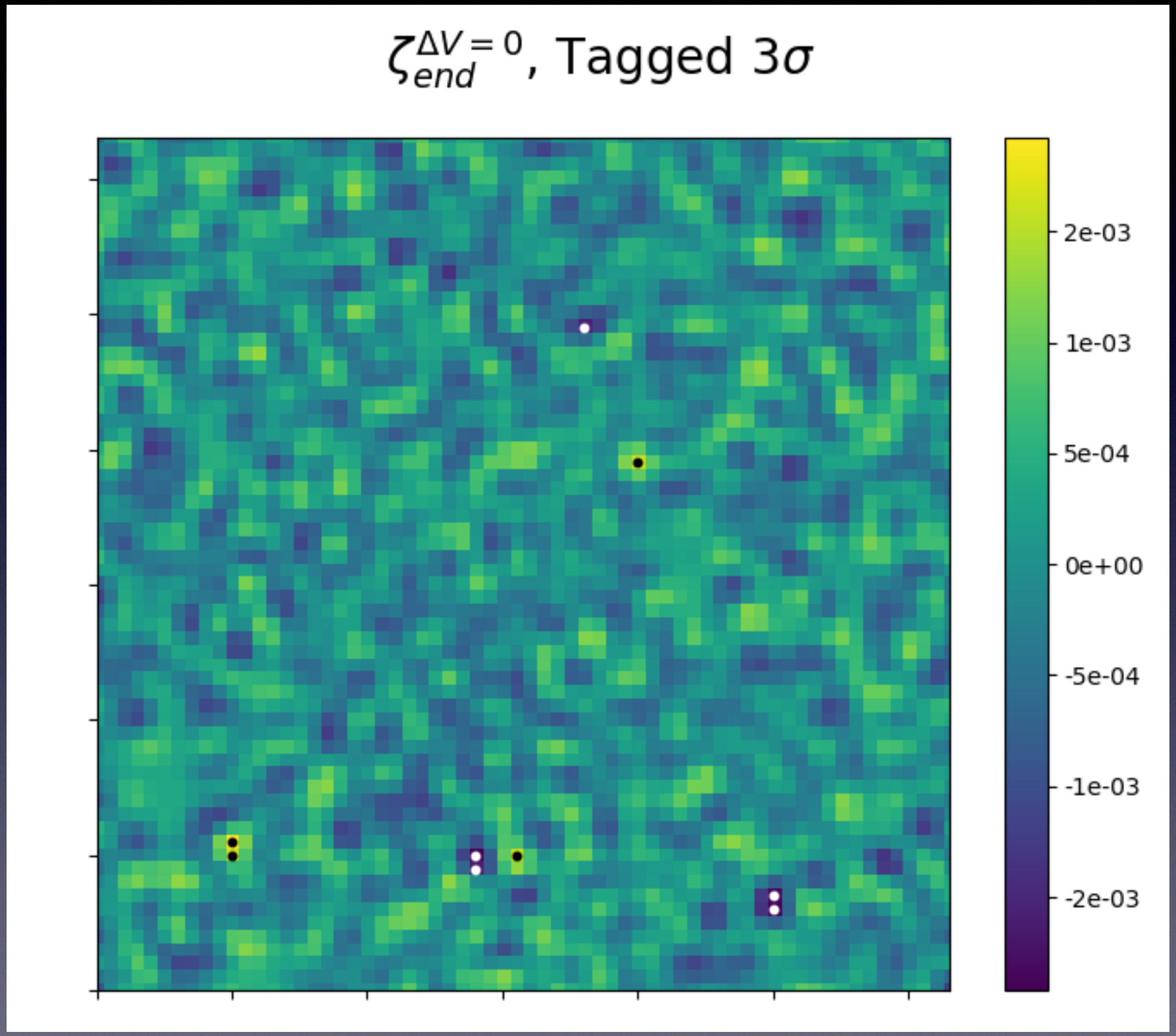


Development of Structure

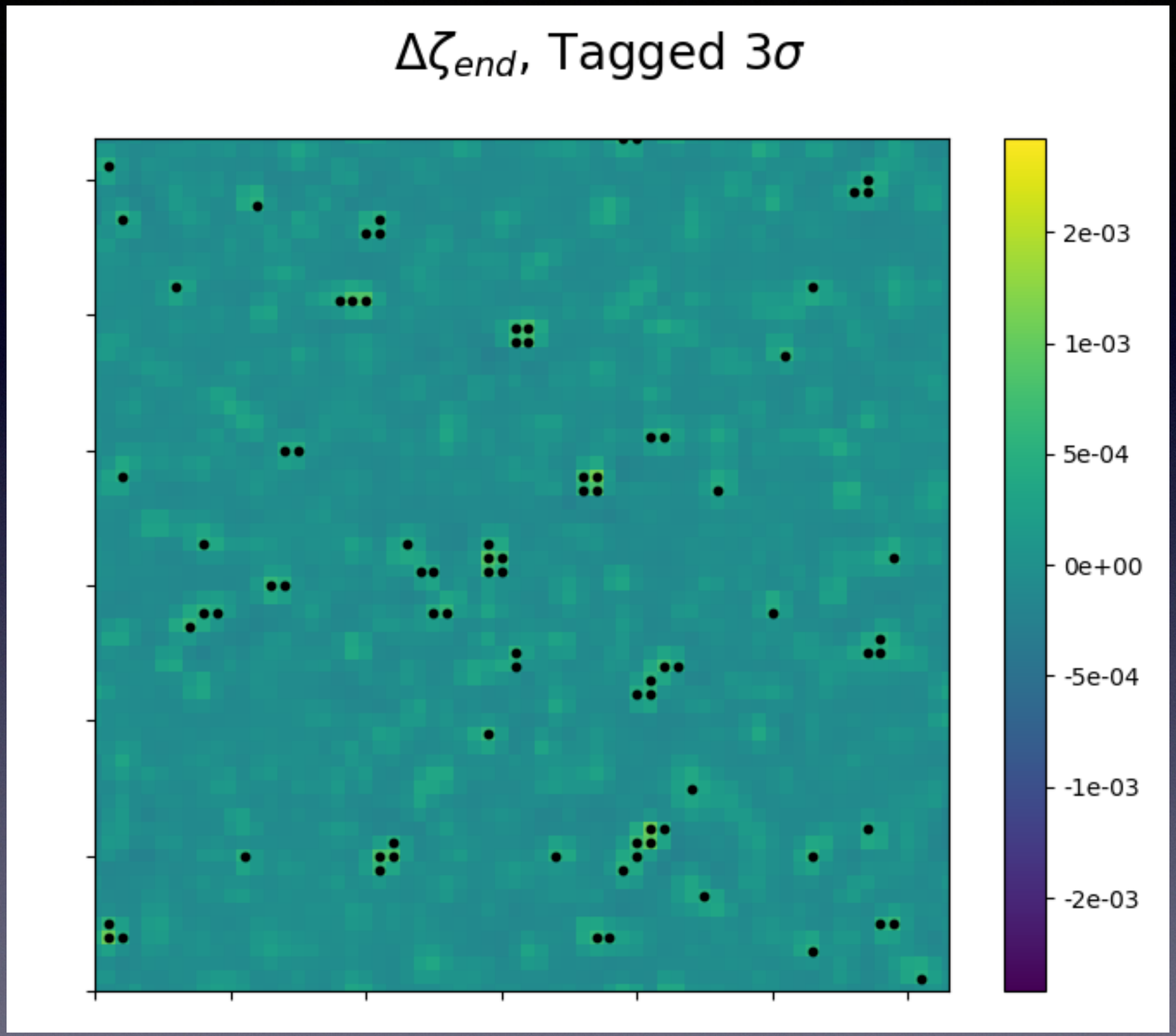


Freezeout of large-scale modes after transient

Inflation + Particle Production

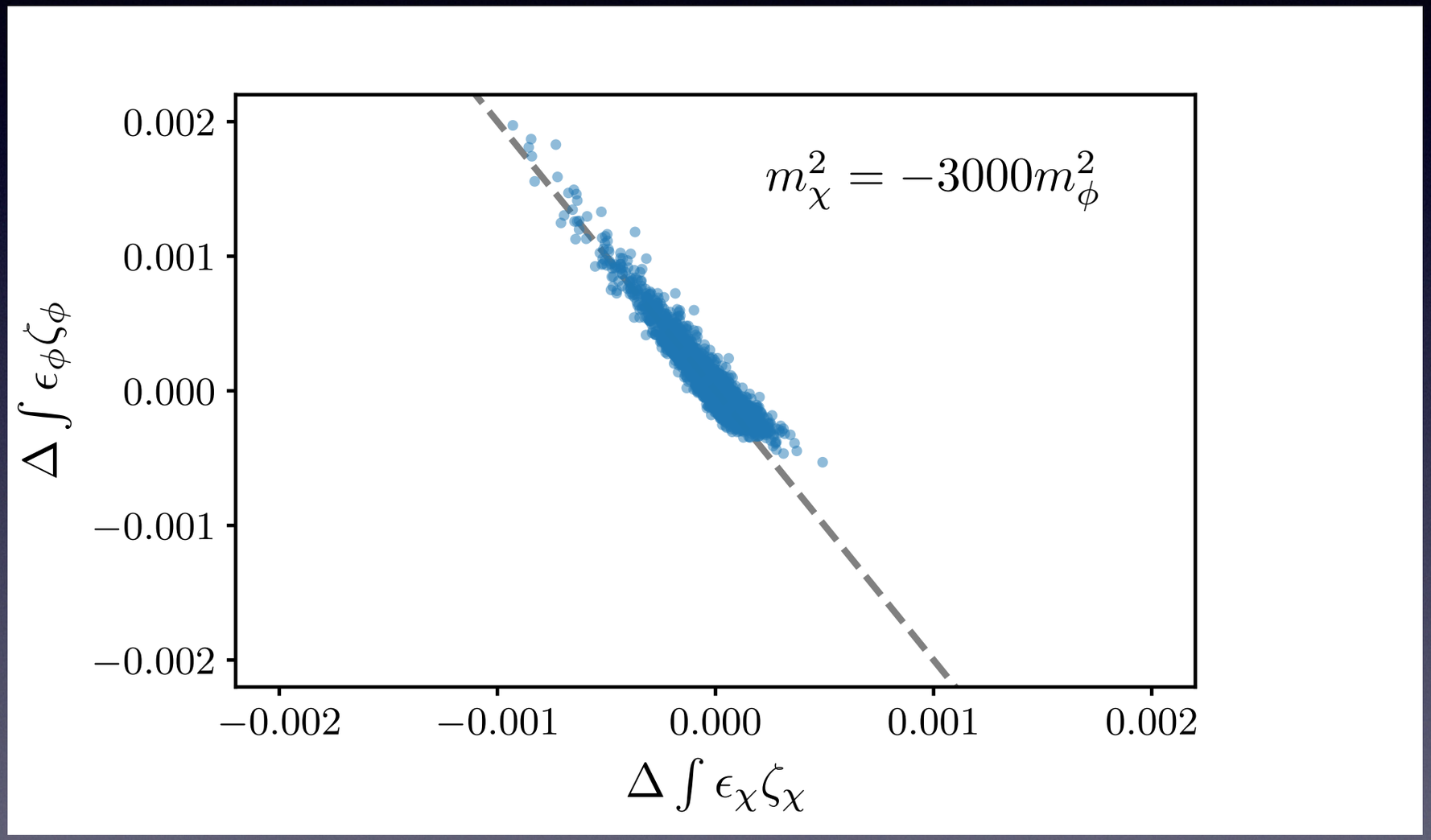


Contribution from Particle Production



$$\zeta(x) = \zeta_{\mathrm{G}}(x) + \sum_i A_i P_i(\Lambda^{-1}(x - x_i))$$

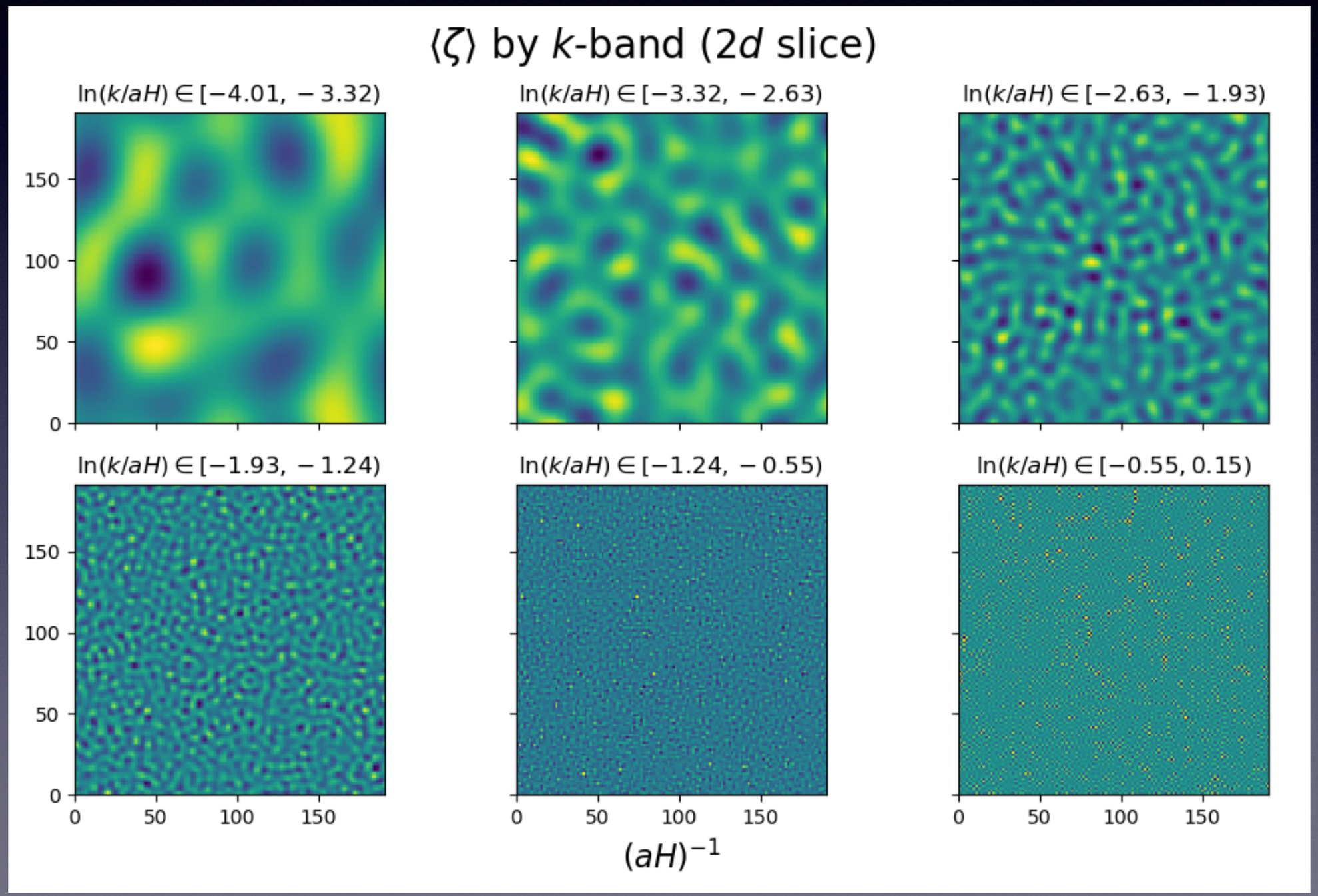
Response of Adiabatic Mode to Entropy Perturbations



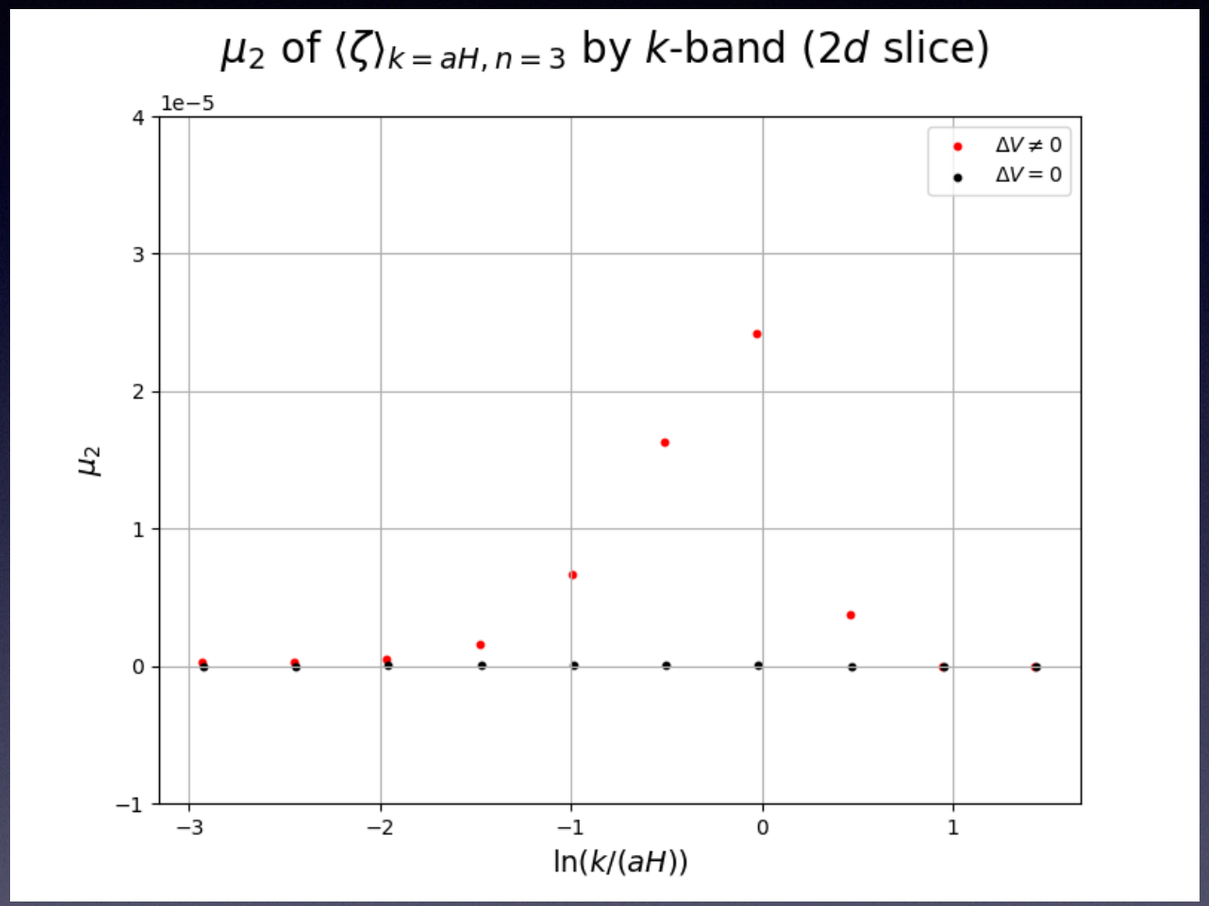
Suggests ζ response function to isocurvature mode

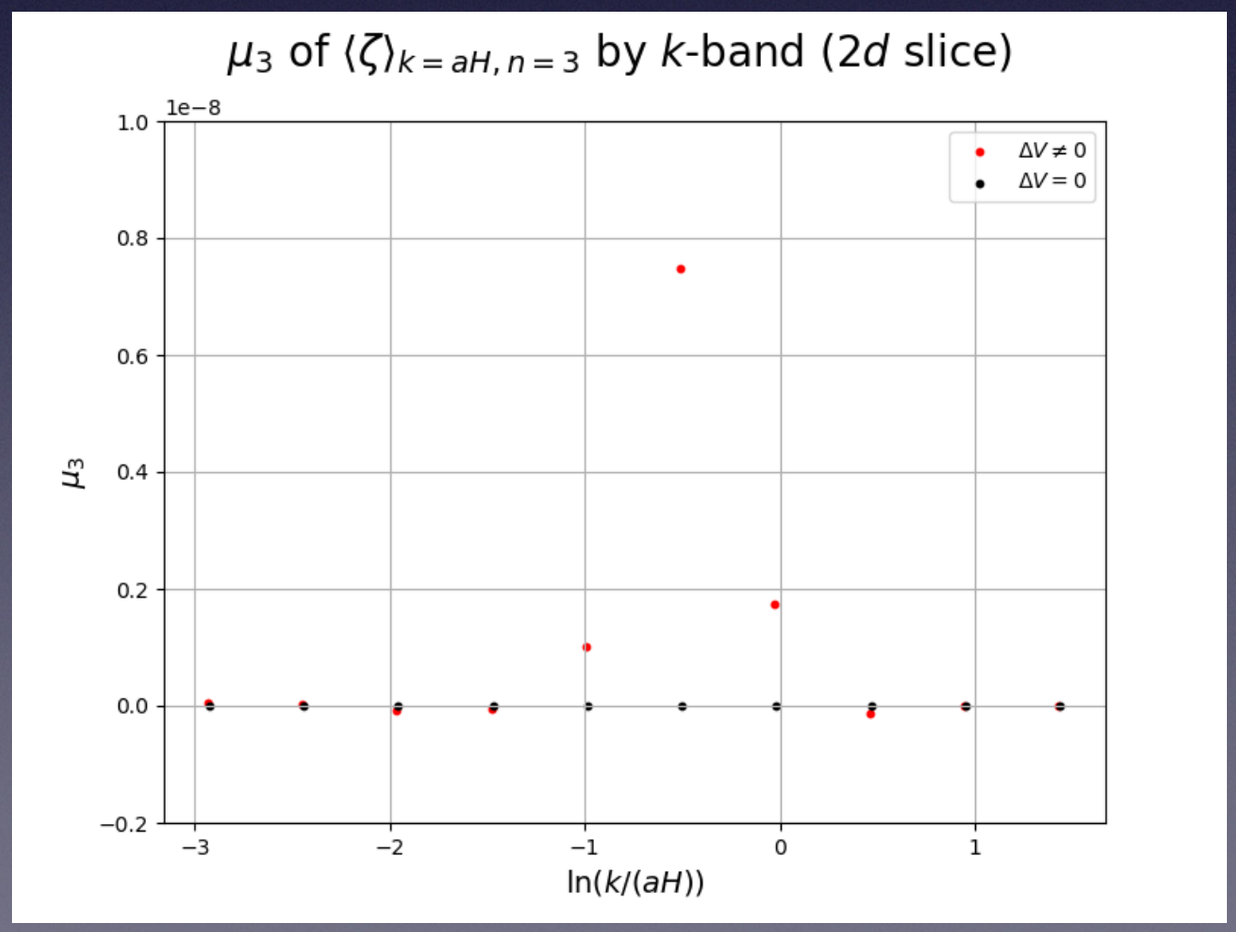
$$\zeta(x) = \zeta_{\rm G} + \zeta_{\rm NL}(\zeta_{\rm iso})$$

Scale Dependence



k-dependent ζ

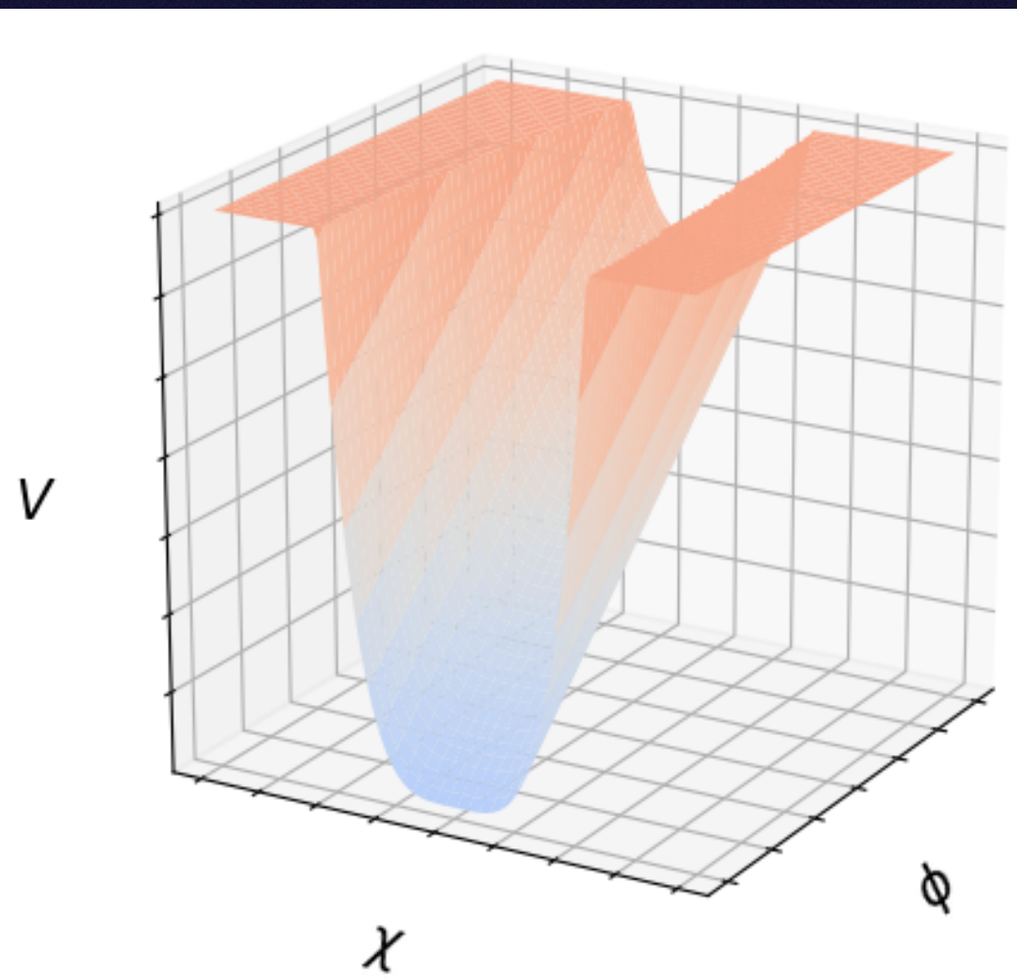




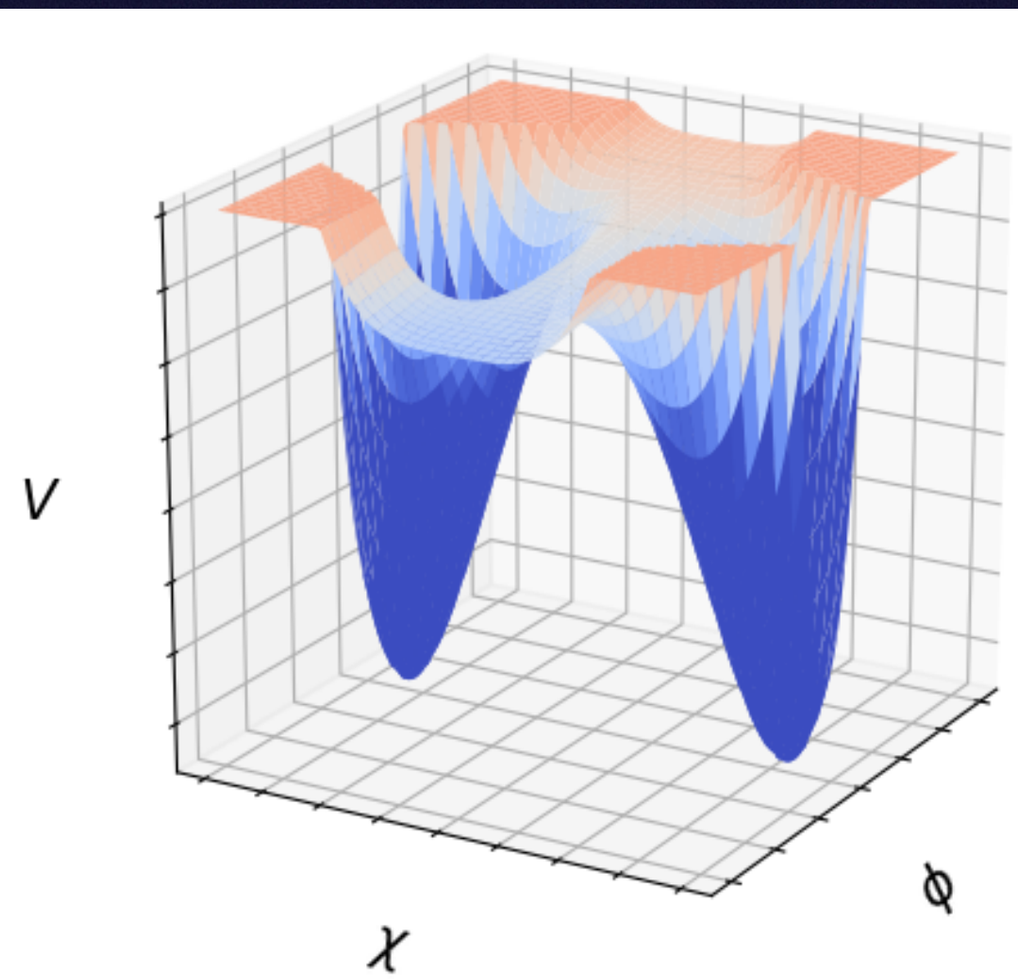
A More Extreme Example

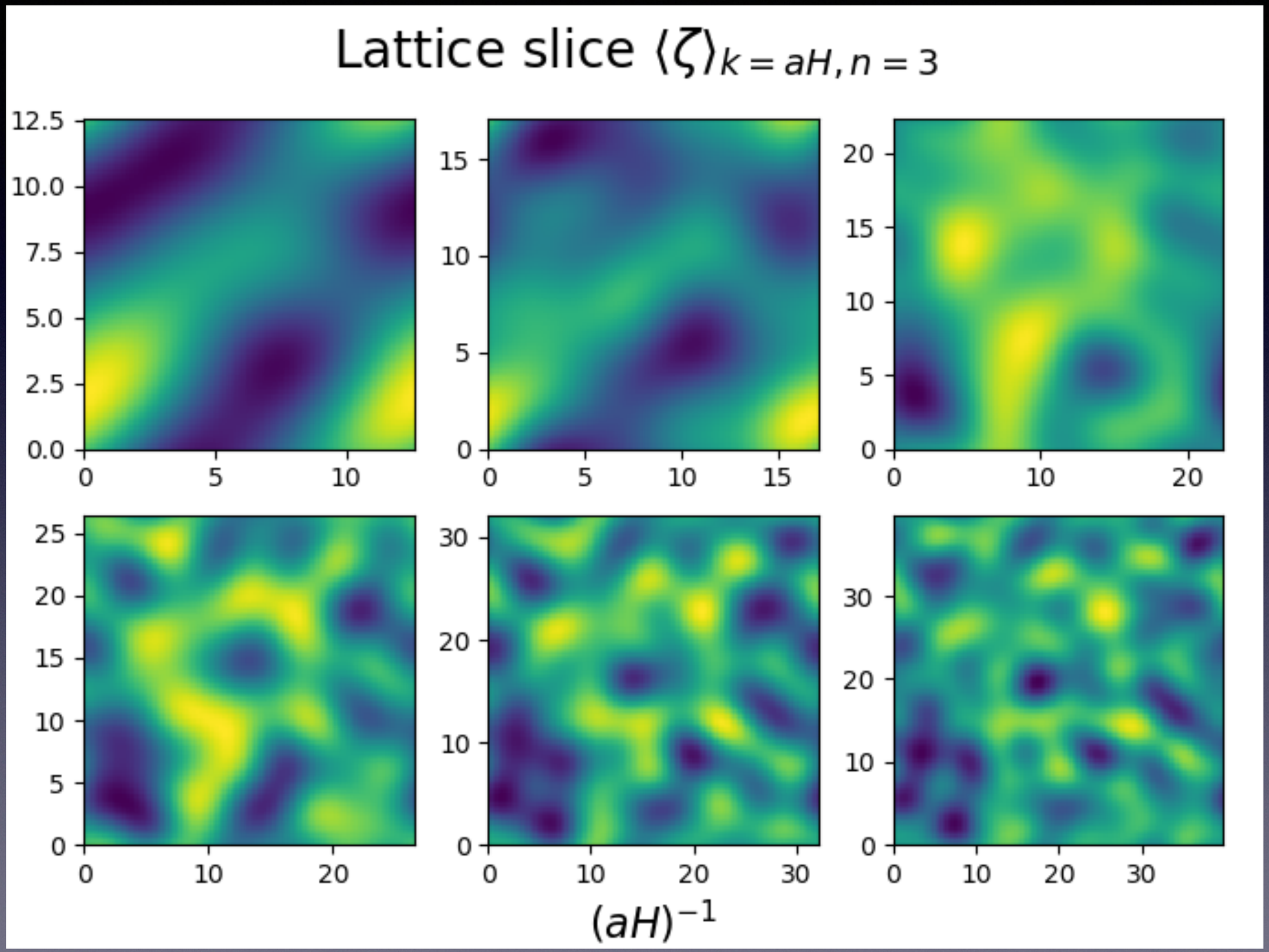
$$V(\phi) = \frac{m^2}{2}\phi^2 + \left(m_\chi^2 + \Delta m^2(\phi)\right)\chi^2 + \frac{\lambda}{4}\chi^4$$

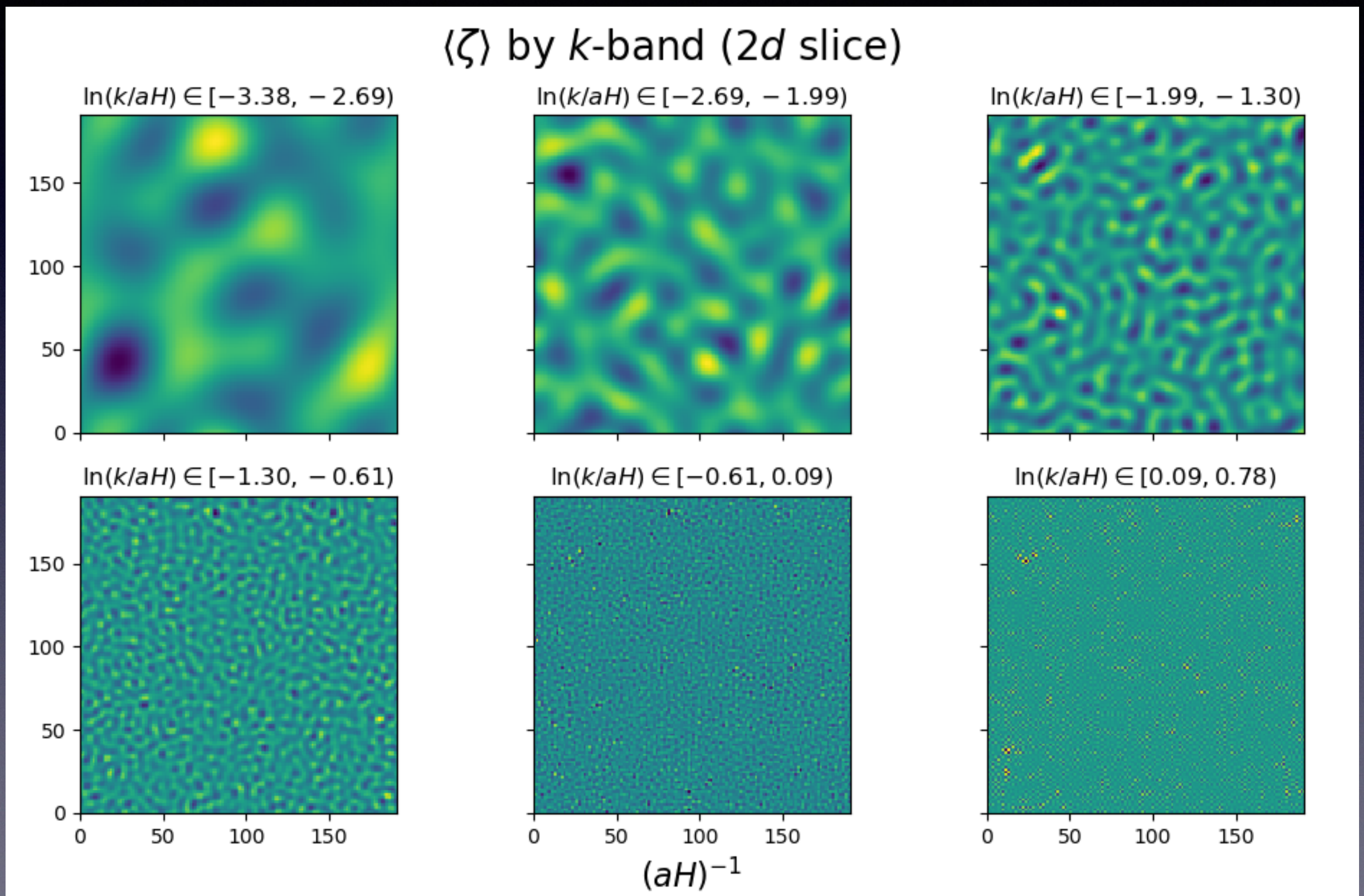
$\Delta m^2 = 0$



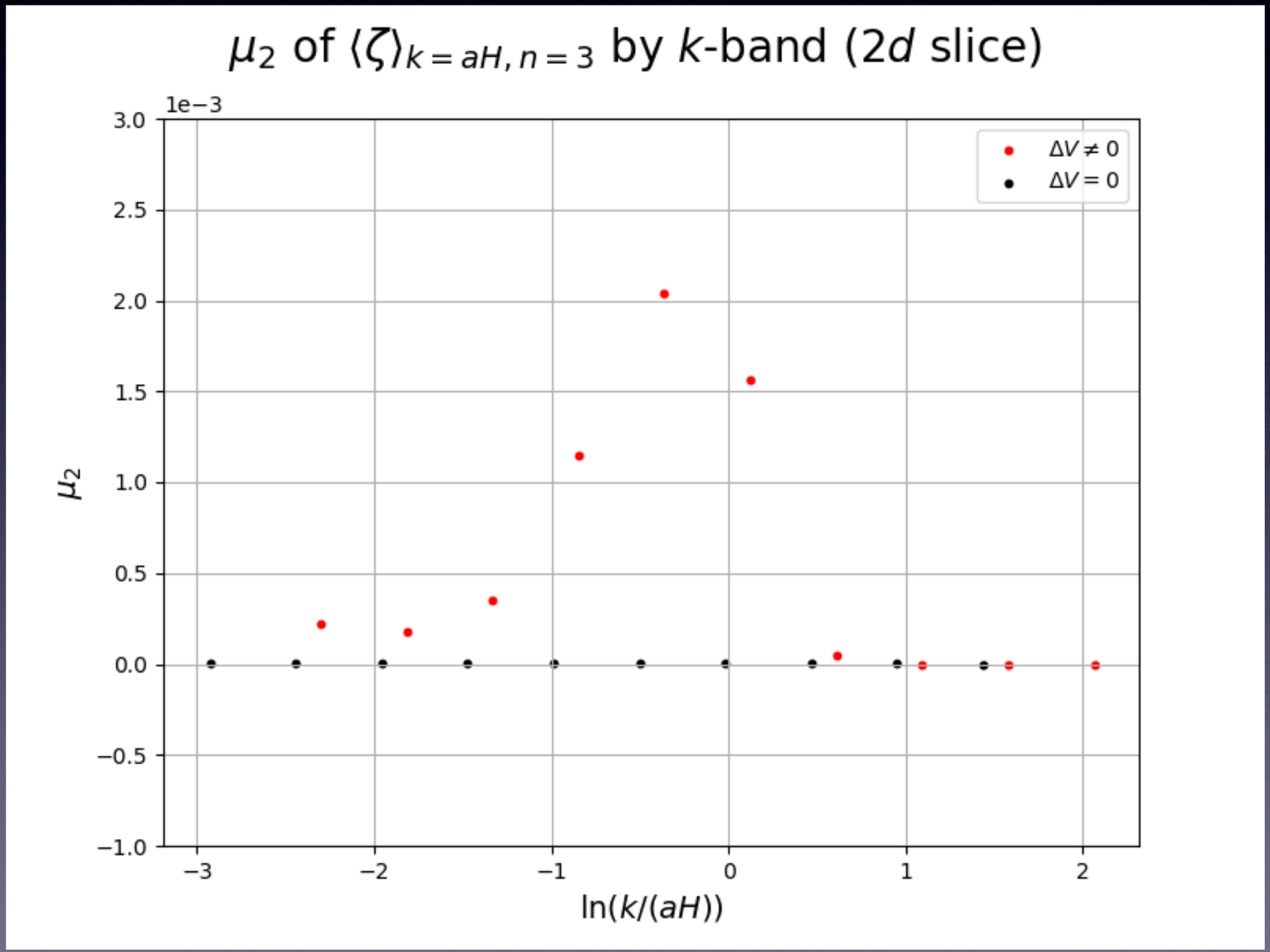
$\Delta m^2 \gg m_\phi^2, m^2\chi$



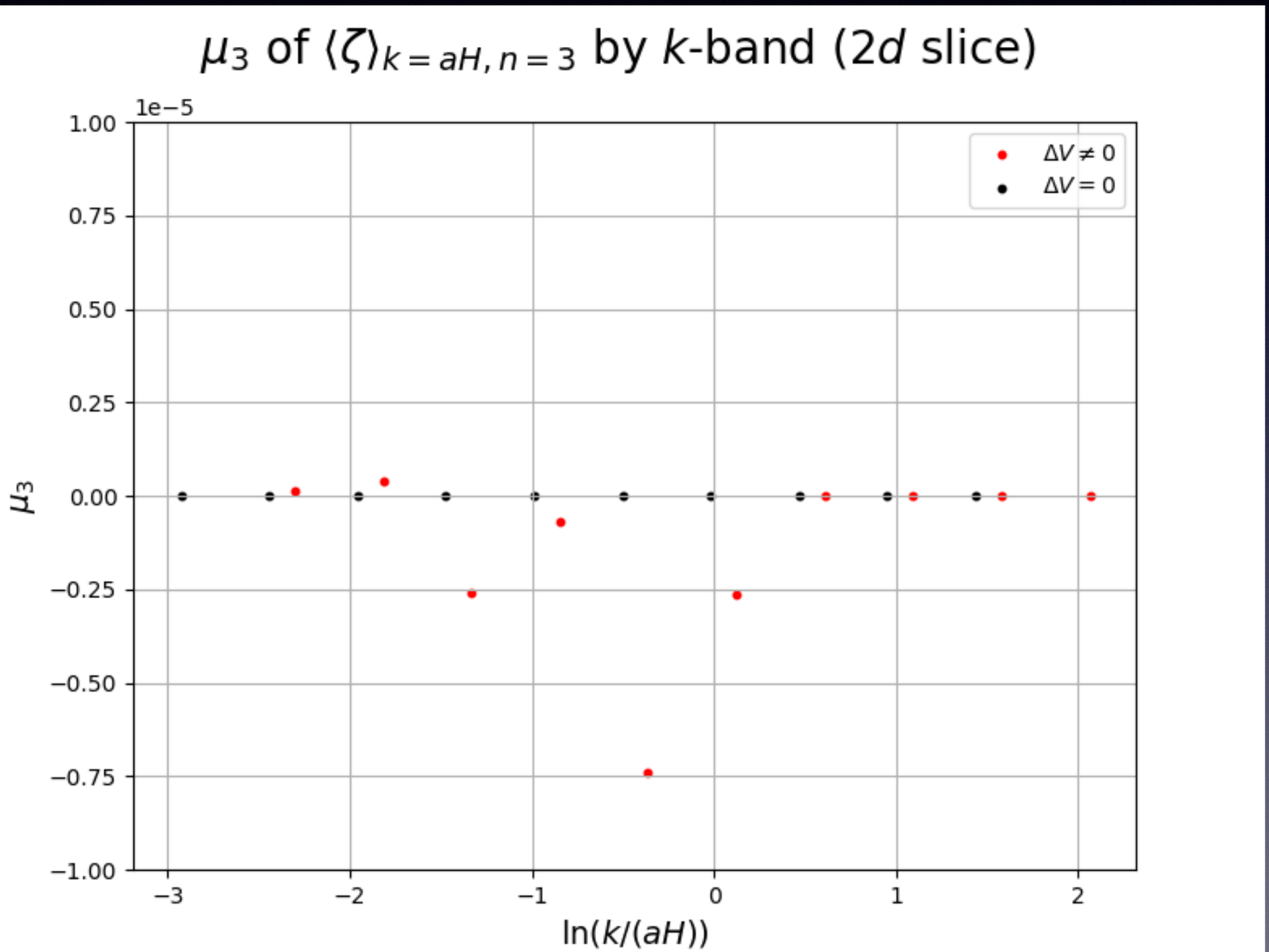

Lattice slice $\langle\zeta\rangle_{k=aH,n=3}$
$(aH)^{-1}$


⟨ζ⟩ by k-band (2d slice)
ln(k/aH) ∈ [−3.38, −2.69)
ln(k/aH) ∈ [−2.69, −1.99)
ln(k/aH) ∈ [−1.99, −1.30)
ln(k/aH) ∈ [−1.30, −0.61)
ln(k/aH) ∈ [−0.61, 0.09)
ln(k/aH) ∈ [0.09, 0.78)
0
50
100
150
(aH)^−1

k-dependent ζ



k-dependent ζ



Simple and "Universal" Form of NonGaussianity

$$\zeta(x) = \zeta_{\rm G} + \zeta_{\rm NL}(\zeta_{\rm iso})$$ Inflationary Particle Prod.

$$\zeta = \zeta_{\rm inf} + \zeta_{\rm NL}(\chi)$$ End-of-Inflation

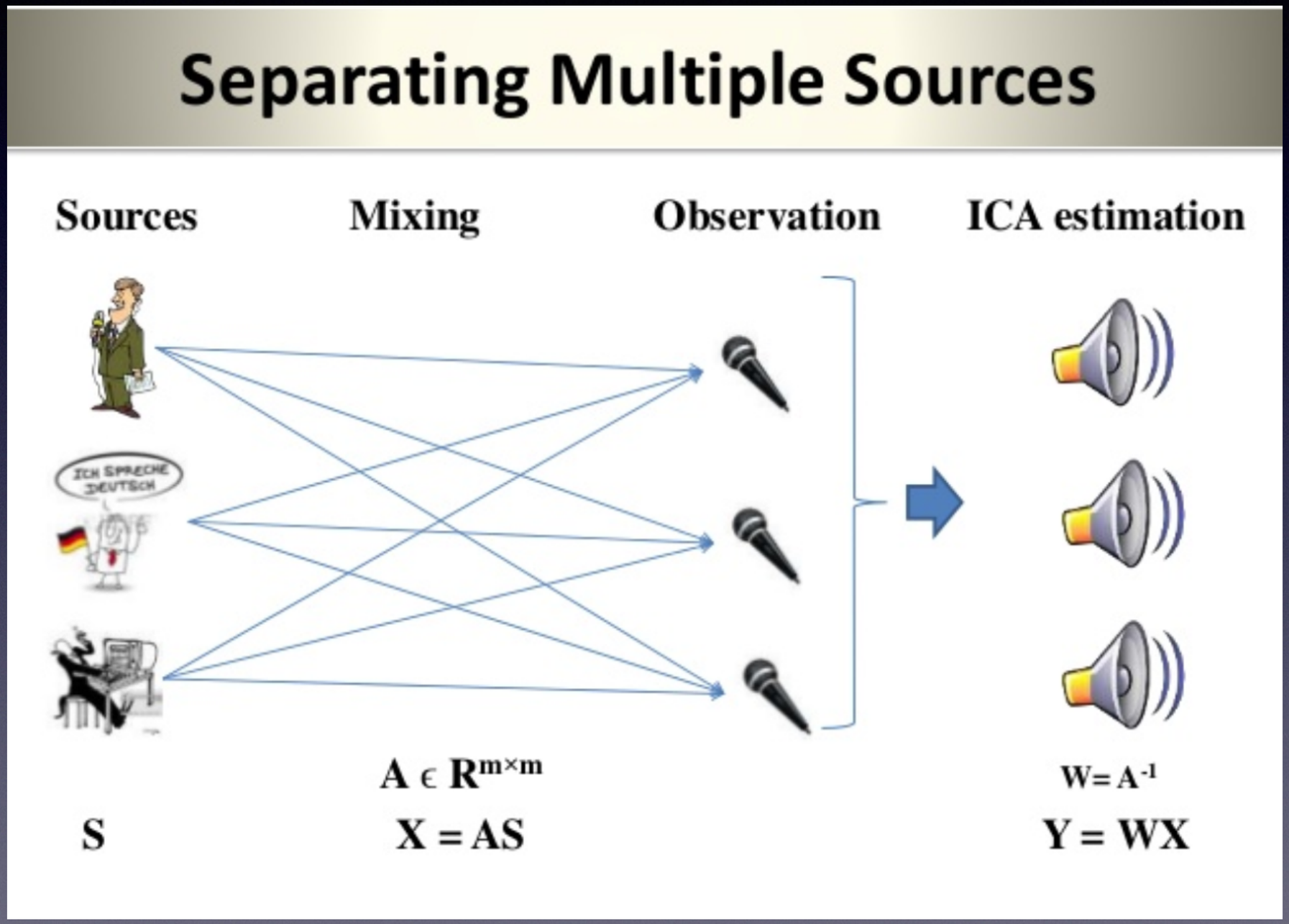
$$\zeta(x) = \zeta_{\rm G}(x) + \zeta_{\rm NG}(\zeta_G)$$ Correlated nonGaussianity

$$\zeta(x) = \zeta_{\rm G}(x) + \sum_i A_i P_i(\Lambda^{-1}(x - x_i))$$ Simplified Peak Model

Sum of Gaussian and nonGaussian signal

How do we separate the nonGaussian component

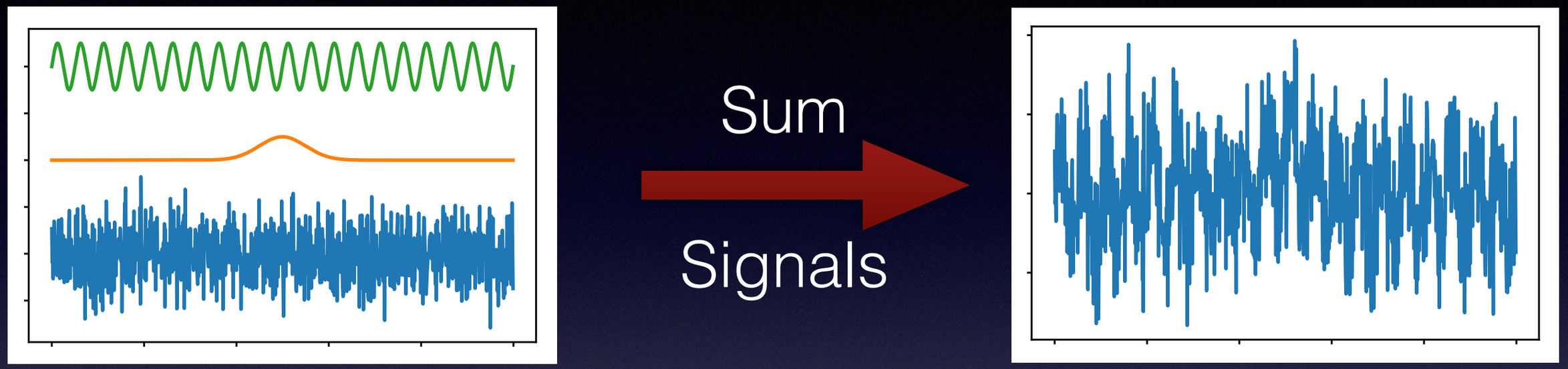
ICA Separation



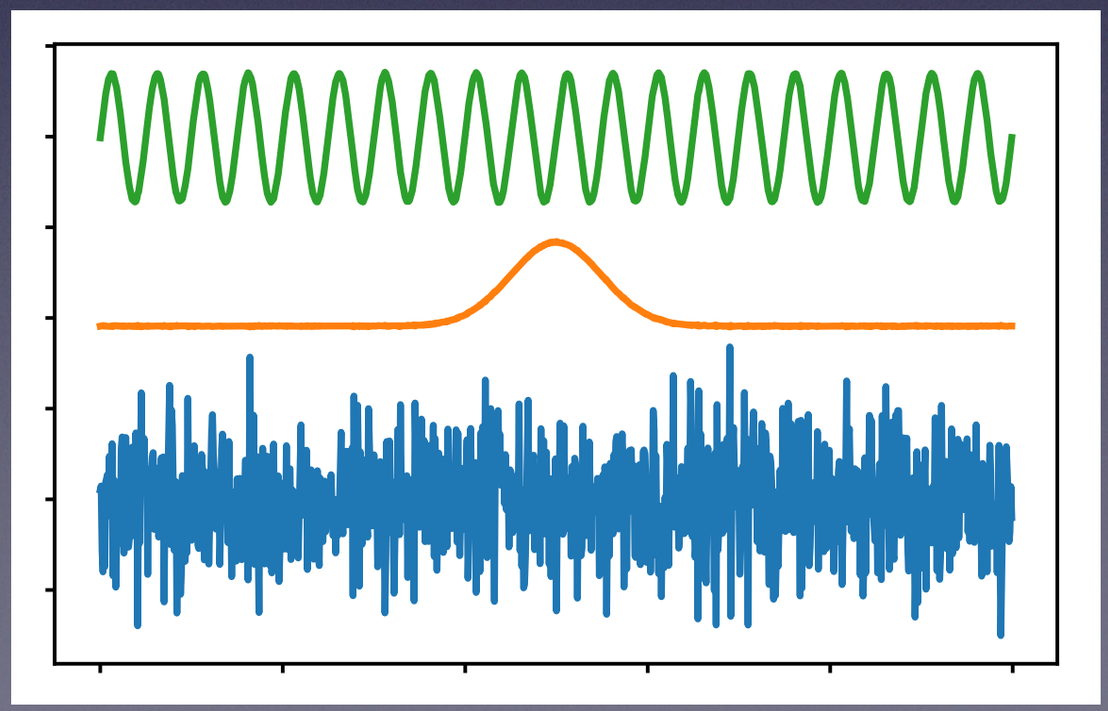
Maximise relative entropy of whitened signal combinations

ICA Separation

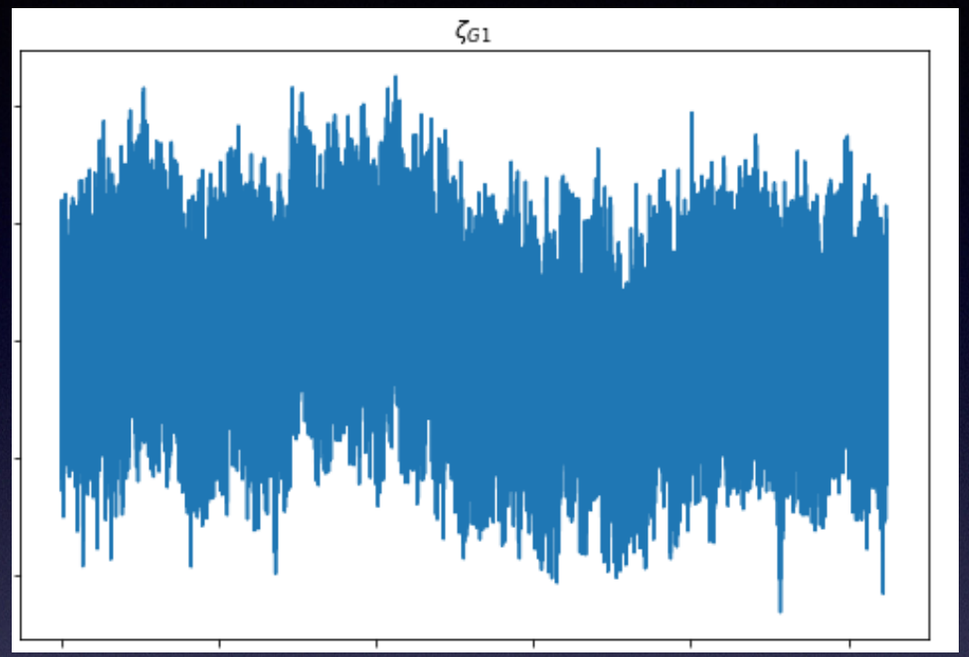
[JB, Bond, Jibran Haider]



Maximise relative entropy of whitened signal combinations



$$\zeta = \zeta_{\mathrm{inf}} + \zeta_{\mathrm{NL}}(\chi)$$



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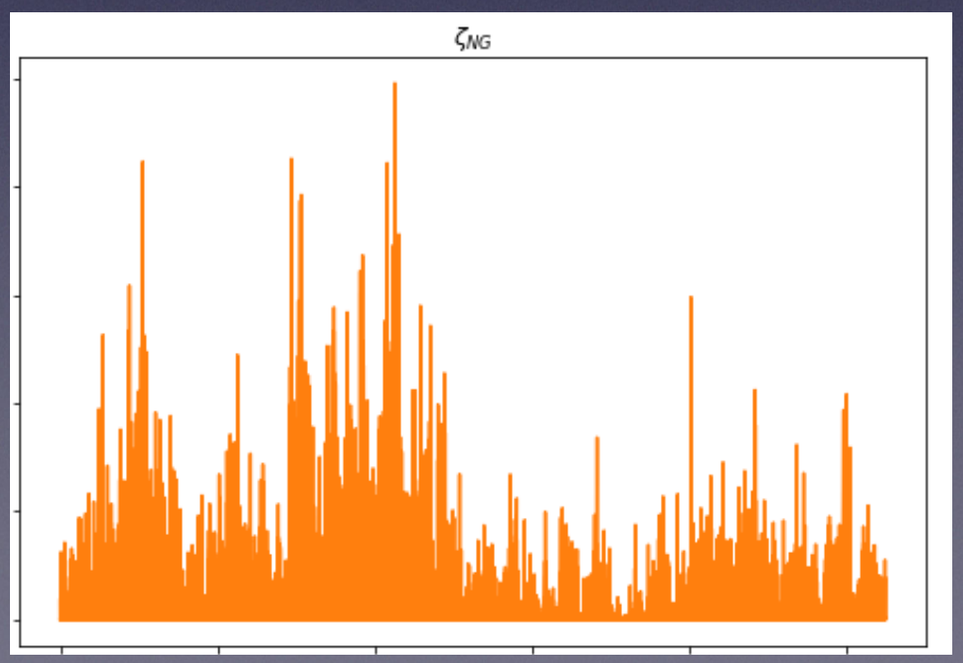

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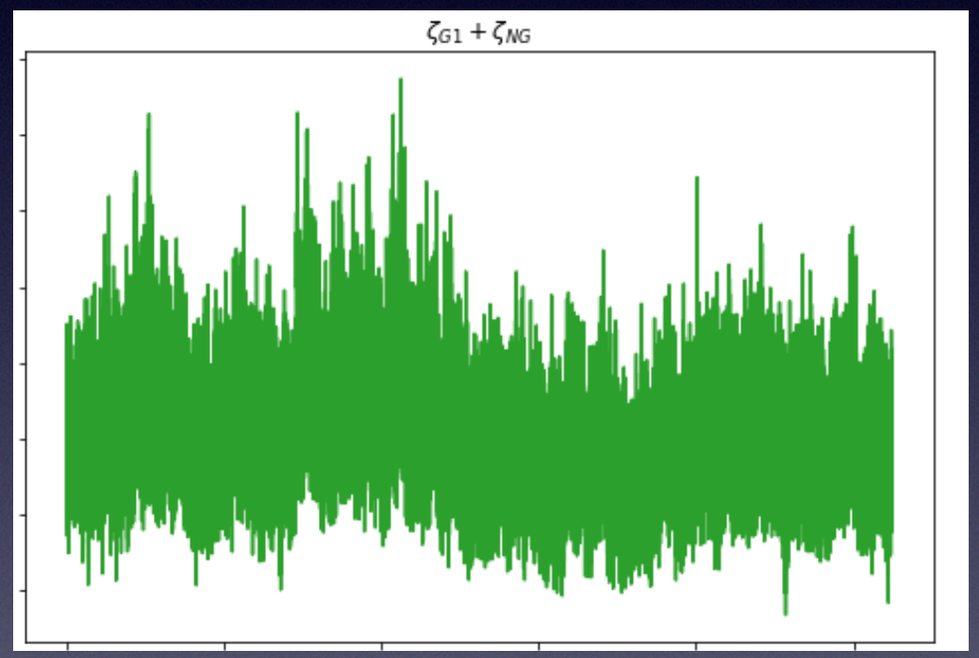
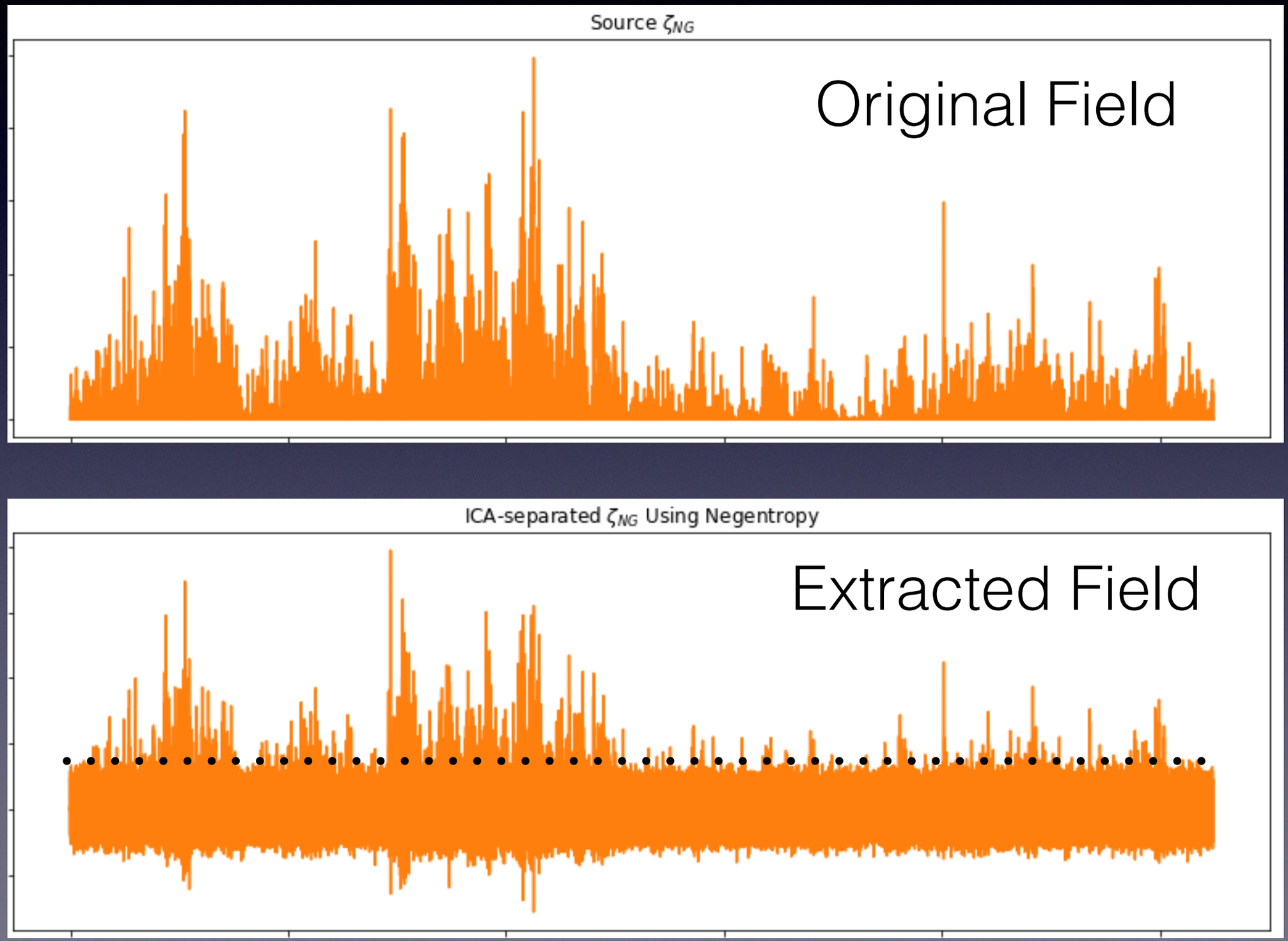


ICA Separation



Conclusions / Future Work

- Interesting nonGaussian ζ can be produced from nonlinear dynamics in the ultra early Universe

- Generically obtain a highly NG signal combined with Gaussian inflationary contribution

- Production of ζ tied to entropy production

- ICA provides a powerful way to separate the nonGaussianity

Bond + Braden + Frolov

Thomas Morrison - Arrives Next Week

Jibran Haider - Arrives in 2 Weeks

Preheating and Vacuum Decay in multi-component BECs

[JB, in prep /
JB, Johnson, Peiris, Pontzen, Weinfurtner]