Inflation & the seek for a common origin to CMB anomalies

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Based on JCBS:
- Phys. Lett. B 739,2014 (arXiv:1405.4913),
- arXiv:1602.06809,
- arXiv:1603.01603

JCBS and Juan P. Beltrán Almeida:
- in preparation
- in progress

21CMBLSS2016, 13 June-1 July. IFT, Madrid

Inflation & CMB anomalies

Absence of non-gaussianity, running index or features in the CMB

Single-field inflation is sufficient to explain the data

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Additional info is required to continue discriminating models of inflation

CMB anomalies assumed to have a primordial origin

Used as a tool to probe the inflaton dynamics + interactions

A framework providing a common origin is desirable

Cold Spot, power deficit and statistical anisotropy

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Disclaimer: this might be the wrong thing to do, but one can learn something interesting in the end

Inflation & CMB anomalies

The question

How much do you need to twist inflation to obtain CMB anomalies?

(i.e. breaking homogeneity & isotropy of the CMB)

The ingredient

Apart from the inflaton, other scalar field(s) contributes to the perturbation spectrum imprinted on the CMB

The set-up

* Inflaton responsible for most of the CMB perturbations (homogeneous & isotropic)
* An initially excited spectator field does not fully decay due to its interactions during inflation

The desired outcome

Inhomogeneous distribution of the spectator field at the end of inflation

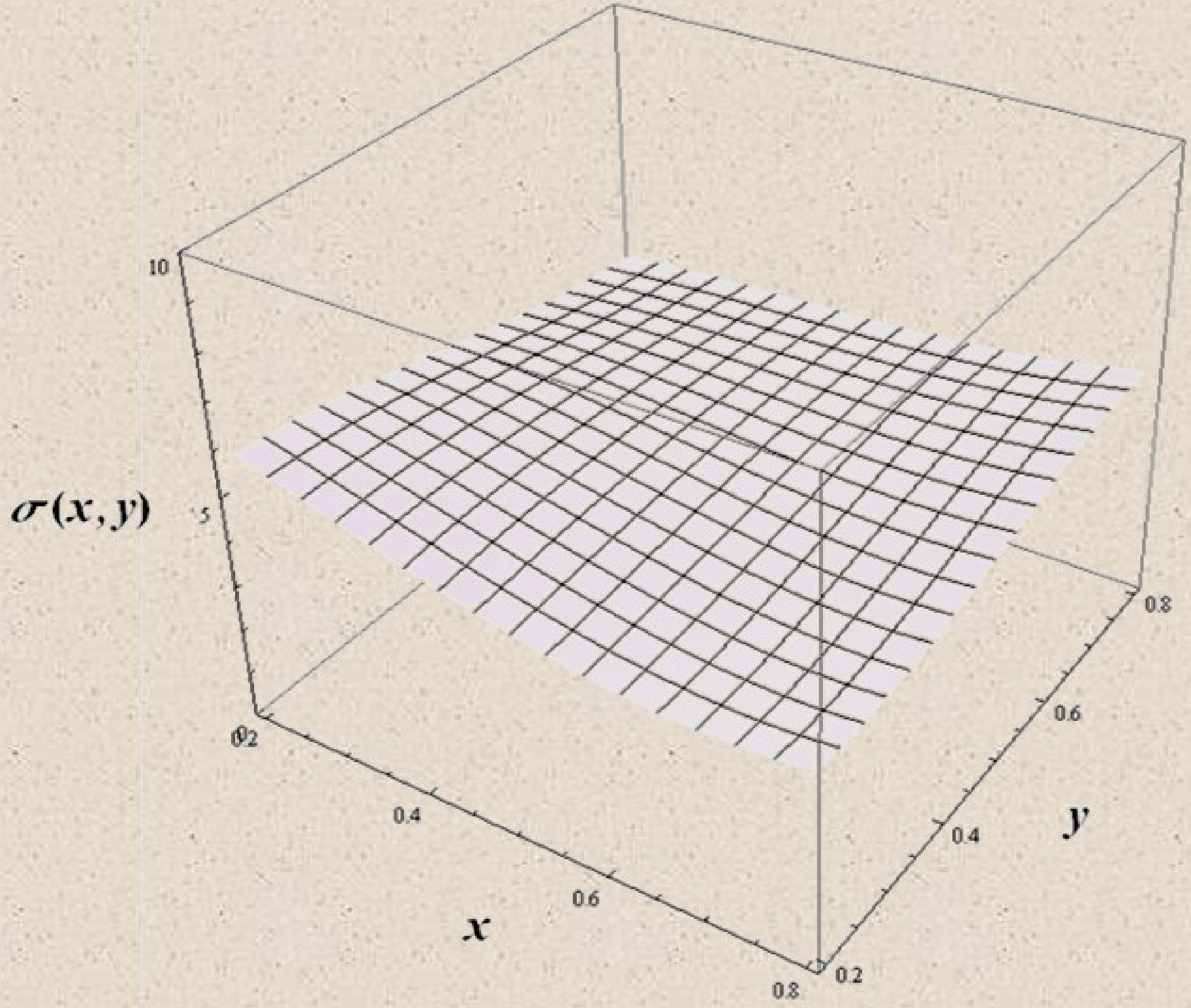
Breaking of statistical homogeneity of the CMB

Avenue towards CMB anomalies

A computer generated 2D fluctuating field

(helping the eye)

Fluctuations of a 2D scalar field



Our Universe emerges from a nearly homogeneous patch

(previous phase of inflation homogenises the field)

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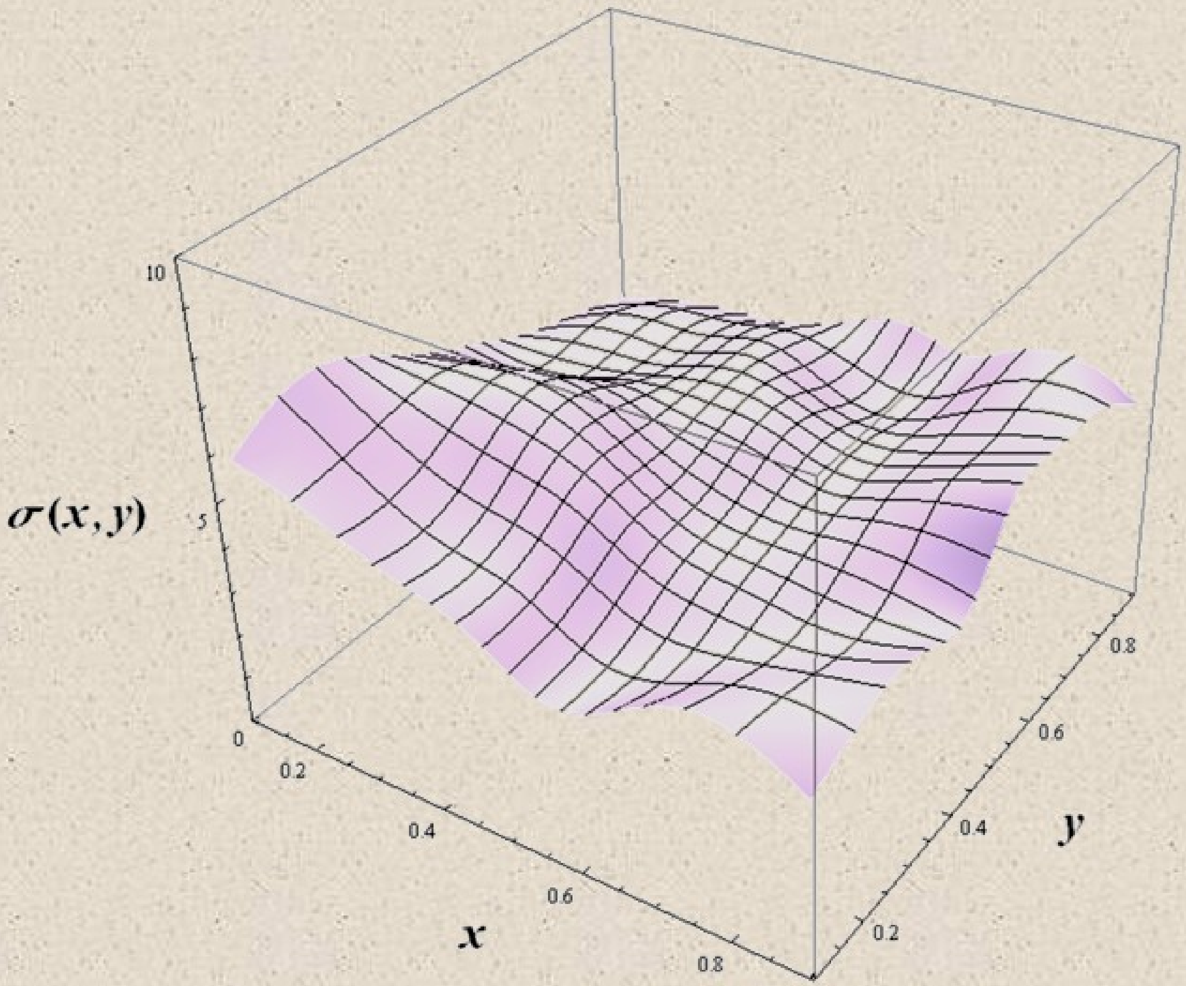

Structure is imprinted on smaller scales as inflation proceeds.

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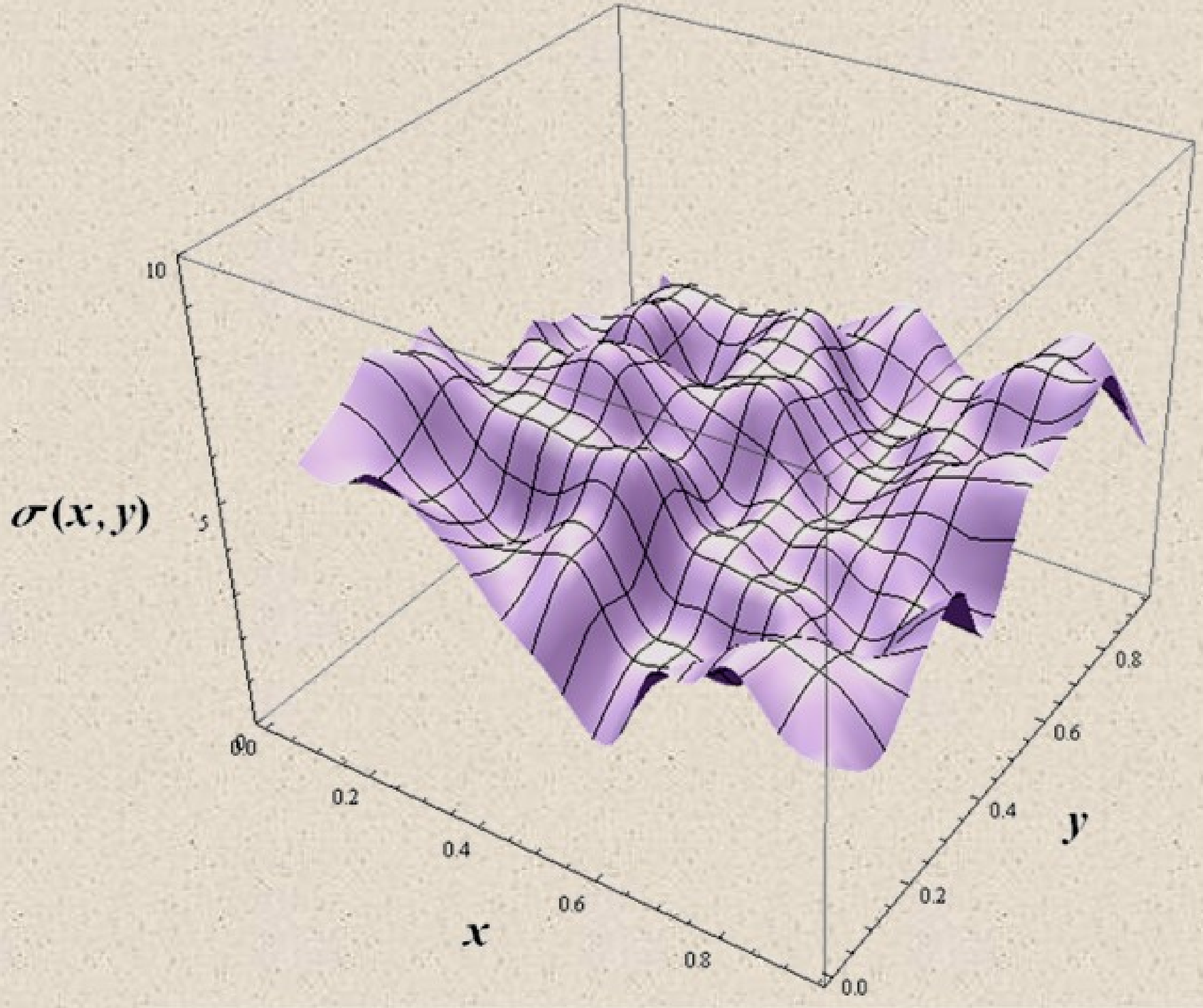

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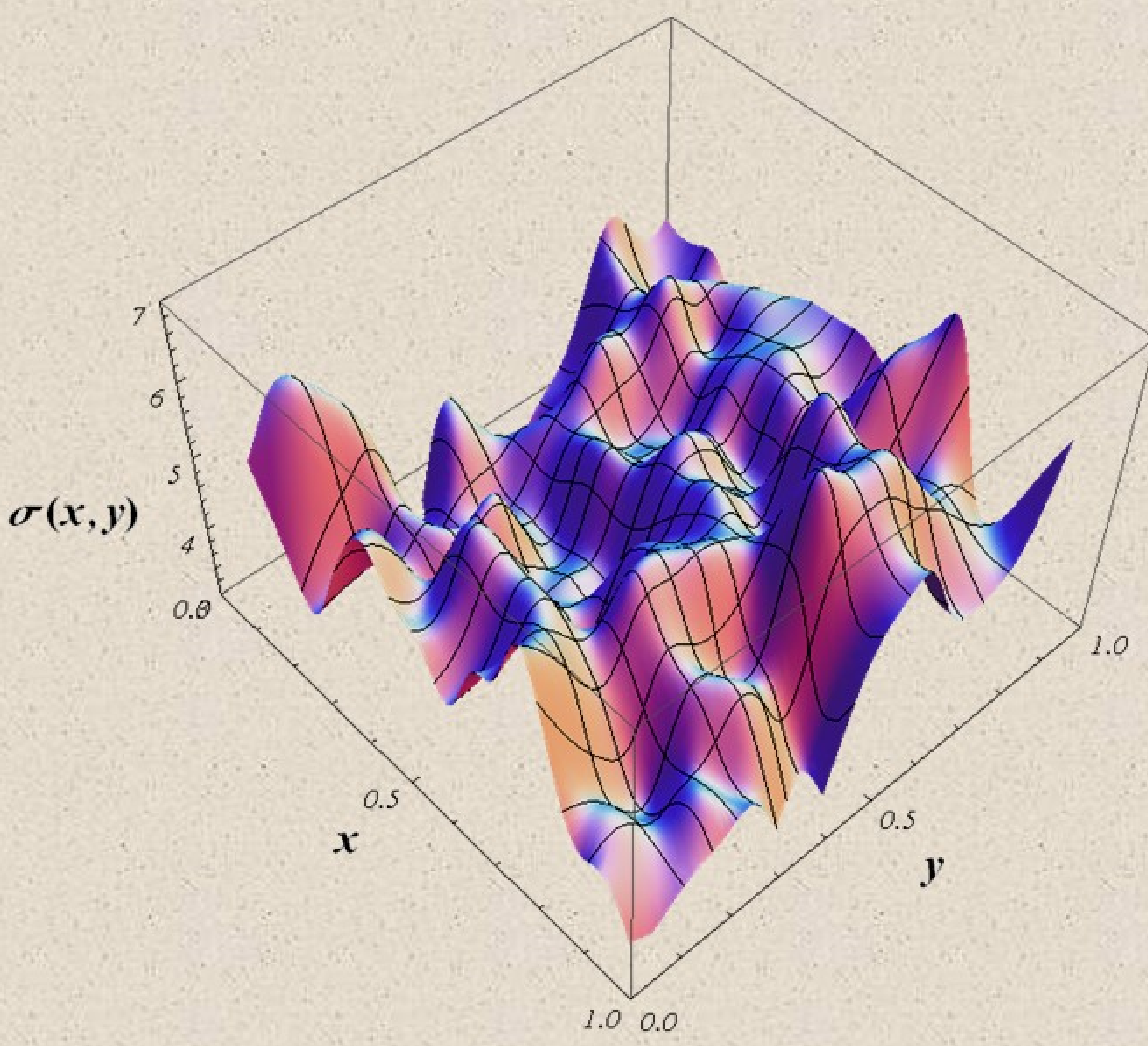

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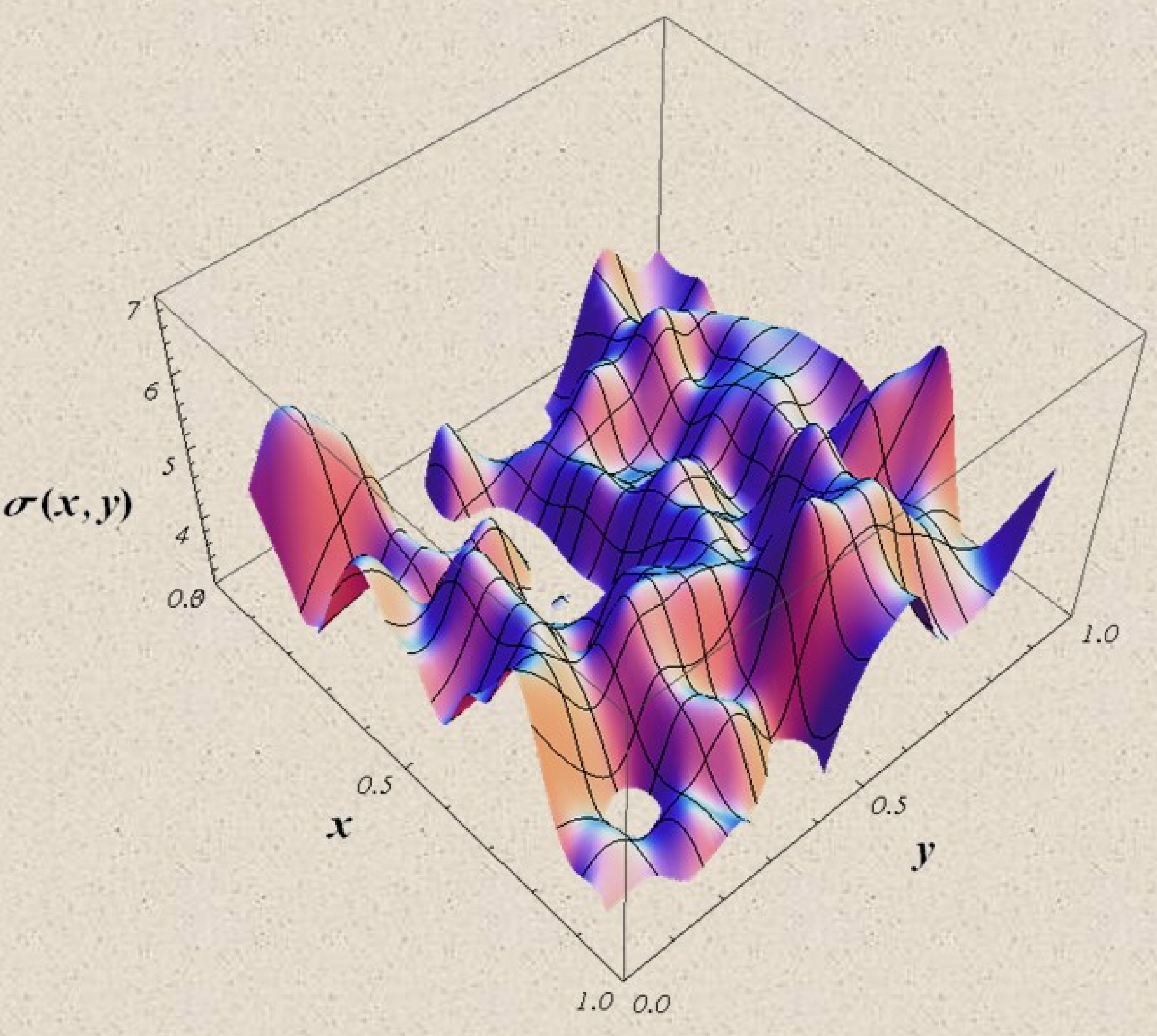

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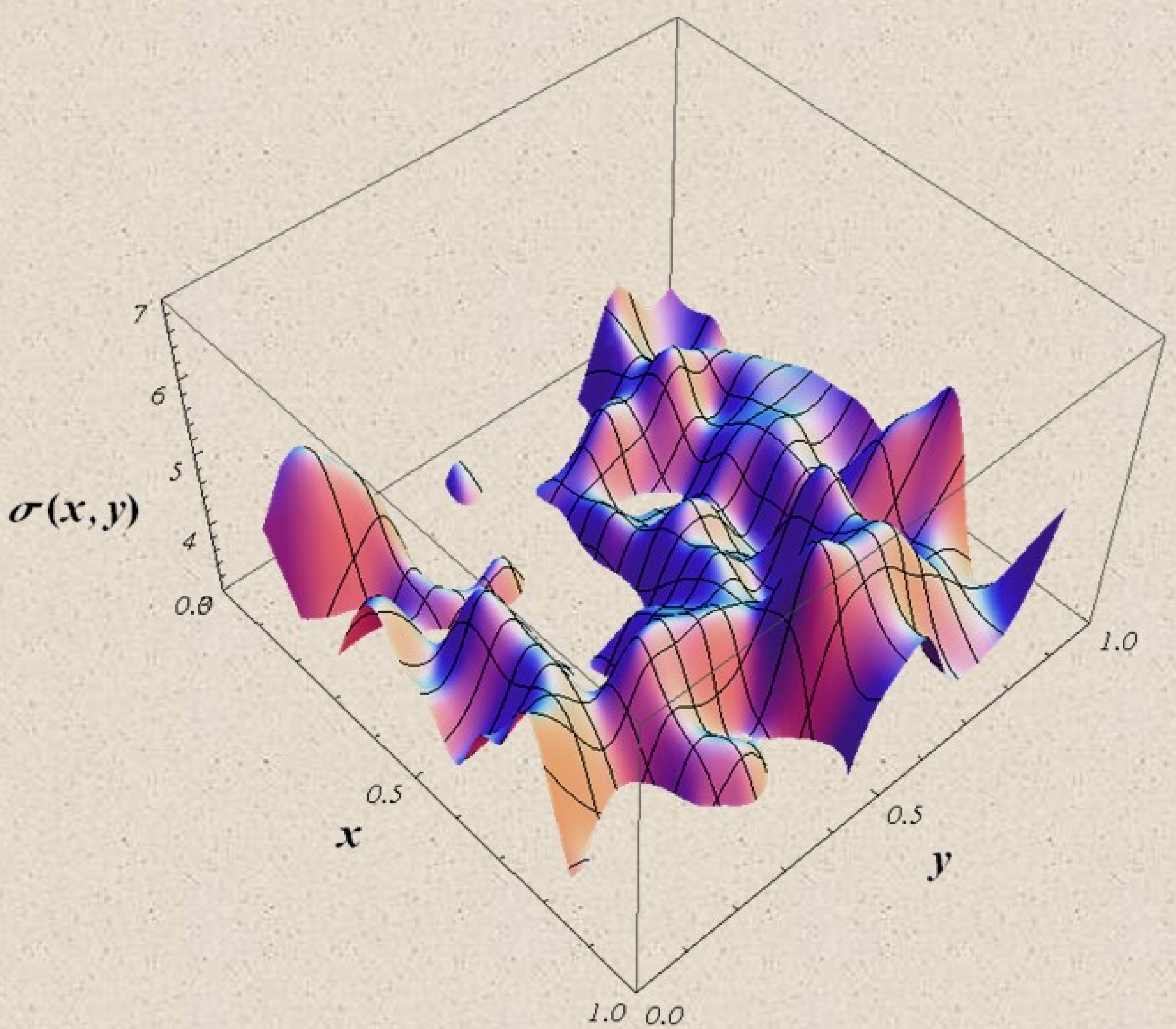

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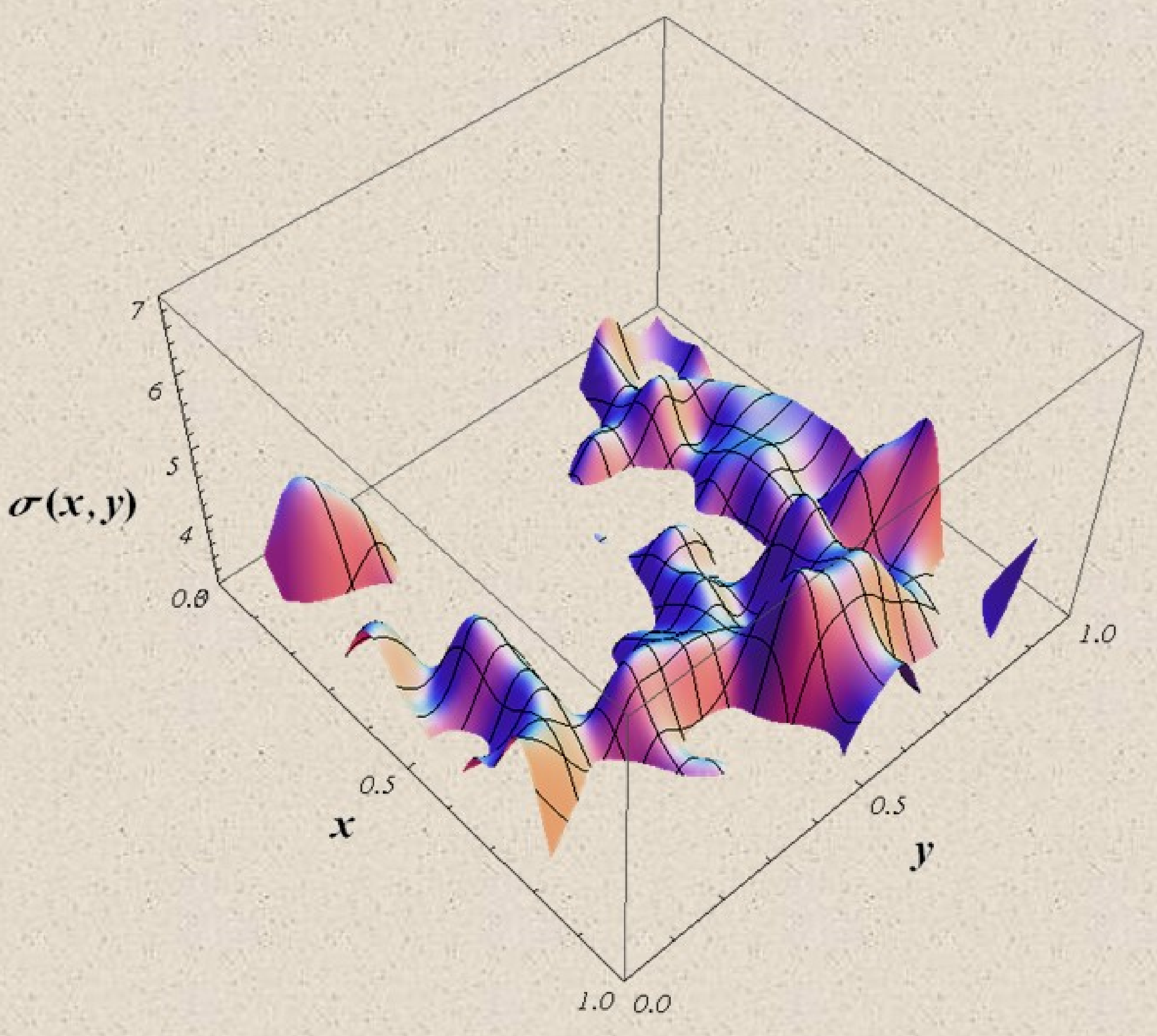

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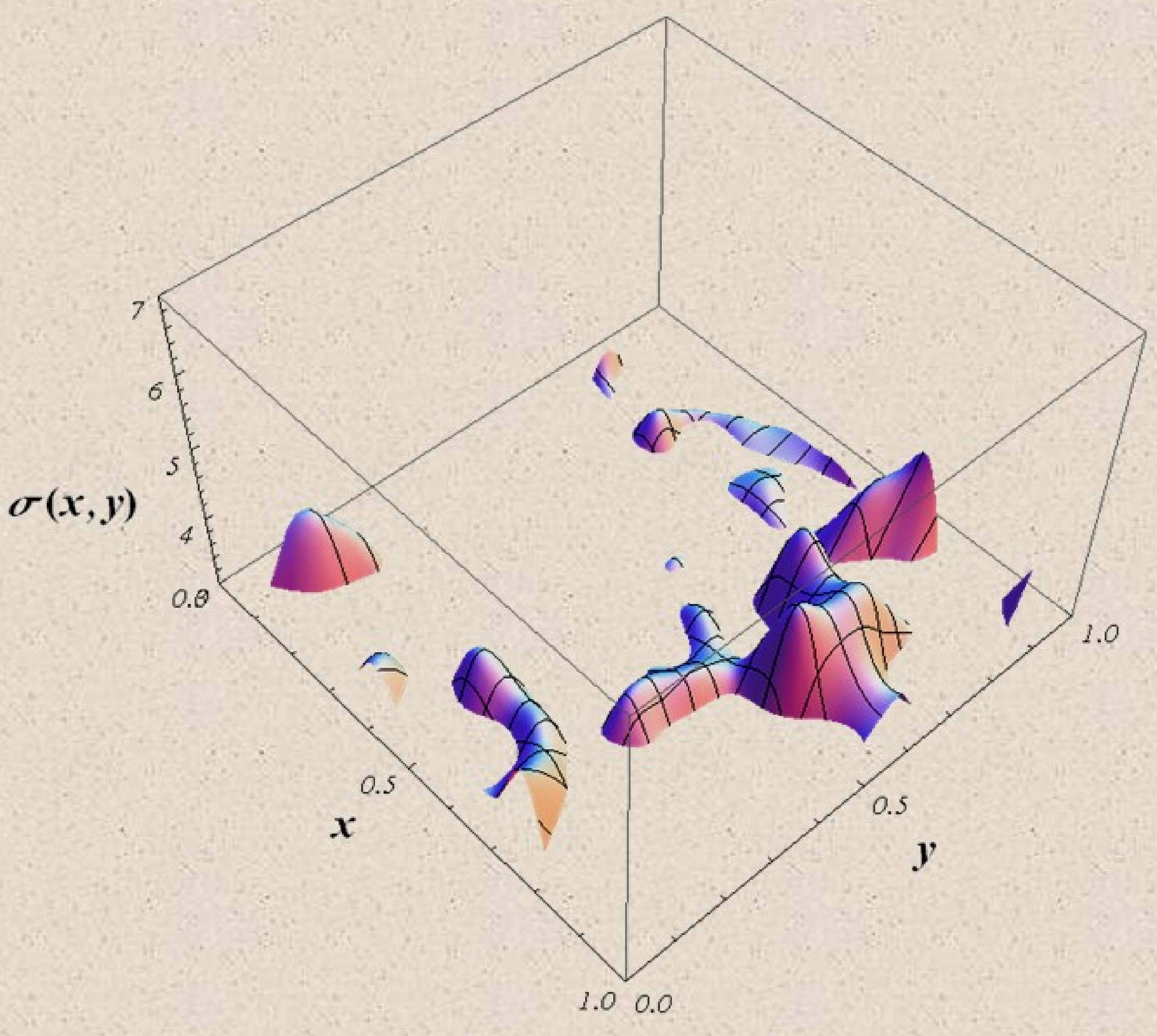

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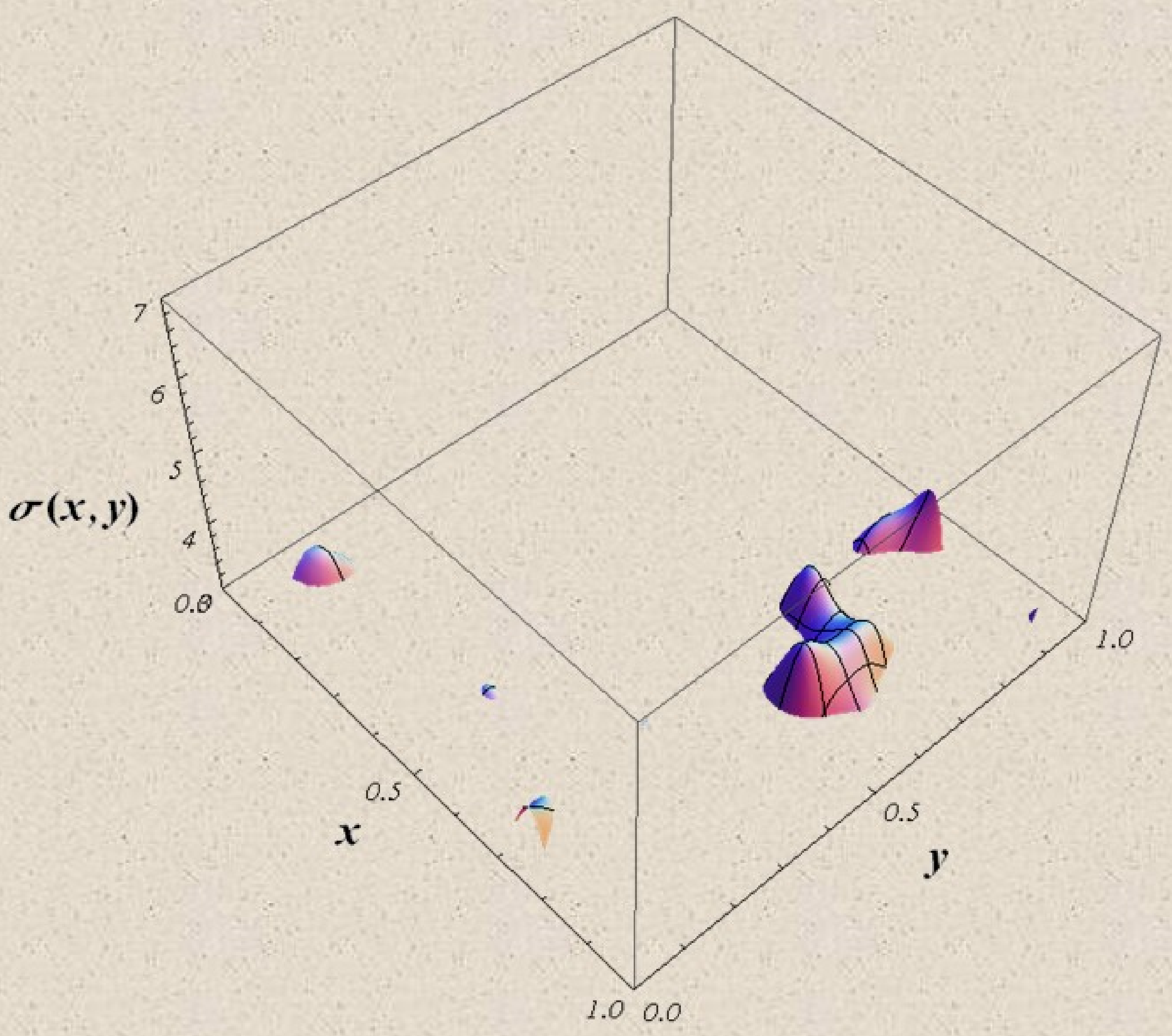

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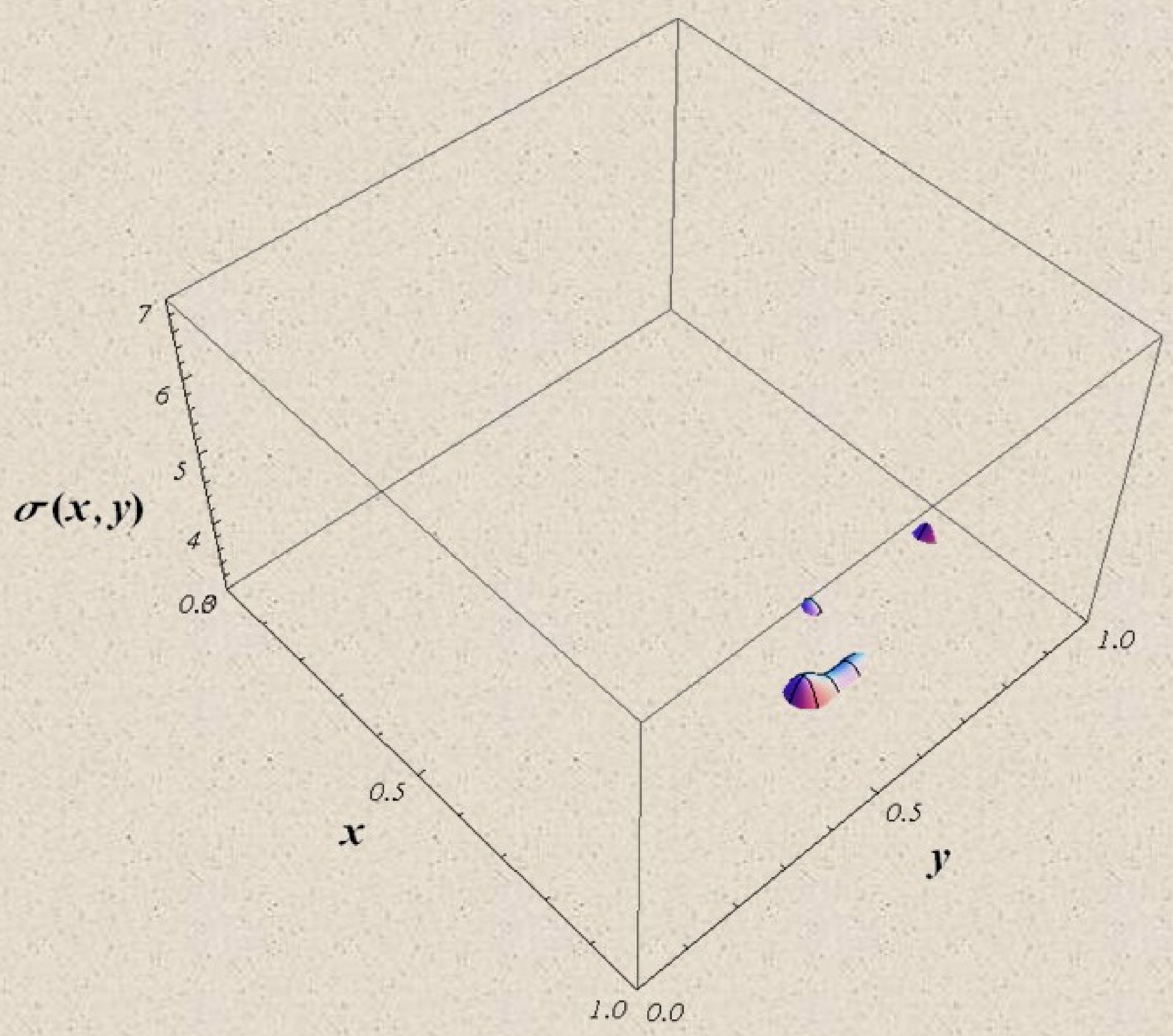

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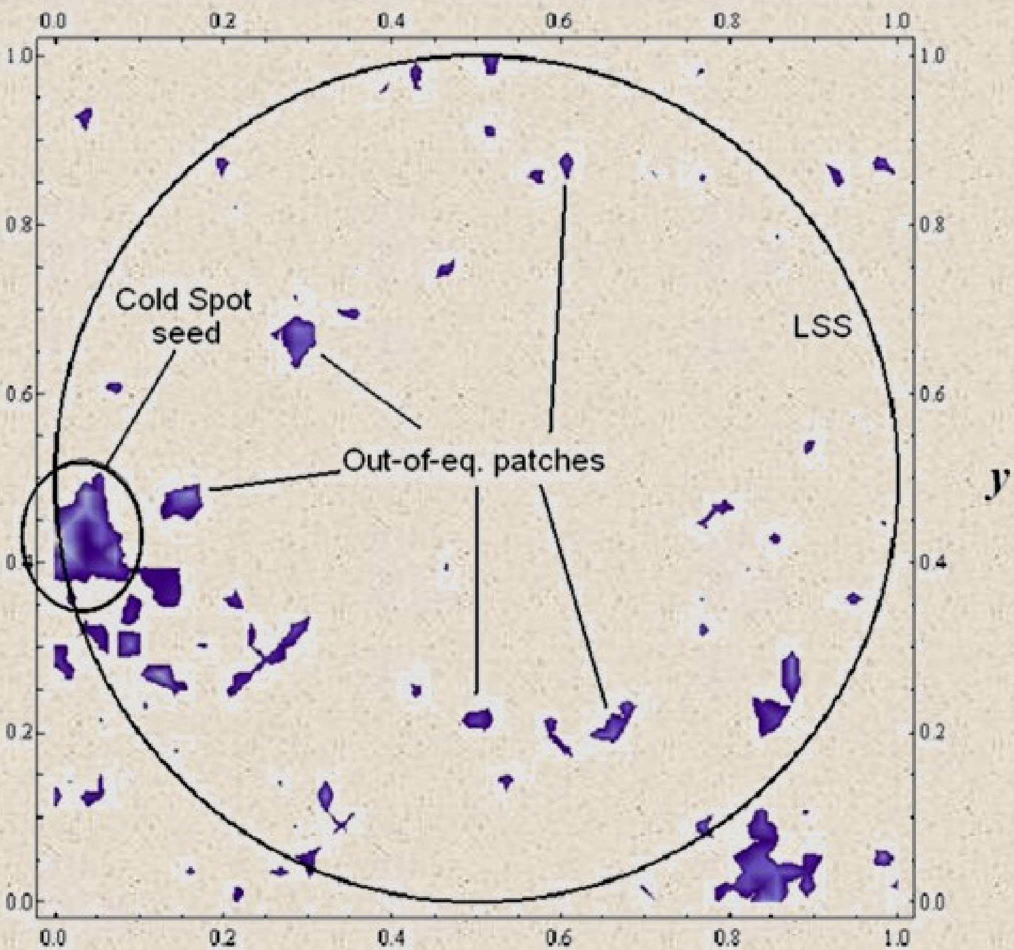


The model in brief

Interacting spectator σ during inflation

$$\mathcal{L} = \frac{1}{2}\partial_\mu\sigma\partial^\mu\sigma + \frac{1}{2}\partial_\mu\chi\partial^\mu\chi - \frac{1}{2}\bar{m}_\sigma^2\sigma^2 - \frac{1}{2}\bar{m}_\chi^2\chi^2 - \frac{1}{2}g^2\sigma^2\chi^2$$

Initial effective masses

$$m_\sigma^2 \simeq c_\sigma H^2 \qquad m_\chi^2 \simeq g^2\sigma^2 \gg H^2 \qquad c_\sigma, c_\chi = \mathcal{O}(1)$$

Difficulty: $m_\sigma^2 \sim H^2$ gives an expectation $\sigma \sim H$, at best:

$$\langle\sigma^2\rangle \sim \frac{3H^2}{8\pi^2 c_\sigma}$$

Patches with large out-of-eq. fluctuations of σ emerge only if $g^2\sigma^2 \gg H^2$

Dynamical regimes (JCBS & Enqvist '13, JCBS '14)

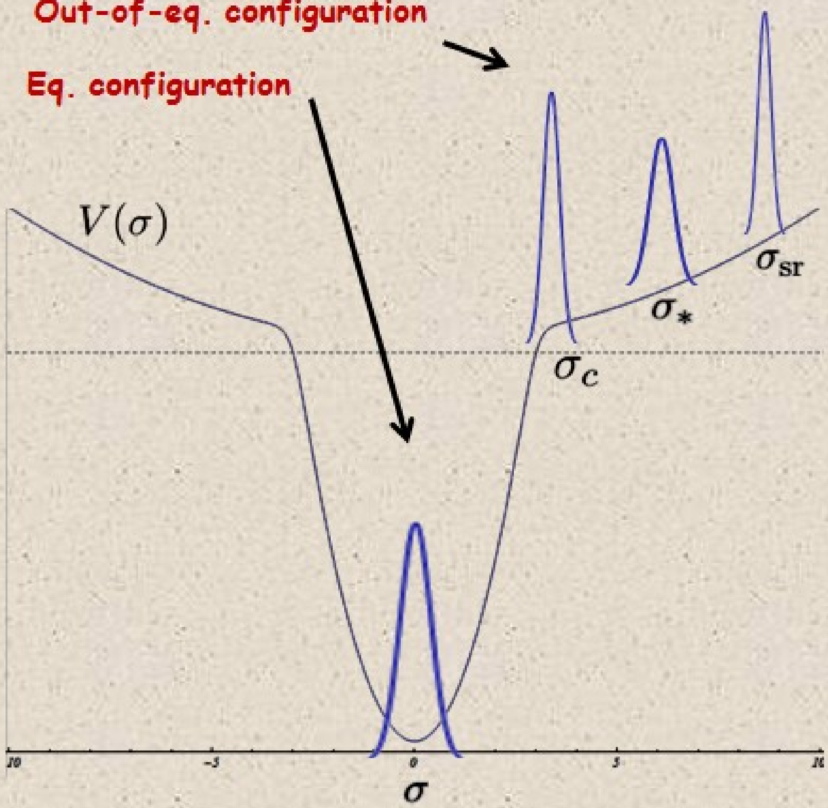
$g\sigma > H \longrightarrow \chi$ integrated out $\longrightarrow$ σ as a free field

$g\sigma \lesssim H \longrightarrow \chi$ undergoes particle production $\longrightarrow$
- Trapping mechanism for σ (Kofman et al. '04)
- σ becomes a heavy field
- σ exponentially suppressed

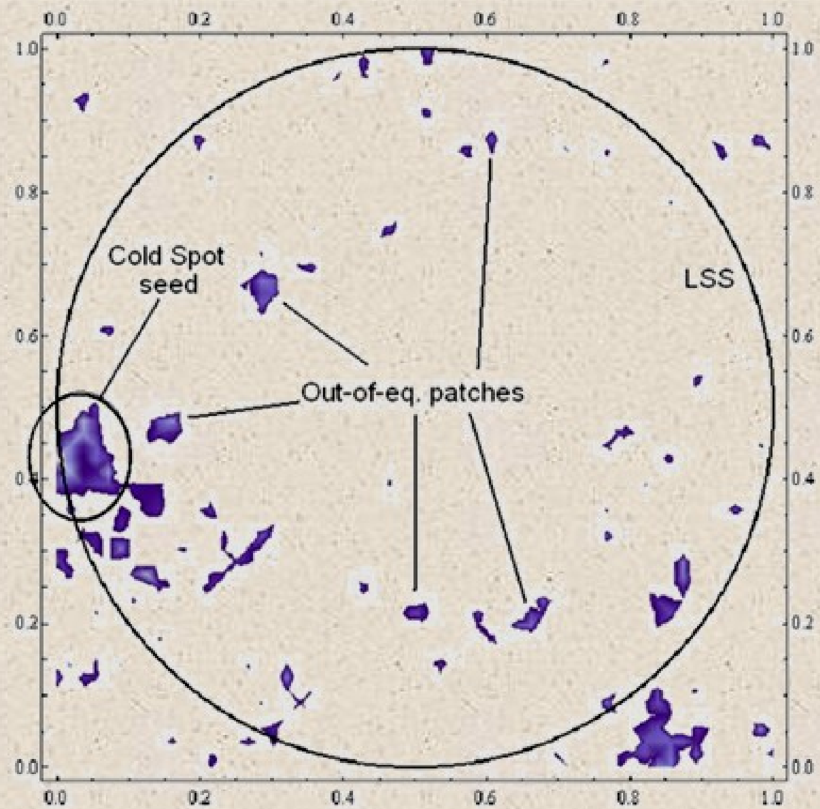
The model in brief

Initially excited, massive, interacting σ

$$g^2\sigma_{\rm sr}^2 \gg H^2 \longrightarrow \sigma_c \sim g^{-1}H$$



Spatial profile



Two important questions to ask

1- How is the initial condition for the spectator field generated?

2- How likely is the apperance of the inhomogeneous distribution?

Getting to the initial condition

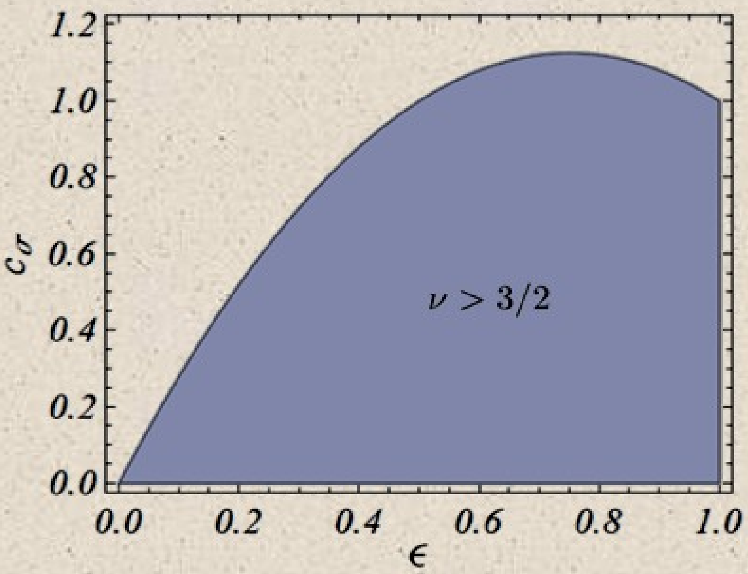
A sustained fast-roll (non-slow-roll) in the primary epoch $\rightarrow \begin{cases} N_{\rm tot} = N_{\rm fr} + N_{\rm sr} \\ N_{\rm sr} = N_{\rm sr}^{p} + N_{*} \end{cases}$

$$\dot{\epsilon} = 0$$

Perturbation modes for the spectator field

$$\delta\ddot{\sigma}_k + 3H\delta\dot{\sigma}_k + \left(\frac{k^2}{a^2} + m_\sigma^2\right)\delta\sigma_k = 0 \xrightarrow{\text{superhorizon}} \begin{cases} \delta\sigma_k/H \propto a^{\epsilon-\alpha} \\ \epsilon - \alpha = \left(\nu - \frac{3}{2}\right)(1-\epsilon) \end{cases}$$

$\nu > 3/2 \rightarrow$ Growth over Hubble scale



Rapid decrease of H implies:

Timescale for H to fall < timescale for σ to fall

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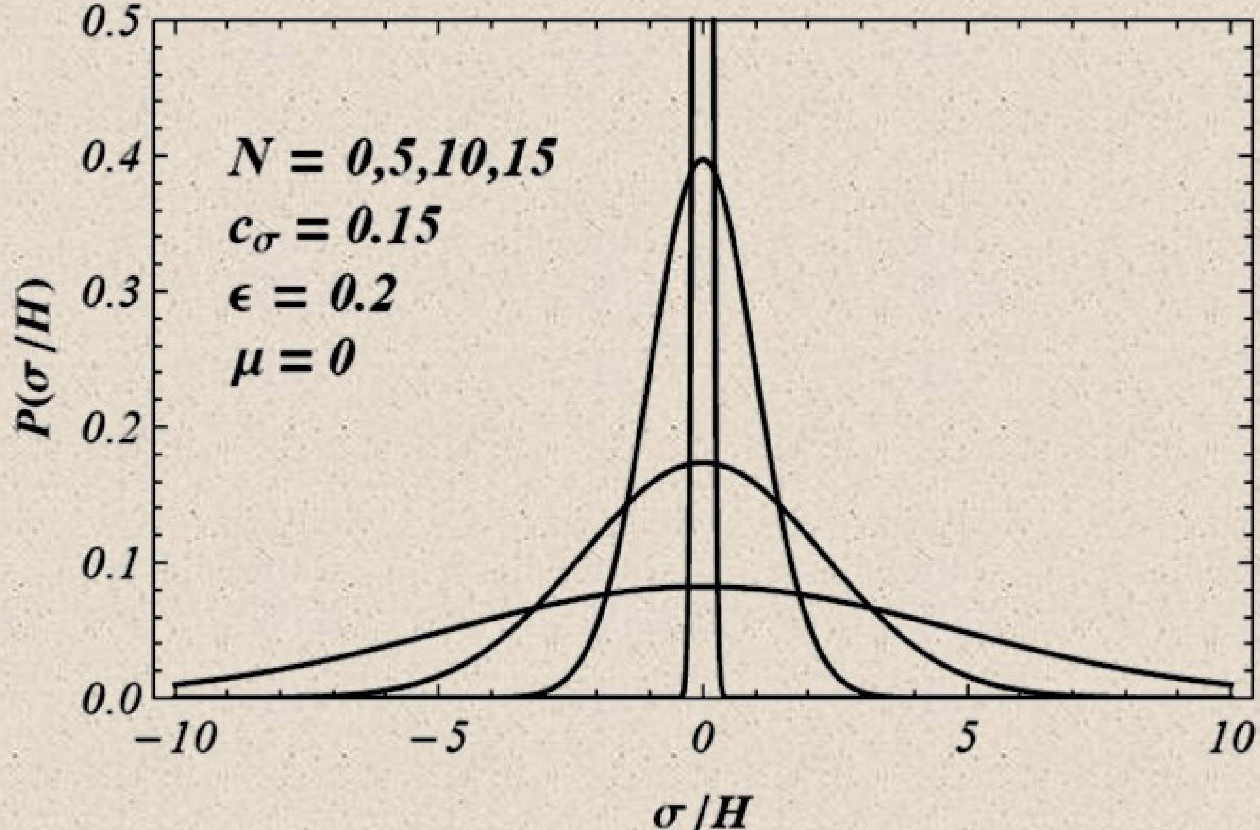
Relative magnitude σ/H grows

Getting to the initial condition

Evolution of the width

$$\Sigma^2 \equiv \langle (\sigma - \bar{\sigma})^2 \rangle = \gamma \frac{H^2}{4\pi^2(3-2\nu)} \left(1 - e^{-(3-2\nu)N_{\rm nsr}}\right)$$

Large values of σ/H become likely as non-slow-roll unfolds



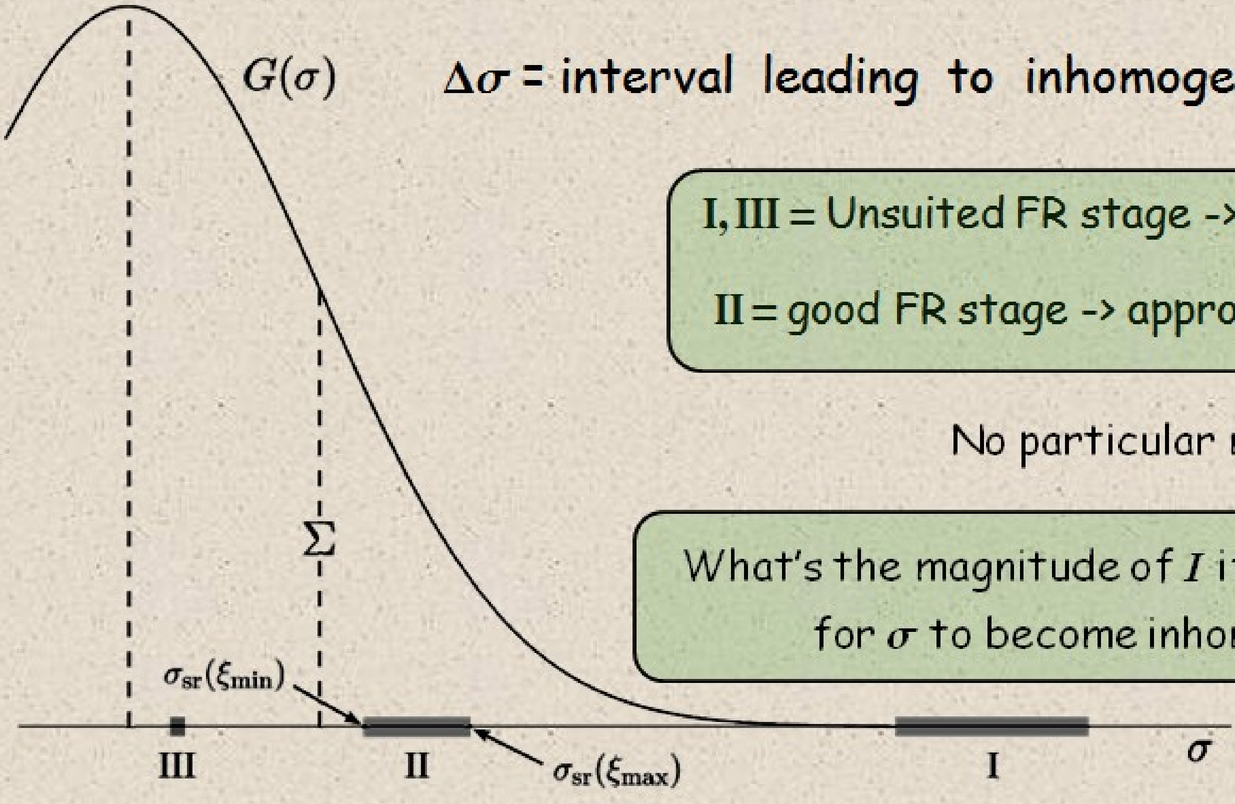
Computing the fine-tuning

To estimate probability just integrate $I \equiv \int_{\Delta\sigma} G \, d\sigma$

$G(\sigma)$ = field distribution when slow-roll begins

Begin inflation with $\sigma = 0$ -> Classical σ generated during non-slow-roll

strongly depends on the inflationary model



$\Delta\sigma$ = interval leading to inhomogeneous distribution of σ

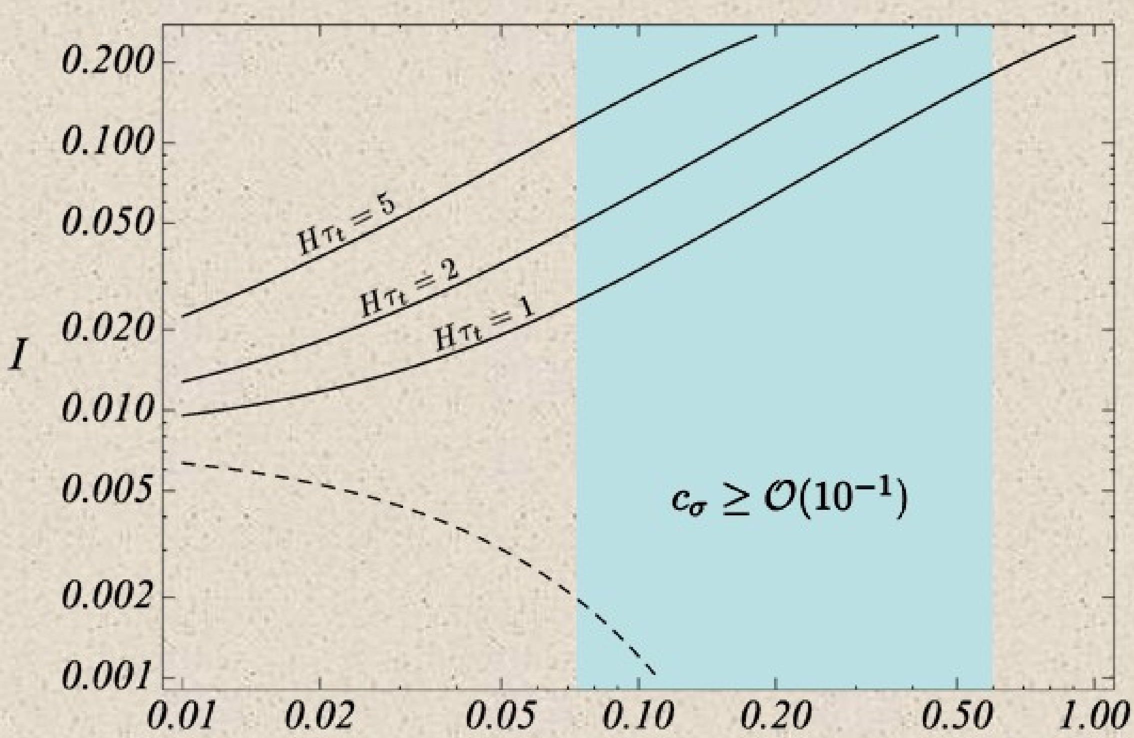
I, III = Unsuited FR stage -> Catastrophically unlikely

II = good FR stage -> appropriate for CMB anomalies

No particular model considered

What's the magnitude of I if **conditions are appropriate** for σ to become inhomogeneousy distributed?

Computing the fine-tuning



Phenomenological model (transition ~ H^{-1})

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Moderate no. χ fields involved in the coupling $g^2\sigma^2\chi^2$

+

Independence from g

$$c_\sigma > \left(\frac{N_{\rm CMB}}{4\pi^2}\right)^{1/2} \exp(-c_\sigma N_*/3)$$

For scalar masses generally predicted by SUGRA and independently of the strength coupling g ⇨ $I \geq \mathcal{O}(10^{-2})$

What's the inflationary model providing the appropriate conditions?

(CMB anomalies to seriously discriminate inflationary models)

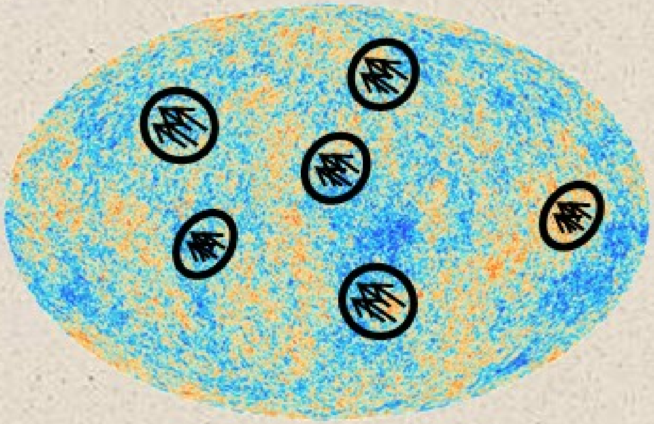
Spots in the GW spectrum

Pseudoscalar model: $\mathcal{L}_{\rm int} = -\frac{\alpha}{4f}\,\sigma F_{\mu\nu}\tilde{F}^{\mu\nu}$

* Production of A_μ driven by a field that becomes statistically inhomogeneous

* A_μ produced with different efficiency in different regions of the CMB

* Gauge field sources the production of GW



GW can be produced with different efficiency in different regions of the CMB

A patchy r suggests →
- Sourced GW production (may be by a gauge field)
- Primary **sustained**, non-slow-roll stage
- Powerful discriminator of inflation models

An inflation model with sustained, non-slow-roll was recently discovered!!

Burgess et al., 1605.03297 [gr-qc]