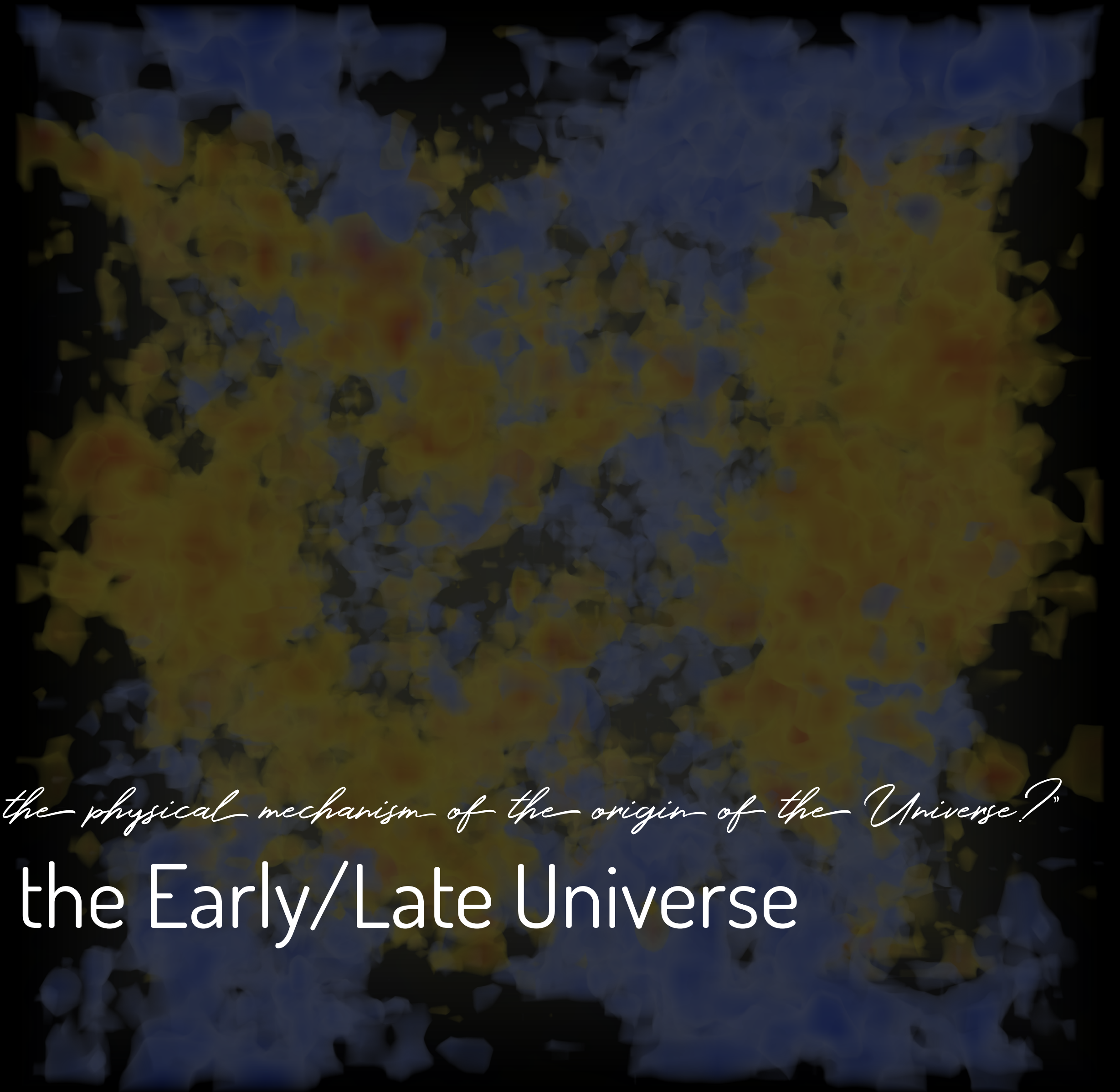




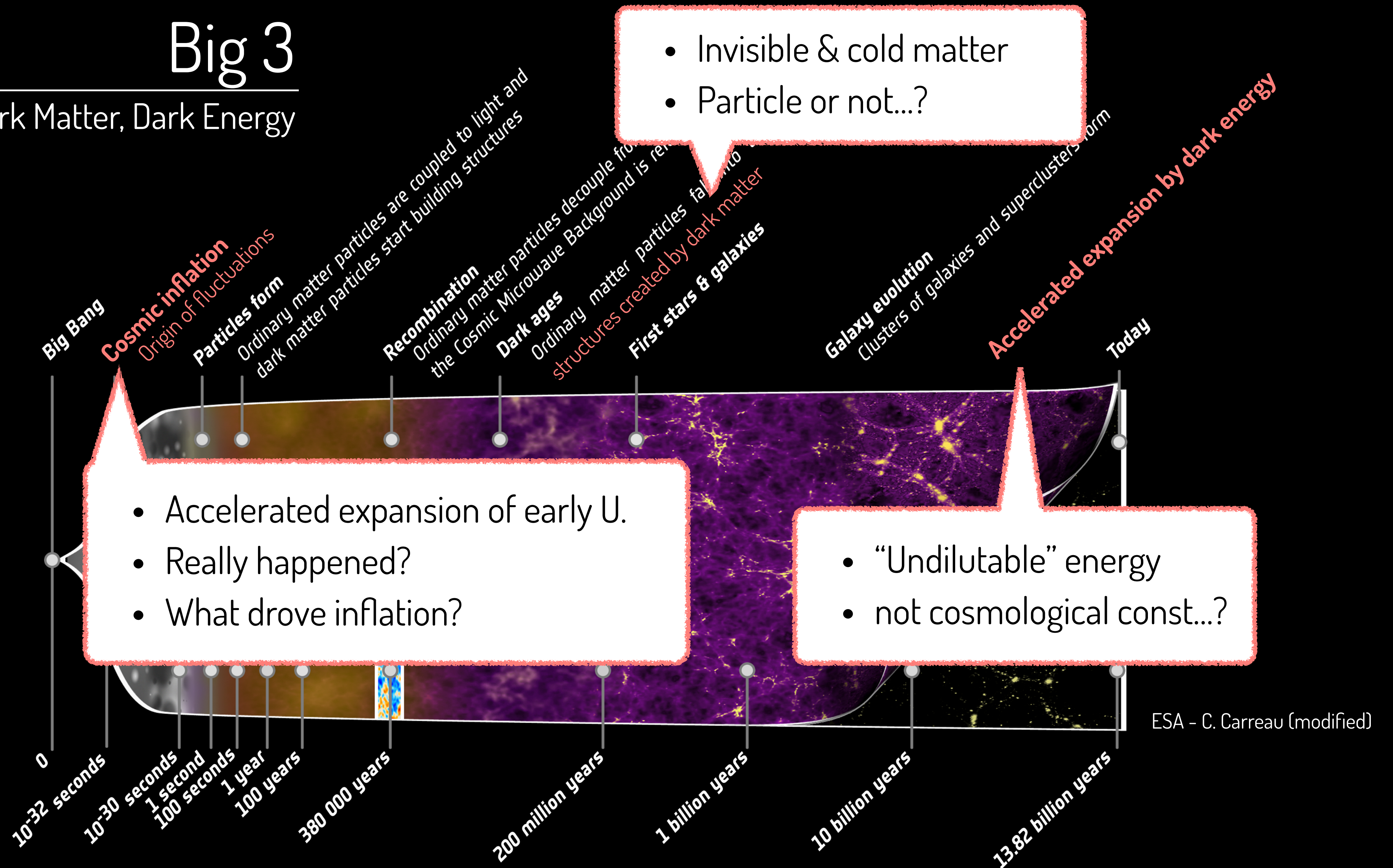
8th July 2026 @ Kick-off Meeting "What is the physical mechanism of the origin of the Universe?"

Simulation-based approach to the Early/Late Universe

Yuichiro TADA (A01) UFukui

Big 3

Inflation, Dark Matter, Dark Energy



Big 3

Inflation, Dark Matter, Dark Energy

- Invisible & cold matter
- Particle or not...?

Simulation

Theory

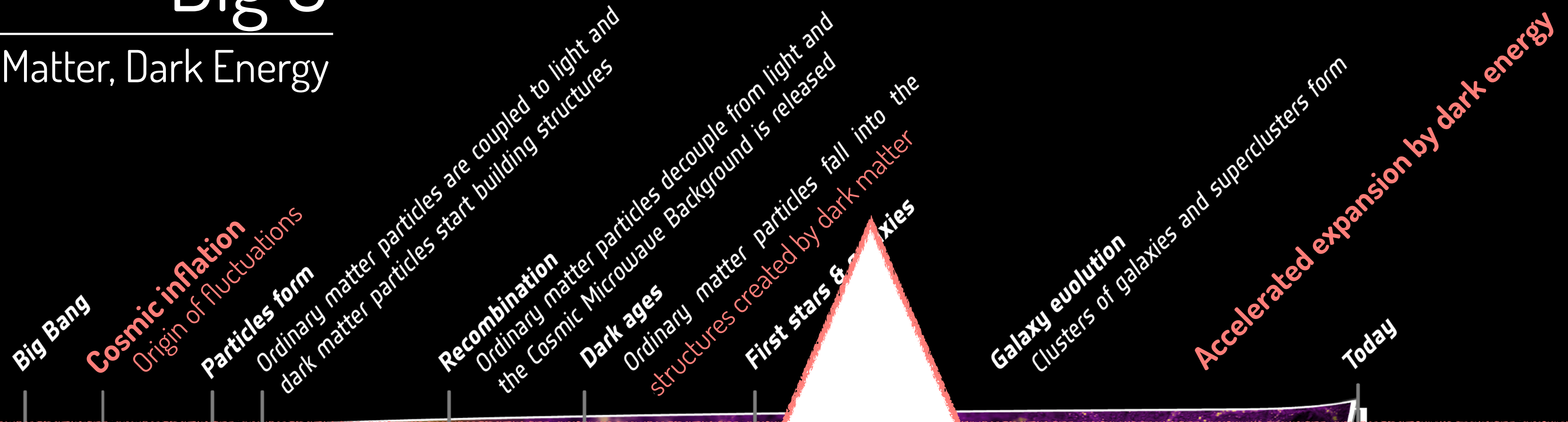
- Accelerated expansion of early U.
- Really happened?
- What drove inflation?

Observation

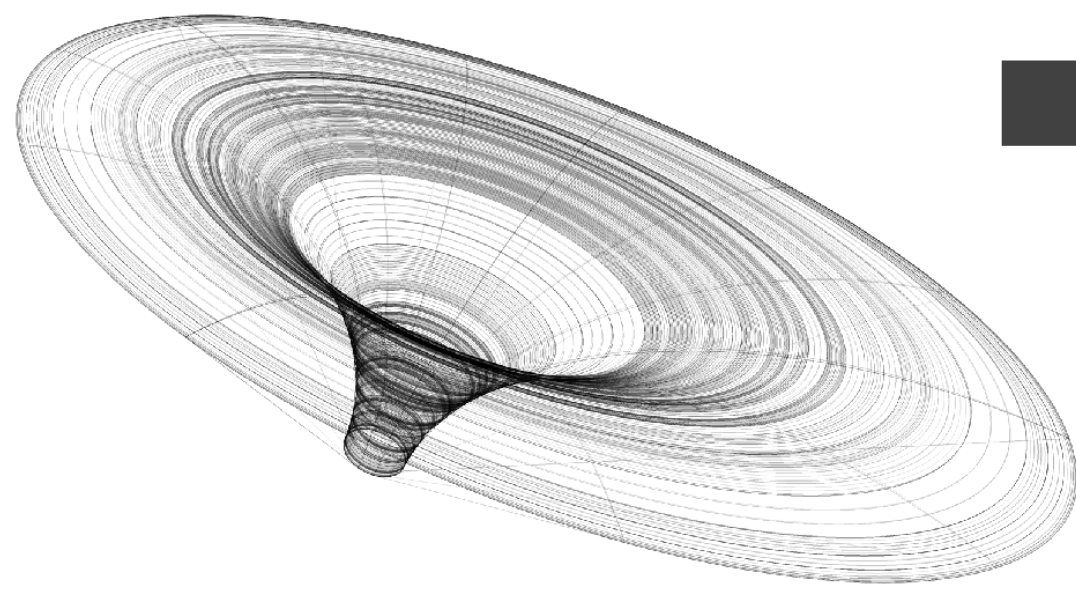
- “Undilutable” energy
- Clusters of galaxies and superclusters form

Big 3

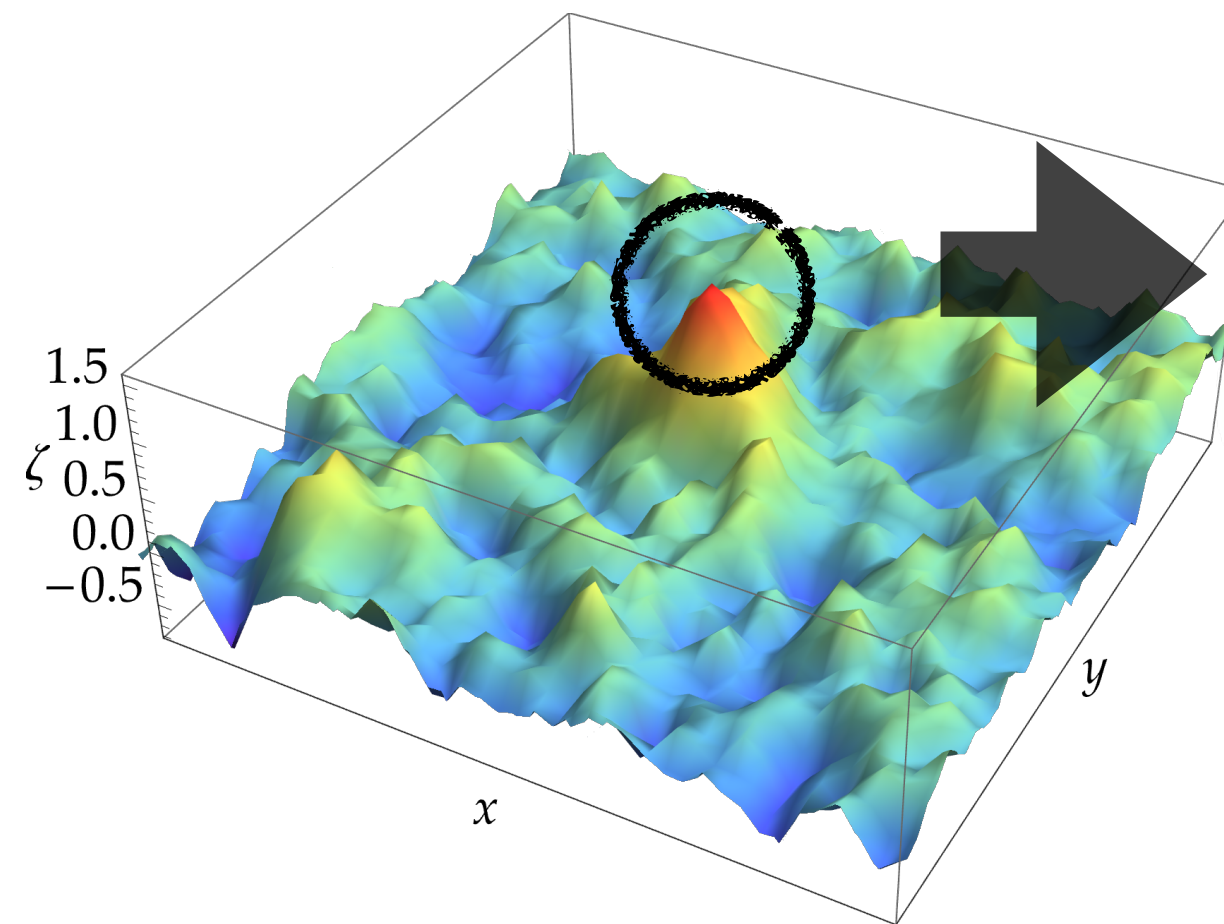
Inflation, Dark Matter, Dark Energy



Cosmic Inflation



Large Prim. PTB



Prim. BH as DM

How many?

- Yoo, Harada, Garriga, Kohri
- Fumagalli, Garriga, Germani, Sheth
- Pi, Sasaki, Takhistov, Wang
- Biagetti, De Luca, Franciolini, Kehagias, Riotto
- Young
- ⋮

No Experimental Test!

Lattice of Inflation

Standard Lattice (e.g. InflationEasy by Caravano)
No Metric PTB.

- ✓ – cheap
- based on public code
(LATTICEEASY, CosmoLattice, ...)
- ✗ – no control param./monitor for ansatz

Full GR by Giblin

- ✓ – most precise
- ✗ – expensive
- not public

STOchastic LAttice Simulation
“Random Walk” as superH EFT



T. Murata

Y. Mizuguchi

- ✓ – controlled by cutoff param.
- ✗ – perturbative at UV
- practically UV must be solved a priori

Locally FLRW

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



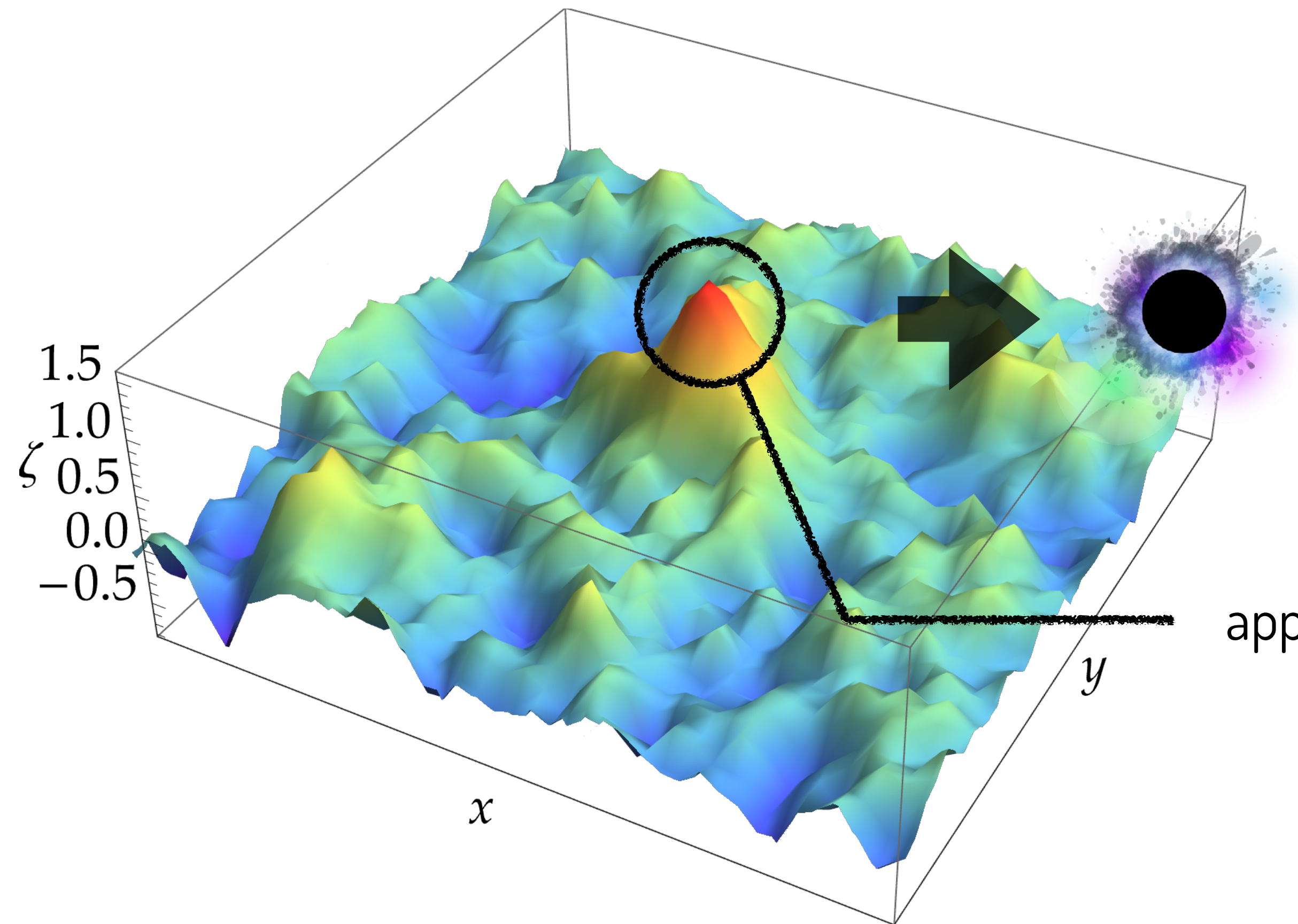
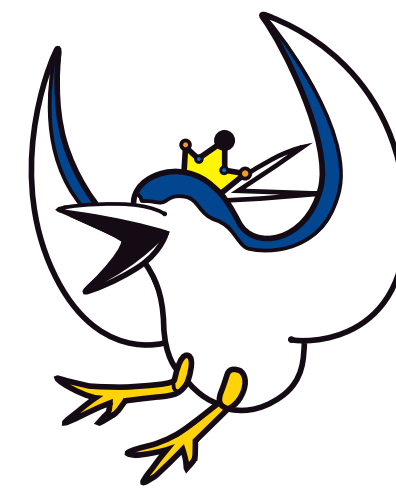
P. Saha

Y. Urakawa

- ✓ – monitor by momentum const.
- similar to STOLAS but non-ptb. for ϕ_{UV}
- ✗ – gravity at UV is not consistent

STOchastic LAttice Simulation

Mizuguchi, Murata, YT '24



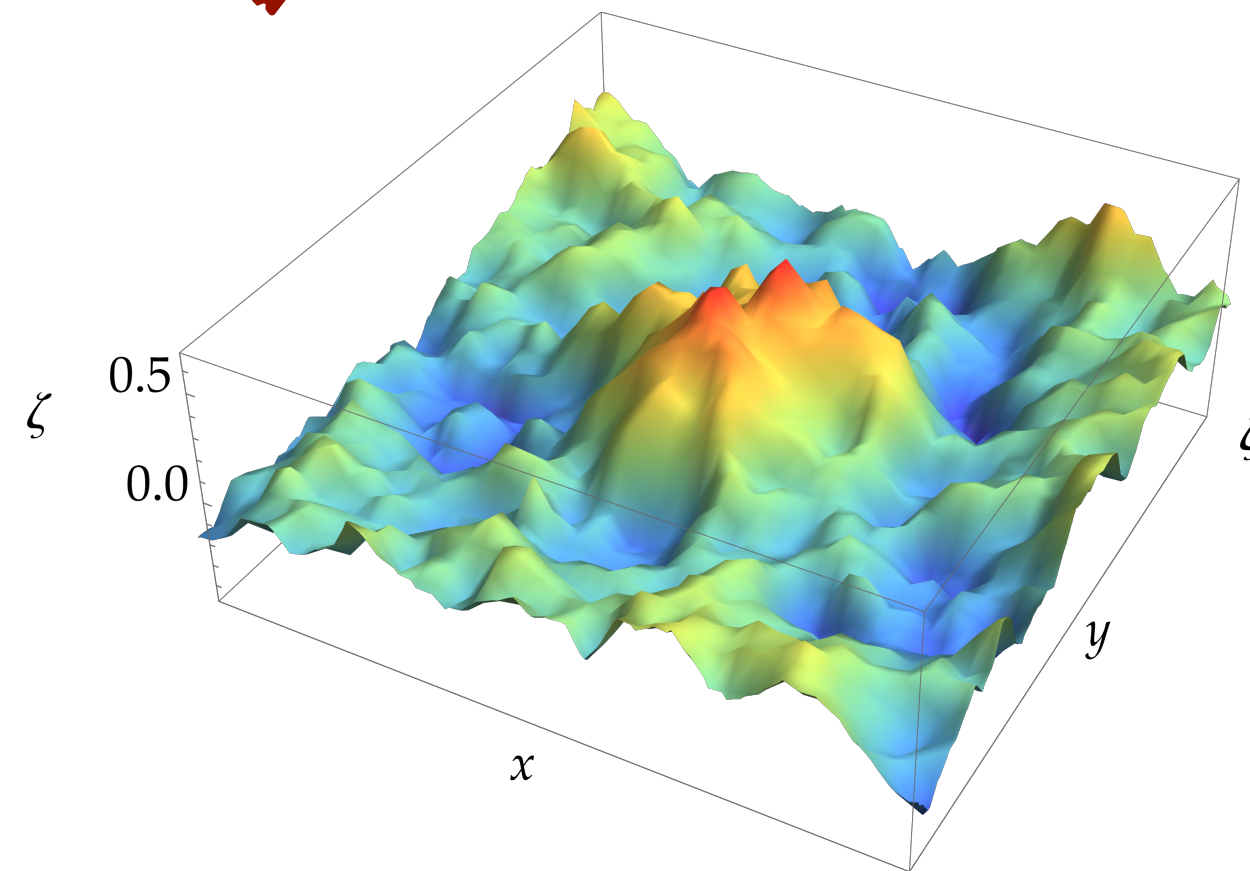
Importance Sampling

see, e.g., Jackson+ '22

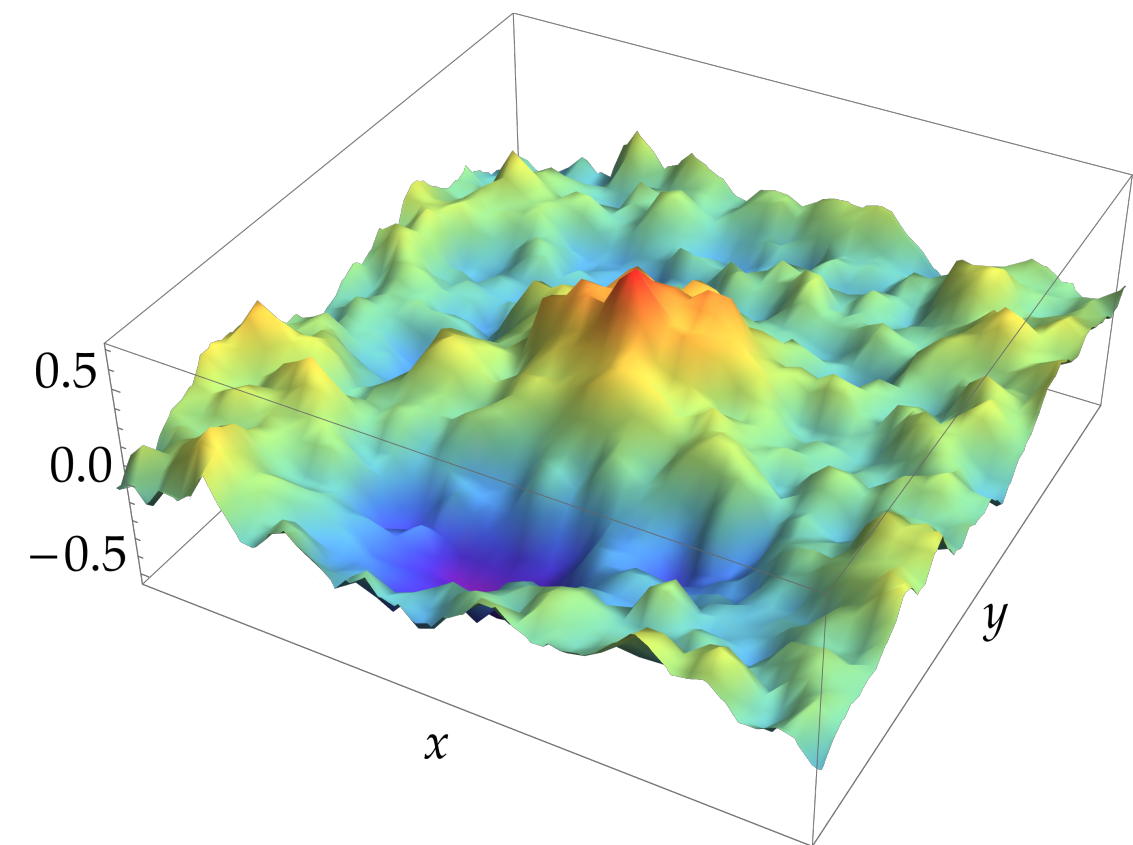
to add large noise intentionally and
sample rare objects intensively.
Correct the histogram by estimating the
probability of such large noise.

apply the numerical-relativity-based criterion

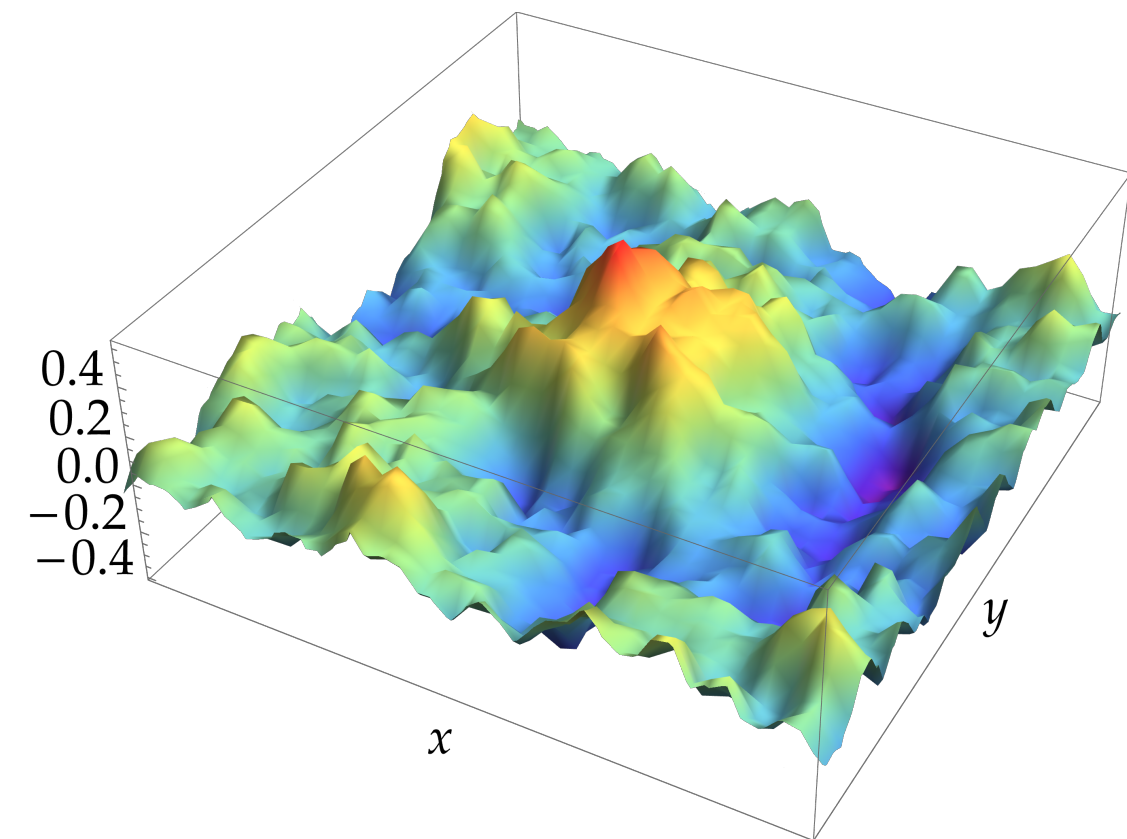
✗ $\bar{\mathcal{E}}_m = 0.387$



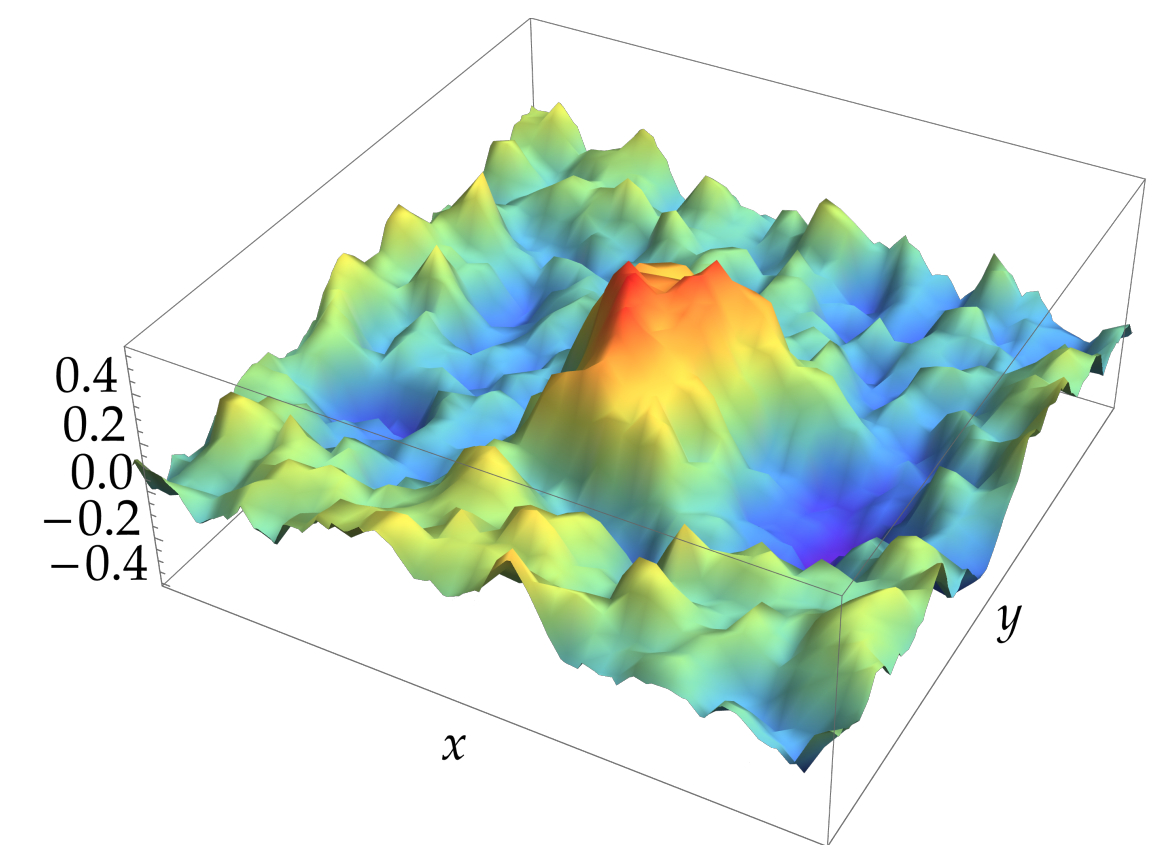
✓ $M = 1.58 \times 10^{20} \text{ g}$
 $\bar{\mathcal{E}}_m = 0.442$



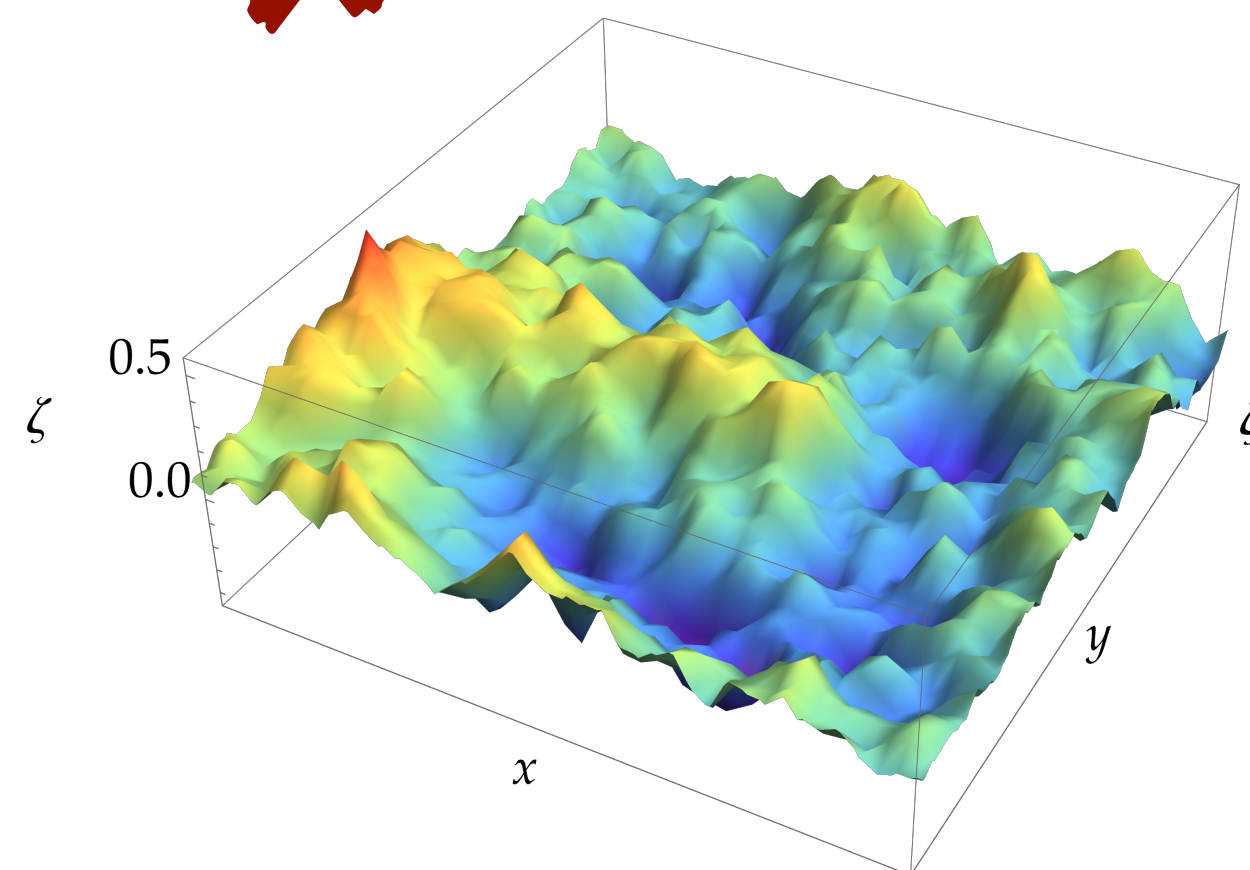
✗ $\bar{\mathcal{E}}_m = 0.372$



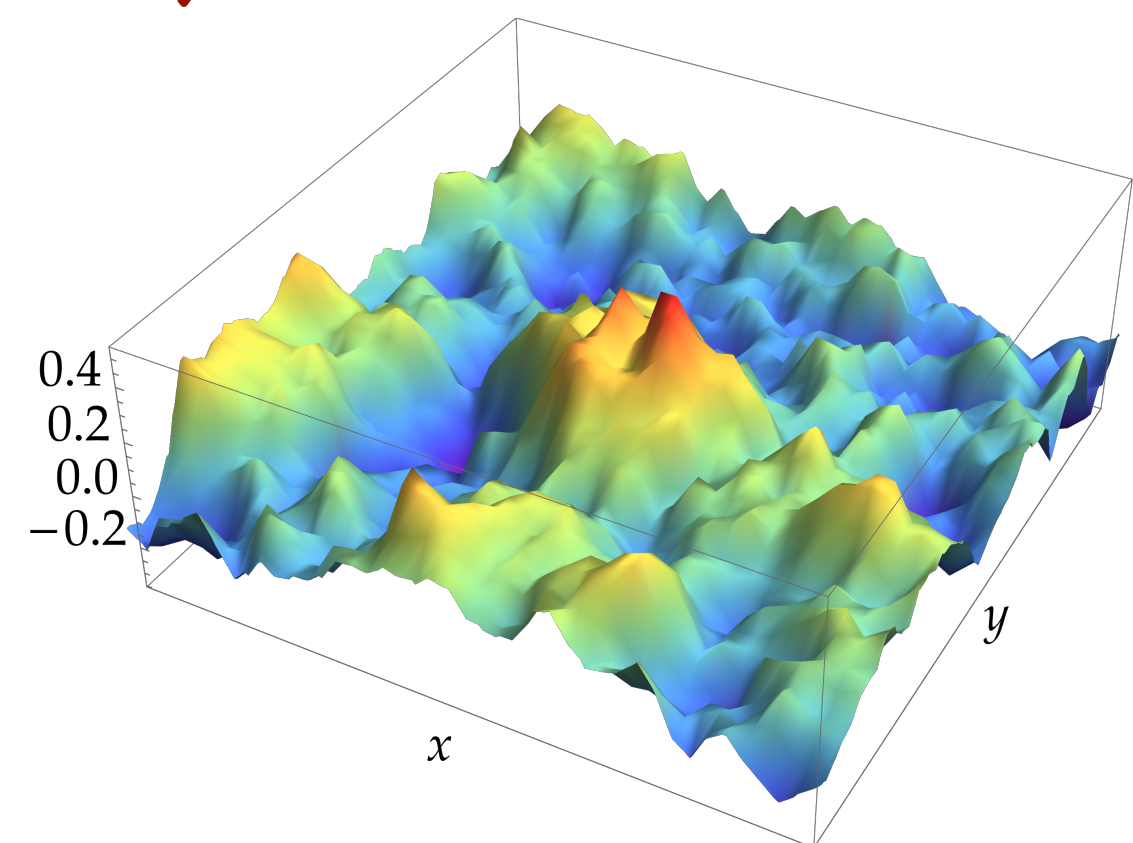
✓ $M = 0.846 \times 10^{20} \text{ g}$
 $\bar{\mathcal{E}}_m = 0.409$



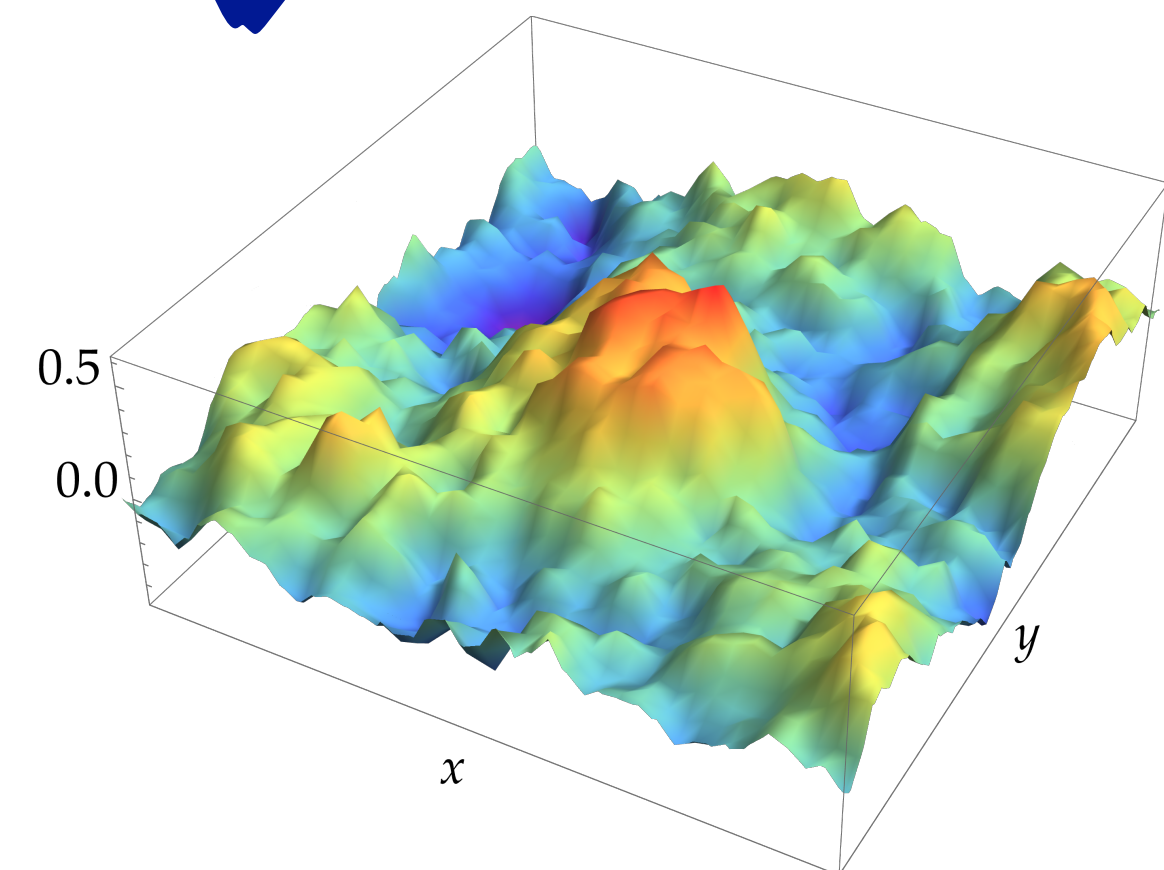
✗ $\bar{\mathcal{E}}_m = 0.268$



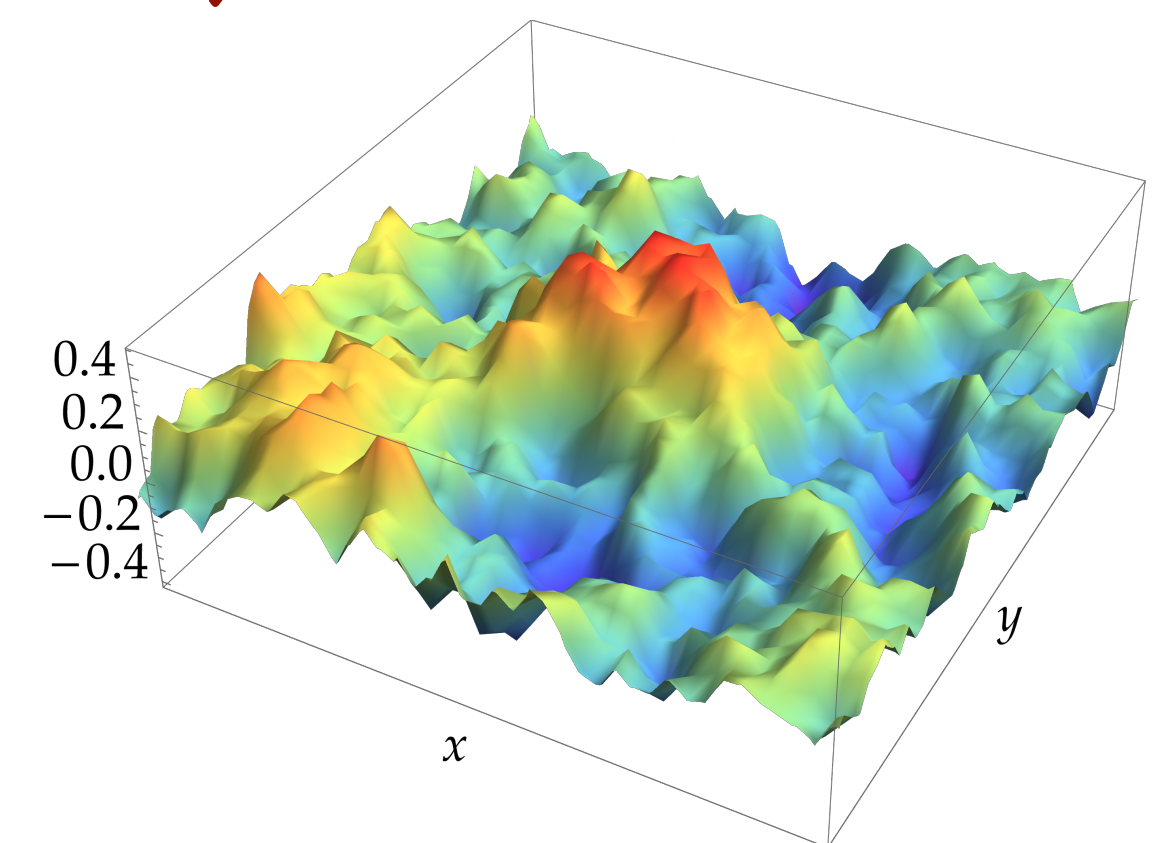
✗ $\bar{\mathcal{E}}_m = 0.310$



✓ $M = 1.21 \times 10^{20} \text{ g}$
 $\bar{\mathcal{E}}_m = 0.416$



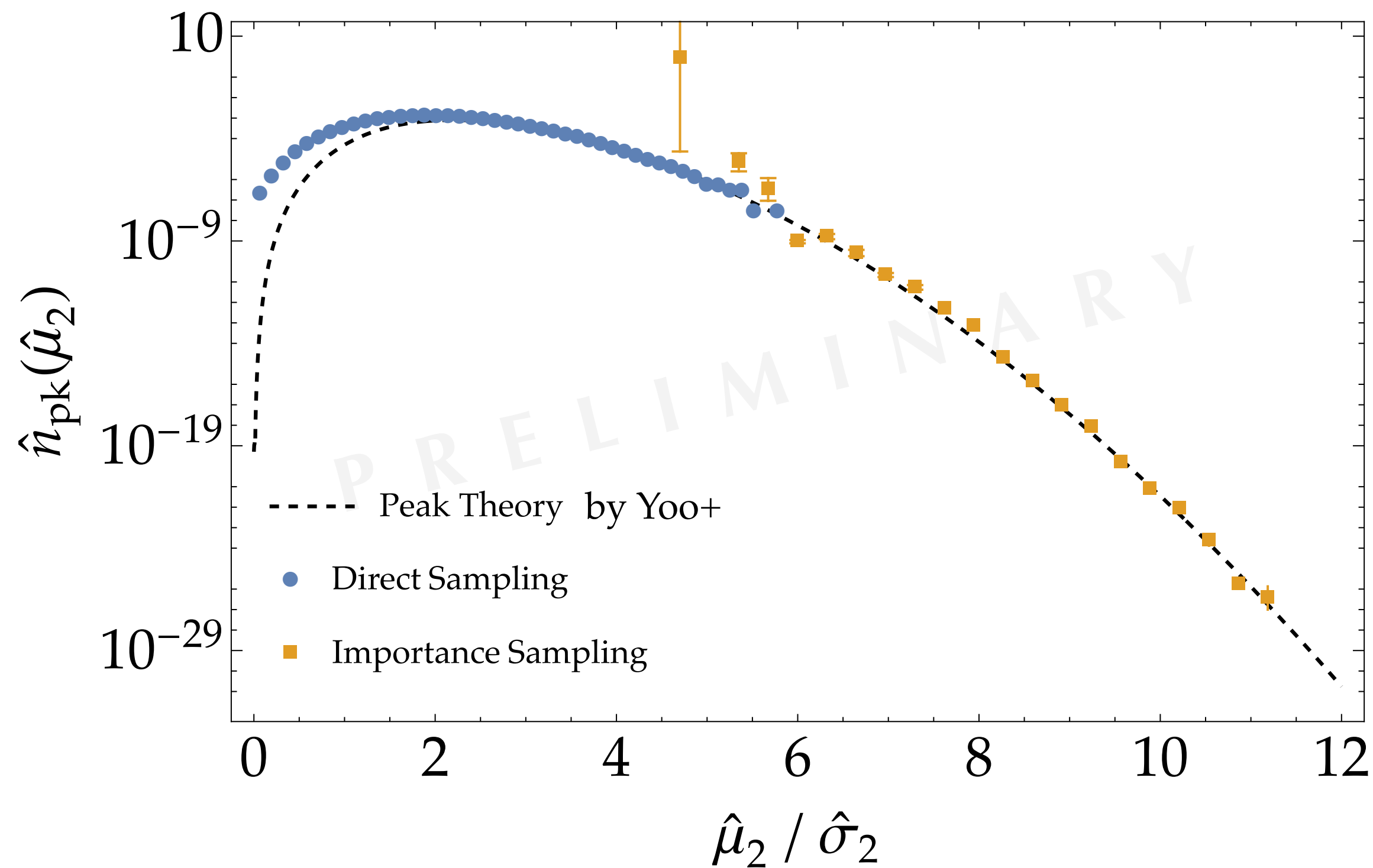
✗ $\bar{\mathcal{E}}_m = 0.383$



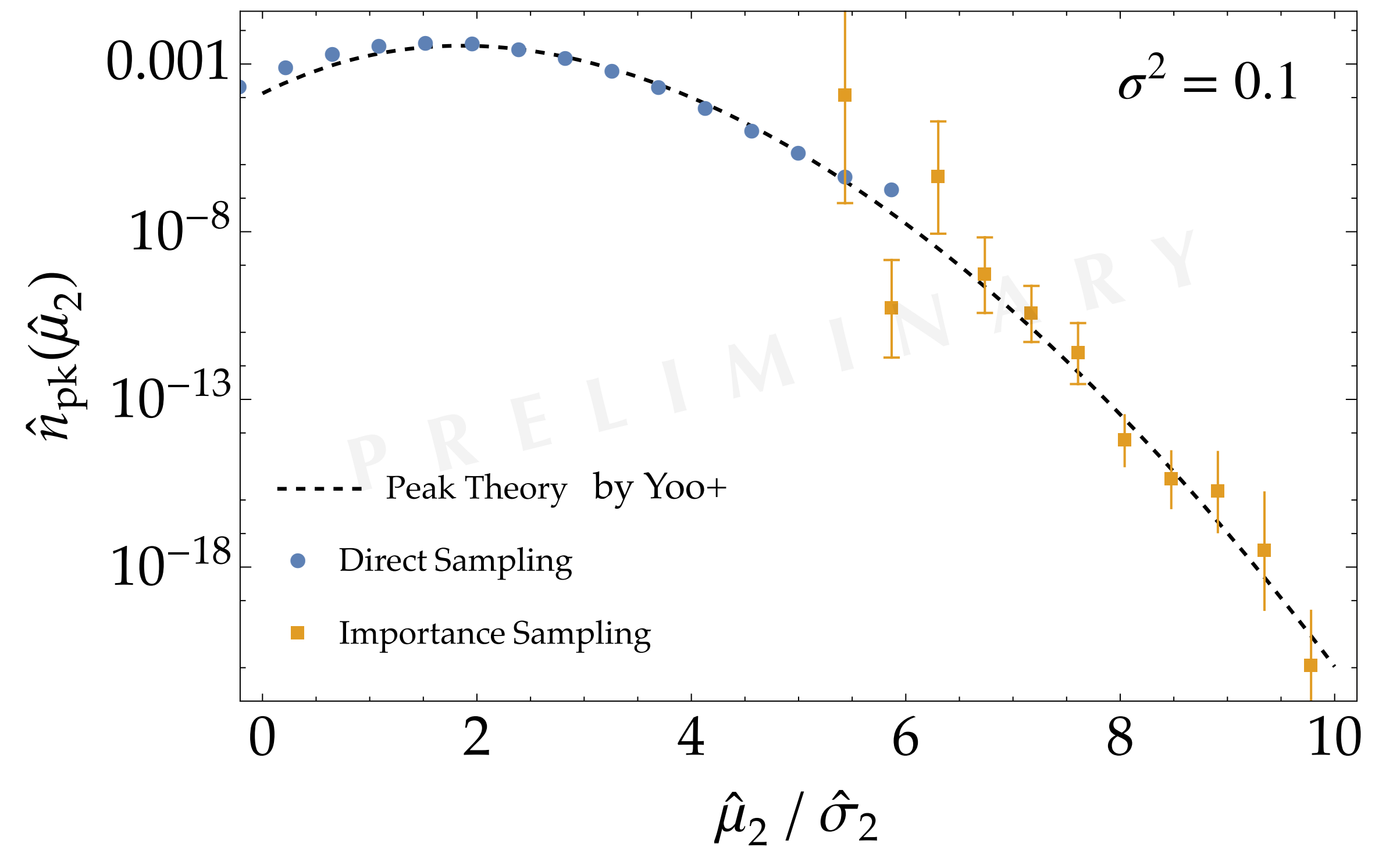
Gaussian Test

in prep.

$$\mathcal{P}_\zeta = A_s \delta(\ln k - \ln k_*)$$



$$\mathcal{P}_\zeta = \frac{A_s}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{(\ln k/k_*)^2}{2\sigma^2}\right)$$

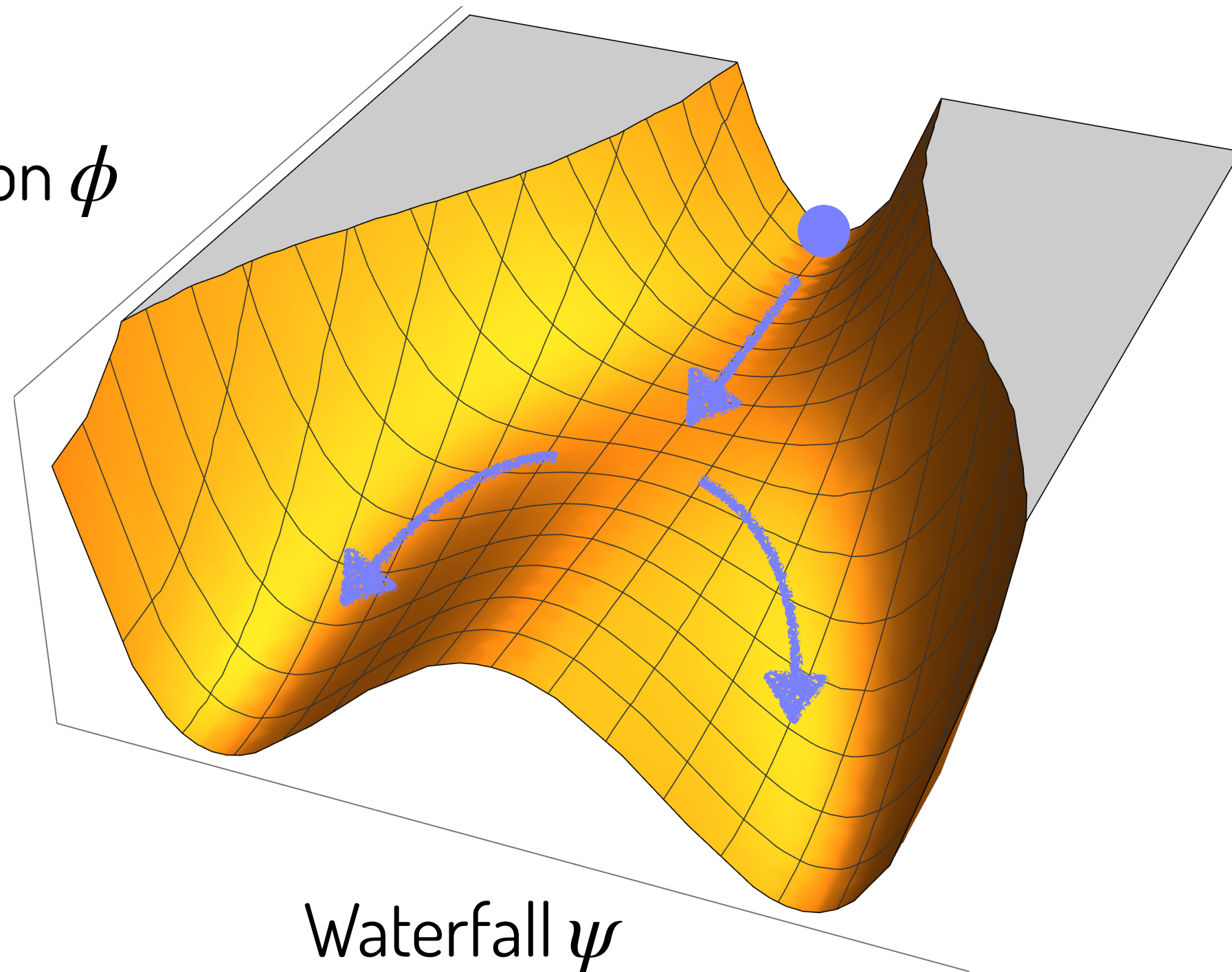


STOLAS in hybrid

Murata & YT '26

$$V(\phi, \psi) = \frac{1}{4\lambda}(M^2 - \lambda\psi^2)^2 + \frac{g^2}{2}\phi^2\psi^2 + V(\phi)$$

Inflaton ϕ



Waterfall ψ

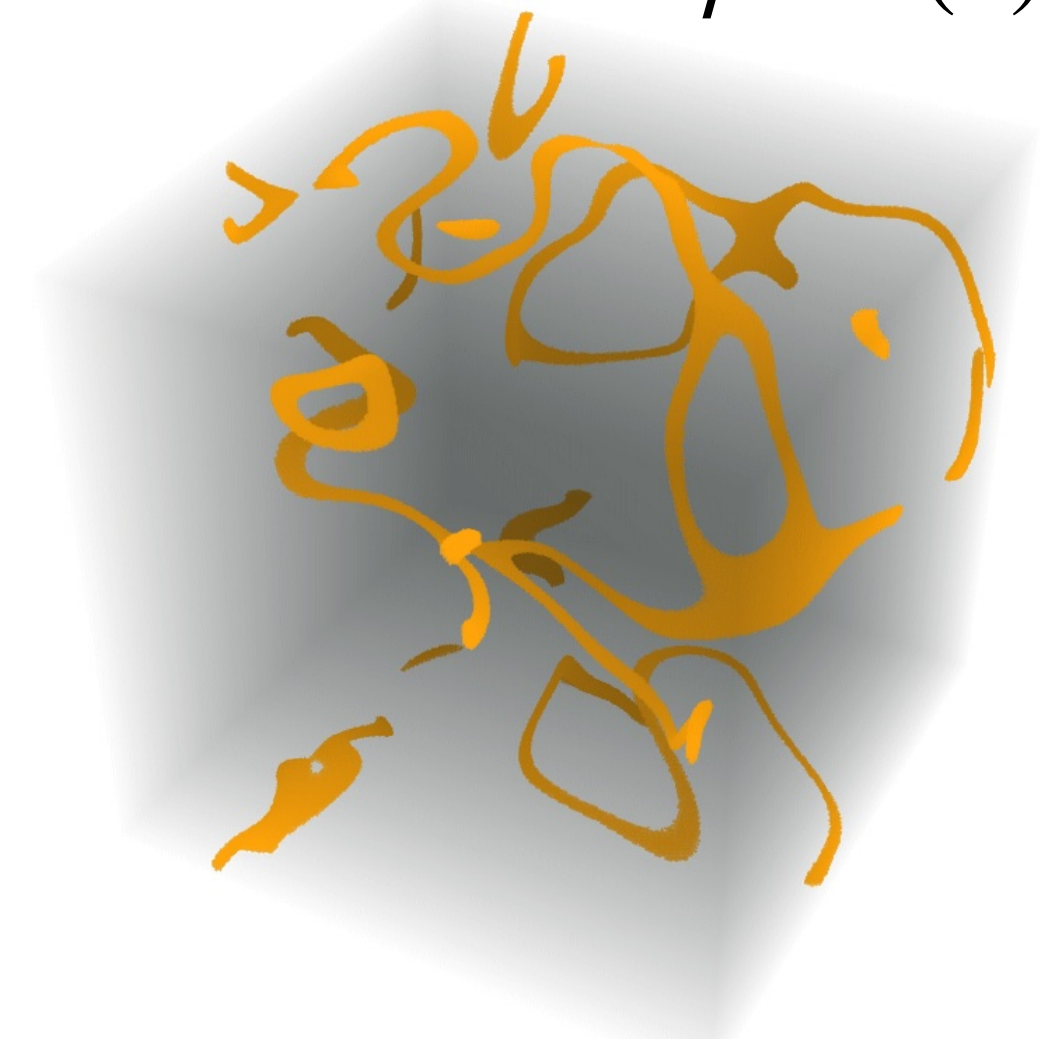
“Stochastic Reconnection” of topological defects

$N = 4.02$

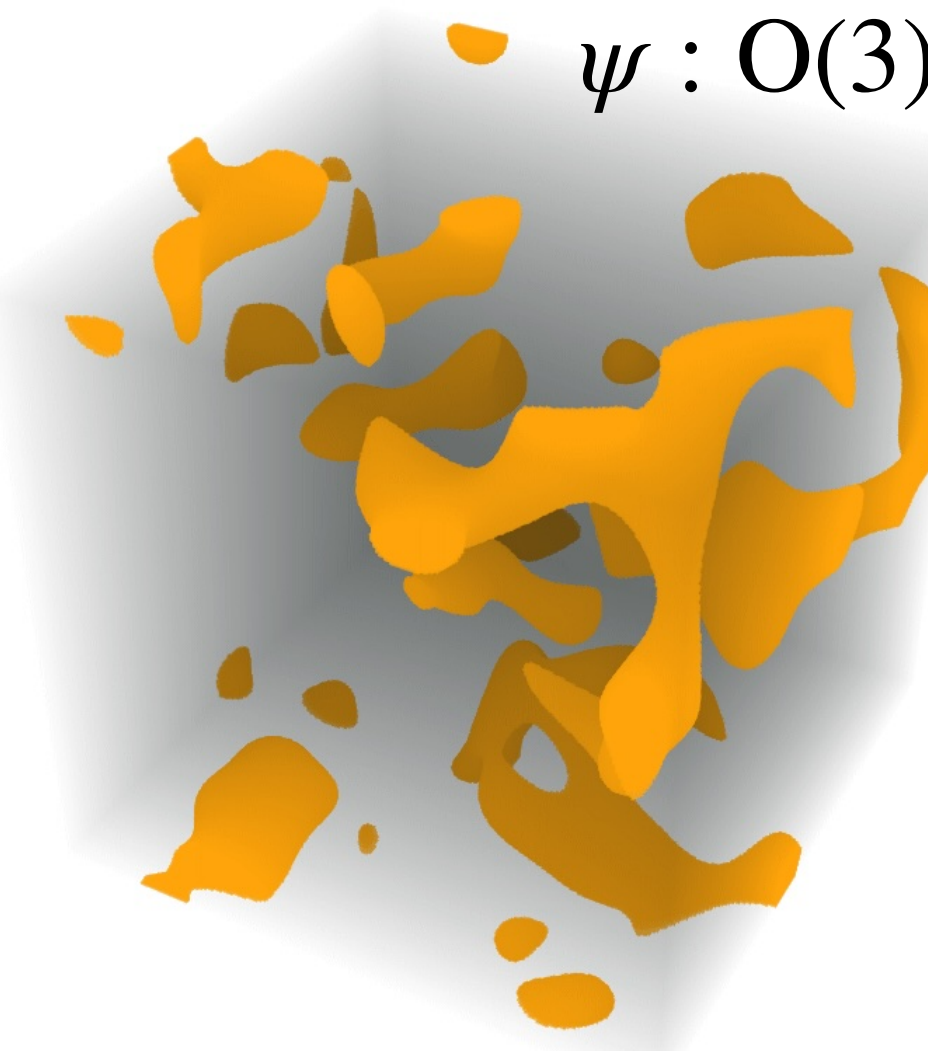
$\psi : \mathbb{Z}_2$



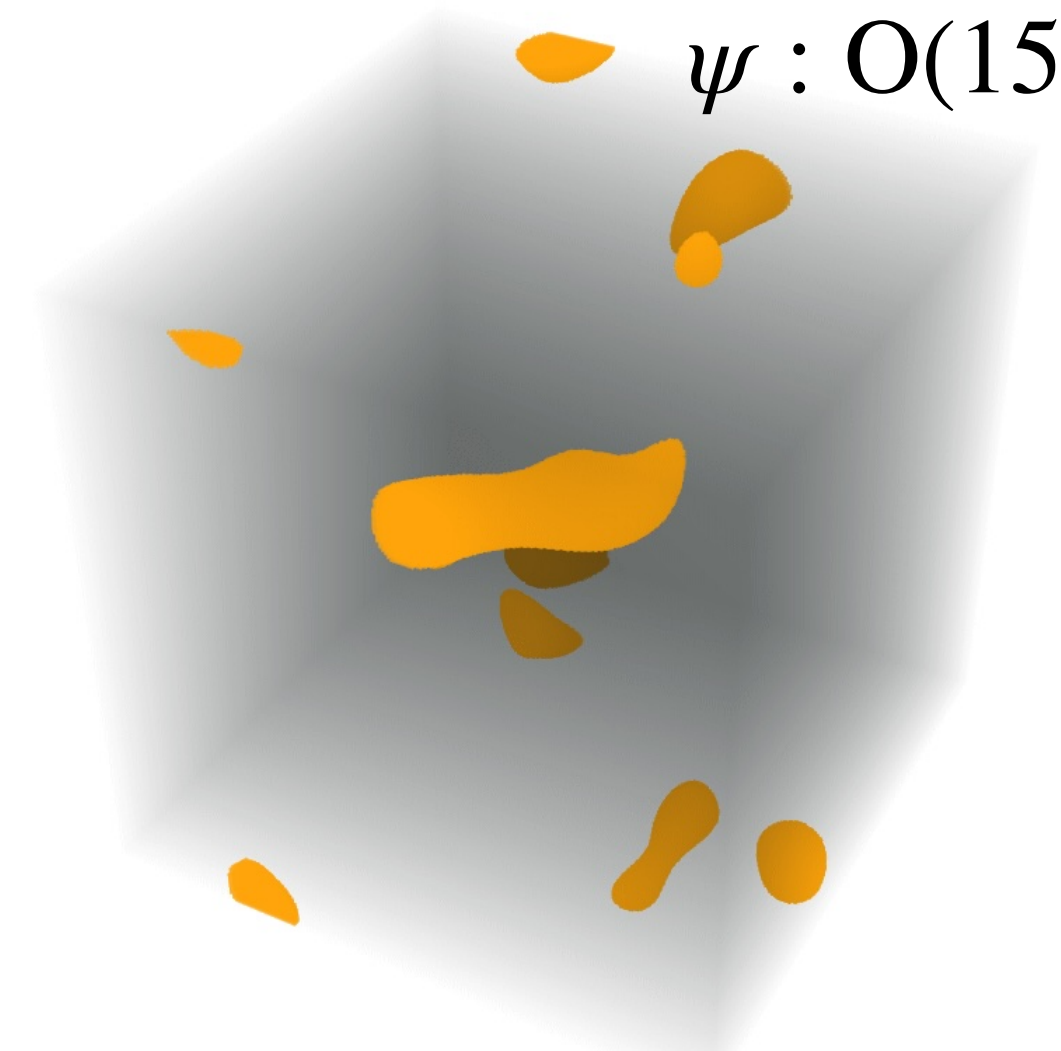
$\psi : \mathbb{O}(2)$



$\psi : \mathbb{O}(3)$



$\psi : \mathbb{O}(15)$

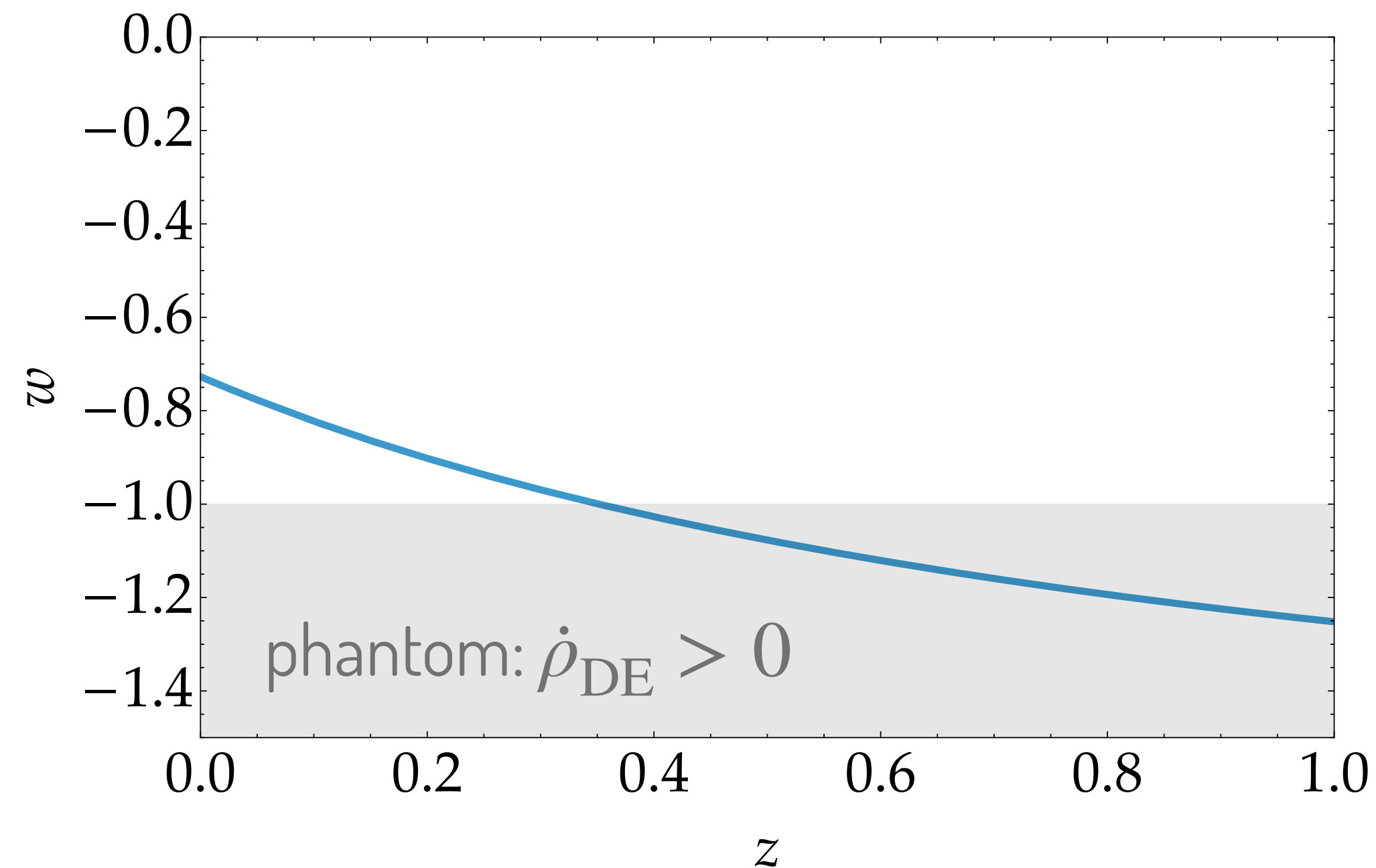


DESI BAO + SNe

Time-evolving Dark Energy

Chevallier–Polarski–Linder

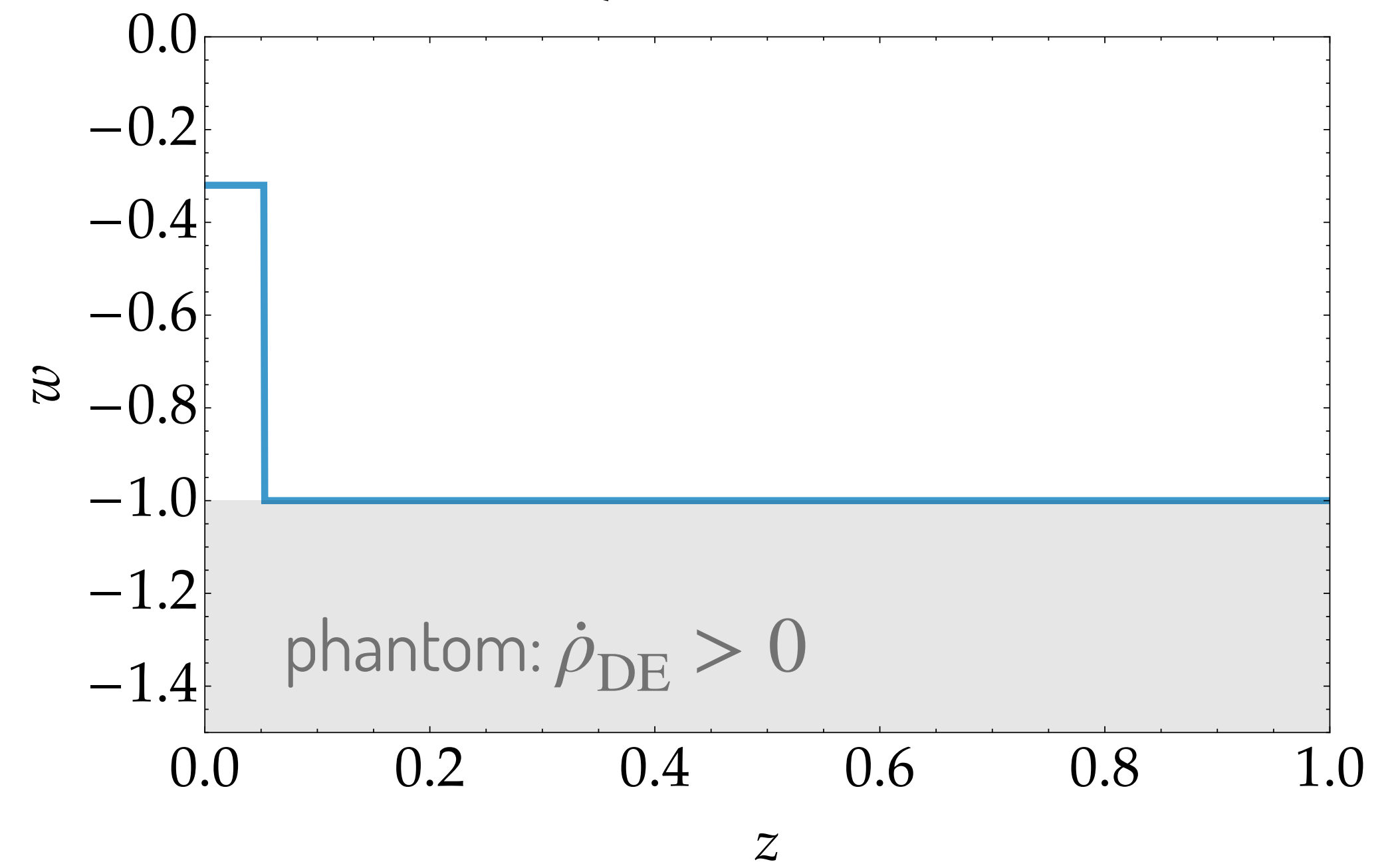
$$w = w_0 + w_a(1 - a)$$



$$w = \frac{p_{\text{DE}}}{\rho_{\text{DE}}}$$

Transitional DE

$$w = \begin{cases} w_0 & a \geq a_t \\ -1 & a < a_t \end{cases}$$



DESI BAO + SNe

Time-evolving Dark Energy

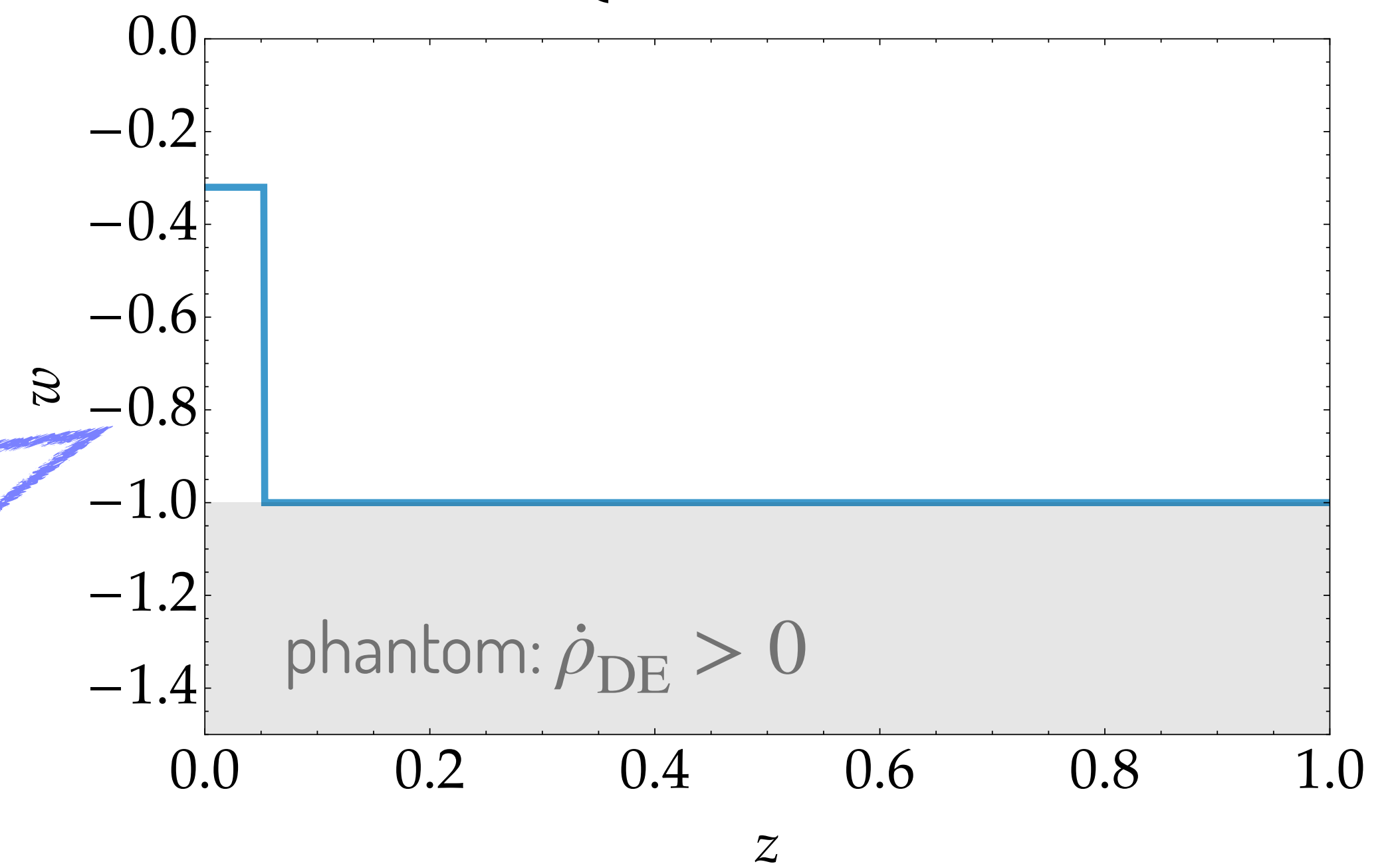
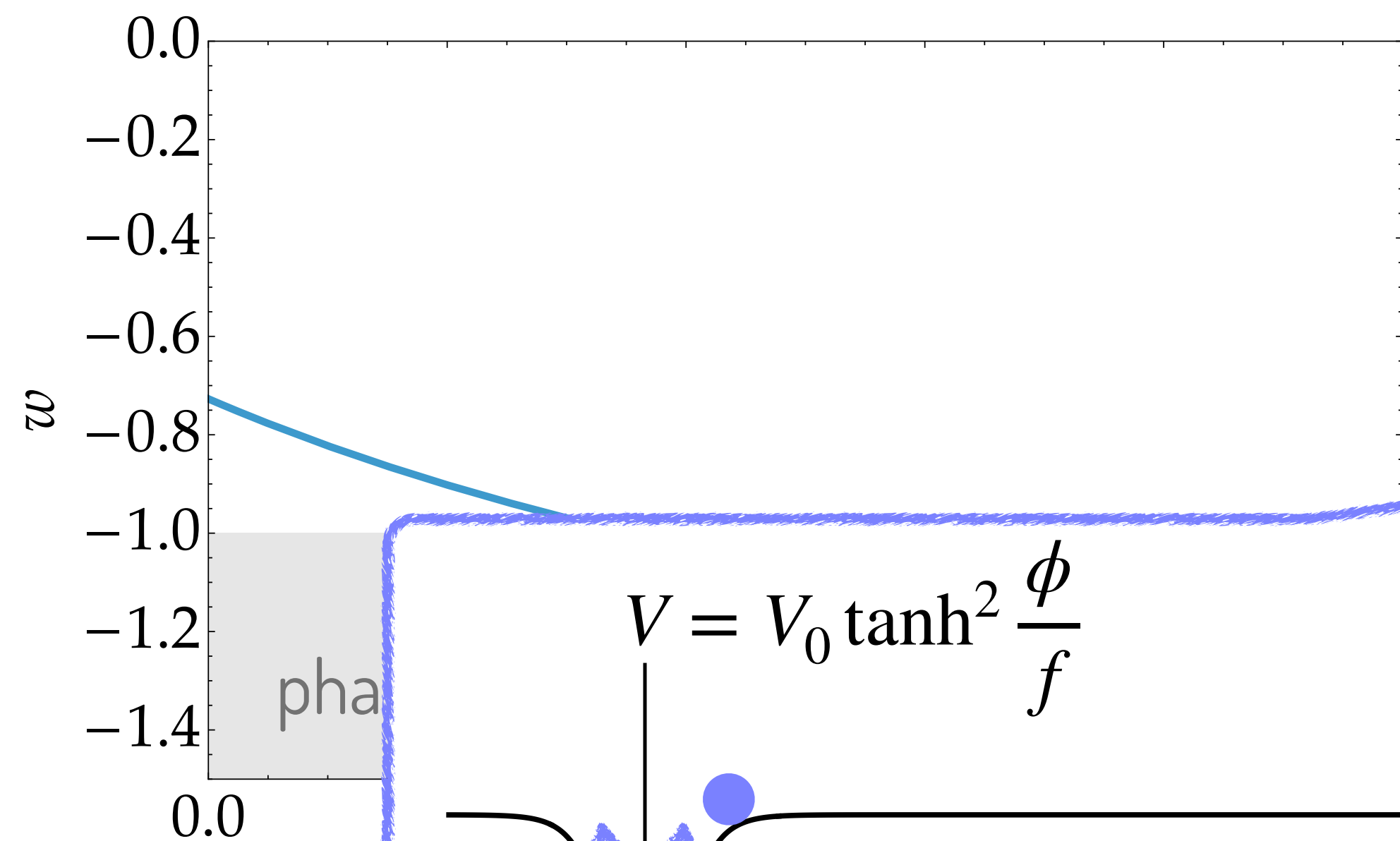
Chevallier–Polarski–Linder

$$w = w_0 + w_a(1 - a)$$

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Transitional DE

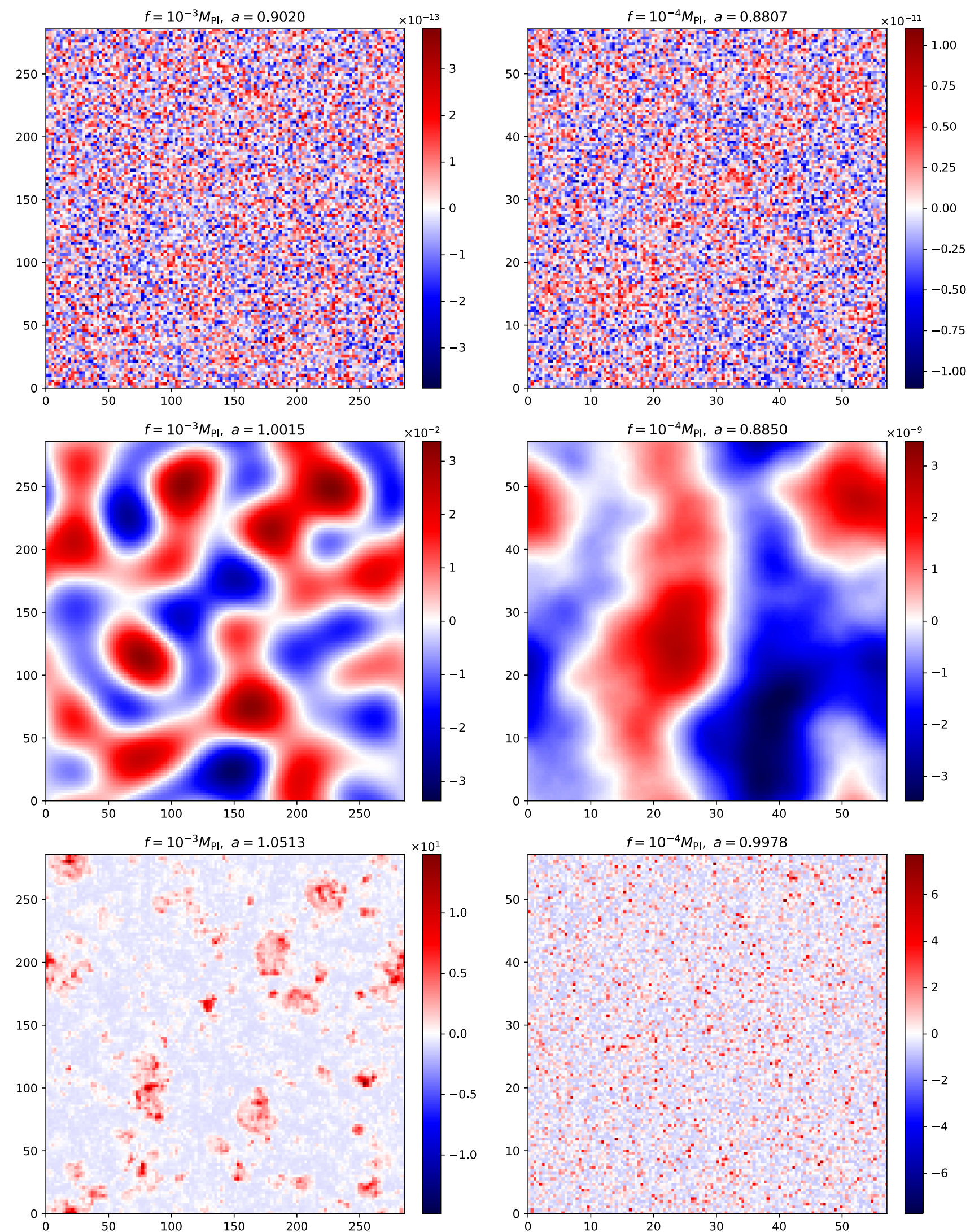
$$w = \begin{cases} w_0 & a \geq a_t \\ -1 & a < a_t \end{cases}$$



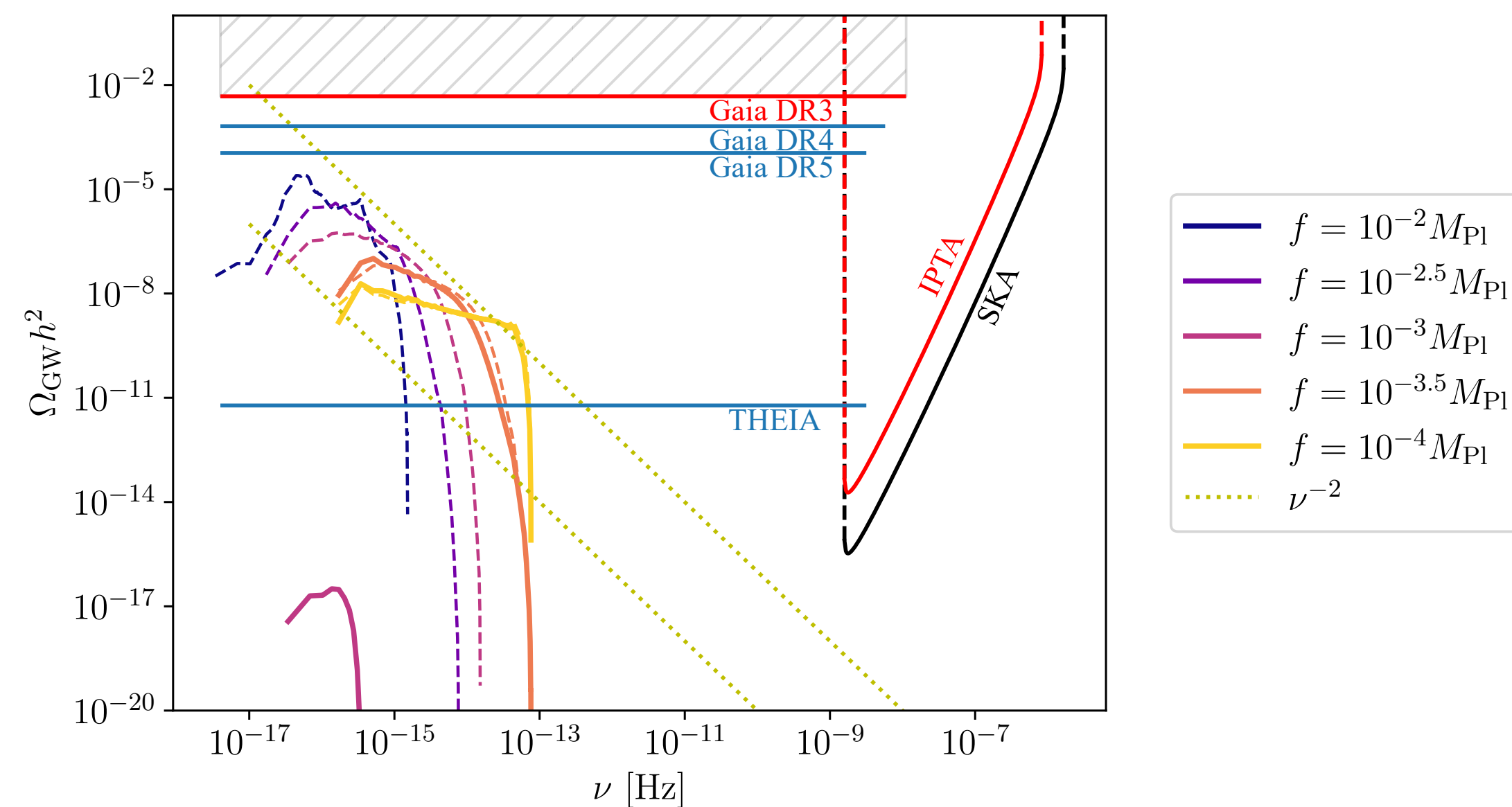
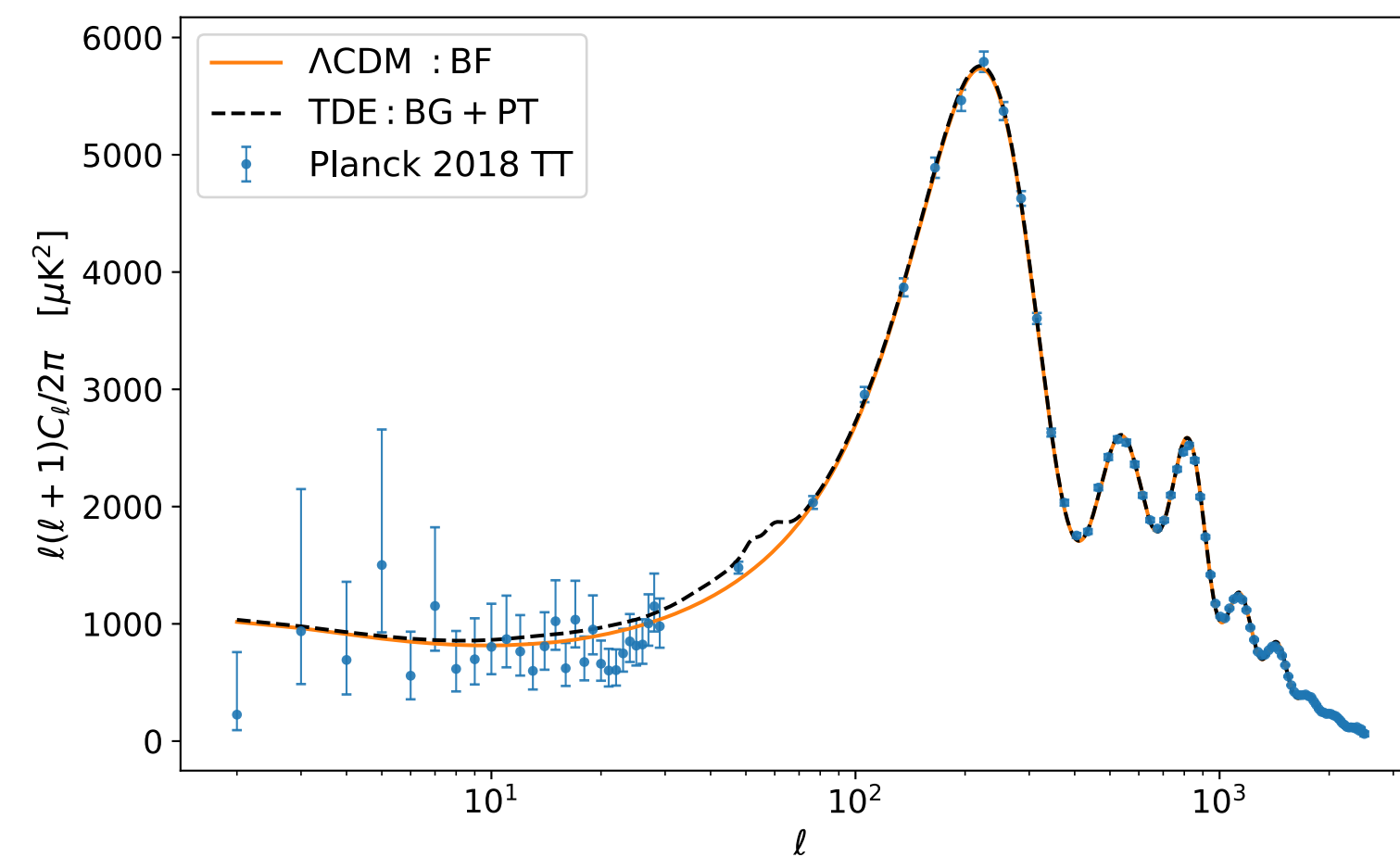
Yoshioka, Ichiki, YT, Terada '26

Resonant TDE

Yoshioka, Ichiki, YT, Terada '26



DE fragmentation by std. lattice



Summary

Why not simulate the universe more?