# DIFFERENT VIEWS OF COSMIC DEFECT EVOLUTION

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# INTRODUCTION

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- What are topological defects?

- Do they play a significant role in the early Universe?

[1]- T.W. B. Kibble 1976

# INTRODUCTION

- What are topological defects?

  Inevitably produced in phase transitions, as the Universe cools down;

    - spontaneous symmetry breaking (Kibble mechanism[1]);

- Do they play a significant role in the early Universe?

  Topological defects carry energy

    - Leads to extra attractive gravitational force

    - Contribute to the origin of several cosmic structures (Why are galaxies clustered?)

- Four types of topological defects: textures and cosmic strings (attractive scenarios), monopoles and domain walls (catastrophic).

[1]- T.W. B. Kibble 1976

# INTRODUCTION

- Domain Walls
  - Discrete symmetry broken at a phase transition;
  - Sections the universe into ‘cells’, ‘bubbles’;

$$\mathcal{L} = \frac{1}{2}\phi_{,\alpha}\phi^{,\alpha} - V(\phi)$$

$$V(\phi) = V_0\left(\frac{\phi^2}{\phi_0^2} - 1\right)^2$$

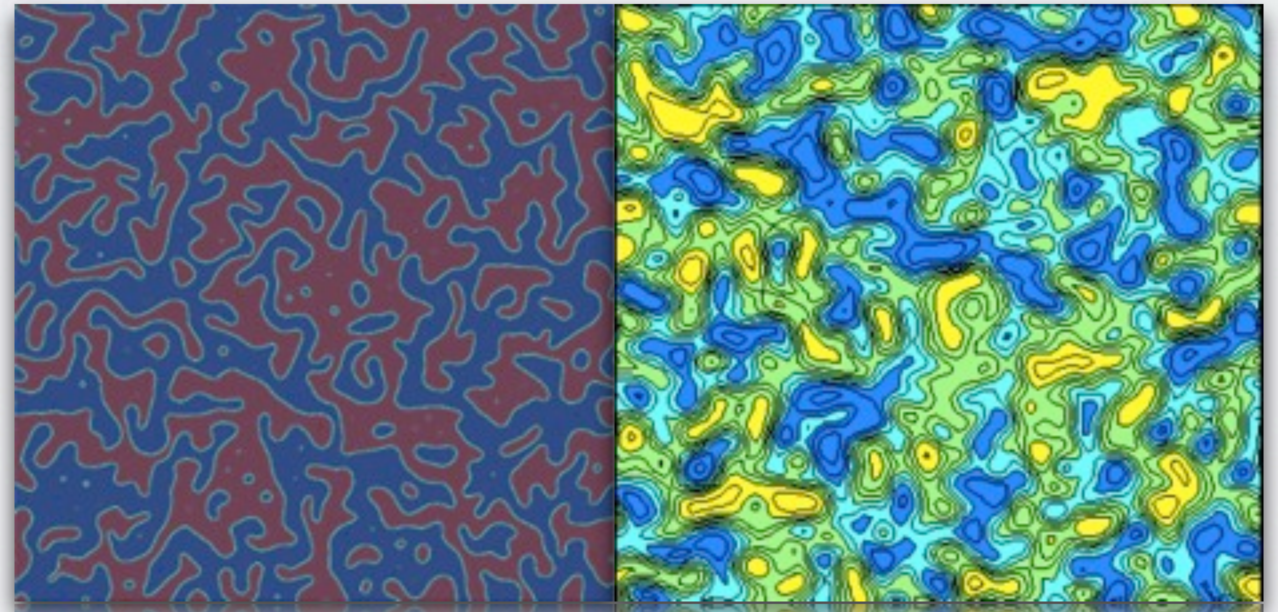
- Evolution equation:

$$\frac{\partial^2 \phi}{\partial \eta^2} + \alpha\left(\frac{dlna}{dln\eta}\right)\frac{1}{\eta}\frac{\partial \phi}{\partial \eta} - \nabla^2\phi = -a^\beta \frac{\partial V}{\partial \phi}$$

| | | |
|---|---|---|
| $d\eta = \frac{dt}{da(t)}$ | $W_0 = \left(\frac{dlna}{dln\eta}\right)\frac{w_0}{\eta_0}$ | $\lambda/(1-\lambda) = \left(\frac{dlna}{dln\eta}\right)$ [2] |
| Conformal Time | Dimensionless Wall Thickness | Era |

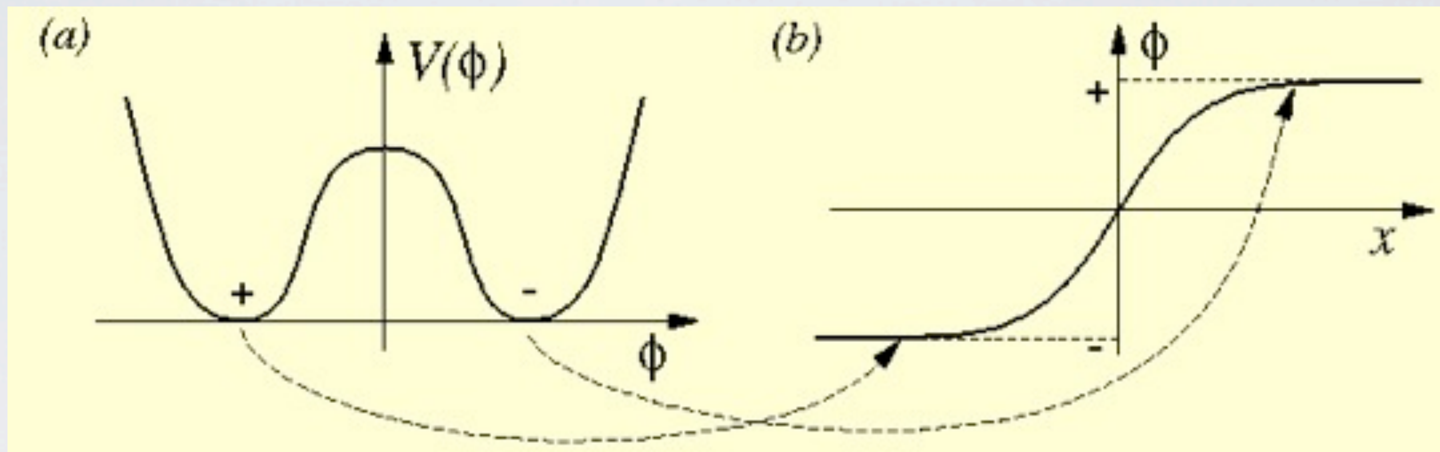
[2] - W. H. Press, B. S. Ryden and D. N. Spergel 1989

# ONE SCALAR FIELD



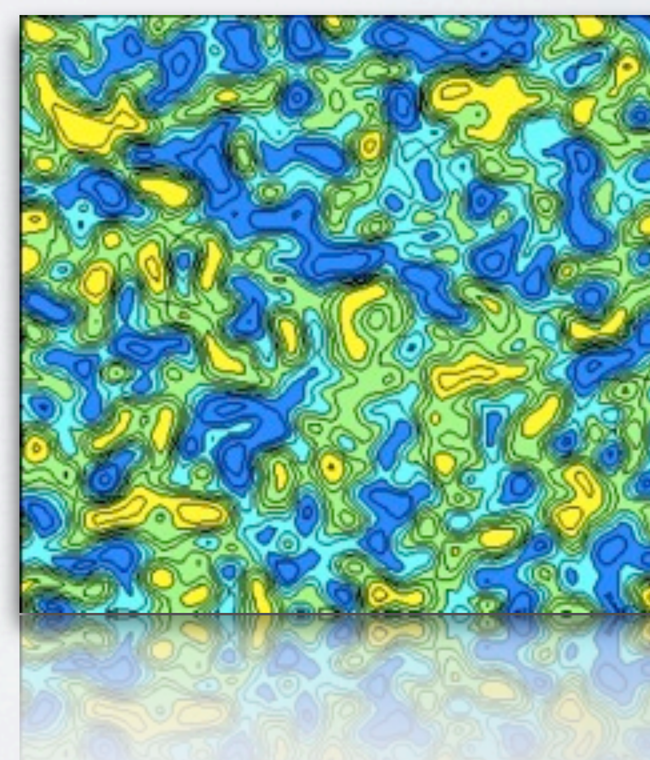
# ONE SCALAR FIELD

1D




Pseudo colour plot

Filled contour plot



2D

# ONE SCALAR FIELD

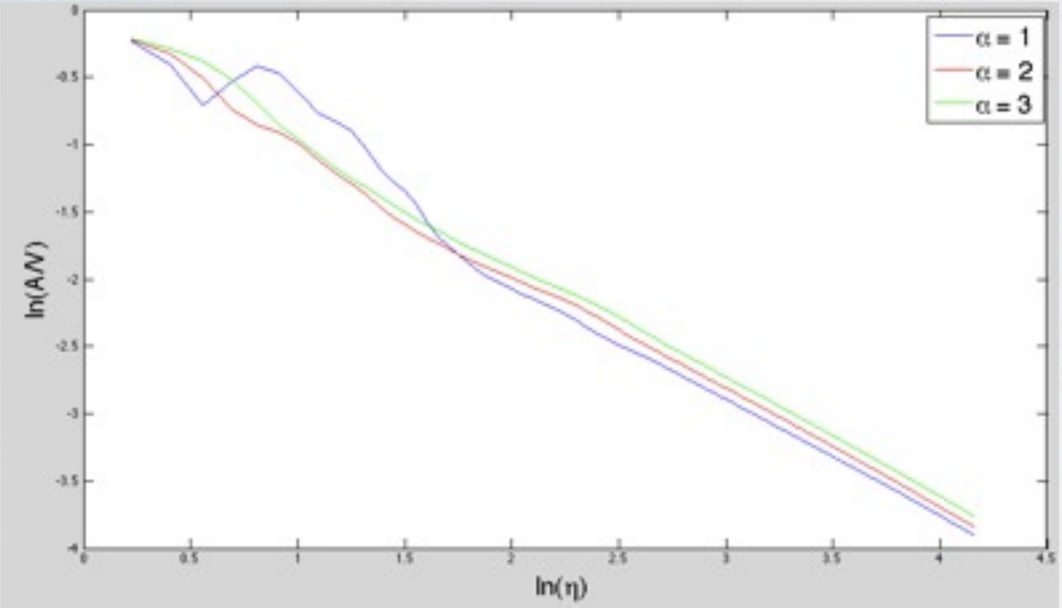
- $\alpha$
  - 1
  - 2
  - <u>3</u>
- $\beta^* = 0$
- $\lambda$
  - 1/2
  - <u>2/3</u>
  - 4/5
- $W_0$
  - <u>10</u>
  - 50
  - 100

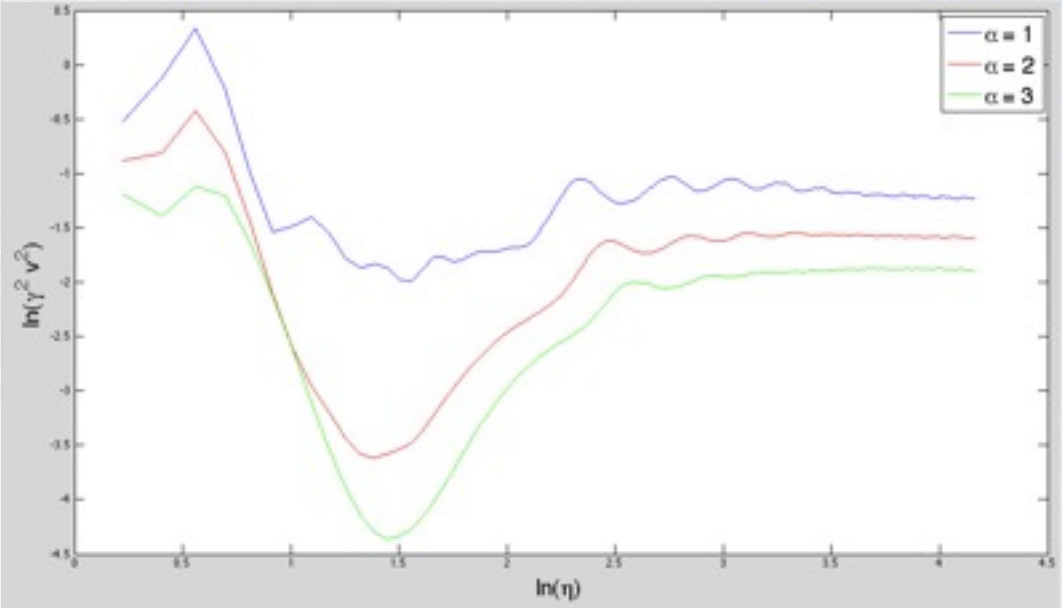
* - walls will have a constant comoving wall thickness

- $\rho \propto A/V \propto \eta^{\mu}$
- $\gamma_V \propto \eta^{\nu}$
- Scaling[3]:
  - $L=\varepsilon t$
  - v=constant

[3] - A. M. M. Leite and C. J. A. P. Martins 2011

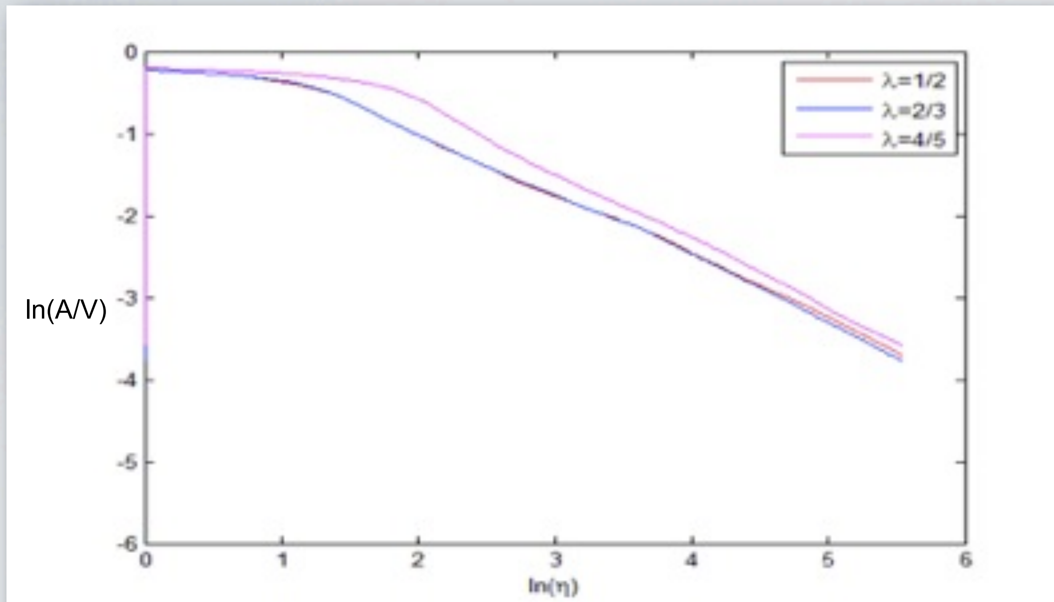
# DAMPING COEFFICIENT

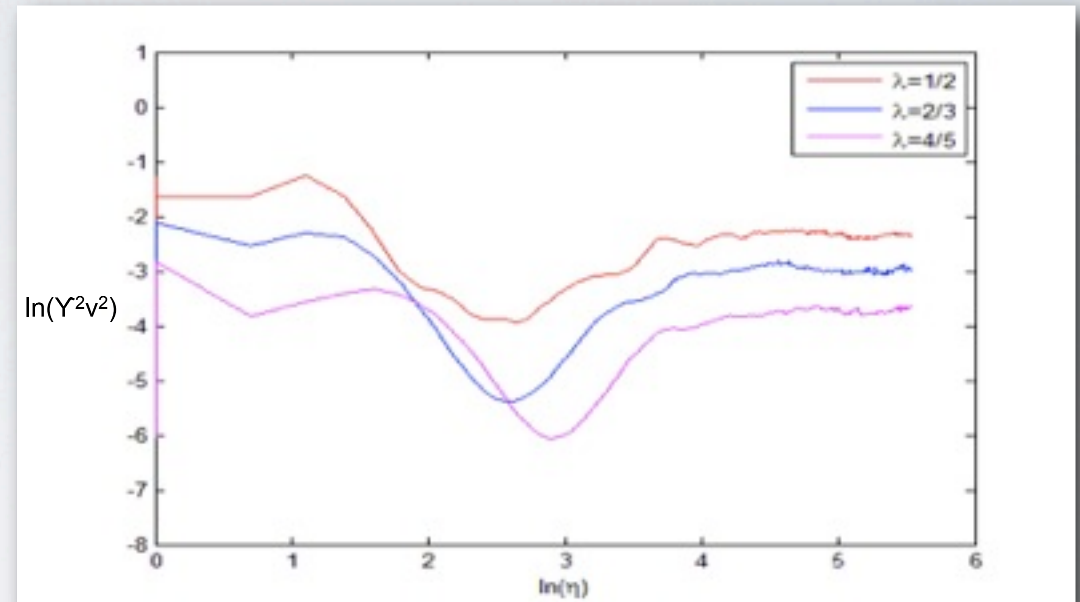


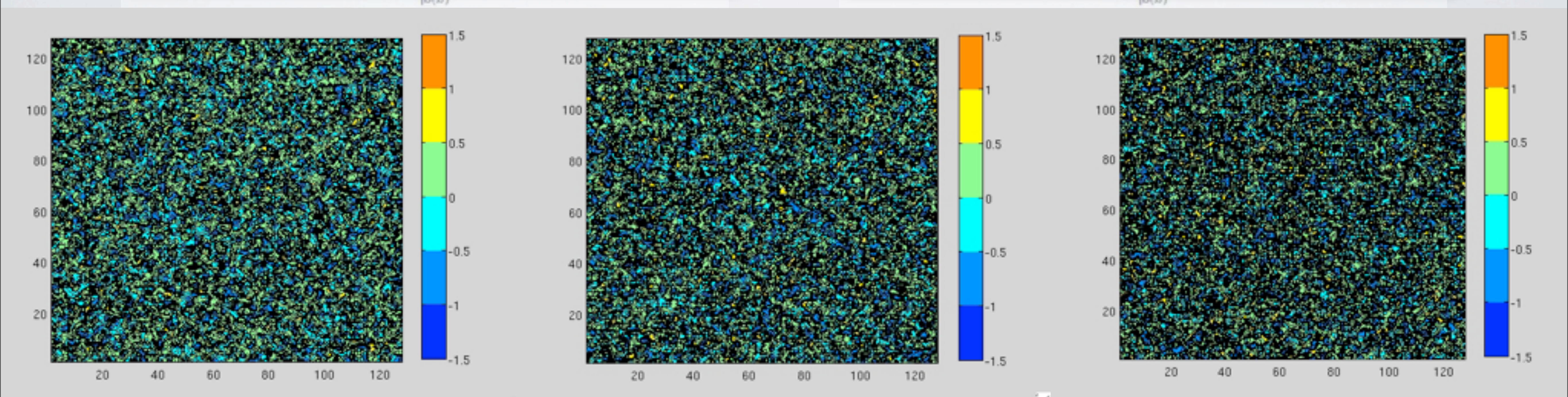




| α=1 | α=2 | α=3 |
|---|---|---|
| | 128^2 | |

# EXPANSION RATE

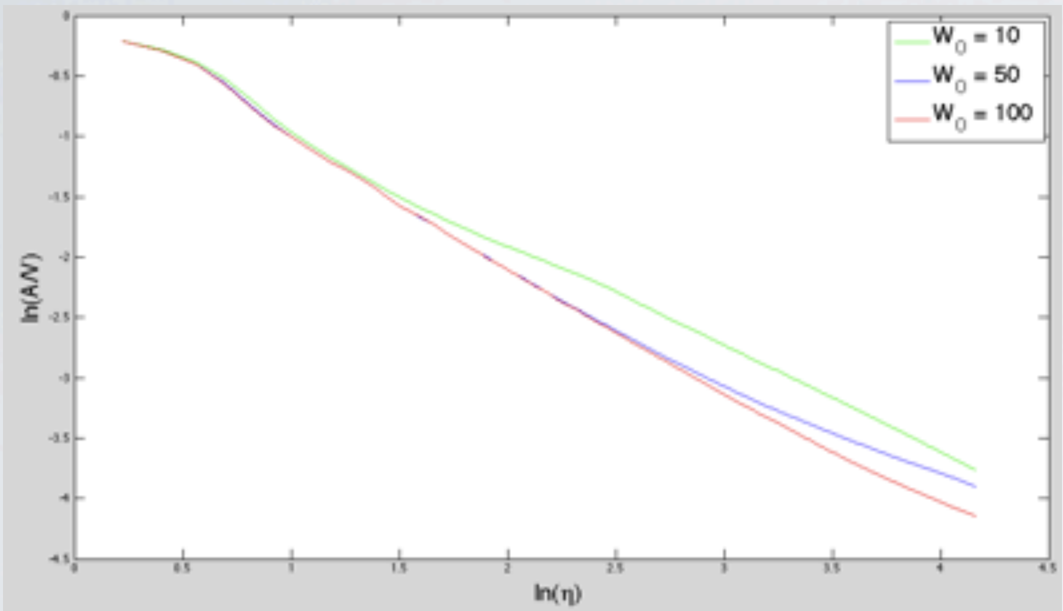


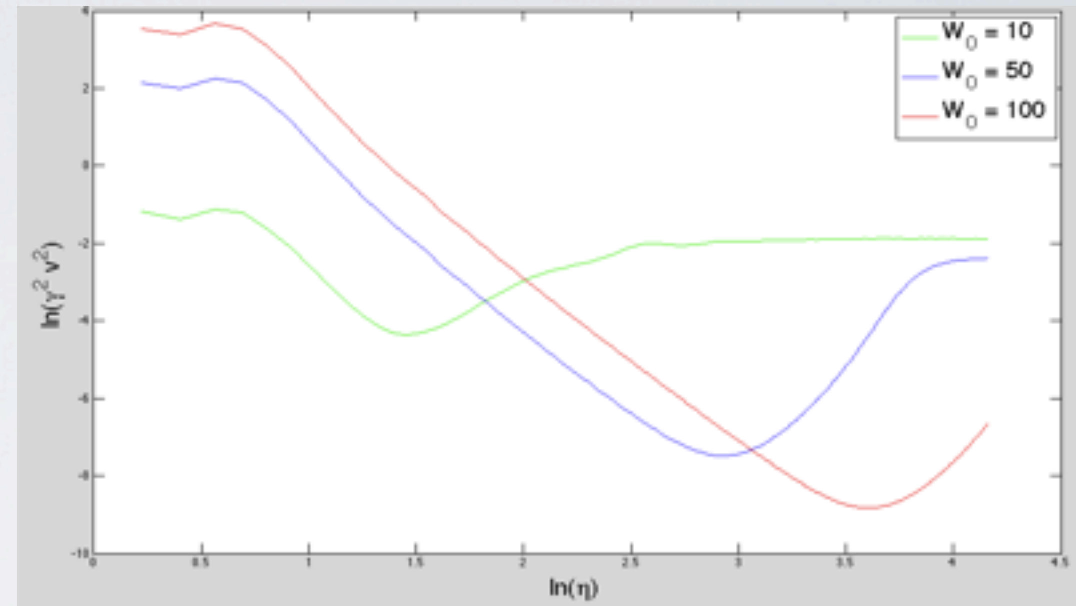



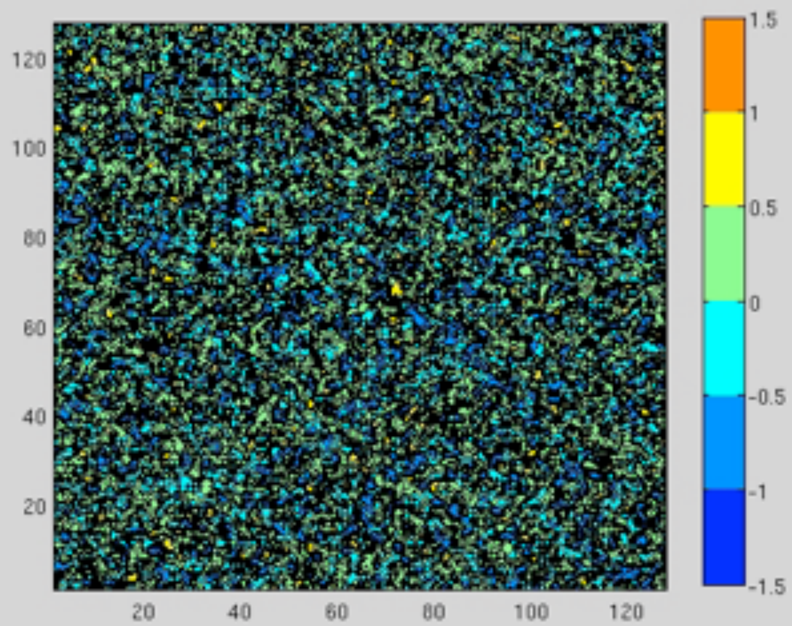



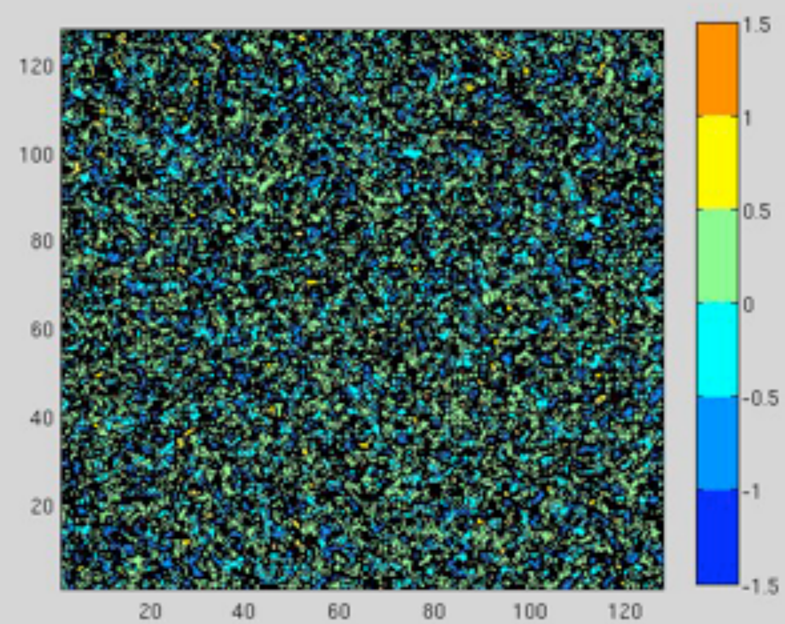
| λ=1/2 | λ=2/3 | λ=4/5 |
|---|---|---|
| | 128^2 | |

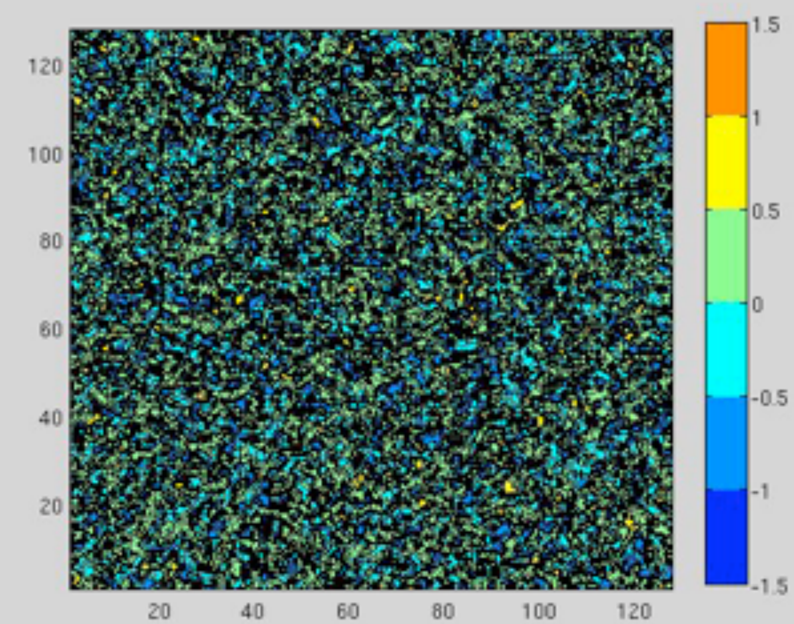
# WALL THICKNESS





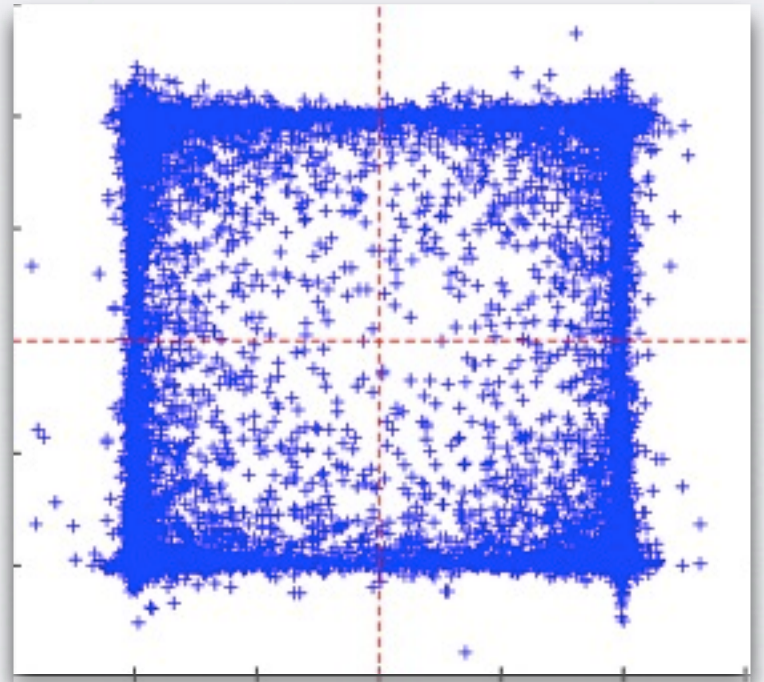


| | | |
|---|---|---|
| $W_0 = 10$ | $W_0 = 50$ | $W_0 = 100$ |
| | 128^2 | |

| | | Isotropic | | Isotropic(Super-Horizon) | | Anisotropic |
|---|---|---|---|---|---|---|
| μ | 1 | -0.99± 0.03 | 1 | -0.99±0.06 | 1 | -0.91±0.01 |
| | 2 | -0.99(±0.03) | 2 | -0.99(±0.06) | 2 | -0.91±(0.01) |
| ν | 1 | 0.08±0.07 | 1 | 0.02±0.01 | 1 | 0.03±0.04 |
| | 2 | 0.04(±0.07) | 2 | 0.02±(0.01) | 2 | 0.03±(0.04) |

Box Size: 4096^2

# TWO SCALAR FIELDS



# TWO SCALAR FIELDS

$$\mathcal{L} = \frac{1}{2}\sum_{i=1}^{2}(\partial_\mu\phi_i\partial^\mu\phi_i) + V(\phi_i)$$

$$V(\phi_i) = \tfrac{1}{2}\textstyle\sum_{i=1}^{2}(r - \frac{\phi_i}{r})^2 + \frac{\epsilon}{4}(\phi_1^4 + \phi_2^4 - 6\phi_1^2\phi_2^2 + 4r^4)$$ [4]

For a well-behaved potential $-2 \leq \varepsilon r^2 \leq 1$

$-1/2 < \varepsilon r^2 < 1$

$$\phi_i^2 = \frac{r^2}{1-\epsilon r^2}$$ $i=1,2,..$

$-2 < \varepsilon r^2 < -1/2$

$$\phi_i^2 = \frac{r^2}{1+\epsilon r^2/2}$$ $\phi_{i\neq j} = 0$

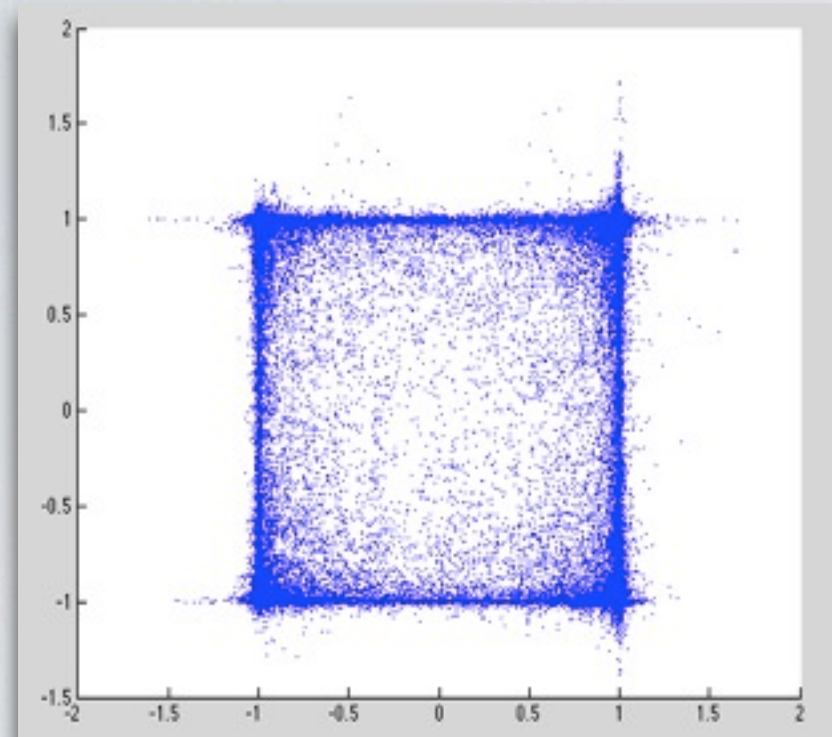
- In field space:

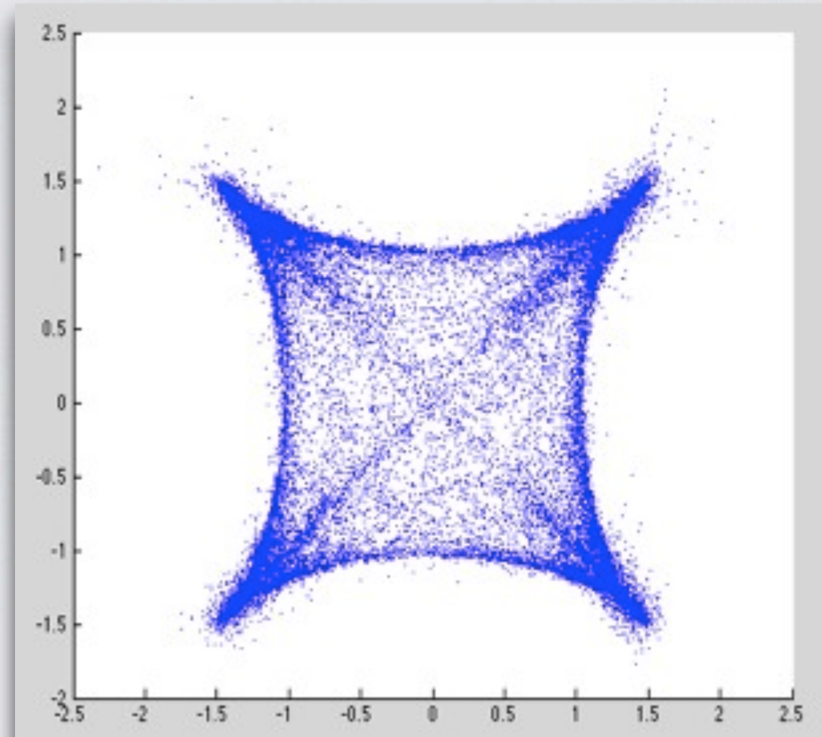
Square

Lozenge

[4] - D. Bazeia, F. A. Brito and L. Losano 2006

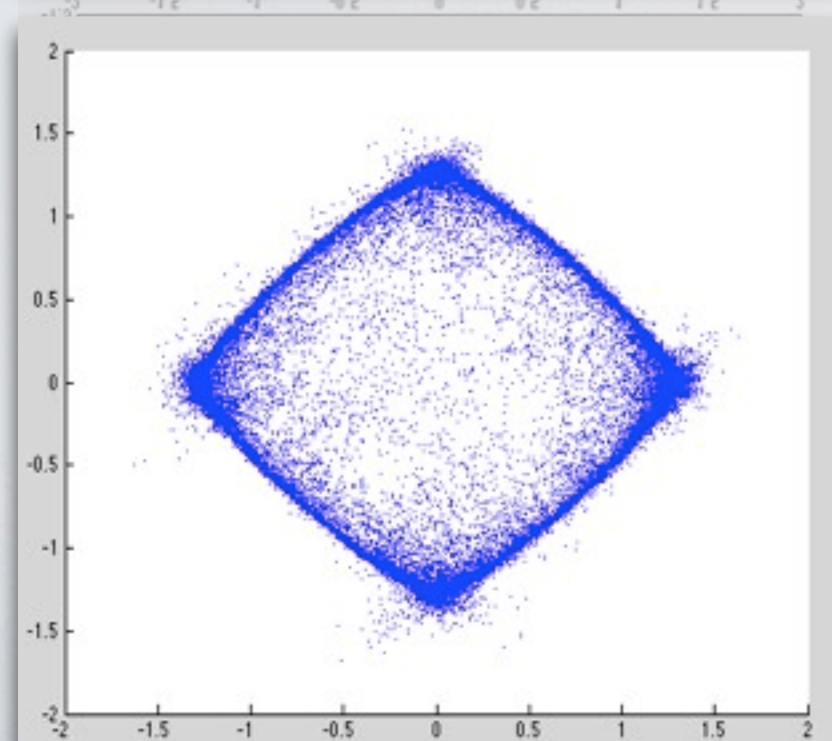
# FIELD SPACE

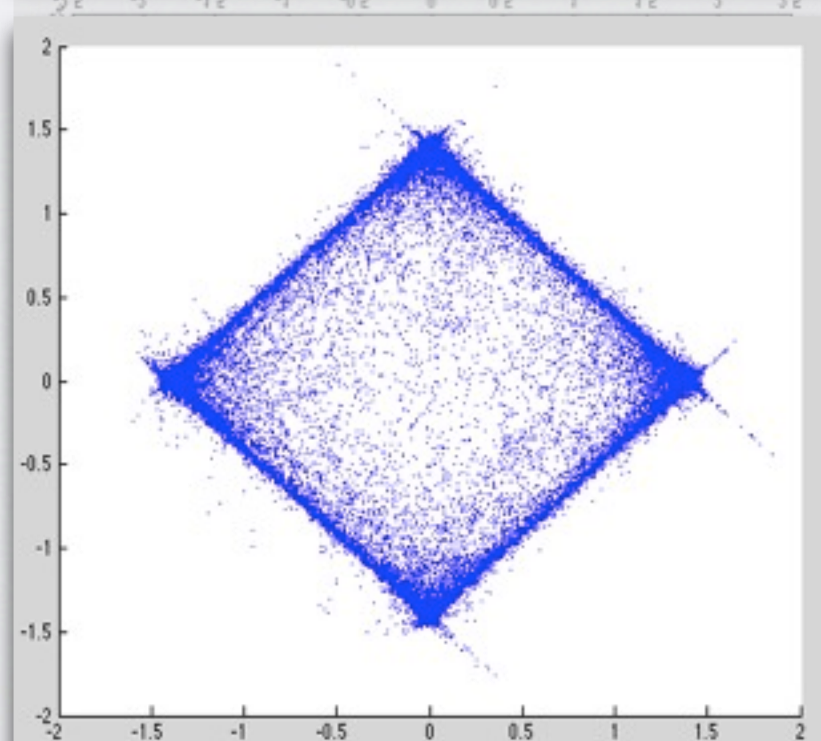


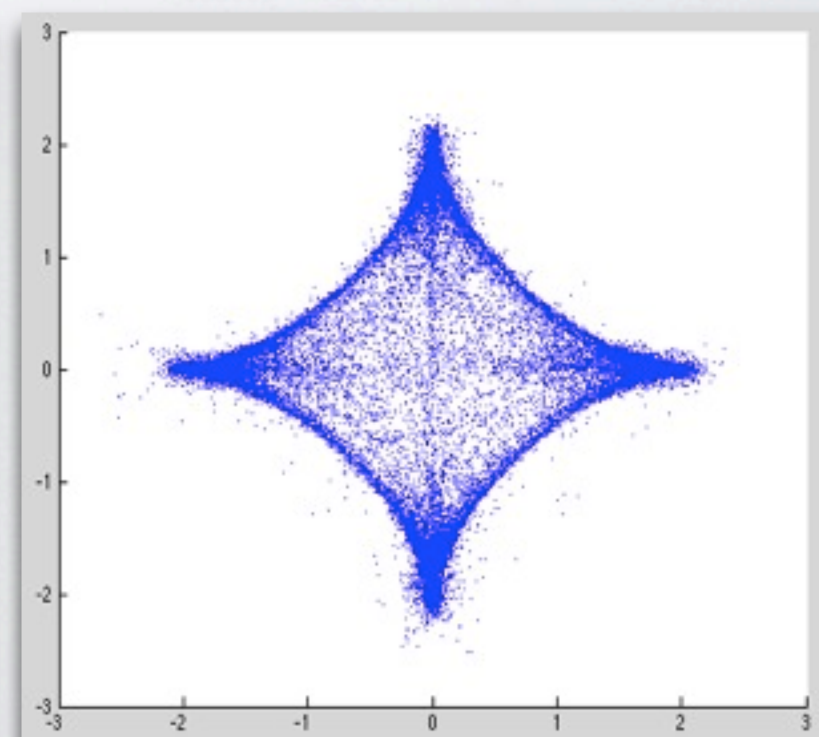


| | | |
|---|---|---|
| ε=0 | ε=0.5 | |
| ε=-0.8 | ε=-1 | ε=-1.5 |

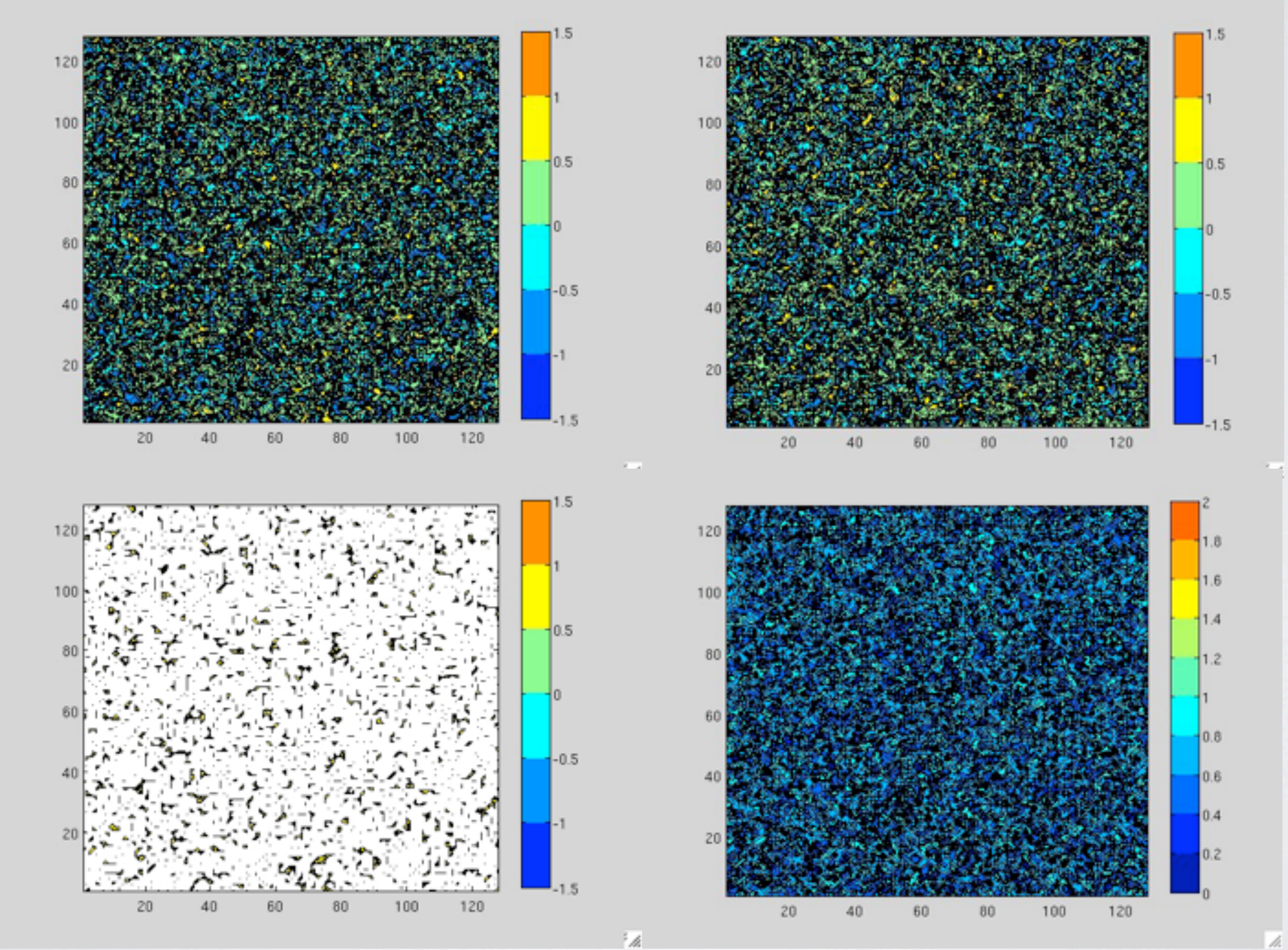
$$V_{\min} = -r^2 \frac{(\epsilon r^2)^2}{1-\epsilon r^2}$$







# COORDINATE SPACE



# CONCLUSION

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Work in progress!

- Further study of variation of parameters in both the "one scalar field" case and the "two scalar fields" case;
- Use larger box sizes;
- Study of the potential in coordinate space;
- Develop scripts for three spatial coordinates;
- Study "many scalar fields" case;
- Optimize animation scripts;

# THE END