

# Is the Universe the same as its Mirror Image?

Matt Craigie

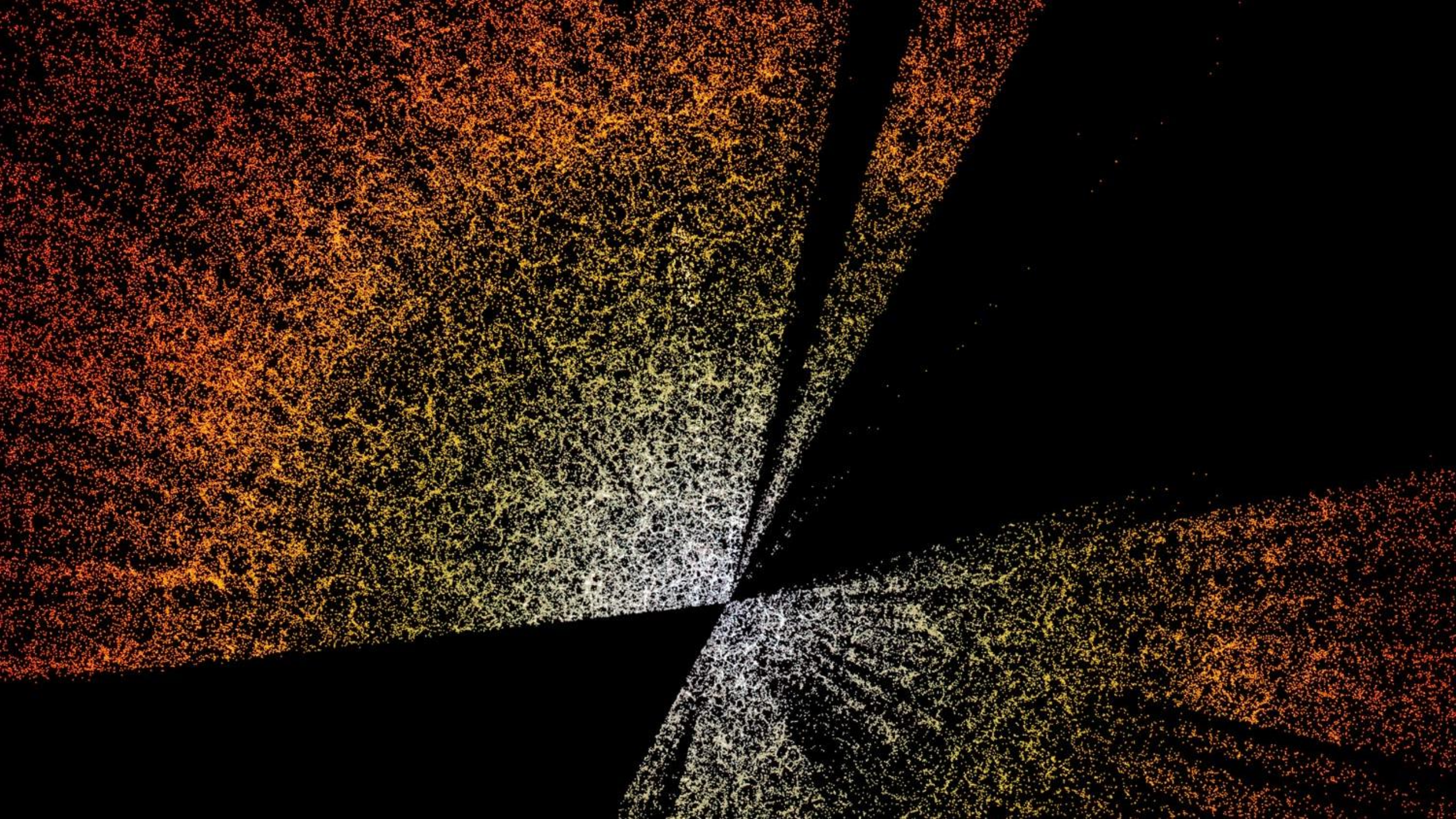
With:

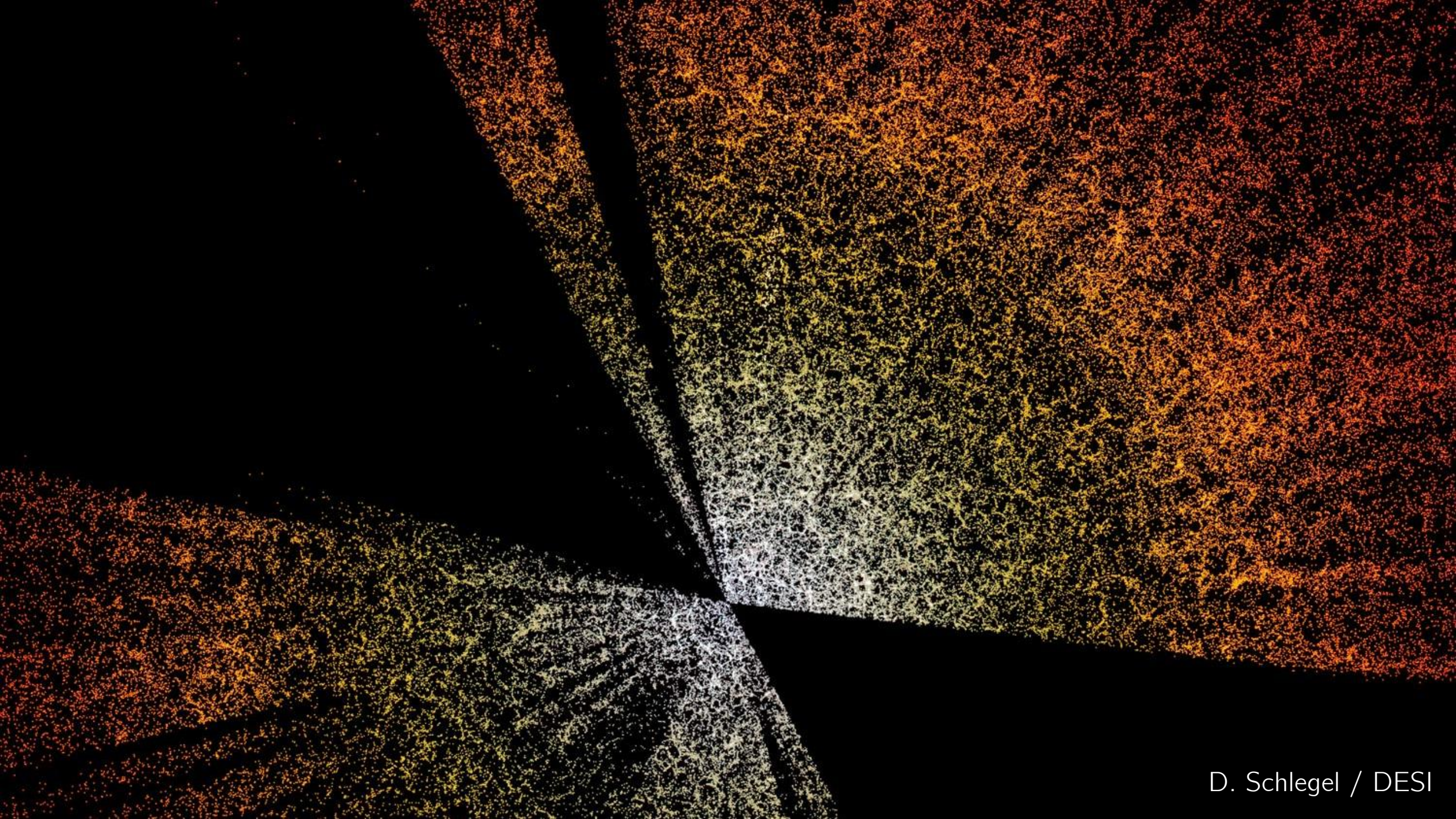
Peter Taylor

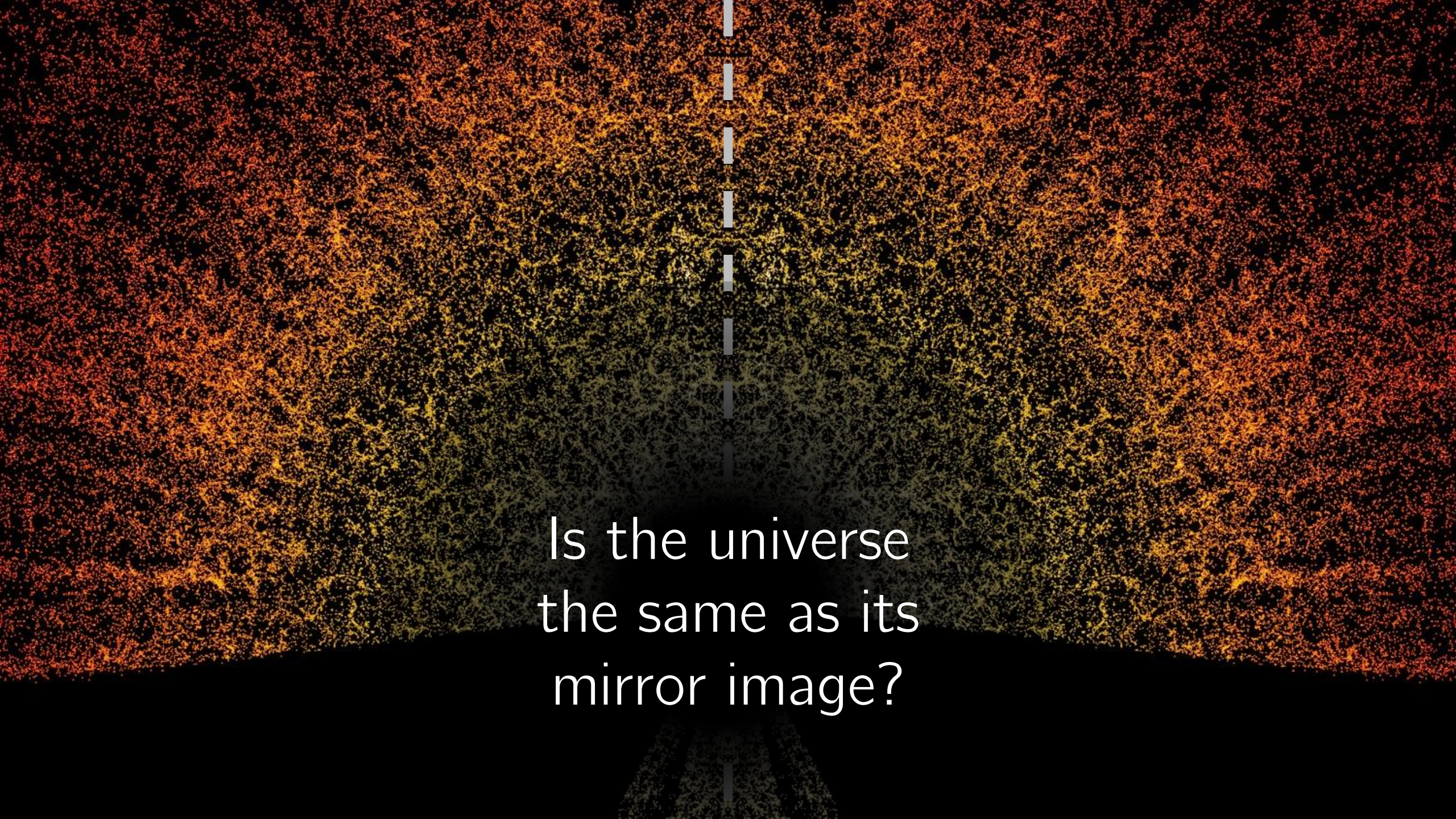
Yuan-Sen Ting

Carolina Cuesta-Lazaro







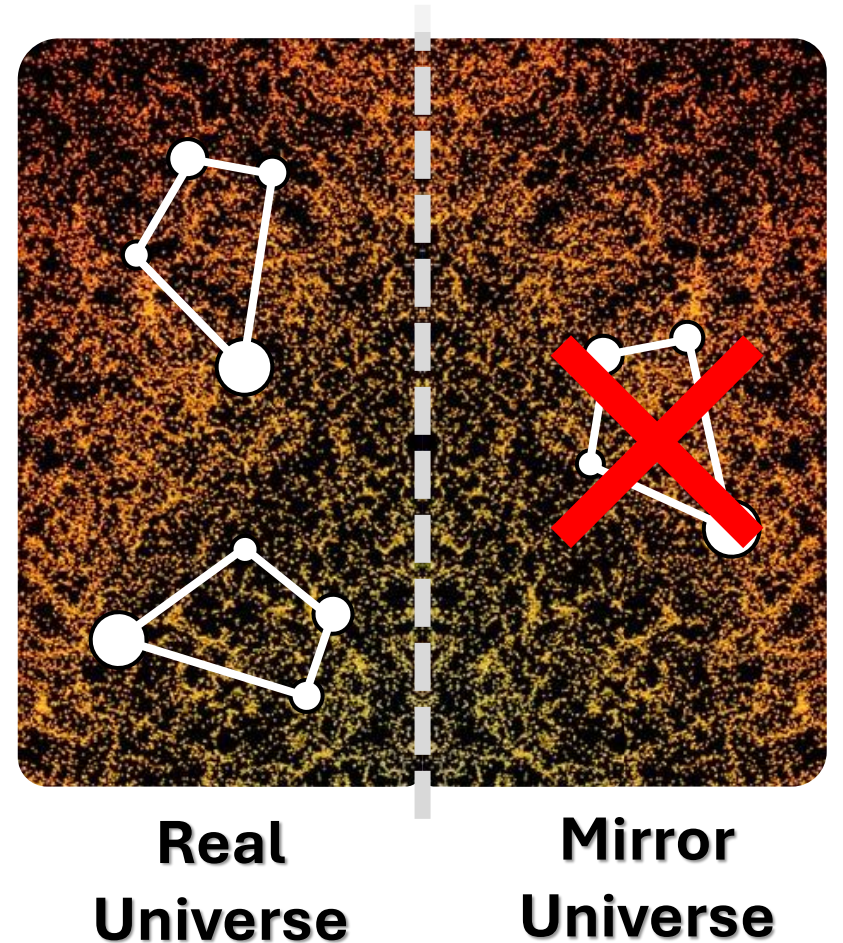


Is the universe  
the same as its  
mirror image?

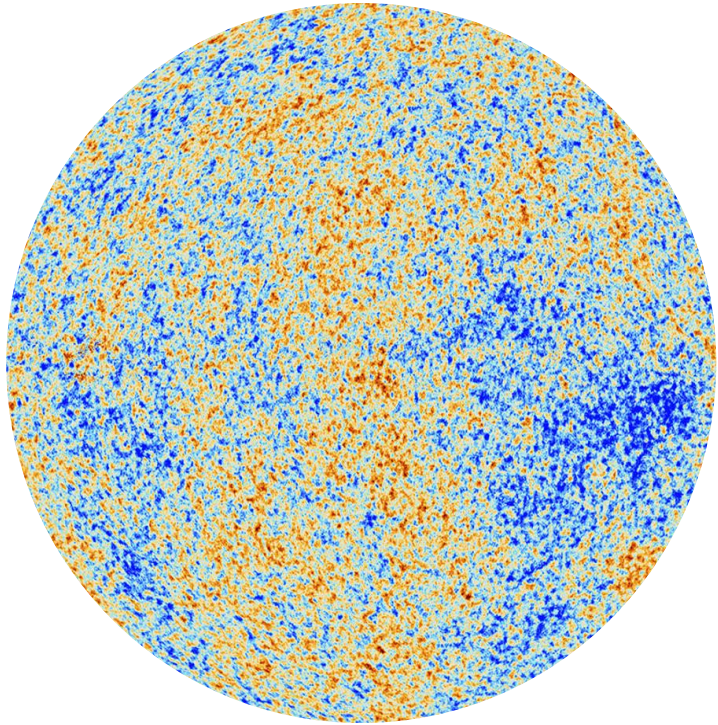
# What is Parity Violation?

Different physics after a parity inversion:  $(x, y, z) \rightarrow (-x, -y, -z)$

We look for different **patterns**



# Why Search for Parity Violation?





Detecting Parity Violation  
*with Unsupervised Learning*

~~CATS + DOGS~~

~~Detecting Parity Violation  
with Unsupervised Learning~~



WOOF





Cats



Dogs



Machine  
Learning  
Model



Machine Learning Model



Cat

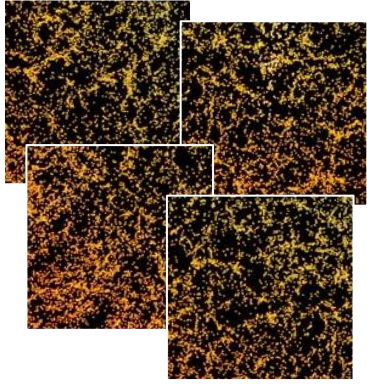


Machine Learning Model

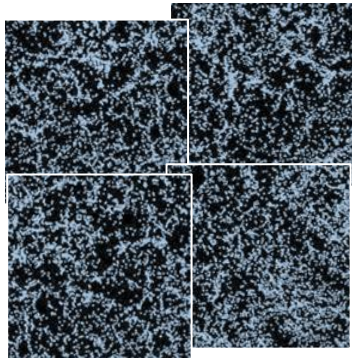


Dog

Our Universe

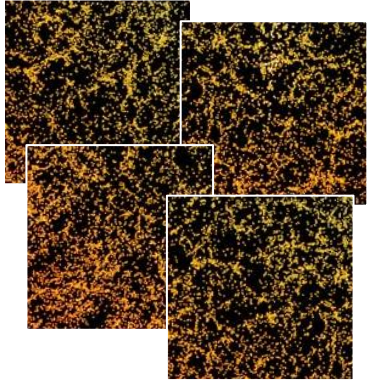


Mirror Universe

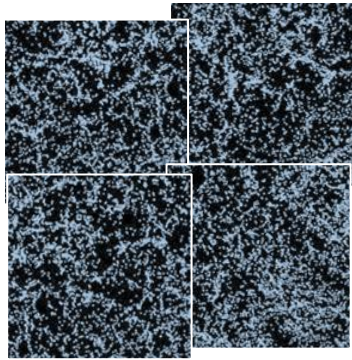


Machine  
Learning  
Model

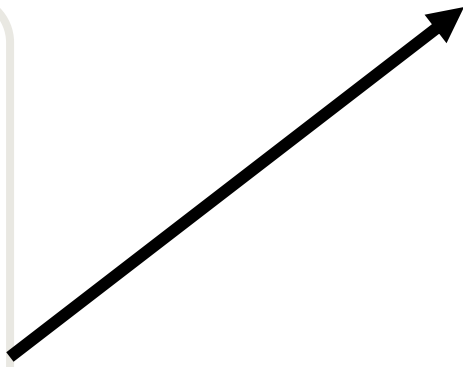
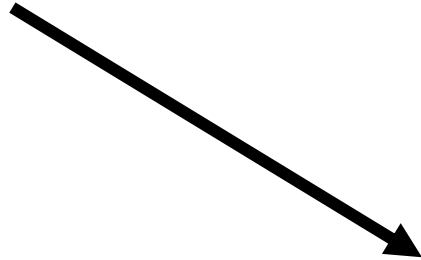
Our Universe

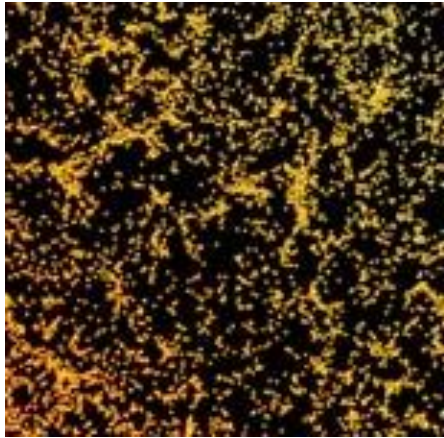


Mirror Universe



Machine  
Learning  
Model

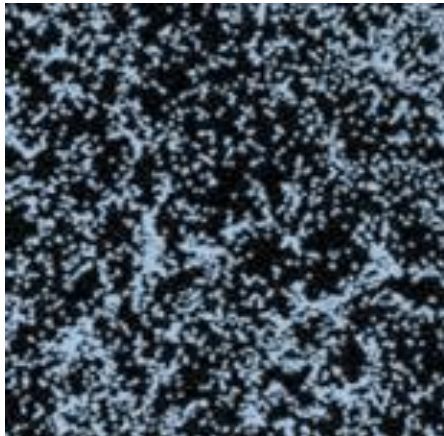




Machine  
Learning  
Model



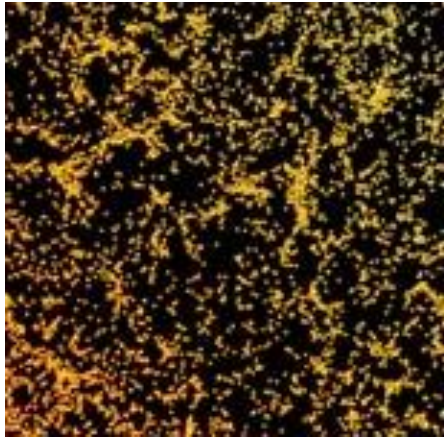
Real



Machine  
Learning  
Model



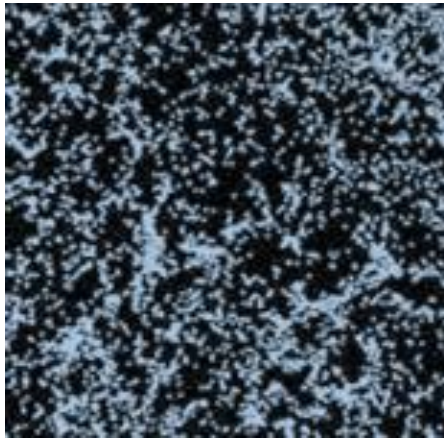
Mirror



Machine  
Learning  
Model



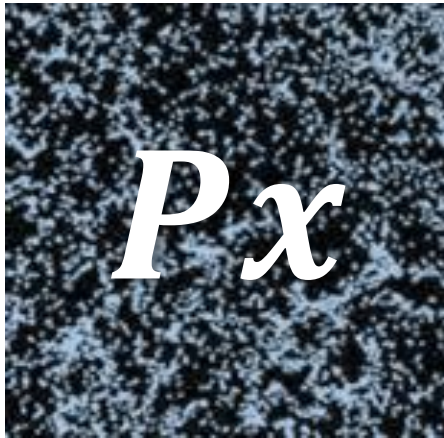
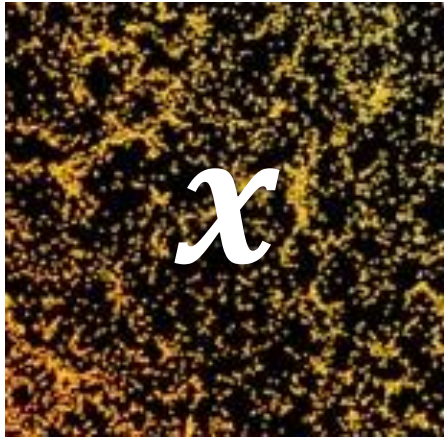
1.02

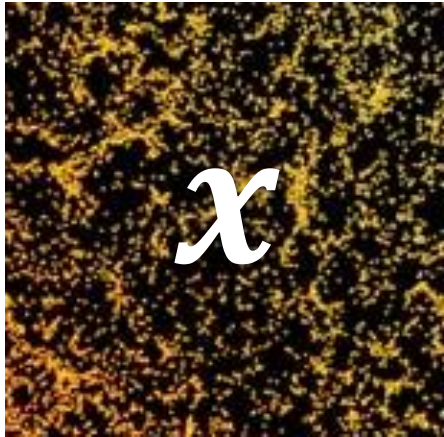


Machine  
Learning  
Model



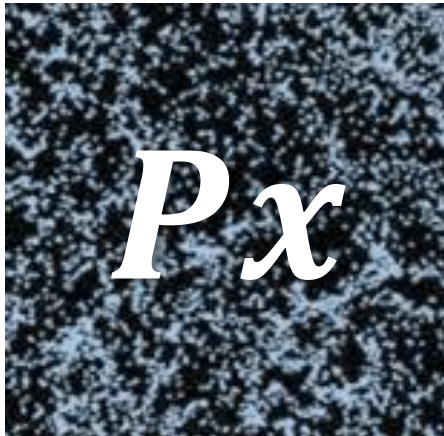
-0.98



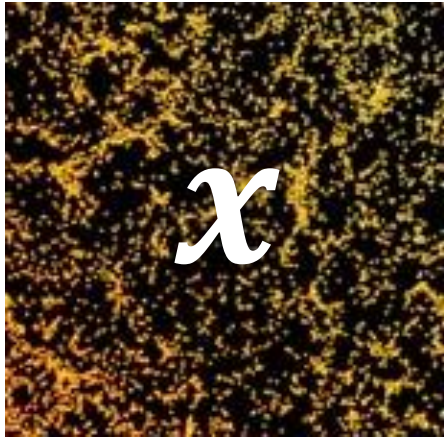


$g(\cdot) :$

Machine  
Learning  
Model

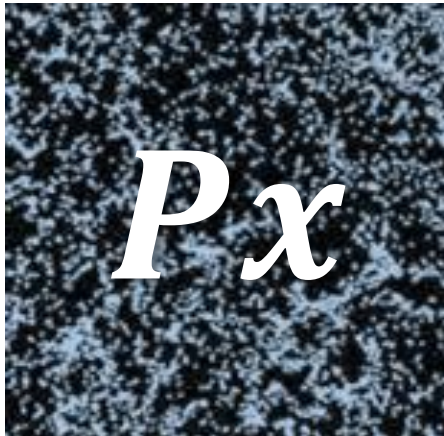






$g(\cdot) :$

Machine  
Learning  
Model



The difference:  $g(x) - g(Px)$

# How do we make a detection?

Look for a difference in *unseen* test data,

$$g(x) - g(Px) \neq 0$$

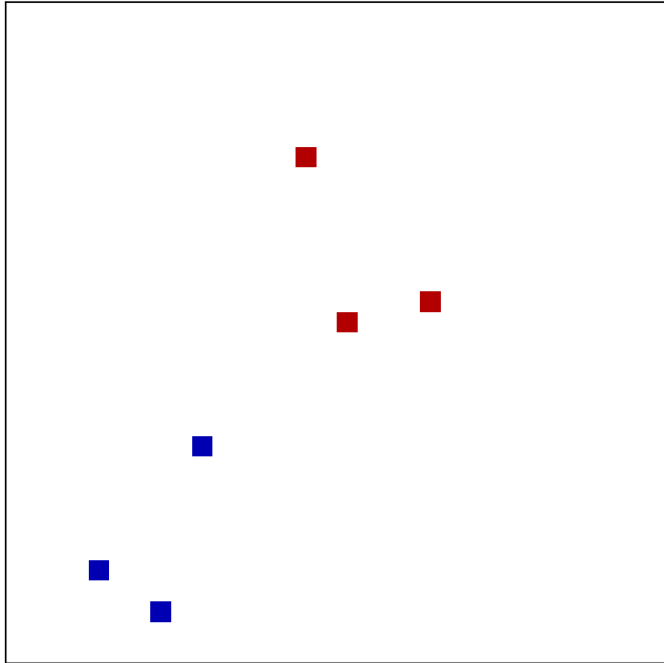
1. Calculate the mean  $g(x) - g(Px)$  over test data
2. Bootstrap resample to understand natural variability
3. Calculate a  $\sigma$ -level of detection



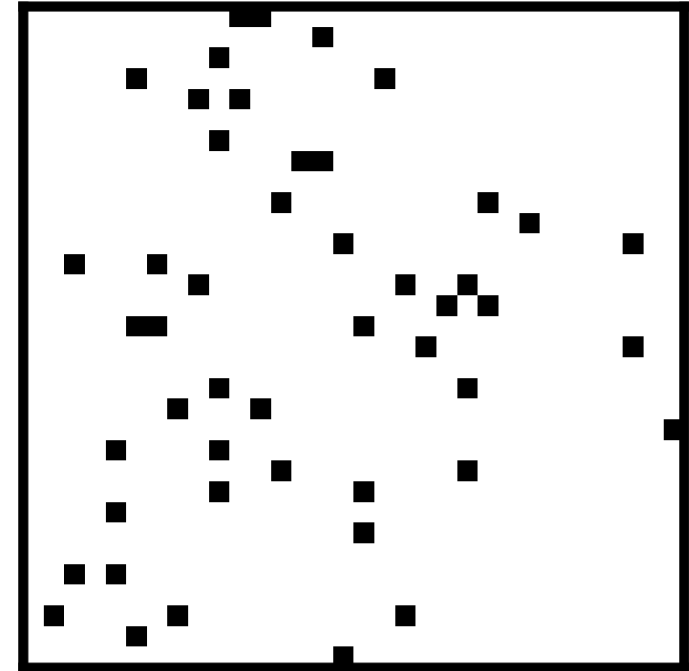
# Proof-of-concept Results

# Simplified Data

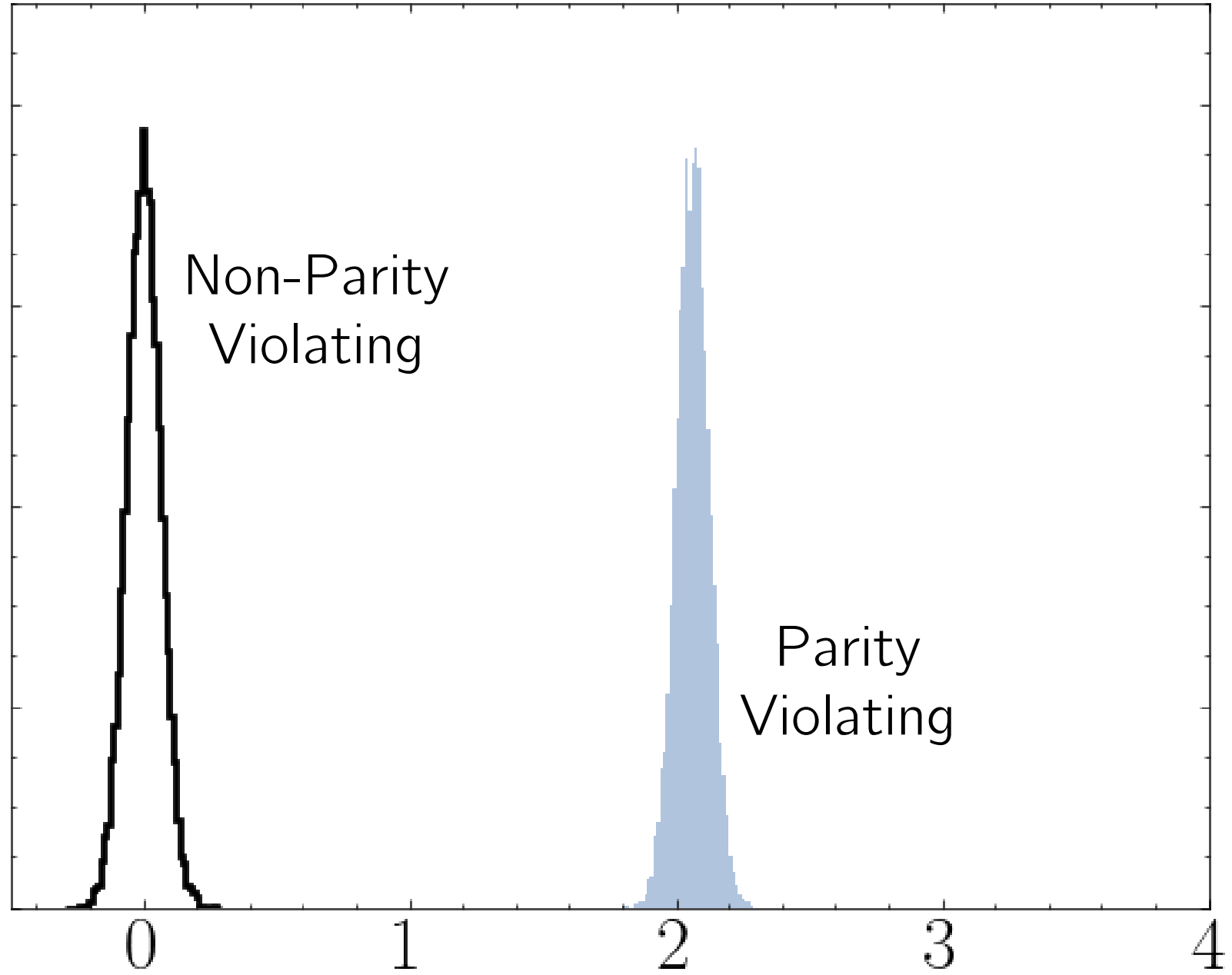
2 Triangles



16 Triangles



Number of  
Bootstrapped Means



Non-Parity  
Violating

Parity  
Violating

0

1

2

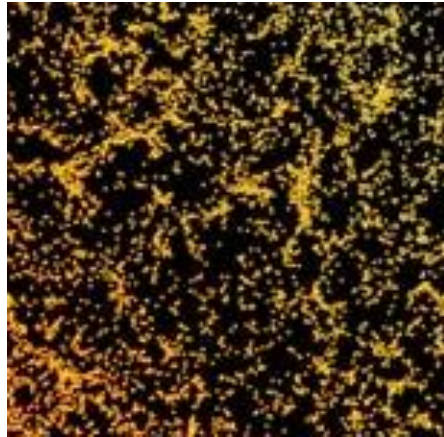
3

4

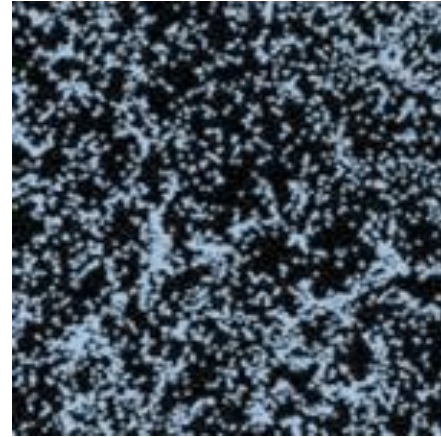
Learned Parity Difference

# The perks of Unsupervised Learning

1. It's simple and familiar

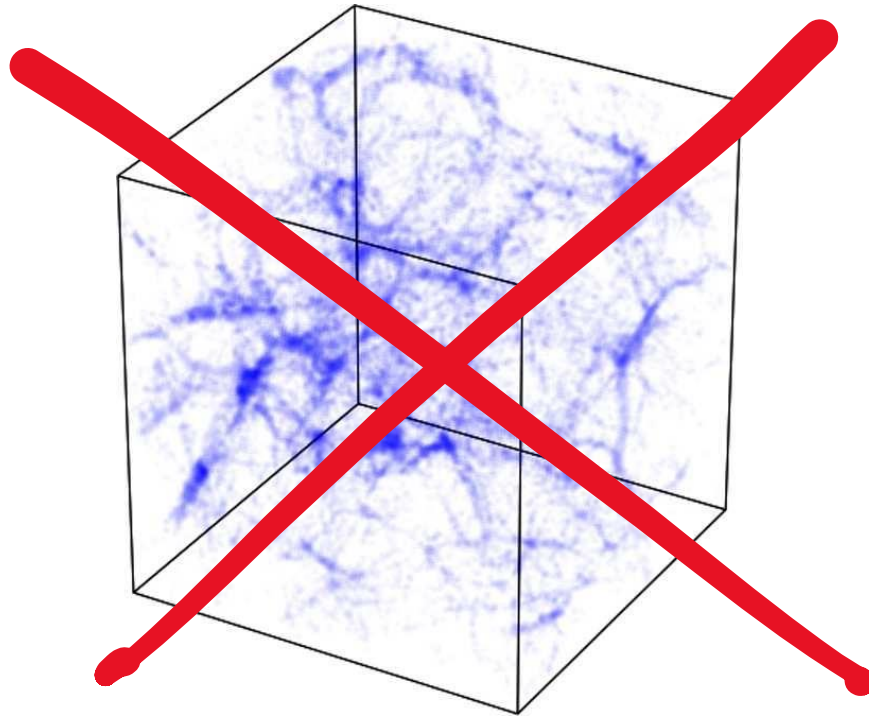


VS



# The perks of Unsupervised Learning

2. We only need observational data



# The perks of Unsupervised Learning

3. No false detections

$$g(x) - g(Px) \neq 0$$





# Future Directions

1. Extend to 3D
2. Search in simulations with known parity violation
3. Search in the real universe

- Parity violation might be present in the galaxy distribution.
- Unsupervised learning is a good way to find it, with many perks!
- Look out for the 3D application soon!

arxiv: 2405.13083

arxiv: 2312.09287



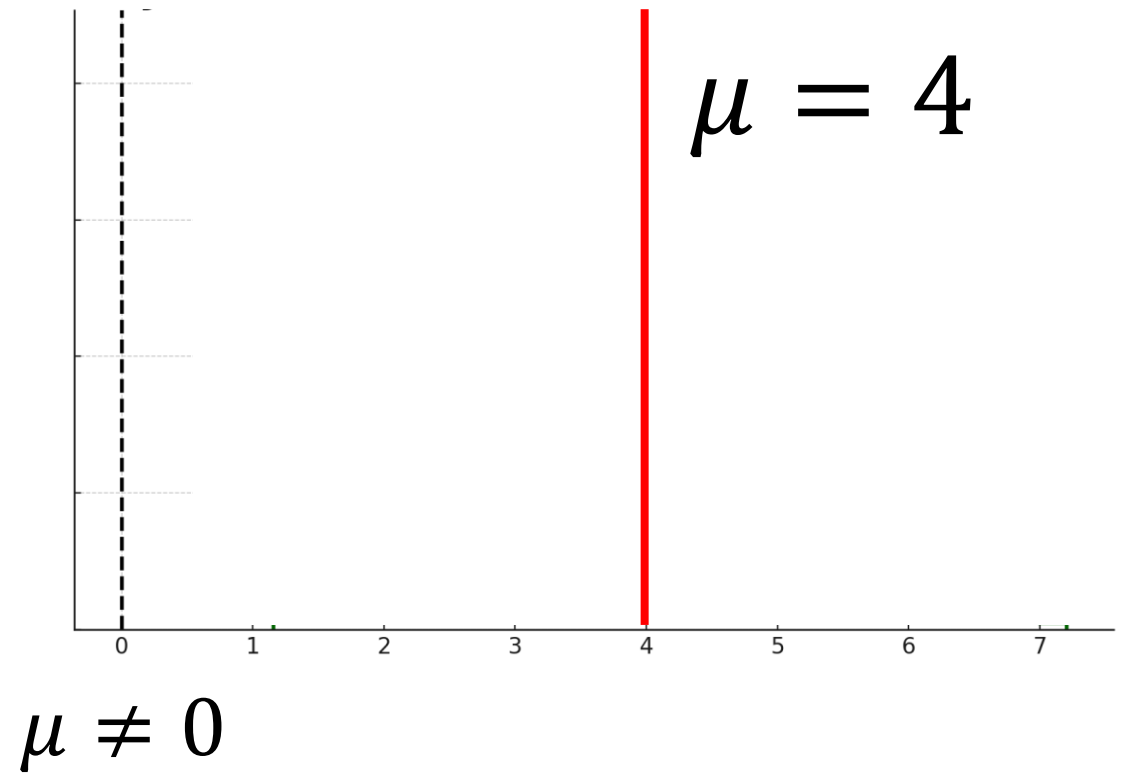
**EXTRAS**



1. What's the average parity violation?

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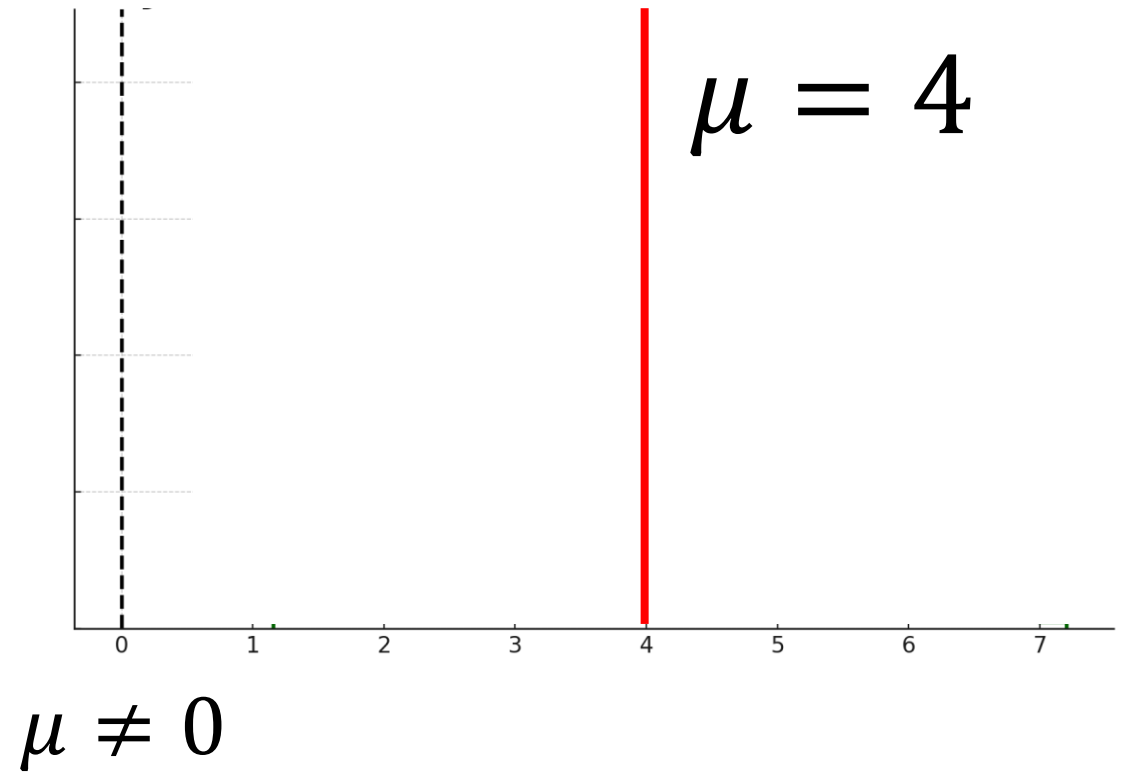
$$\mu = \text{Mean}[g(x) - g(Px)] \text{ over test set}$$



1. What's the average parity violation?

$$\mu = \text{Mean}[g(x) - g(Px)] \text{ over test set}$$

2. Is this nonzero because of signal or just noise?

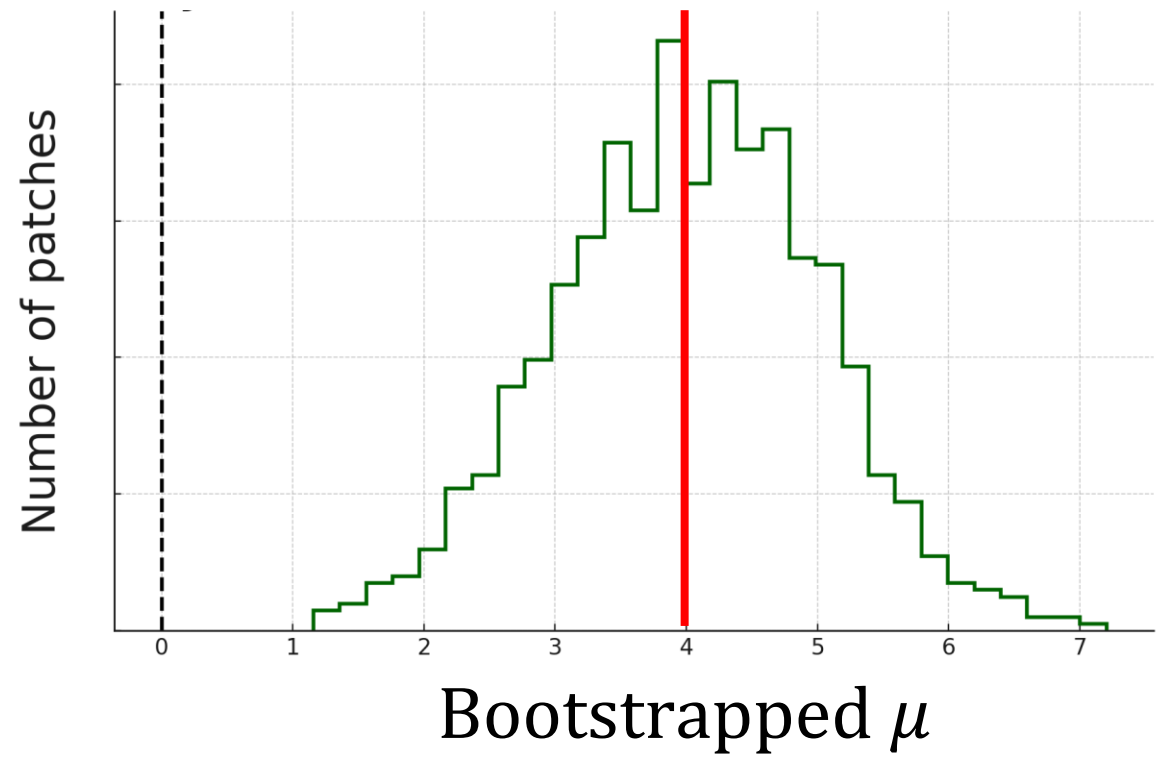


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$$\mu^* = \text{Bootstrapped } \mu \text{ over test set}$$



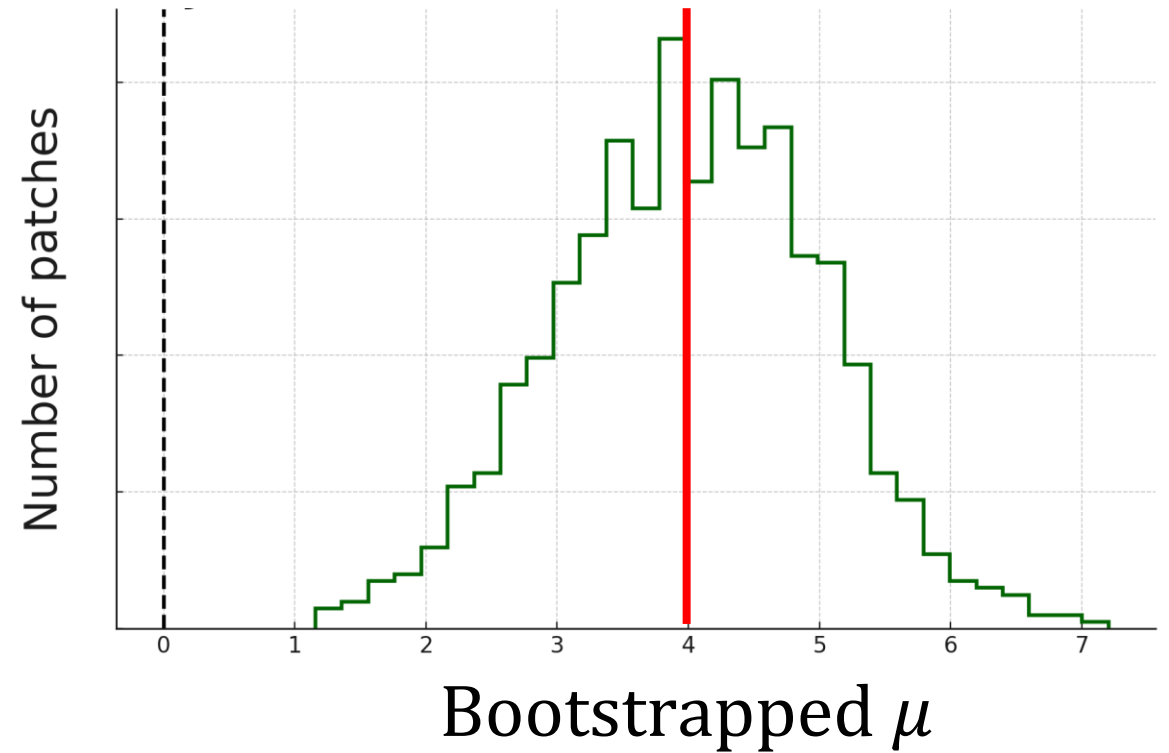
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3. How confident are we in this detection?





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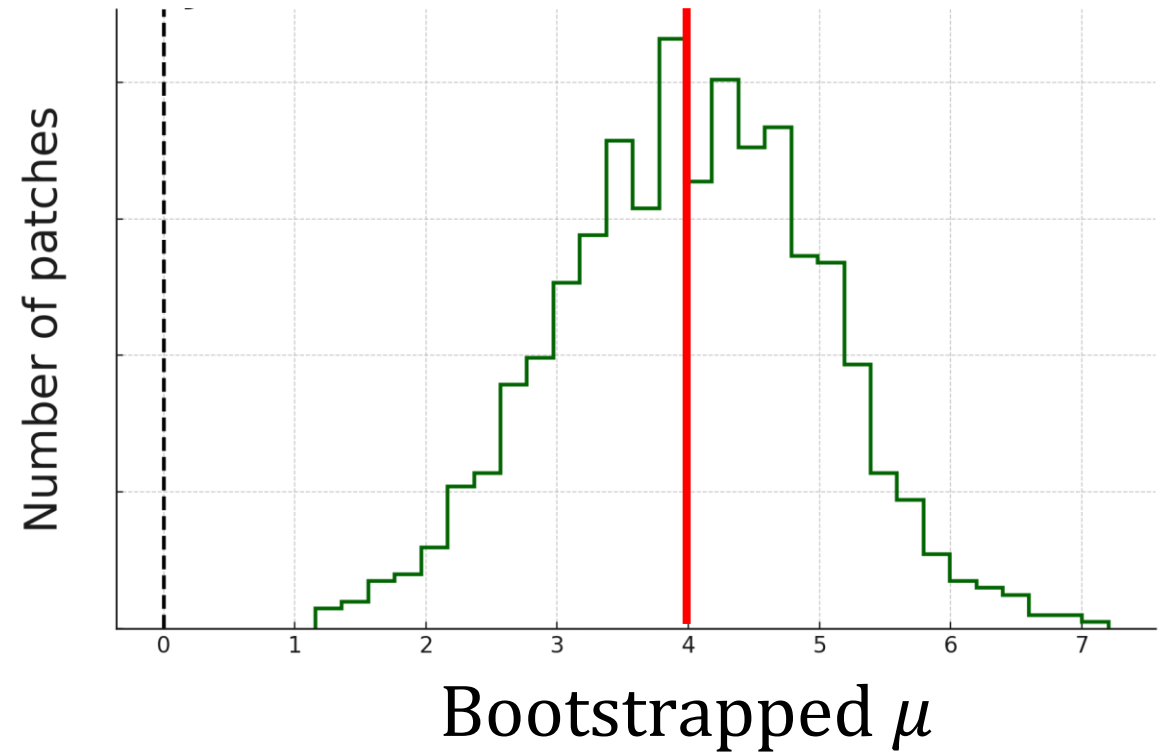
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$$\eta = \frac{\text{mean}[\mu^*]}{\text{std}[\mu^*]}$$



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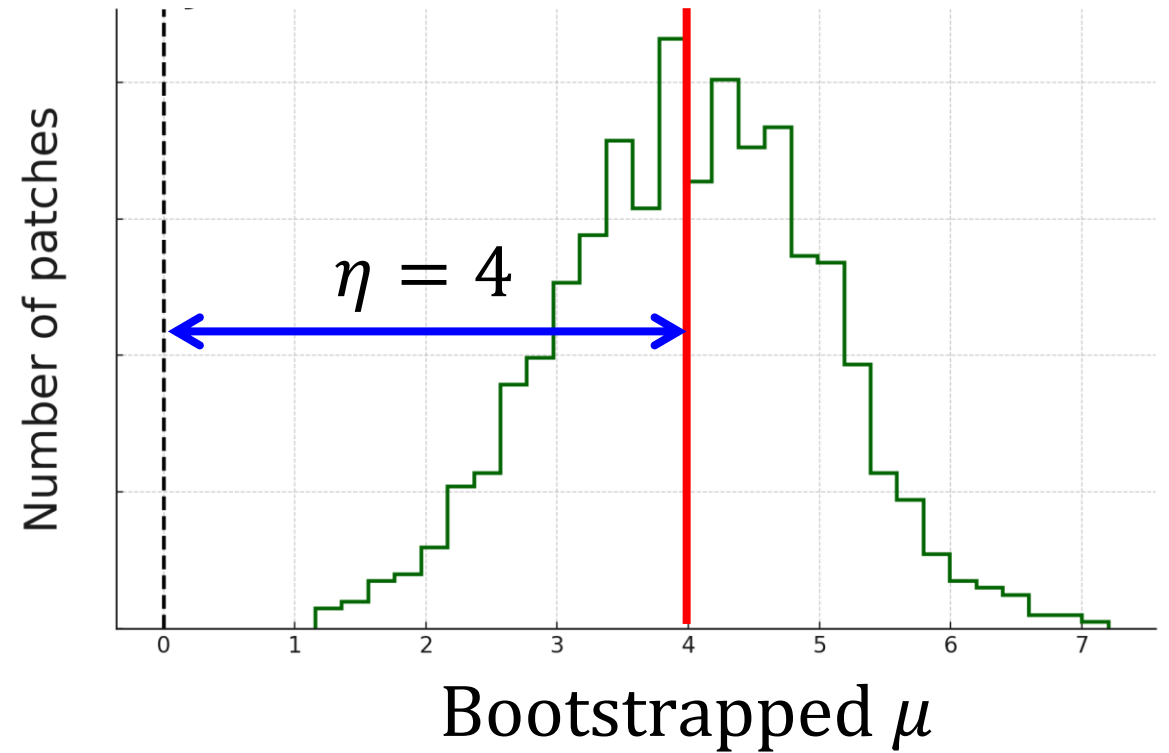
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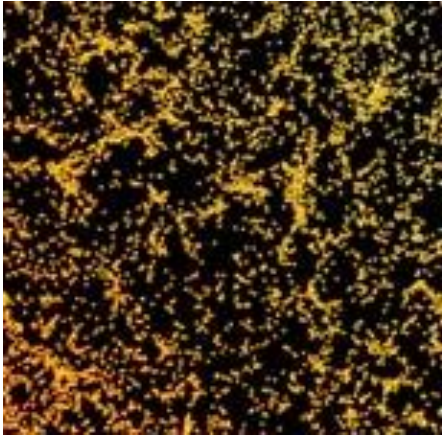
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$g(x)$



Data Compression



Field  
Summary  
Statistics

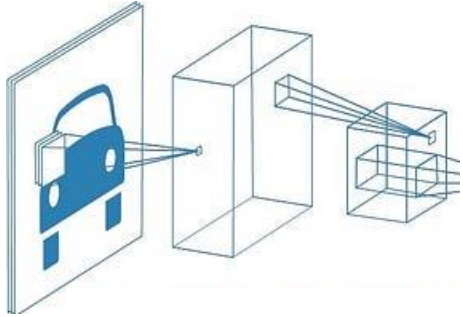
Fully Connected Network



Parity  
Statistic

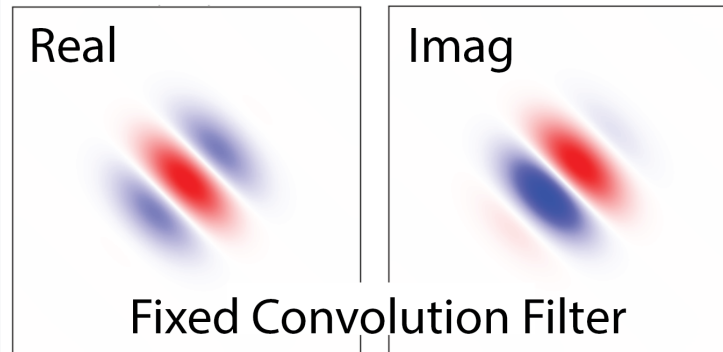
# Types of Compression Model

## Convolutional Neural Networks (CNNs)



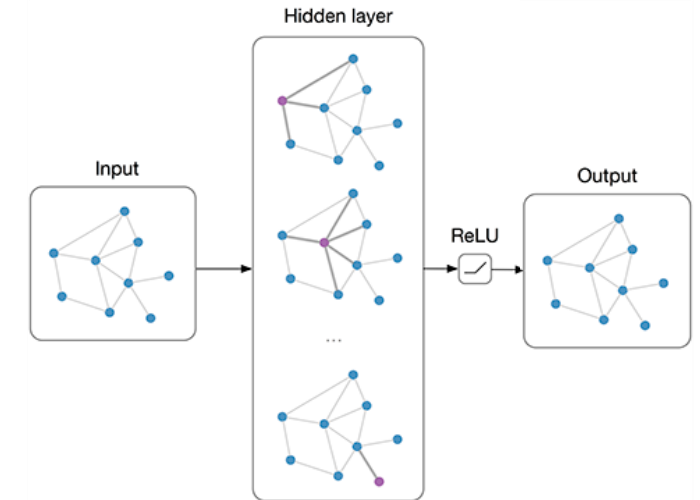
- Very flexible
- Fails in 3D (overtraining)

## Wavelet Scattering Transforms (WSTs)



- Very robust
  - Symmetries
- Not flexible enough

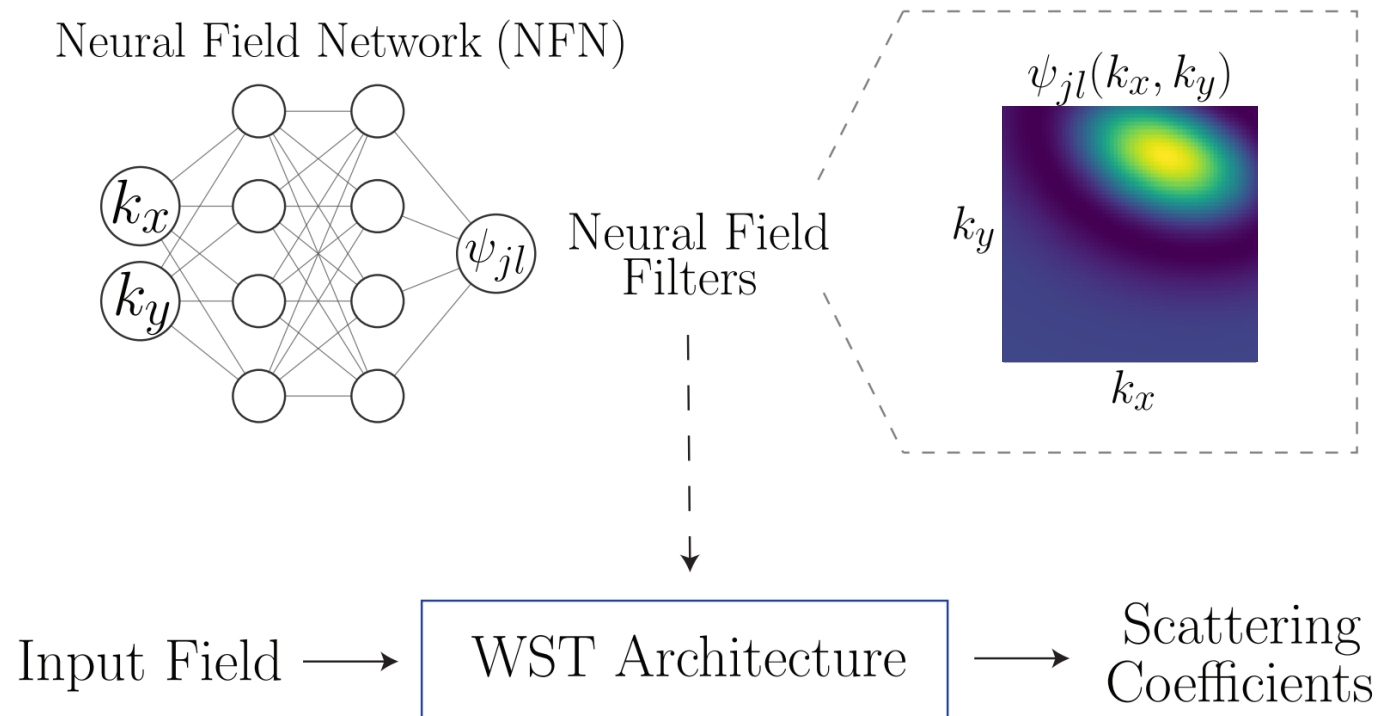
## Graph Neural Networks (GNNs)



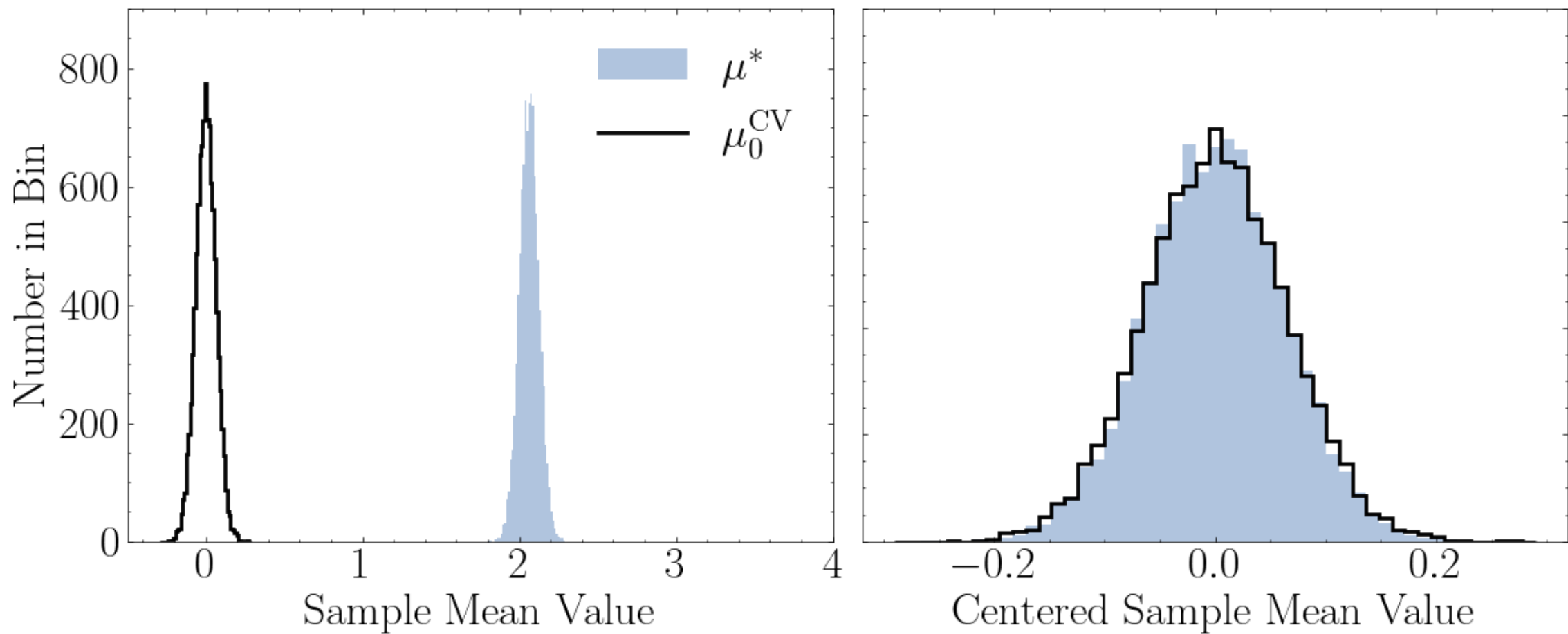
- Great in 2D
- 3D Under Development

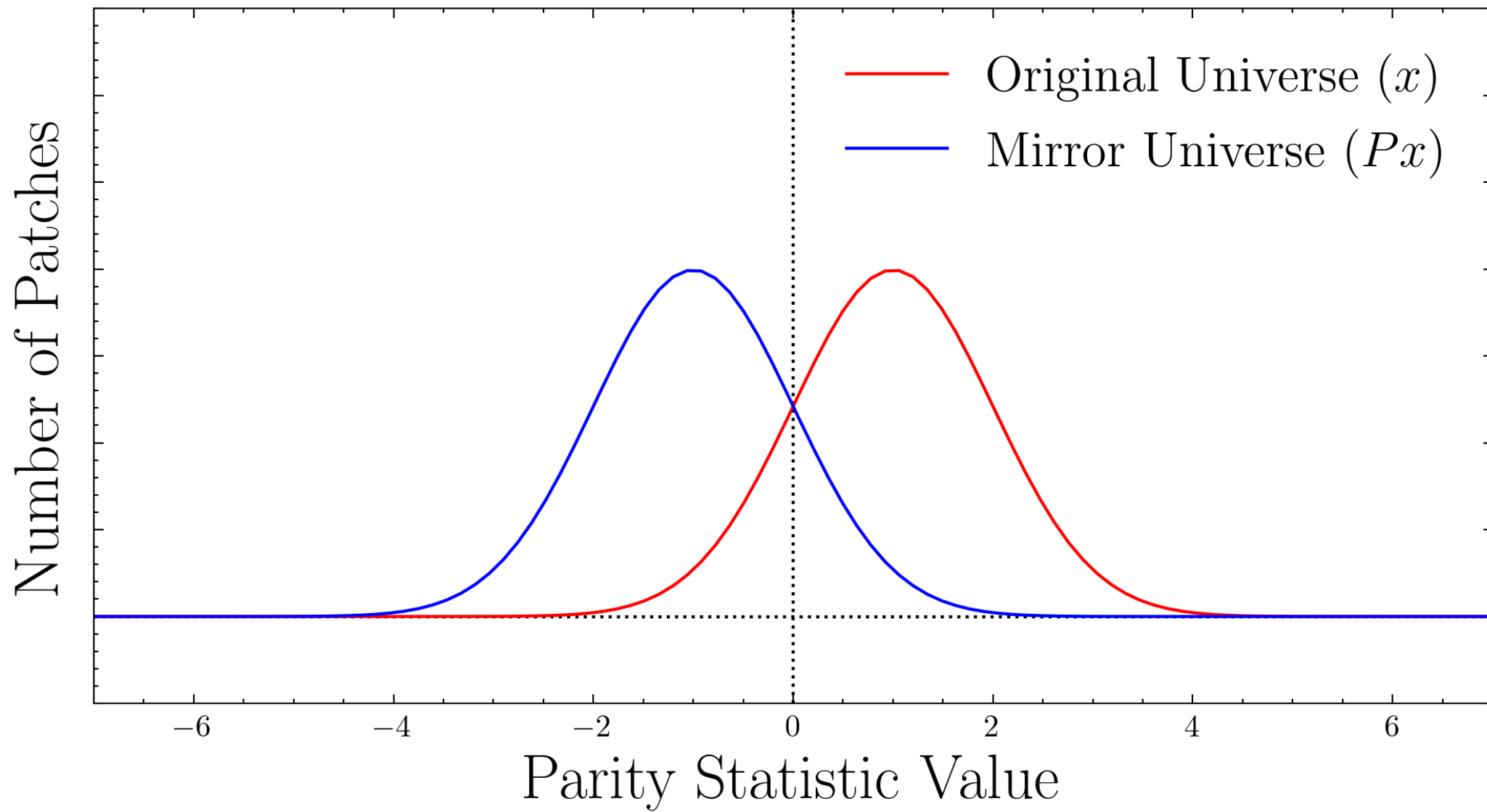
# Types of Compression Model

## Neural Field Scattering Transform (NFST)

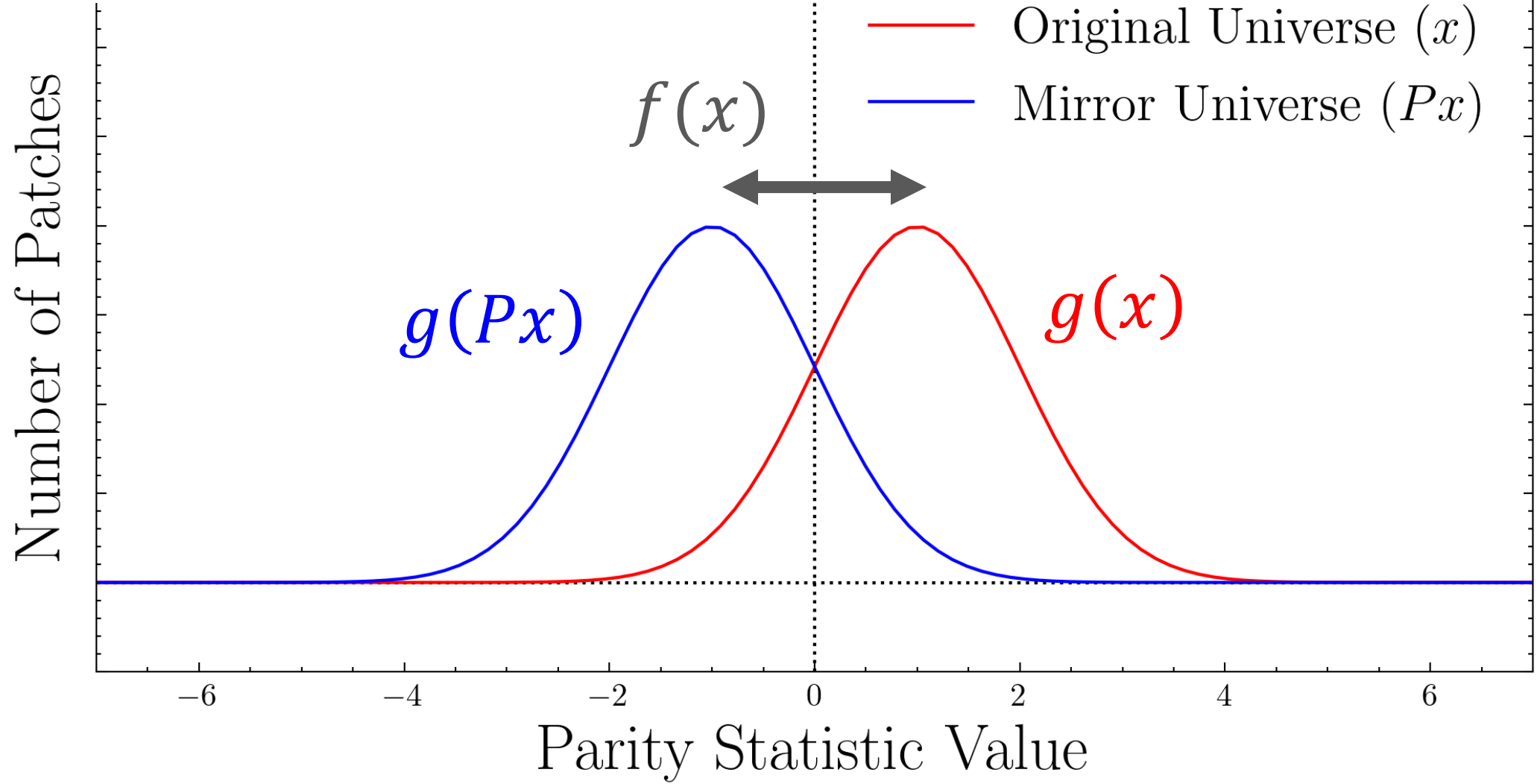


- Flexible
- Robust
- Works in 3D!

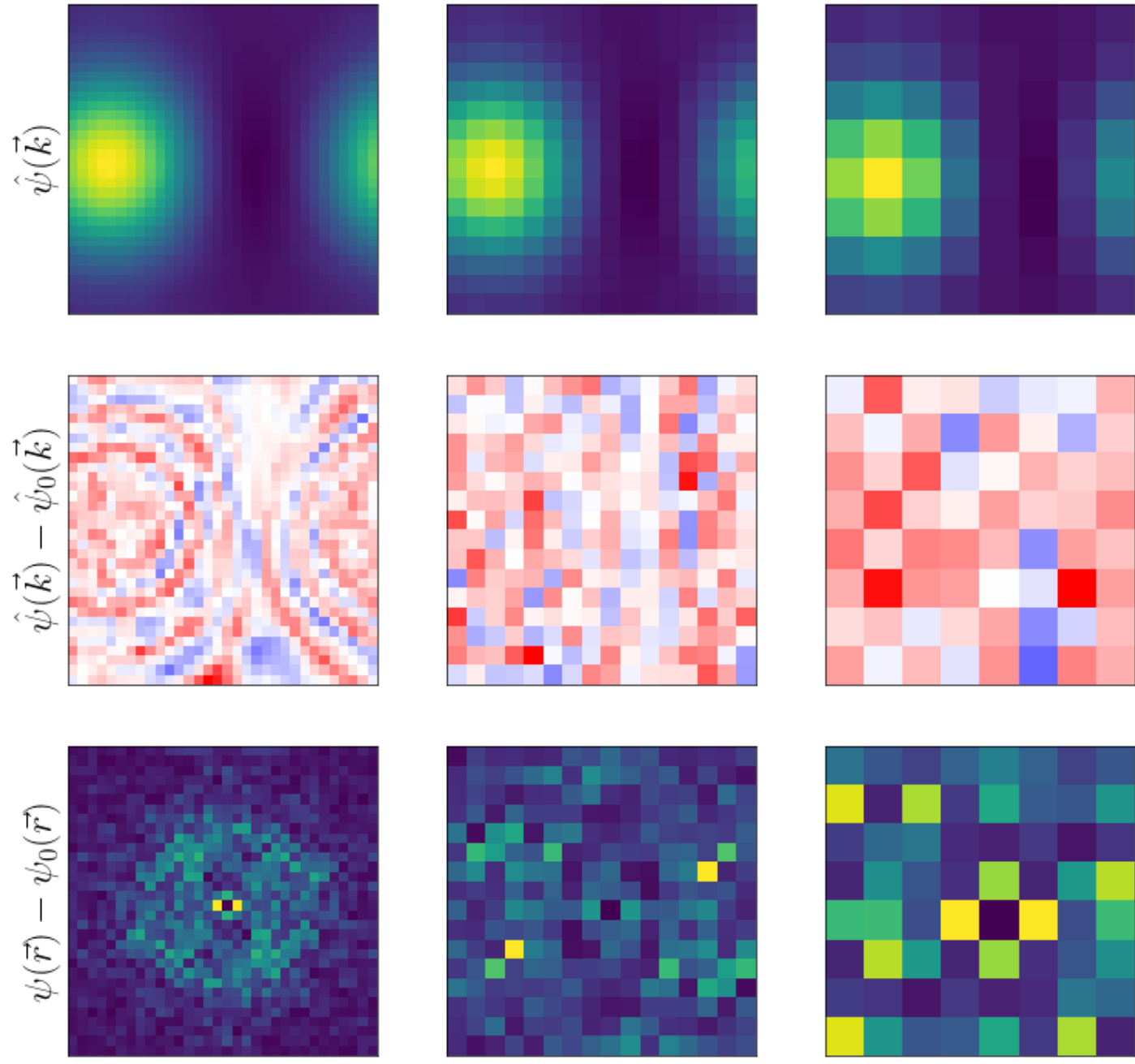




$$f(x) = g(x) - g(Px)$$







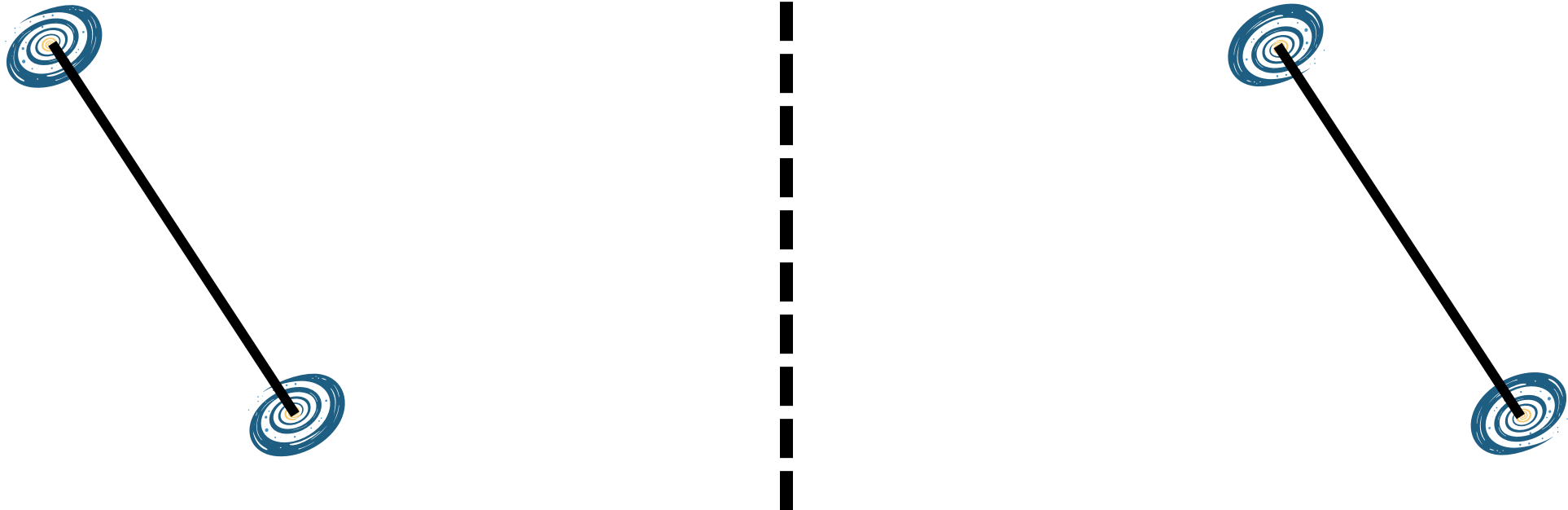
# Parity *Violation*

What does handedness look like?



# Parity *Violation*

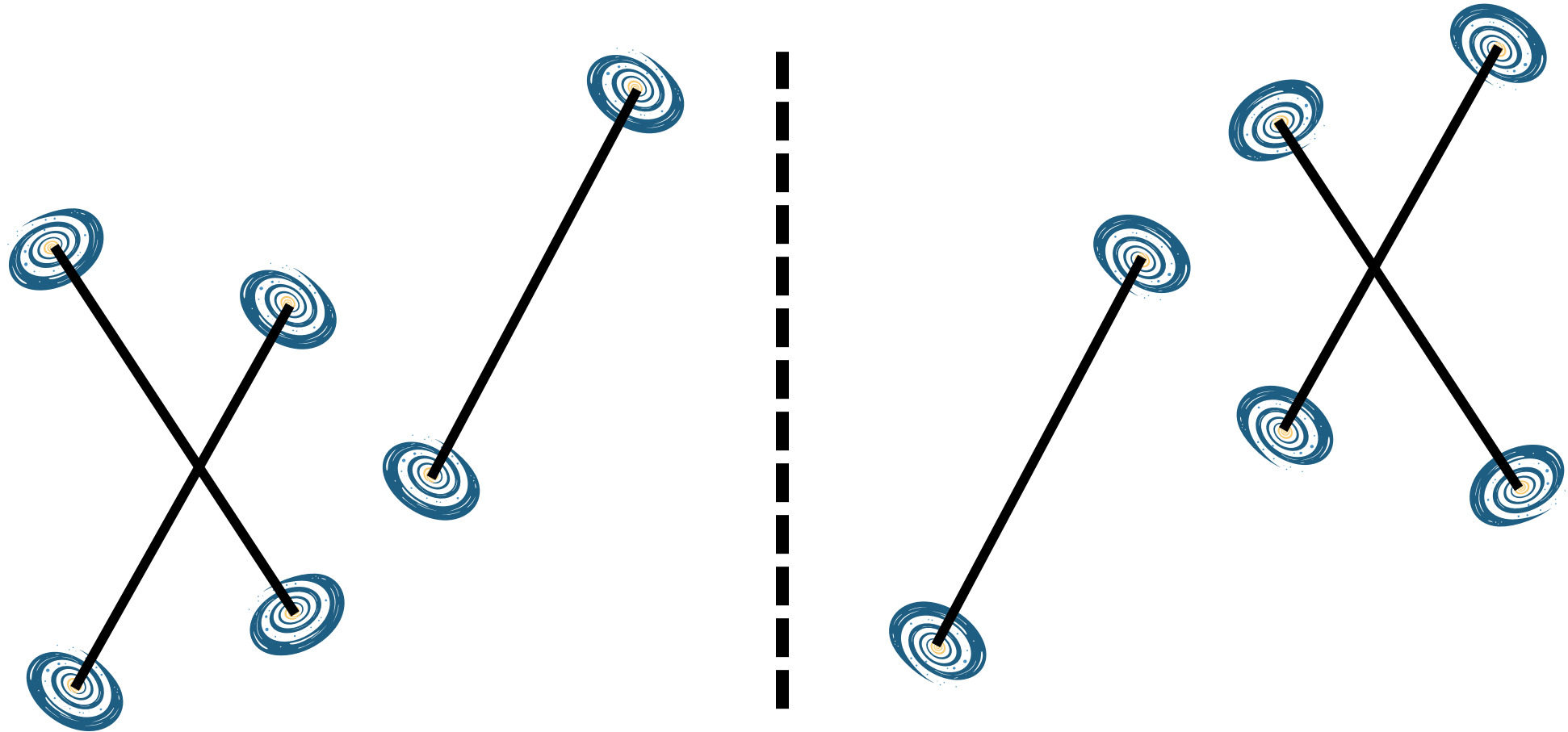
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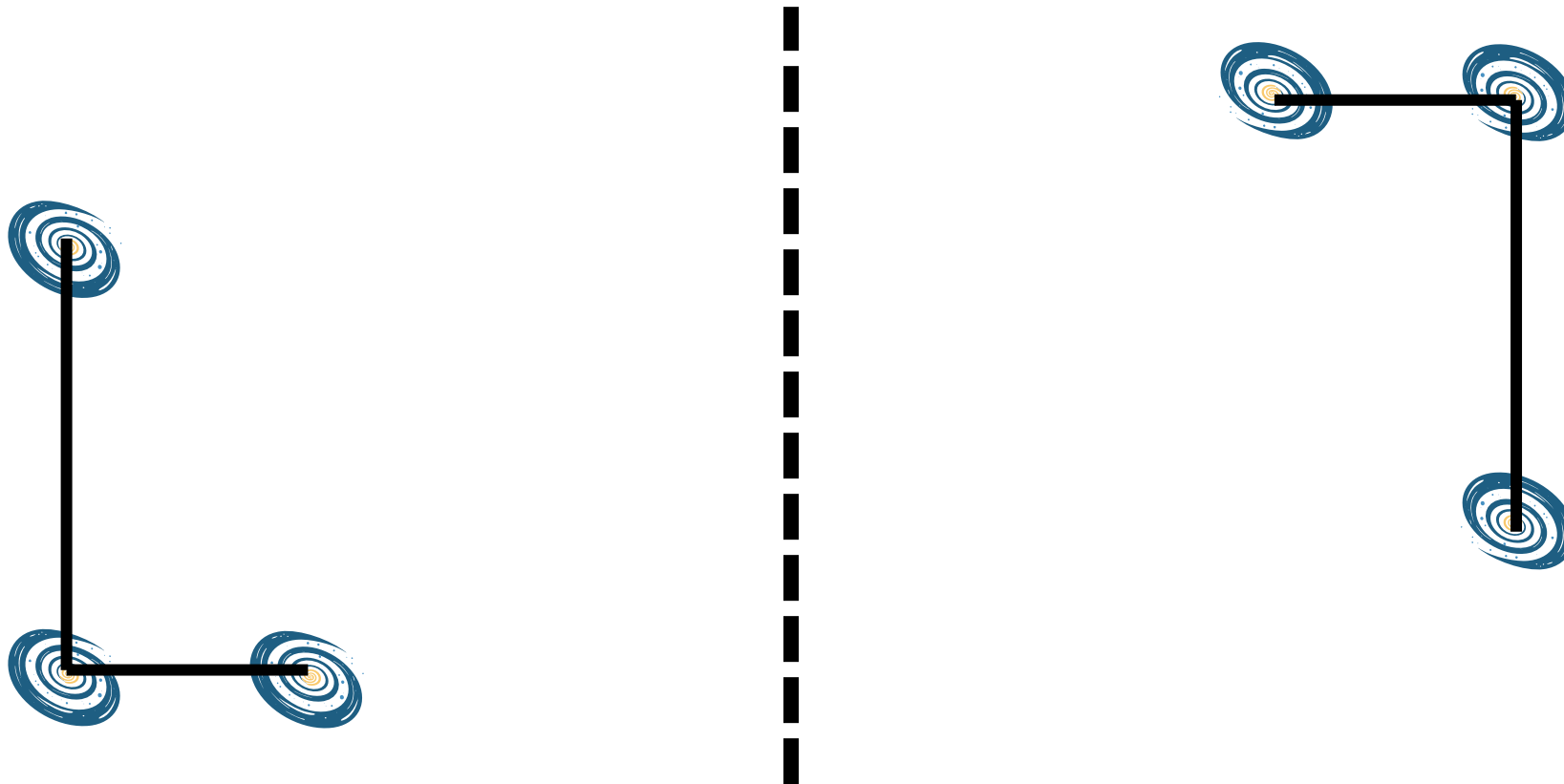
What does handedness look like?

Isotropic Universe

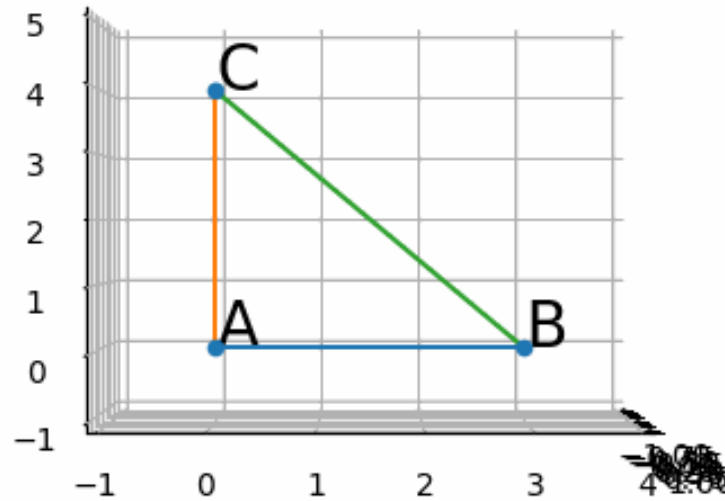


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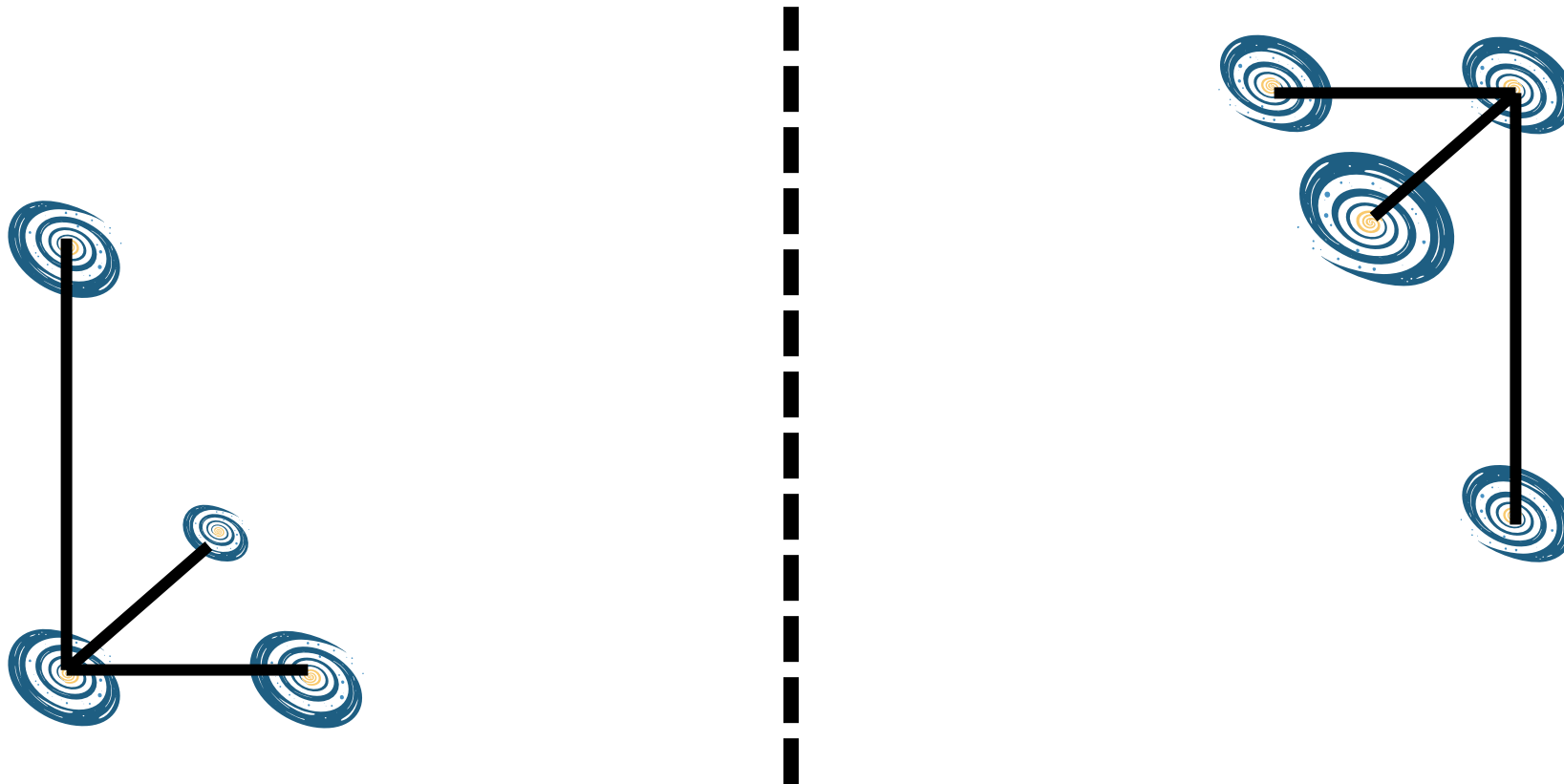


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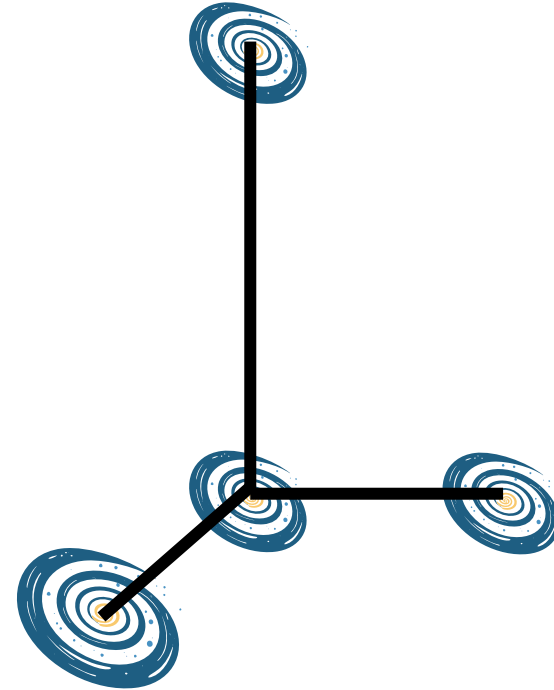
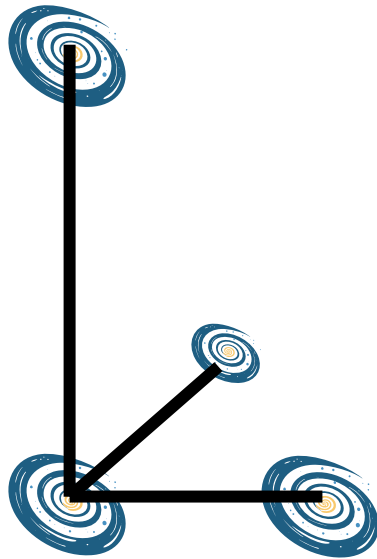
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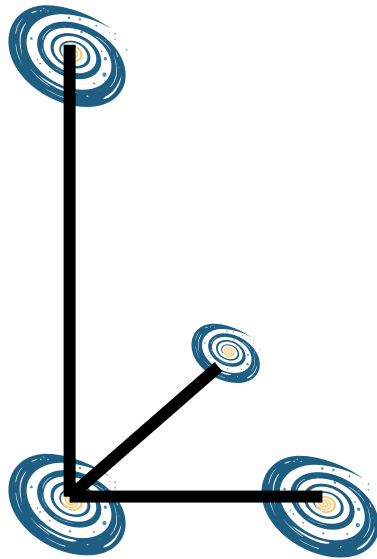
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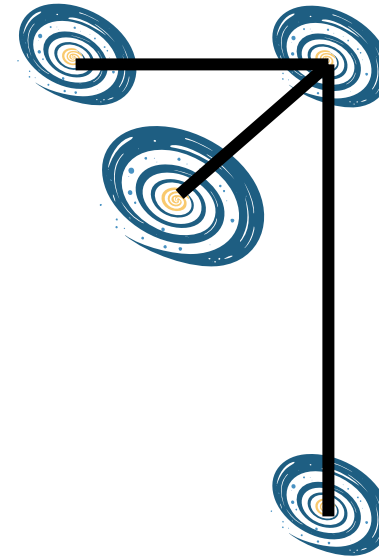


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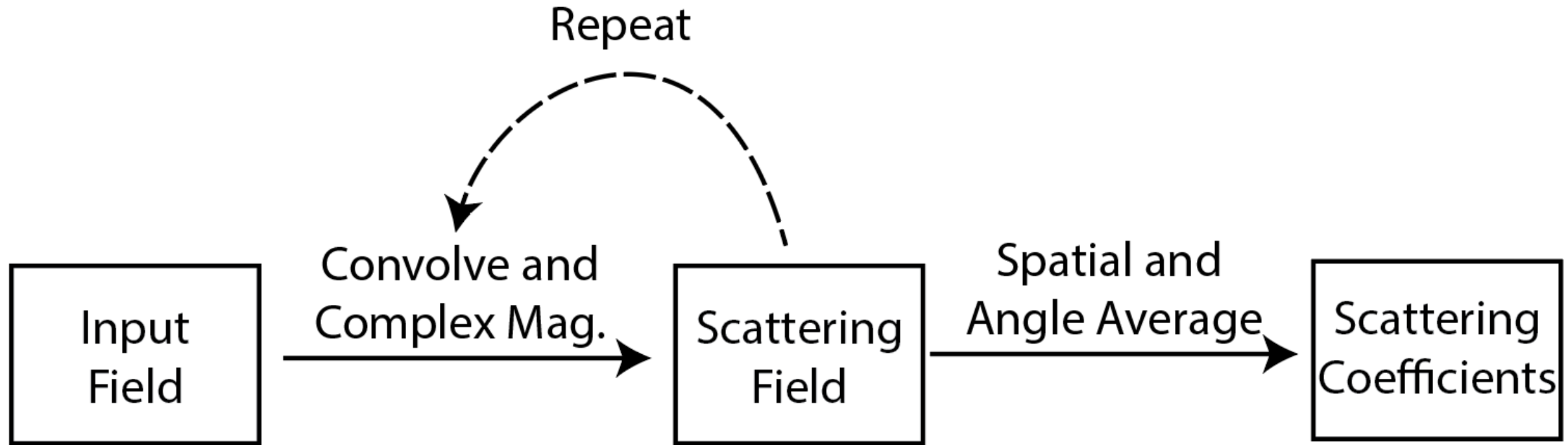
In the case of parity violation:



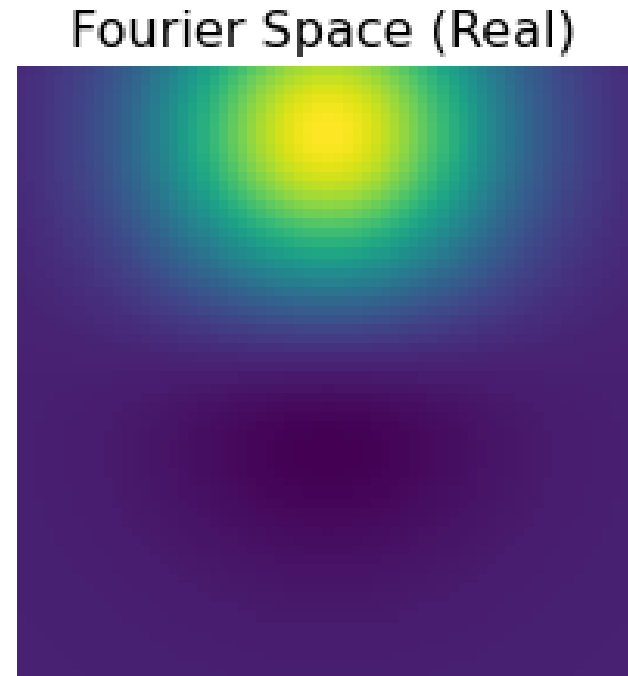
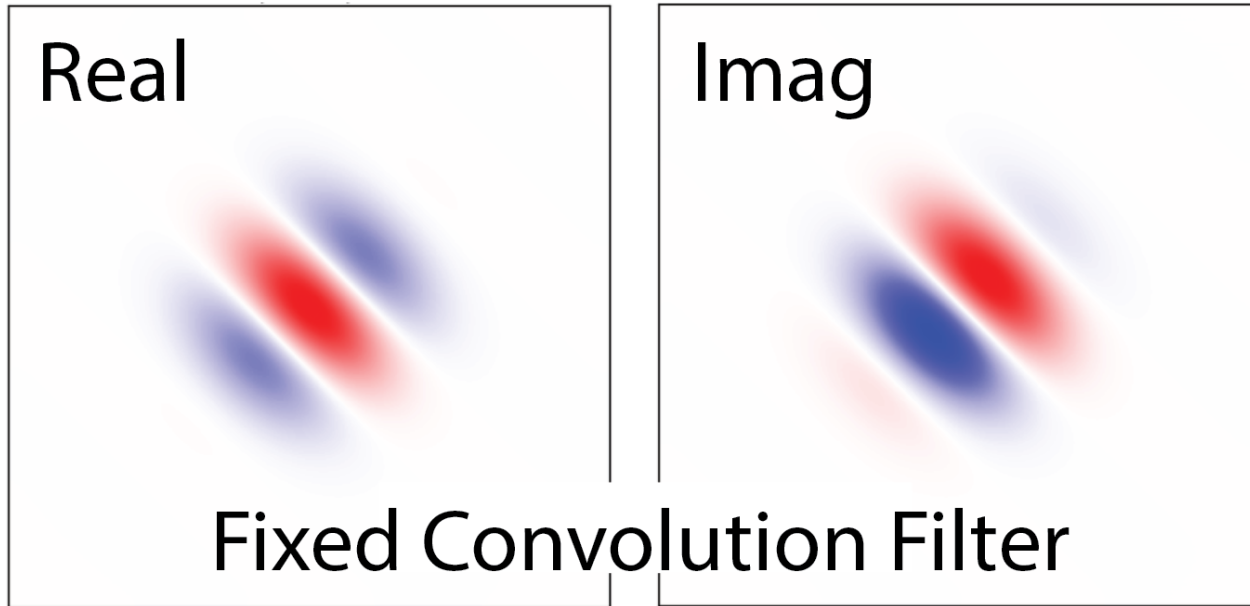
$\neq$



# The Wavelet Scattering Transform



# The *Wavelet* Scattering Transform



# Parity Violation in the ~~Galaxy Distribution~~

Cats



# The Parity Inversion

$$(x, y, z) \rightarrow (-x, -y, -z)$$



# The Parity Inversion

$$(x, y, z) \rightarrow (-x, -y, -z)$$



# The Parity Inversion

$$(x, y, z) \rightarrow (-x, -y, -z)$$

