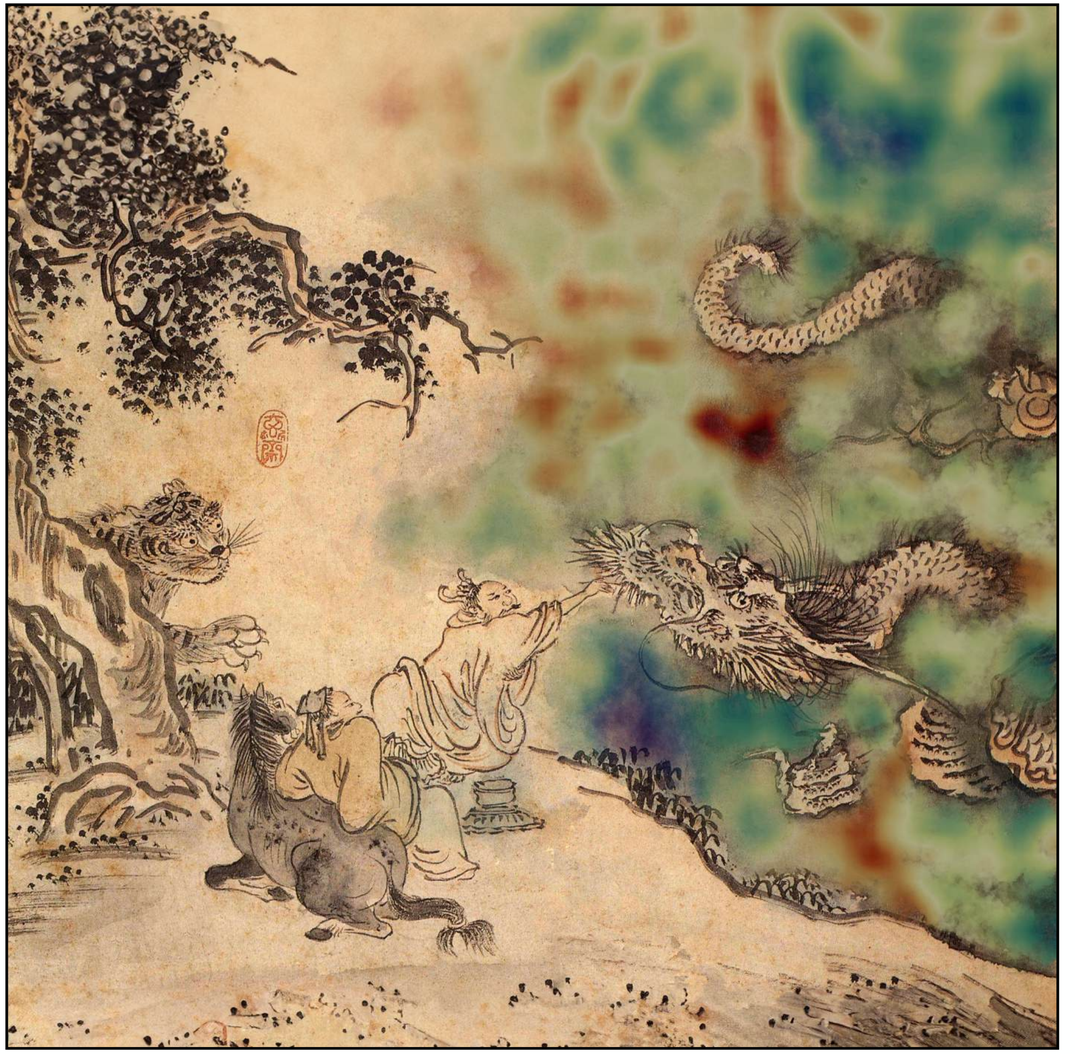
Local Universe with Cosmicflows-4

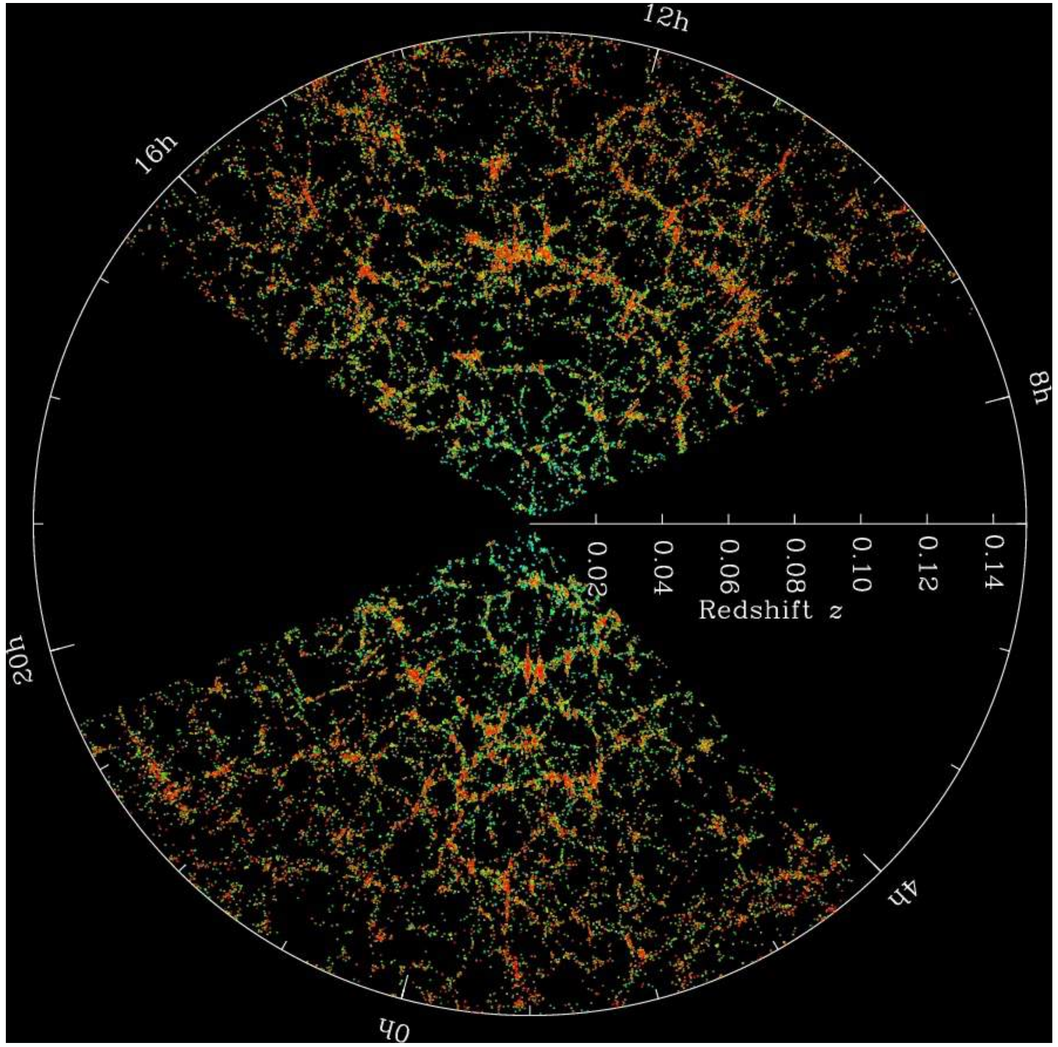
Alexandra Dupuy (KIAS), Donghui Jeong (PSU), Sungwook Hong (KASI), Hoseong Hwang (SNU), Juhan Kim (KIAS), Hélène Courtois (IP2I Lyon)



2024/10/29

The 11th KIAS workshop on Cosmology and Structure Formation

Large-scale structures and peculiar velocities



SDSS's map of the Universe
M. Blanton and SDSS

Gravitation ⟷ Expansion

Peculiar velocities: Probe total matter

$\Omega_m = \Omega_b + \Omega_{cdm}$

Observations:

Redshift *Hubble constant*

$\mu \longrightarrow d_{[Mpc]} = 10^{(\mu-25)/5} \longrightarrow v_{pec} = cz - H_0 d$

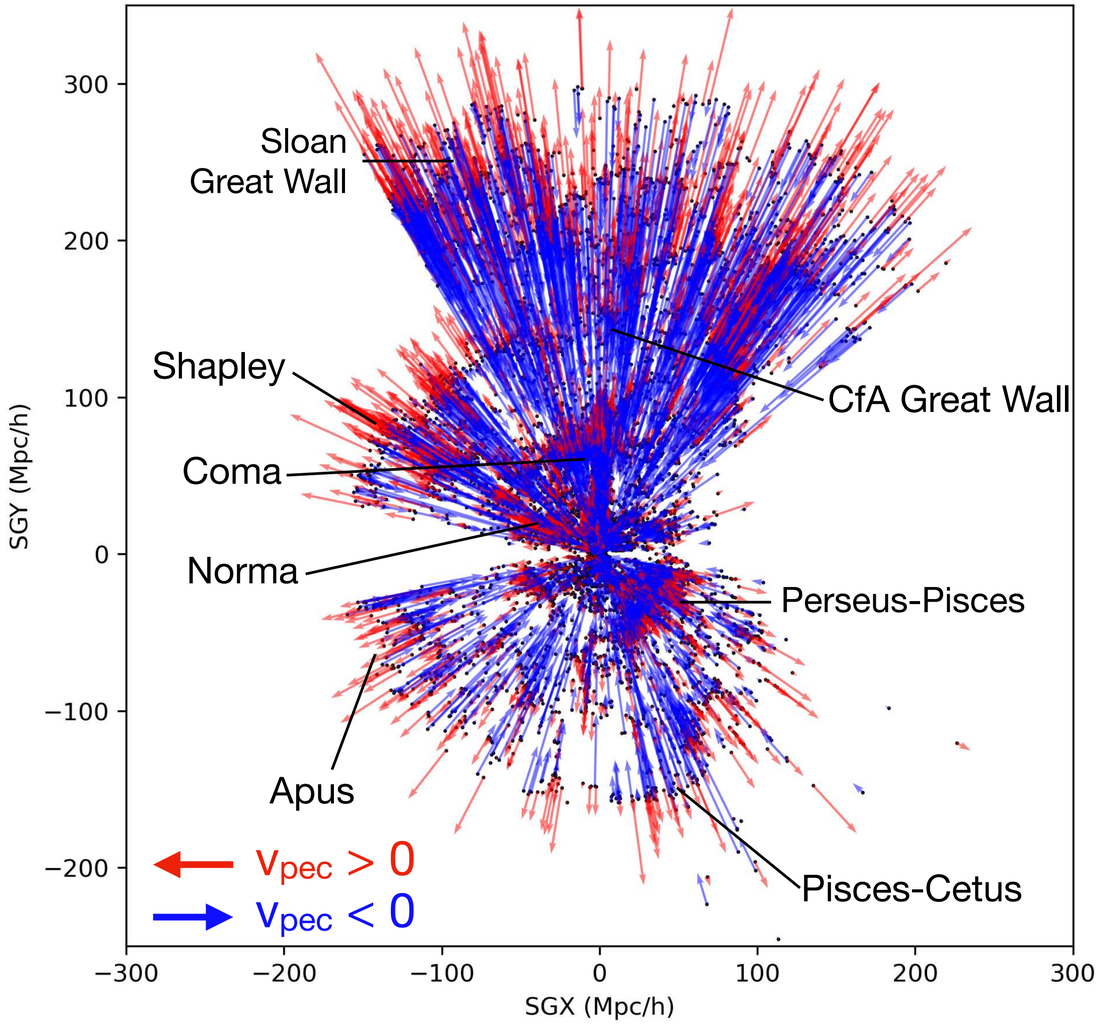
Distance modulus — Distance — **Radial** peculiar velocity

Cosmicflows-4 catalog of galaxy distances

Cosmicflows-4: catalog of observed peculiar velocities

Tully et al. (2023)

Compilation of 55,877 galaxy distances up to 300 Mpc/*h*



8 different methodologies:

Tully-Fisher, Fundamental Plane, Surface Brightness Fluctuations, Supernova Type Ia, Supernova Type II, Tip of the Red Giant Branch, Cepheid Period-Luminosity, MASERS

reconstruction →

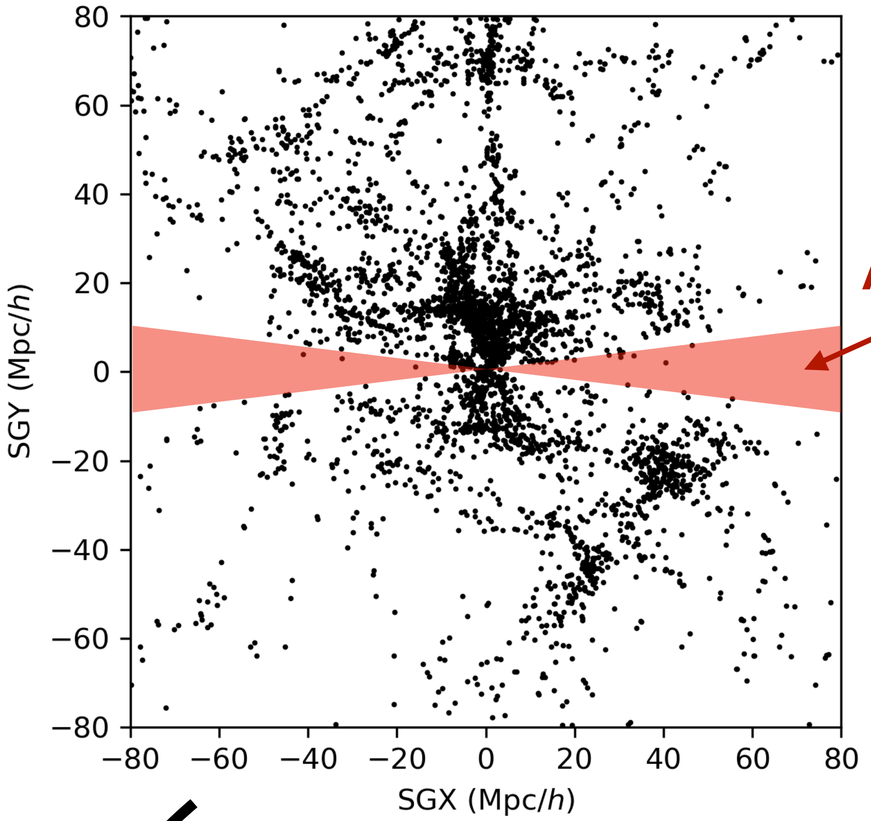
HMC (Courtois et al. 2023, Graziani et al. 2019)
HAMLET (Valade et al. 2022)
WF (Zaroubi et al. 1995)
And more…
But also: Deep Learning (Hong et al. 2021)

3D density field

3D peculiar velocity field

Peculiar velocities, Zone of Avoidance and Great Attractor

17,373 galaxies within ~80 Mpc/*h*

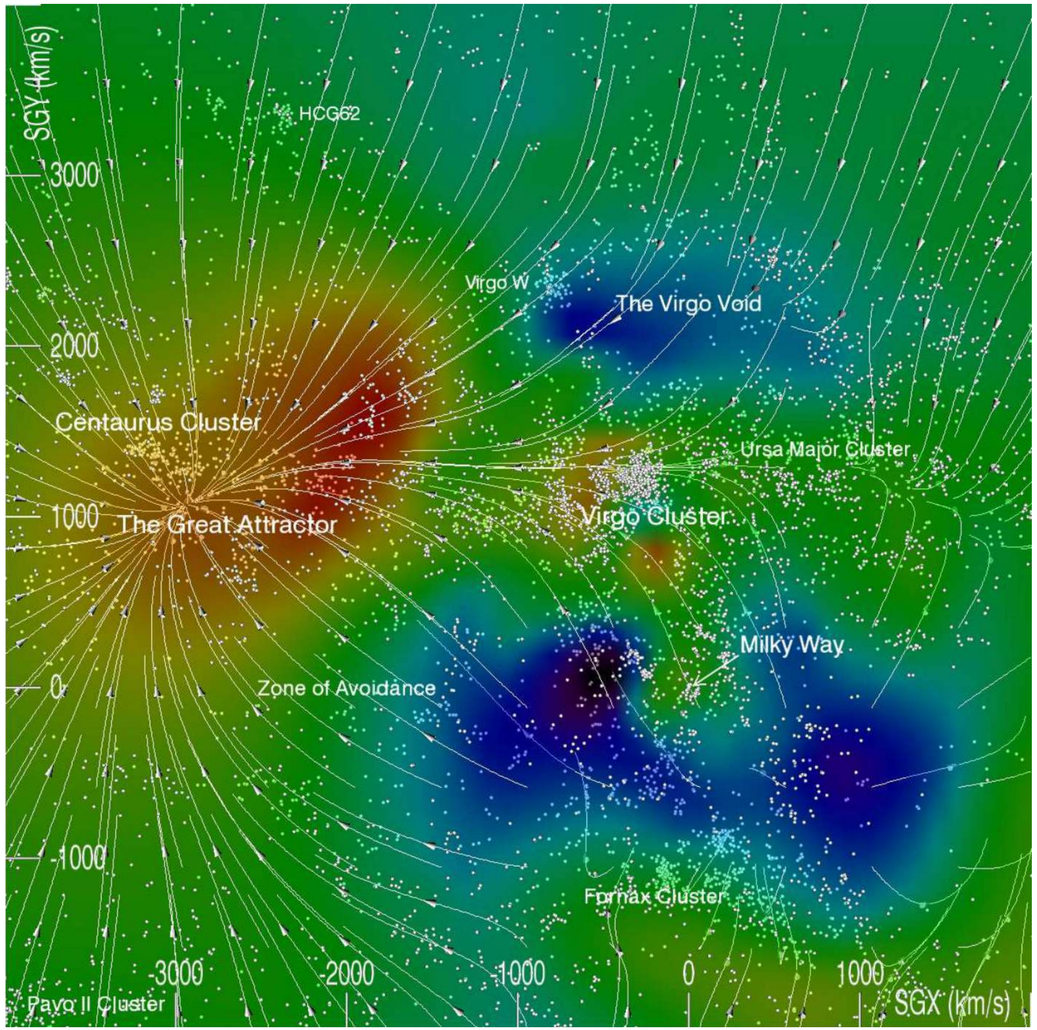


Zone of Avoidance

Deep Learning

Dark Matter density field
Peculiar velocity field

Cosmicflows-1 reconstruction + V8k galaxies (Courtois et al. 2013)

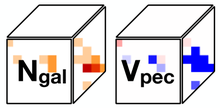


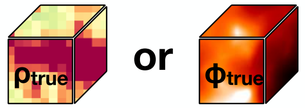
Identify the Great Attractor

Deep Learning architecture: Convolutional Neural Network

INPUT: observational data
- galaxy positions
- radial peculiar velocities

OUTPUT: fields to predict
- dark matter density ρ
- gravitational potential Φ

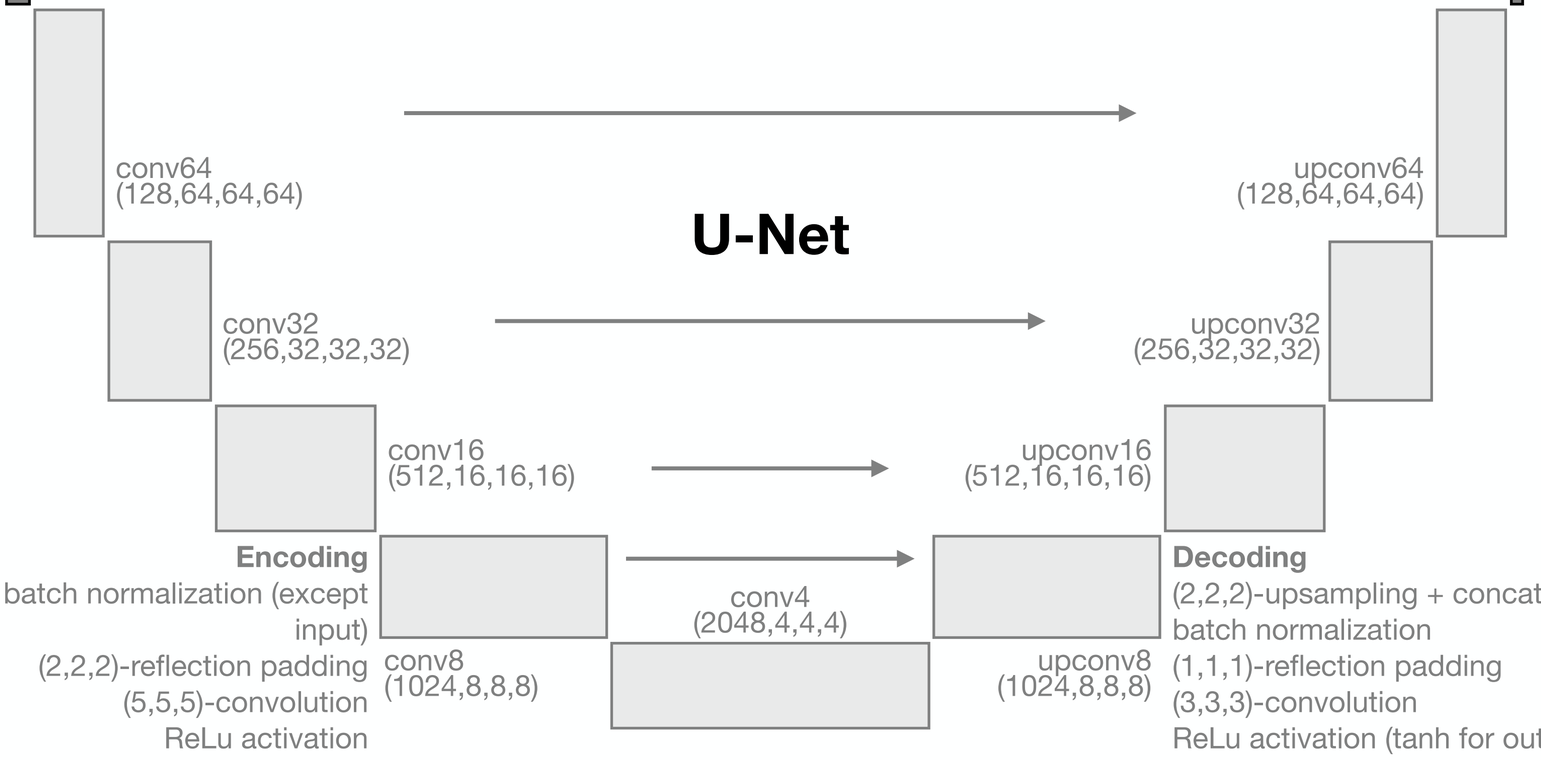




2-channel input
(2,128,128,128)

concatenation

1-channel output
(1,128,128,128)



U-Net

Encoding
batch normalization (except input)
(2,2,2)-reflection padding
(5,5,5)-convolution
ReLu activation

Decoding
(2,2,2)-upsampling + concatenation
batch normalization
(1,1,1)-reflection padding
(3,3,3)-convolution
ReLu activation (tanh for output)

(from Hong et al. 2021, density field only)

2. Predicting

Observational data
positions and v_{pec}

1. Training

Simulation data
positions and v_{pec}

Simulation data
true ρ and Φ

CNN model

Predicted ρ and Φ

Predicted δ and v

Preparing training samples with A-SIM

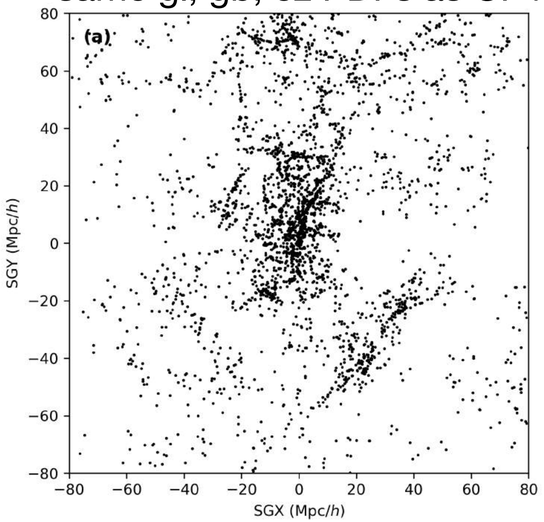
A-SIM N-Body simulation:
WMAP5 cosmology
$N_p = 4096^3$
$m_p \sim 1.95 \times 10^9\ M_\odot$
$L_{box} = 1228.8$ Mpc/*h*
$N_{box} = 983^3$

input quantities: A-SIM galaxy catalog

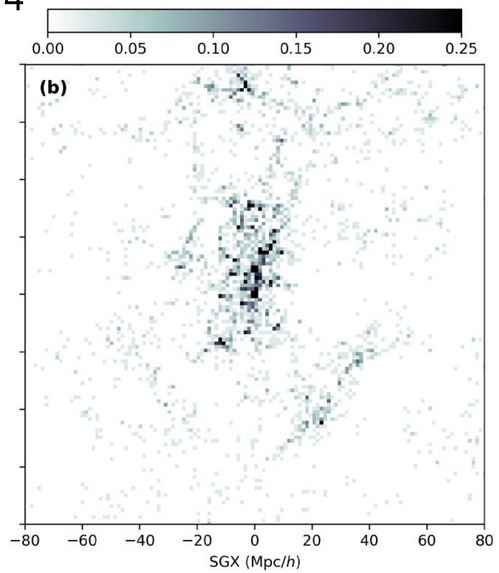
output quantities: A-SIM TSC dark matter density and potential fields

CF4-like mock

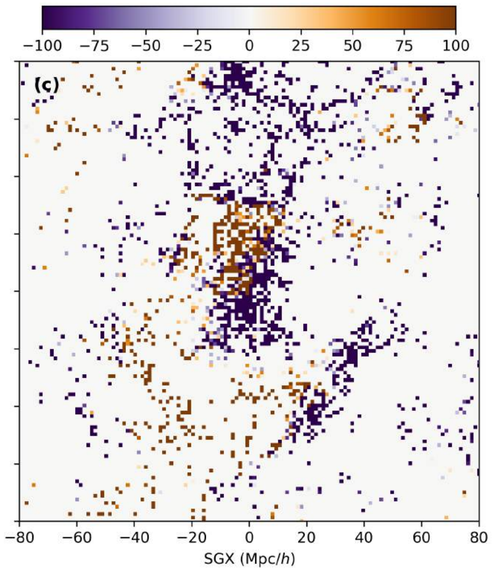
MW-like galaxy as observer
same number of galaxies as CF4
same gl, gb, cz PDFs as CF4



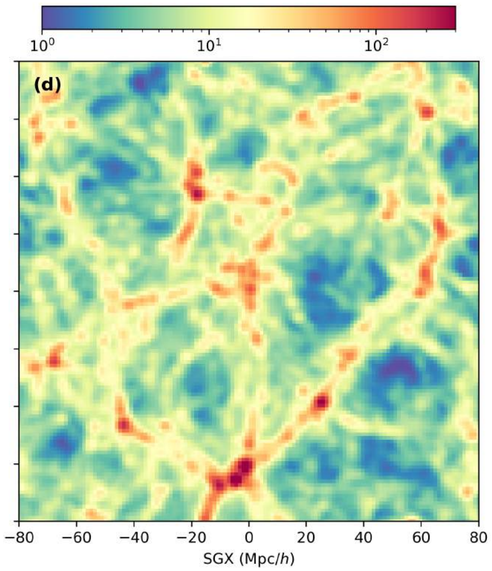
Galaxy number density N_{gal}



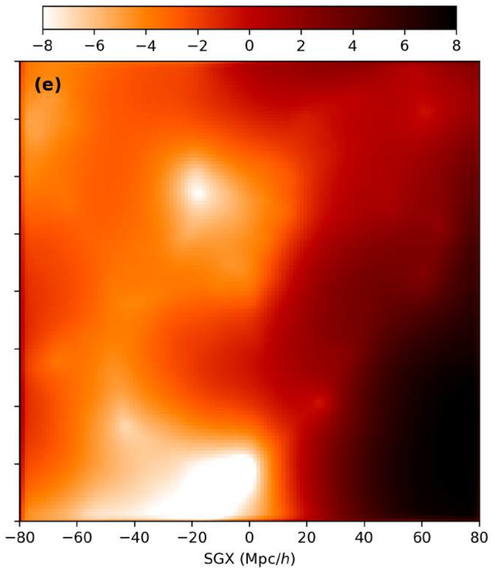
Mean radial peculiar velocity V_{pec} (km/s)



True dark matter density field ρ_{true}



True gravitational potential field Φ_{true}



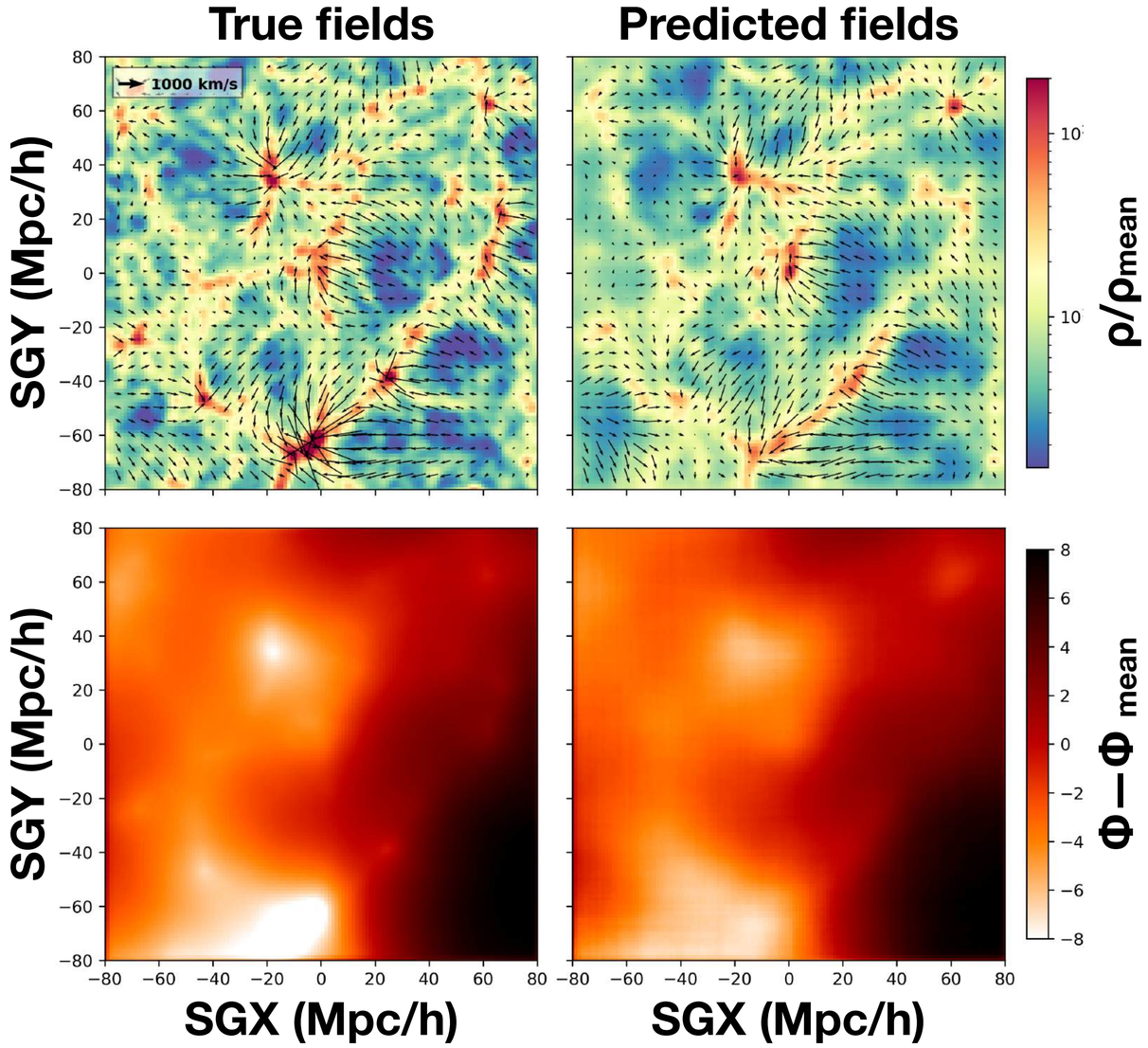
Dupuy et al. (in preparation)

11,512 samples (10,248 in training set ; 1,264 in validation set)
grids of size 128^3 and side length 160 Mpc/*h*

Performance of the trained CNN model

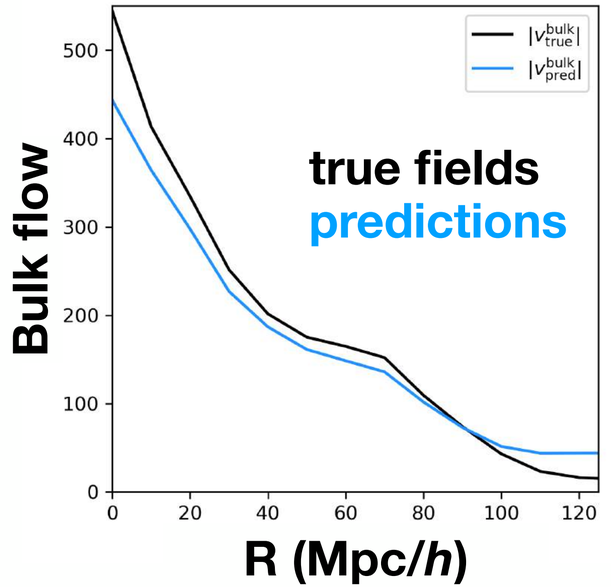
Mean of the norm of the velocity field in sphere of radius R centered on observer

Applying a random validation sample to the CNN model

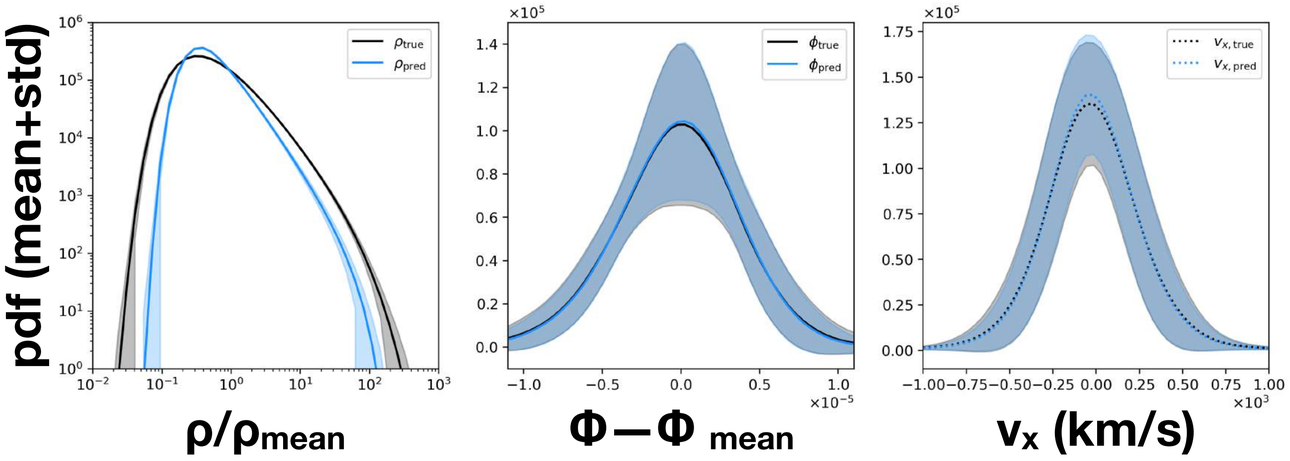


Peculiar velocity field from potential field

$$\vec{v} = -\frac{2f}{3H_0\Omega_m}\vec{\nabla}\phi$$



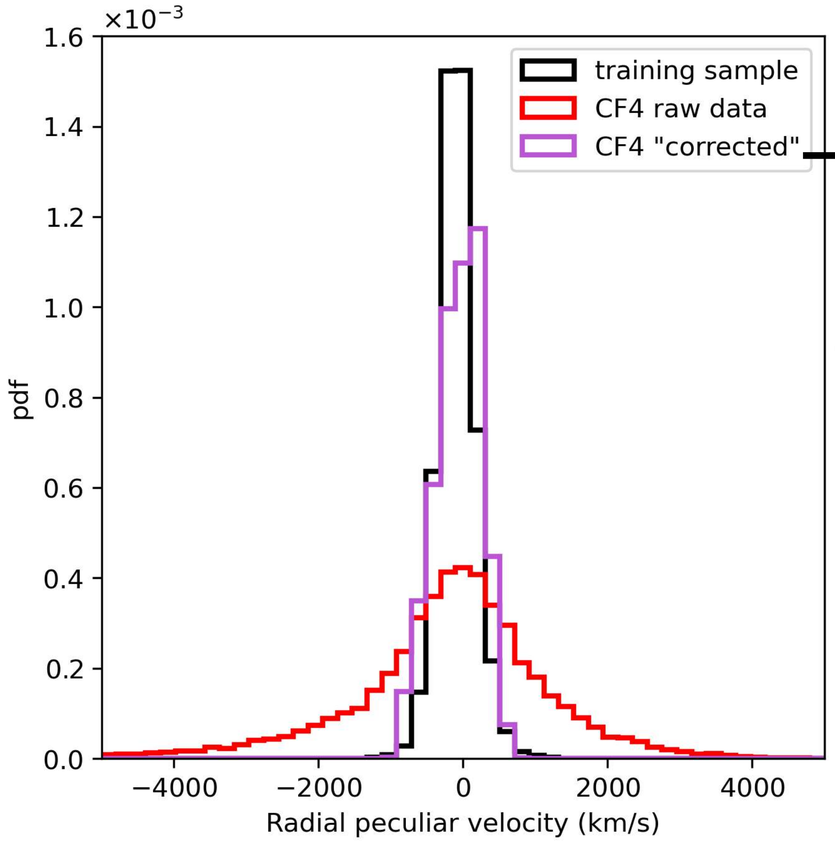
Model applied to all validation samples



Dupuy et al. (in preparation)

Local Universe from CF4

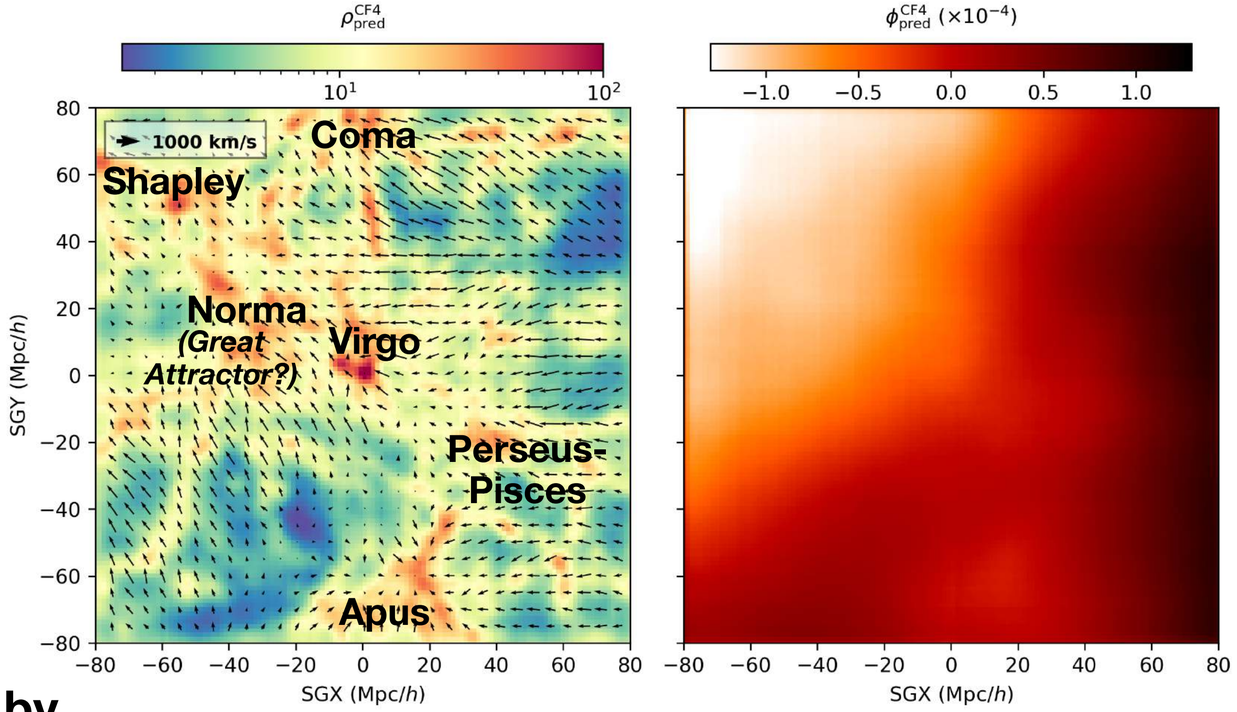
Problem: CF4 observed peculiar velocities are actually (very) biased!

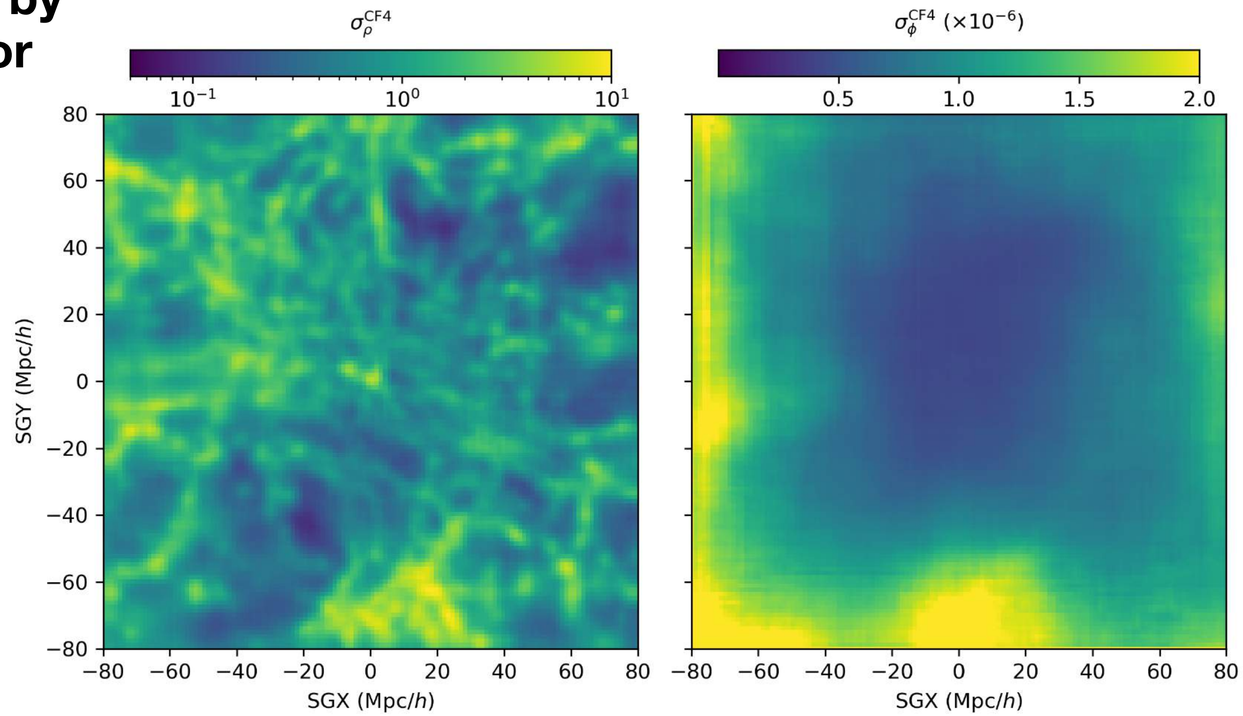


CNN model

$$v_{\rm pec}^{\rm HMC} \pm \sigma_{v_{\rm pec}^{\rm HMC}}$$

1,000 realizations by propagating error



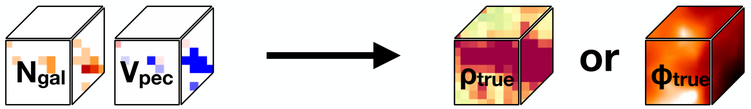


Instead: use a “corrected” CF4 (velocities extracted from the HMC reconstructed velocity field)

Dupuy et al. (in preparation)

Summary

- **CNN architecture** (U-Net) taking as **<u>input</u>: galaxy positions (N_{gal})** and **radial peculiar velocities (V_{pec}) ;** as **<u>output</u>: dark matter density field ρ** and **gravitational potential field Φ**



- **Training on 11,512 samples** prepared using **A-SIM** (**CF4-like inputs** and **true output fields**)

- **Performance tests** show a **good coherence** between true and predicted fields

- Trained CNN model **applied to the "corrected" CF4 data**: reconstructed known structures, including ***possibly*** the **Great Attractor**

Future directions

- **Extract the coordinates** of the Great Attractor (convergence of streamlines)

- **<u>Incorporate bias treatments in the Deep Learning approach</u>**

  Not that easy as CF4 is a compilation of distances obtained through various methodologies (all with differently defined uncertainties), with no clearly defined selection function