Estimation of peculiar velocity of individual galaxy and eliminating RSD effect, using neural networks

Hongxiang Chen（陈鸿翔）

NAOC

Collaborator: Jie Wang, Juntao Ma, Baojiu Li

Background

Redshift Space Distortion and peculiar velocity

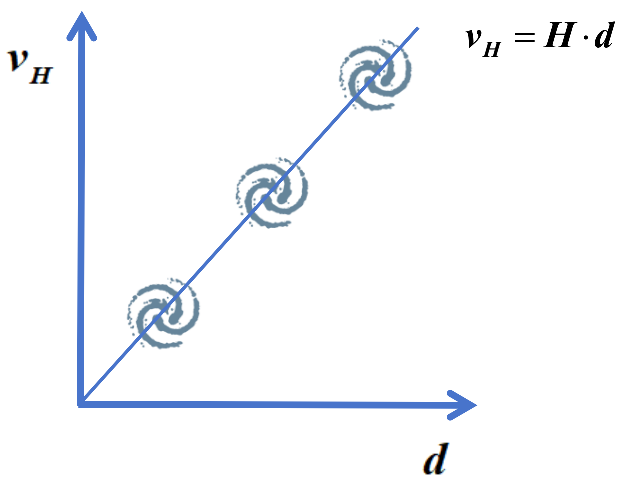
$$v = v_H + v_p$$

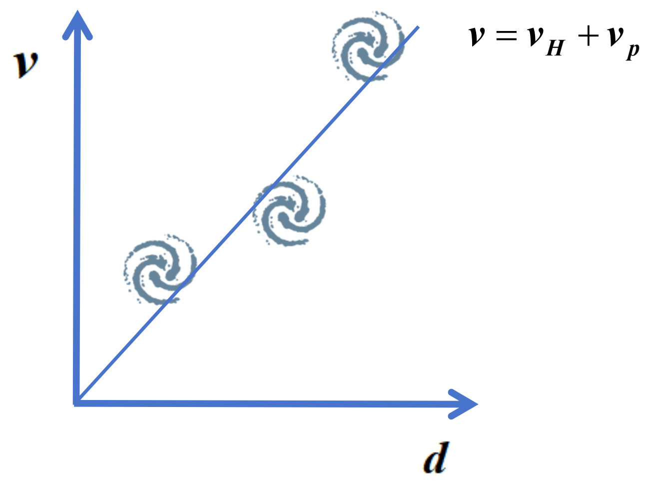
$v_H = H \cdot d$

Hubble flow

v_p : Peculiar velocity

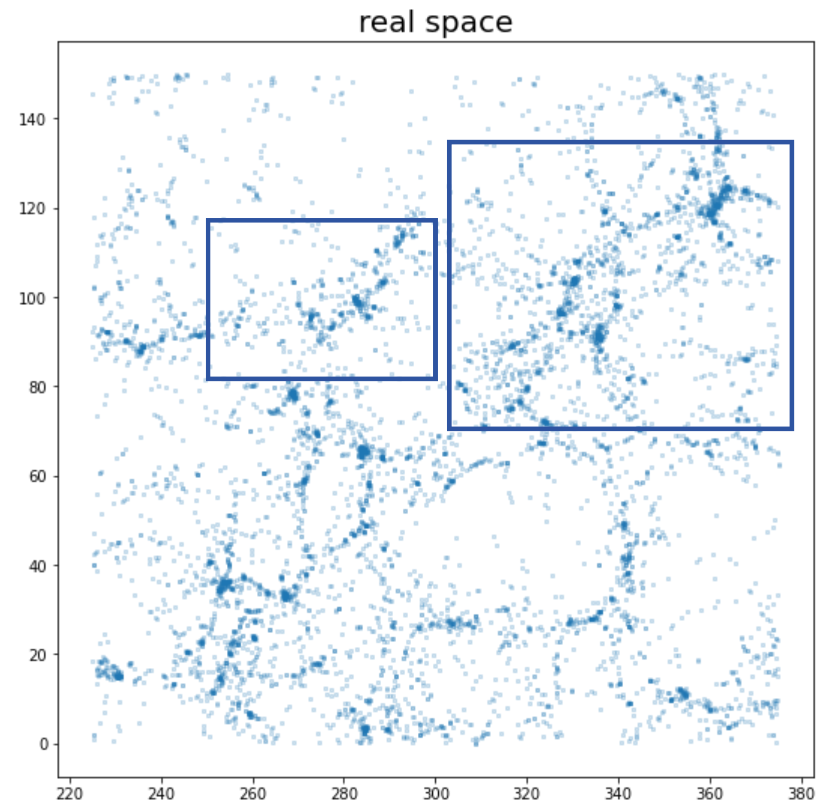
Source of RSD



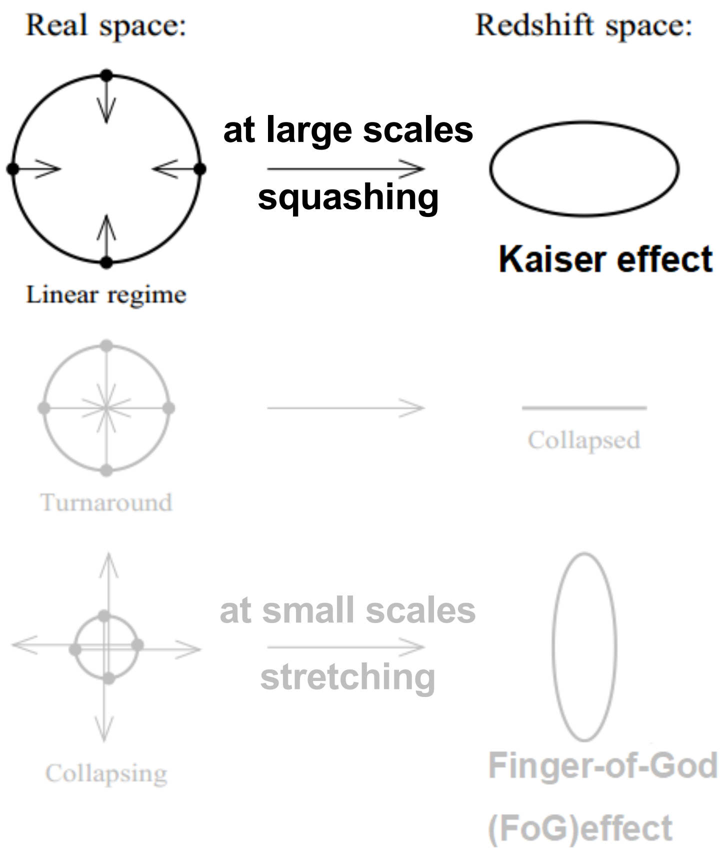


Background

Redshift Space Distortion and peculiar velocity

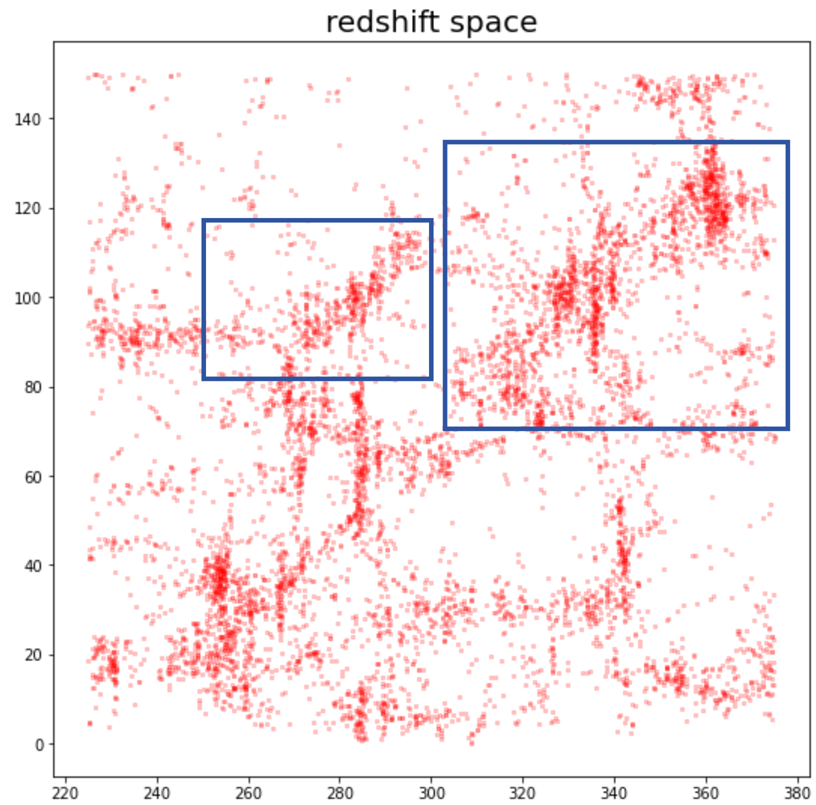


millennium simulation



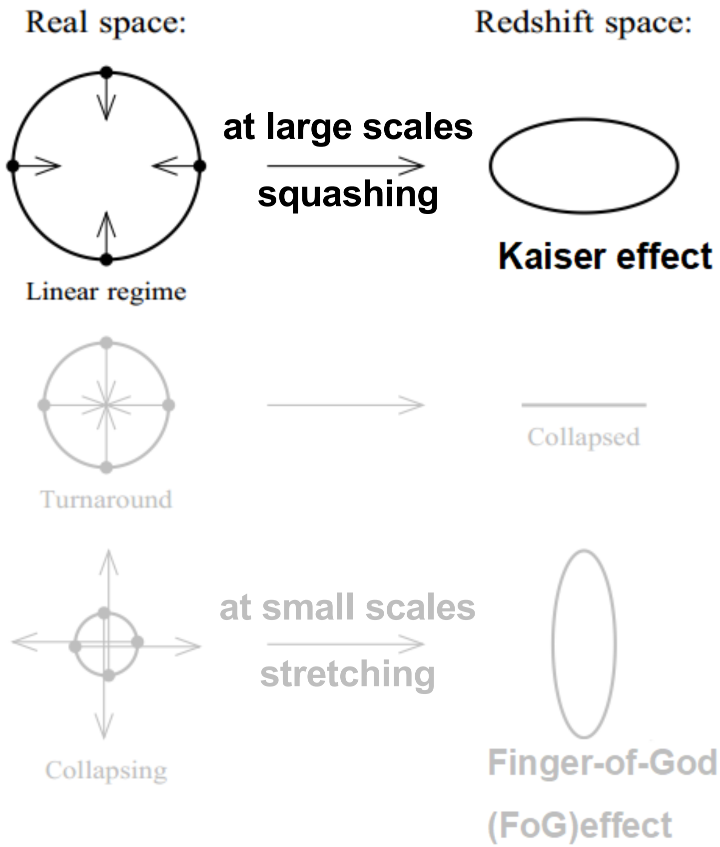
Background

Redshift Space Distortion and peculiar velocity



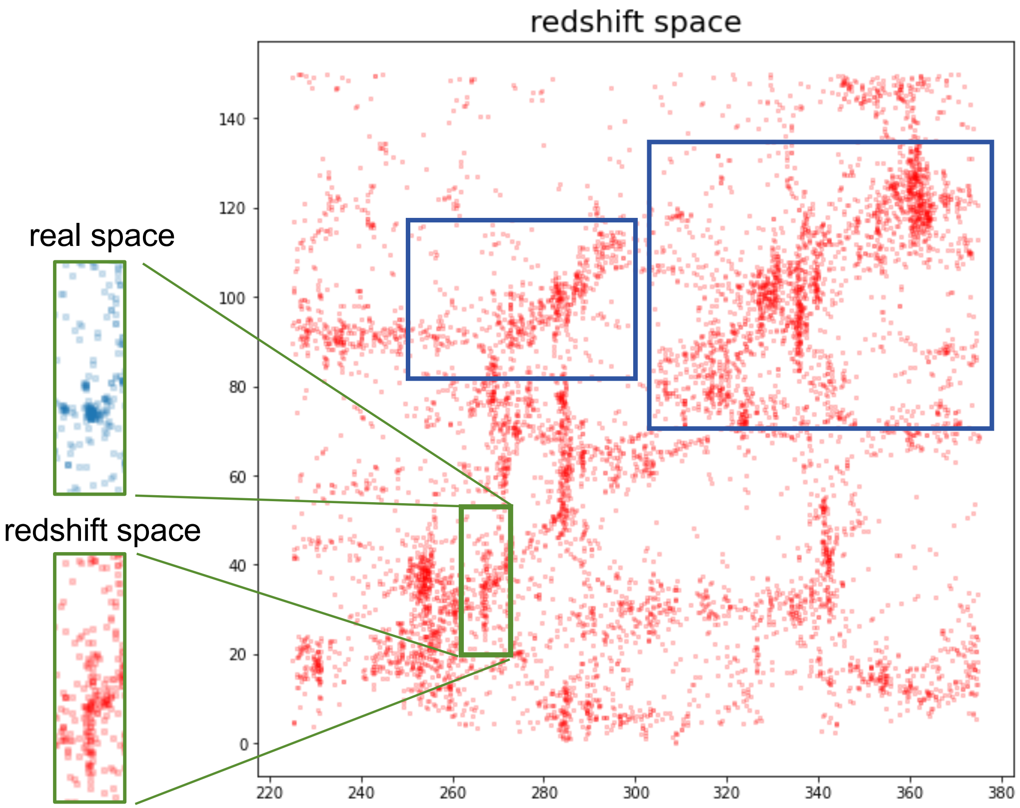
millennium simulation

Kaiser effect
squashing



Background

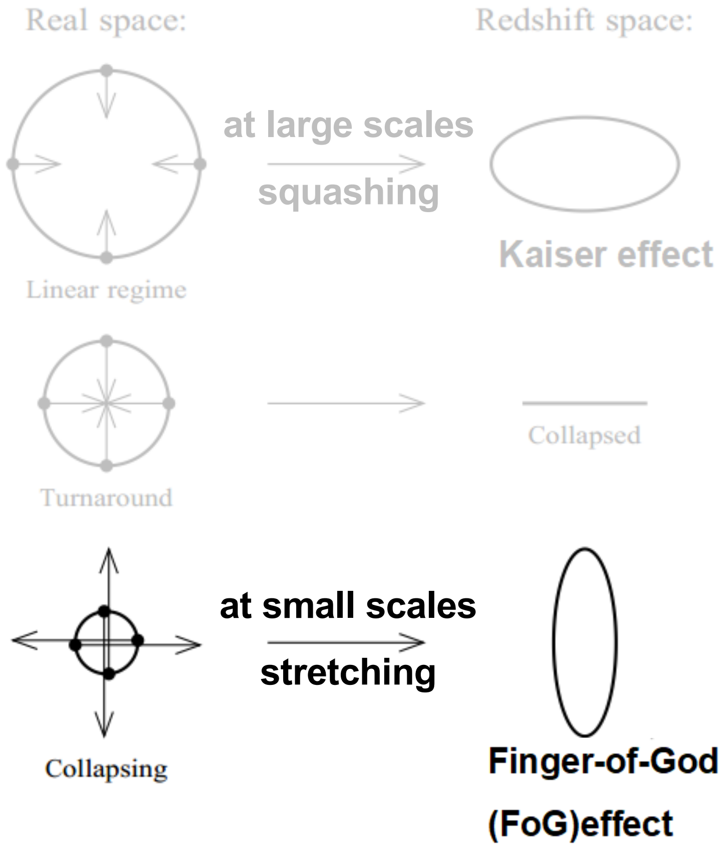
Redshift Space Distortion and peculiar velocity



FoG effect
stretching

millennium simulation

Kaiser effect
squashing



Aims

To Eliminate the RSD effect at nonlinear region

↓

Design a neural network model,use only observable quantities

↓

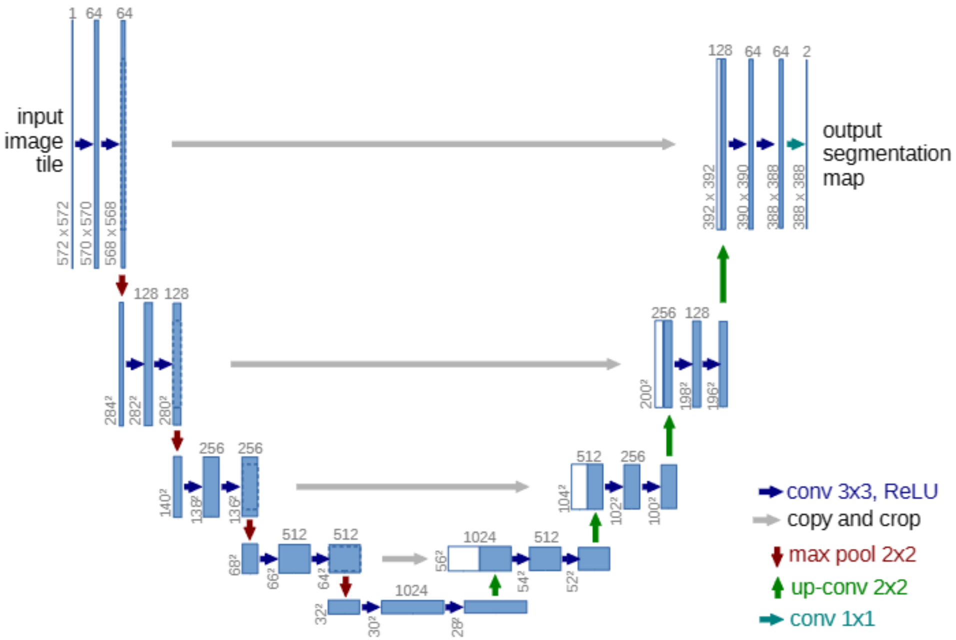
Estimate the line-of-sight peculiar velocities of individual galaxies

↓

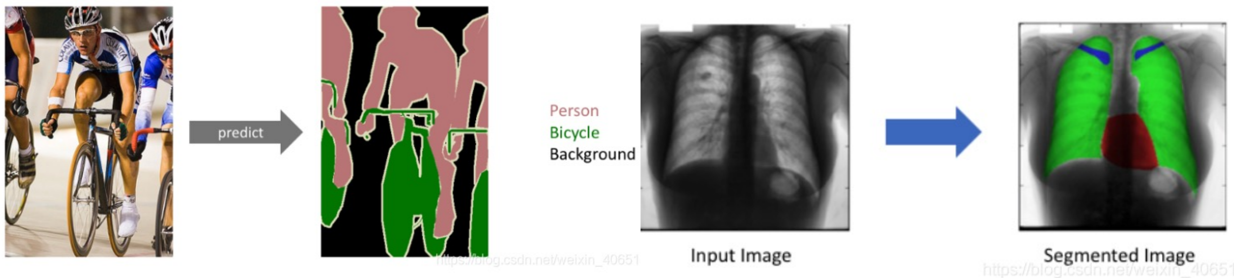
Eliminate RSD effect Successfully

Method

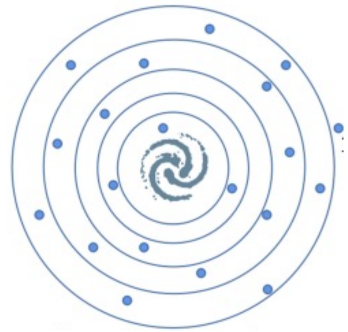
Ready-made network or physical model based network



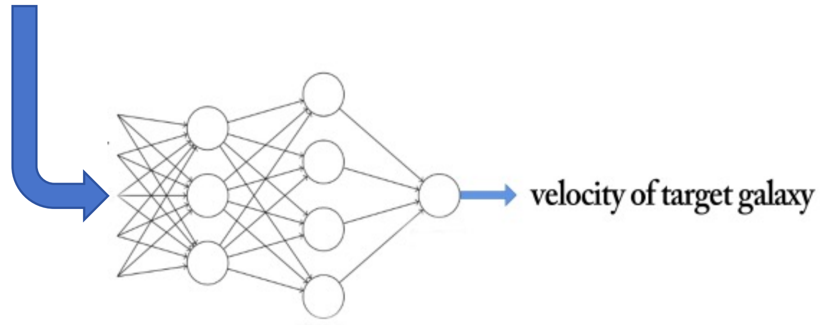
U-net Structure



or



Extract physical information in simulation



ANN

Combine physical models with neural networks

Method

physical model based network

$$\nabla \cdot \mathbf{v}(\mathrm{r}) = -\beta\delta(\mathrm{r})$$

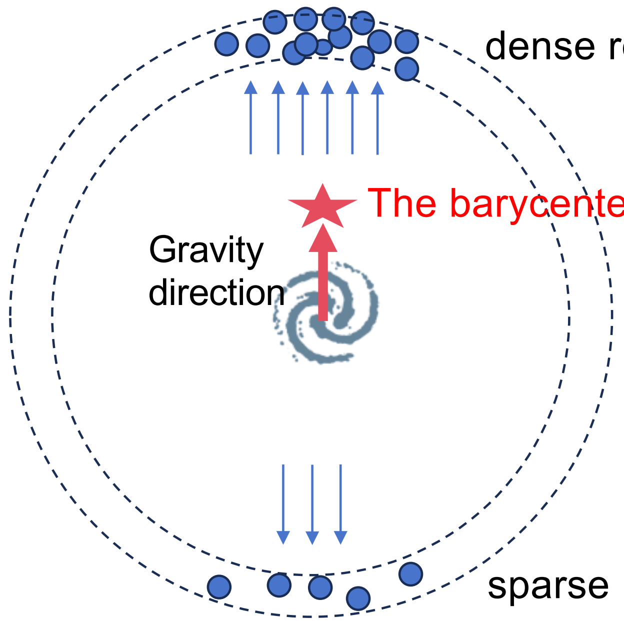
velocity -- gravitational acceleration -- matter density

$$\boldsymbol{a}_j = \sum_{r_j<r_k<r_{j+1}}^{k} \frac{G m_k \vec{\boldsymbol{x}}_k}{r_k^3}.$$

the shell is thin

$$\boldsymbol{a}_j = \sum_{r_j<r_k<r_{j+1}}^{k} \frac{G m_k \boldsymbol{x}_k}{r_k^3} \approx \frac{G}{r_j^3} \sum_{r_j<r_k<r_{j+1}}^{k} m_k \boldsymbol{x}_k \approx \frac{G}{r_j^3} M_j \cdot \boldsymbol{X}_j,$$

gravitational acceleration of the j-th spherical shell
∝ shell mass ×barycenter



The barycenter of this spherical shell is positive
The gravity direction is positive

Method

physical model based network

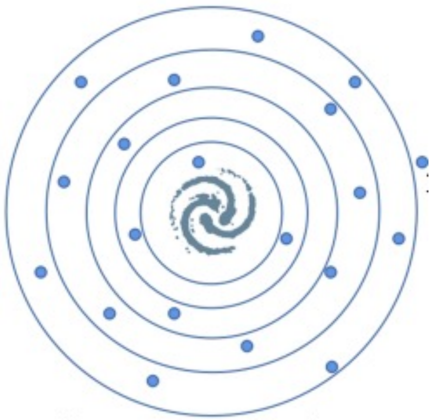
$$\nabla \cdot \mathbf{v}(\mathrm{r}) = -\beta\delta(\mathrm{r})$$

velocity -- gravitational attraction -- matter density

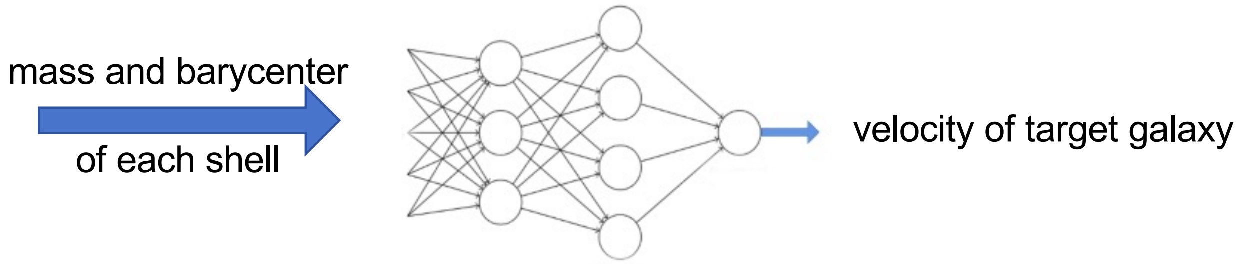
$$\boldsymbol{a}_j = \sum_{r_j<r_k<r_{j+1}}^{k} \frac{Gm_k\vec{\boldsymbol{x}}_k}{r_k^3}.$$

$$\boldsymbol{a}_j = \sum_{r_j<r_k<r_{j+1}}^{k} \frac{Gm_k\boldsymbol{x}_k}{r_k^3} \approx \frac{G}{r_j^3} \sum_{r_j<r_k<r_{j+1}}^{k} m_k\boldsymbol{x}_k \approx \frac{G}{r_j^3} M_j \cdot \boldsymbol{X}_j,$$

gravitational acceleration of the j-th spherical shell ∝ shell mass ×barycenter



divide many shell around target galaxy
calculate mass and barycenter of each shell
In redshift space, in Indra simulation



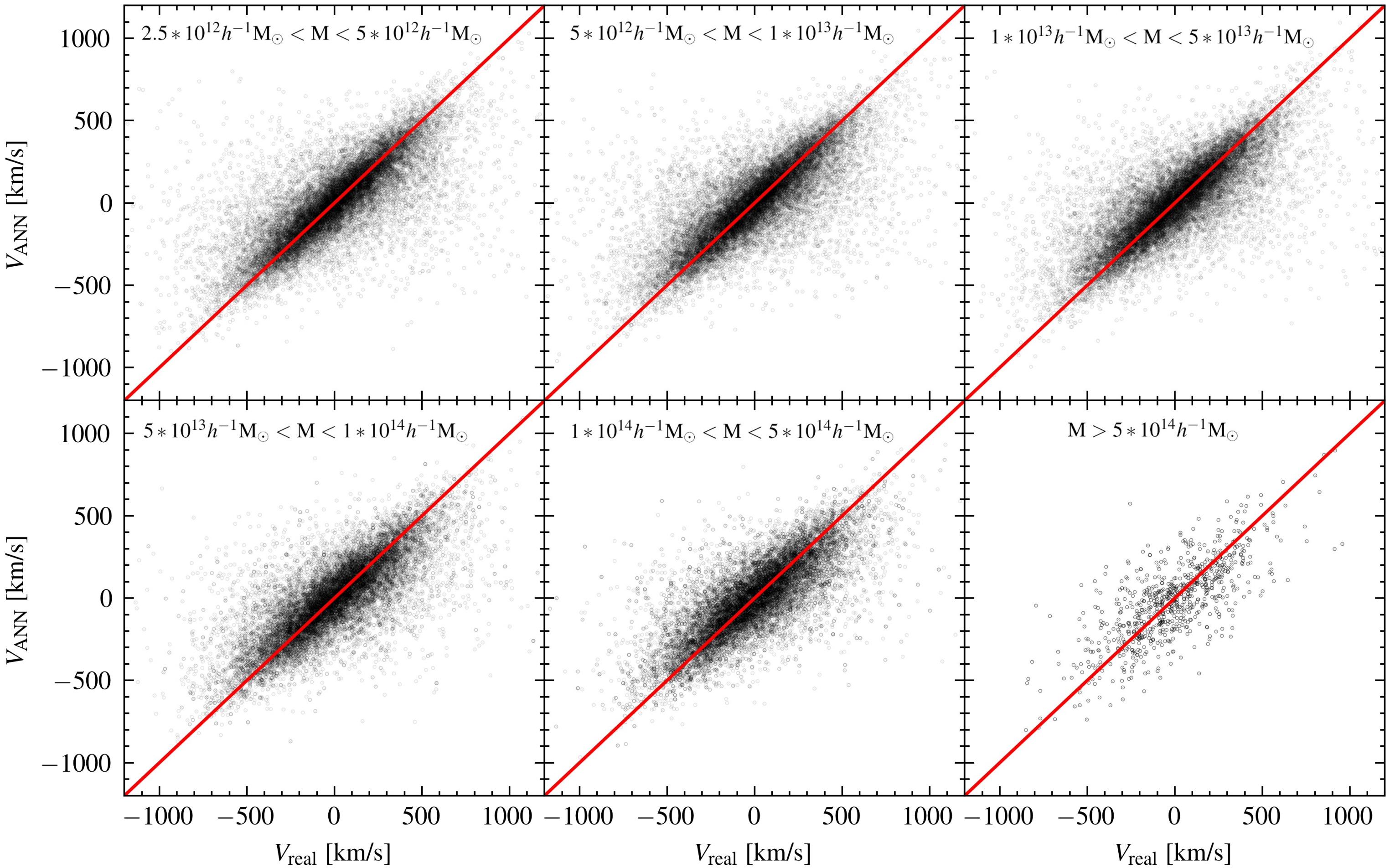
ANN

simple 5 layers fully connected network
Loss function: MAE

Training set: 3 simulation boxes
Validation set: 1 box
Test set : 8 boxes

Results

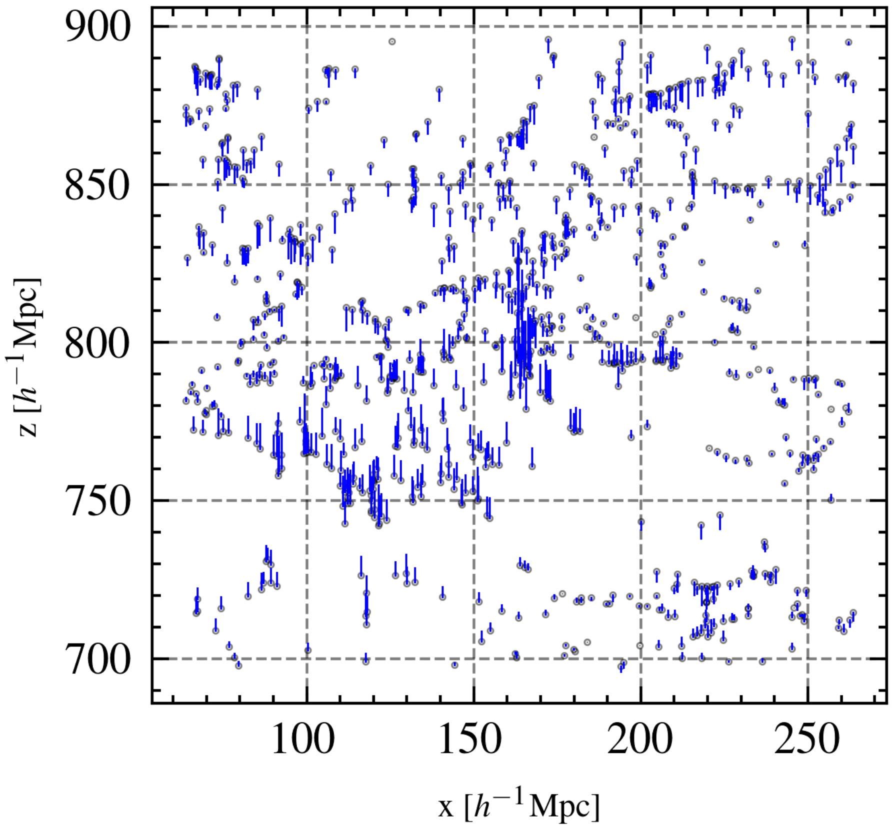
Line-of-sight velocity of individual galaxy



Unbiased LoS velocity prediction over all mass ranges

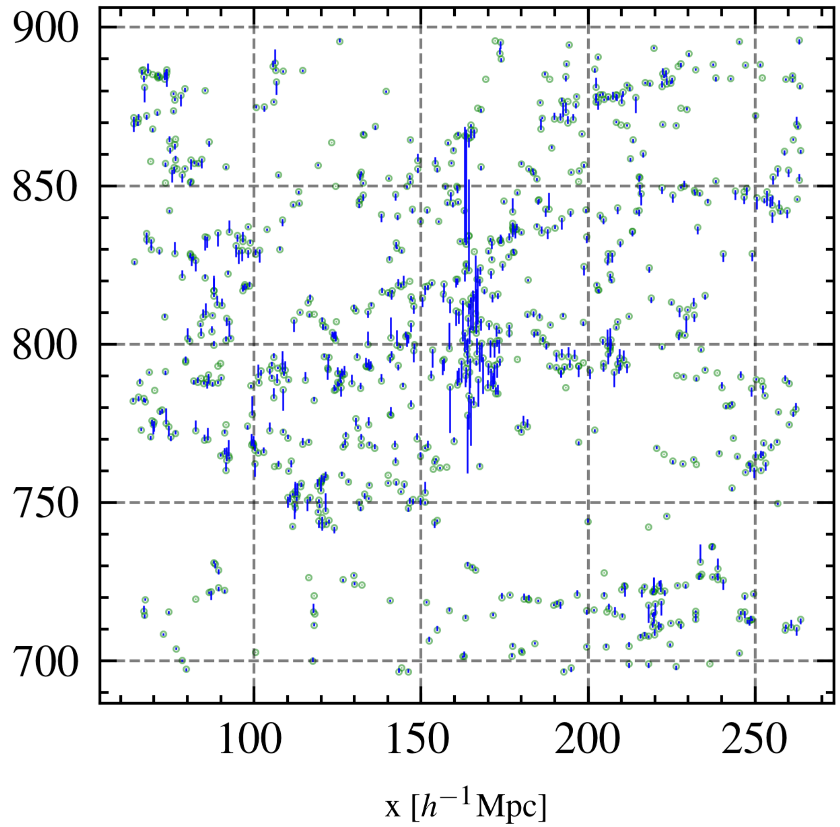
Results

Galaxy position and displacement



real space distribution

|: displacement between redshift and real space



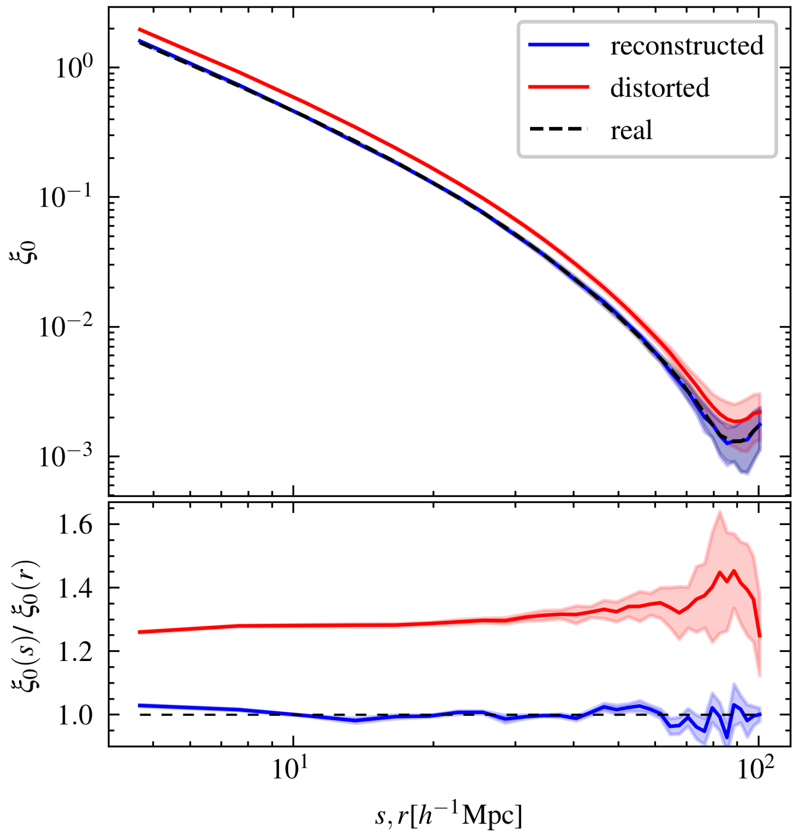
reconstructed space distribution

|: displacement between reconstructed and real space

Reconstructed means galaxy distribution after eliminating RSD effect

Results

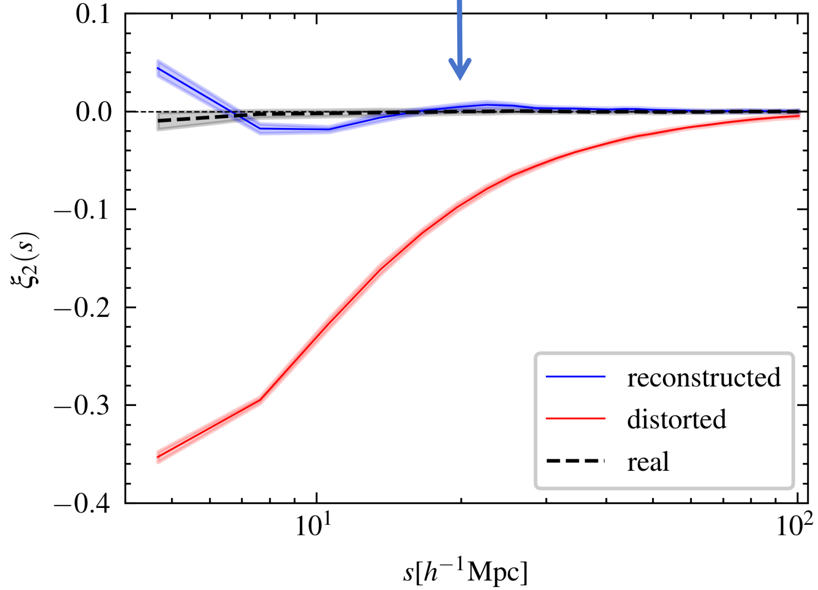
Two-point correlation function



monopoles

The reconstructed distribution result agrees with the real distribution very well over all scales. Error is less than 1%.

The anisotropy from RSD is eliminated.

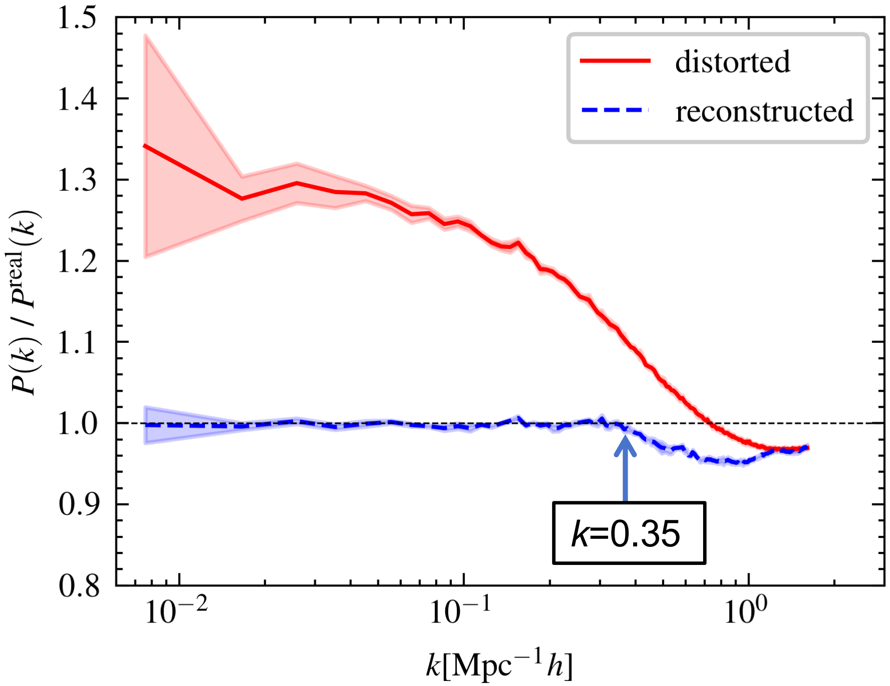


quadrupoles

Results

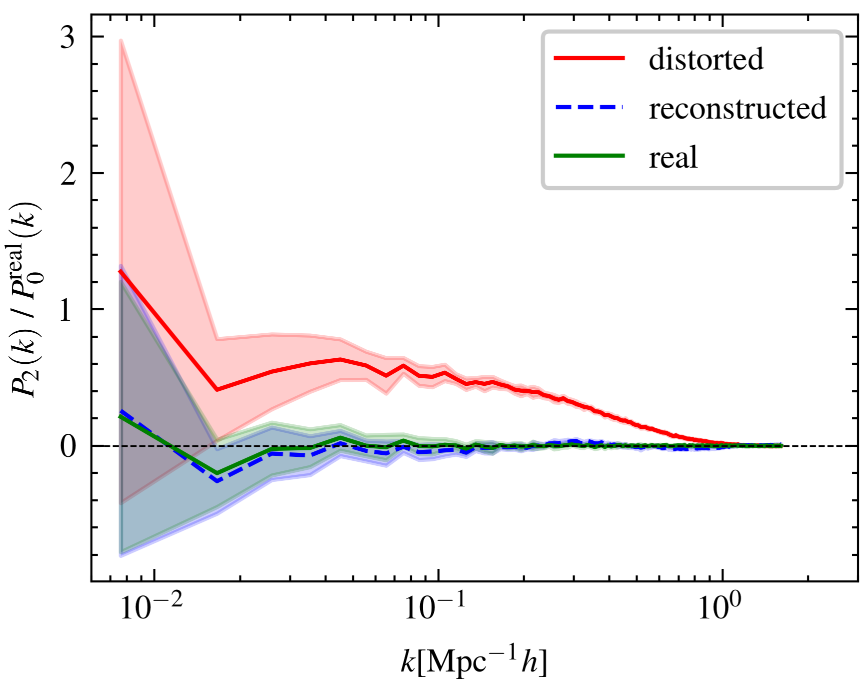
Power spectrum

Deviation less than 1% at k<0.35
Deviation less than 5% over all scales



monopoles

The anisotropy from RSD is eliminated.

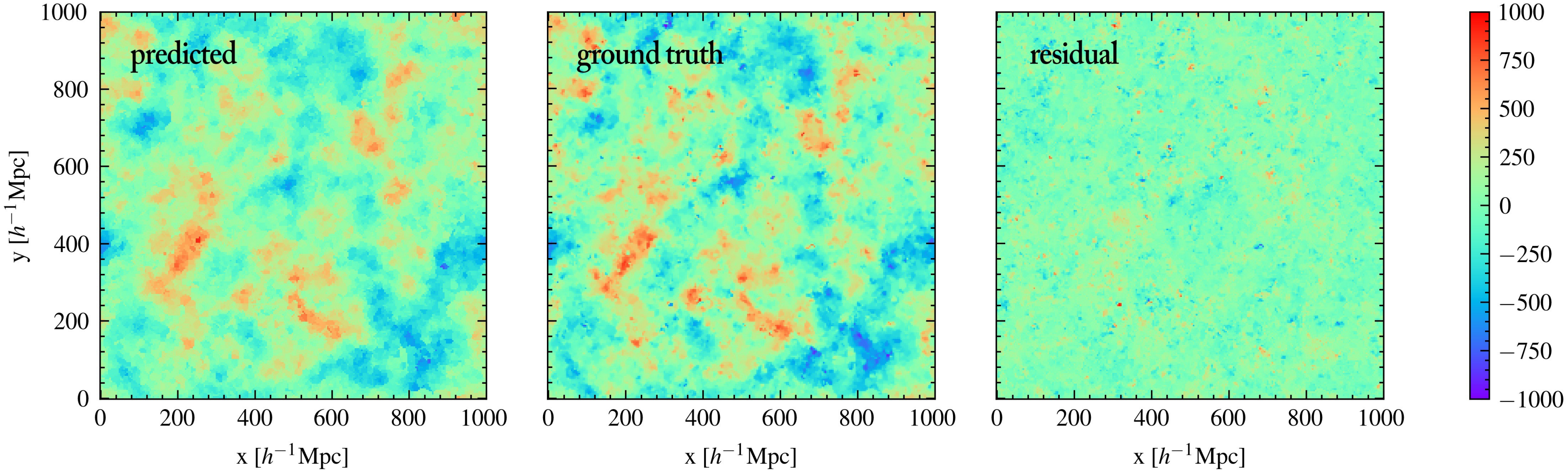


quadrupoles

Applications

Cosmic velocity field

The predicted map converges with the ground truth very well.

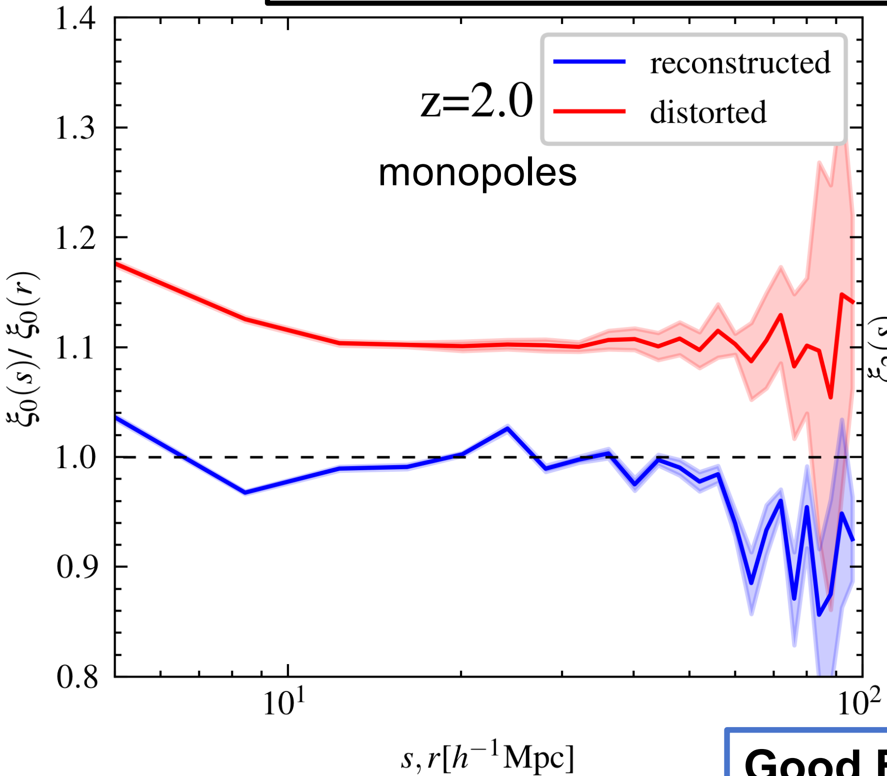


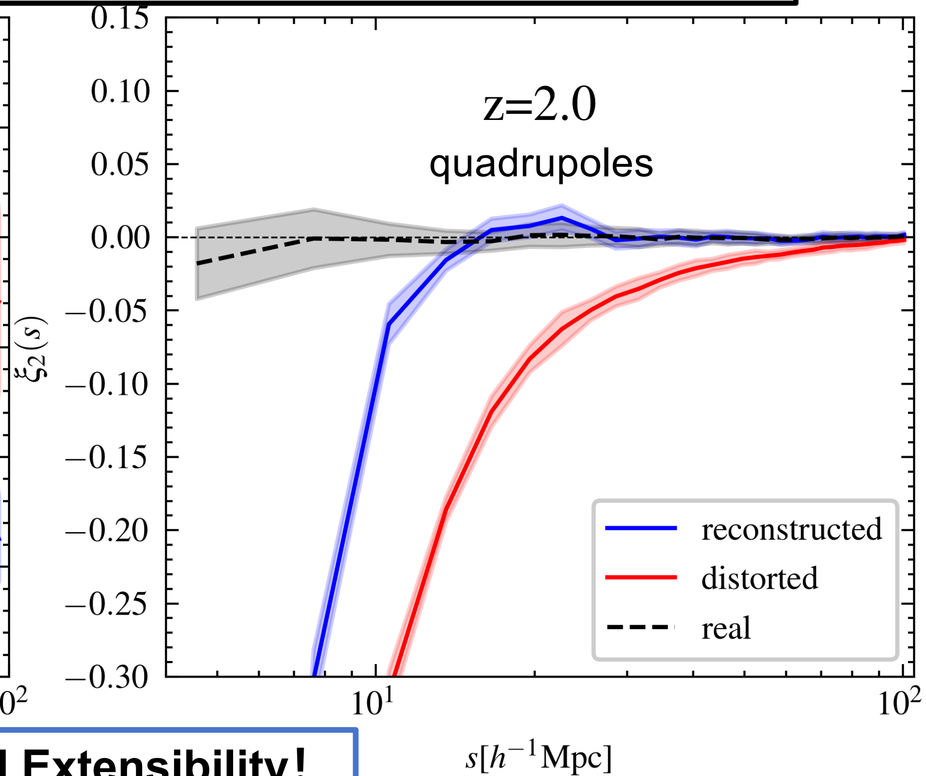
Interpolate the velocity of the nearest target galaxy to the grid.

Applications

Network performance at high redshift

The networks perform well even at high redshift where the redshift space distortion is already different from that in the training data at z=0.





Good Extensibility!

The networks are trained at z=0, but tested at z=2.0.

Conclusion

A new scheme to directly estimate the line-of-sight velocities of individual galaxies from the redshift space galaxy distribution, using artificial neural networks (ANN).

Eliminate the RSD effect:

- Two-point correlation function of our result can be recovered within 1% deviation at s > 8 Mpc/h compared to the real space.
- Power spectrum of our result achieve less than 3% deviation on the scale of k< 0.5 h/Mpc, and less than 5% at all scales compared to real space power spectrum.

Application:

- The predicted cosmic velocity field converges with the ground truth very well.
- The networks are trained at z=0, but perform well with the test sets at z=2.0， with good **extensibility**.