CosmicFlows-3 analysis

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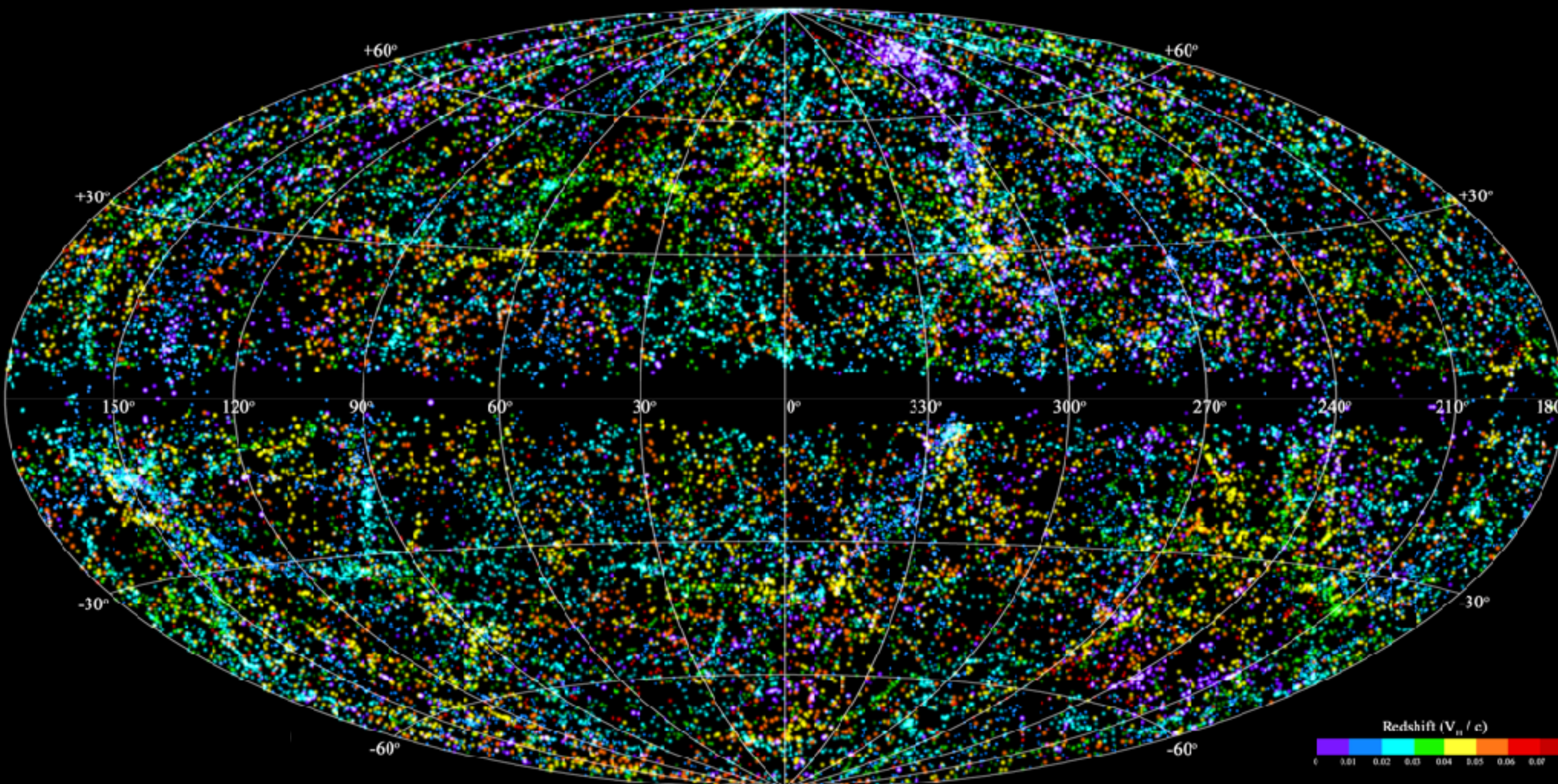
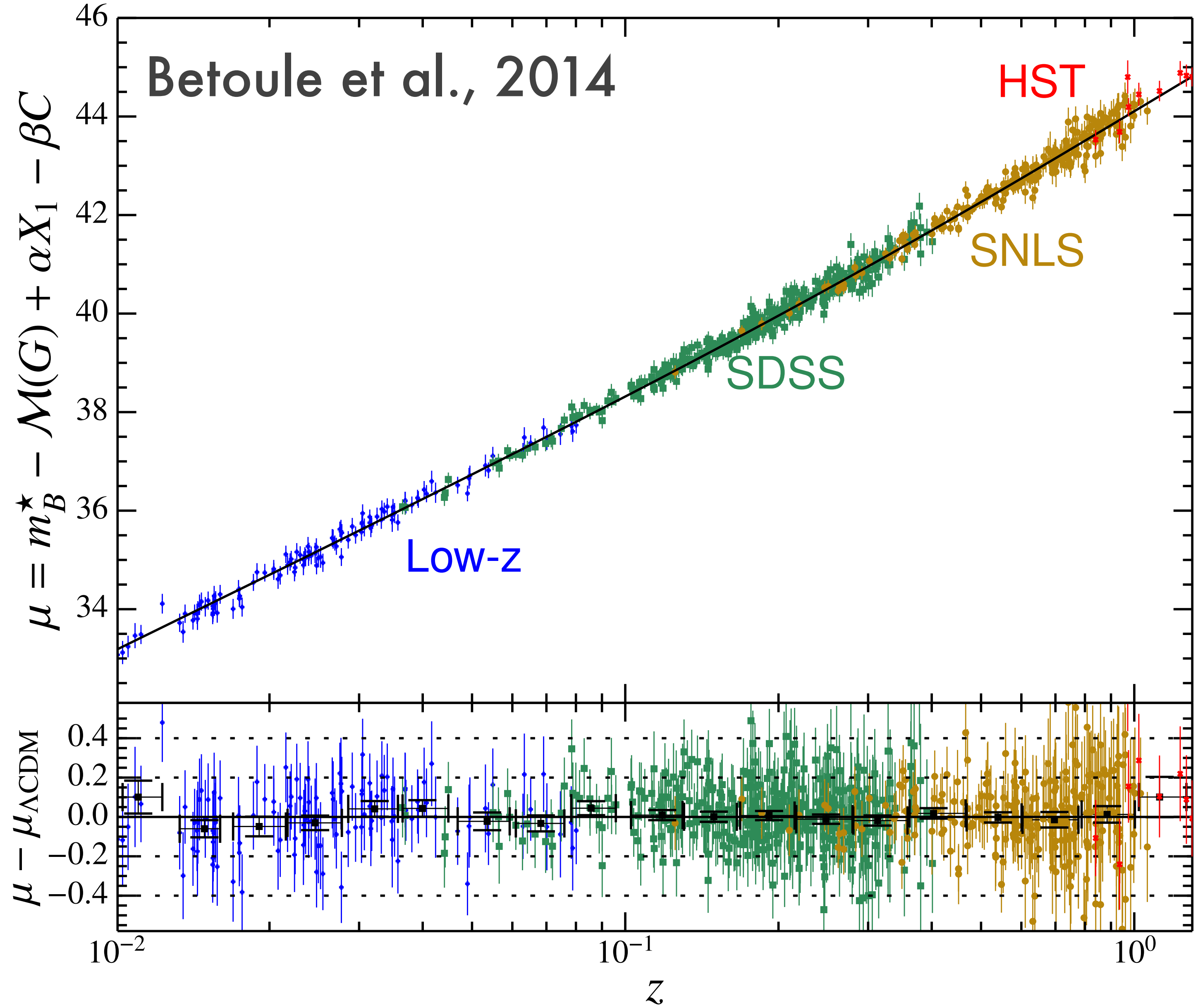
Collaborations :
CLUES & CosmicFlows

Why CosmicFlows ?



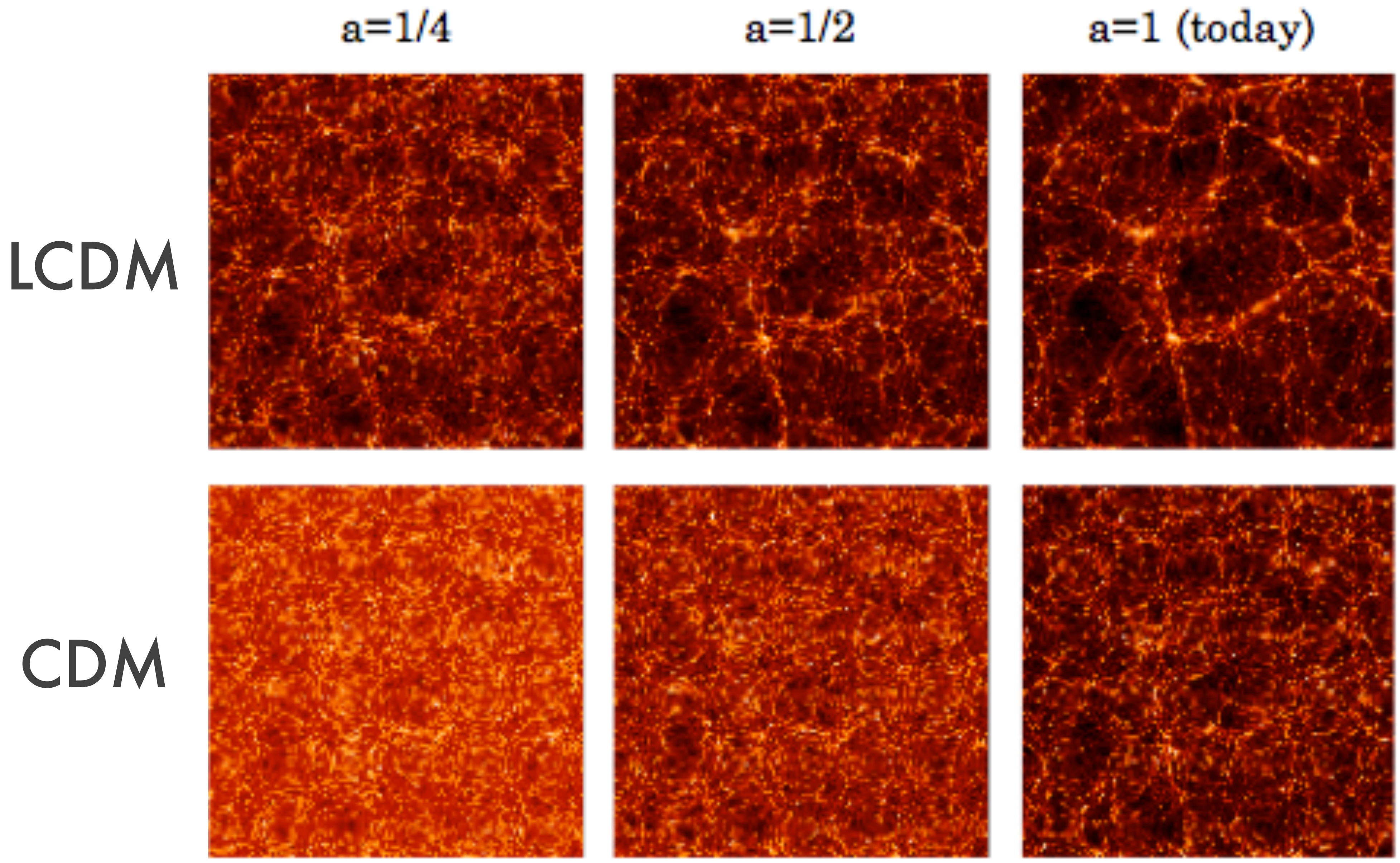
2MRS collaboration

The Hubble law



$$d = \frac{c(1+\bar{z})}{H_0} \int_0^{\bar{z}} \frac{\mathrm{d}x}{\sqrt{\Omega_m (1+x)^3 + \Omega_\Lambda}} \quad \sim \frac{c\bar{z}}{H_0}$$

Growth rate of structures



$$\sigma_8^2 = \langle \delta^2 \rangle_{8\ \mathrm{Mpc}/h}$$

Huterer et al., 2013

The observed redshift

$$(1+z) = \left(1 + \frac{v^r}{c}\right)(1 + \bar{z}(d))$$

The observed redshift

σ_8 $\qquad$ H_0

$$(1+z) = \left(1 + \frac{v^r}{c}\right)(1 + \bar{z}(d))$$

What is CosmicFlows-3 ?

The observed redshift

$$(1+z) = \left(1 + \frac{v^r}{c}\right)(1 + \bar{z}(d))$$

$$\longrightarrow \quad v^r = c\frac{z - \bar{z}}{1 + \bar{z}}$$

Distance indicators

$$\mu = 5\log_{10}\frac{d}{10\ \mathrm{pc}} = m - \boxed{M}$$

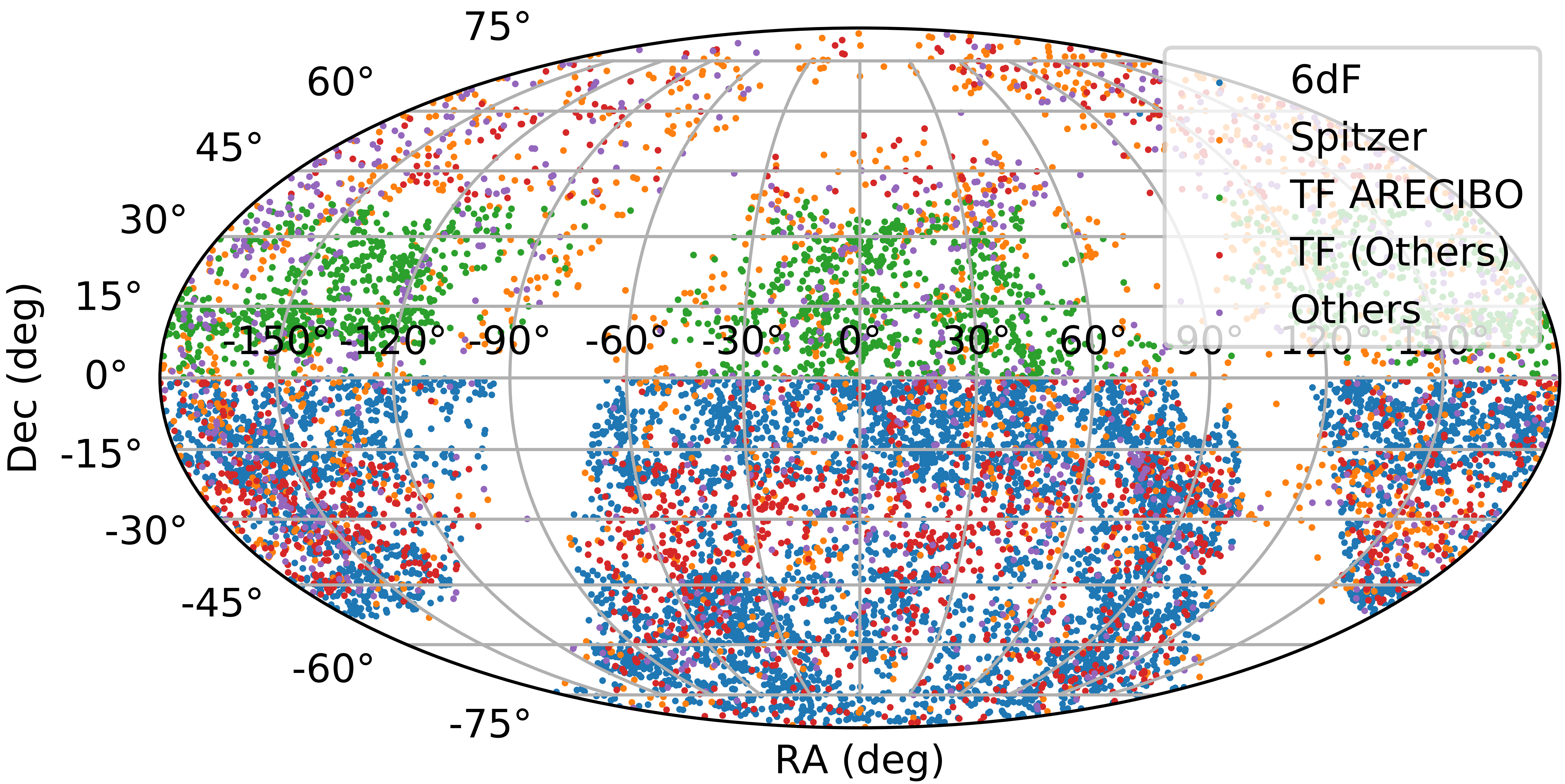
?

Distance indicators

$$\mu = m - M$$

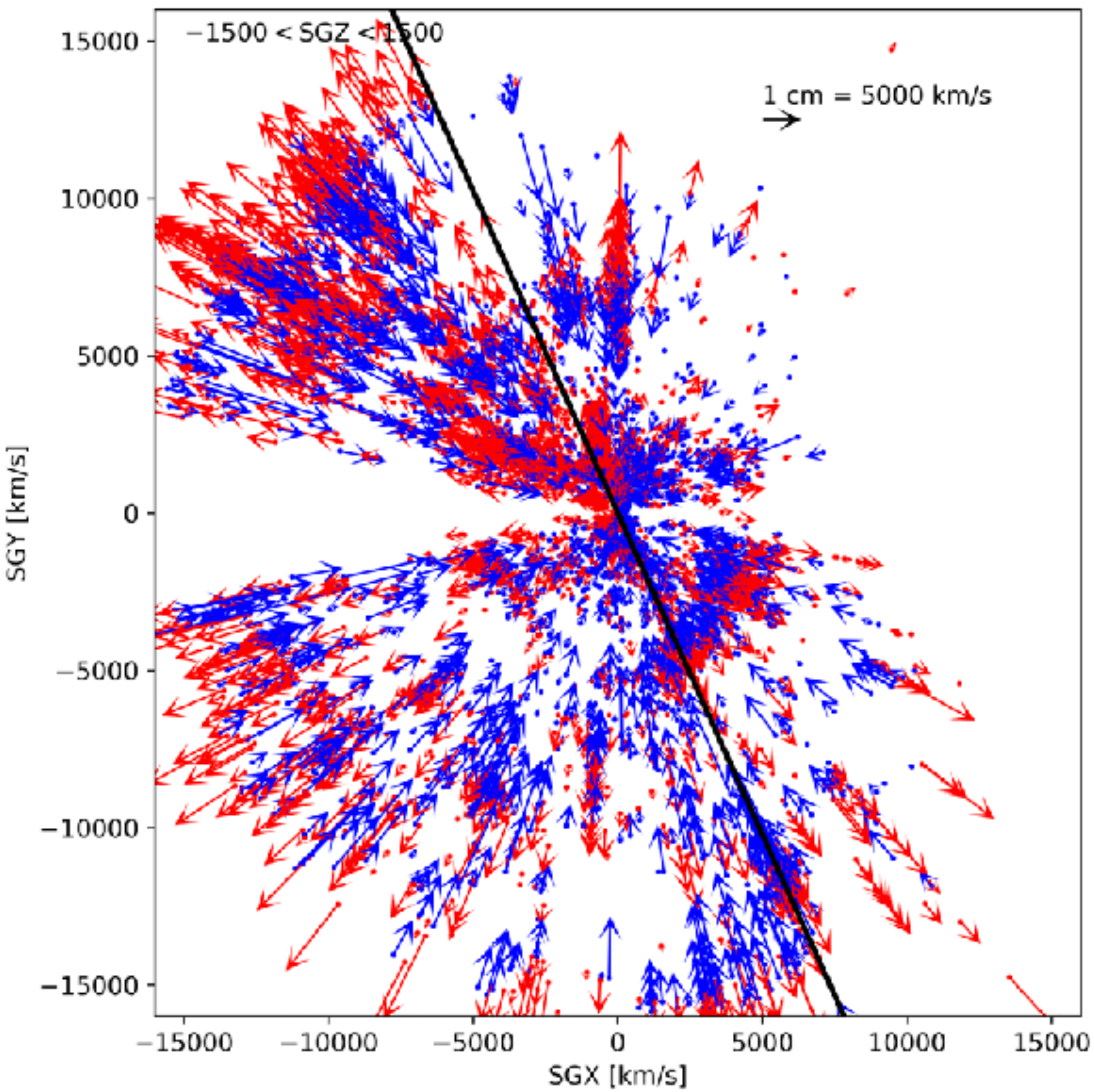
Cepheids	$L \sim T$	$\sigma_\mu \sim 0.1$	$z \sim 0.005$
Tully-Fisher Relation	$L \sim V^4$	$\sigma_\mu \sim 0.4$	$z \sim 0.1$
Fundamental Plane	$L \sim R, \sigma$	$\sigma_\mu \sim 0.5$	$z \sim 0.1$
SNeIa	$L \sim \text{constant}$	$\sigma_\mu \sim 0.14$	$z \sim 1$

CosmicFlows-3 on the sky

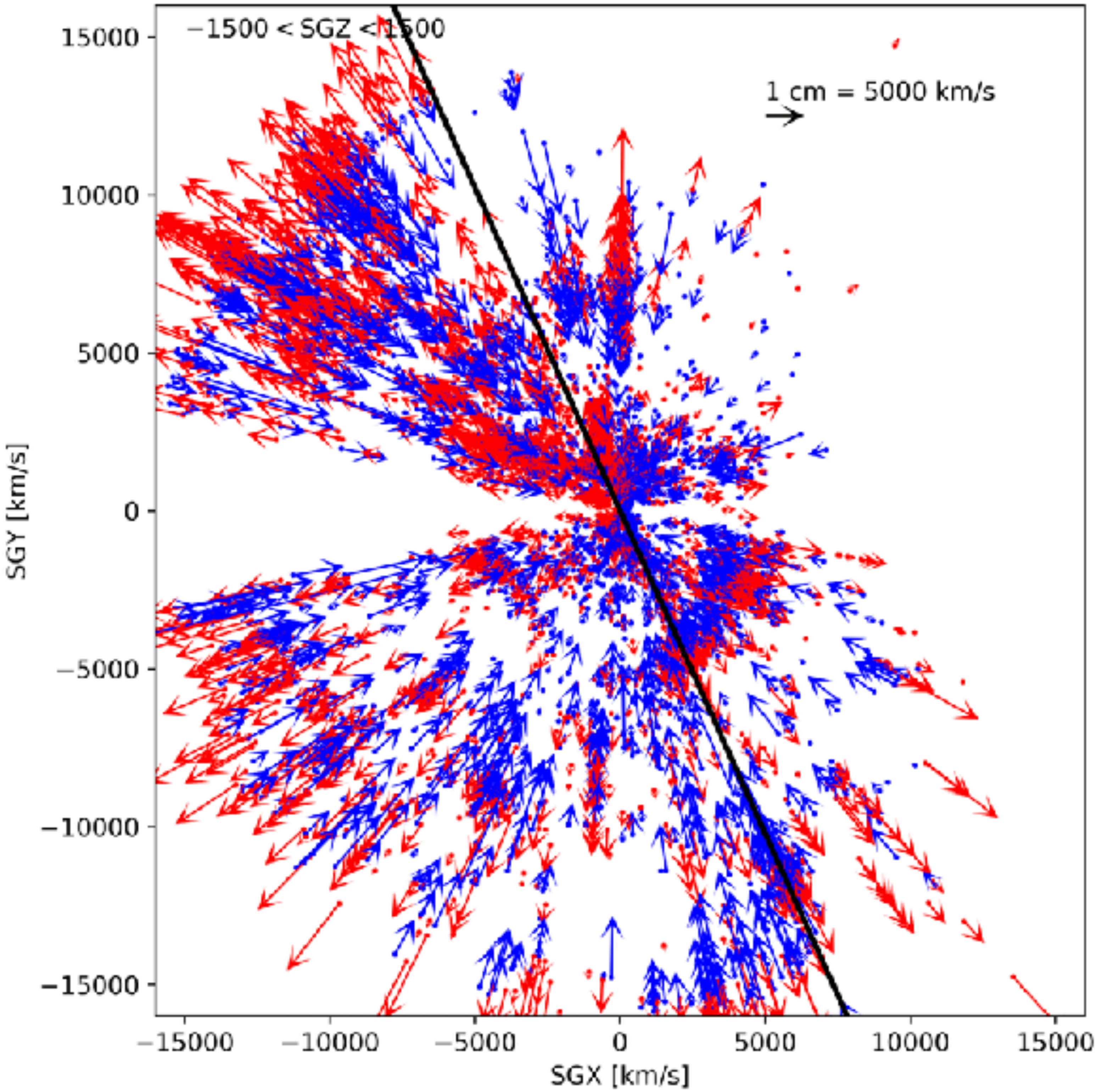


18 000 distances et redshifts

Radial peculiar velocity measurement : an exemple



Radial peculiar velocity measurement : an exemple

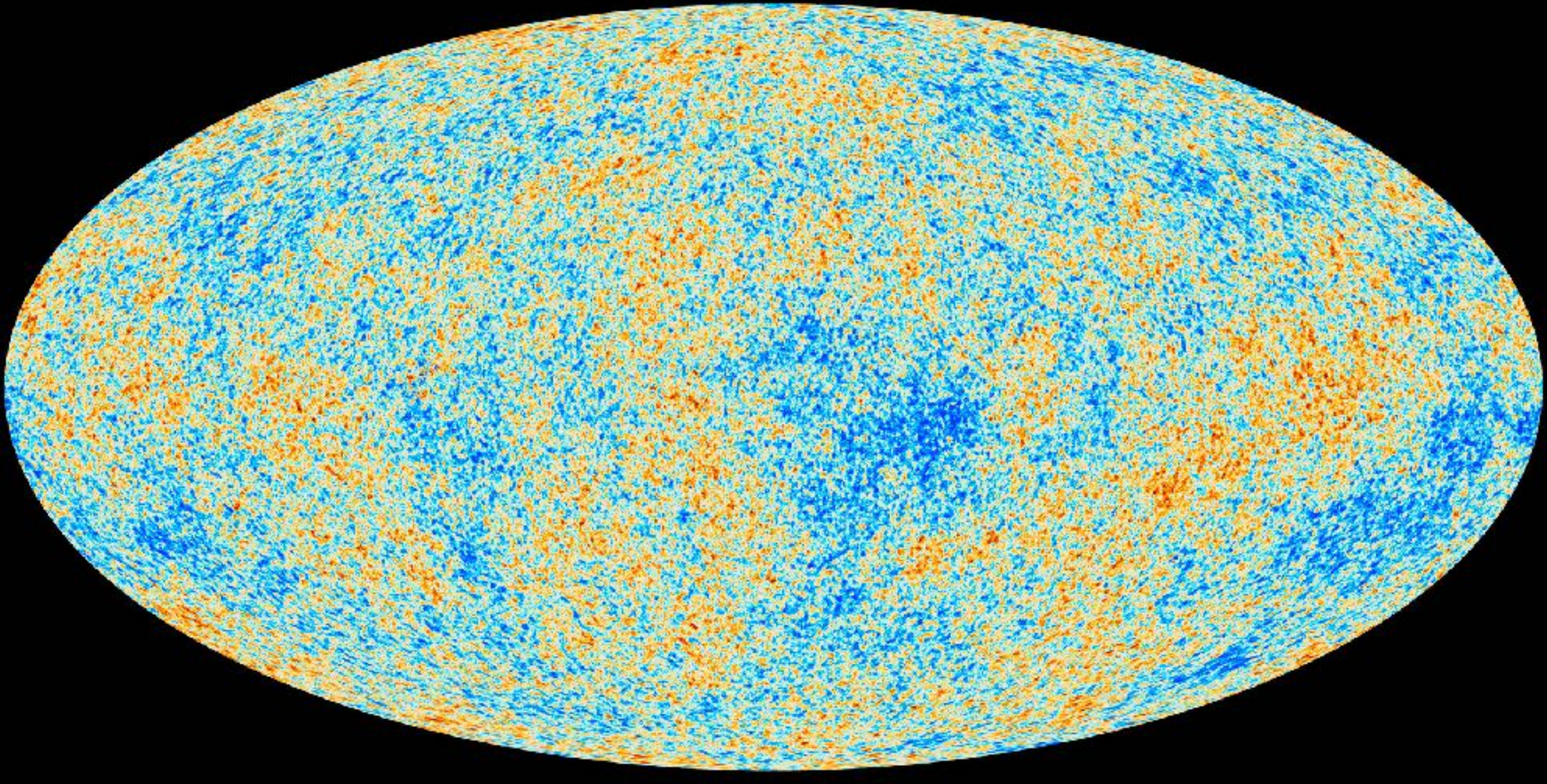


$$d = 100 \pm 20 \text{ Mpc}$$

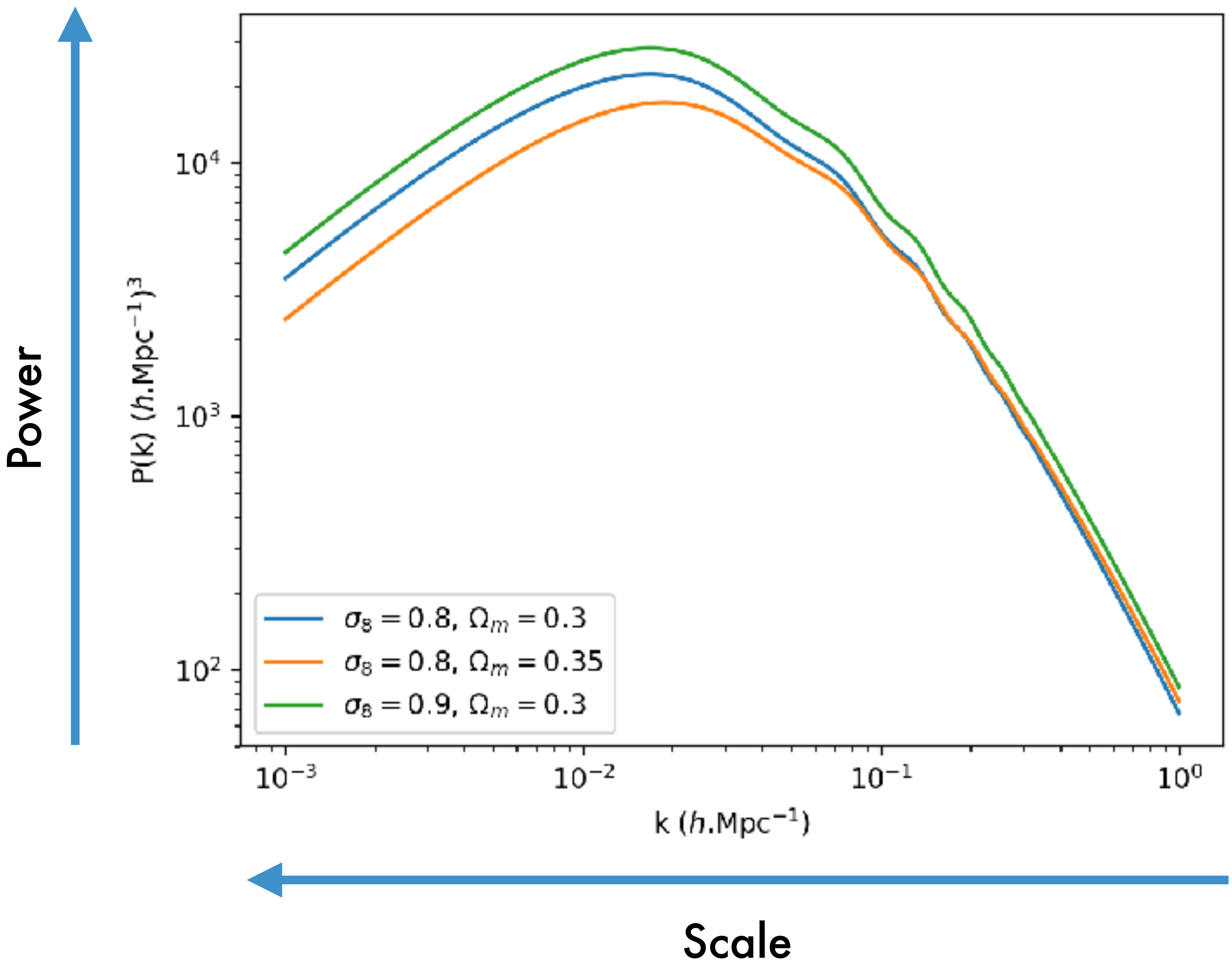
$$cz = 6500 \text{ km/s}$$

$$v^r = -500 \pm 1400 \text{ km/s}$$

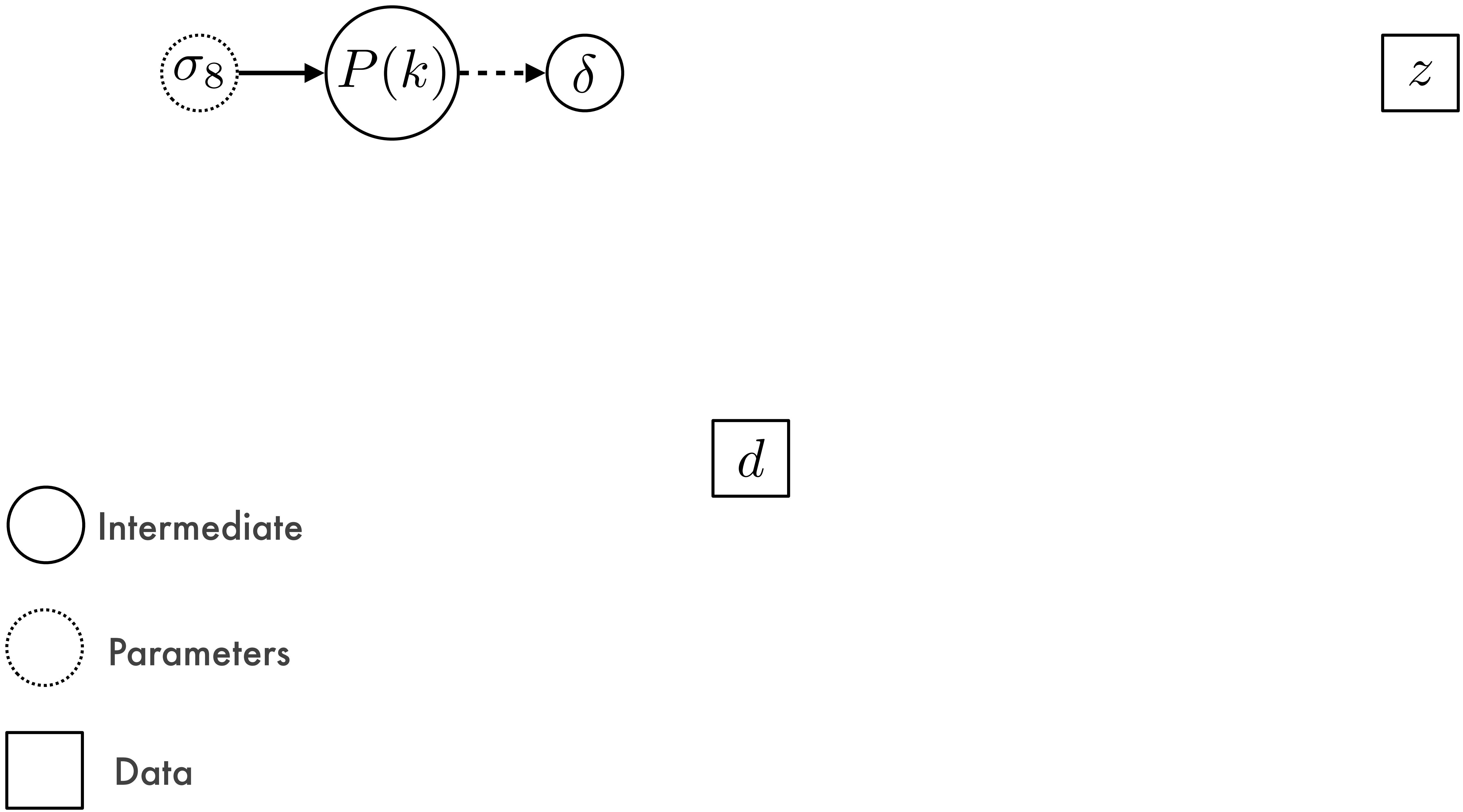
$$\sigma_{v^r} = \frac{\log 10}{5} H_0 \sigma_\mu d$$



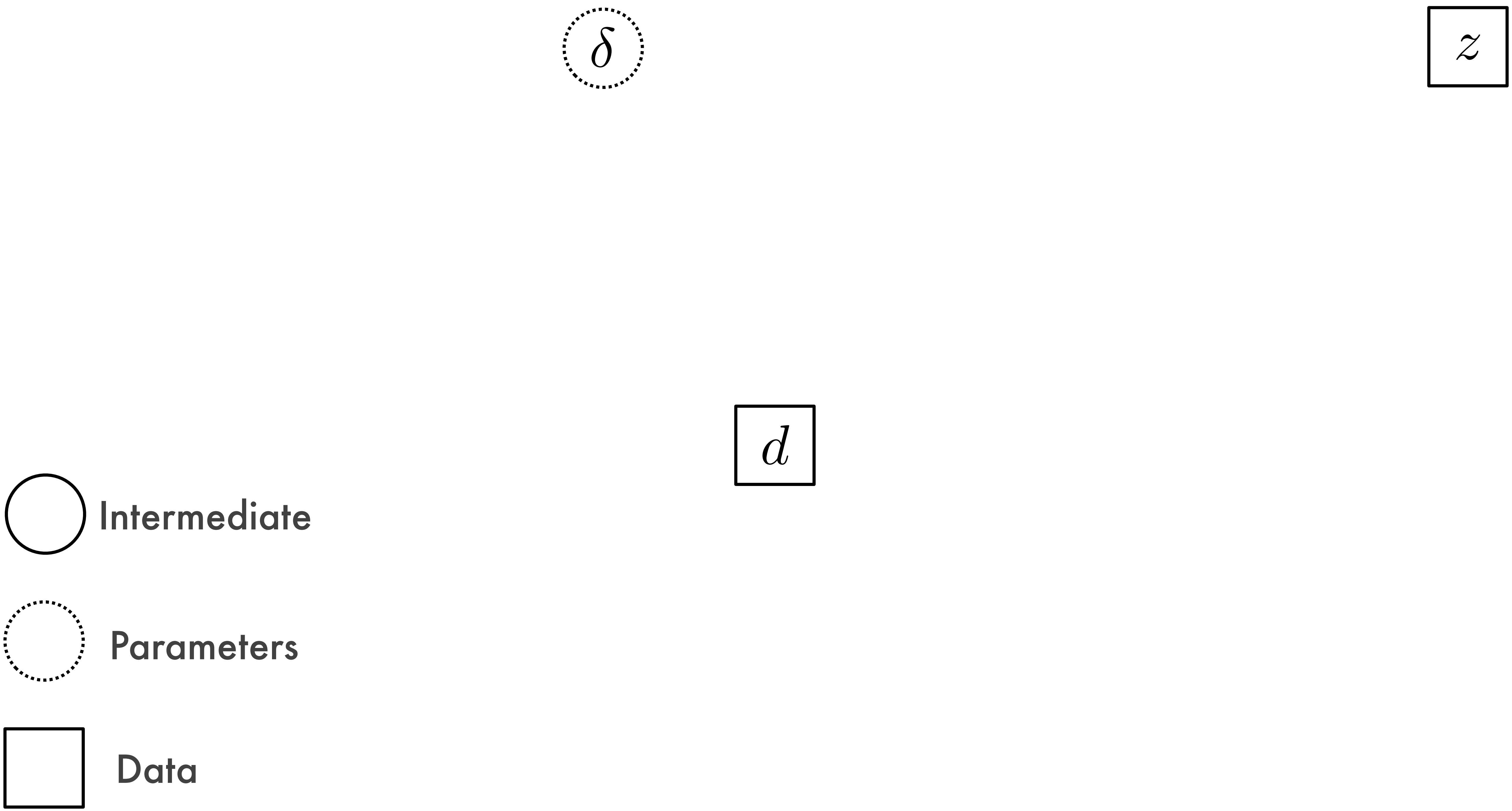
$$+\vec{\nabla}\cdot\vec{v} = -H_0 f \delta$$



Forward modeling



Forward modeling



Forward modeling

z

Bayes theorem

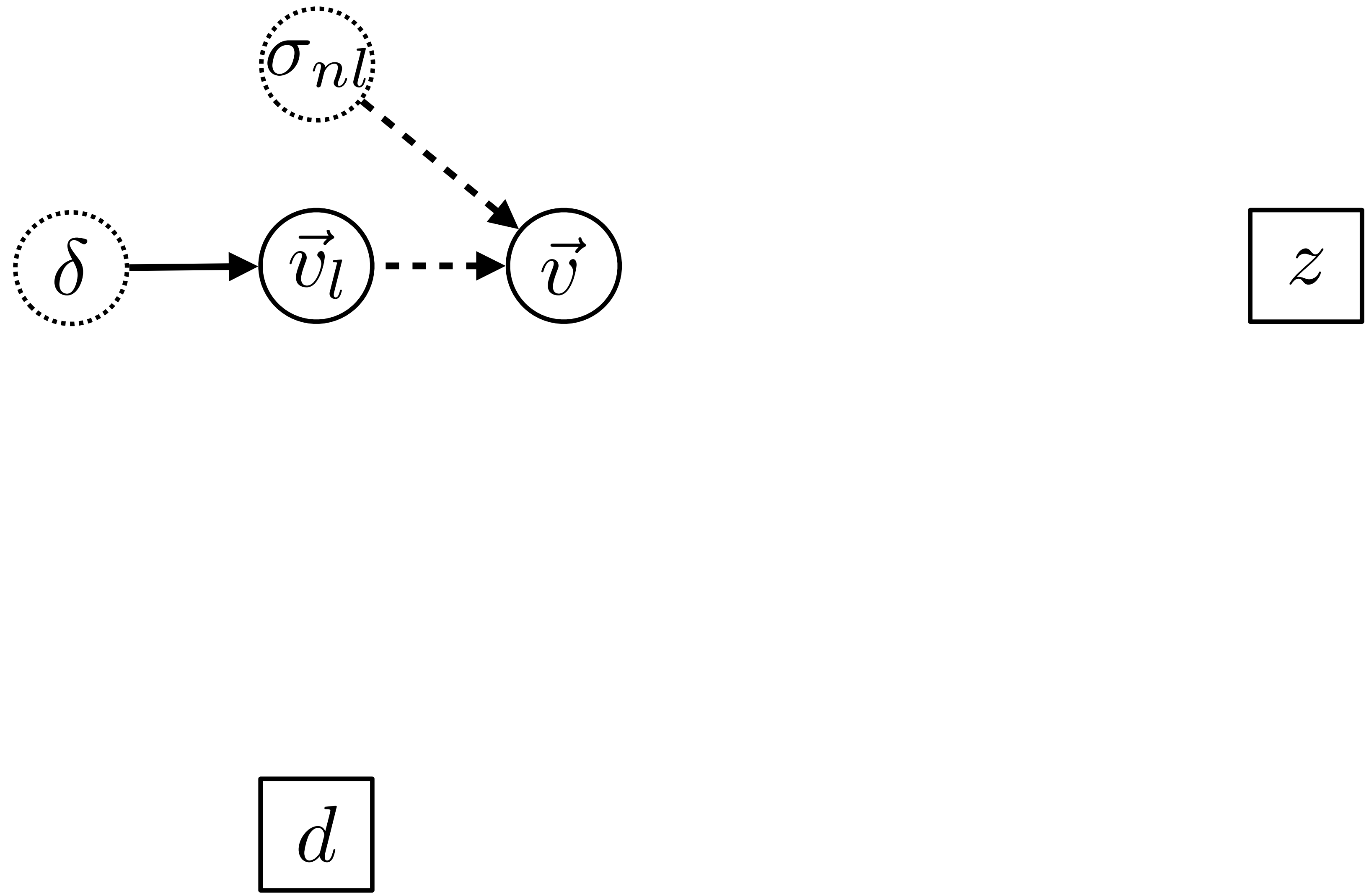
$$\mathcal{P}(\delta|d) = \frac{\mathcal{P}(d|\delta)\mathcal{P}(\delta)}{\mathcal{P}(d)}$$

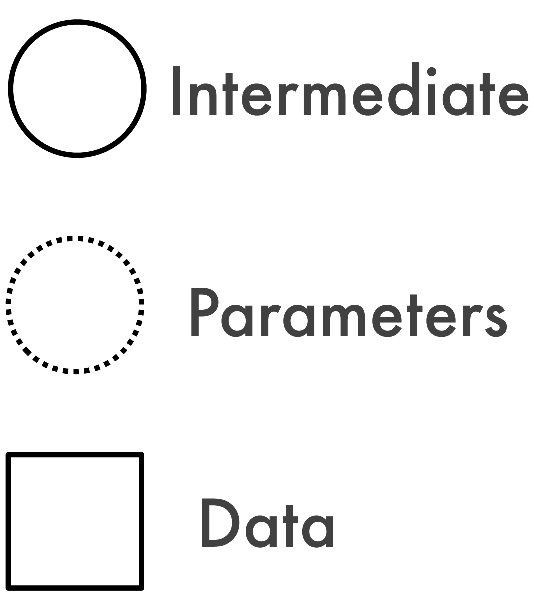
Intermediate

Parameters

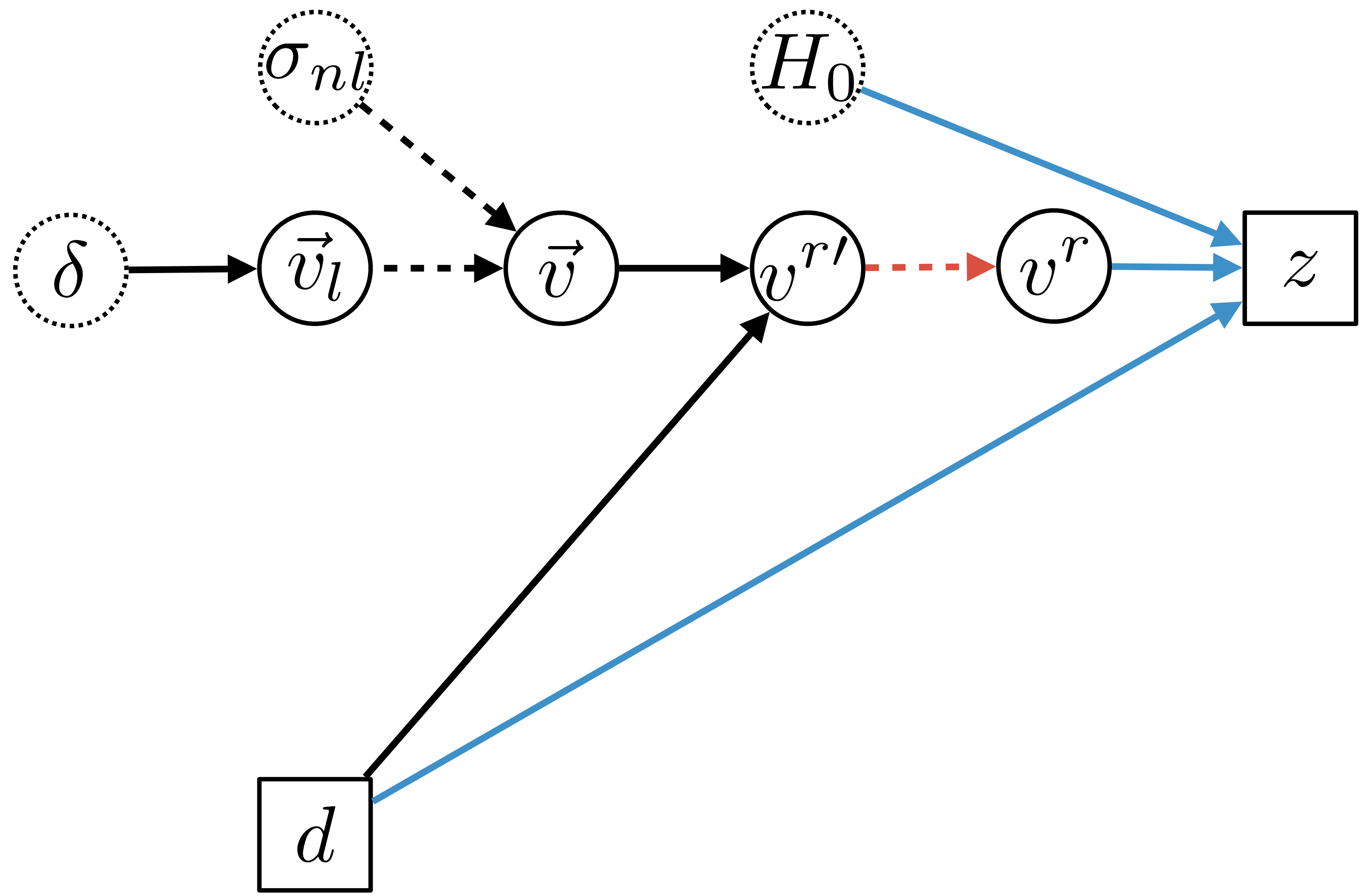
Data

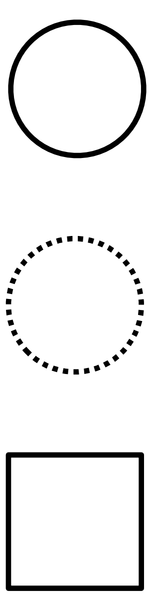
Non-linearities





Peculiar velocities from distances

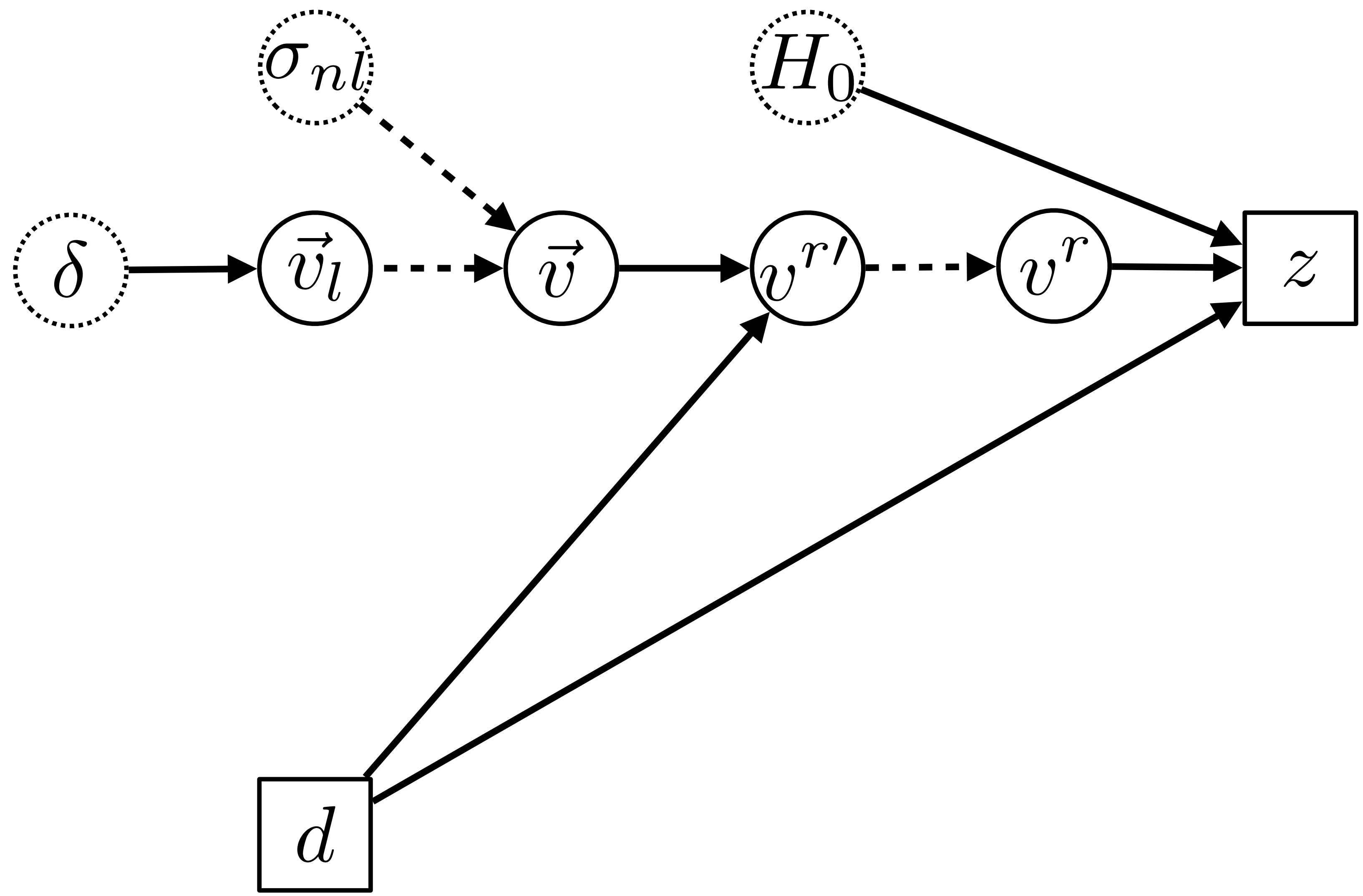


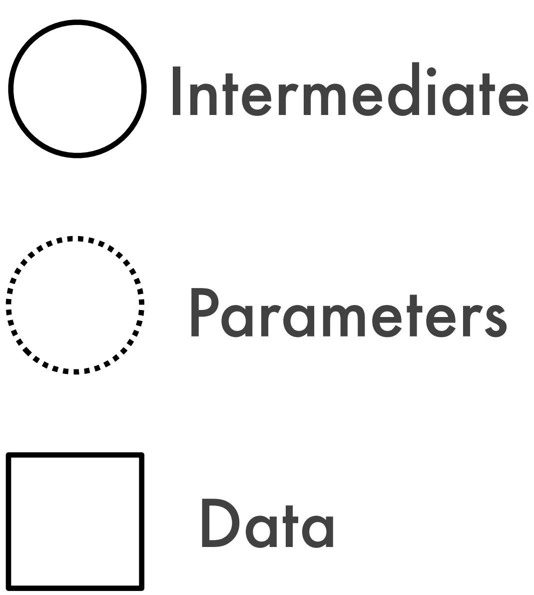


$$\sigma_{v^r} = \frac{\log 10}{5} H_0 \sigma_\mu d$$

$$cz \sim v^r + H_0 d$$

Peculiar velocities from distances

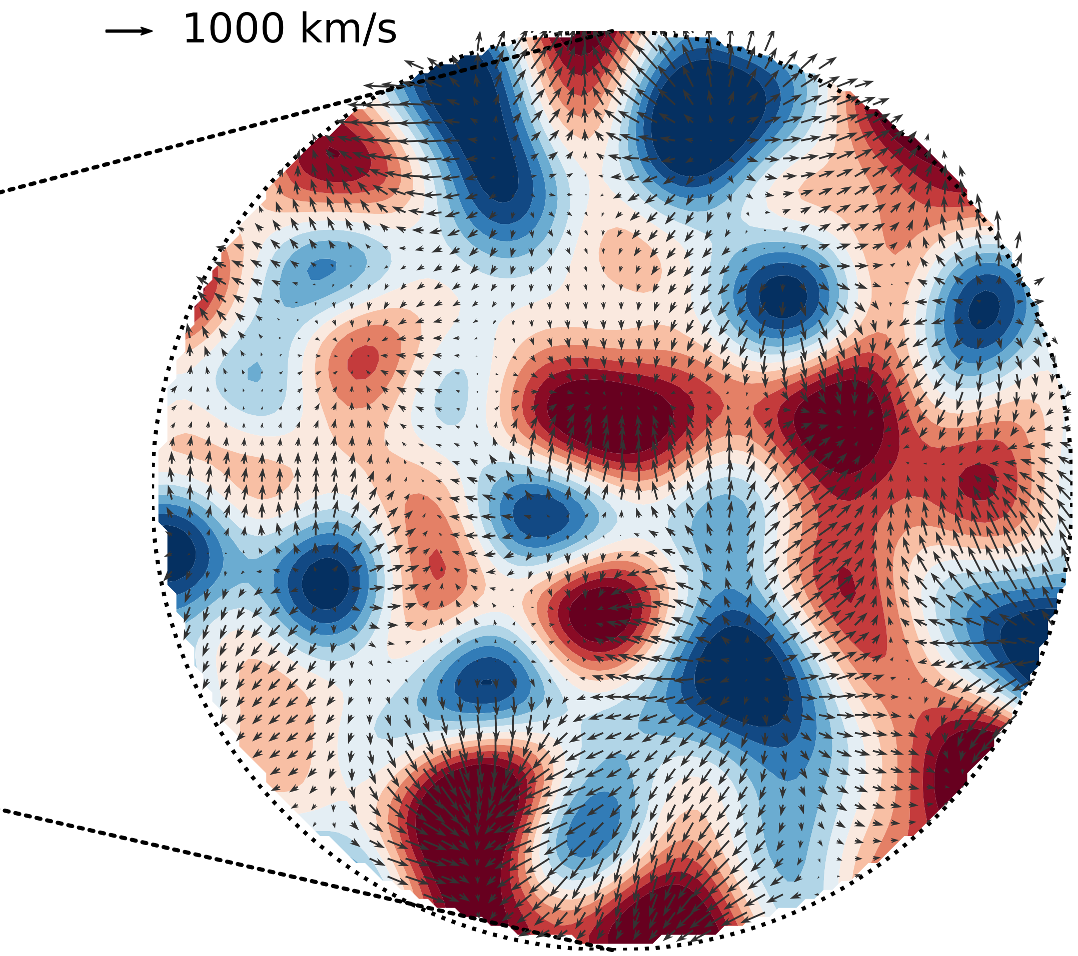


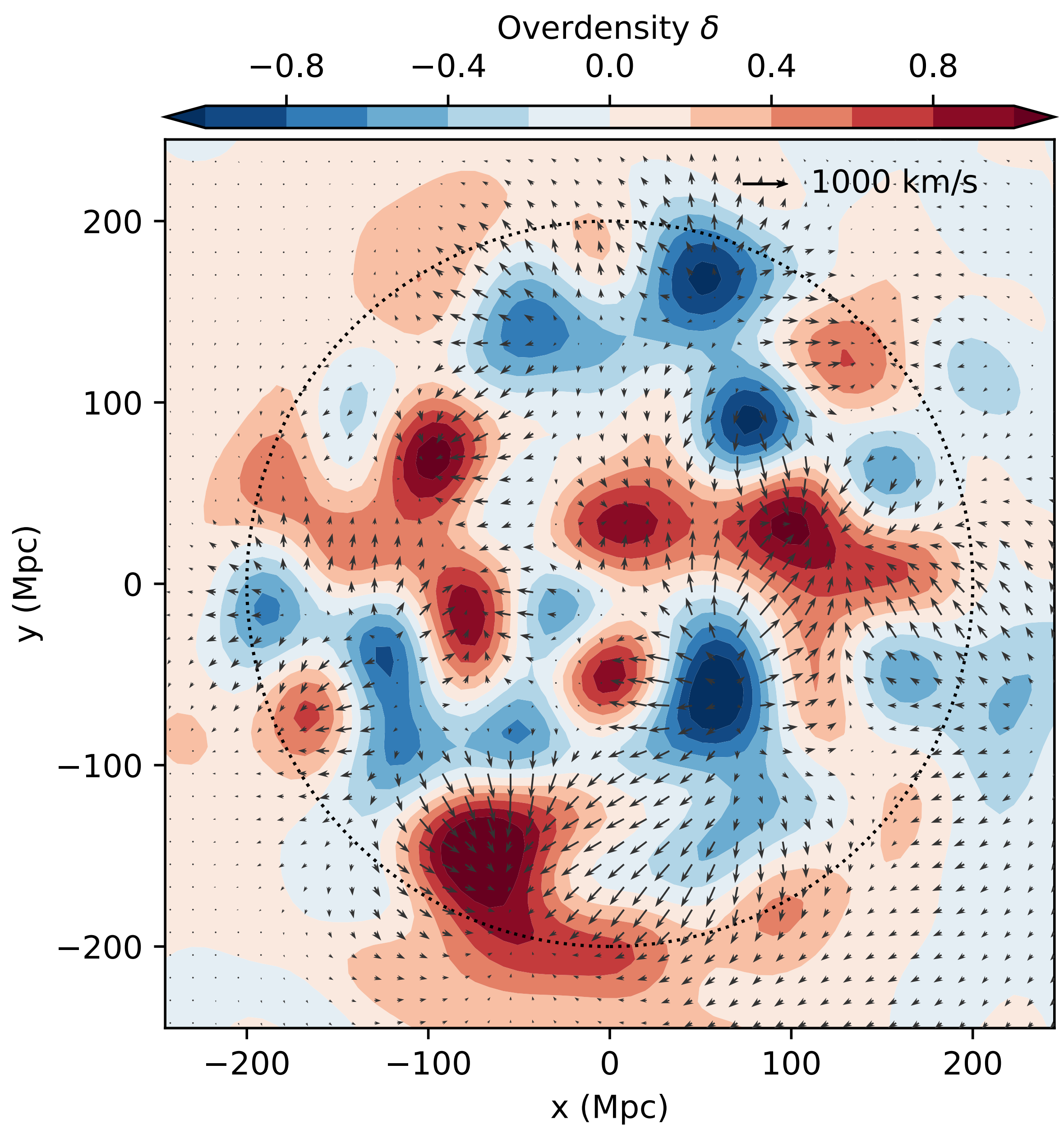


$$\mathcal{P}(\delta|d,z) \propto \exp\left(-\frac{(v^r - \vec{v}_\delta(\vec{r})\cdot\hat{r})^2}{2\sigma_{v^r}^2}\right)\exp\left(-\frac{|\delta(\vec{k})|^2}{2P(k)}\right)$$

Hoffman-Ribak algorithm : WF/CR

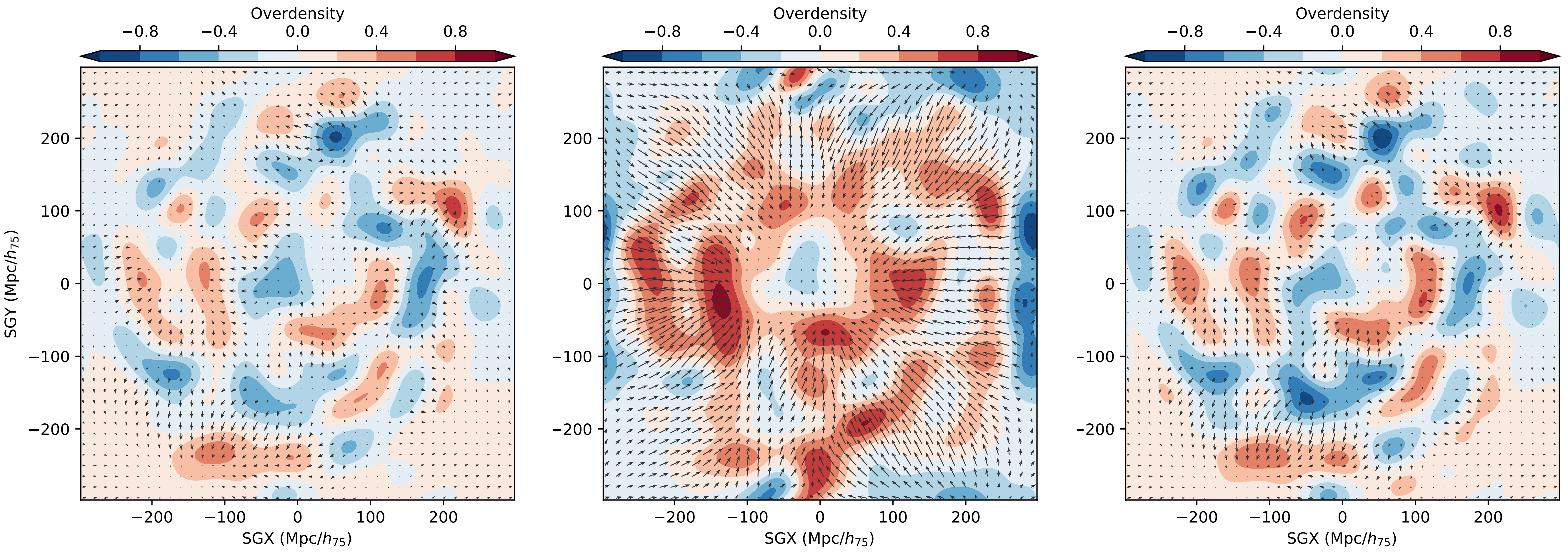
Power spectrum, Hubble constant and non-linearities are fixed
Galaxy distances are supposedly known





Hoffman, Ribak, 1991

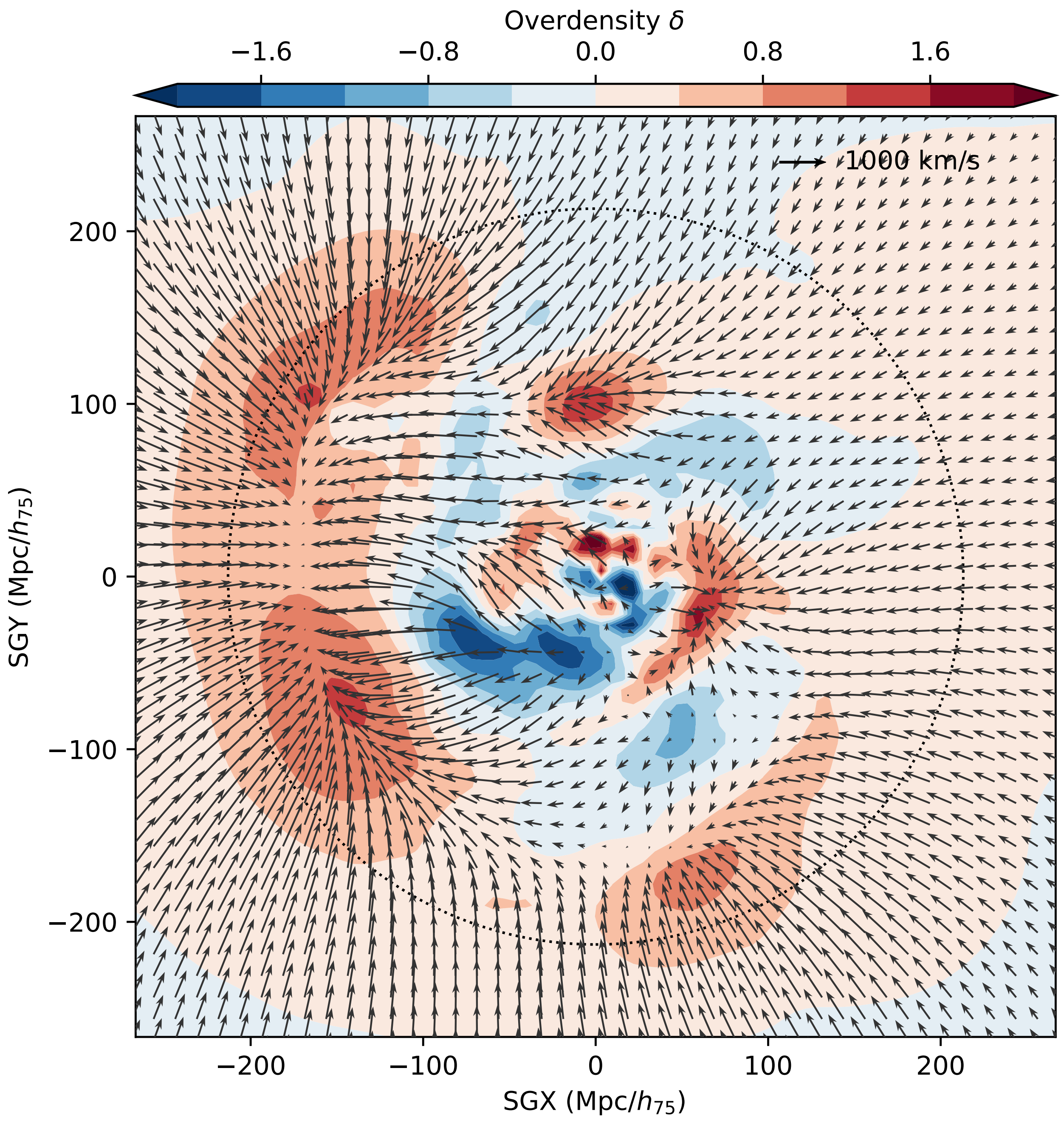
WF/CR : Influence of the cosmological parameters



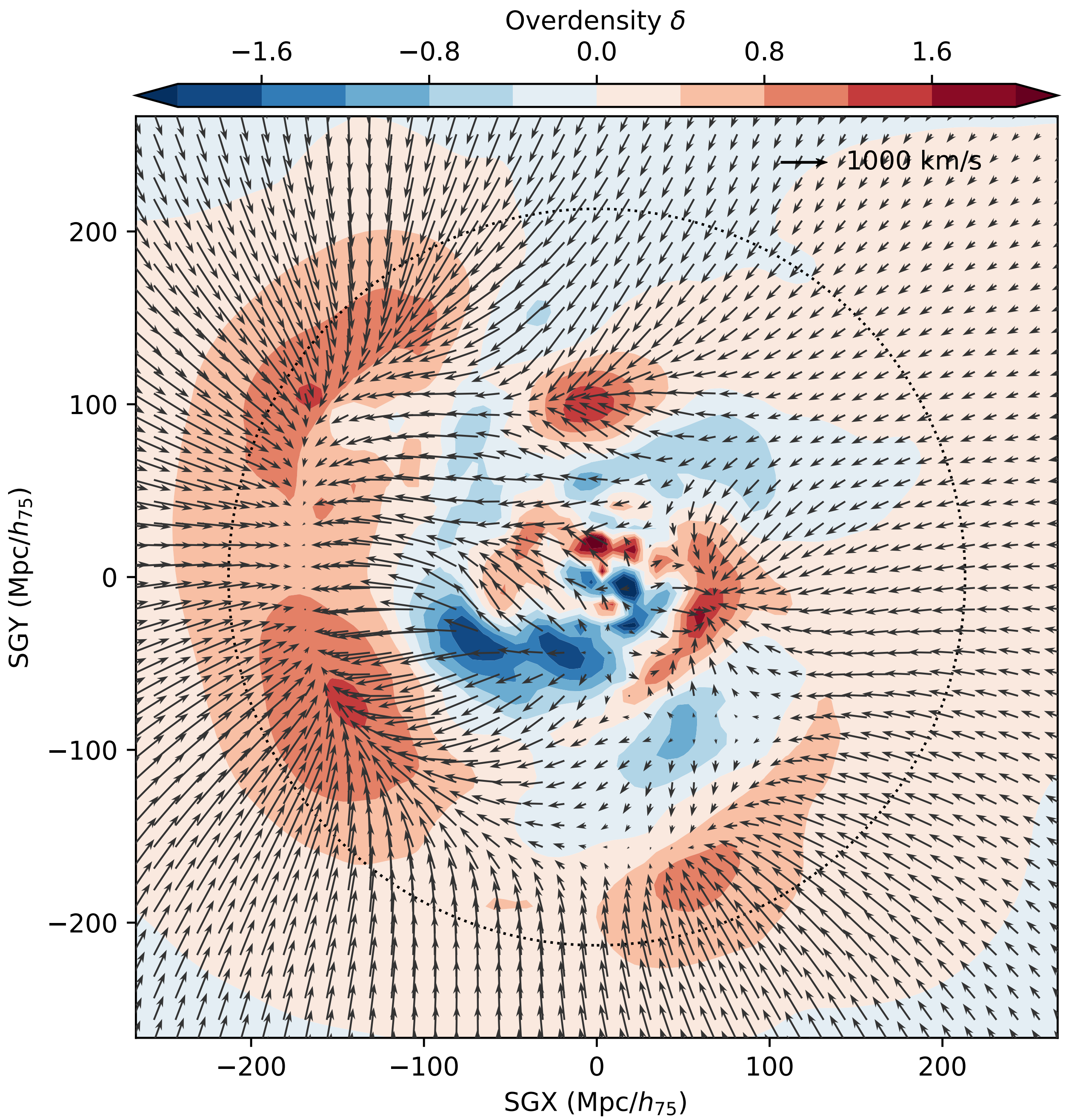
Fiducial $H_0 \mathrel{+}= 5\%$ $\sigma_8 \mathrel{+}= 50\%$

Bayesian analysis of CF3

WF/CR on CosmicFlows-3



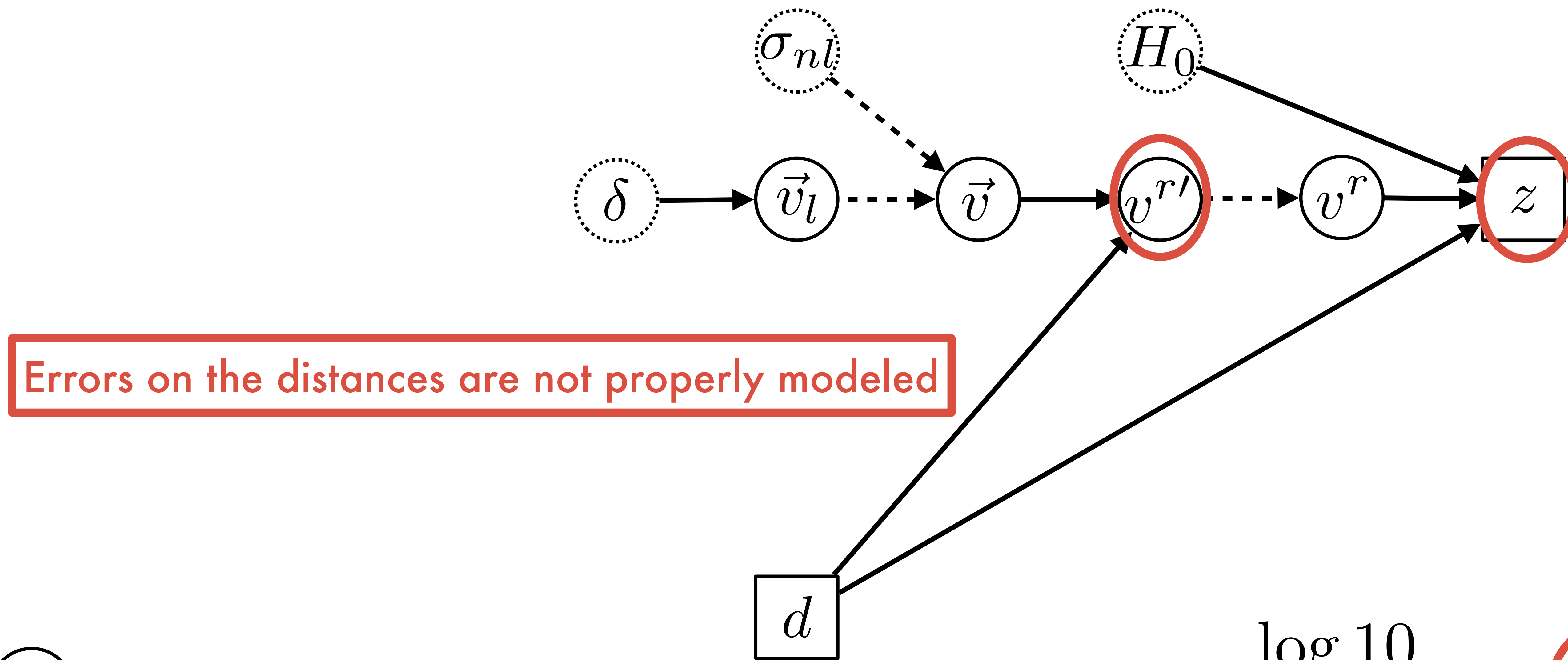
WF/CR on CosmicFlows-3



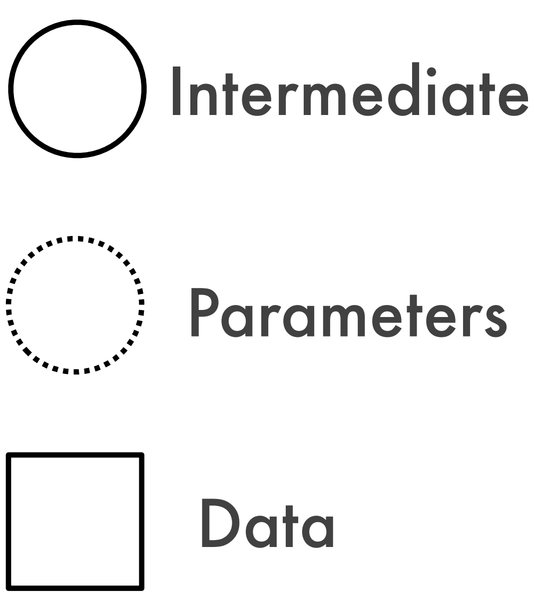
- Voids only in the center
- Distant structures larger
- Global inflow

Is this physical ?

WF/CR



$$\sigma_{v^r} = \frac{\log 10}{5} H_0 \sigma_\mu d$$

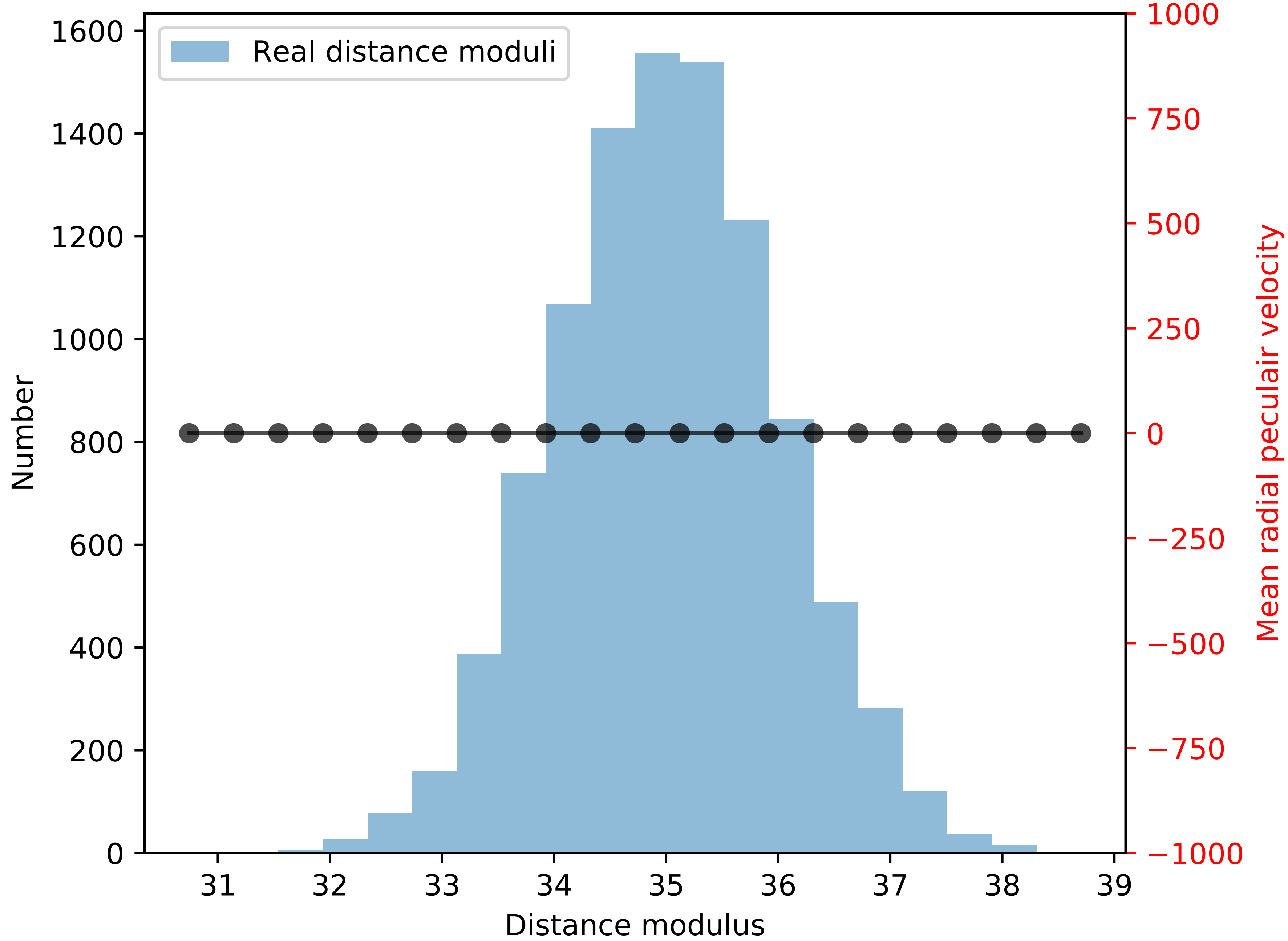


Peculiar velocities from distances

- Position bias
- Error bias
- Density bias

Position bias

- Position bias
- Error bias
- Density bias



Position bias

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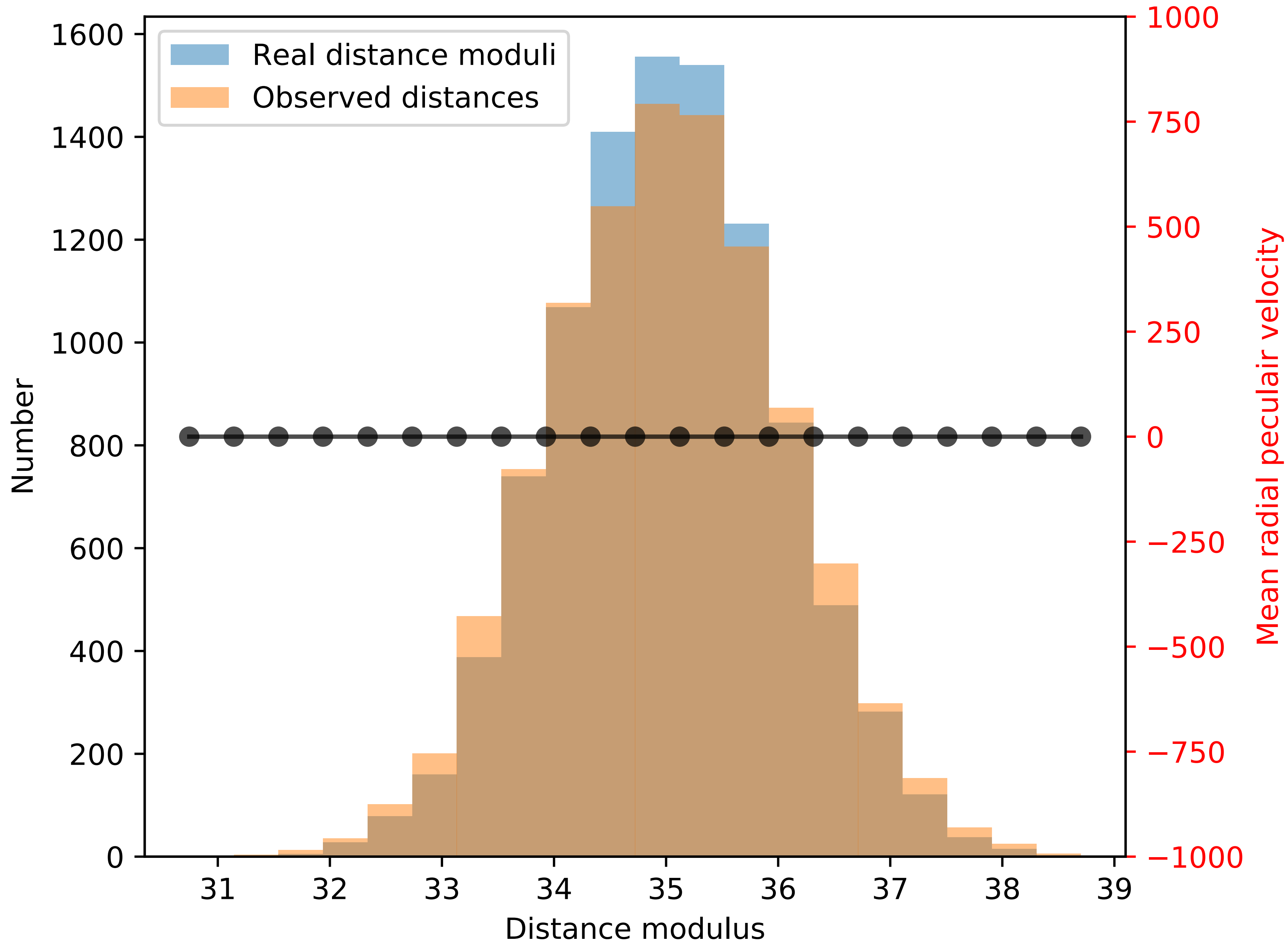

Position bias

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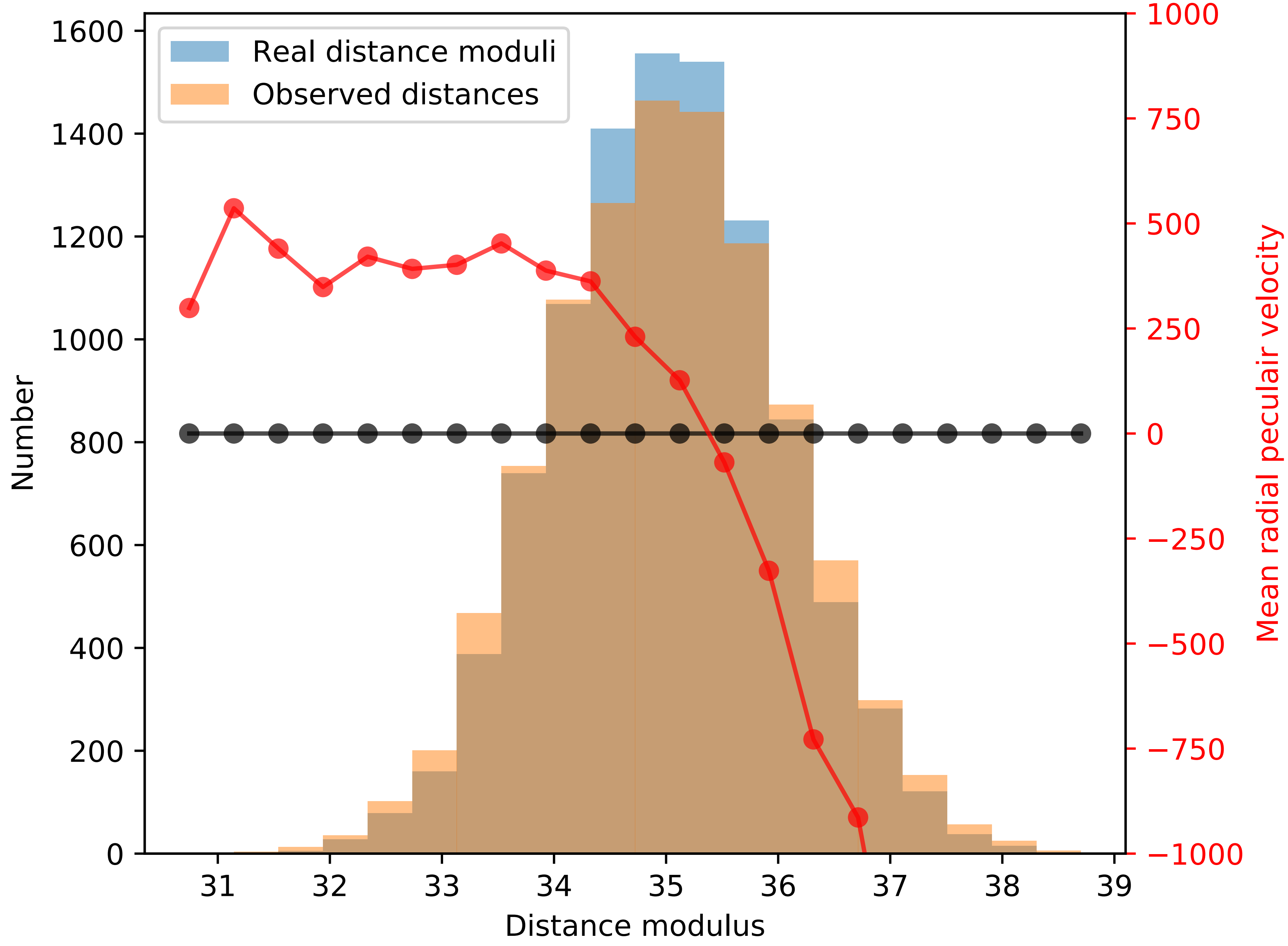


Error bias

- Position bias
- Error bias
- Density bias

$$cz \sim v^r + H_0 d$$

$$\sigma_{v^r} \propto d$$

Error bias

- Position bias
- Error bias
- Density bias

$$cz \sim v^r + H_0 d$$

$$\sigma_{v^r} \propto d$$

We underestimate the errors on the underestimated distances,
Creating a global outflow

Density bias

- Position bias
- Error bias
- Density bias

$$\mathcal{P}(d| \ldots) \propto \mathcal{P}(d)$$

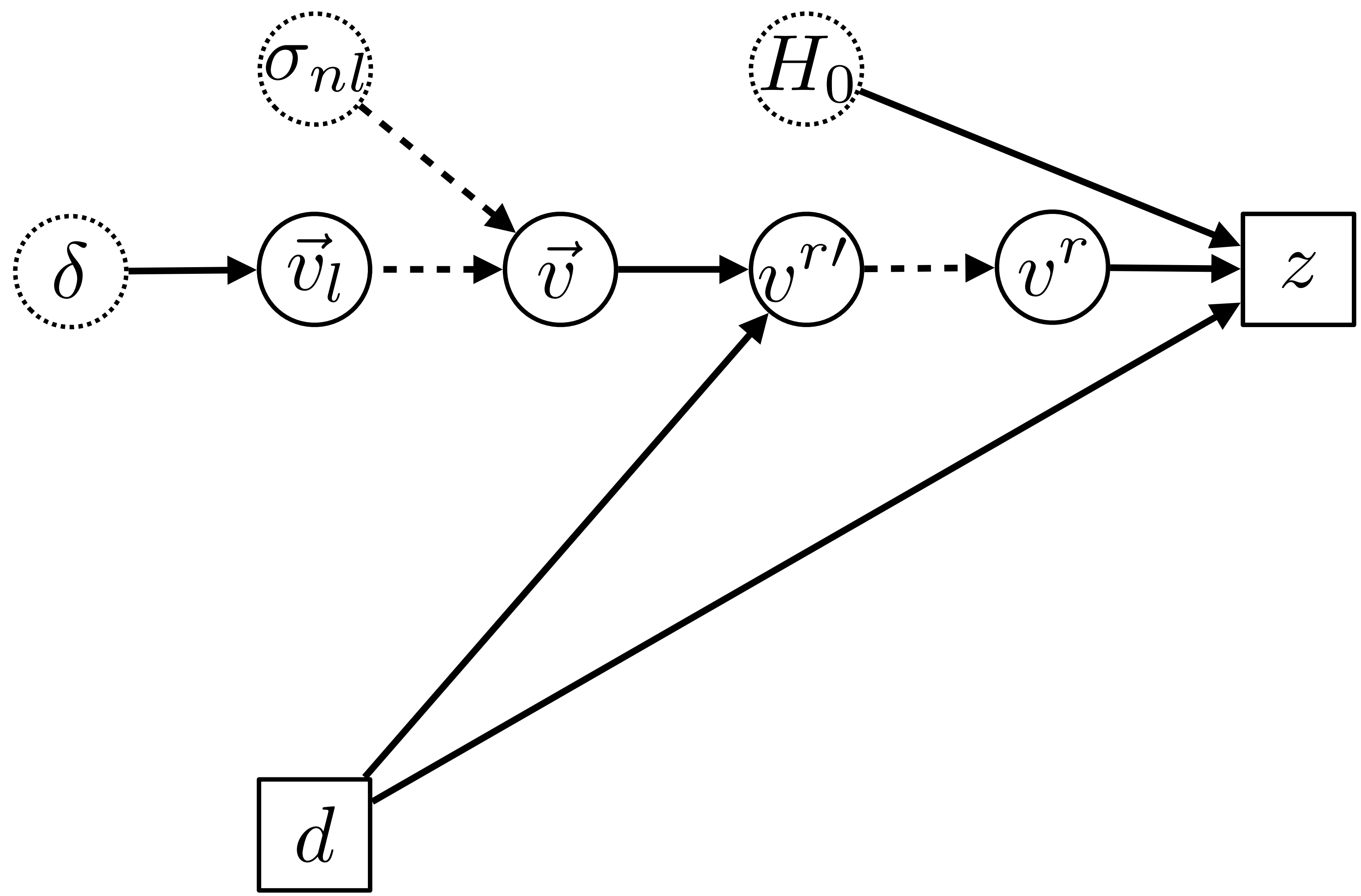
Density bias

- Position bias
- Error bias
- Density bias

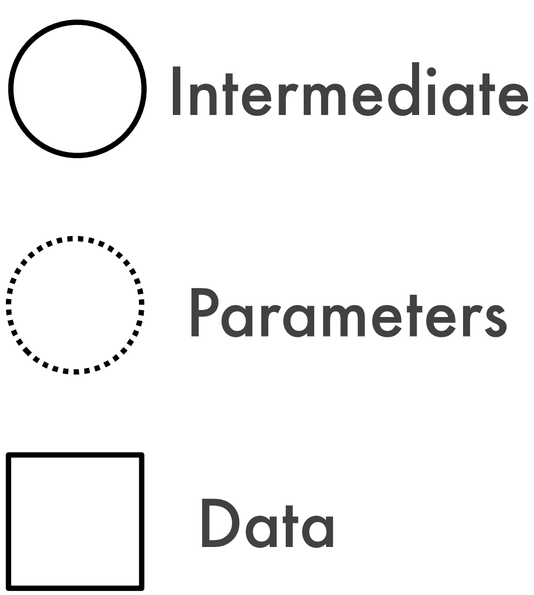
$$\mathcal{P}(d|\ldots) \propto \mathcal{P}(d)$$

Volume effects + depends on the over density field

WF/CR

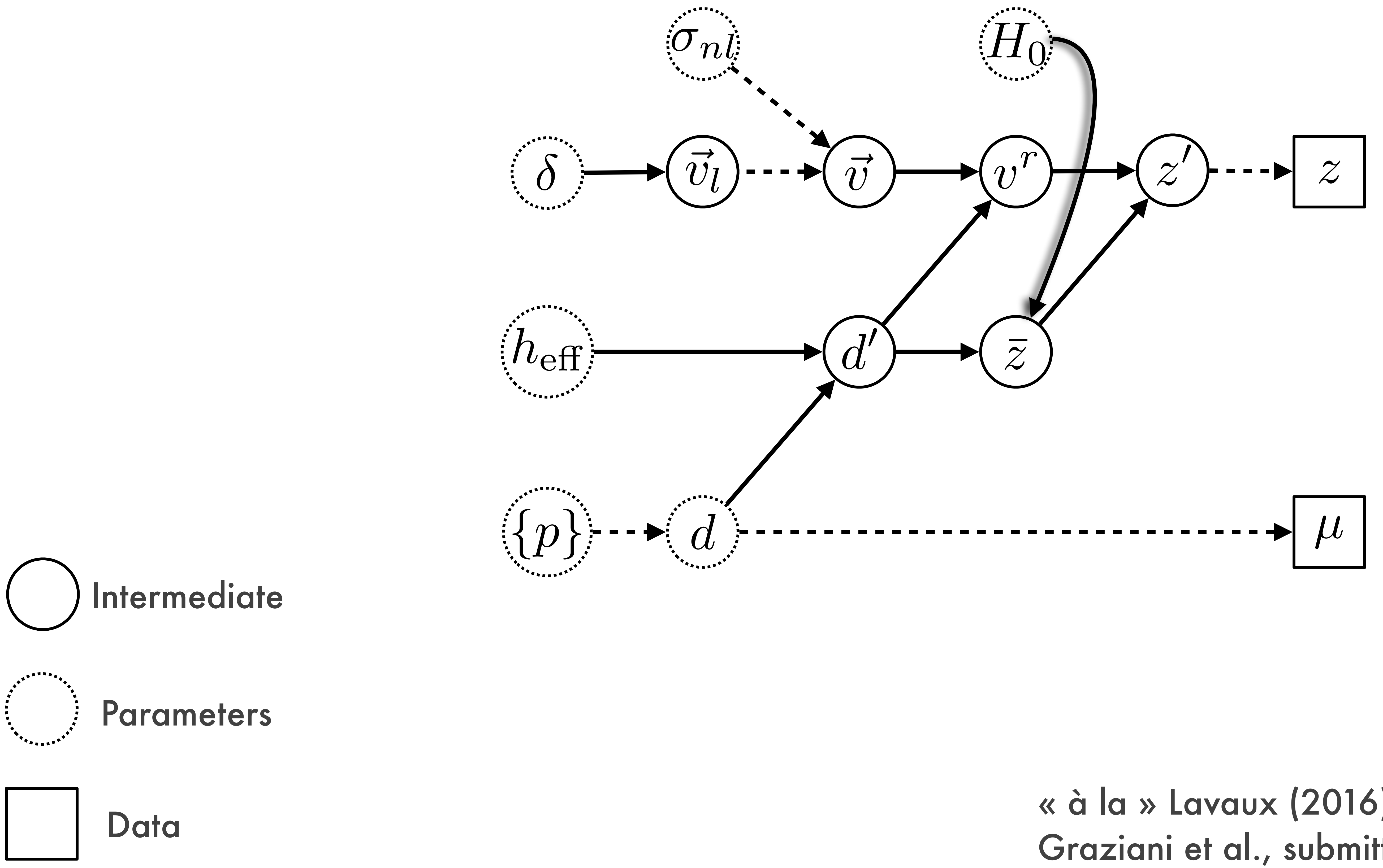


σ_{nl}
H_0
δ
$\vec{v}_l$
$\vec{v}$
$v^{r\prime}$
v^r
z
d



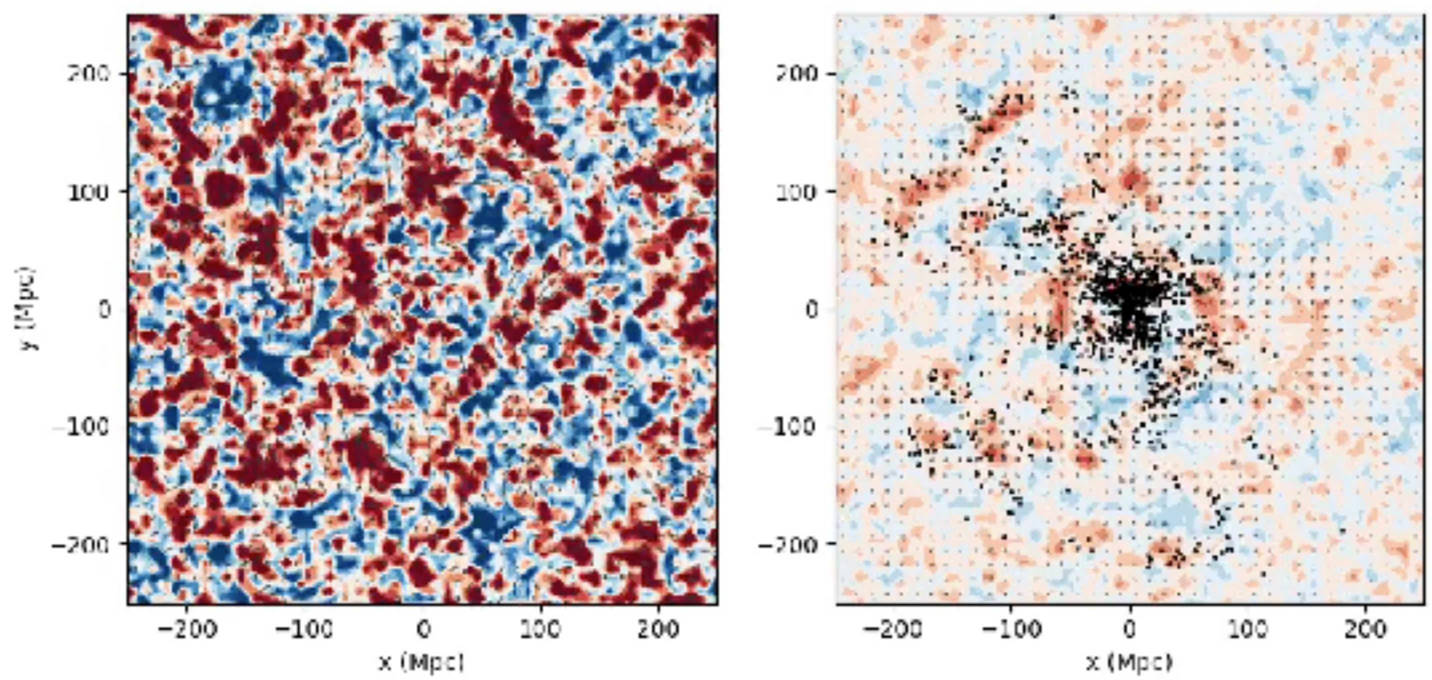
Intermediate
Parameters
Data

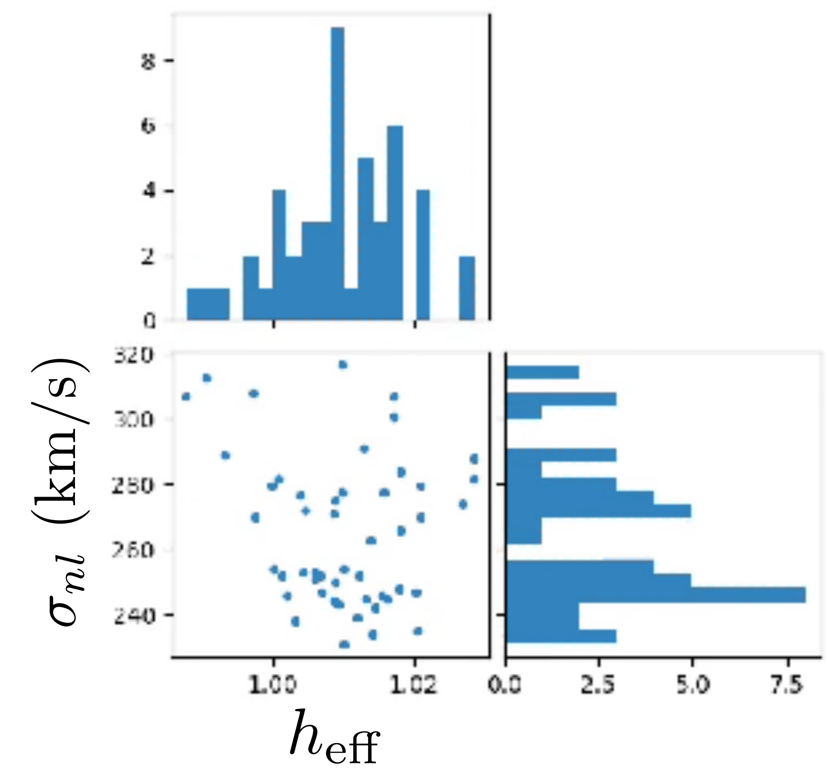
A fully bayesian model



« à la » Lavaux (2016)
Graziani et al., submitted

CosmicFlows-3





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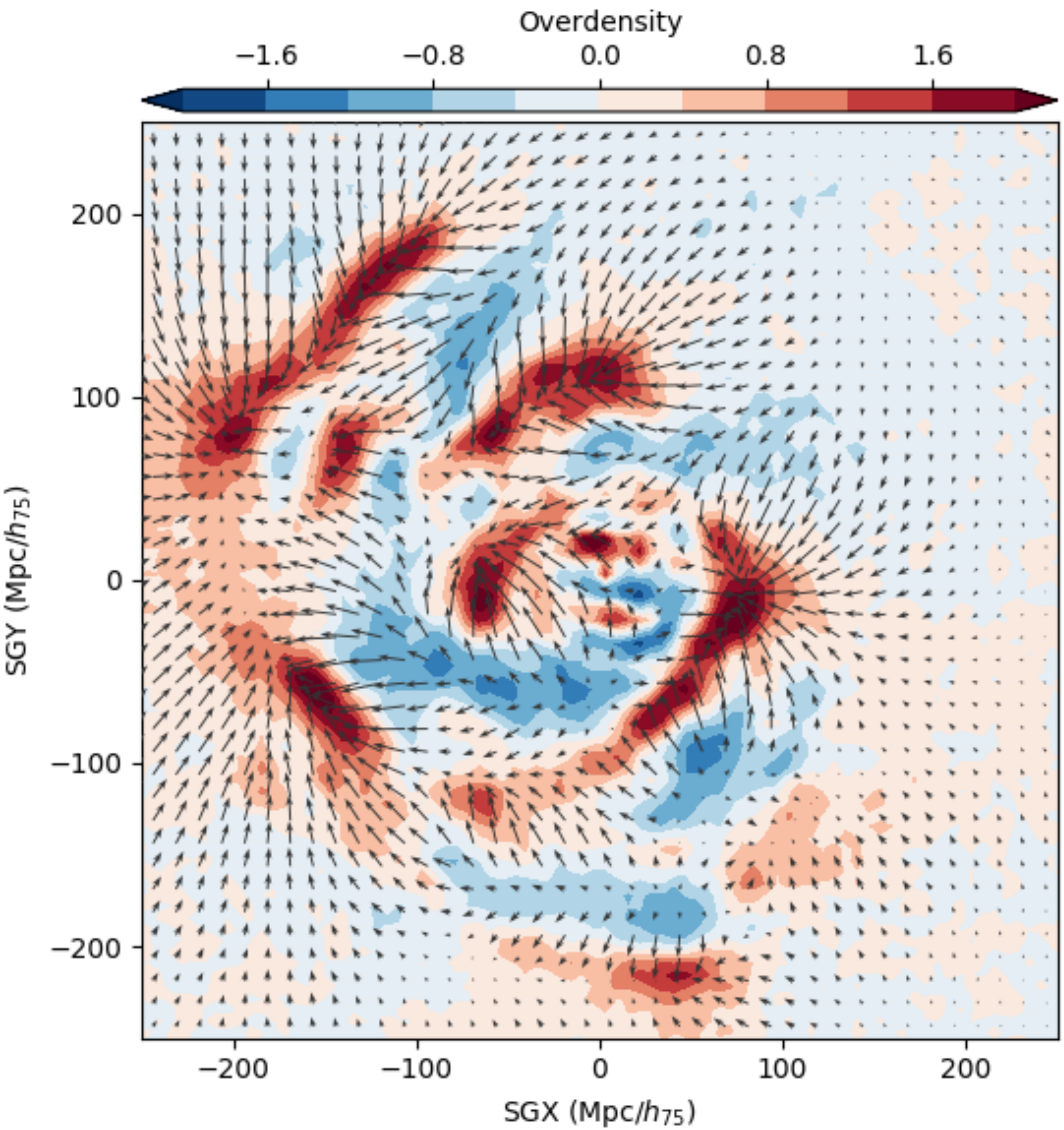

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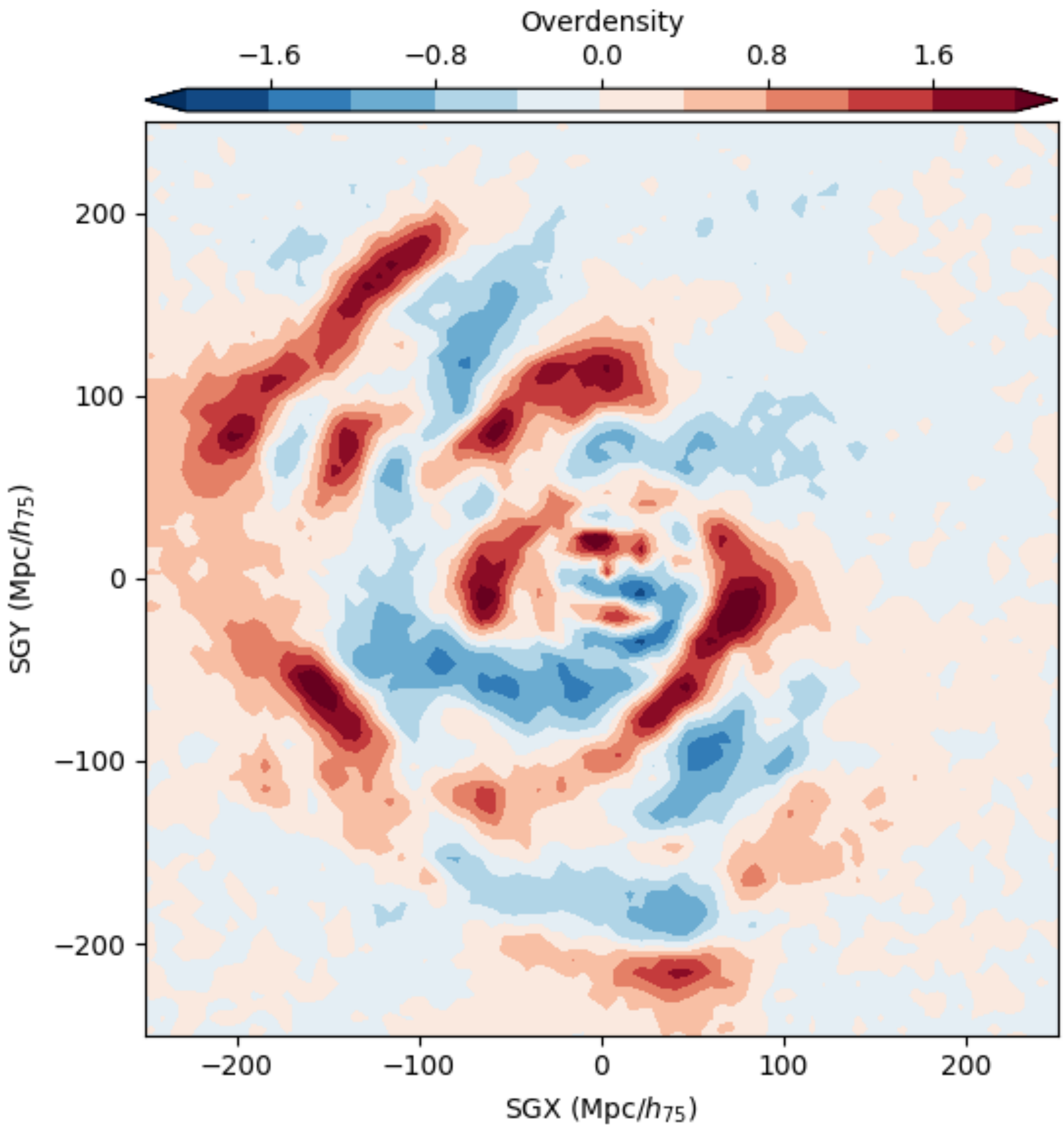

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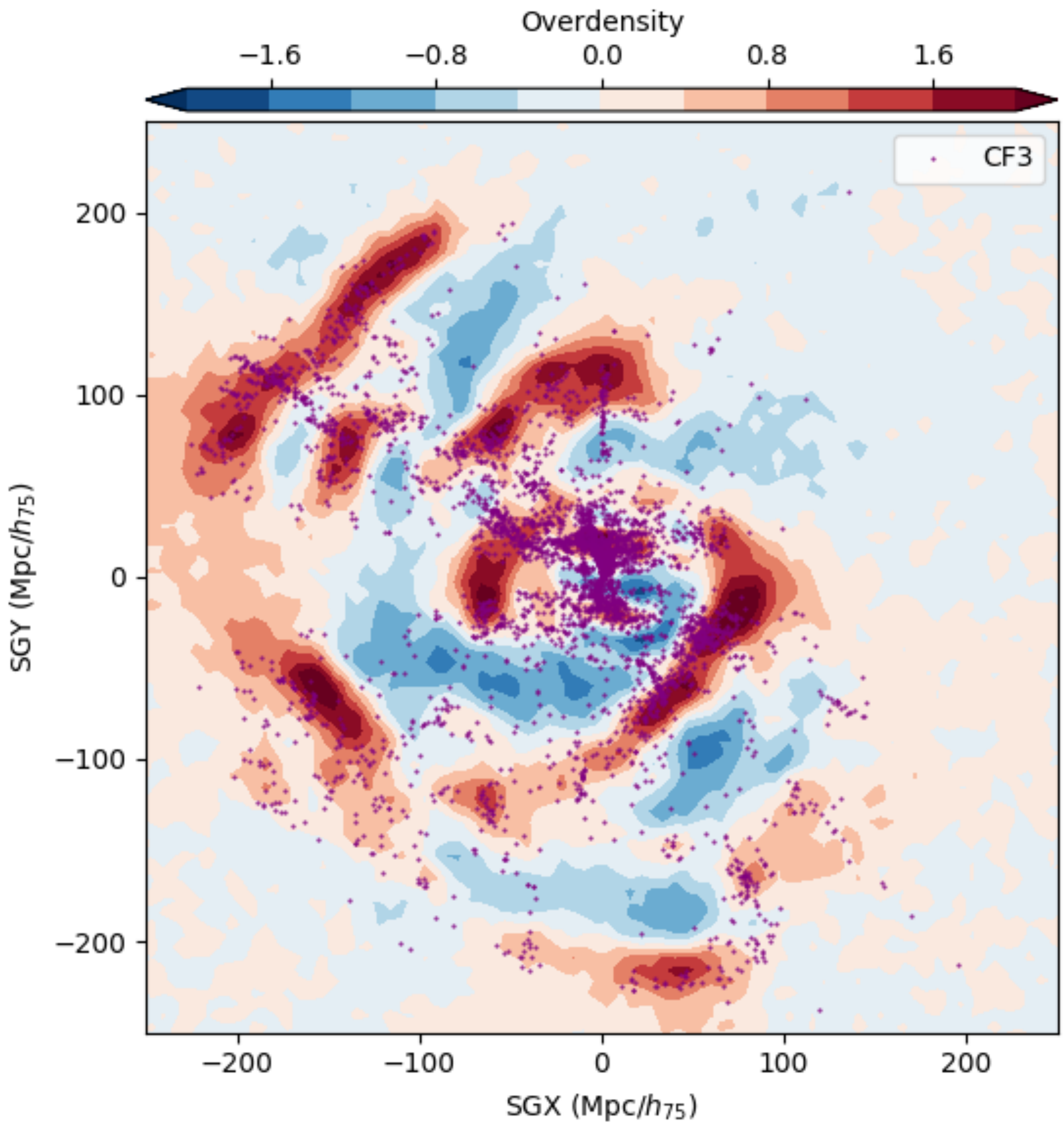

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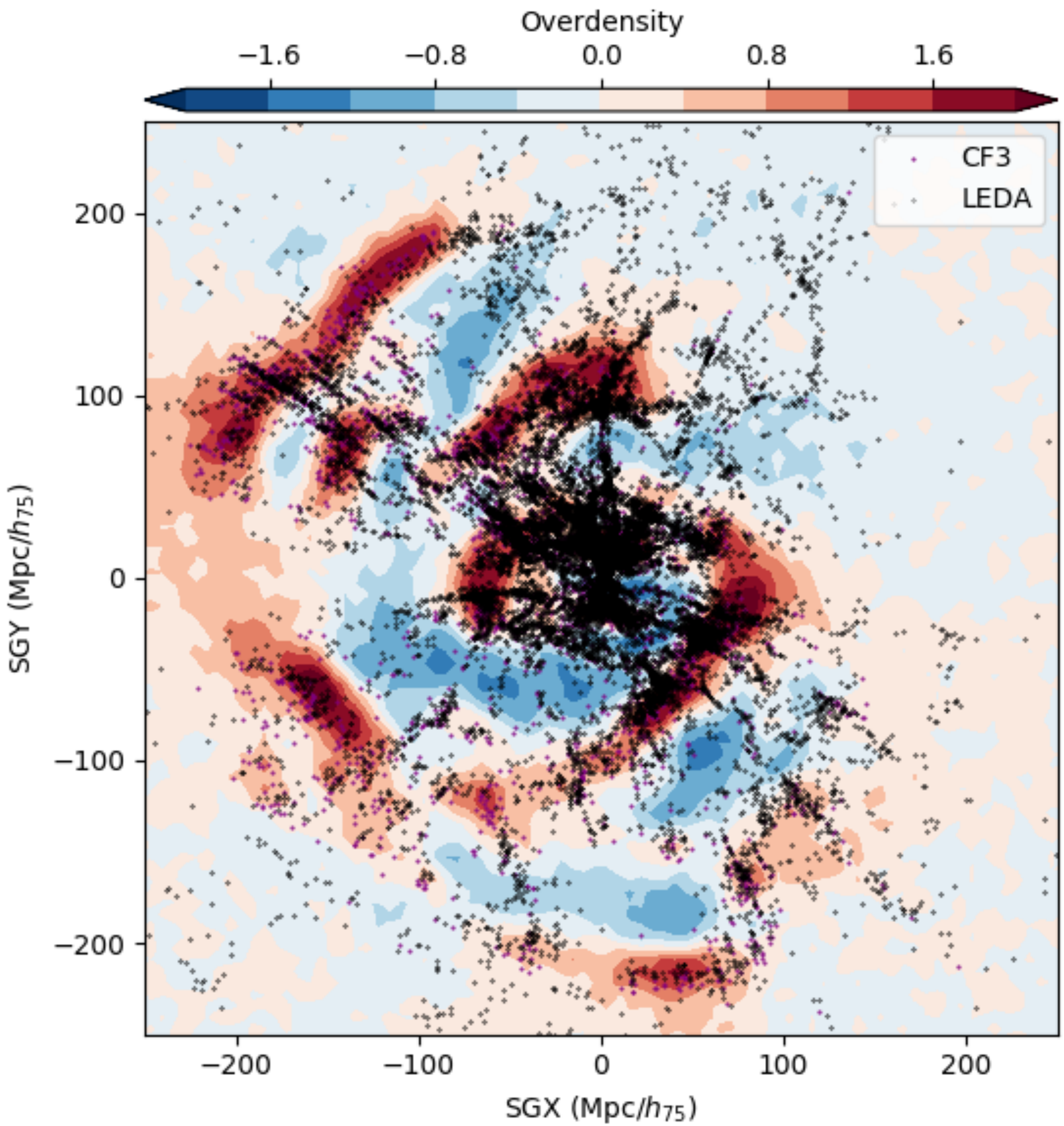
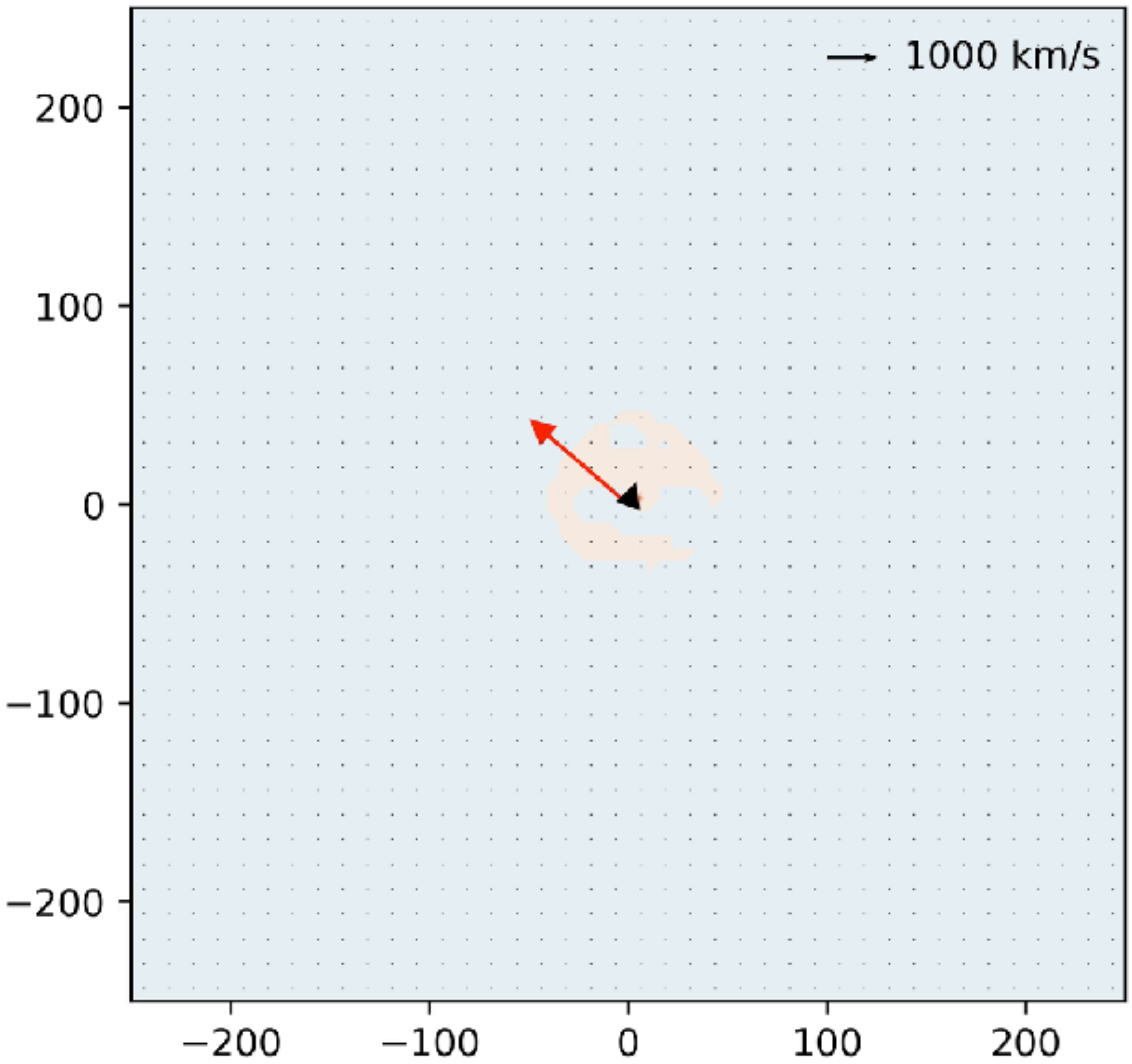
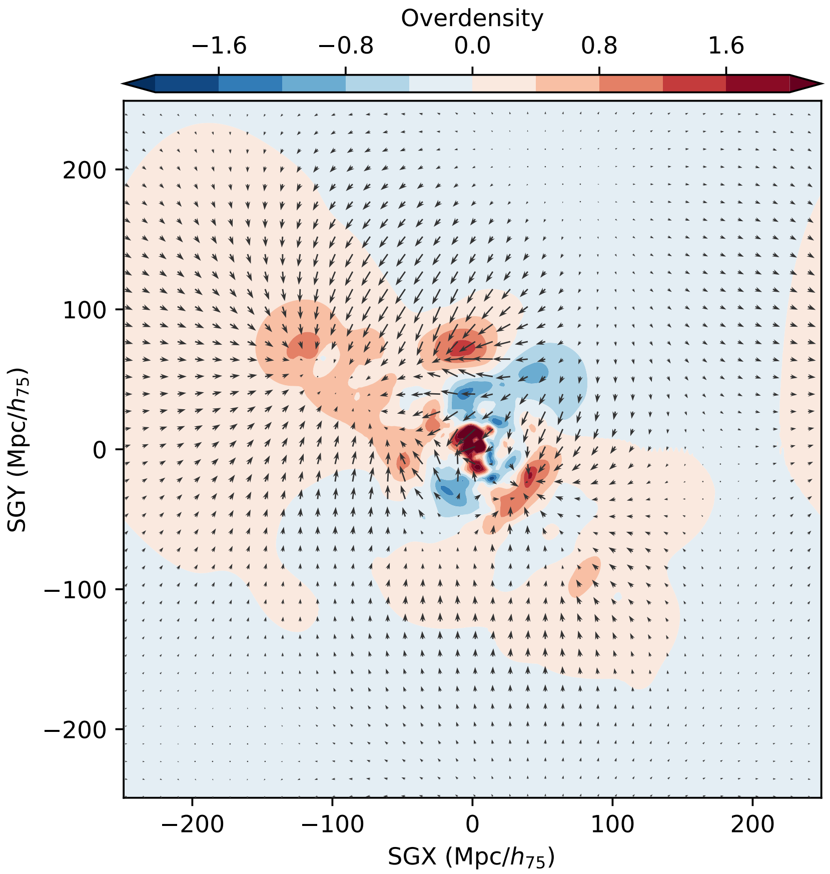
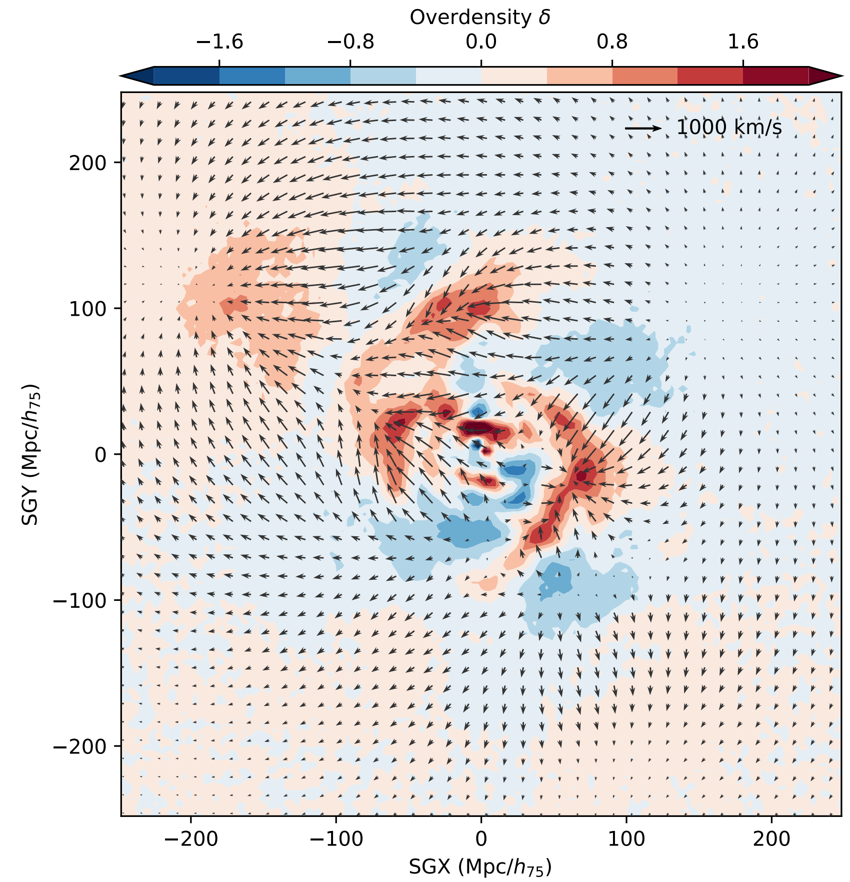



1000 km/s
200
100
0
−100
−200
−200
−100
0
100
200

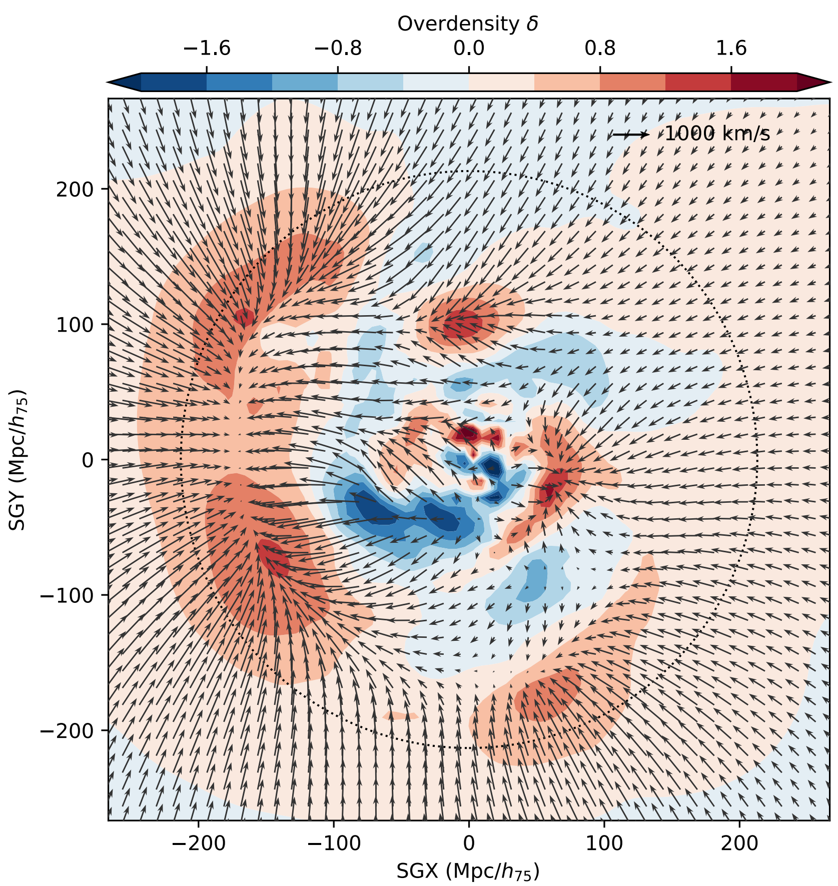
CF2 WF

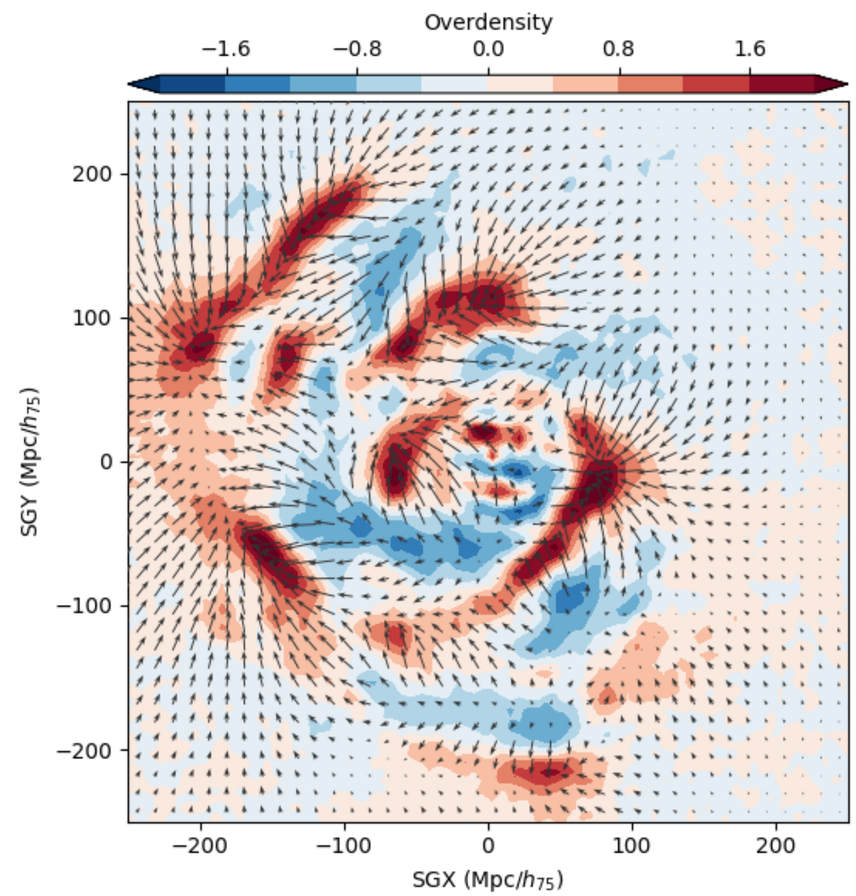




New CF2

CF3 WF

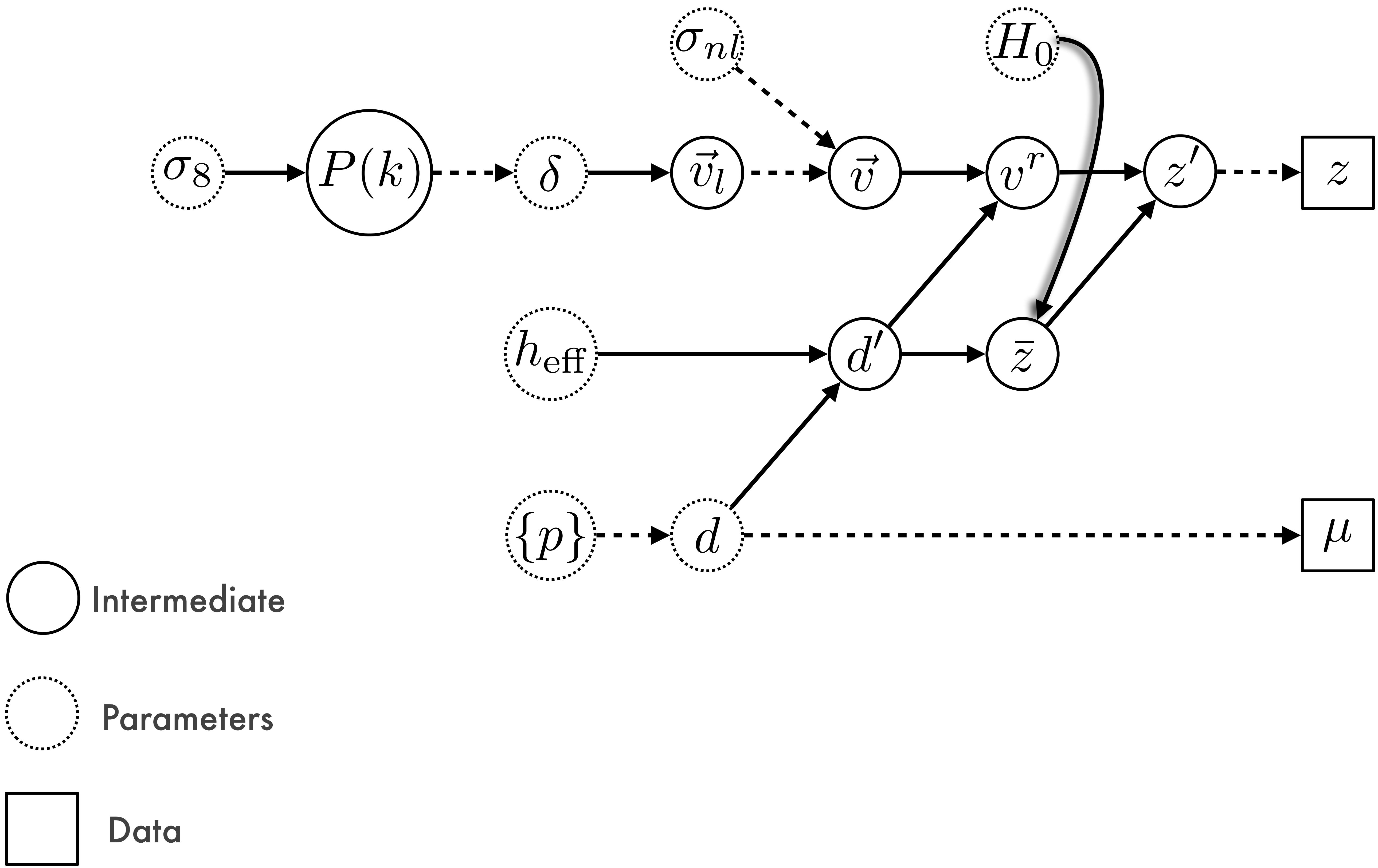




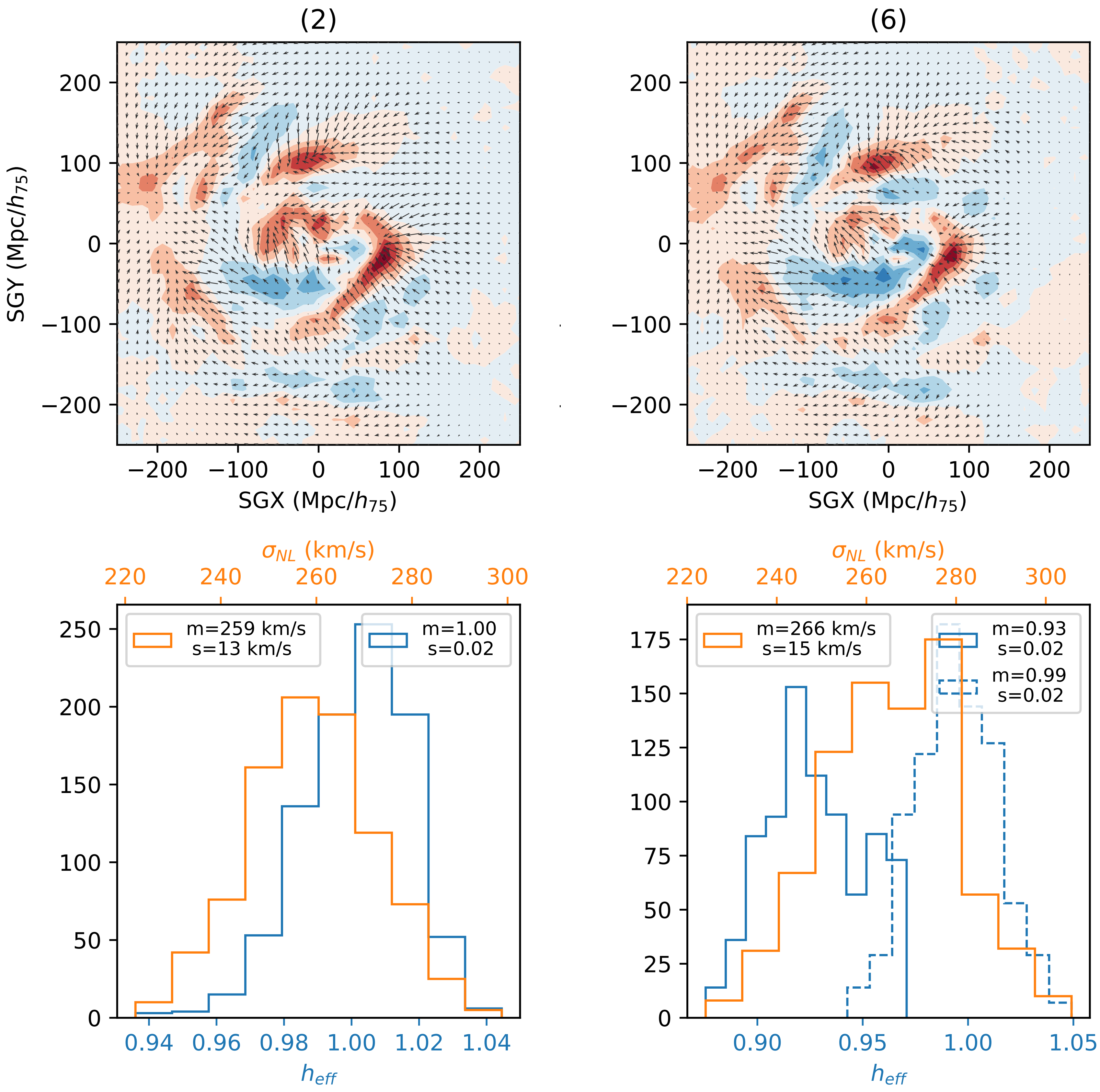
New CF3

Extension to the Tully-Fisher relation

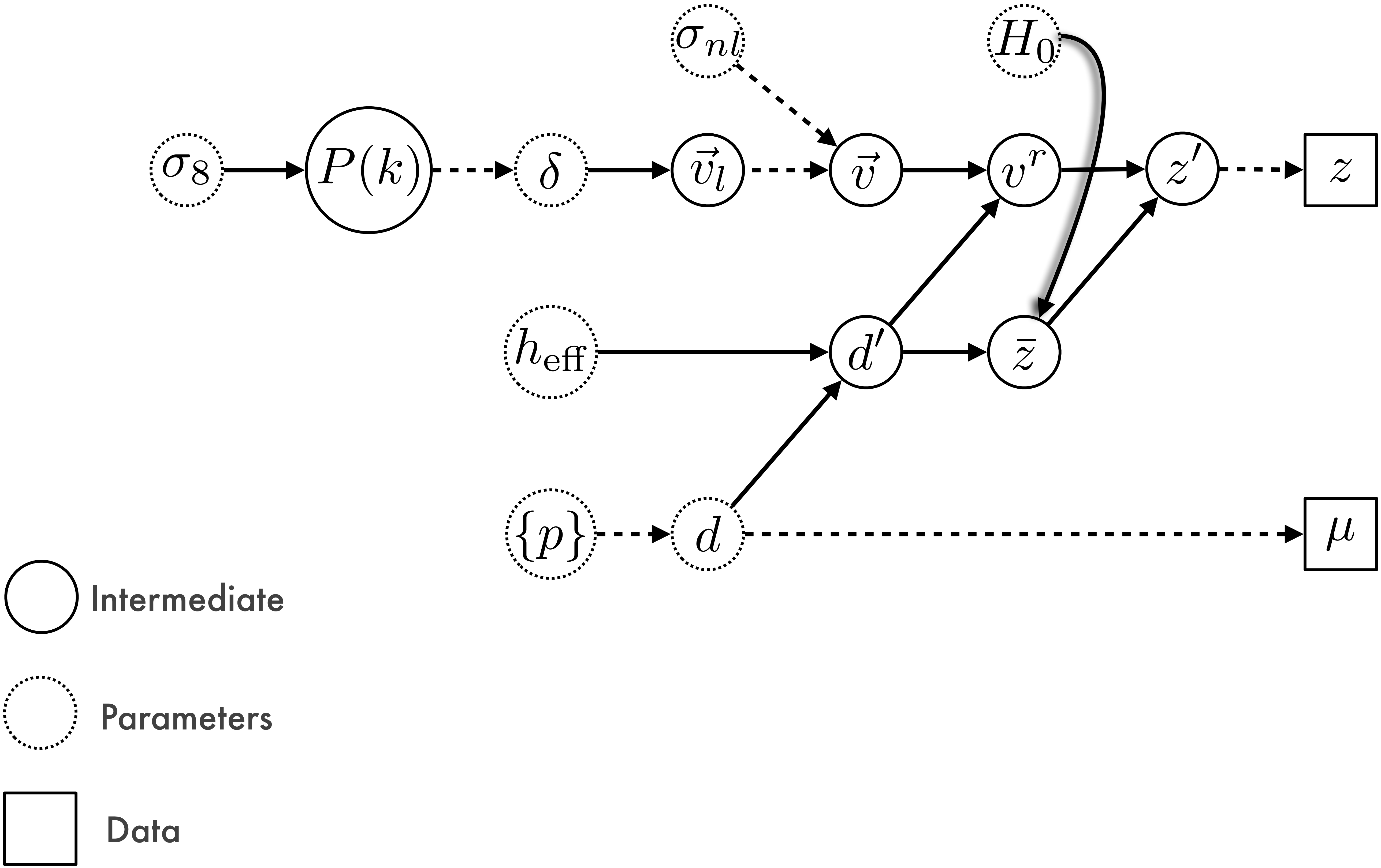
Limitations



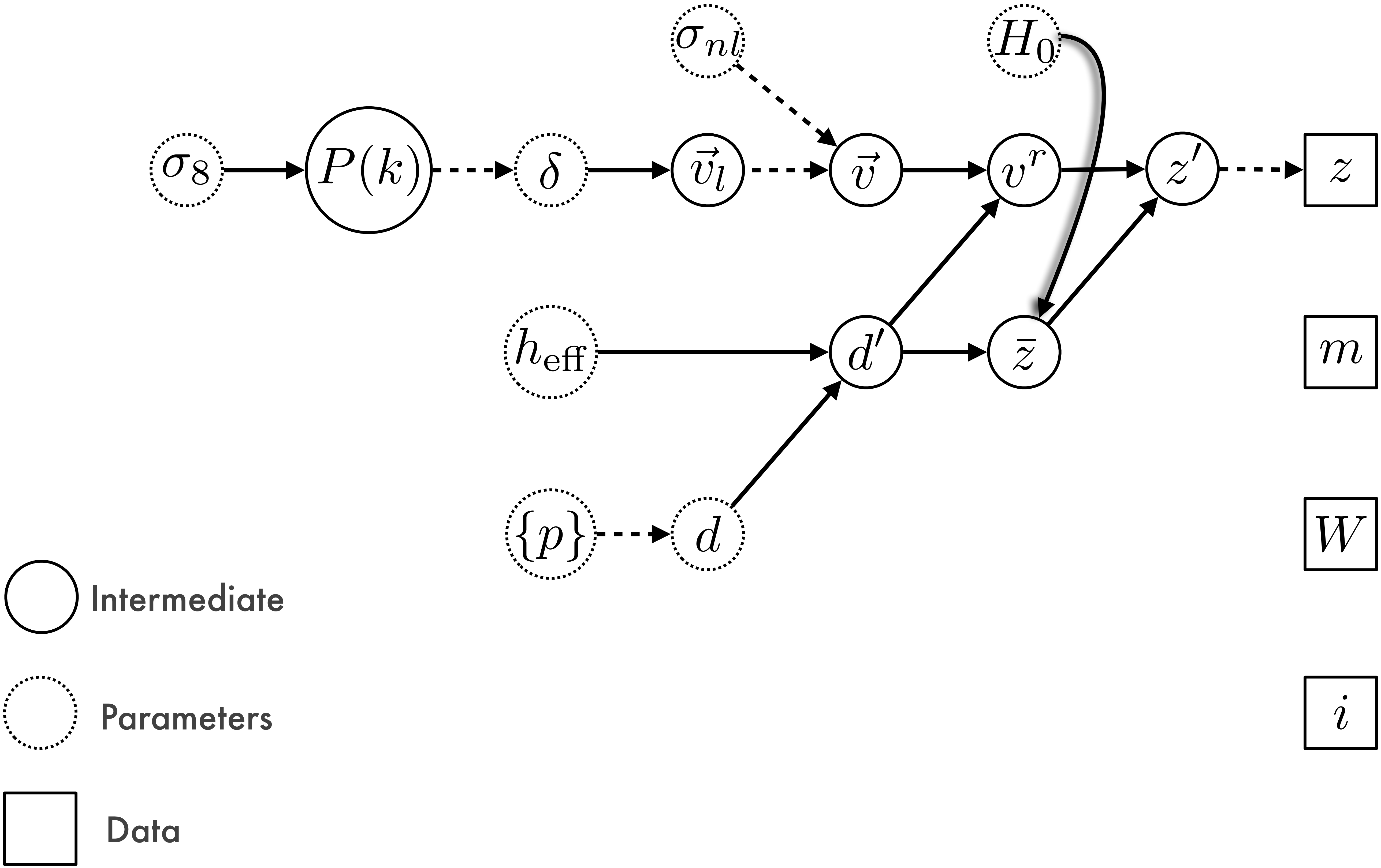
Limitations



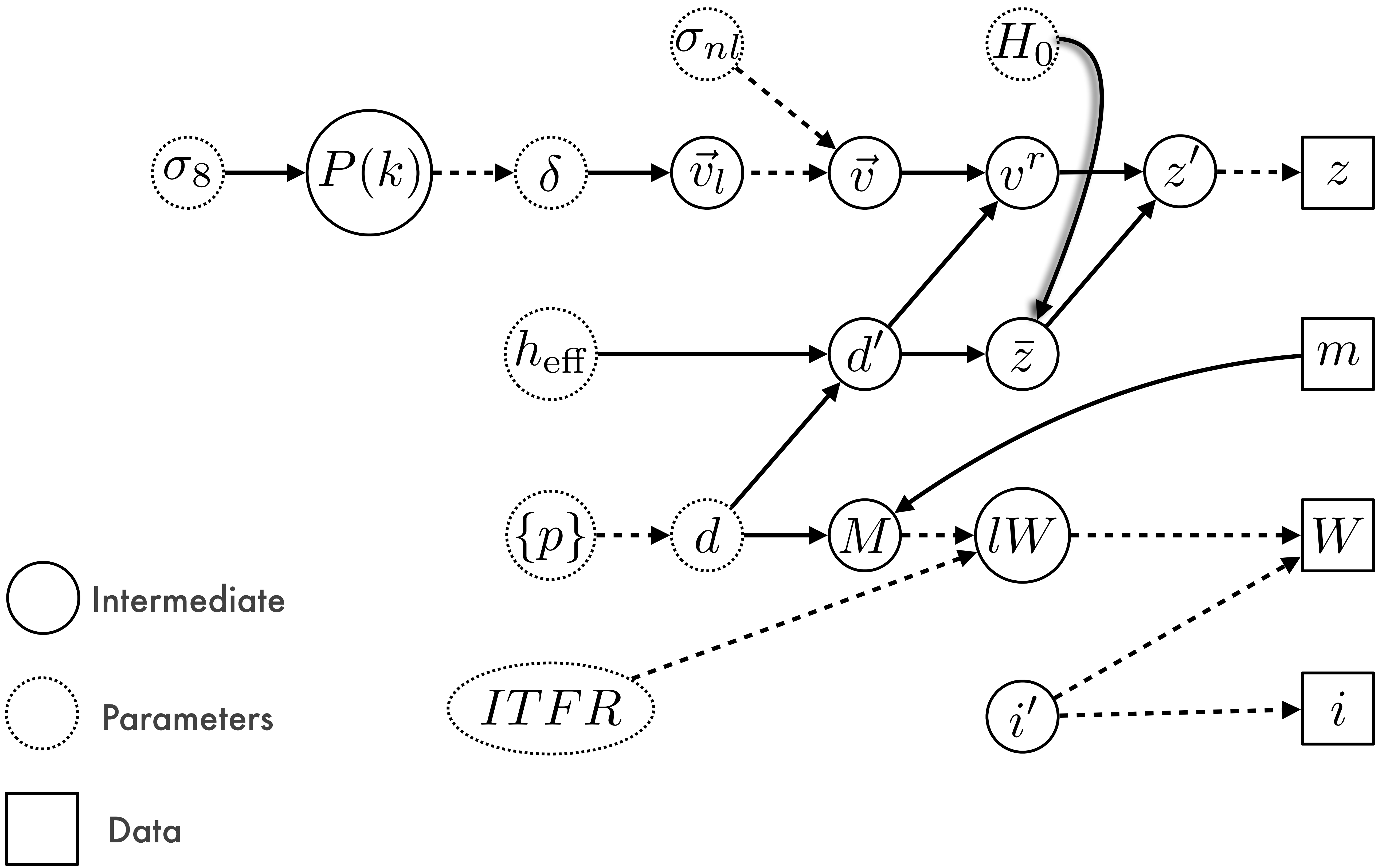
Limitations



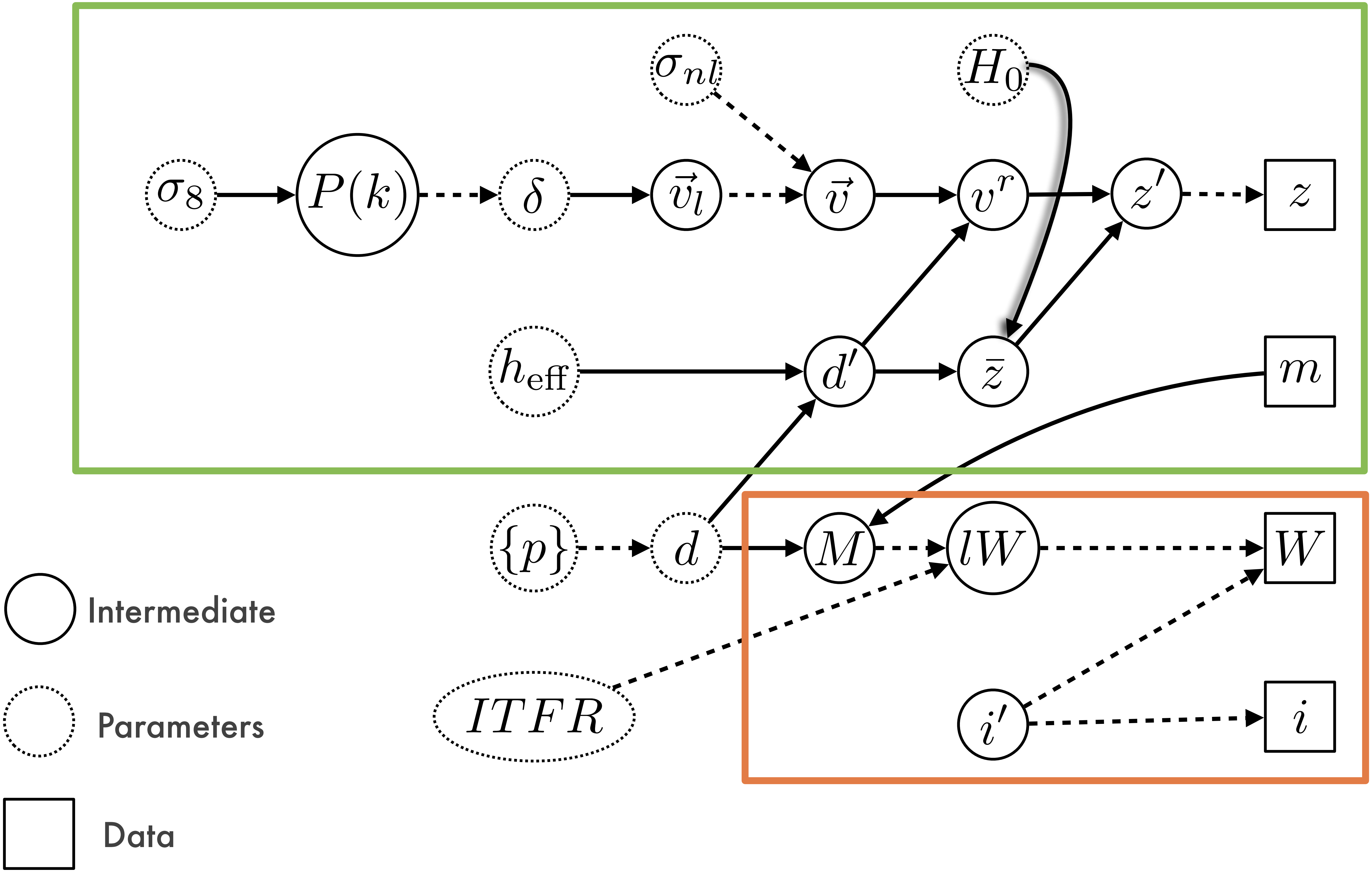
Tully-Fisher relation within the model



Tully-Fisher relation within the model



Block sampling



Exemple : inverse Tully-Fisher relation

$$\text{Also sample : } \mathcal{P}(M|m, W, i, ZP, s, \sigma_{\text{int}}, c)$$

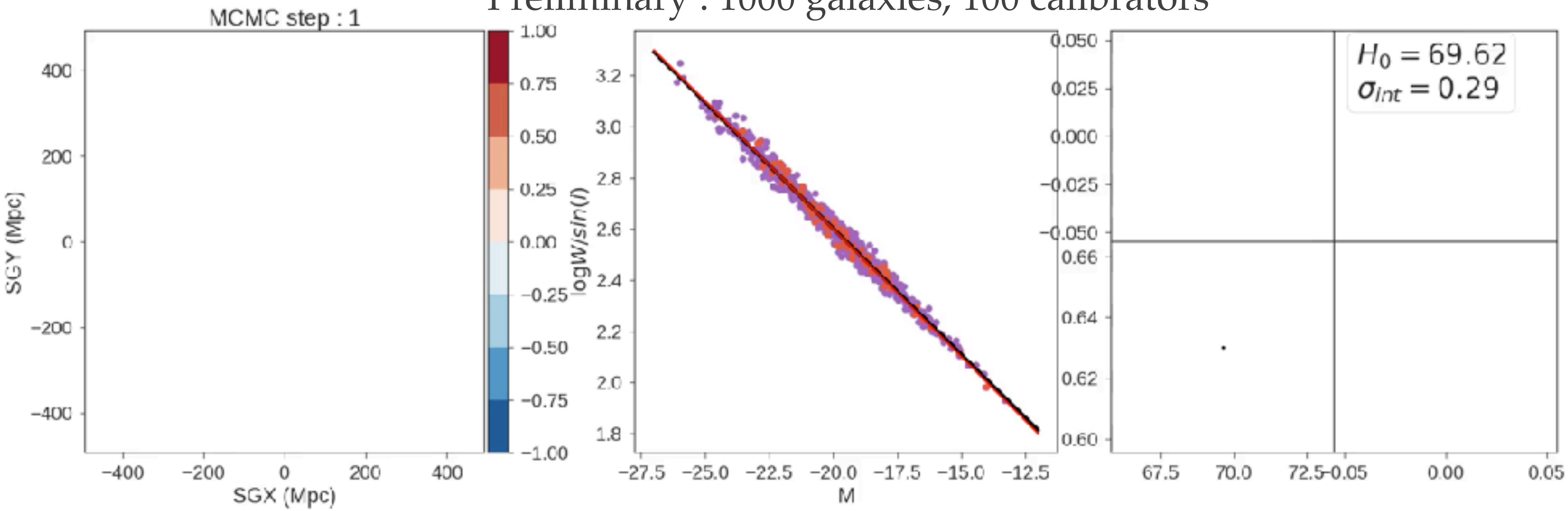
Gibbs sampling adapted from Kelly (2006)

Exemple : inverse Tully-Fisher relation

$$\text{Also sample : } \mathcal{P}(M|m, W, i, ZP, s, \sigma_{\text{int}}, c)$$

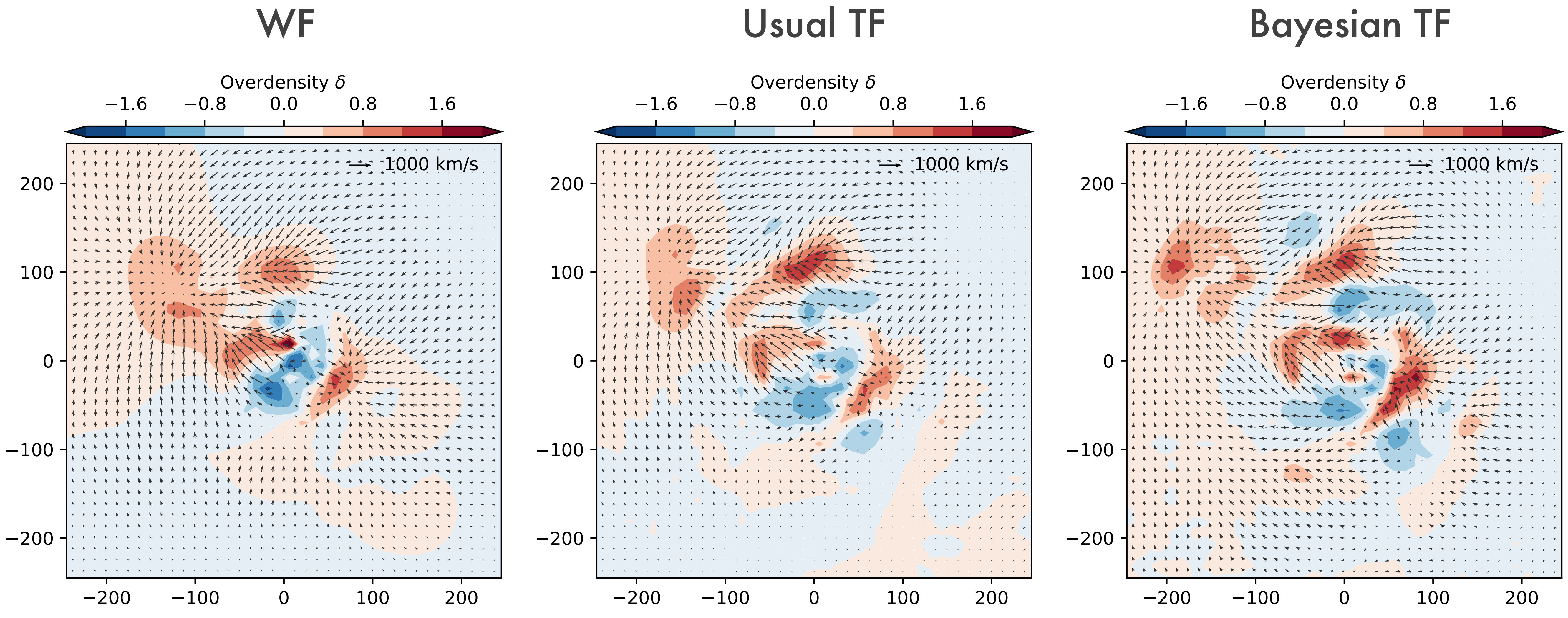
Gibbs sampling adapted from Kelly (2006)

Preliminary : 1000 galaxies, 100 calibrators



Application on the SFI++ sample

Preliminary



Application on the SFI++ sample

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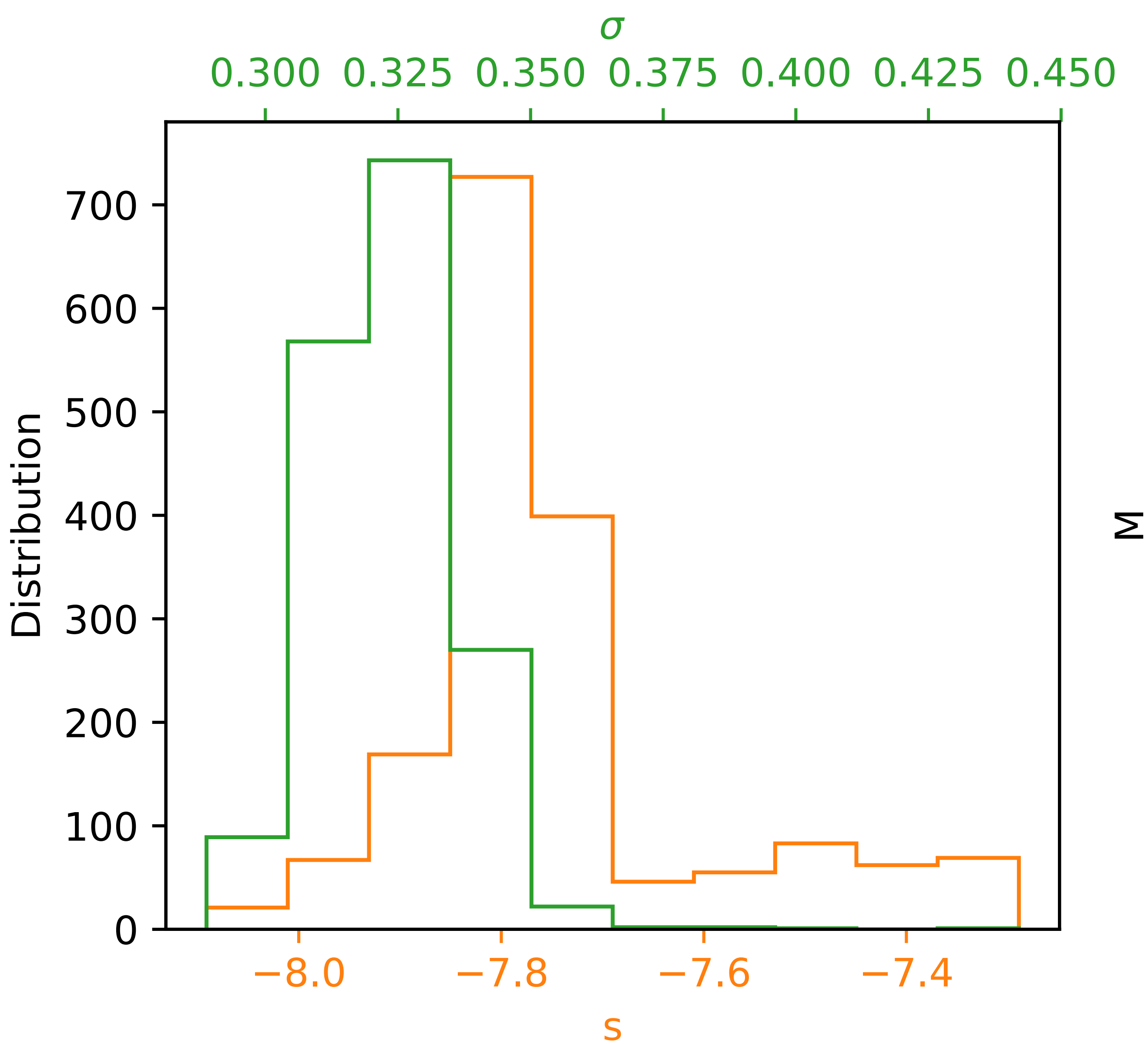
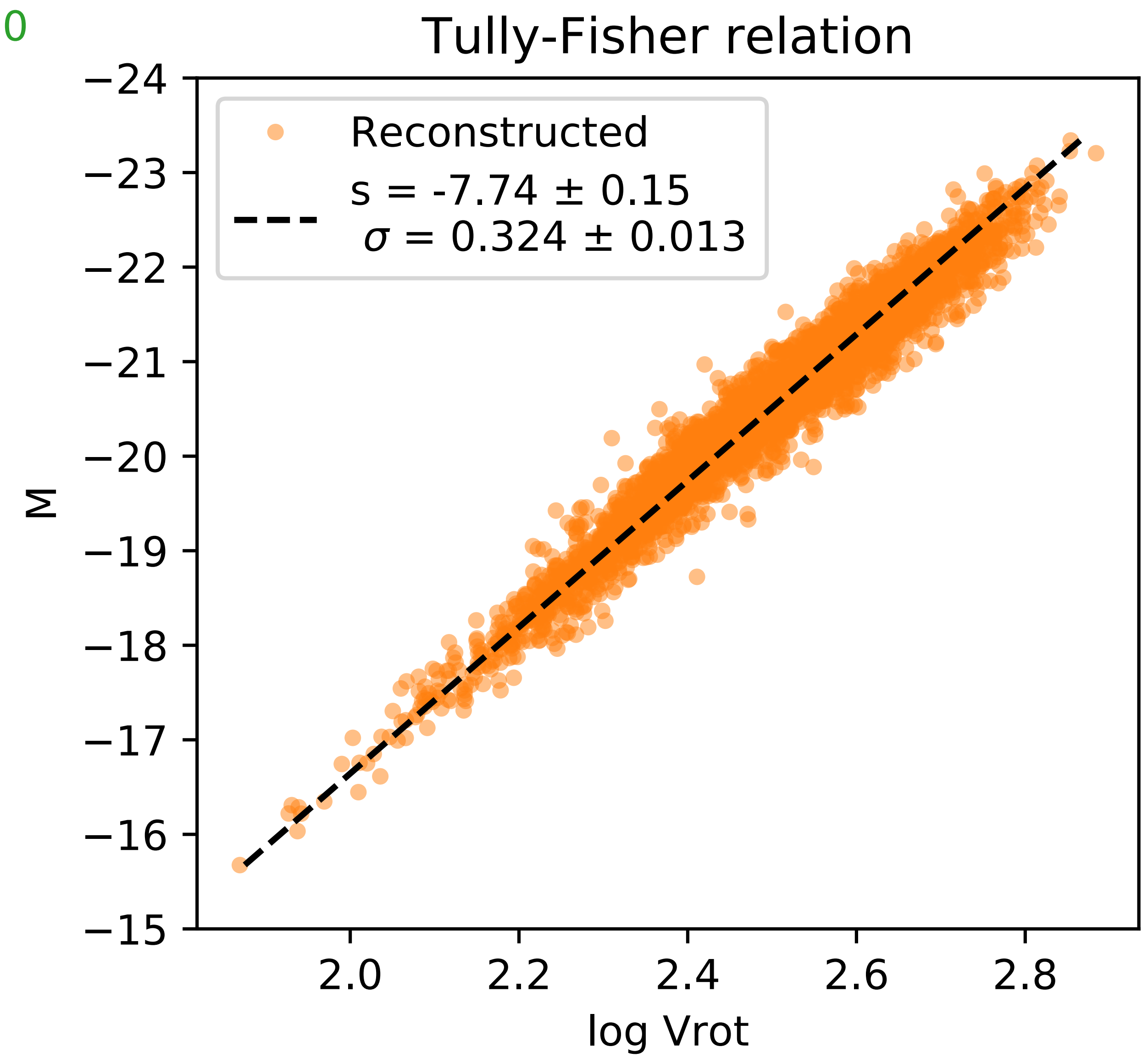
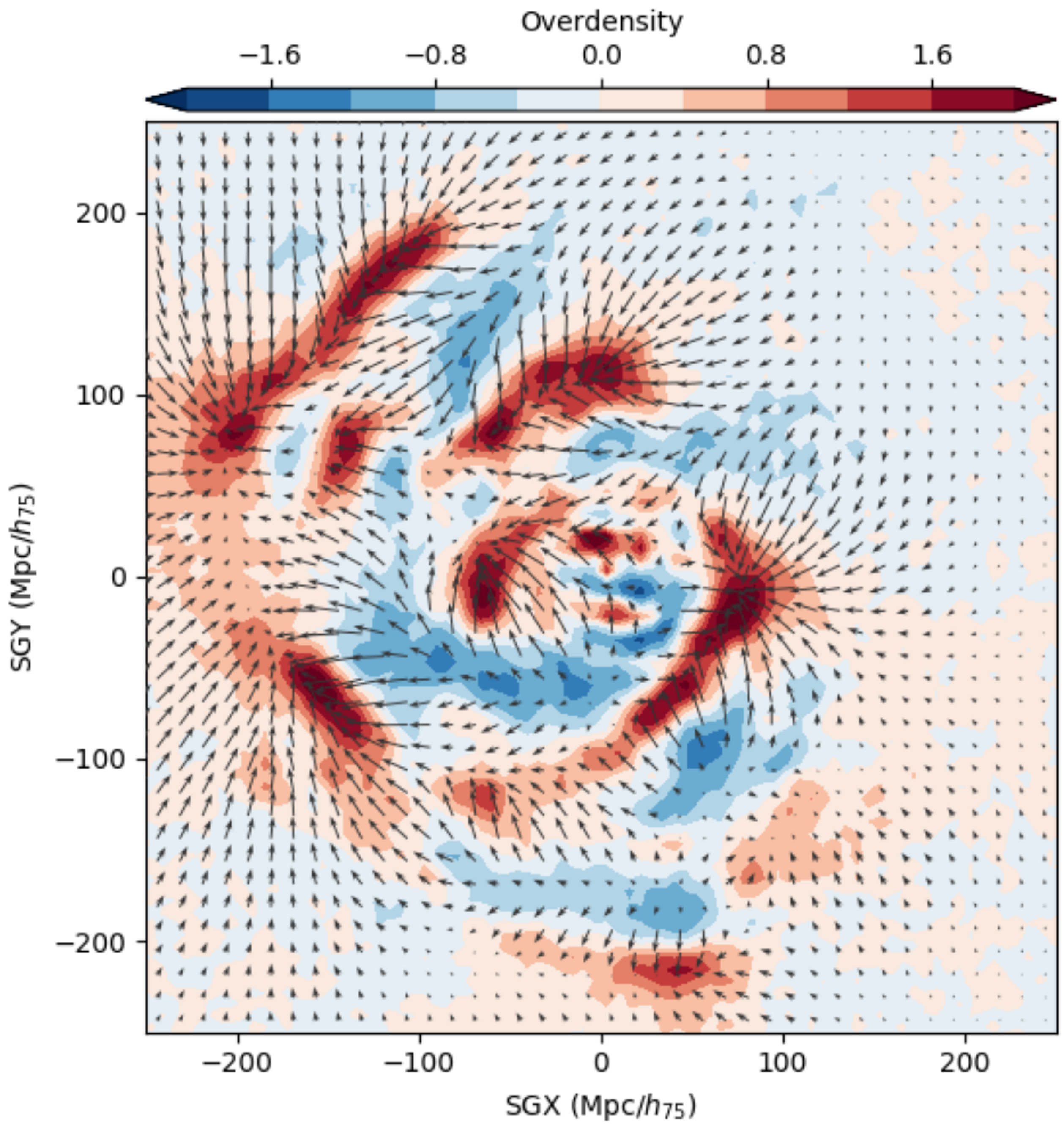




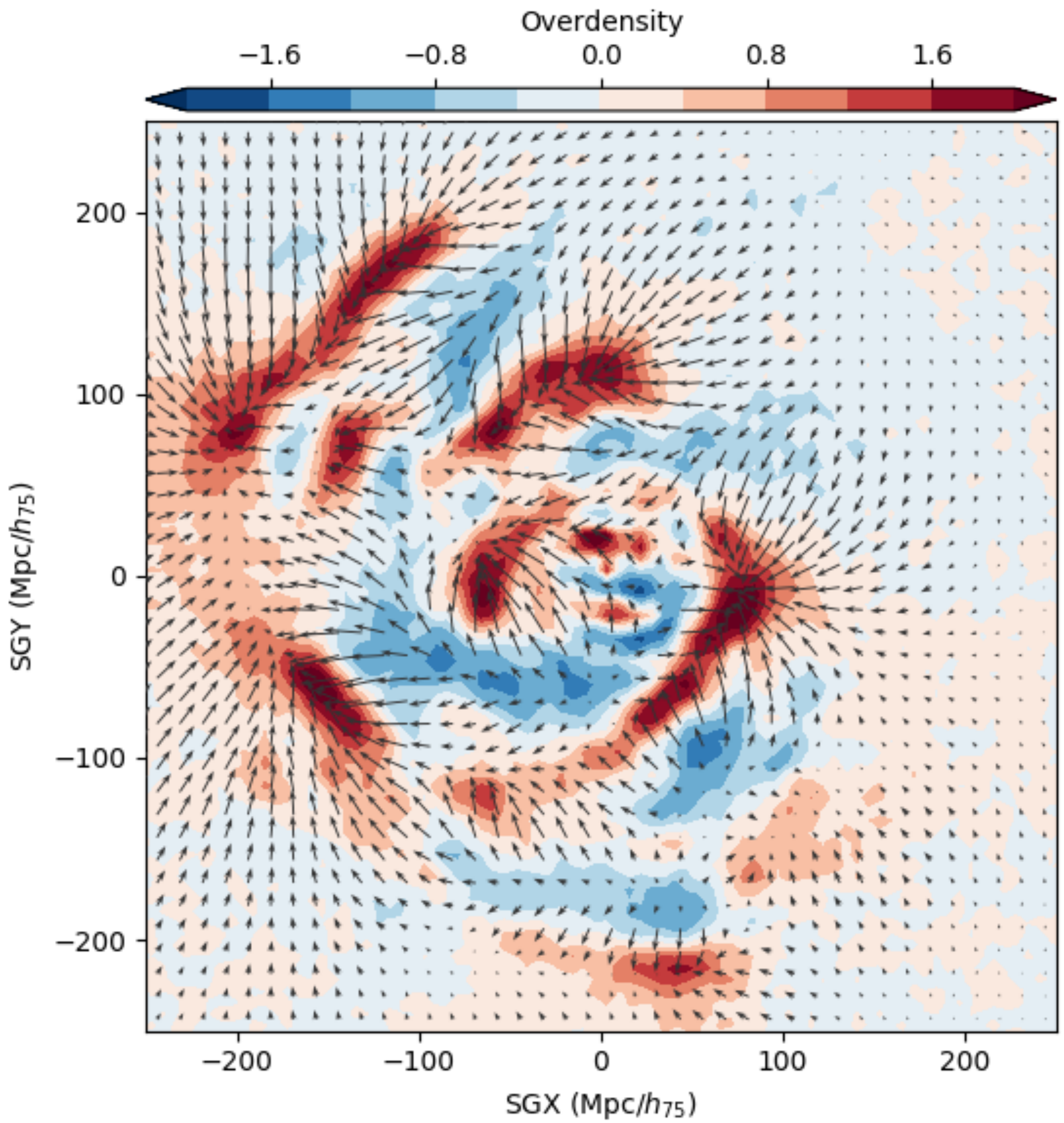
Conclusions

Conclusion

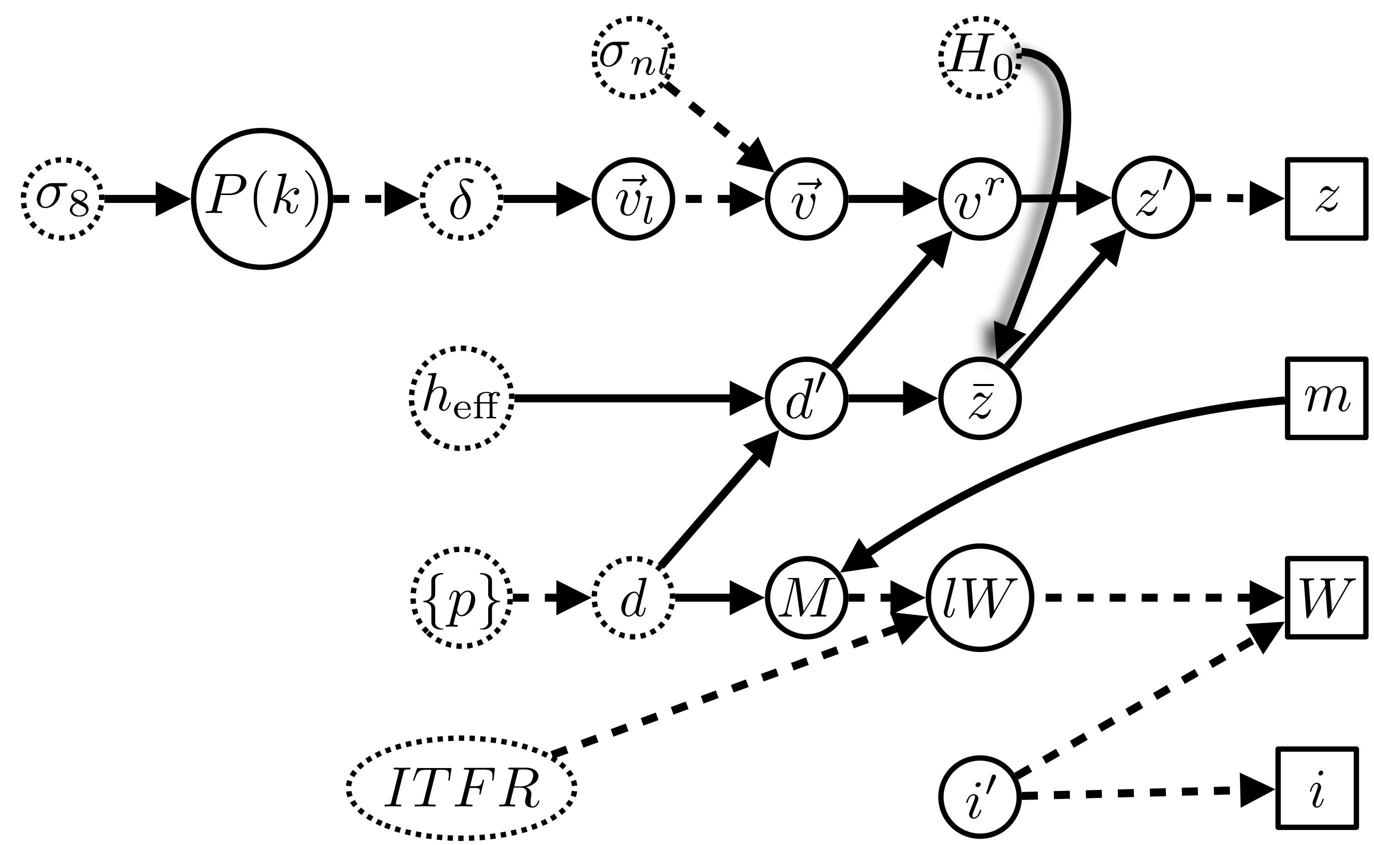


The kinematic map of our Local Universe

Conclusion

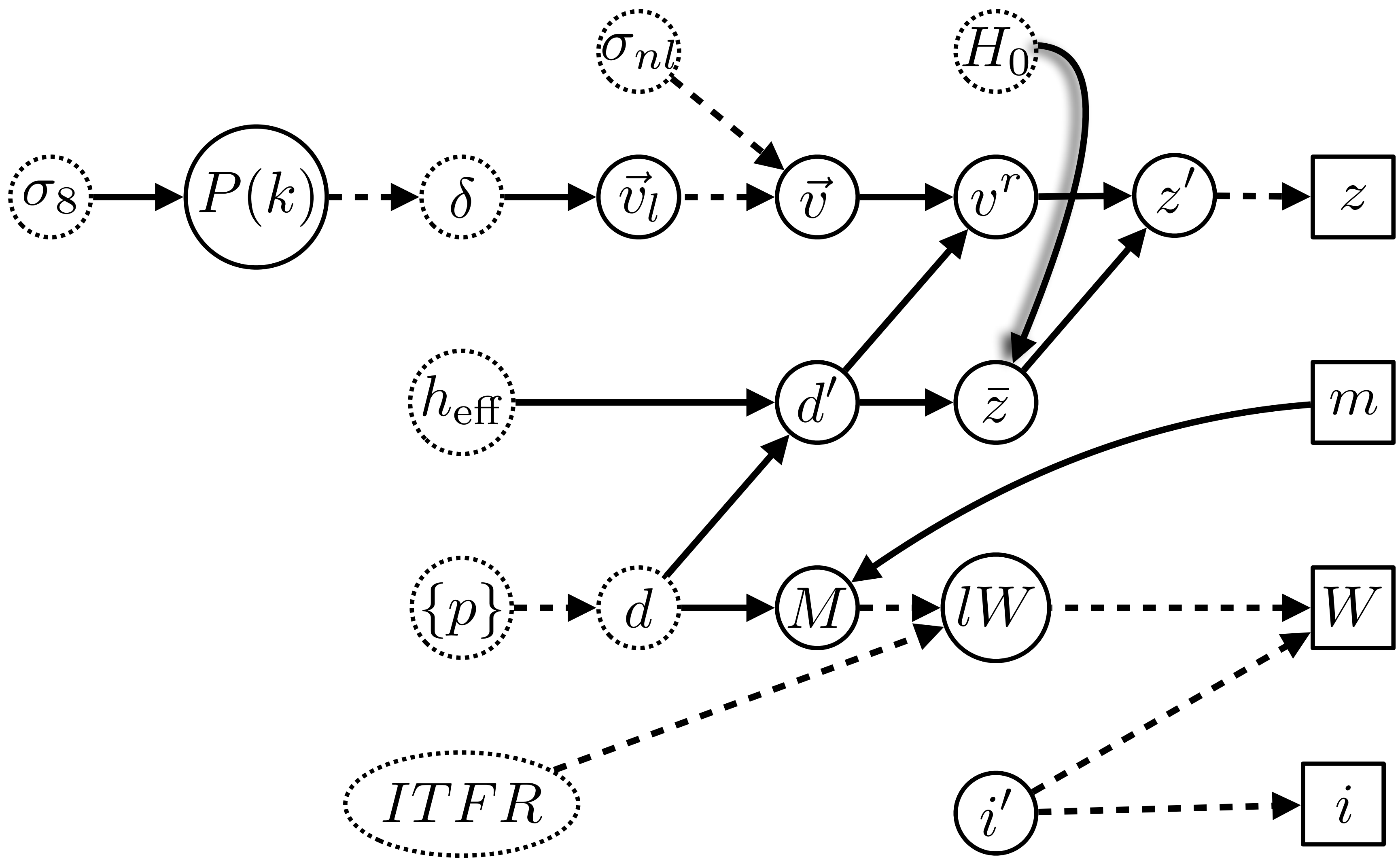


The kinematic map of our Local Universe



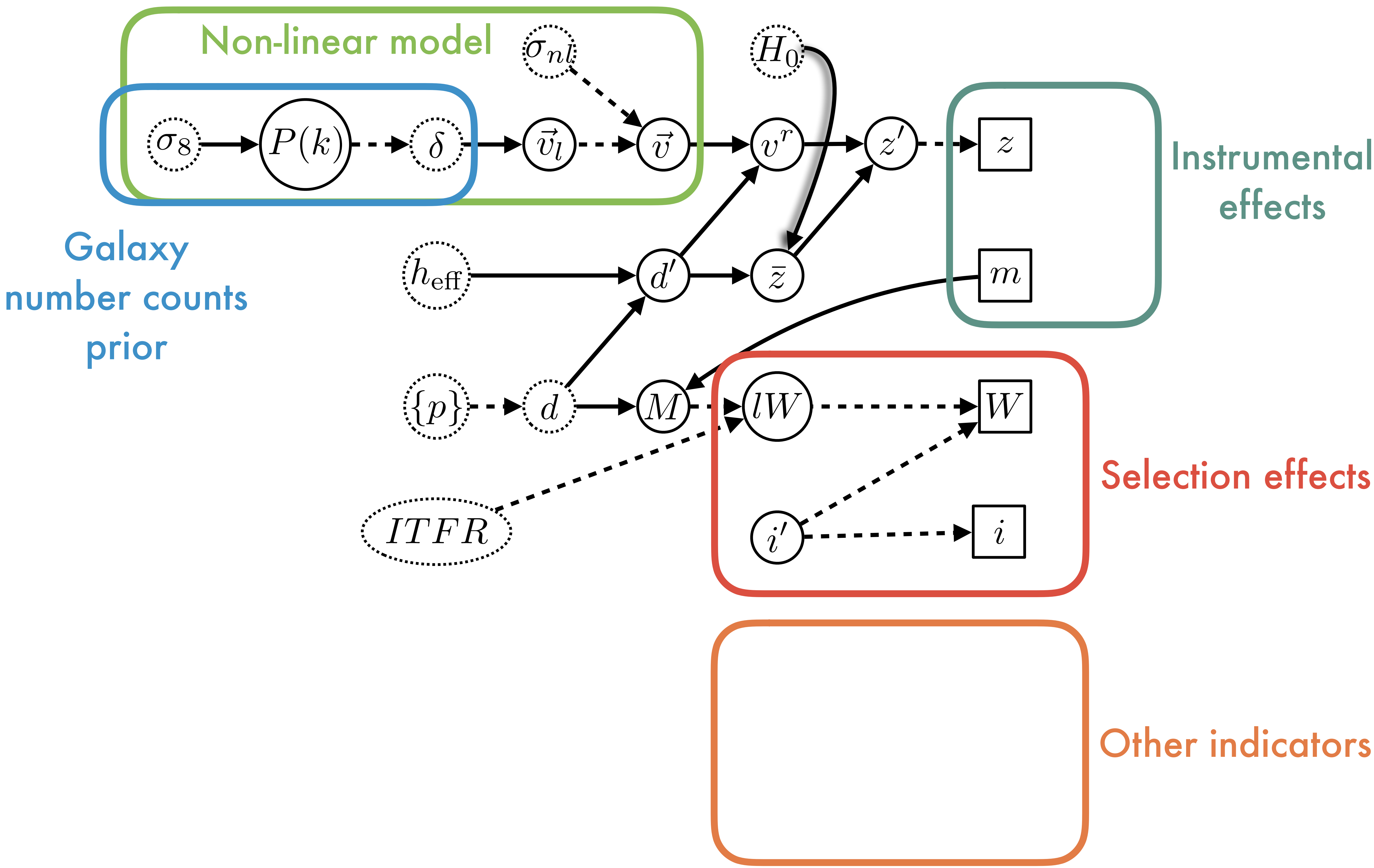
A fully Bayesian model
for peculiar velocity analyses

Bayesian modeling of peculiar velocity



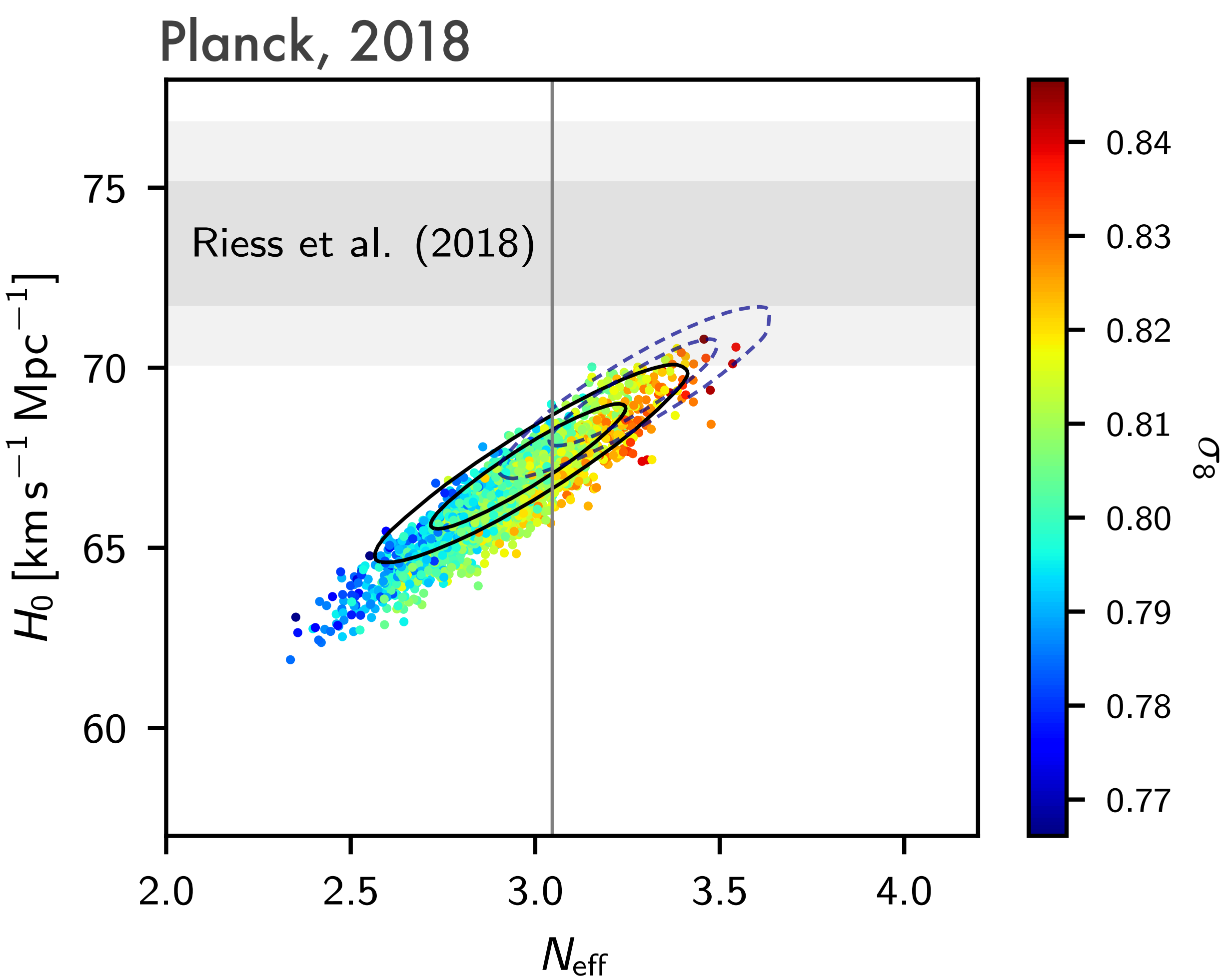
- Models the possible biases instead of correcting them *a priori*
- Maximizes the information extracted from the data
- Is modular

Modularity and possible extensions

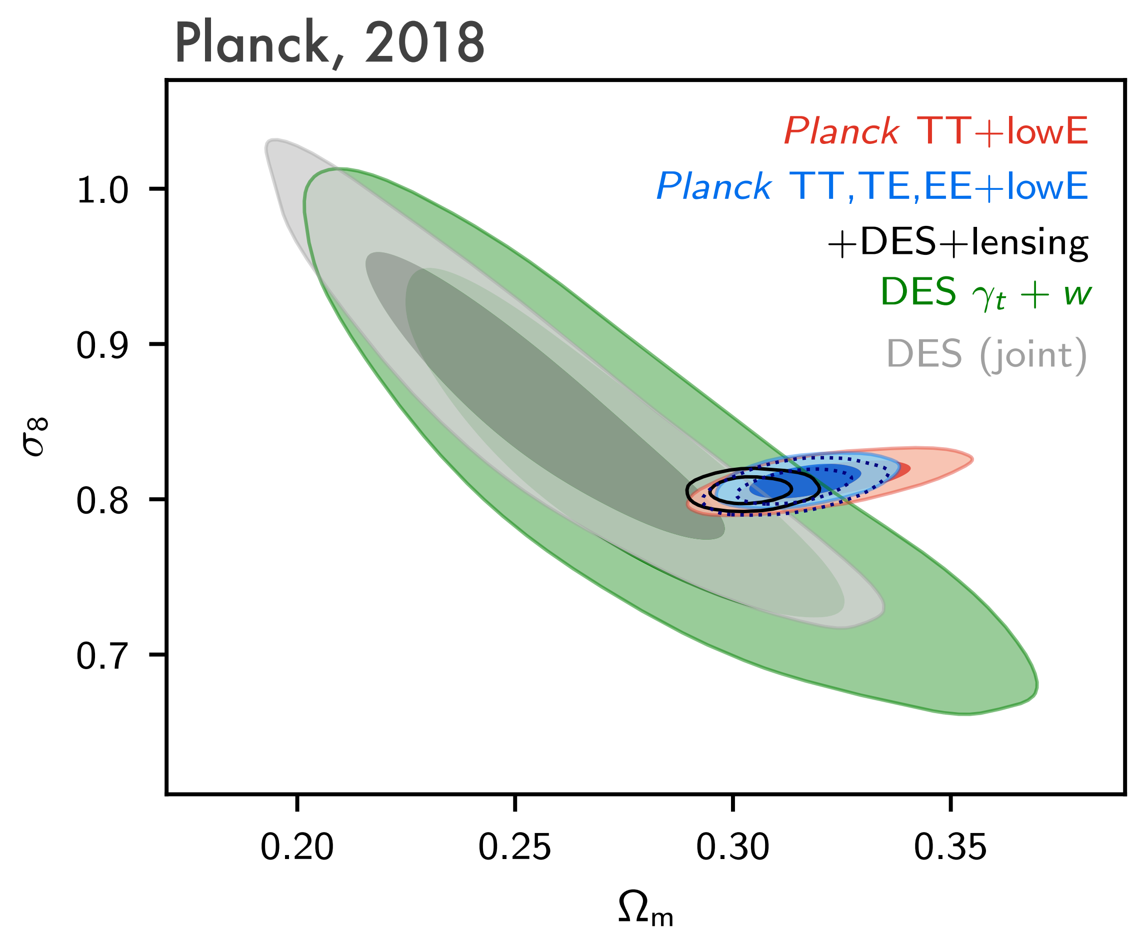


A cosmological probe for a LCDM in tension

Expansion

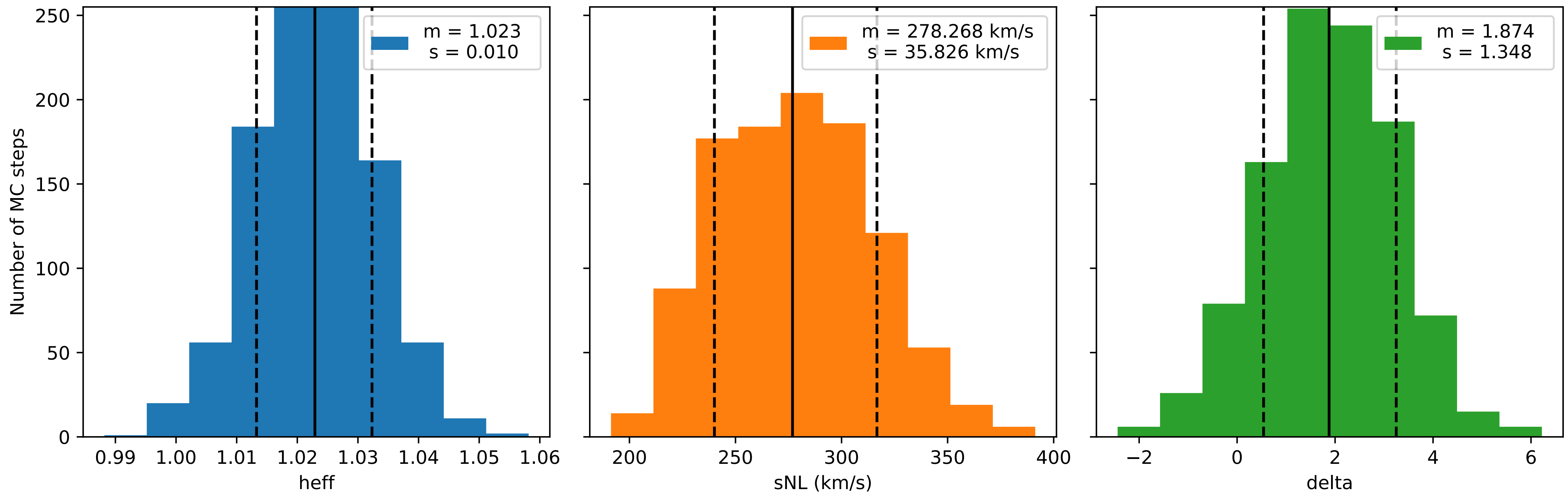


Gravity

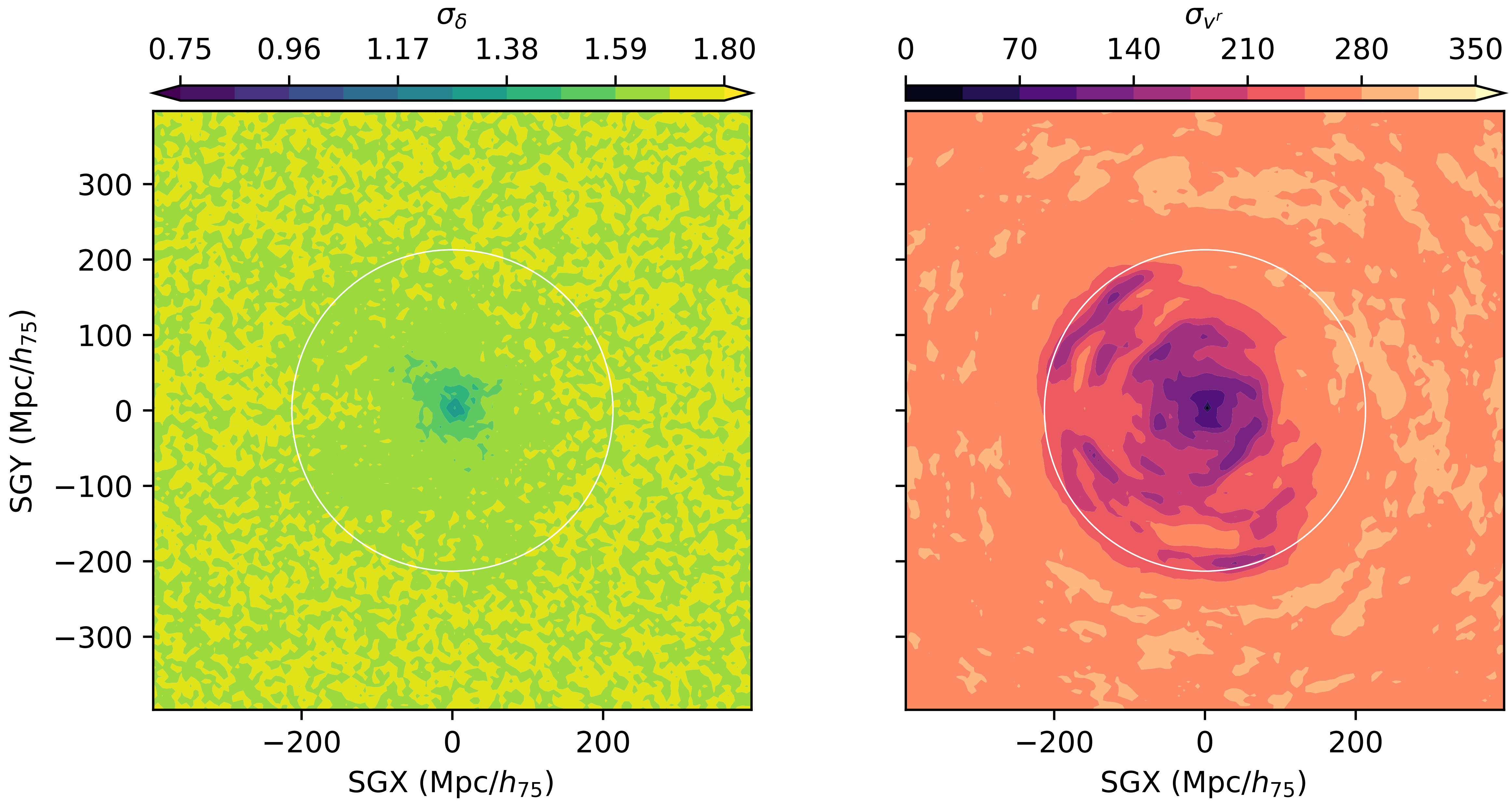


The present model will be able to provide
a **direct**, **local** and **independent** measurement of the cosmological parameters

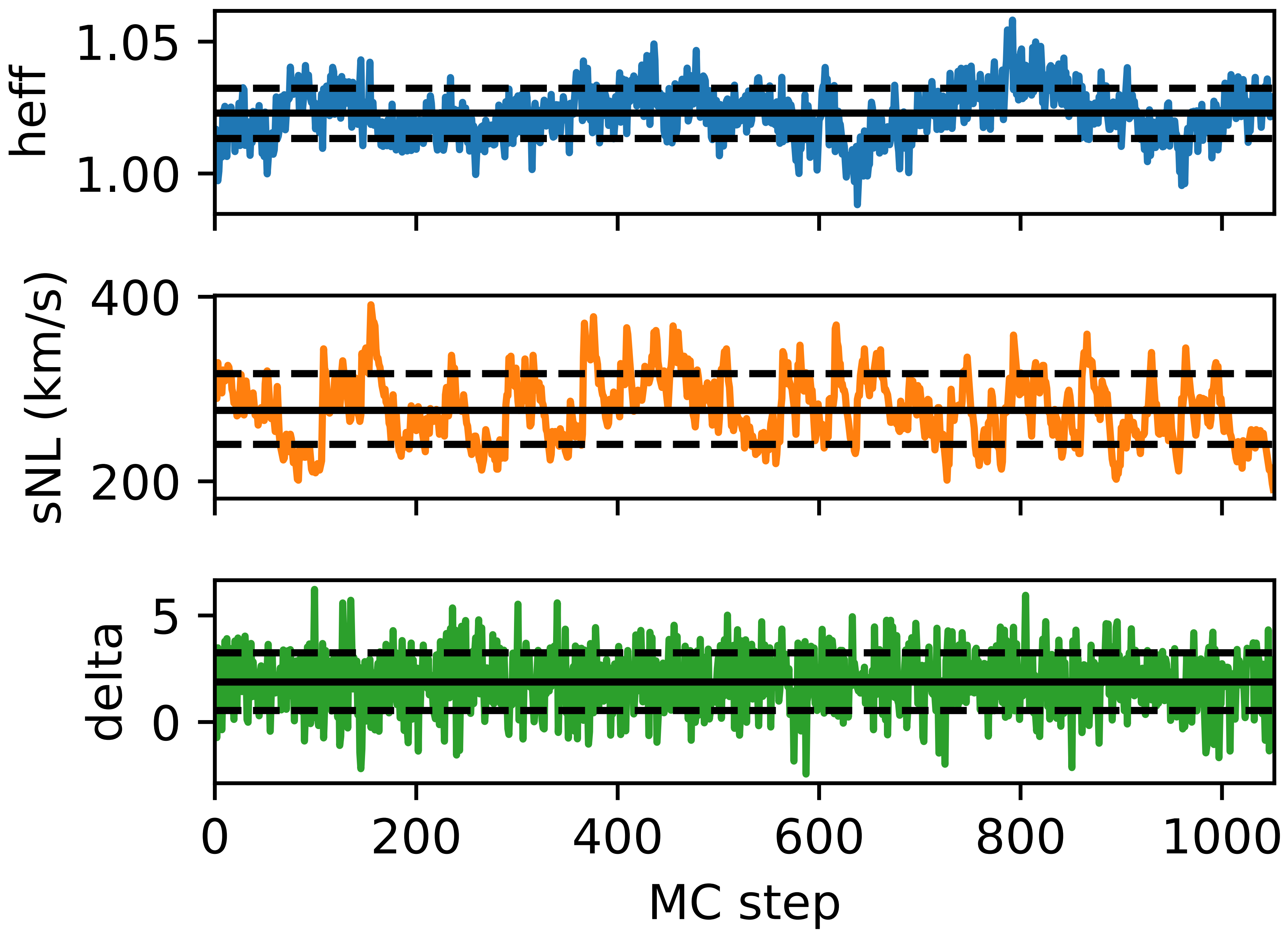
Thank you

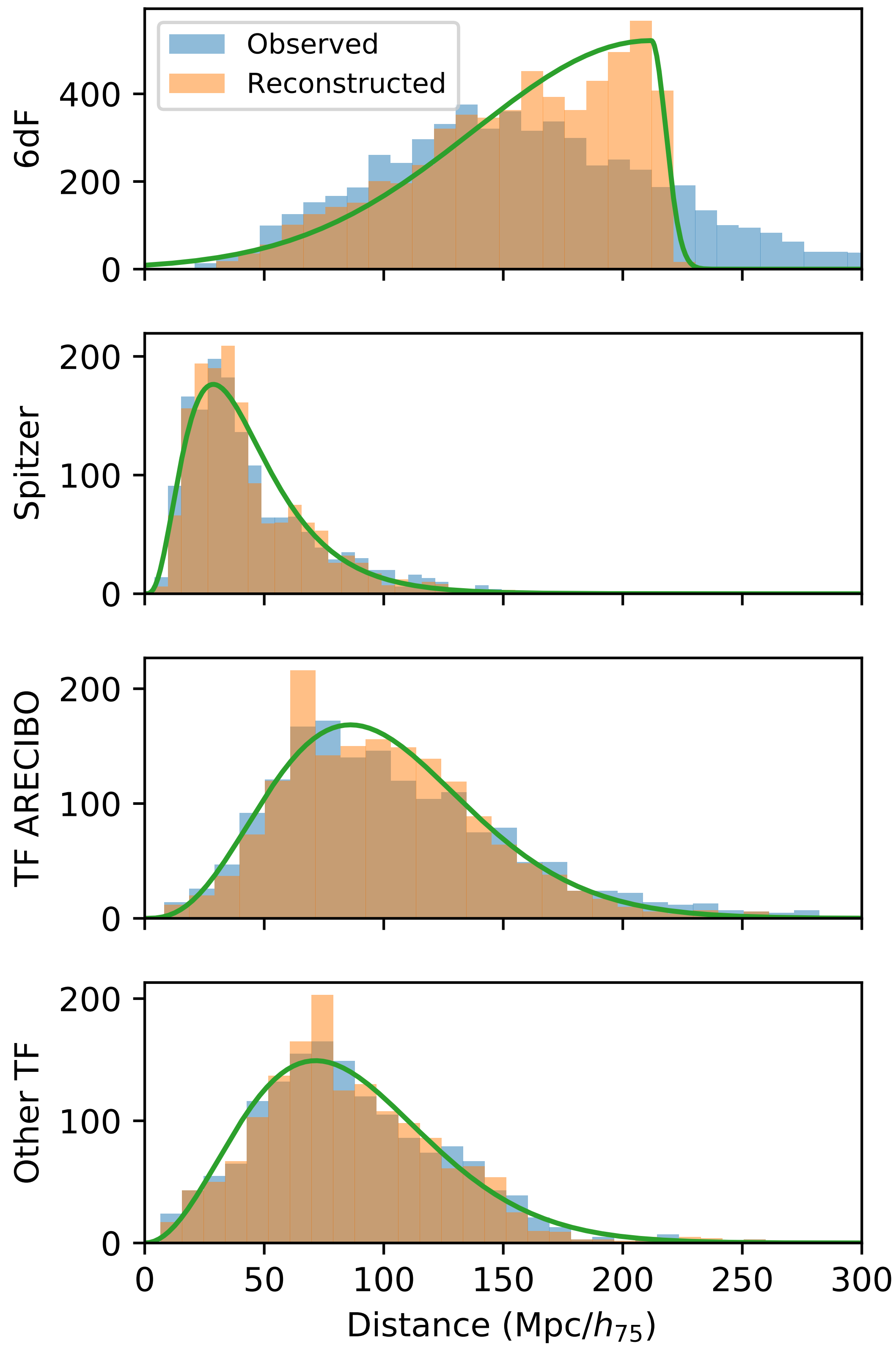


Number of MC steps
m = 1.023
s = 0.010
heff
m = 278.268 km/s
s = 35.826 km/s
sNL (km/s)
m = 1.874
s = 1.348
delta

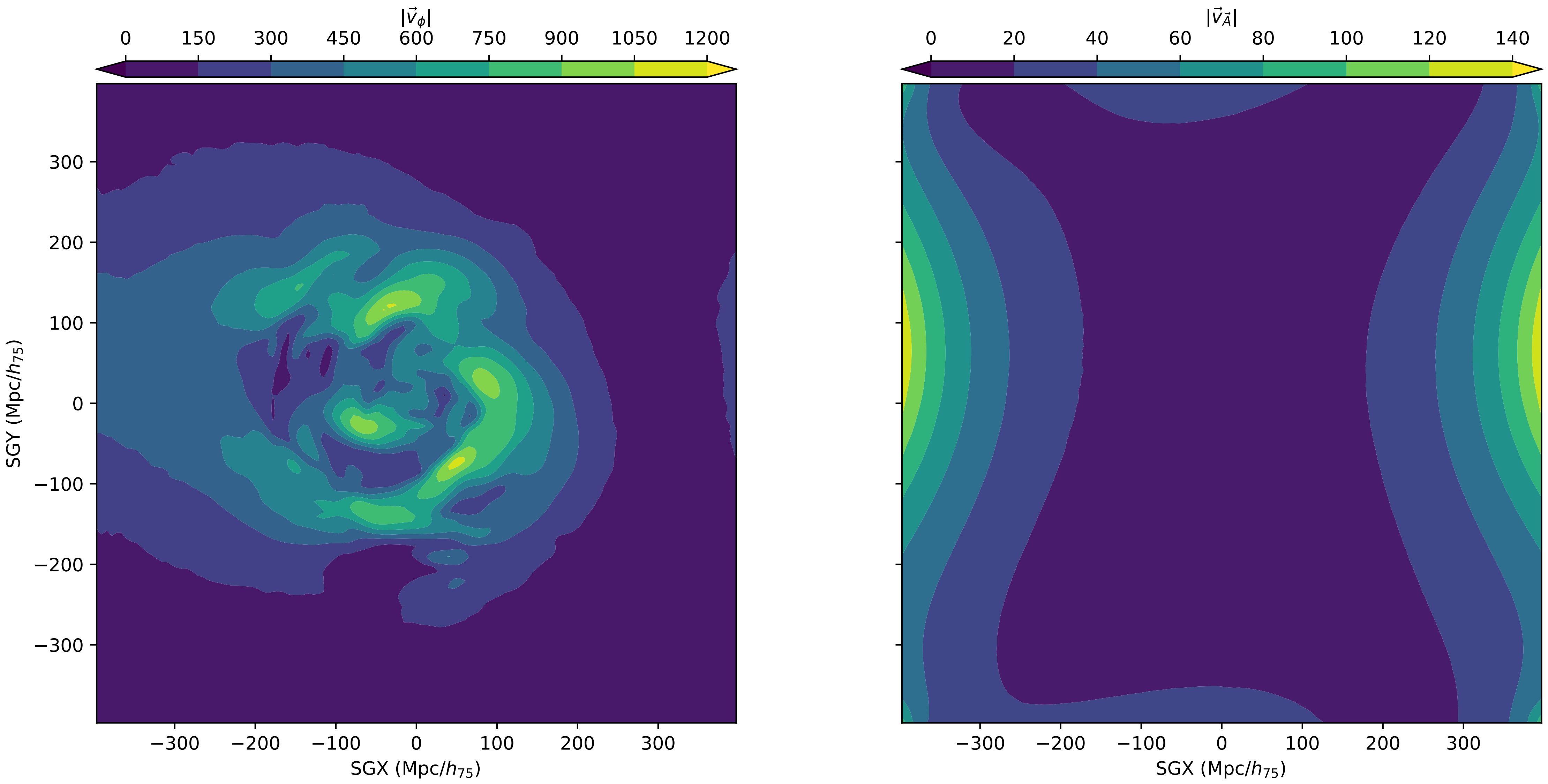


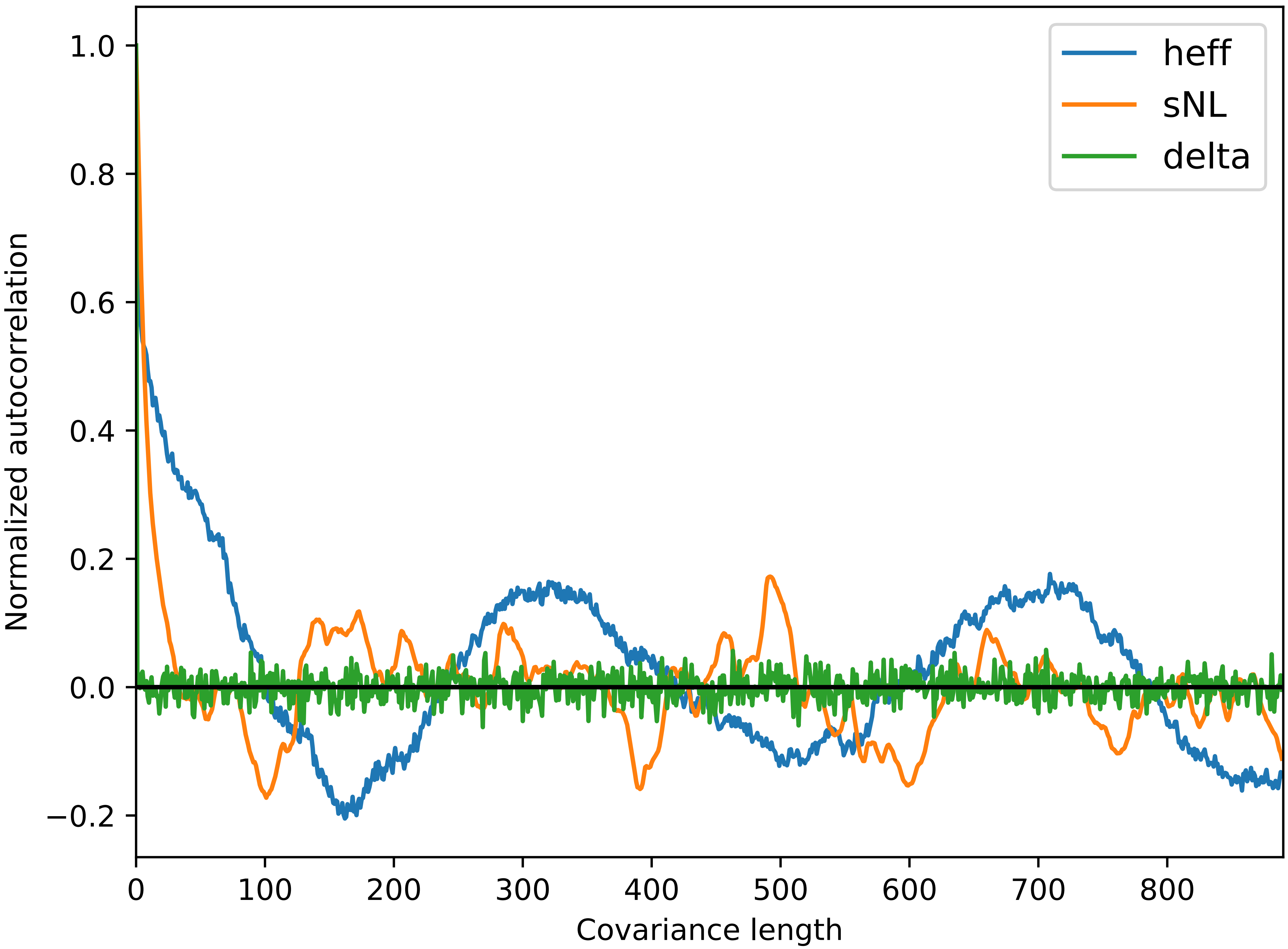
σ_δ
0.75
0.96
1.17
1.38
1.59
1.80
300
200
100
0
−100
−200
−300
SGY (Mpc/h_{75})
−200
0
200
SGX (Mpc/h_{75})
σ_{v^r}
0
70
140
210
280
350
−200
0
200
SGX (Mpc/h_{75})


1.05
1.00
heff
400
200
sNL (km/s)
5
0
delta
0
200
400
600
800
1000
MC step

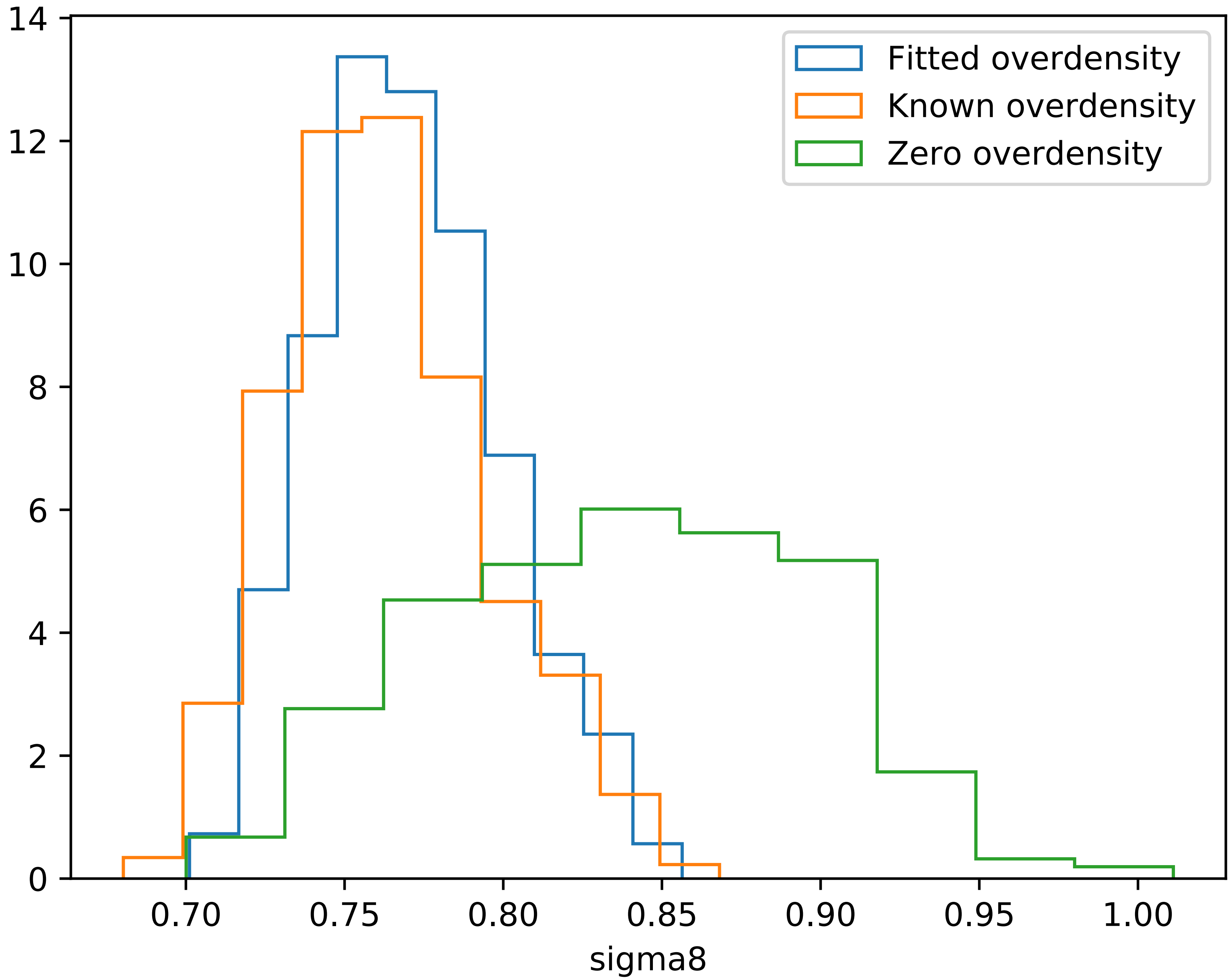


Observed
Reconstructed
6dF
400
200
0
Spitzer
200
100
0
TF ARECIBO
200
100
0
Other TF
200
100
0
0
50
100
150
200
250
300
Distance (Mpc/h_{75})

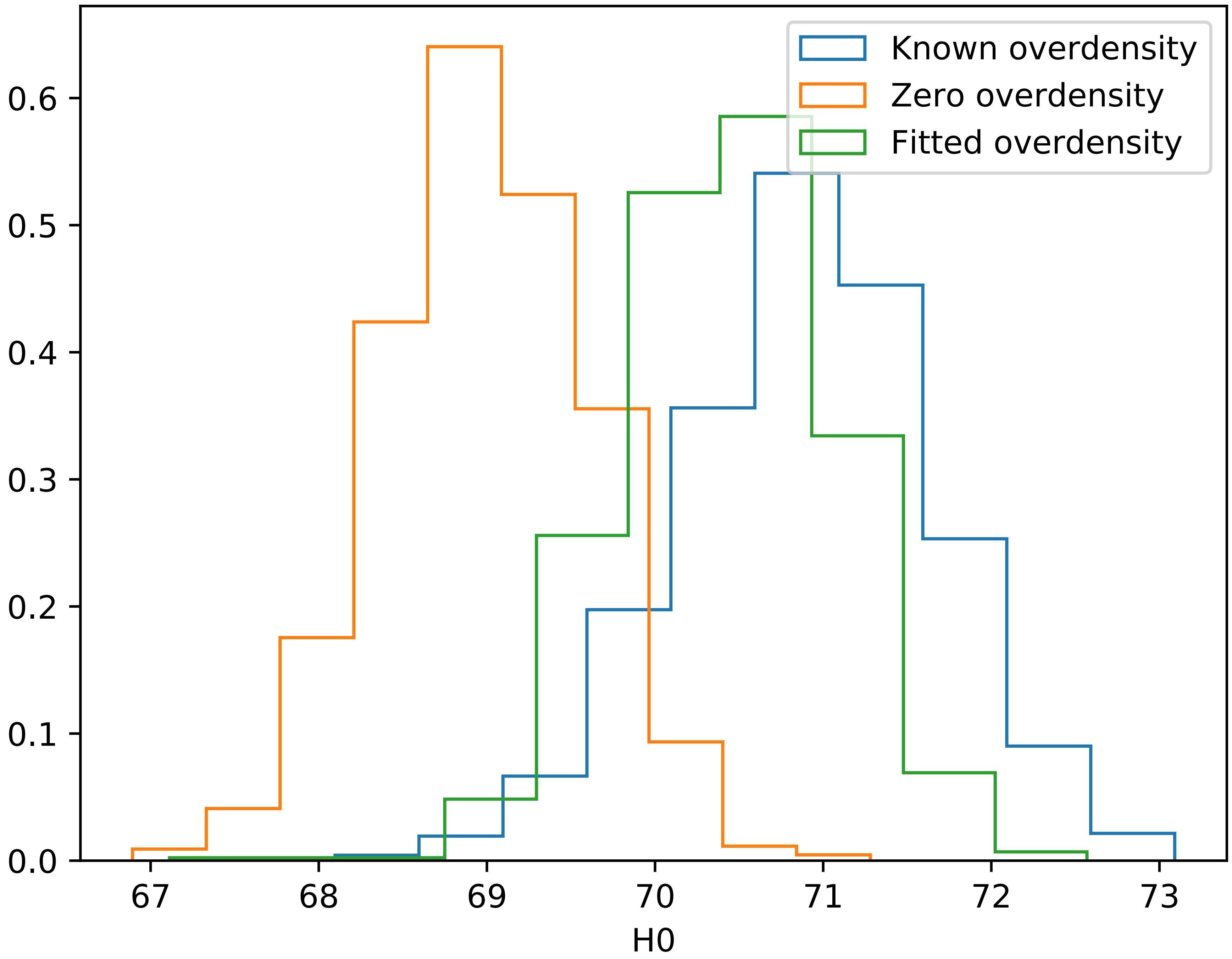

$|\vec{v}_\phi|$
0 150 300 450 600 750 900 1050 1200
300
200
100
0
−100
−200
−300
SGY (Mpc/h_{75})
−300 −200 −100 0 100 200 300
SGX (Mpc/h_{75})
$|\vec{v}_{\vec{A}}|$
0 20 40 60 80 100 120 140
−300 −200 −100 0 100 200 300
SGX (Mpc/h_{75})


heff
sNL
delta
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
Normalized autocorrelation
0
100
200
300
400
500
600
700
800
Covariance length

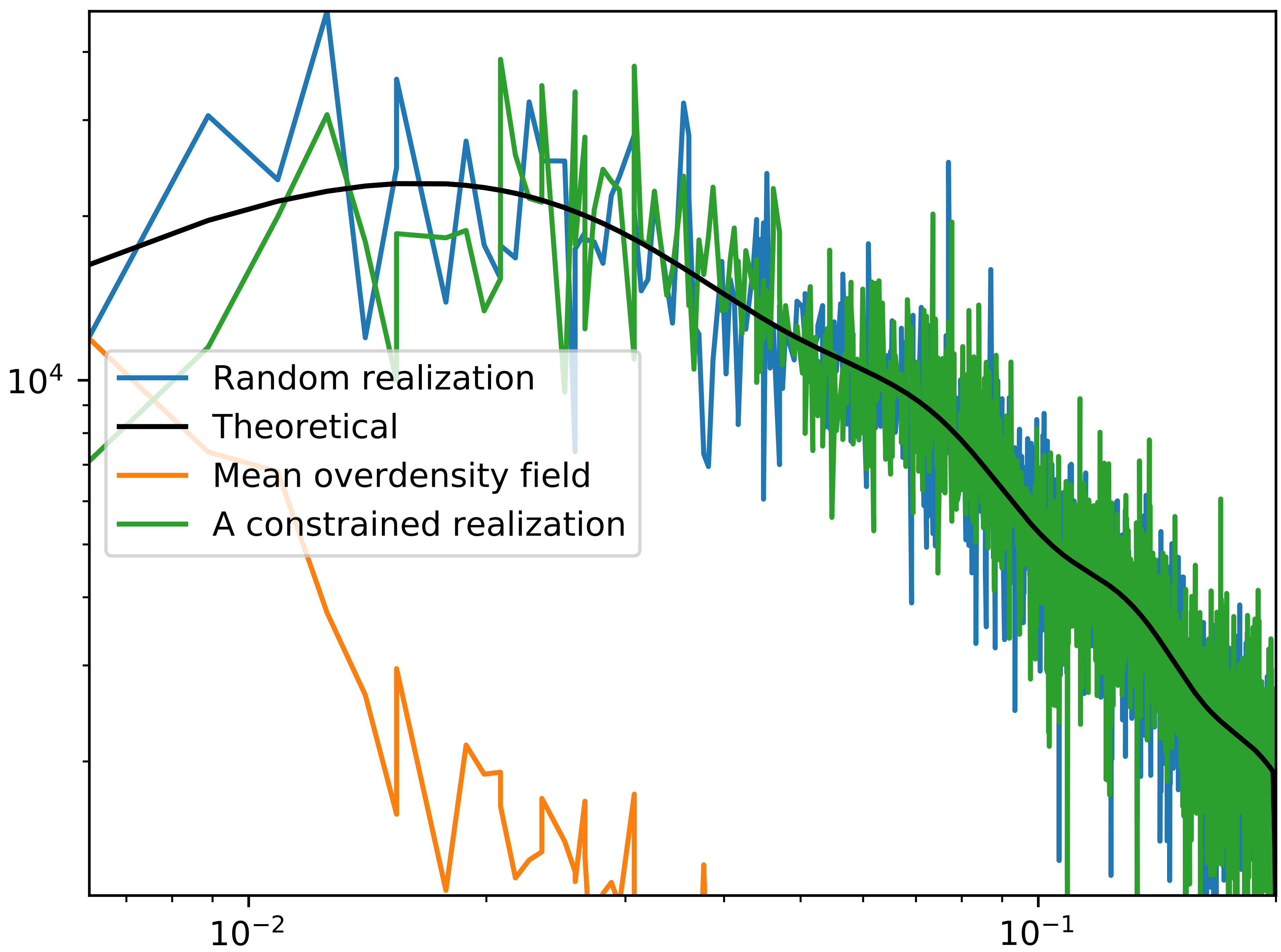
Mock and cosmology



Mock and cosmology



Mock and cosmology



Selection effects

$$\mathcal{P}_{\mathcal{S}}\left(\mu|r\right) = \frac{\mathcal{P}\left(\mathcal{S}|\mu, r\right)\mathcal{P}\left(\mu|r\right)}{\mathcal{P}\left(\mathcal{S}|r\right)}$$

$$\mathcal{P}\left(r|\mu\right) = \frac{\mathcal{P}\left(\mathcal{S}|\mu, r\right)\mathcal{P}\left(\mu|r\right)\mathcal{P}(r)}{\mathcal{P}\left(\mathcal{S}|r\right)\mathcal{P}(\mu)}$$

Non-linearity

Likelihoods