Observational problems in reconstruction of peculiar velocities of galaxies

Guilhem Lavaux, IAP (Paris/France)

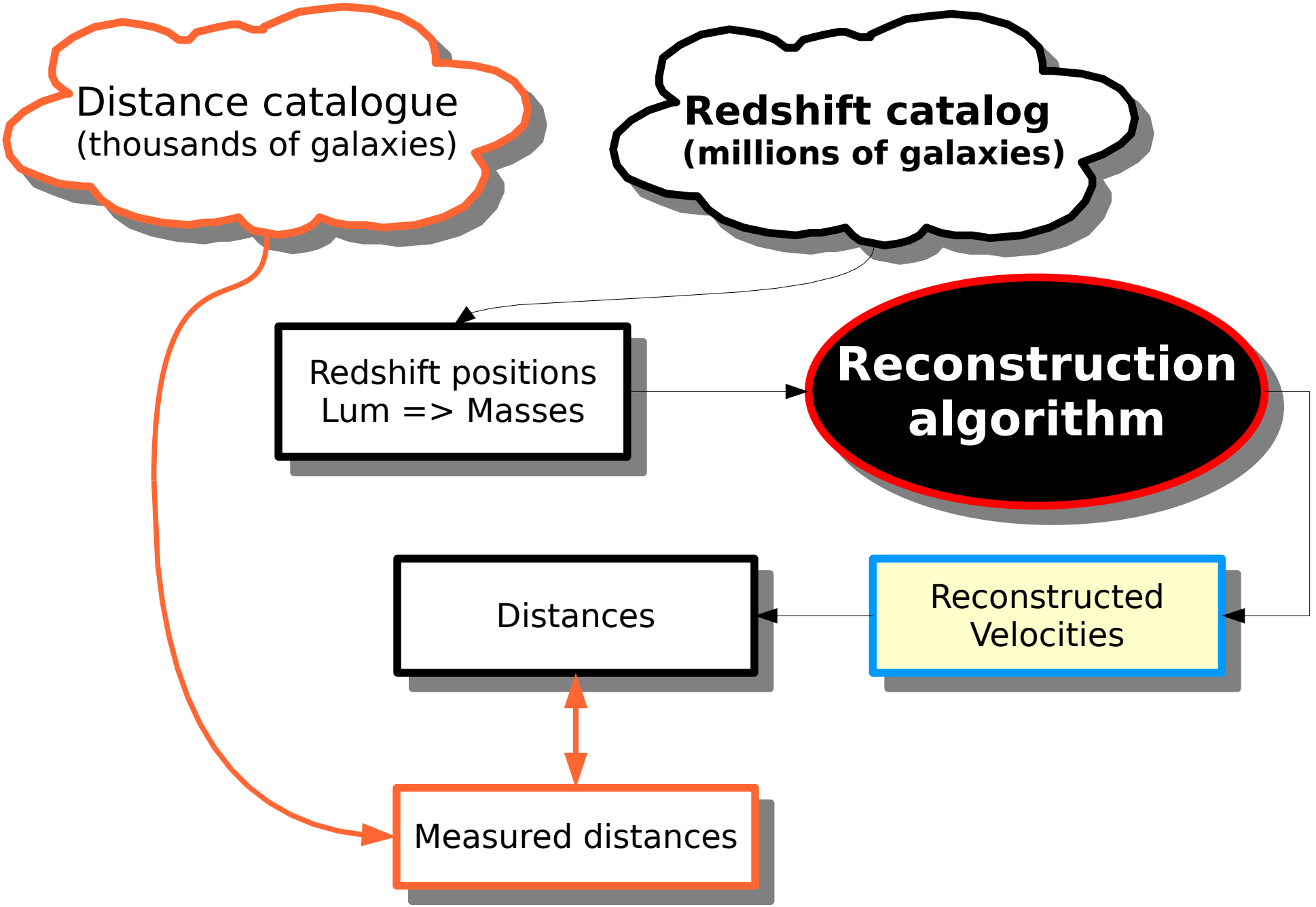
Ph.D. subject: “Reconstruction of primordial density fluctuations”

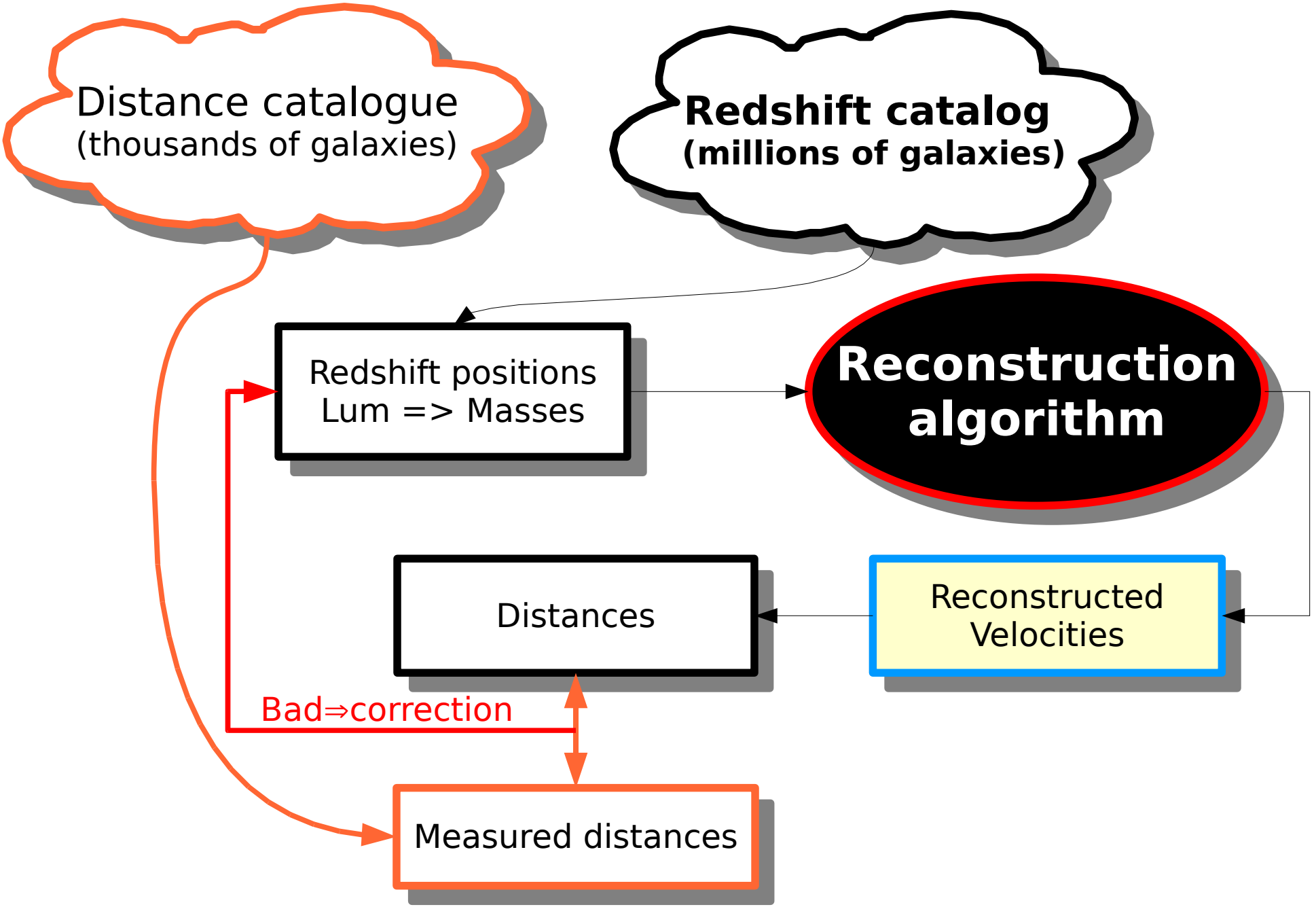
Advisors: Roya Mohayaee (IAP/Paris), Brent Tully (IfA/Honolulu)
Stéphane Colombi (IAP)

Astro-ph **0707.3483, MNRAS**
G. Lavaux, R. Mohayaee, S. Colombi, R. B. Tully, F.Bernardeau, J. Silk

Tuesday 30th October 2007

Fermilab


Distance catalogue
(thousands of galaxies)
Redshift catalog
(millions of galaxies)
Redshift positions
Lum => Masses
Reconstruction
algorithm
Distances
Reconstructed
Velocities
Measured distances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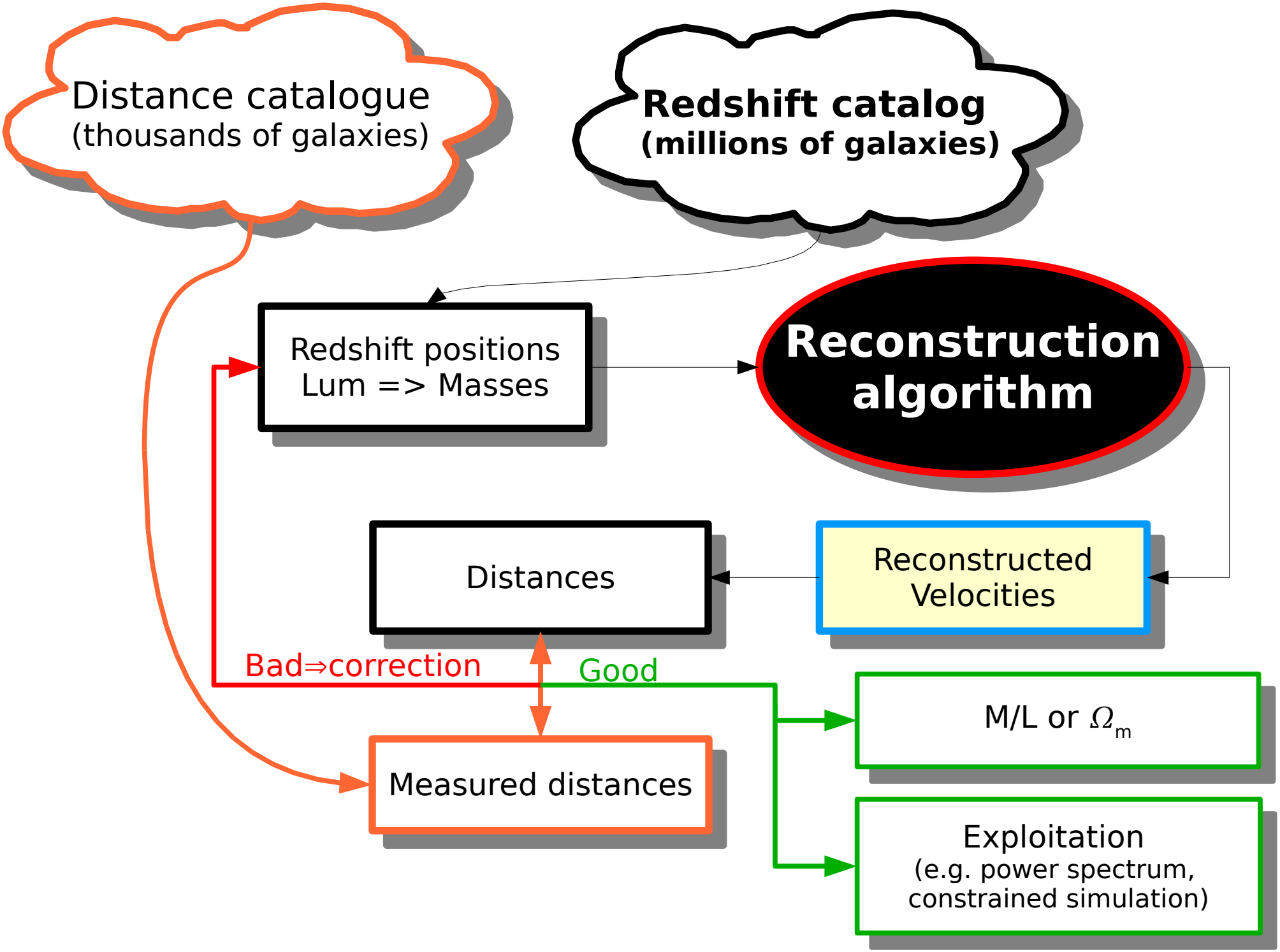
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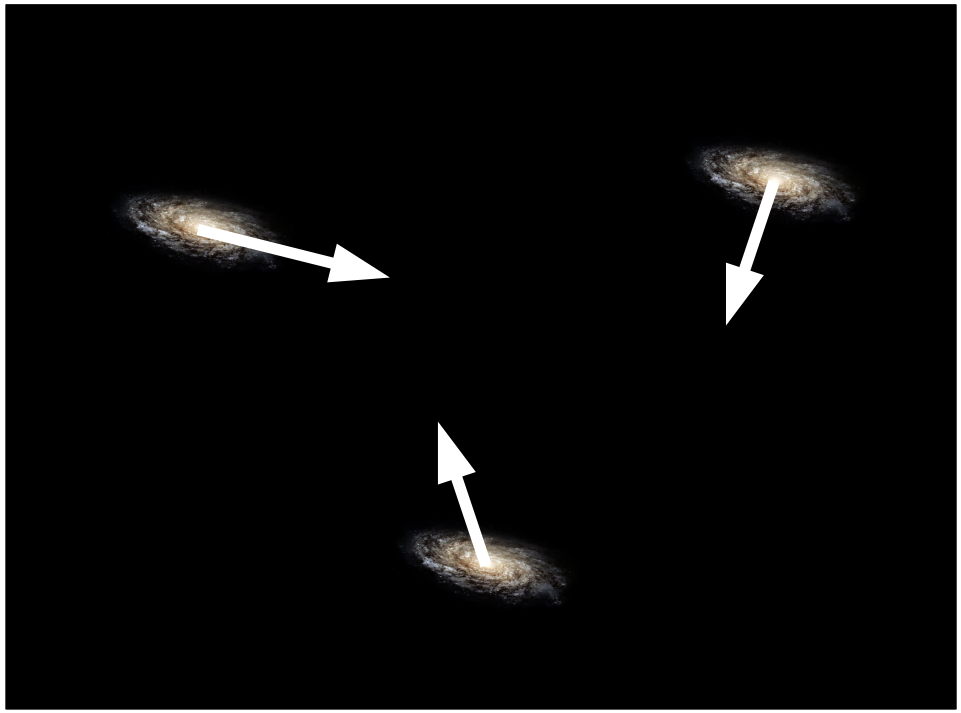
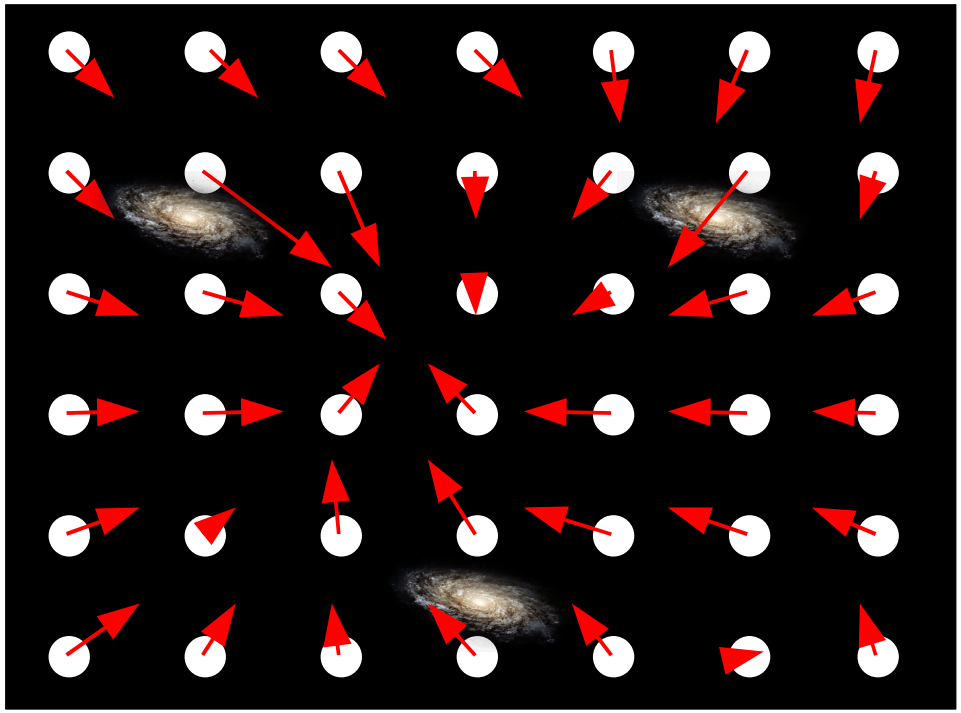
Reconstructed Velocities
Bad⇒correction
Good
Measured distances
M/L or Ω_m
Exploitation
(e.g. power spectrum, constrained simulation)

The algorithms

- Lagrangian reconstructions:
  - Least-Action (Peebles 1989)
  - MAK (Monge-Ampère-Kantorovitch) (Brenier et al. 2003, Lavaux et al. 2007)



- Eulerian reconstructions
  (e.g. POTENT Bertschinger&Dekel 1989)



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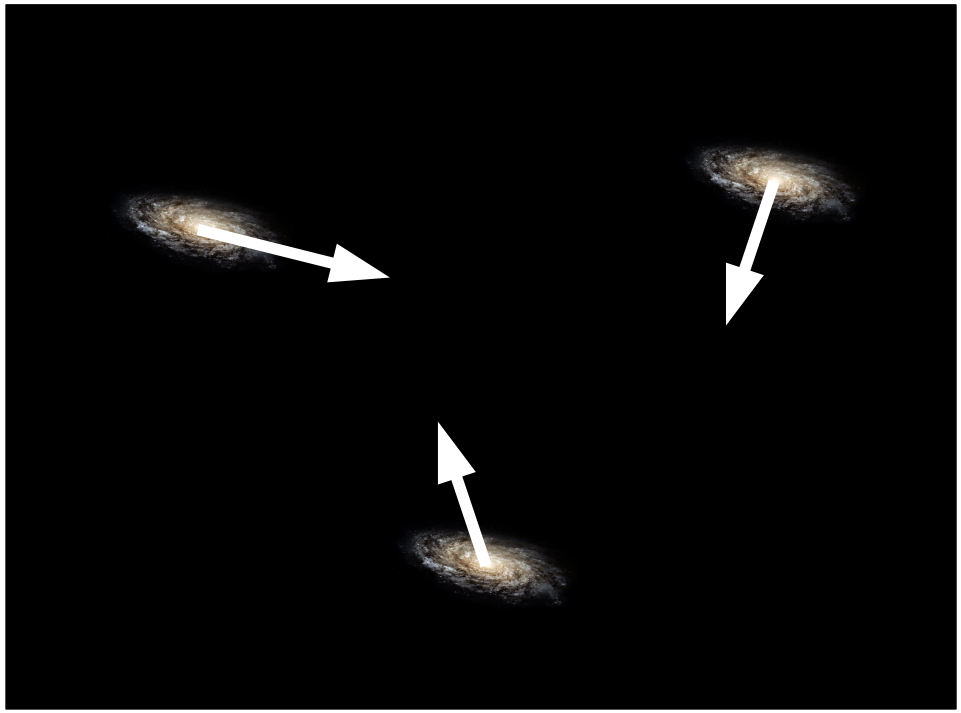

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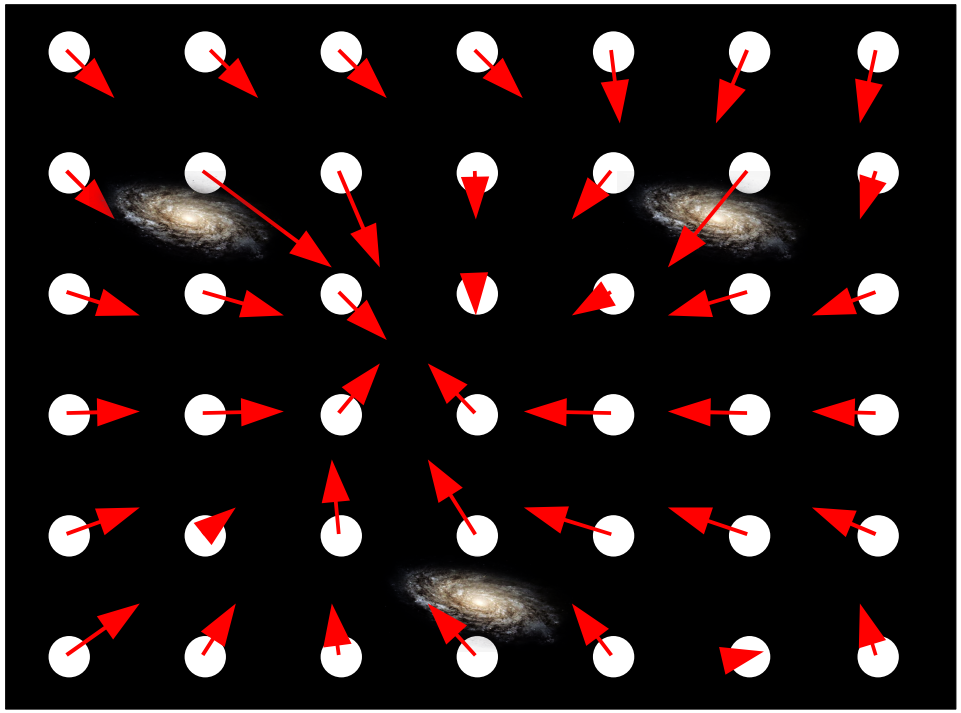
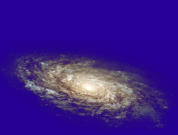


Advantages

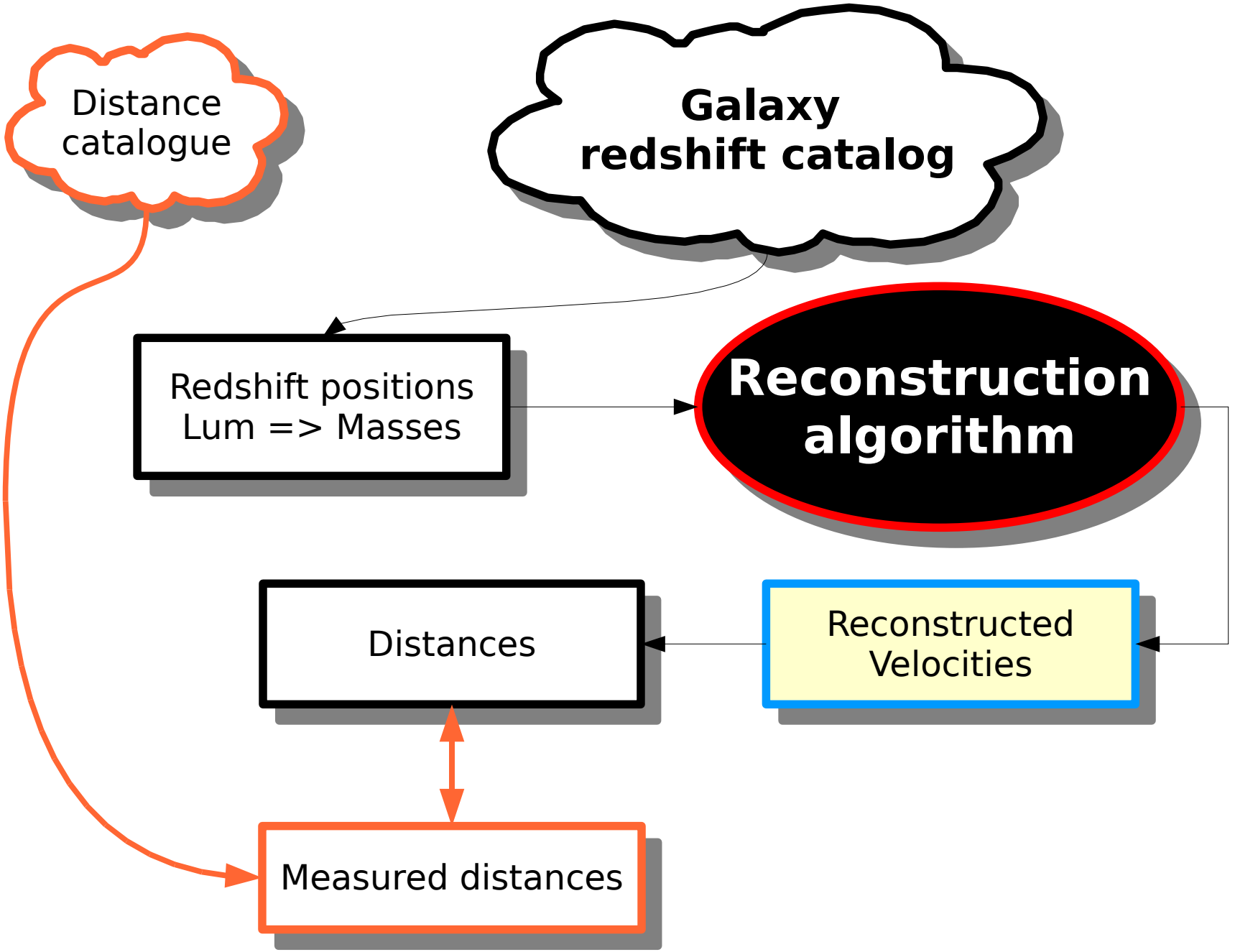


- Particle-oriented description (e.g. galaxies) ⇨ No need for a smooth field.
- Linear regime of **Lagrangian** perturbation theory already gives non-linear phenomena in **Eulerian** perturbation theory.

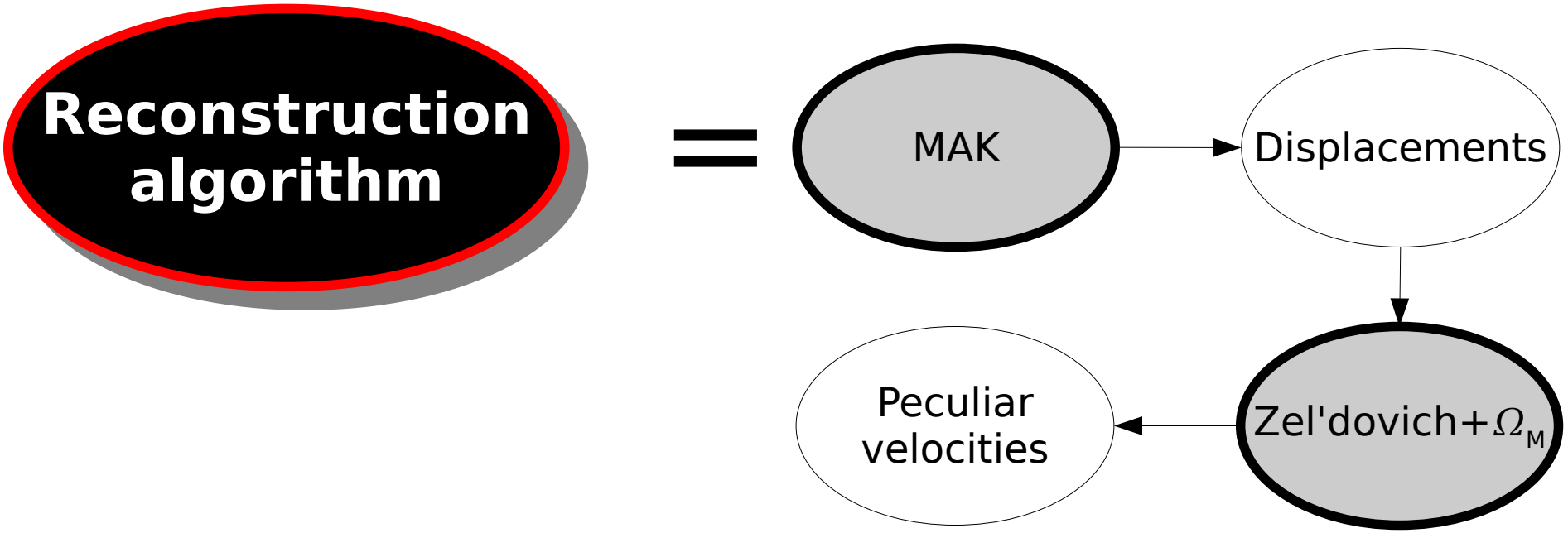
Outline

1. The MAK reconstruction
2. Presentation of mock catalogs
3. Presentation of observational biases
4. Preliminary results on NBG-3k catalog
5. Ongoing work on 2MASS redshift survey...
6. Future work: SDSS

1. The MAK reconstruction


Distance catalogue
Galaxy redshift catalog
Redshift positions
Lum => Masses
Reconstruction algorithm
Distances
Reconstructed Velocities
Measured distances

The MAK “black box”



Hypothesis displacement field is convex potential ⇔ **no** shell crossing

motivated by Lagrangian perturbation theory, N-body simulation

\+ Mass conservation

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motivated by Lagrangian perturbation theory, N-body simulation

Mass conservation

Monge-Ampère problem: $\left|\frac{\partial^2 \Phi}{\partial x_i \partial x_j}\right|_{i,j} = \frac{\rho(\boldsymbol{x})}{\rho_0}$

Brenier et al. 2003

Monge-Kantorovitch problem: $I[\boldsymbol{q}(\boldsymbol{x})] = \int \rho(\boldsymbol{x}) |\boldsymbol{x} - \boldsymbol{q}(\boldsymbol{x})|^2 d^3\boldsymbol{x}$

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Discretization: $S_\sigma = \sum_i (\boldsymbol{x}_i - \boldsymbol{q}_{\sigma(i)})^2$ ~ Inertial least-action principle

Gravity effects are yet included

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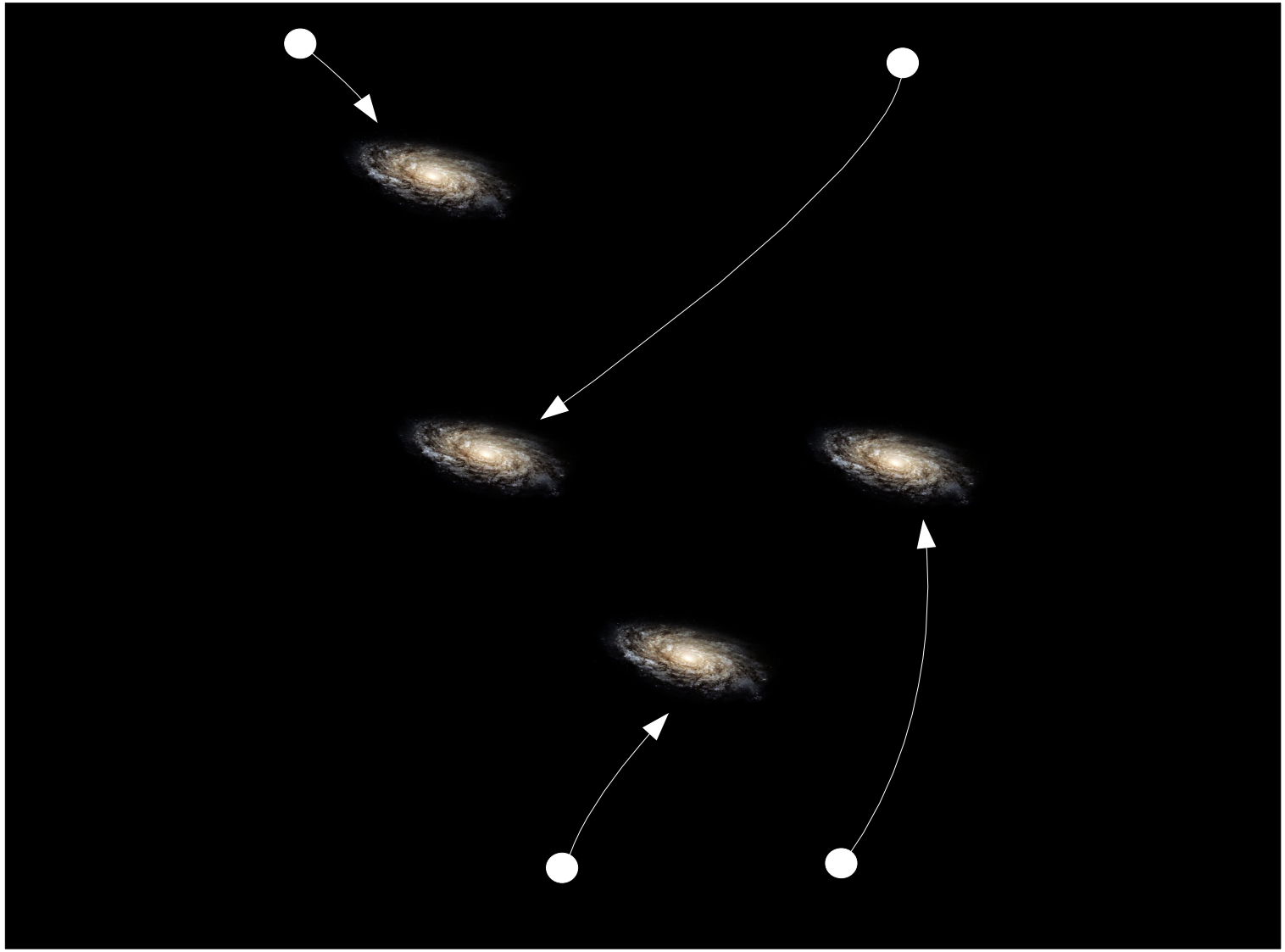
Gravity effects are yet included

Zel'dovich approximation: $\boldsymbol{v}_i = H\beta(\boldsymbol{x}_i - \boldsymbol{q}_i)$ with $\beta \approx \Omega_m^{5/9}$

Only dependence on cosmology

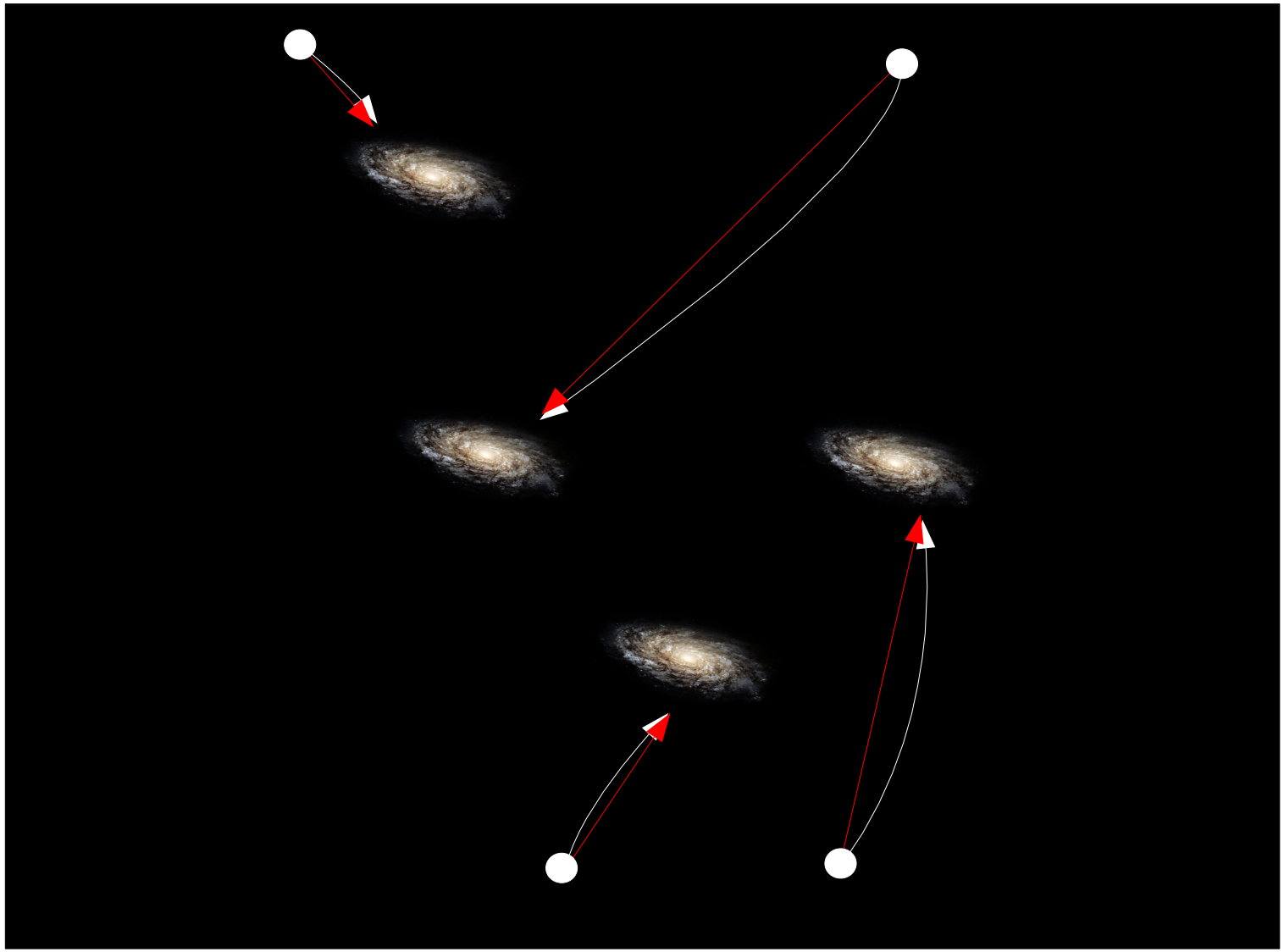
The MAK reconstruction

The true galaxy orbits



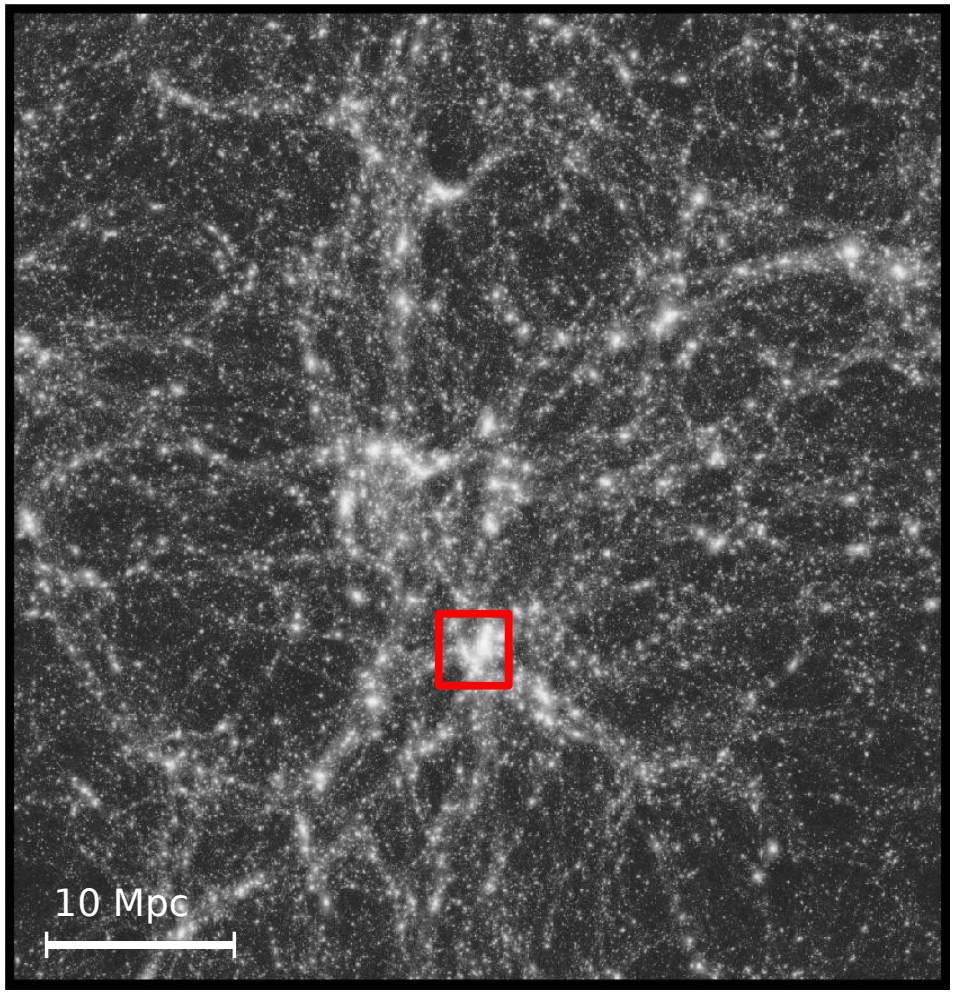
The MAK reconstruction

The **MAK** displacements



Comoving coordinates

MAK Scale ?



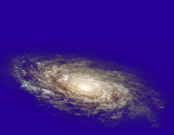
Slightly non-linear regime: MAK

Images: Projet Horizon, Springel 99

Algorithmic

- Direct solving of the minimization problem is practically impossible (O(N!) time complexity).

Algorithmic

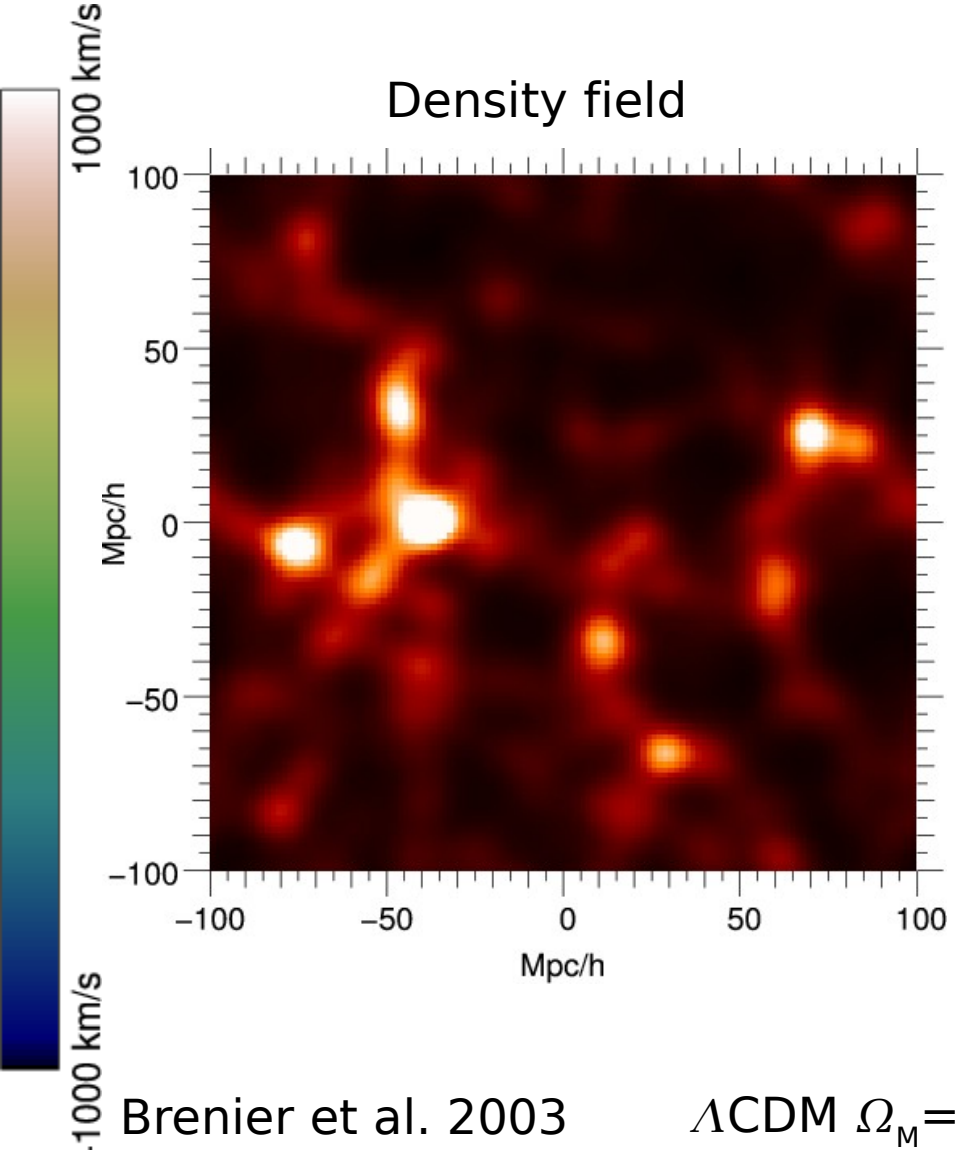


- Direct solving of the minimization problem is practically impossible (O(N!) time complexity).
- Use a better algorithm developed by Dimitri Bertsekas (originally to solve economics problem). $\Rightarrow$ $O(N^{2.25})$ time complexity.
- MPI/OpenMP implementation (publicly available later this year http://www.iap.fr/users/lavaux/)

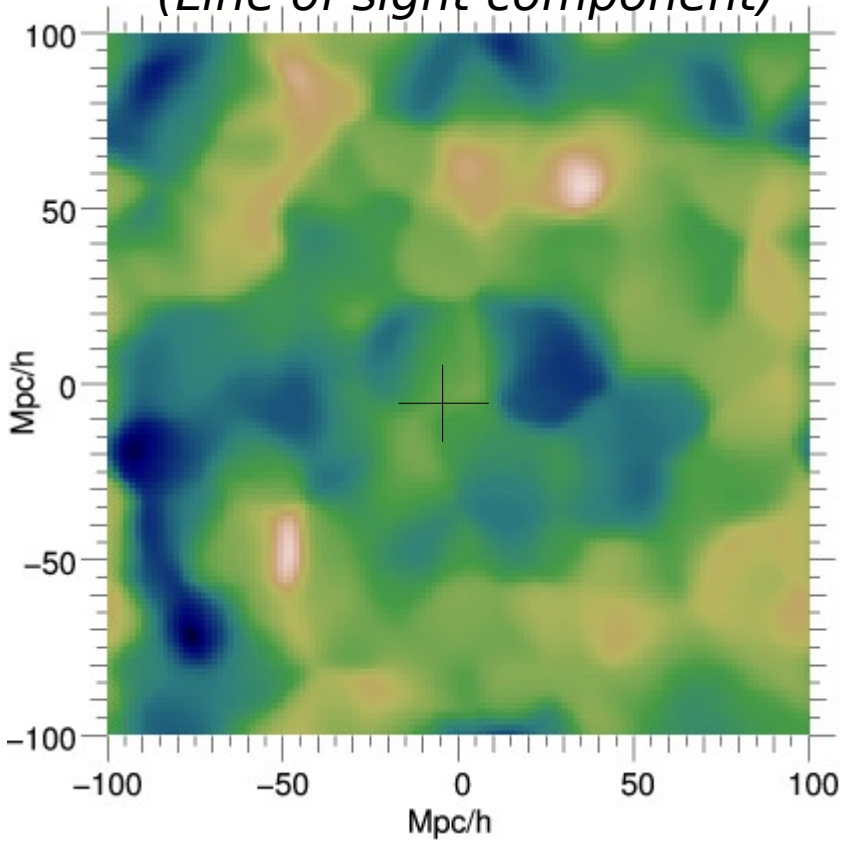
Direct testing on simulation

Simulation

Density field



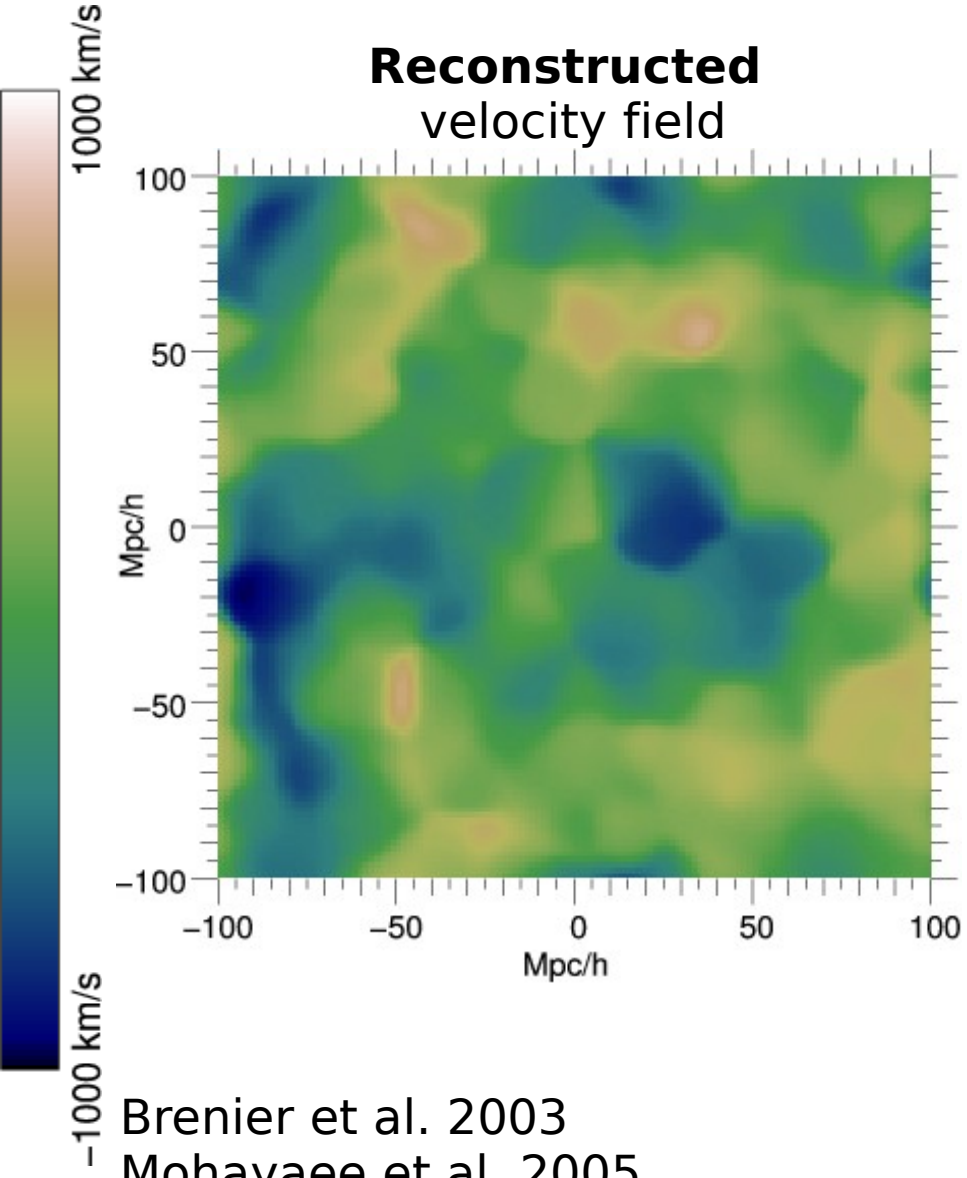
Simulated velocity field
(Line of sight component)

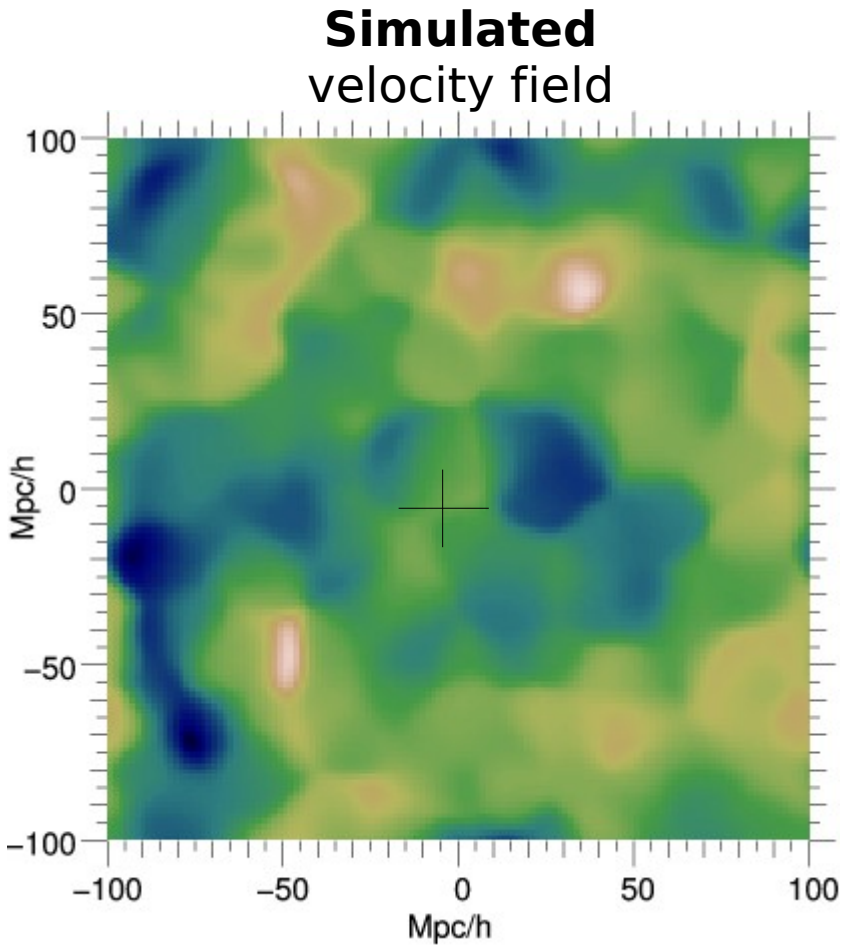


Brenier et al. 2003
Mohayaee et al. 2005

ΛCDM Ω_M=0.30, Ω_Λ = 0.70, σ_8=1.0, BBKS power spectrum
128^3 particles (but results do not change with a 512^3)

Direct testing on simulation





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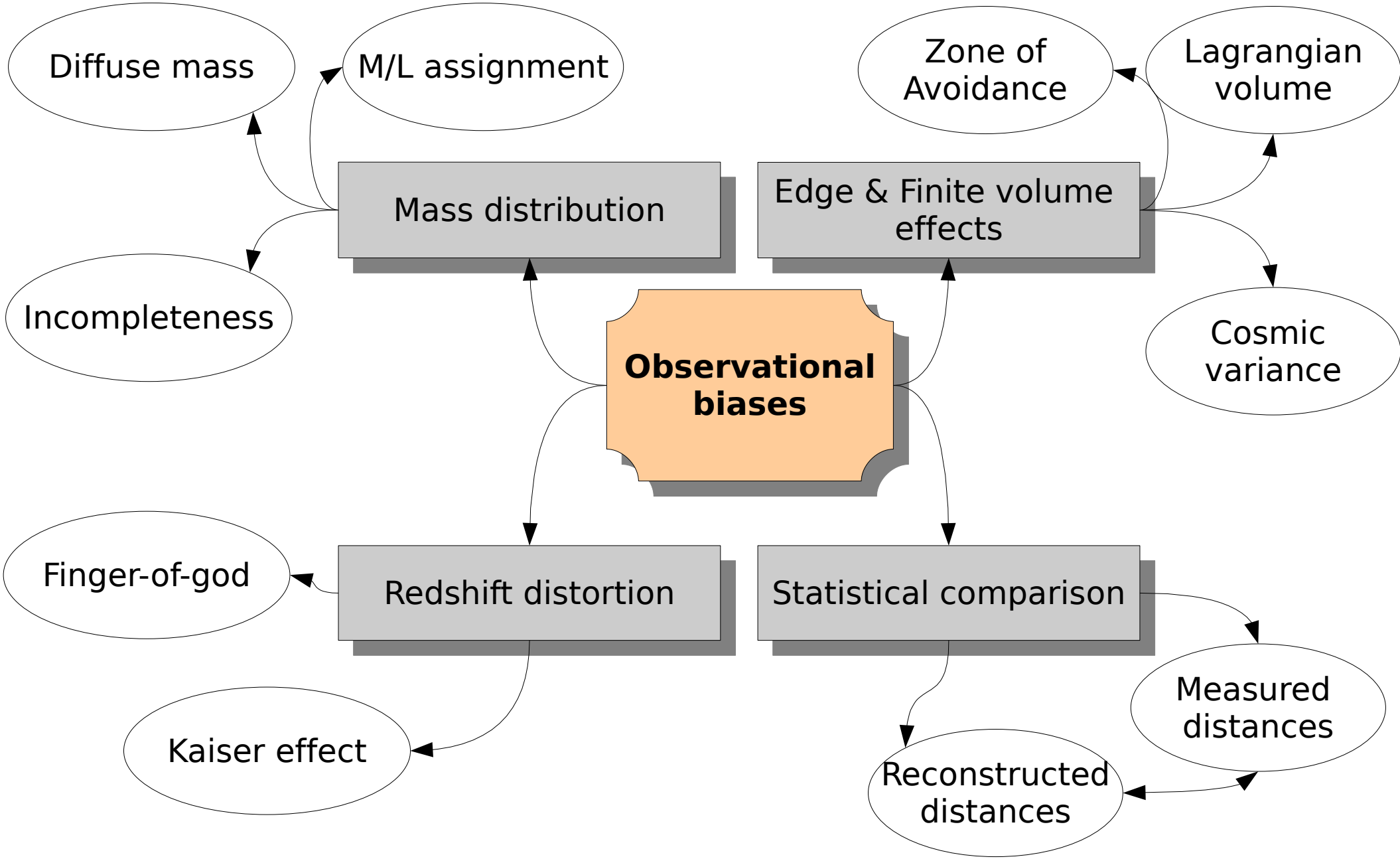
Diffuse mass
M/L assignment
Zone of Avoidance
Lagrangian volume
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Incompleteness
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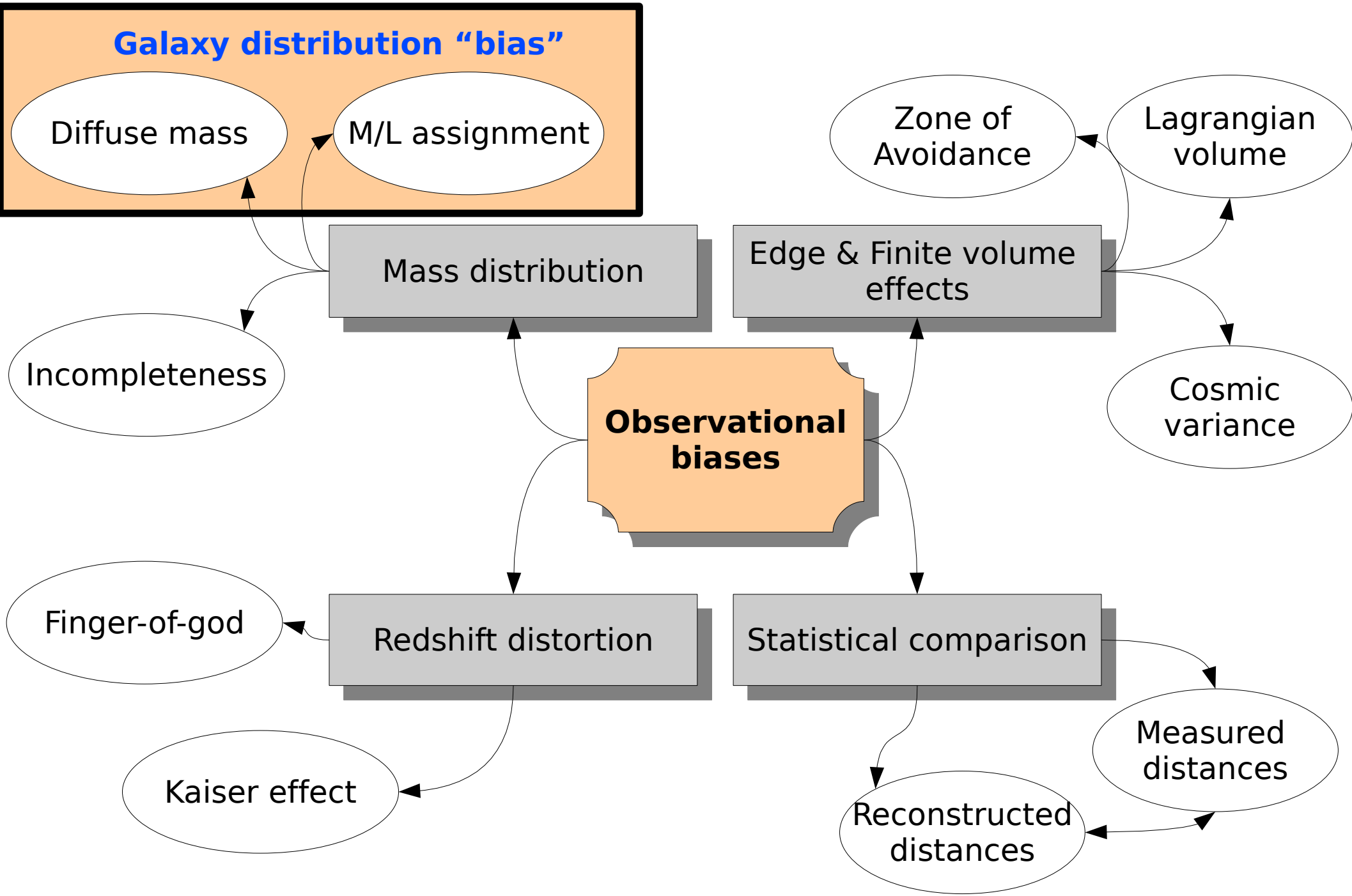
Observational biases
Finger-of-god
Redshift distortion
Statistical comparison
Measured distances
Kaiser effect
Reconstructed distances


Galaxy distribution “bias”
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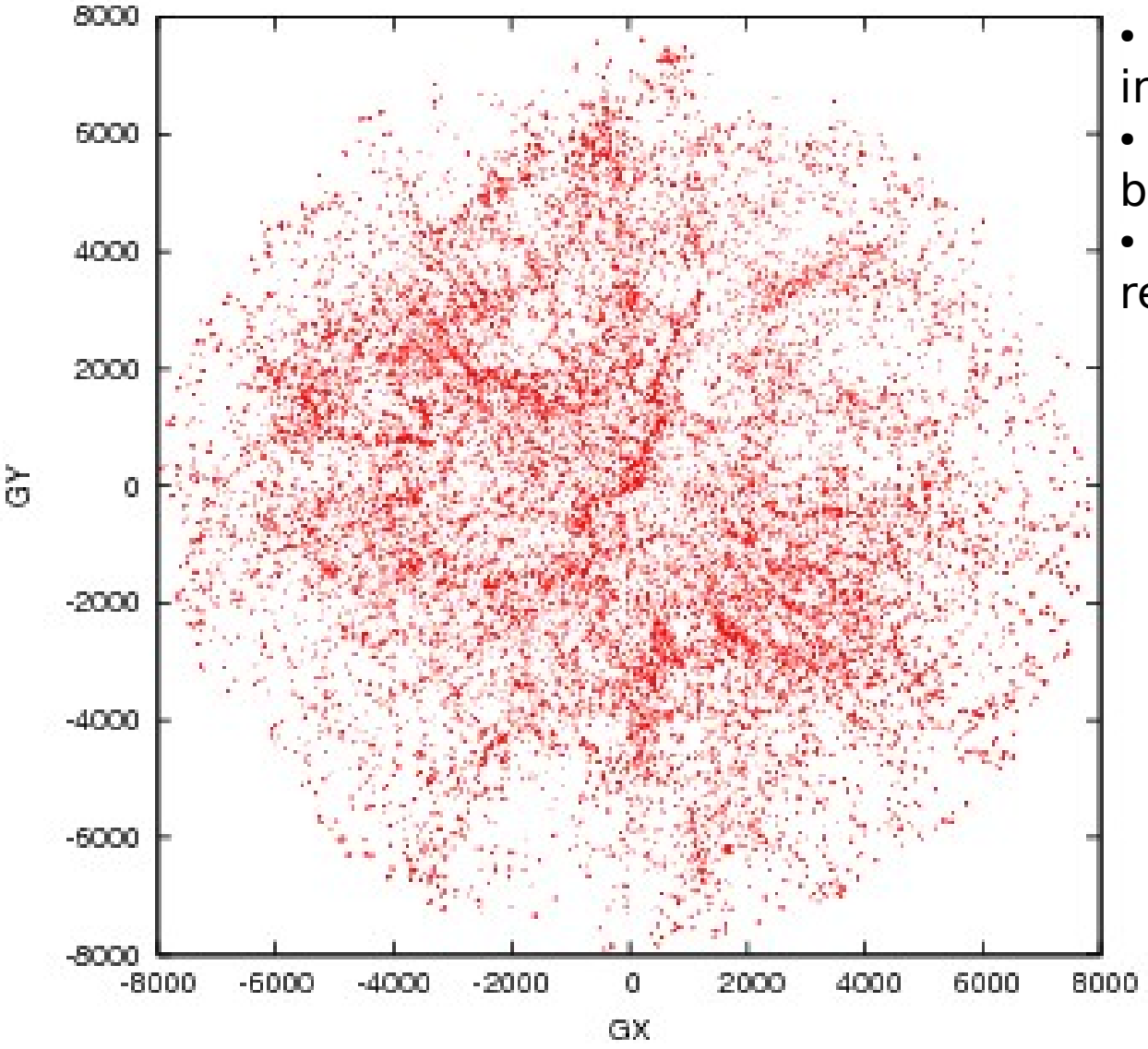
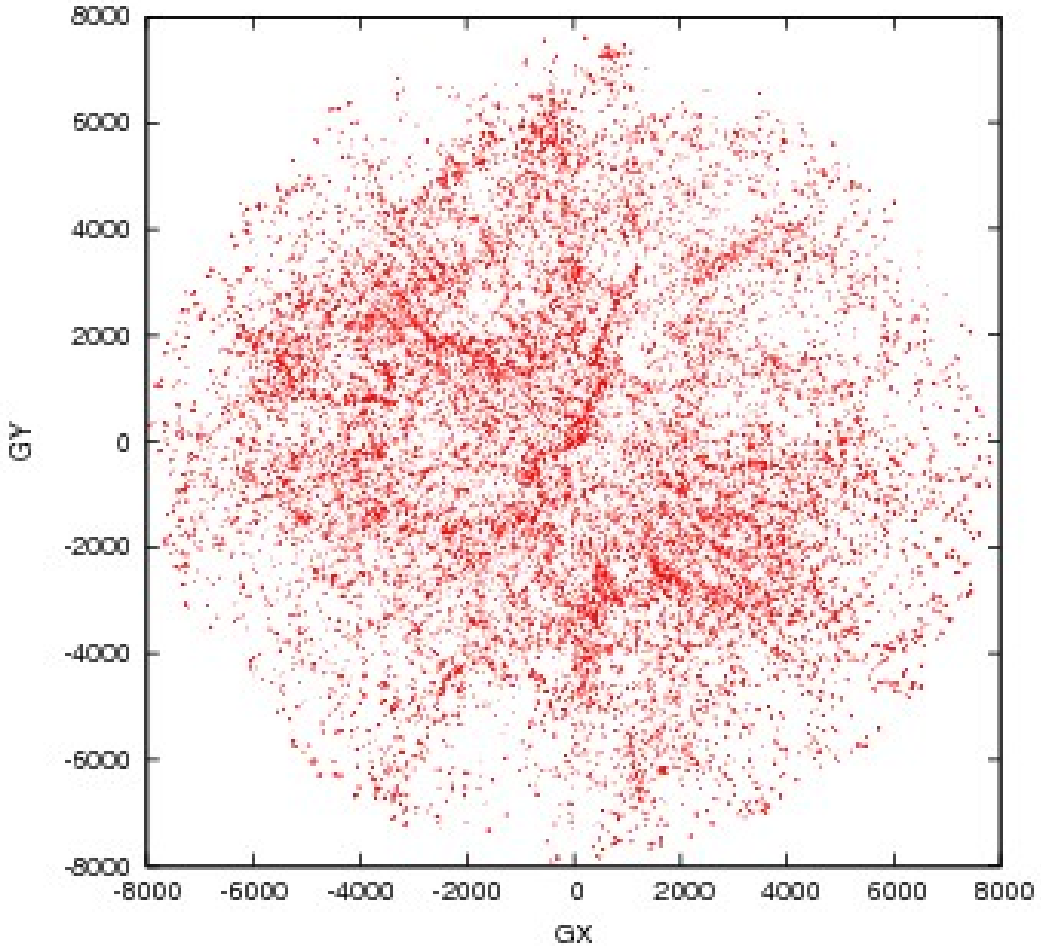
2. The mock catalogs

The NBG-8k catalog

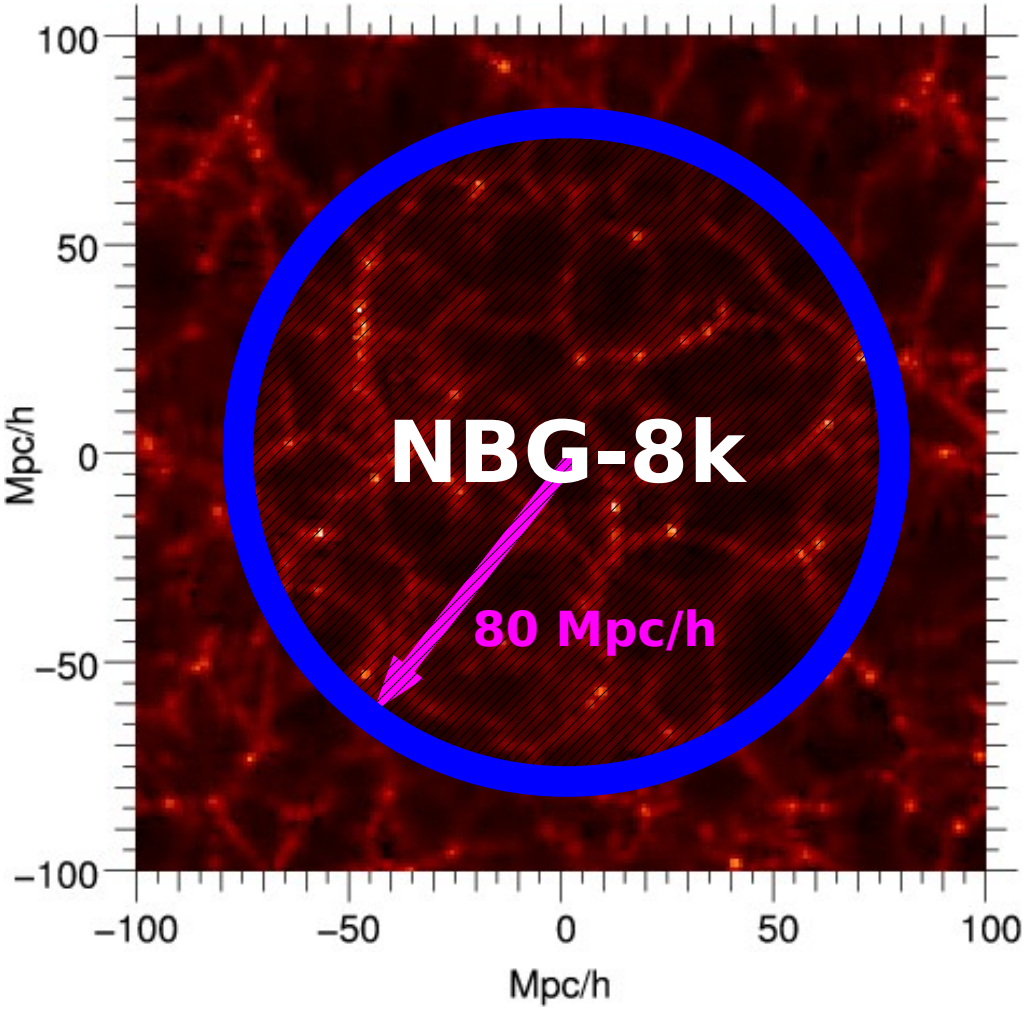


- ~25000 galaxies within 80 Mpc/h including their redshift
- built principally from ZCAT (B band)
- similar incompleteness as 2MASS redshift survey

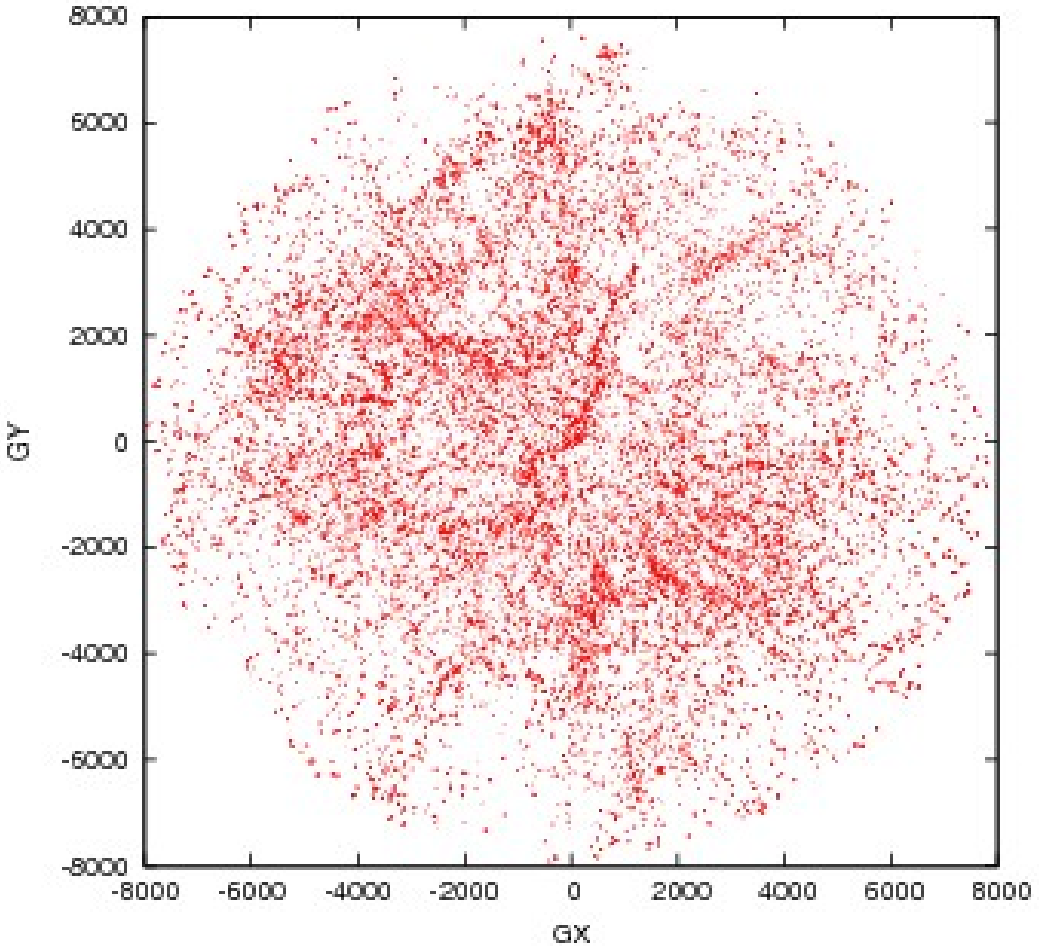
NGB-8k catalog



Mock NBG-8k catalog



NGB-8k catalog



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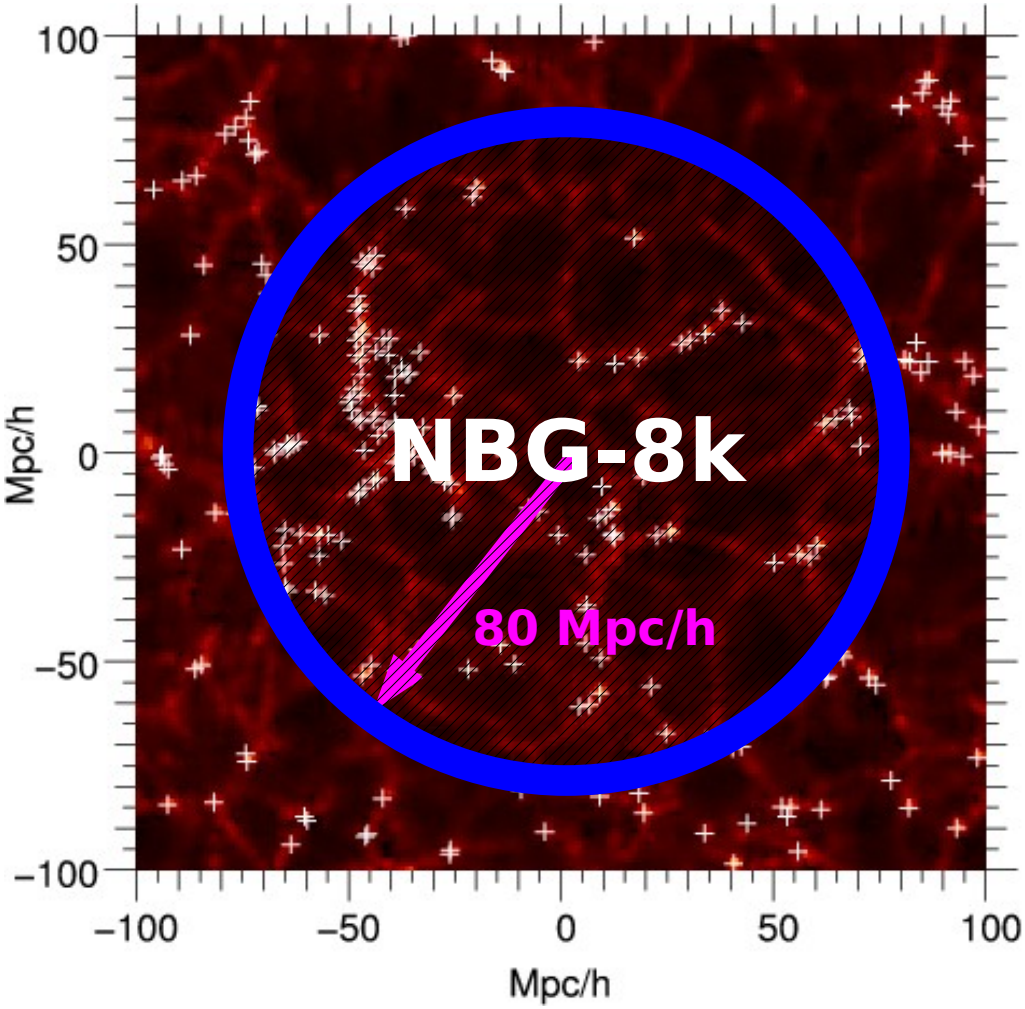
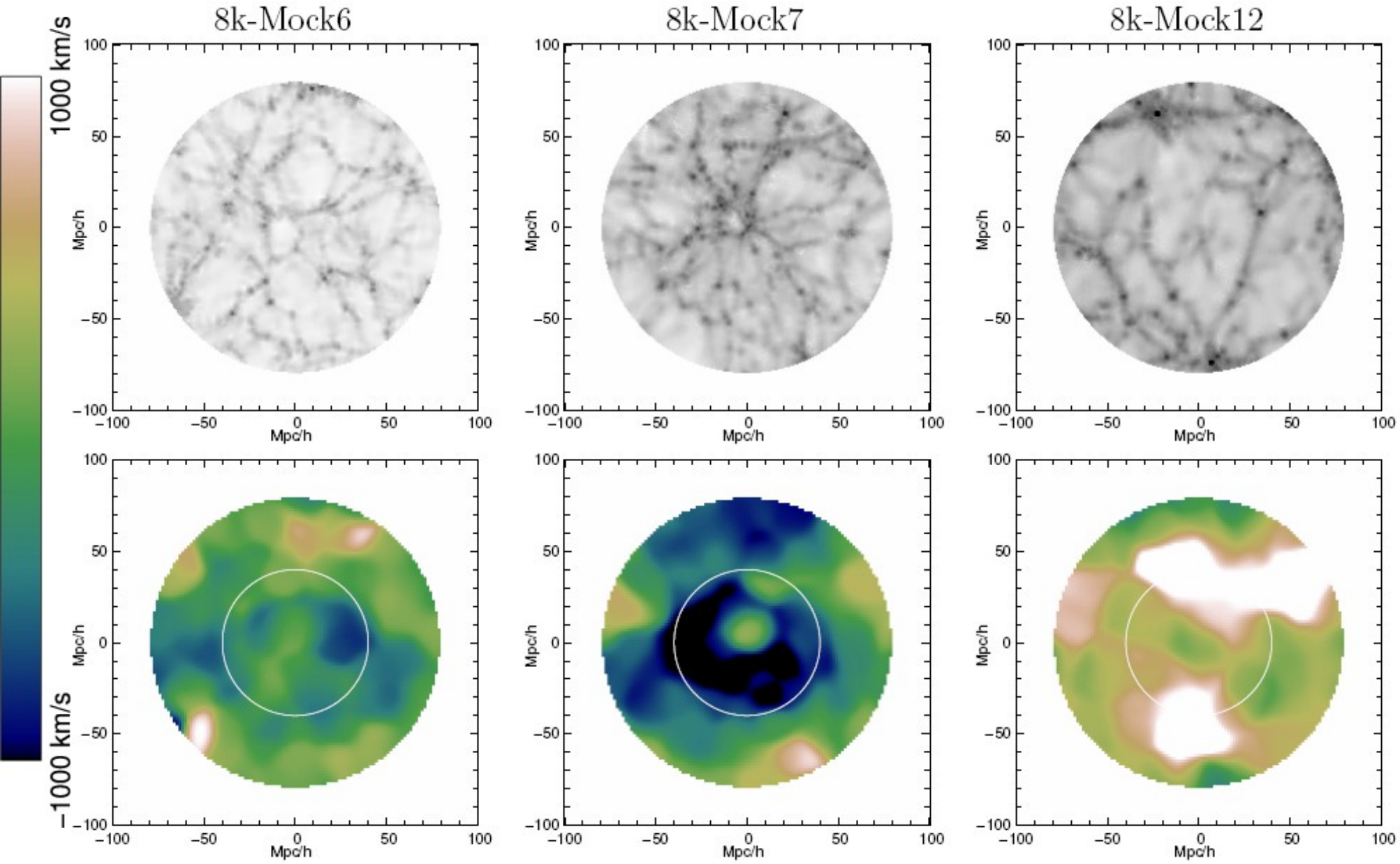


Three basic mock catalogs



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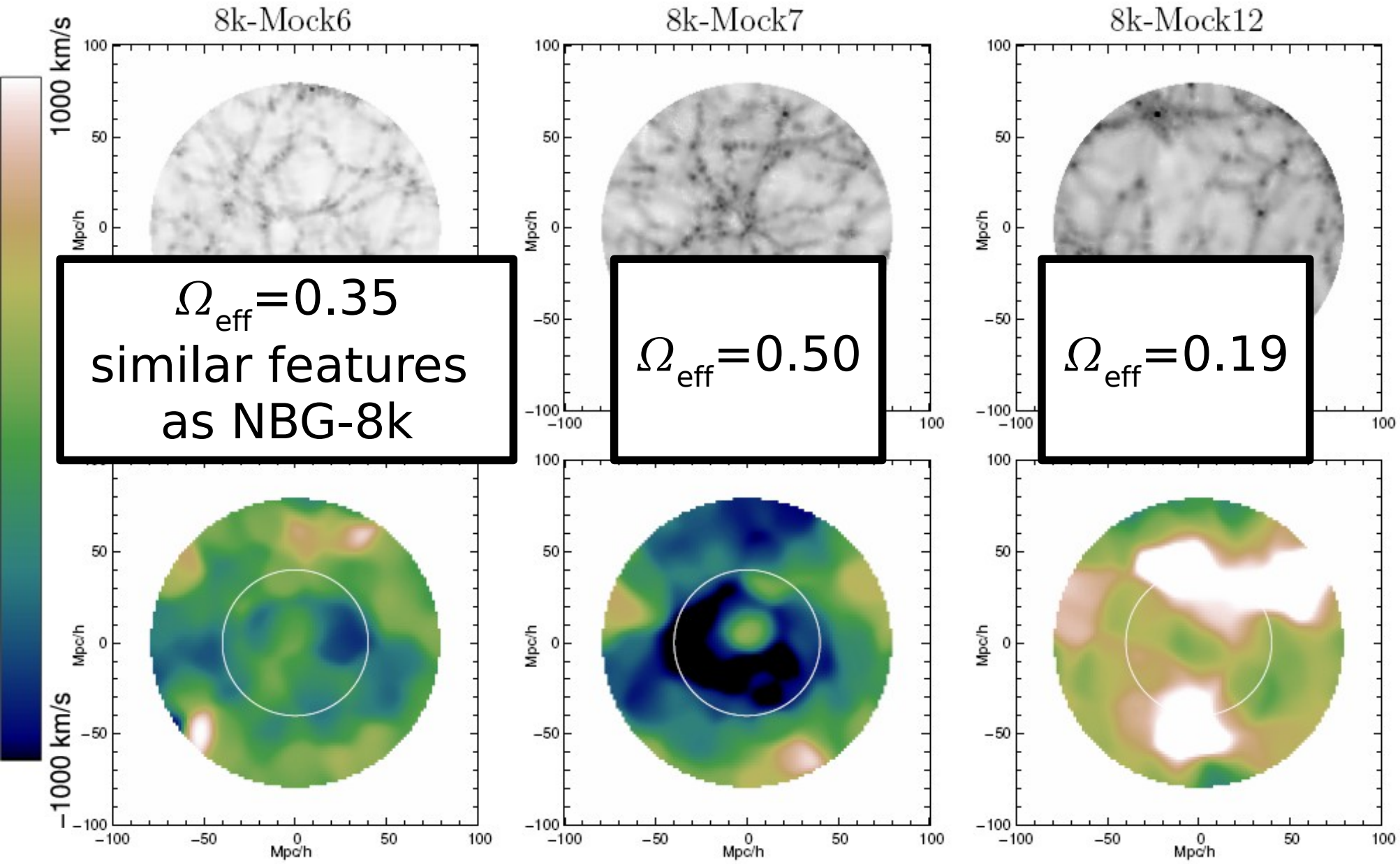
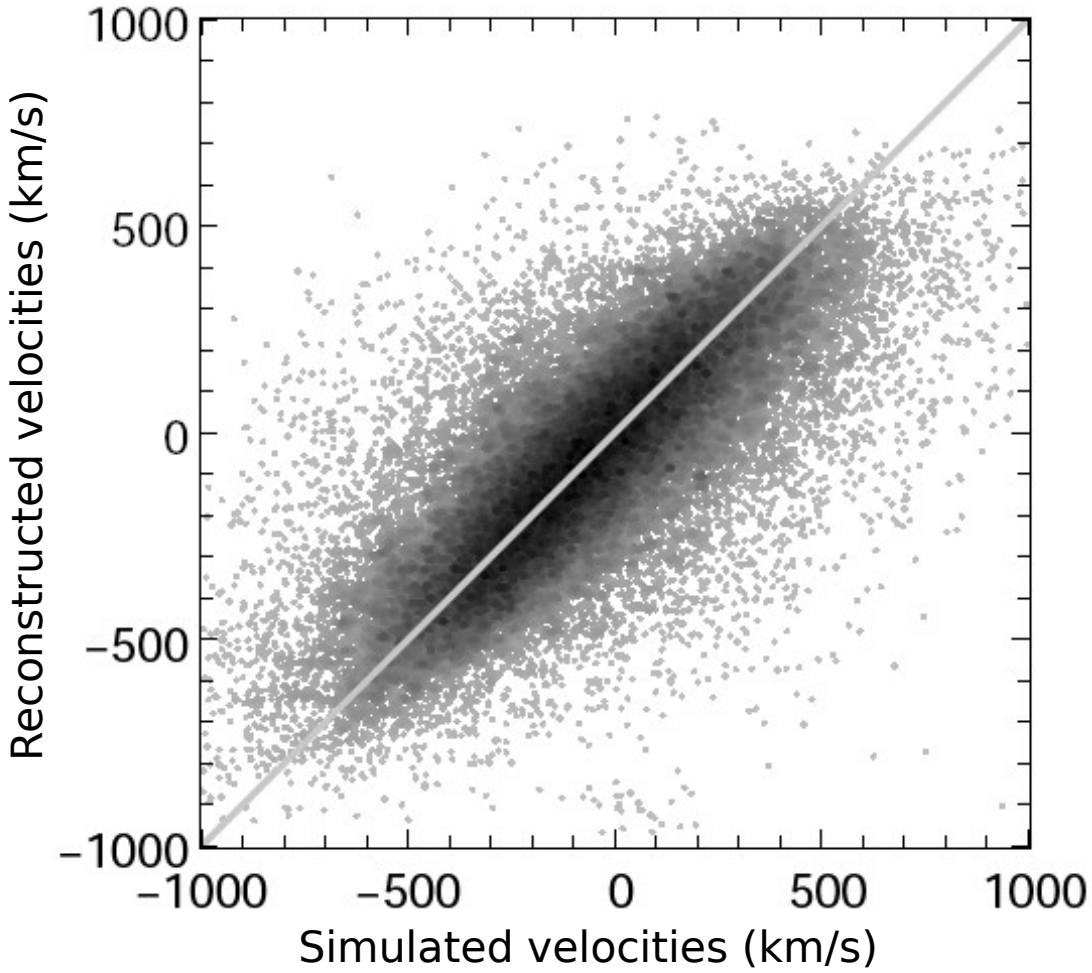
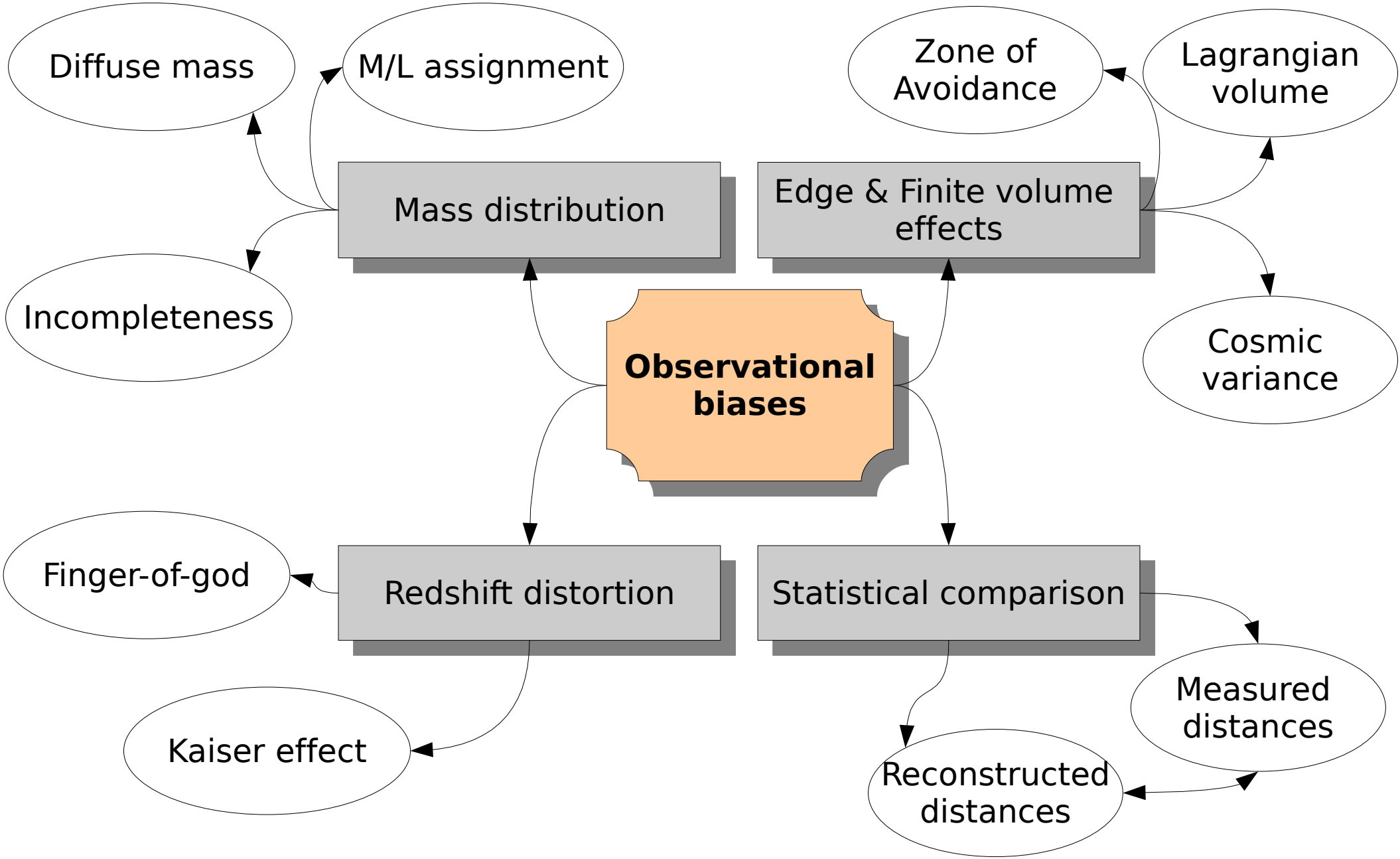


Example for 8k-mock6



3. Observational biases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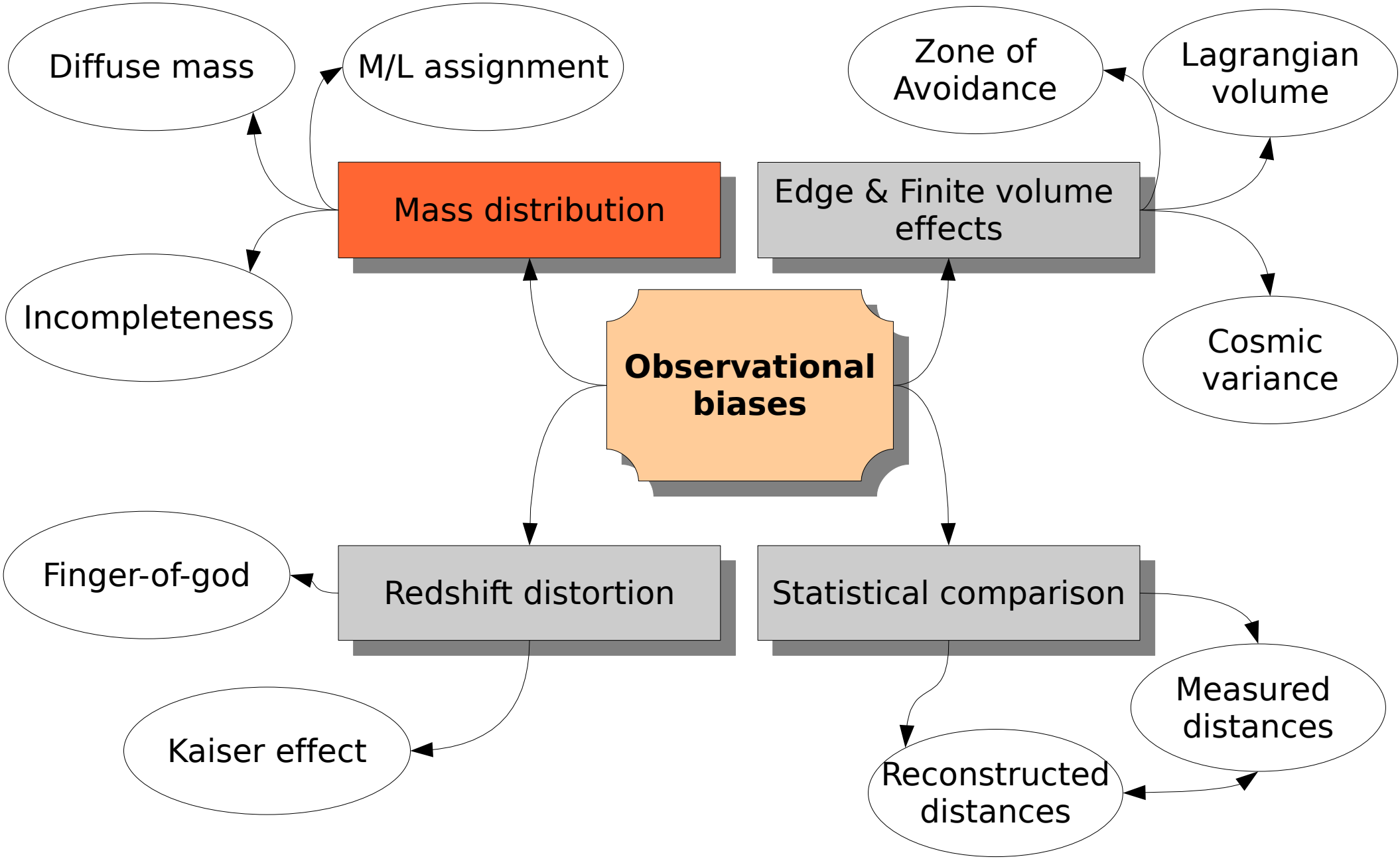
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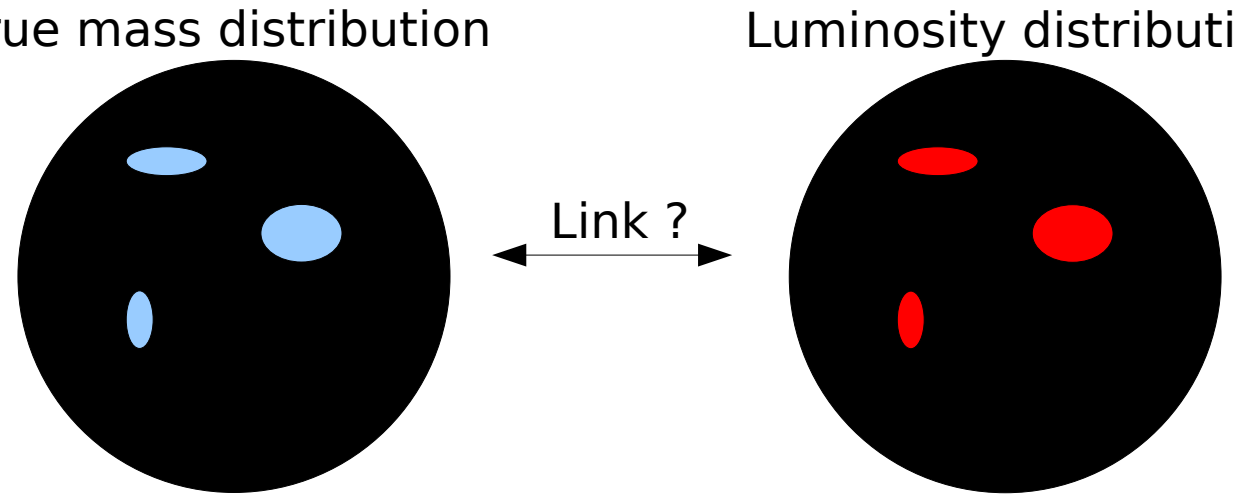
M/L assignment



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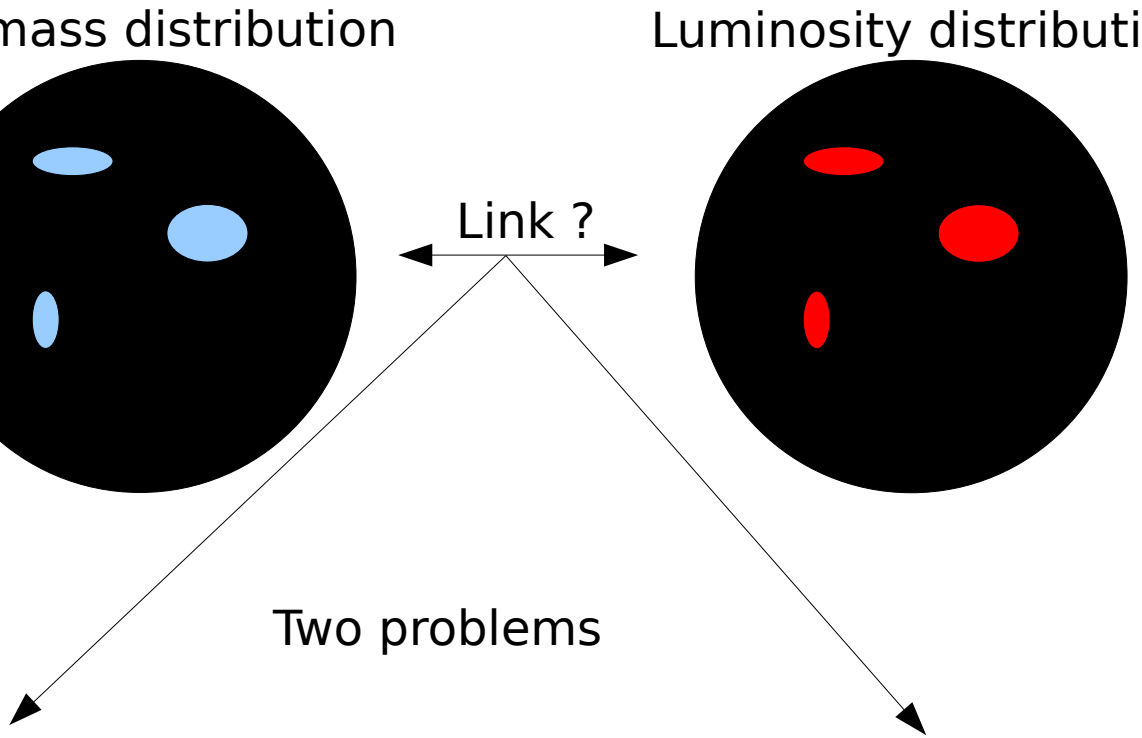

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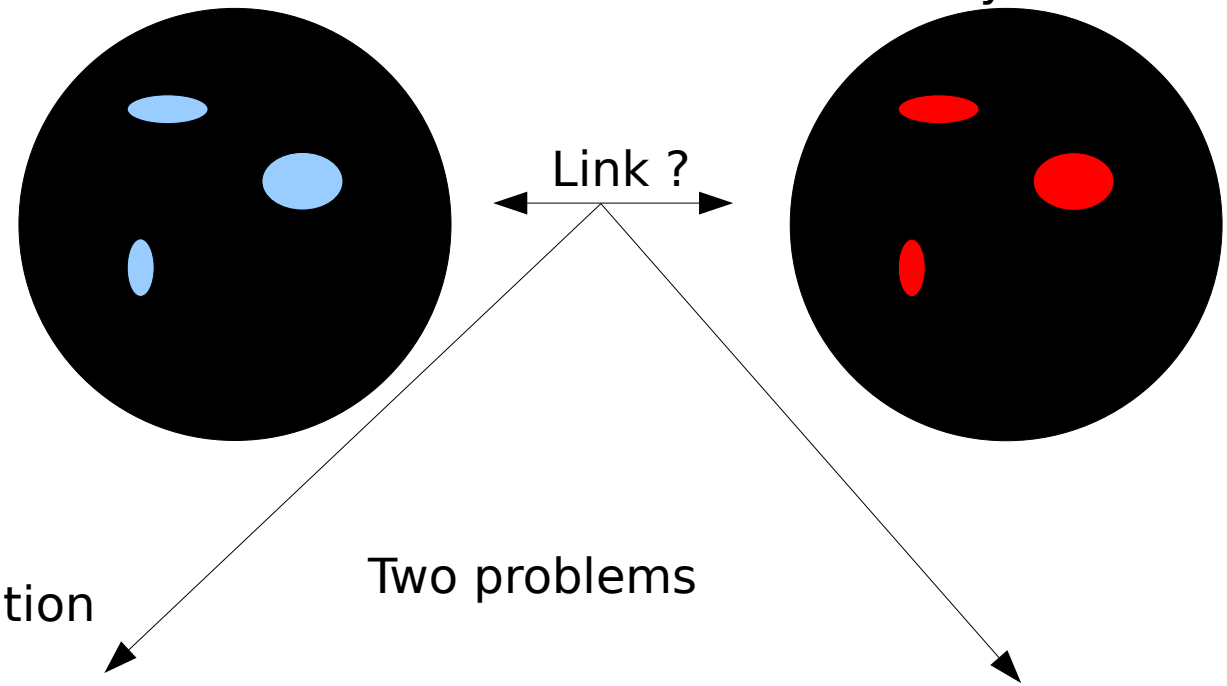
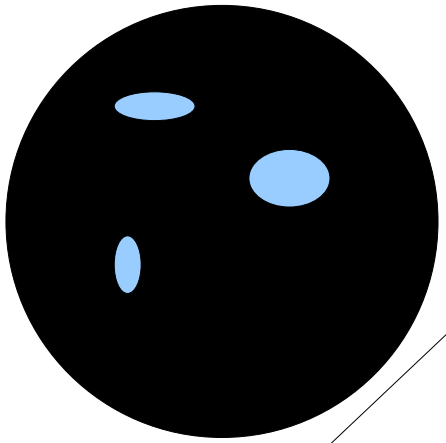


Simulated in Mock Catalogs by injecting a scatter|ΔLog M|=1

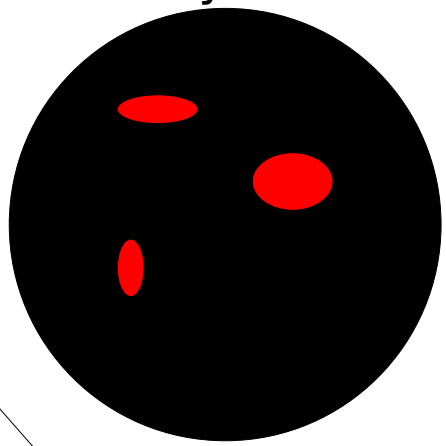
M/L assignment

True mass distribution

Luminosity distribution



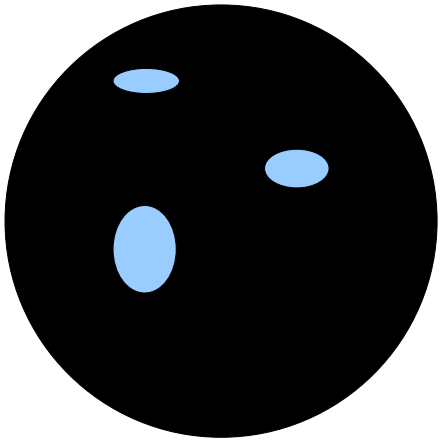
Link ?

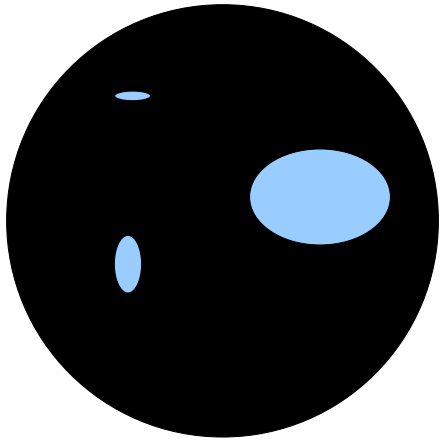


Two problems

M/L = average relation
⇒ **Scatter**

Systematic effects

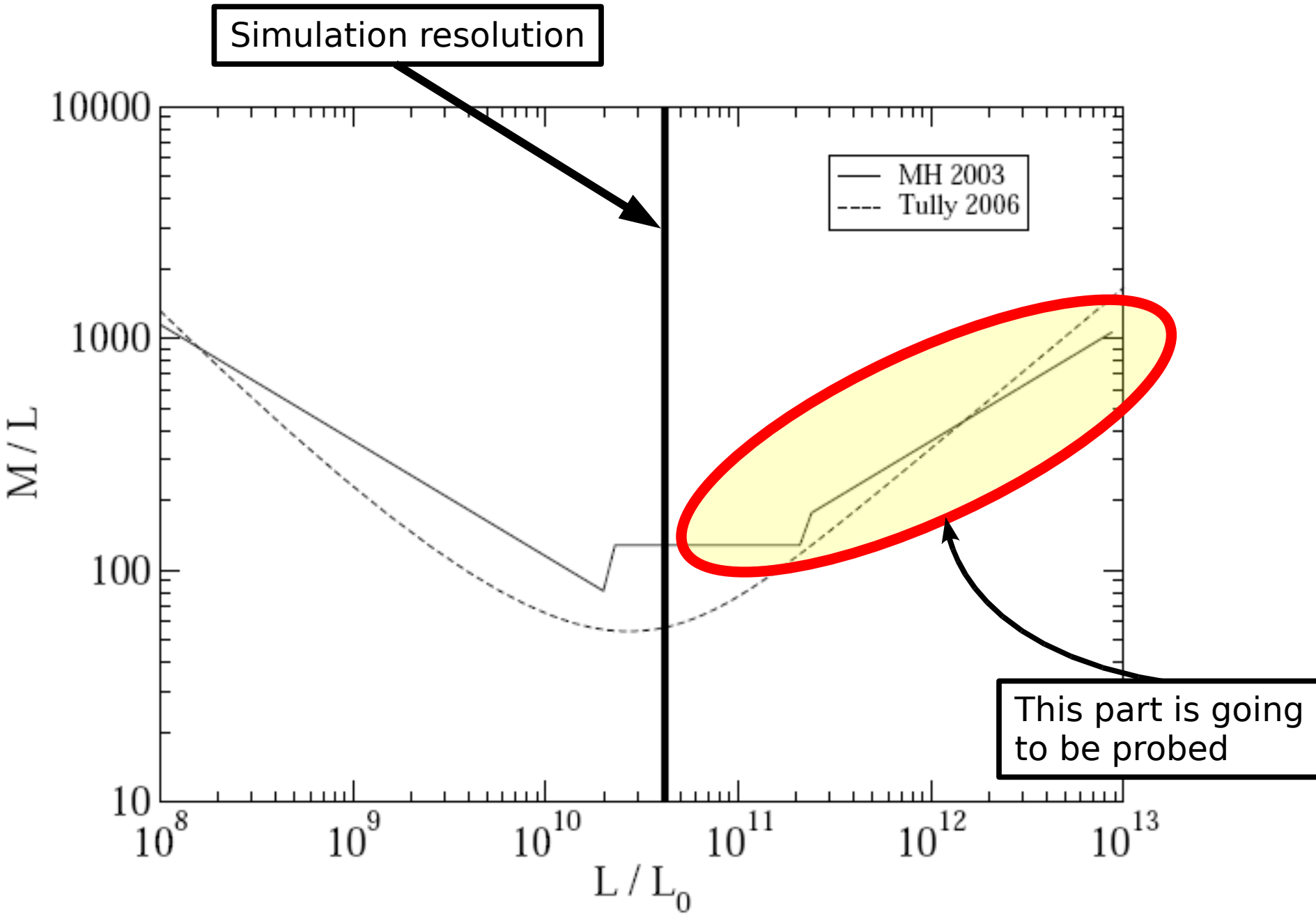




Simulated in Mock Catalogs by injecting a scatter|ΔLog M|=1

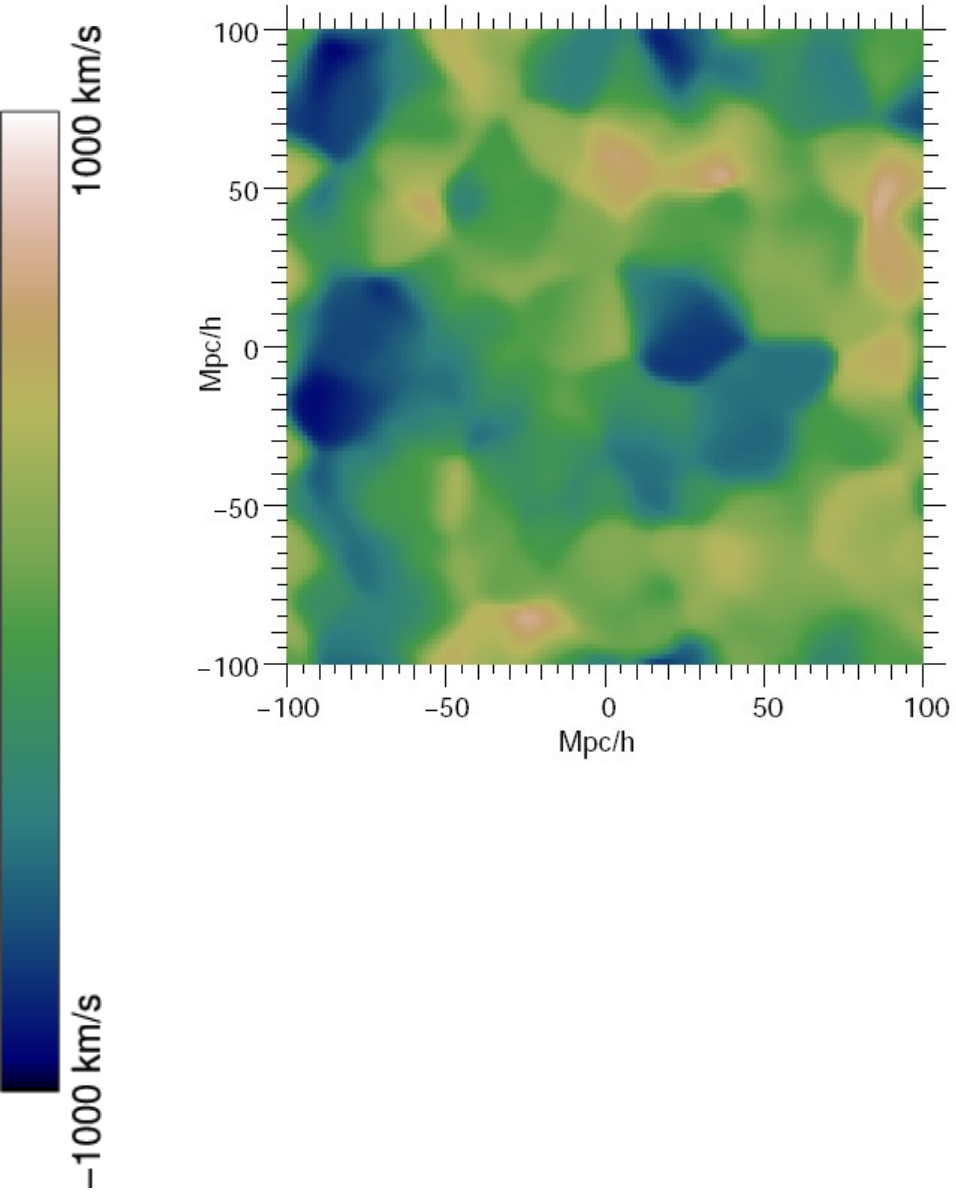
Studied using M/L = constant on a luminosity catalog produced using Tully's M/L

M/L functions

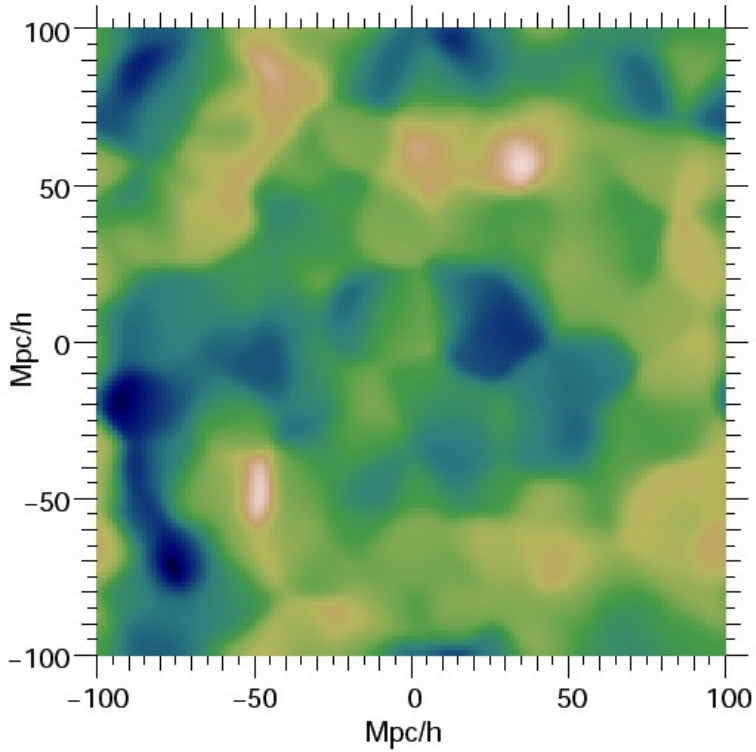


M/L assignment, scatter

Reconstruction with scatter on masses



Simulation



M/L assignment, scatter

Reconstruction with scatter on masses

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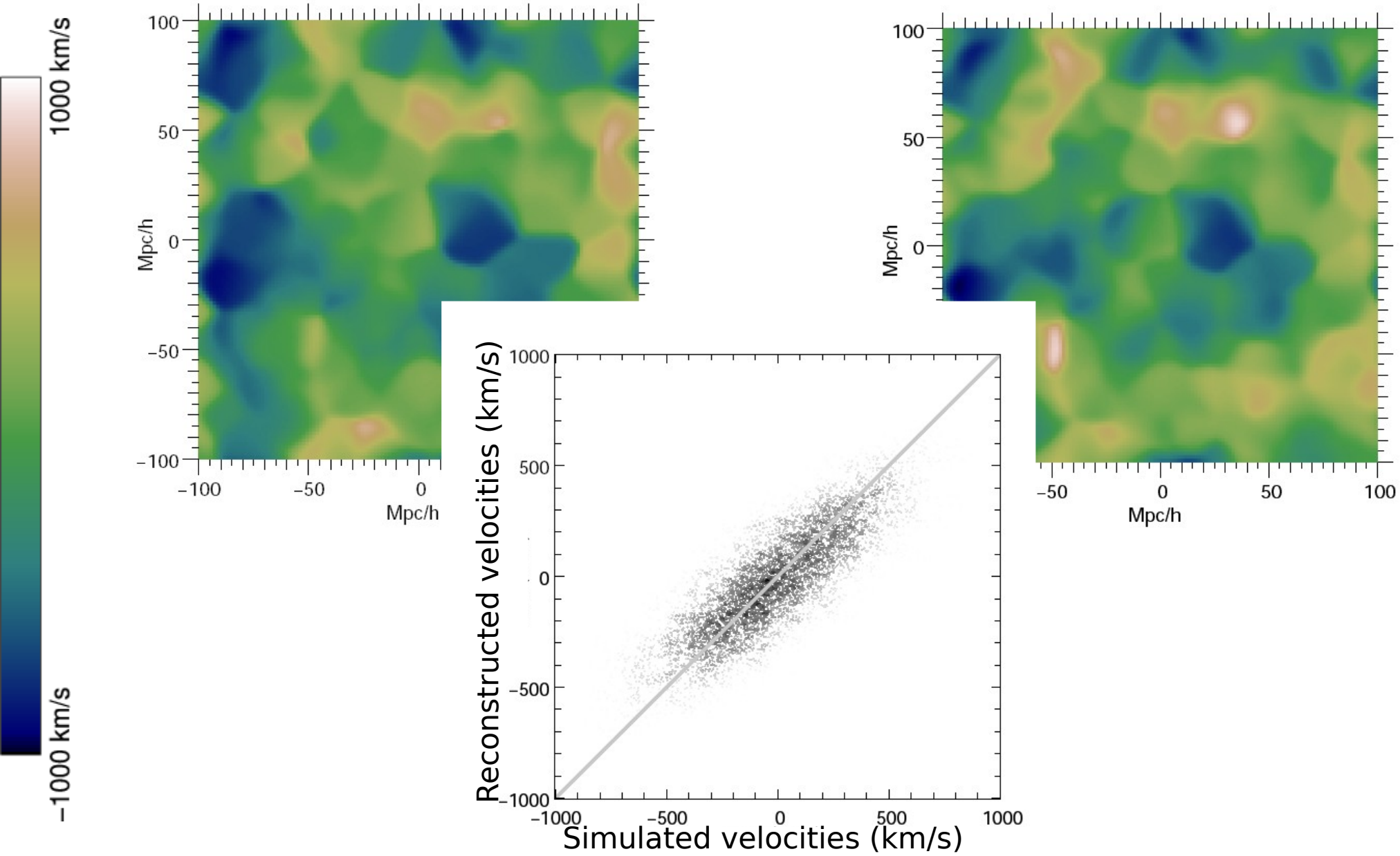
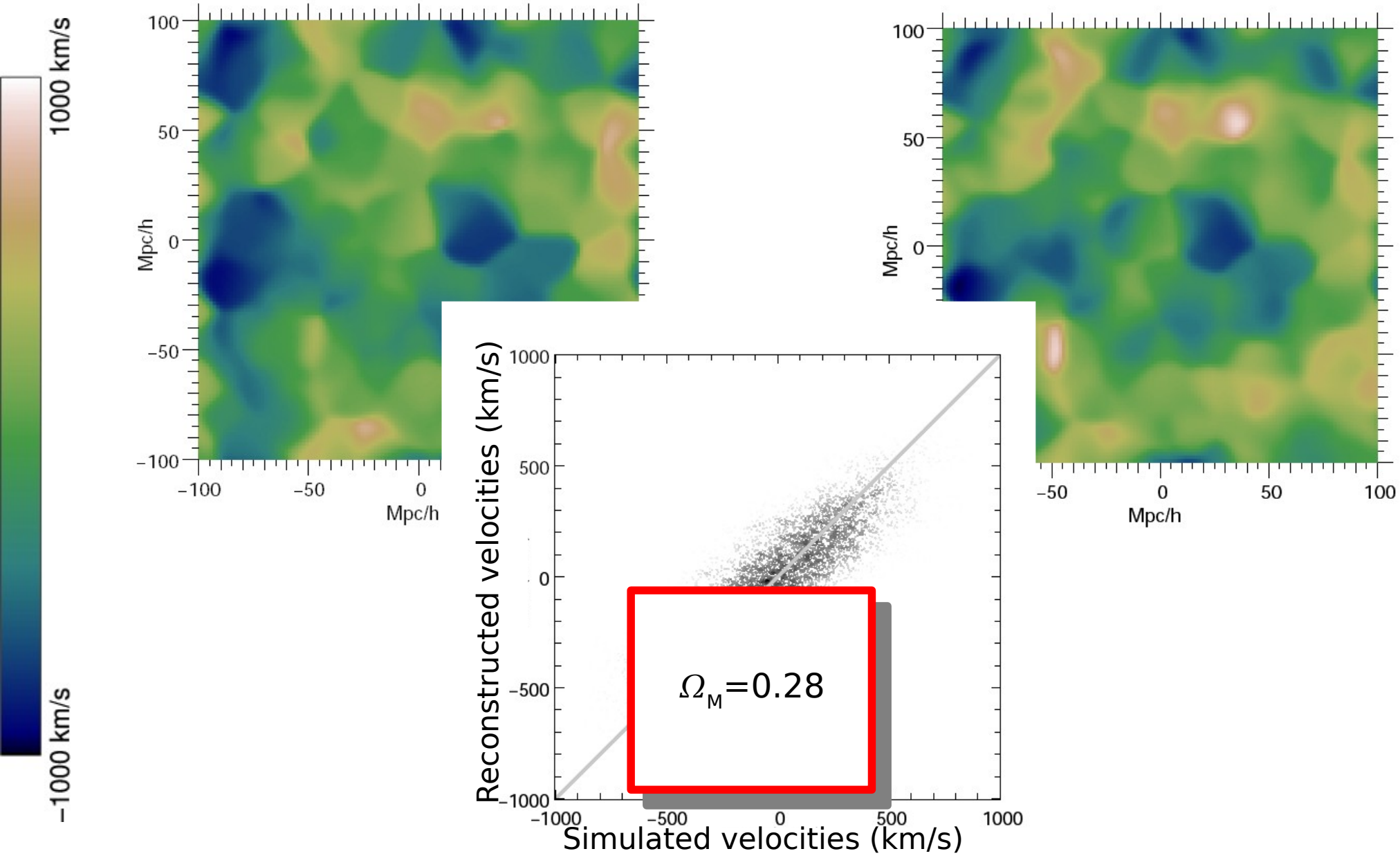


M/L assignment, scatter

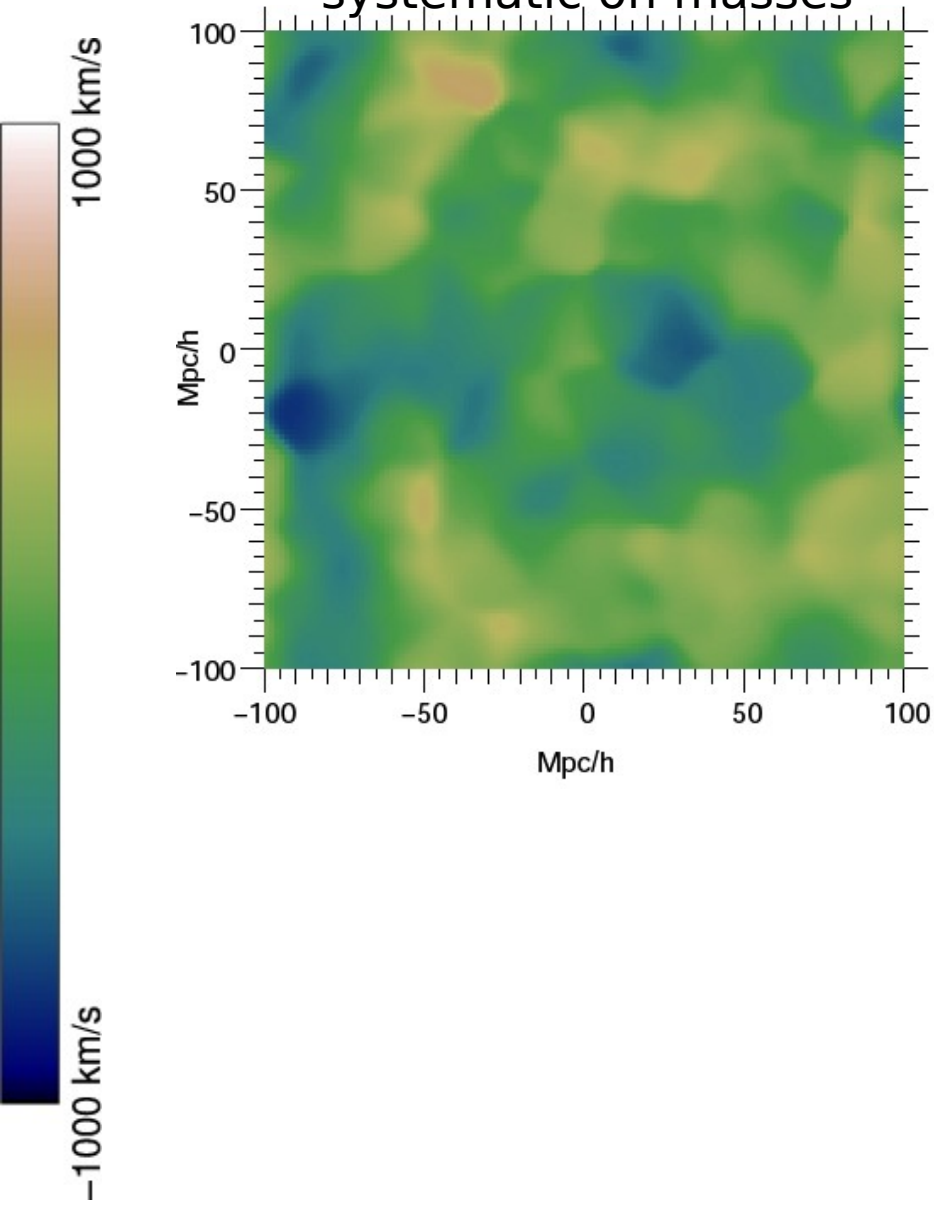
Reconstruction with scatter on masses

Simulation

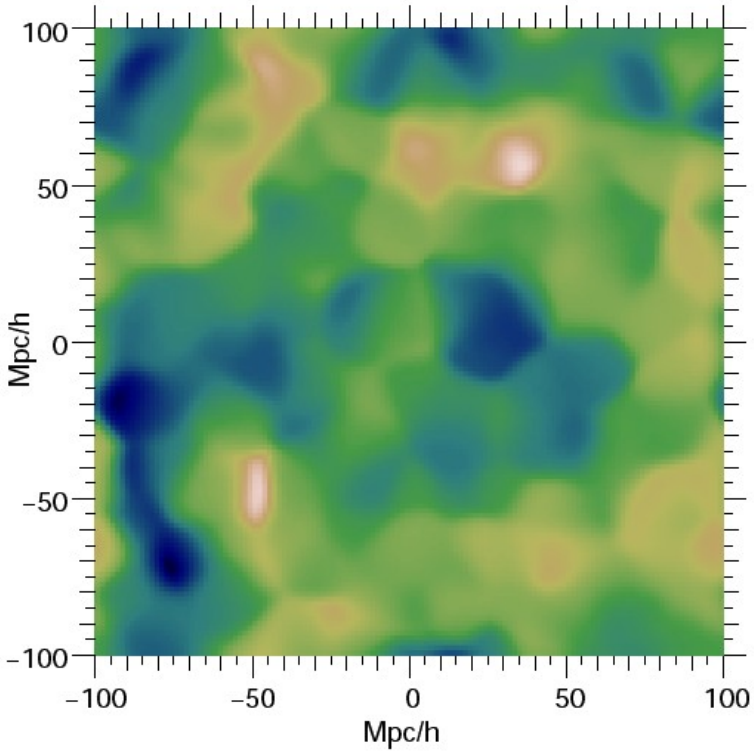


M/L assignment, systematic effect

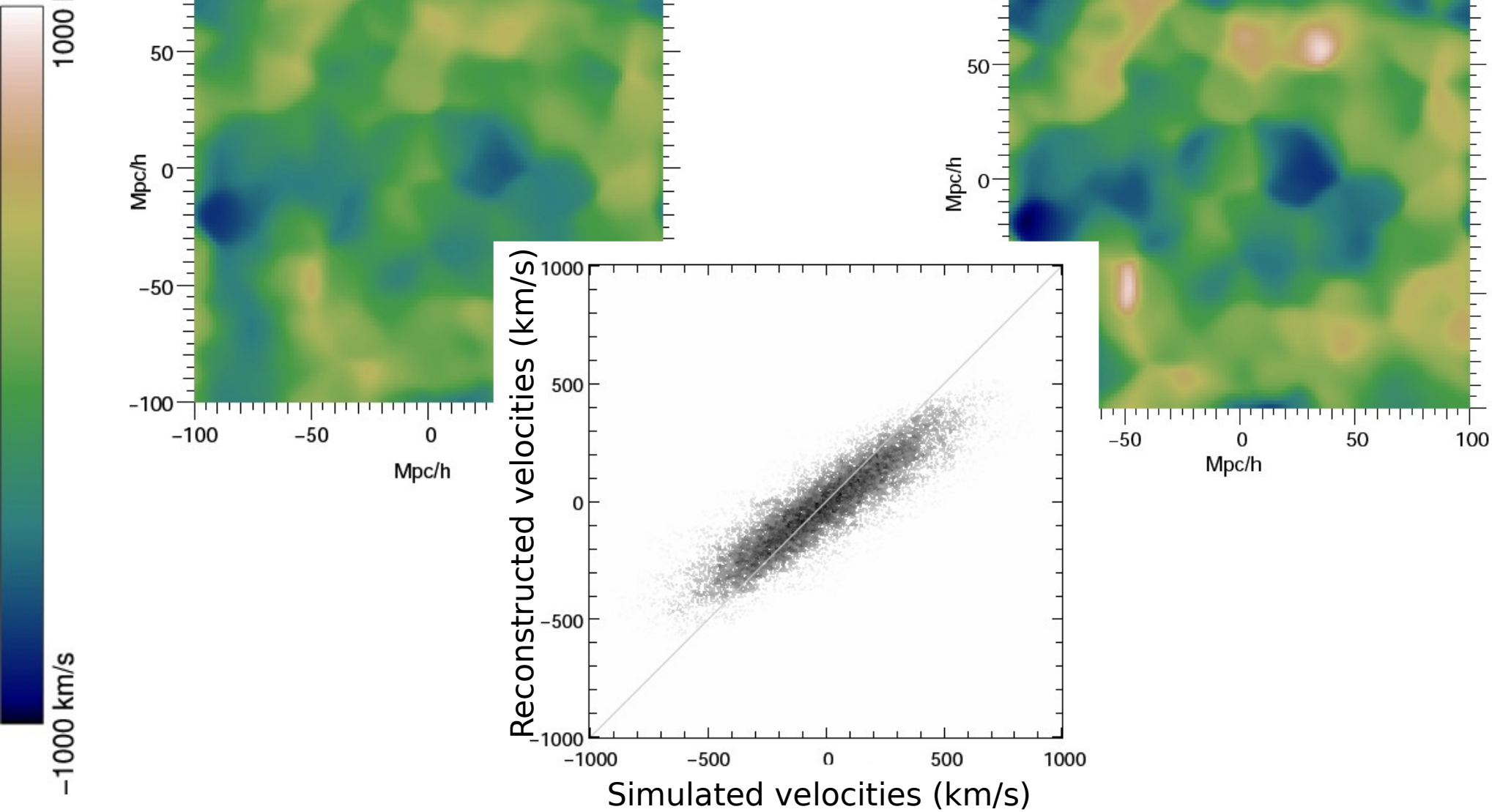
Reconstruction with systematic on masses



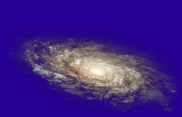
Simulation



M/L assignment, systematic effect

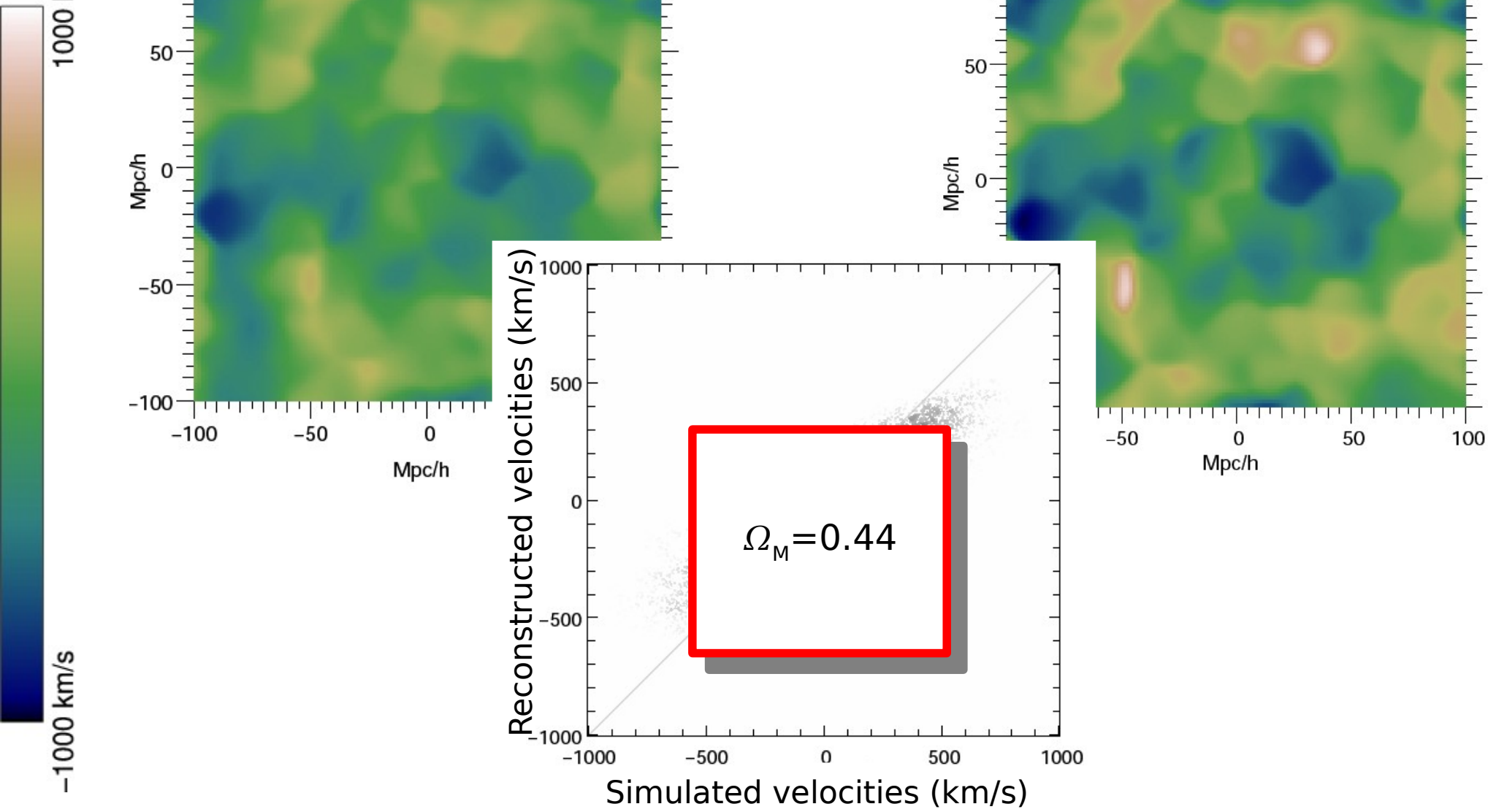


M/L assignment, systematic effect

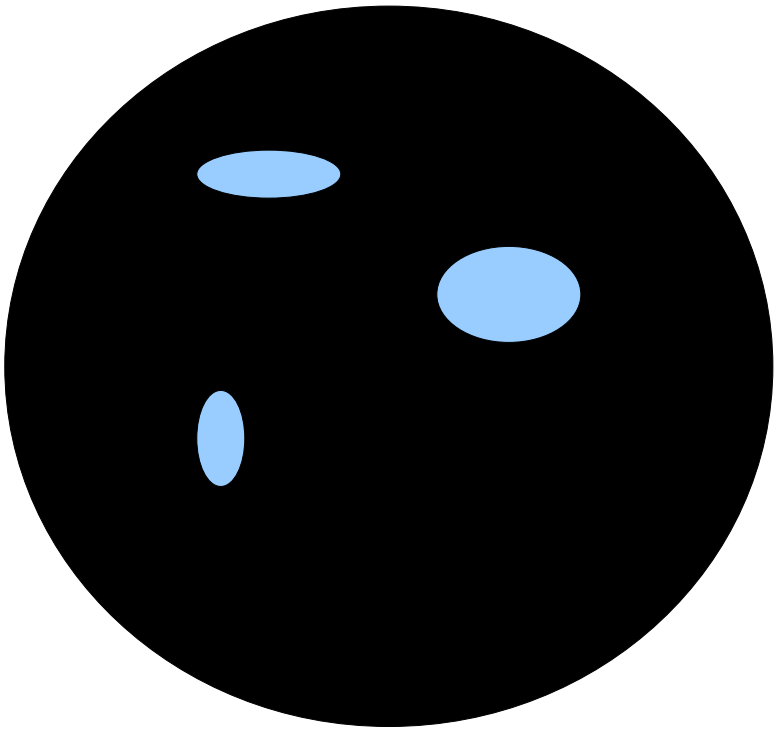


Reconstruction with systematic on masses

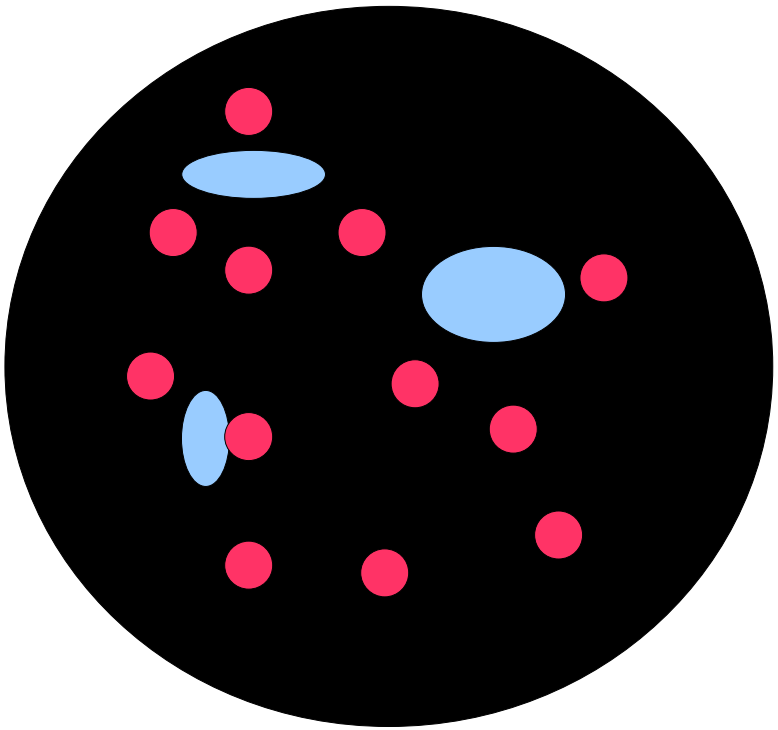
Simulation



Unobserved mass



Detected galaxies

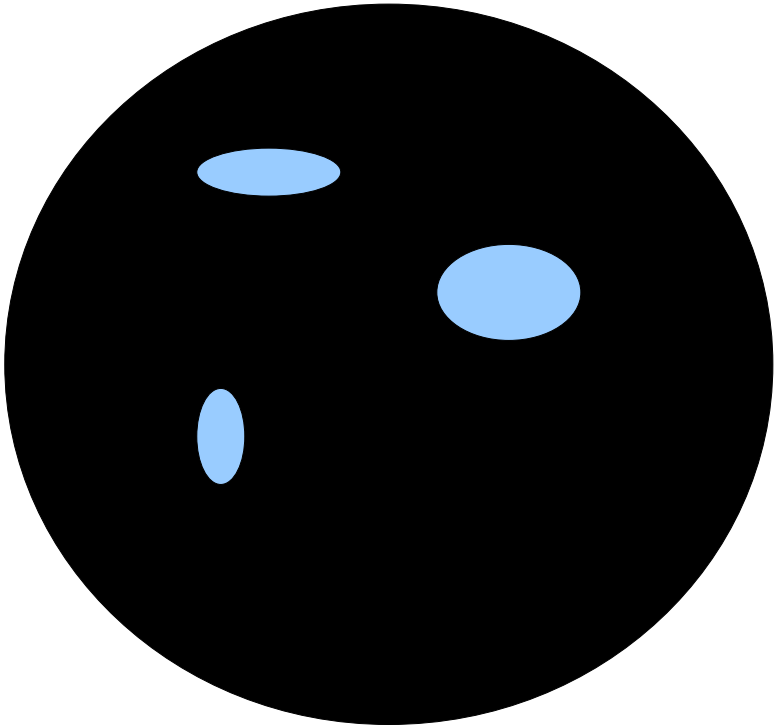


True mass distribution

HIGH DENSITY CONTRASTS

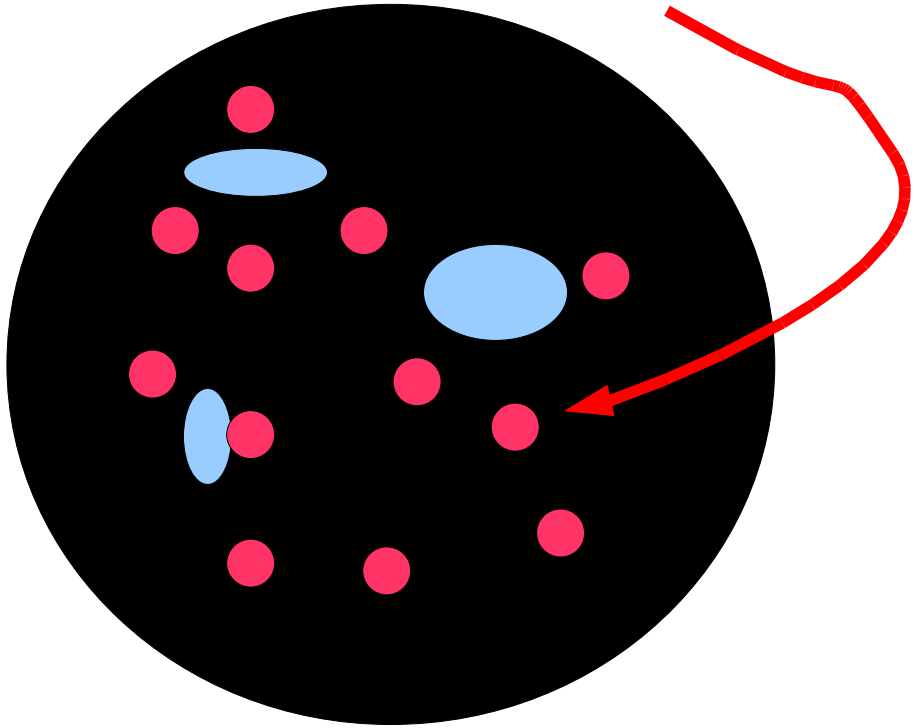
LESS DENSITY CONTRASTS

Unobserved mass



Detected galaxies

Position of the red objects ???



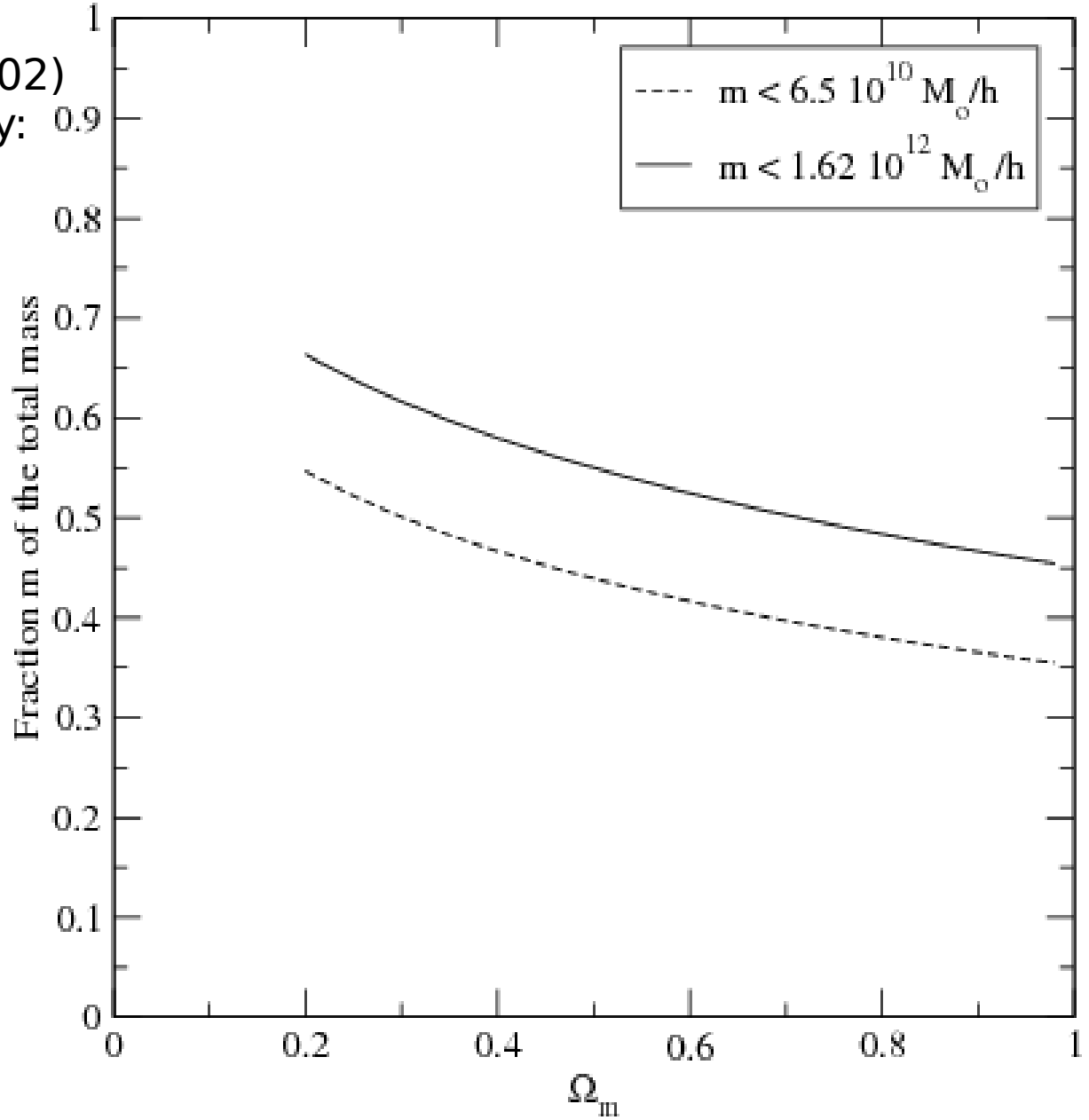
True mass distribution

HIGH DENSITY CONTRASTS

LESS DENSITY CONTRASTS

Unobserved mass

As given by Sheth&Tormen (2002)
for a standard LCDM cosmology:
H=65 km/s/Mpc
σ_8=1.0



Unobserved mass

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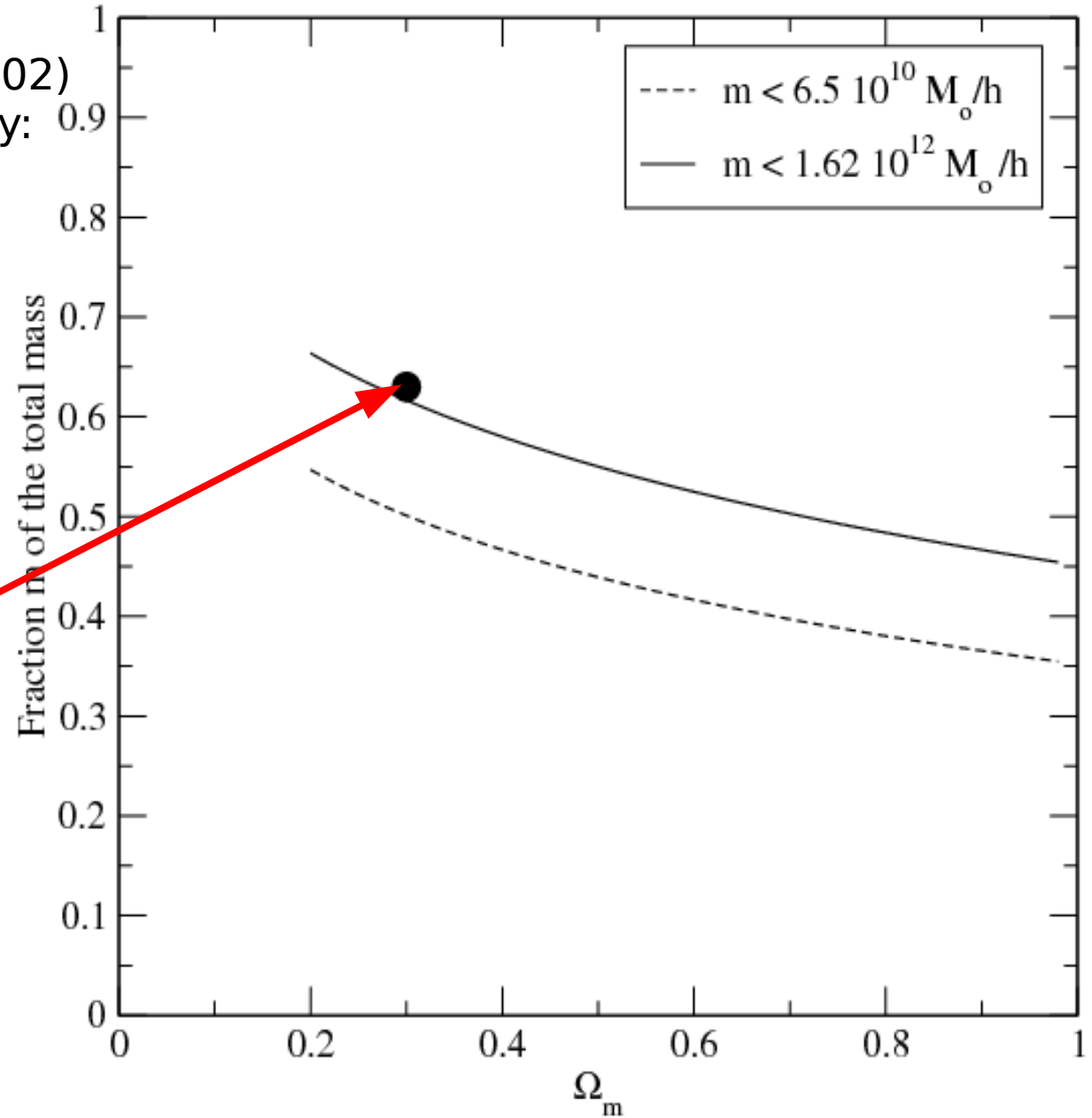
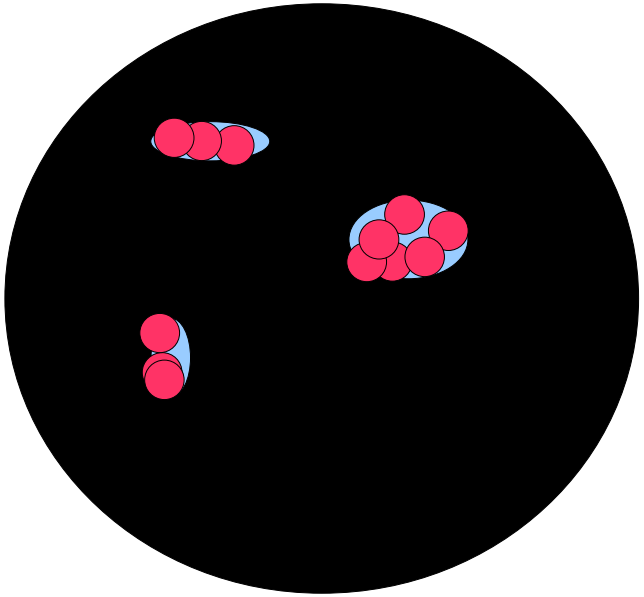
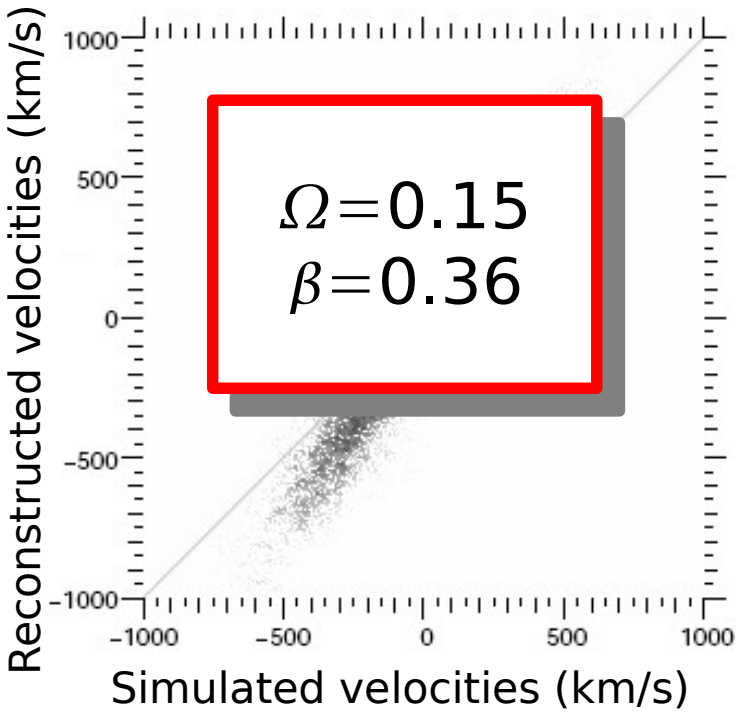


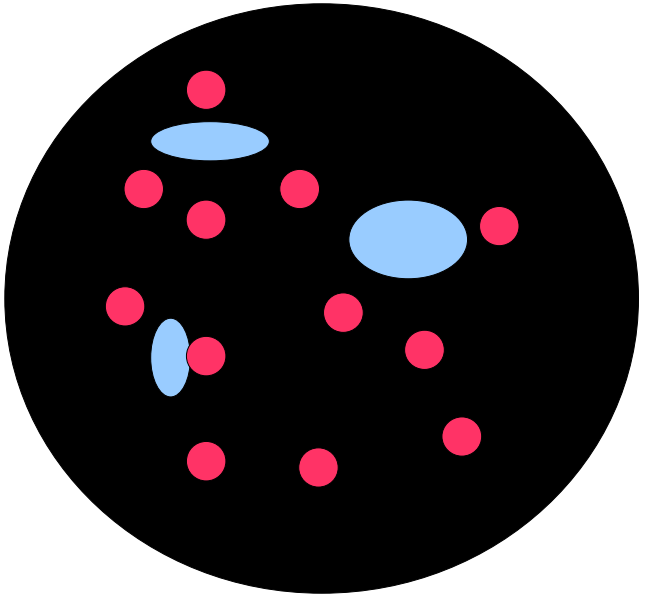
Measured in simulation

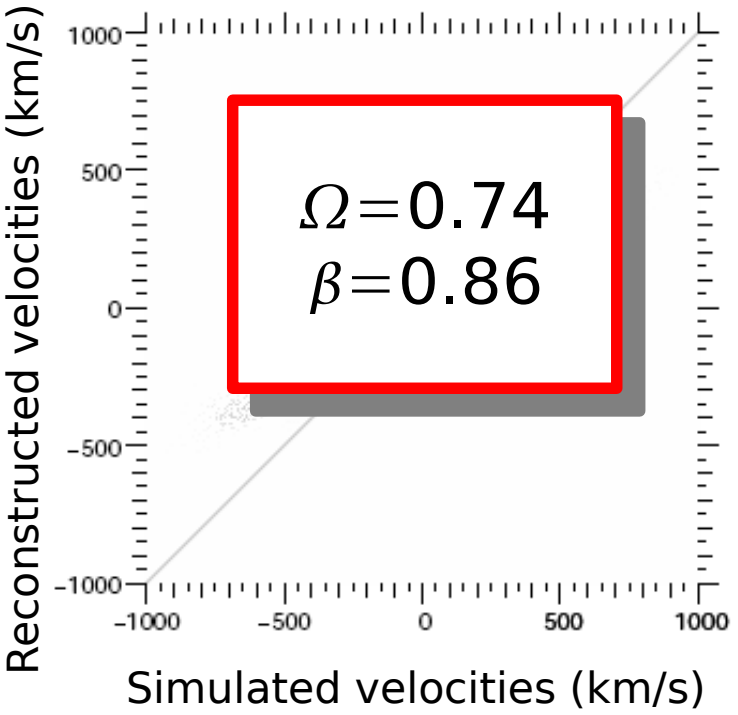
Unobserved mass put in halo





Unobserved mass put in background

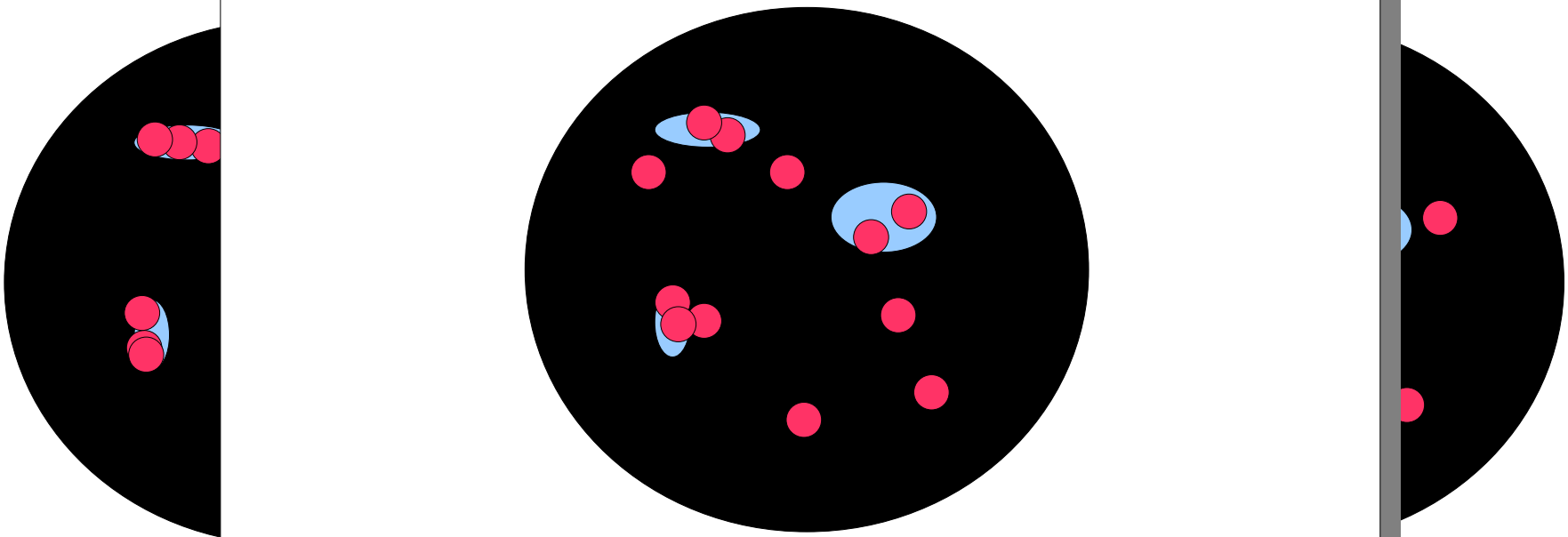


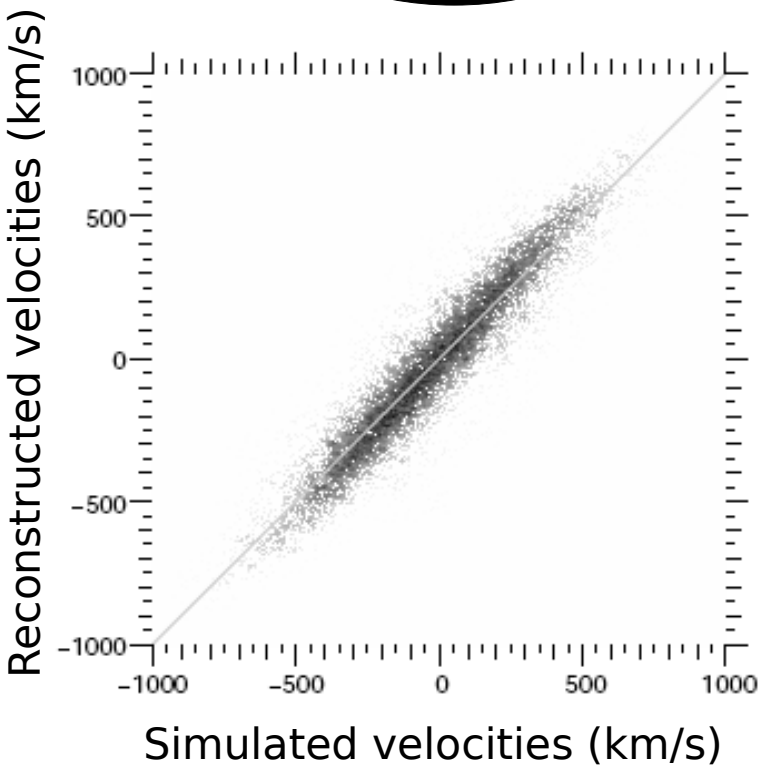


Unobserved

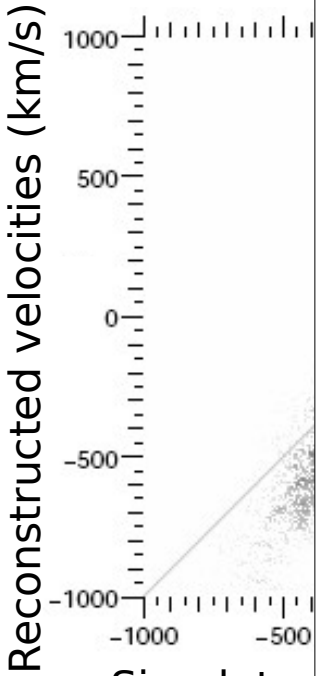
s put in
d

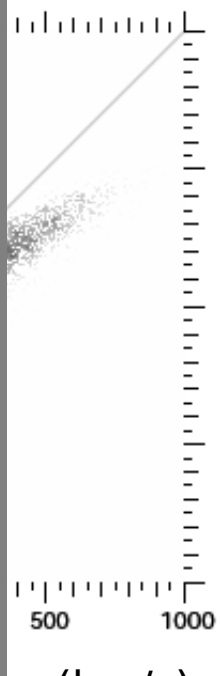
Optimal compromise: 60% in halo, 40% in background



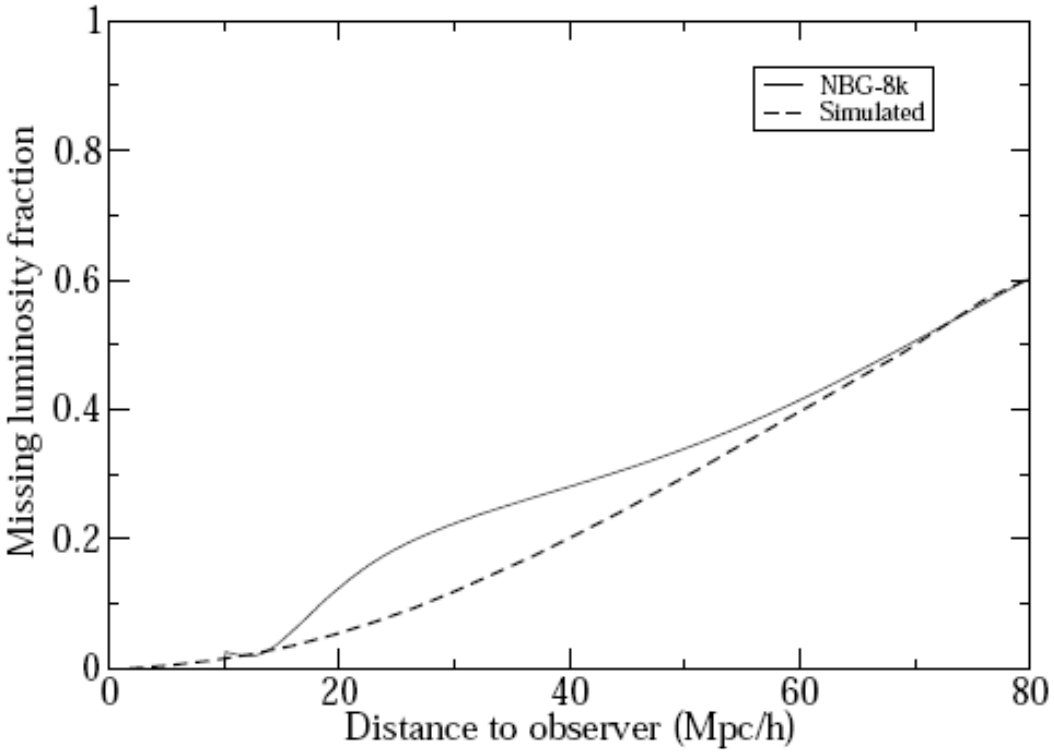


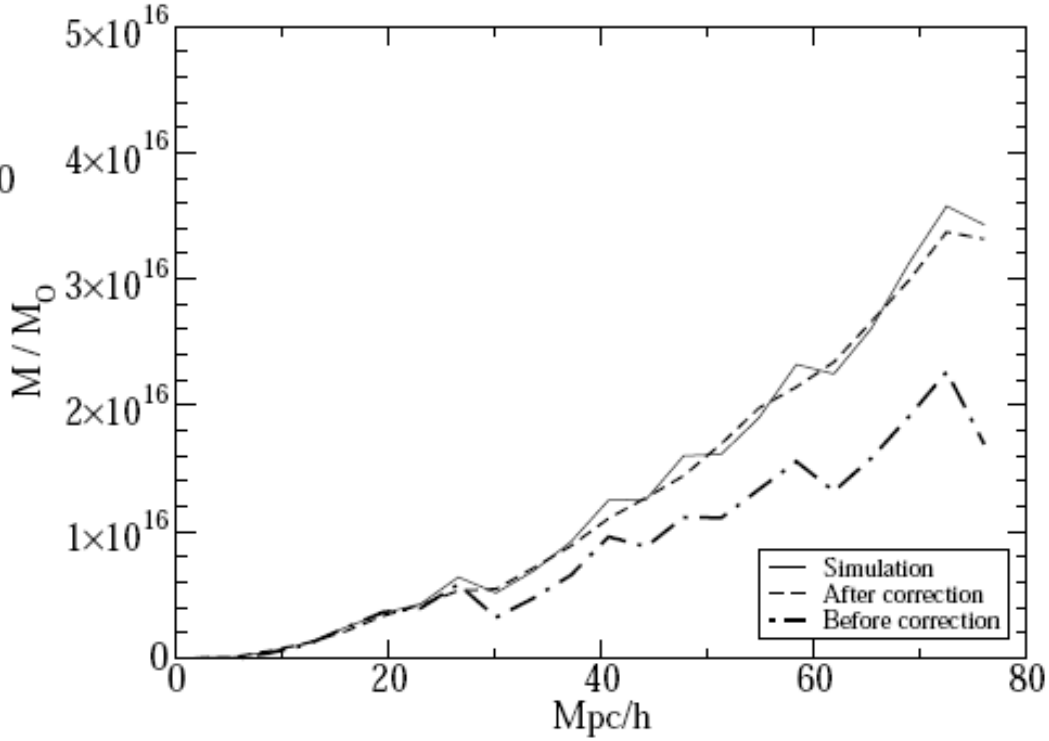
$\Omega = 0.30$



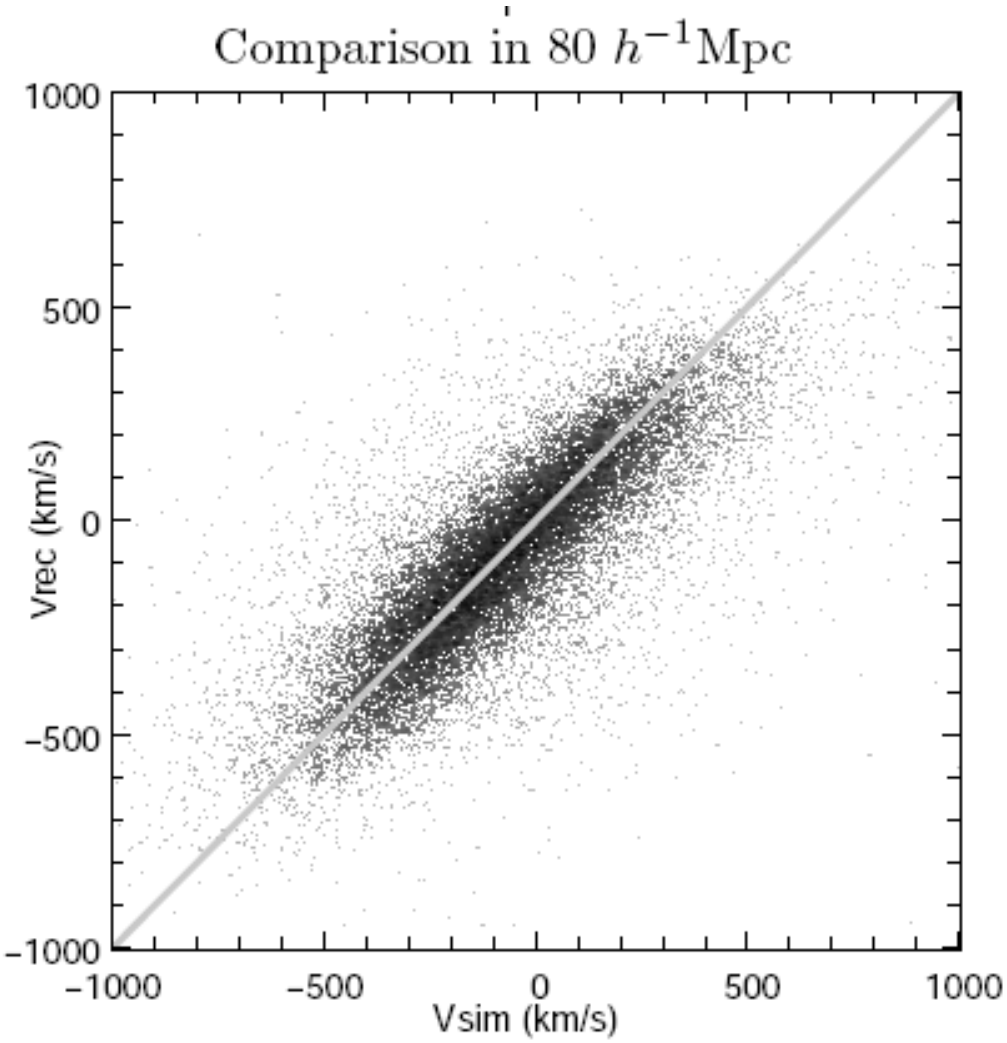


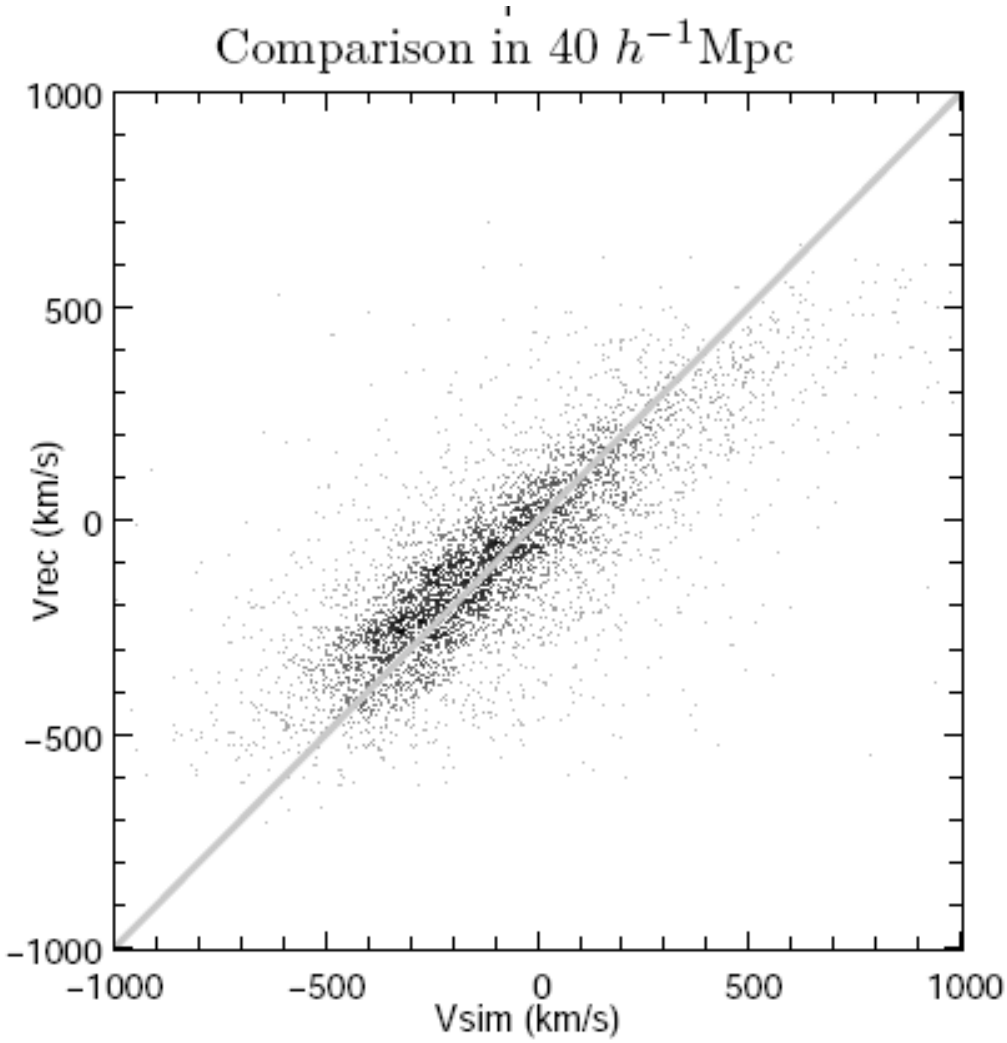
Incompleteness



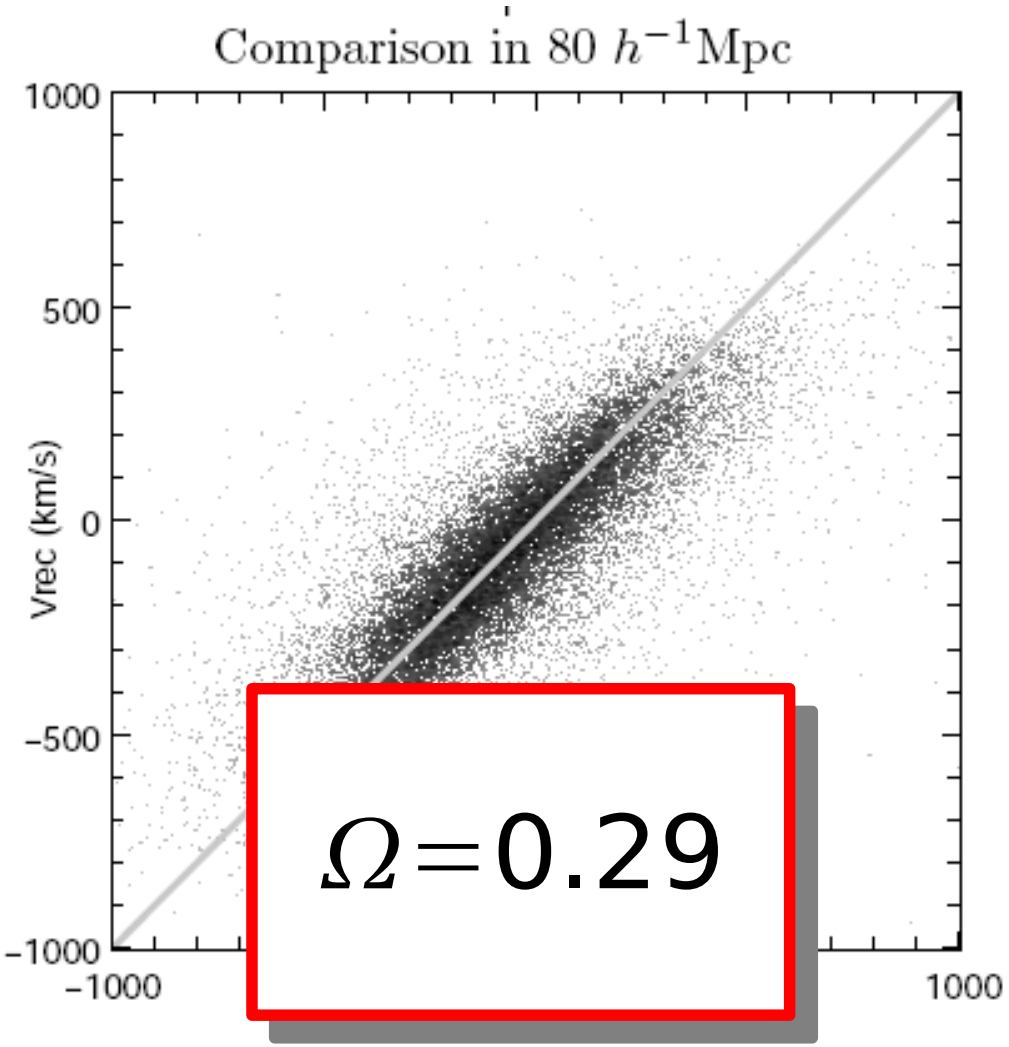


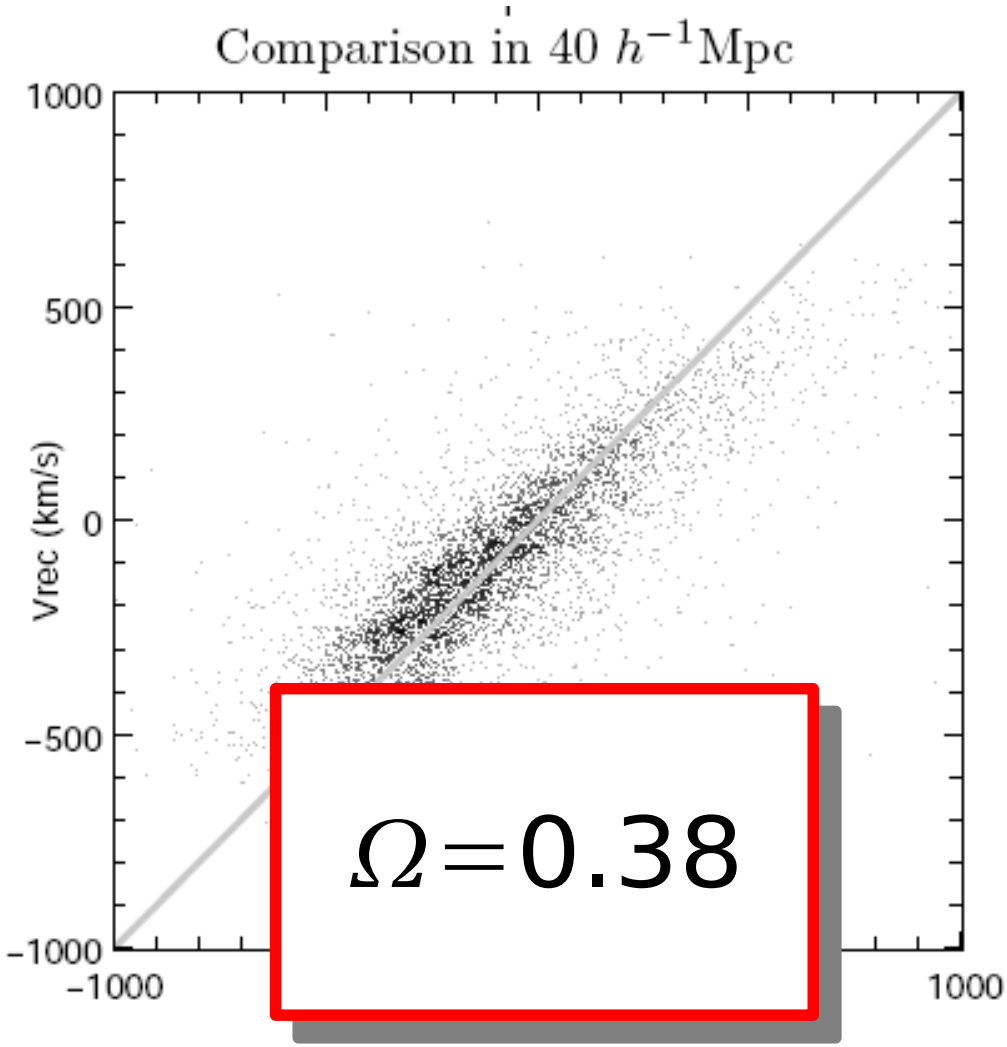
Incompleteness

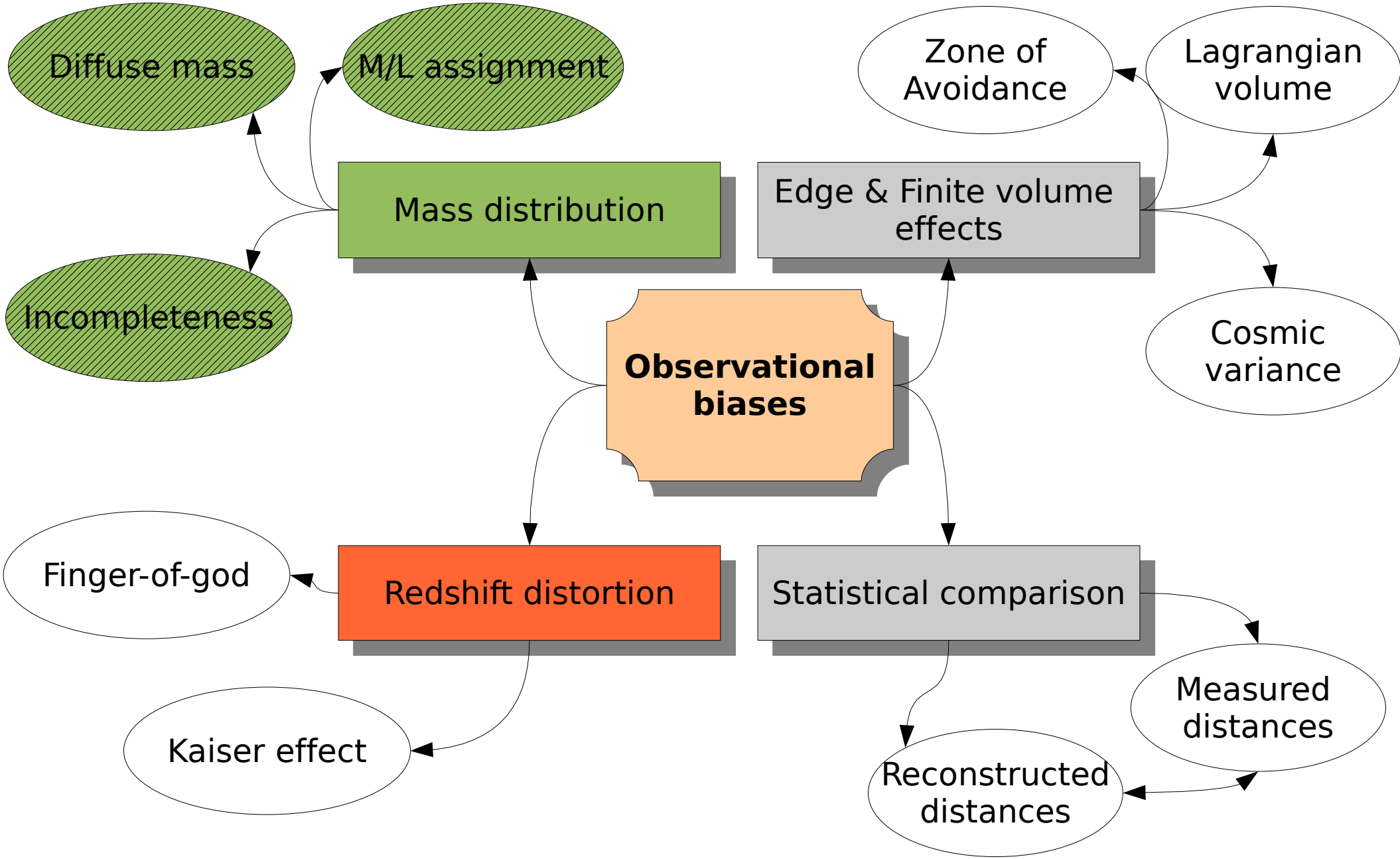




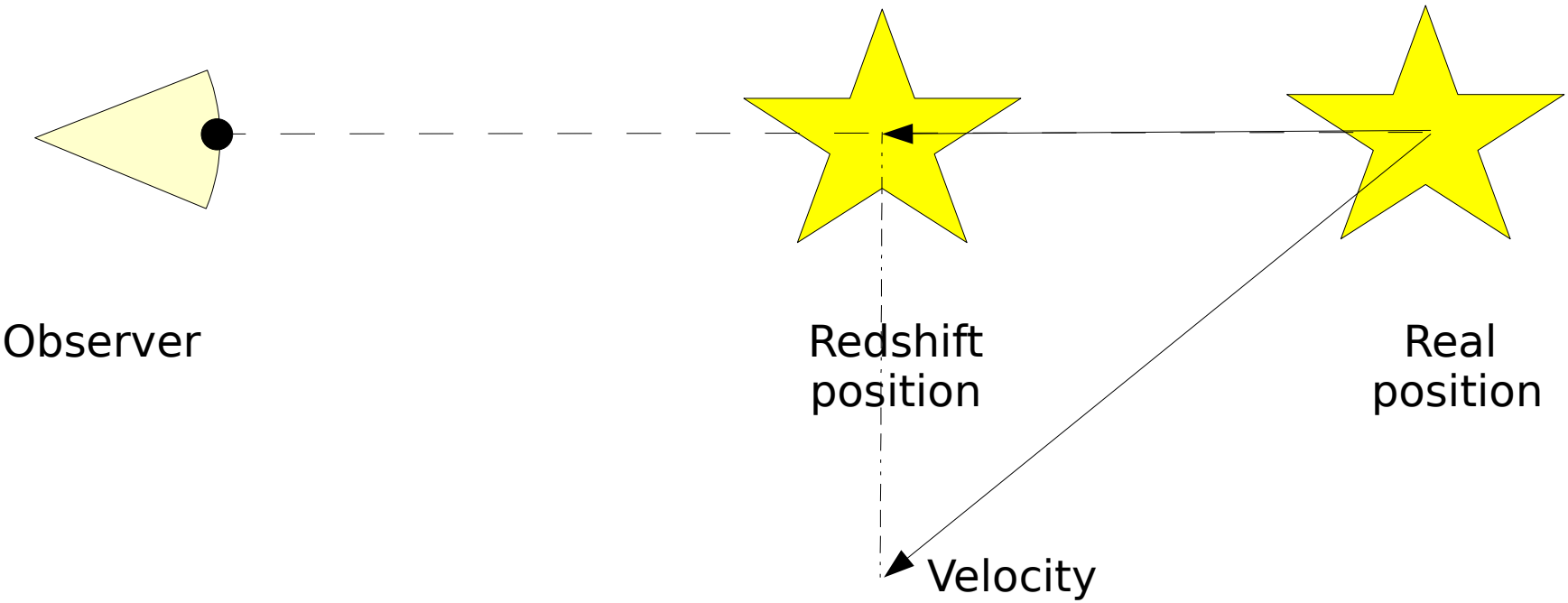
Incompleteness






Diffuse mass
M/L assignment
Zone of Avoidance
Lagrangian volume
Mass distribution
Edge & Finite volume effects
Incompleteness
Observational biases
Cosmic variance
Finger-of-god
Redshift distortion
Statistical comparison
Measured distances
Kaiser effect
Reconstructed distances

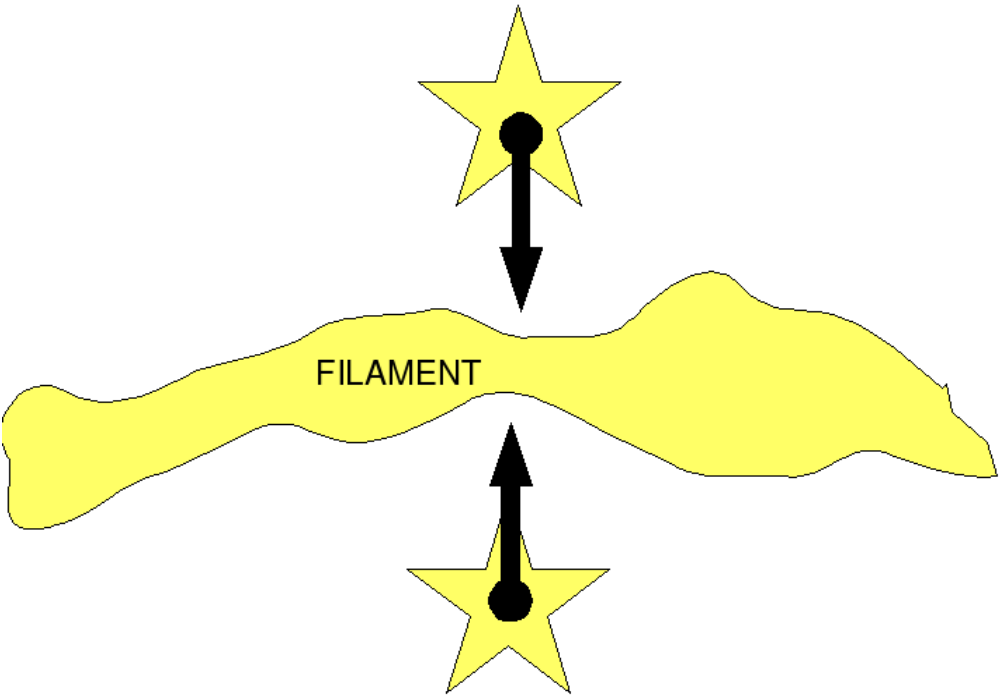
Redshift distortion

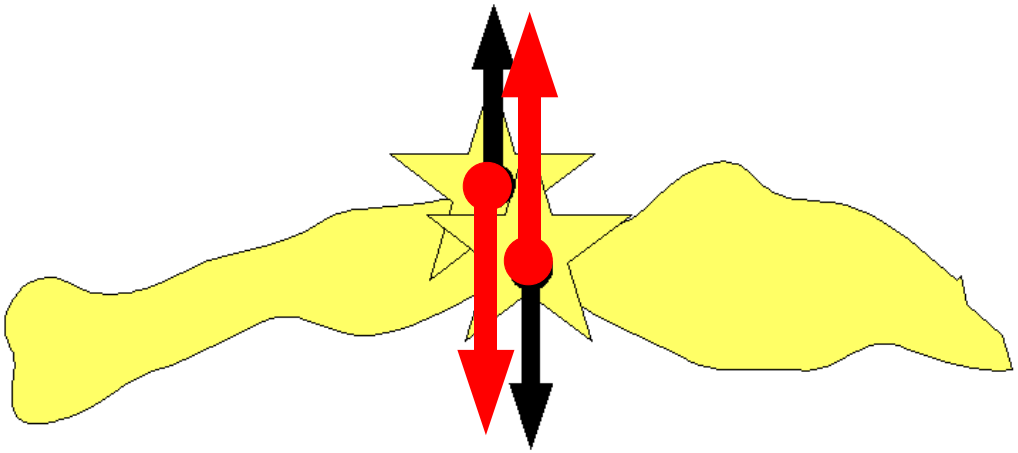


CORRECTIBLE modification of MAK

$$S_\sigma = \sum_i \left(\left(\vec{s}_i - \vec{q_{\sigma(i)}} \right)^2 - f(\Omega_m, \Omega_\Lambda) \frac{\left((\vec{s}_i - \vec{q_{\sigma(i)}}) . \vec{s}_i \right)^2}{\|\vec{s}_i\|^2} \right)$$

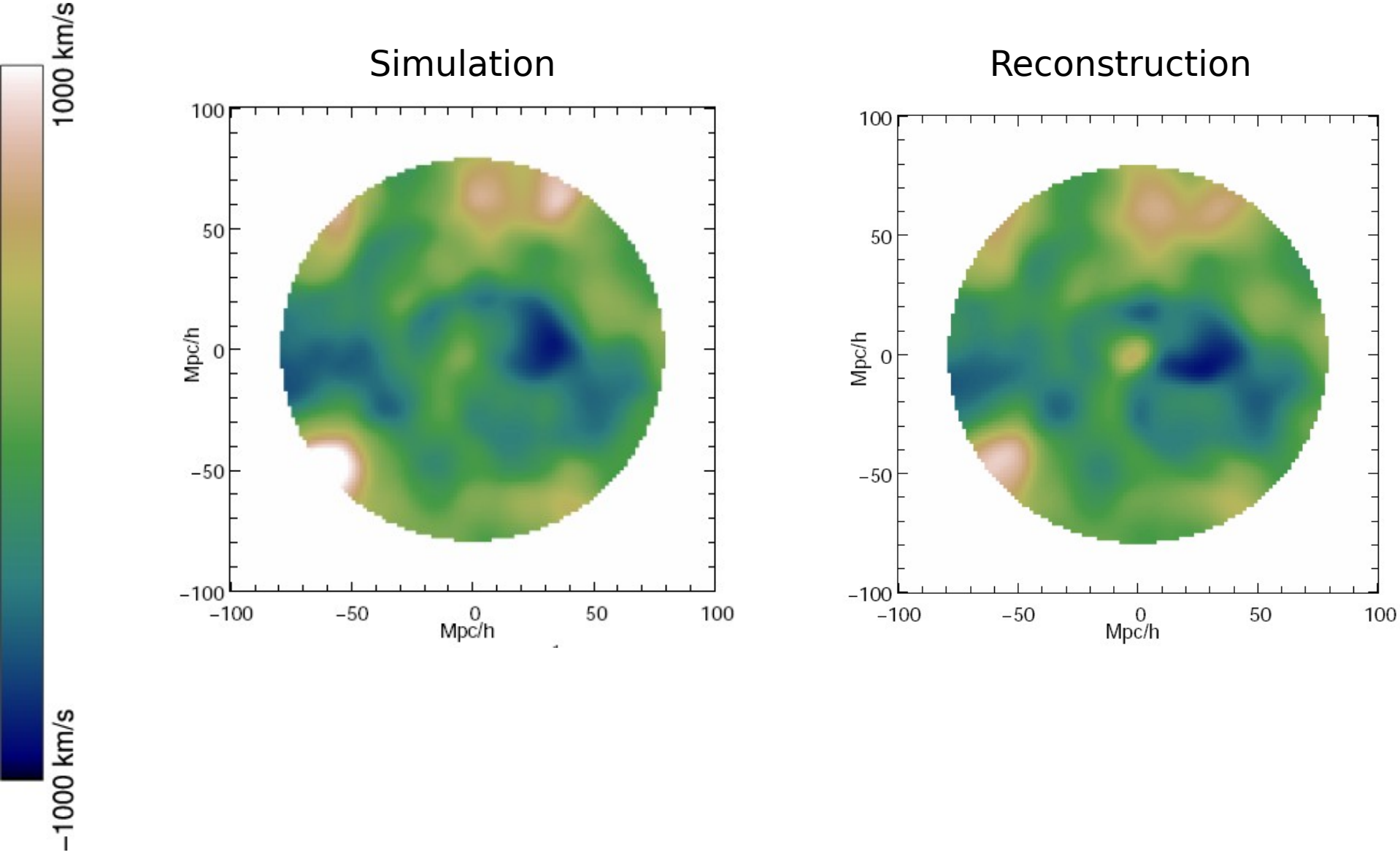
Redshift distortion





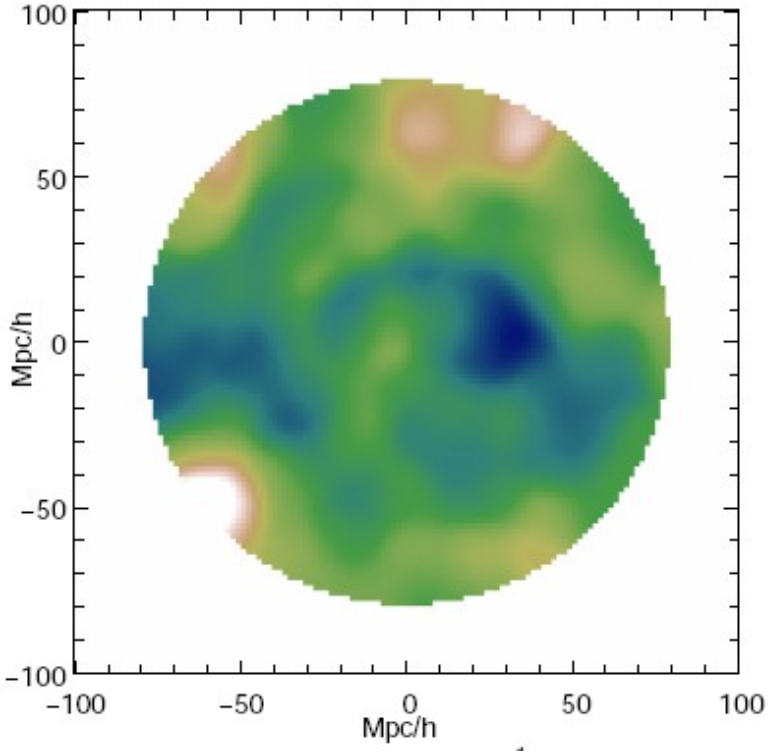
NOT CORRECTIBLE
(SMALL SCALE EFFECT)

Redshift distortion

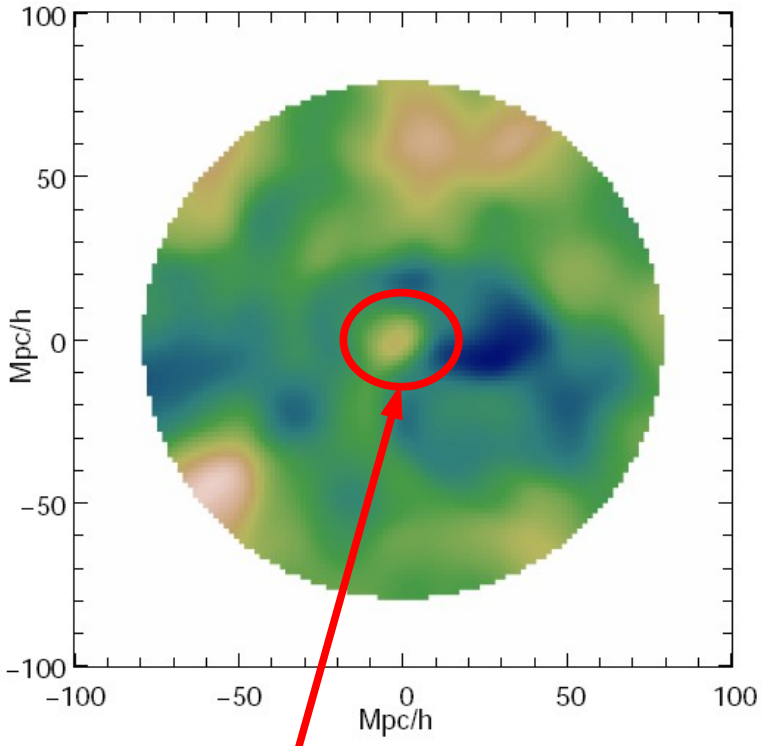


Redshift distortion

Simulation



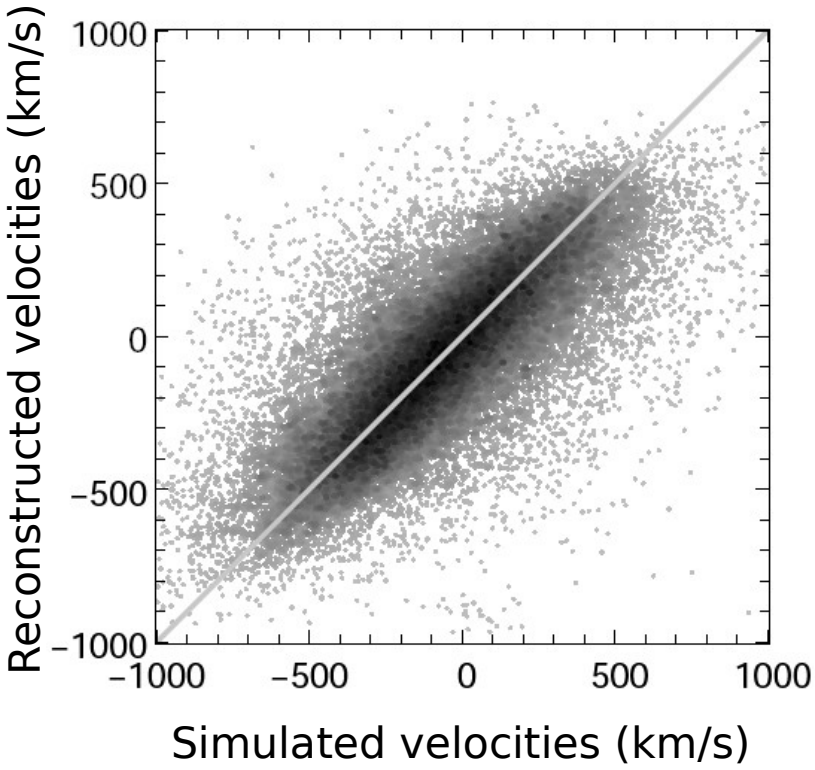
Reconstruction



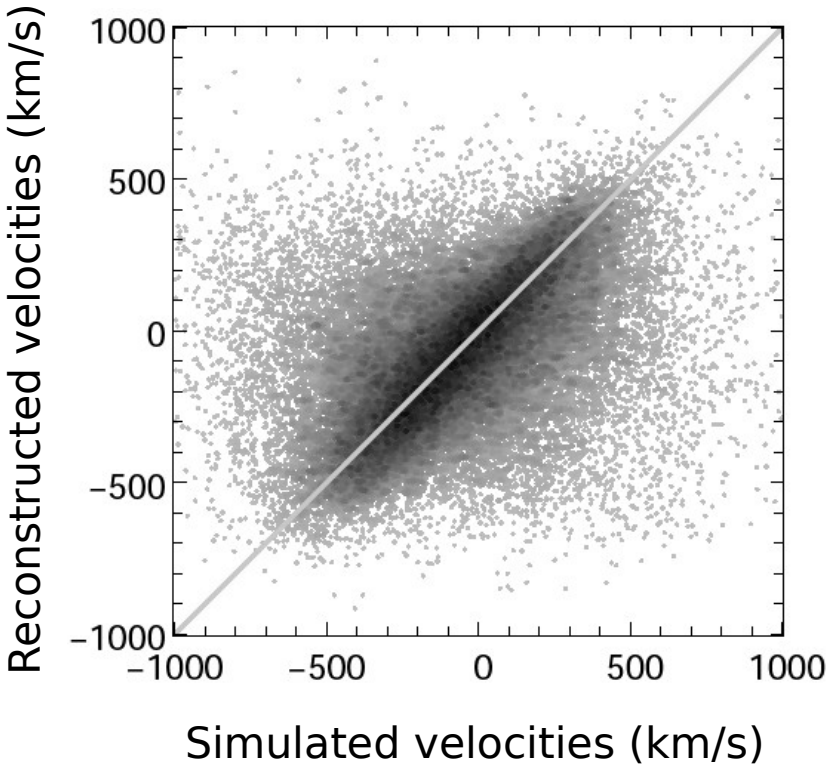
Region near the observer
poorly reconstructed ~ 10 Mpc/h

Redshift distortion

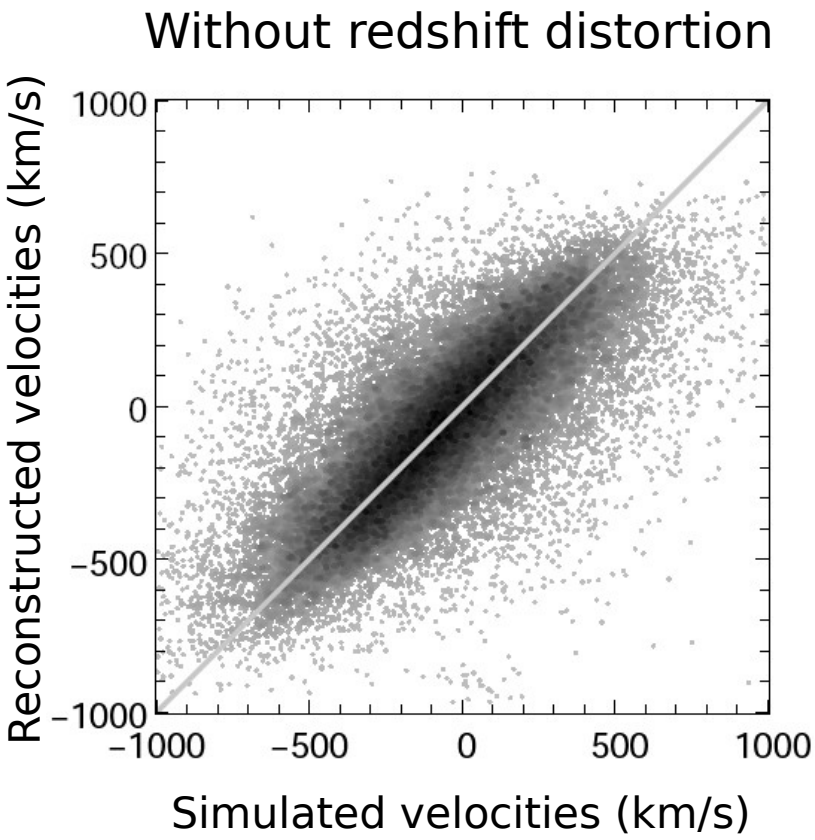
Without redshift distortion

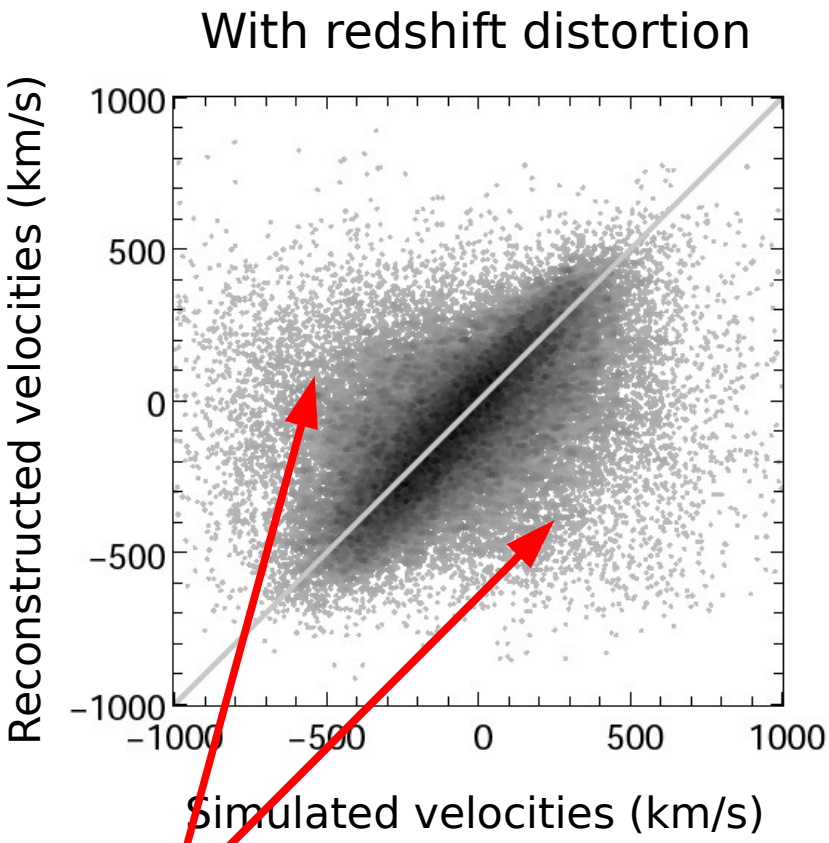


With redshift distortion

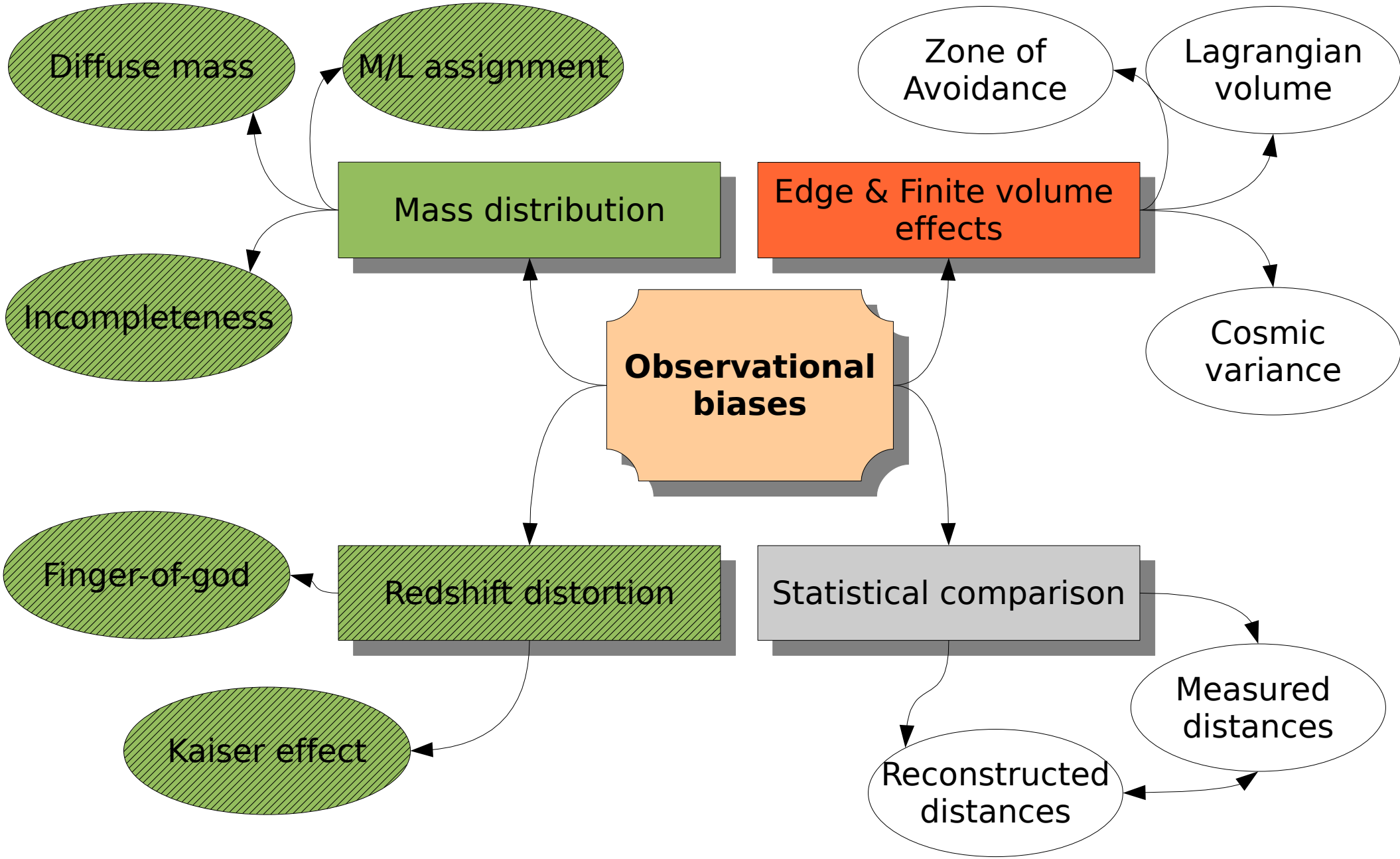


Redshift distortion





Shell crossings due to redshift distortion


Diffuse mass
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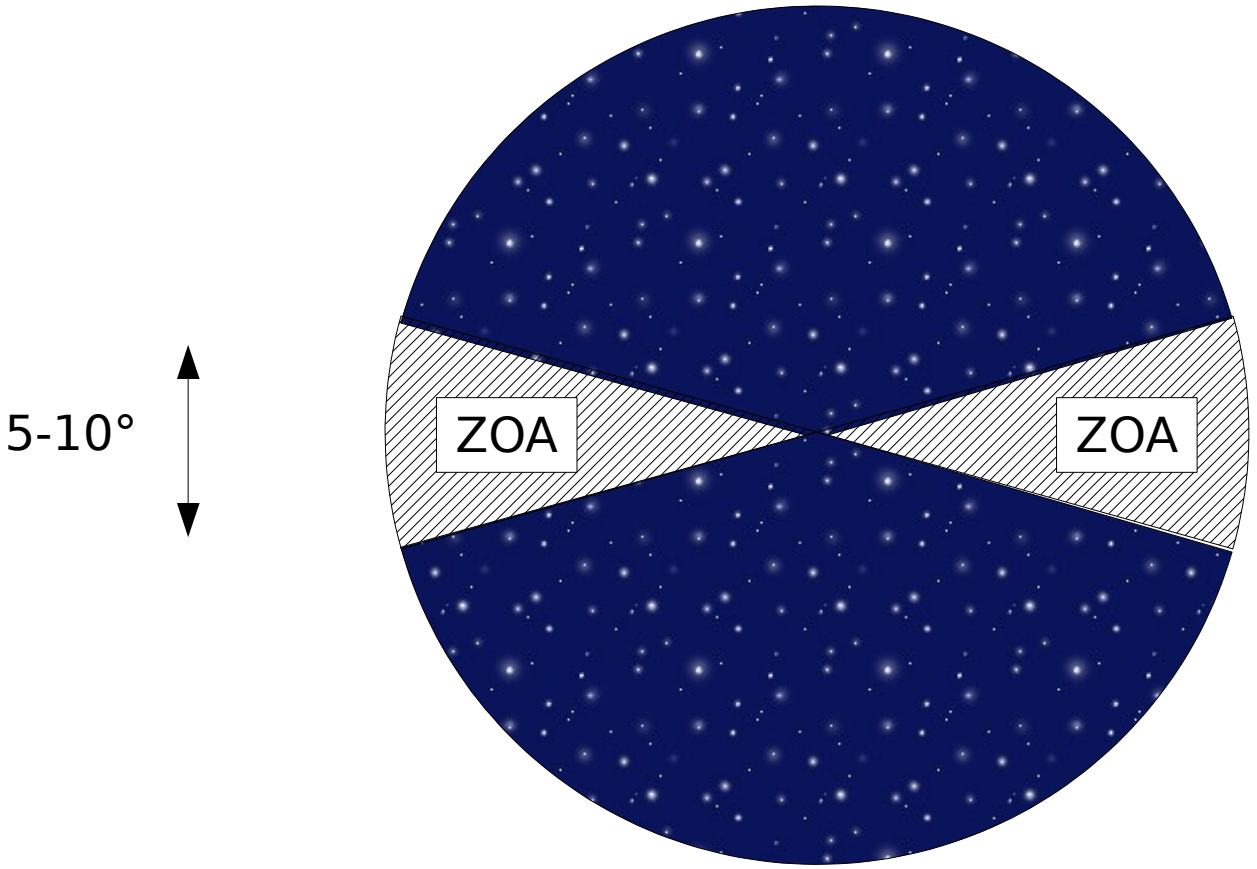
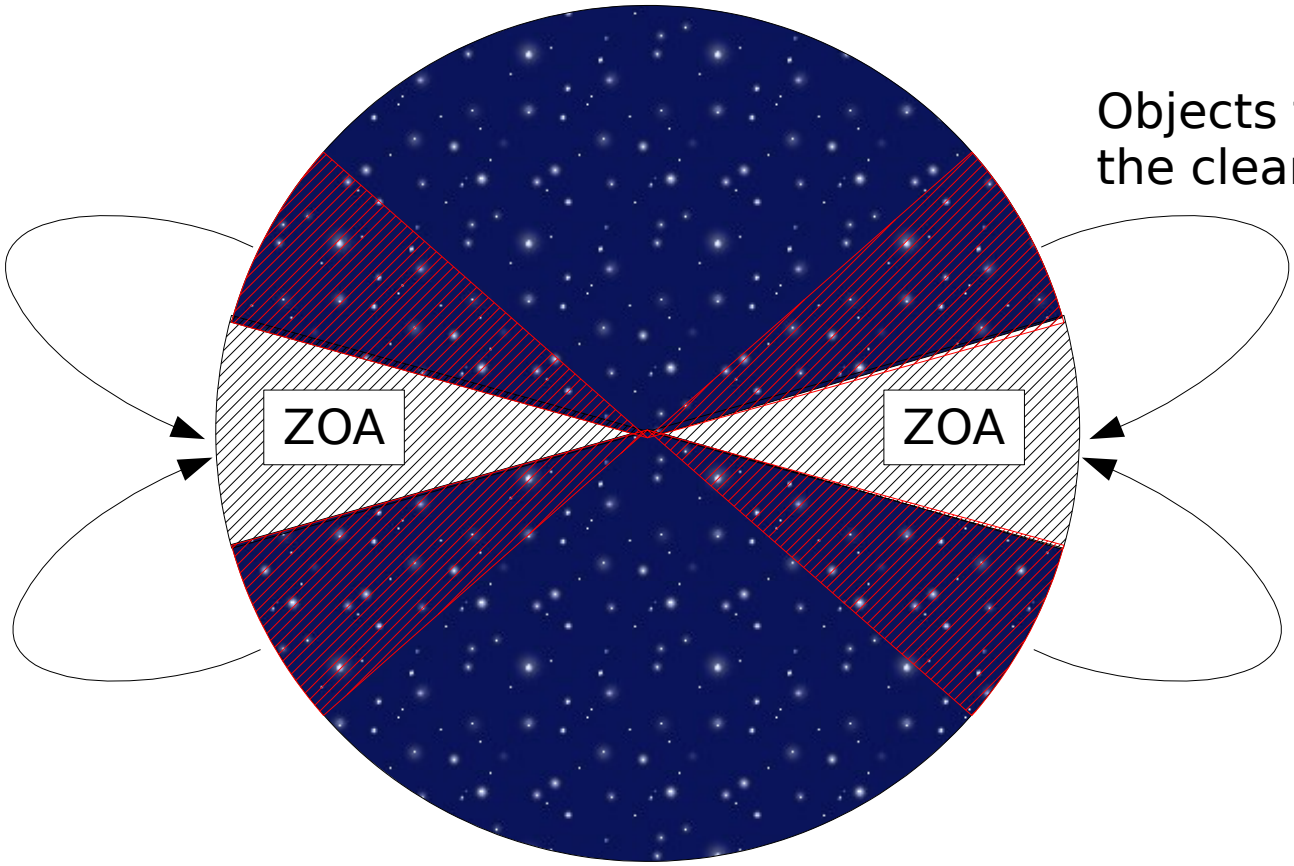
Observational biases
Cosmic variance
Finger-of-god
Redshift distortion
Statistical comparison
Measured distances
Kaiser effect
Reconstructed distances

Zone of Avoidance (ZOA)



Zone of Avoidance (ZOA)

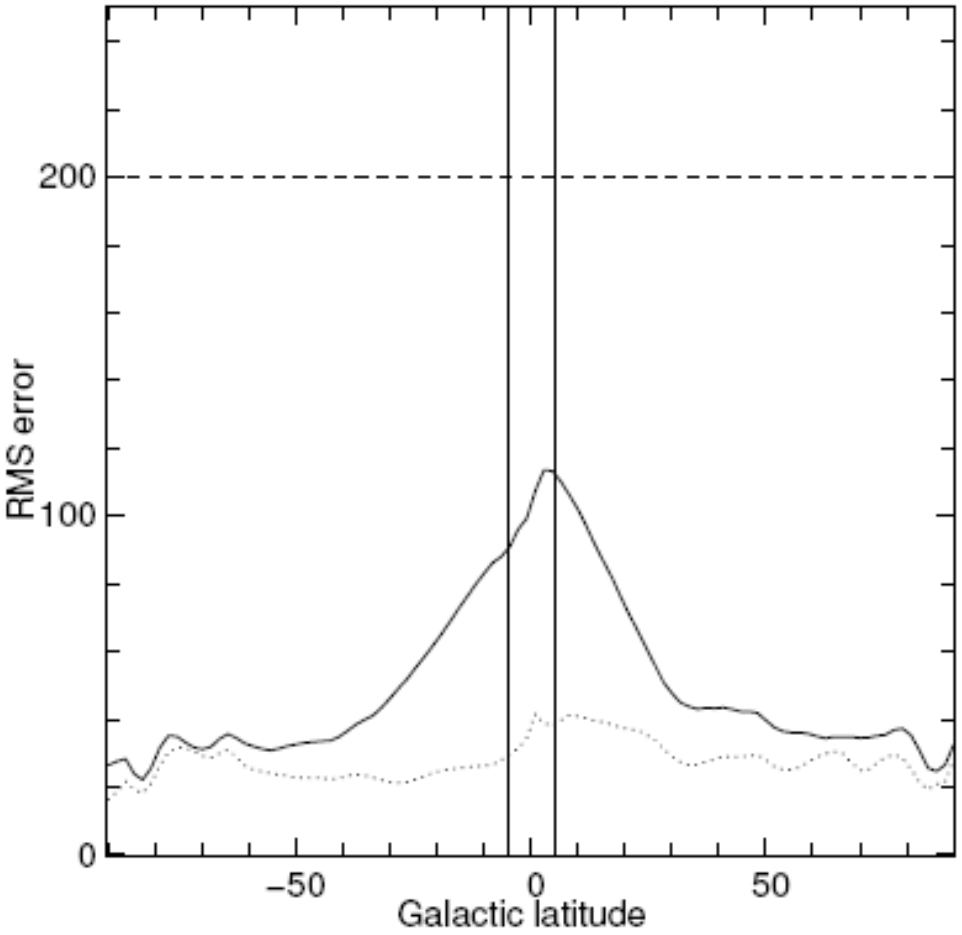
Methods:
- SPH filtering (Fontanot et al. 2003)
- Yahil method (Yahil et al. 1991)
- Shaya method (Shaya et al. 1995) ⇒ simplest

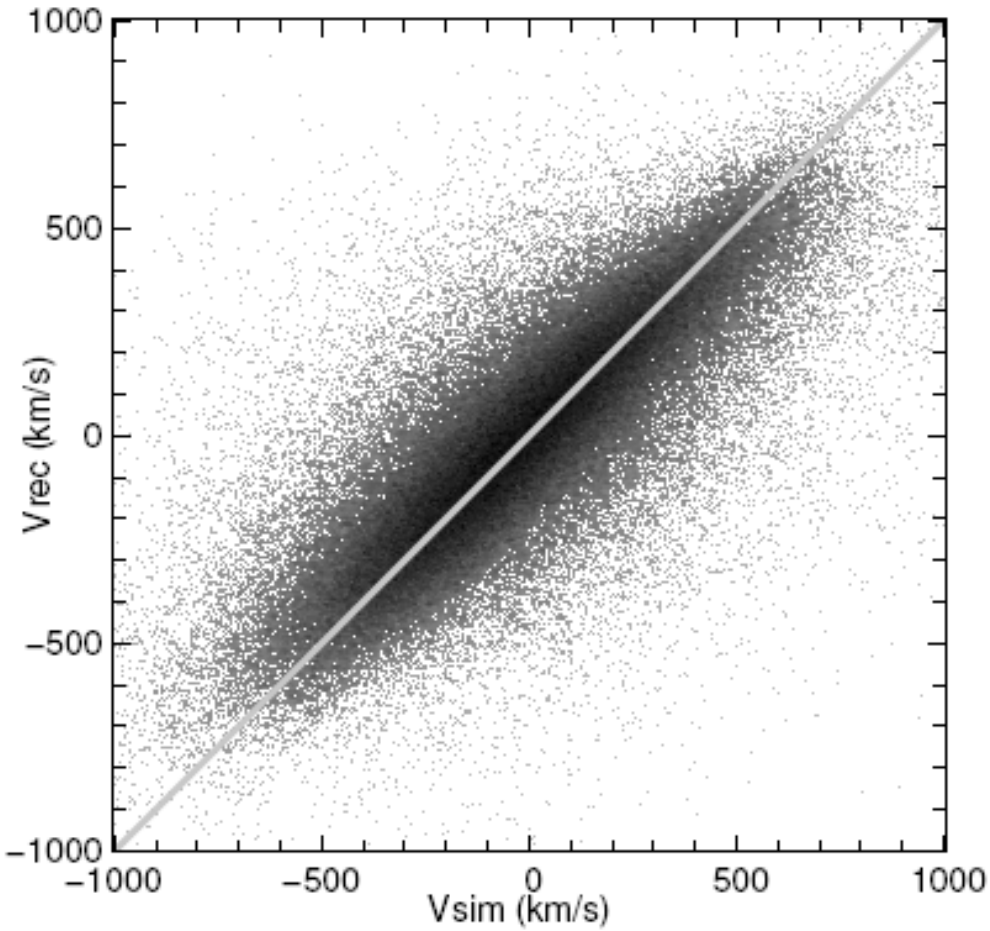


Objects folding into the cleared ZOA

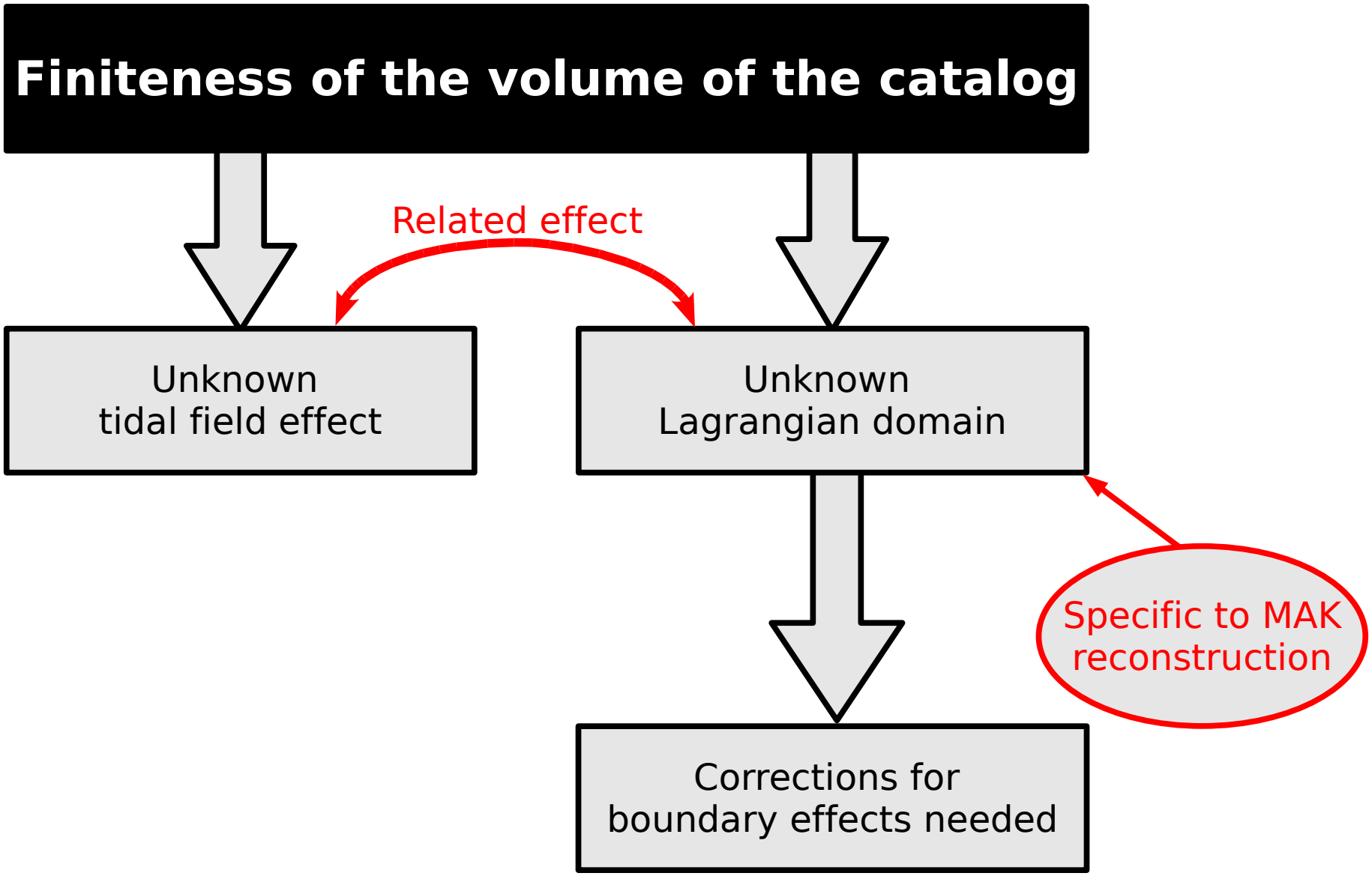
(introduced in Shaya et al. 1995, ApJ)

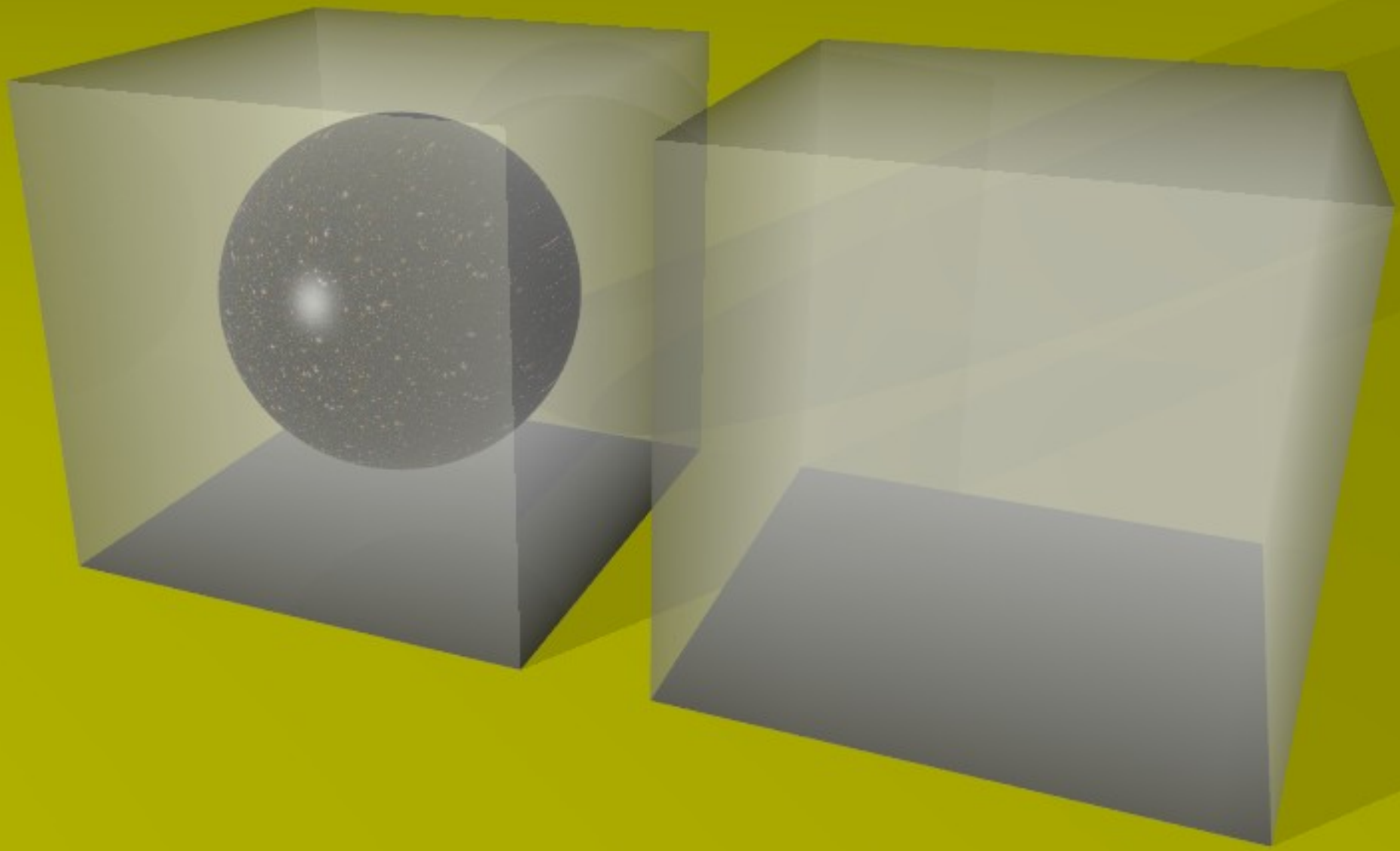
Zone of Avoidance (ZOA)



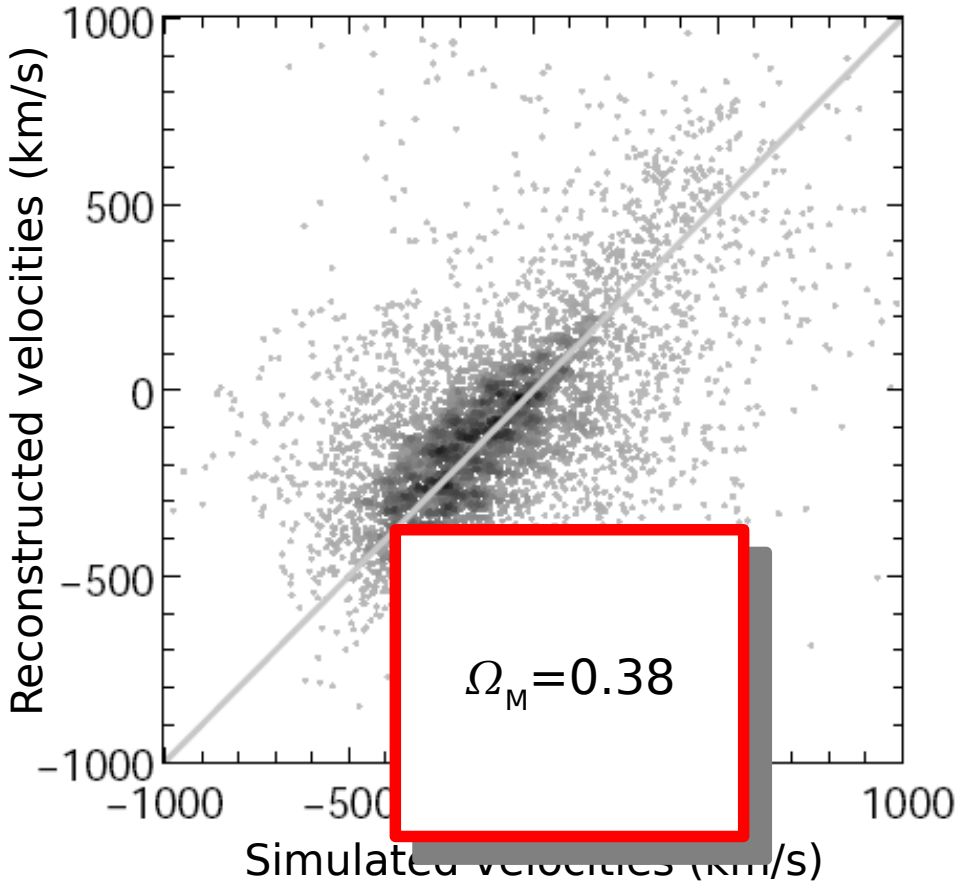


Outer edge effect

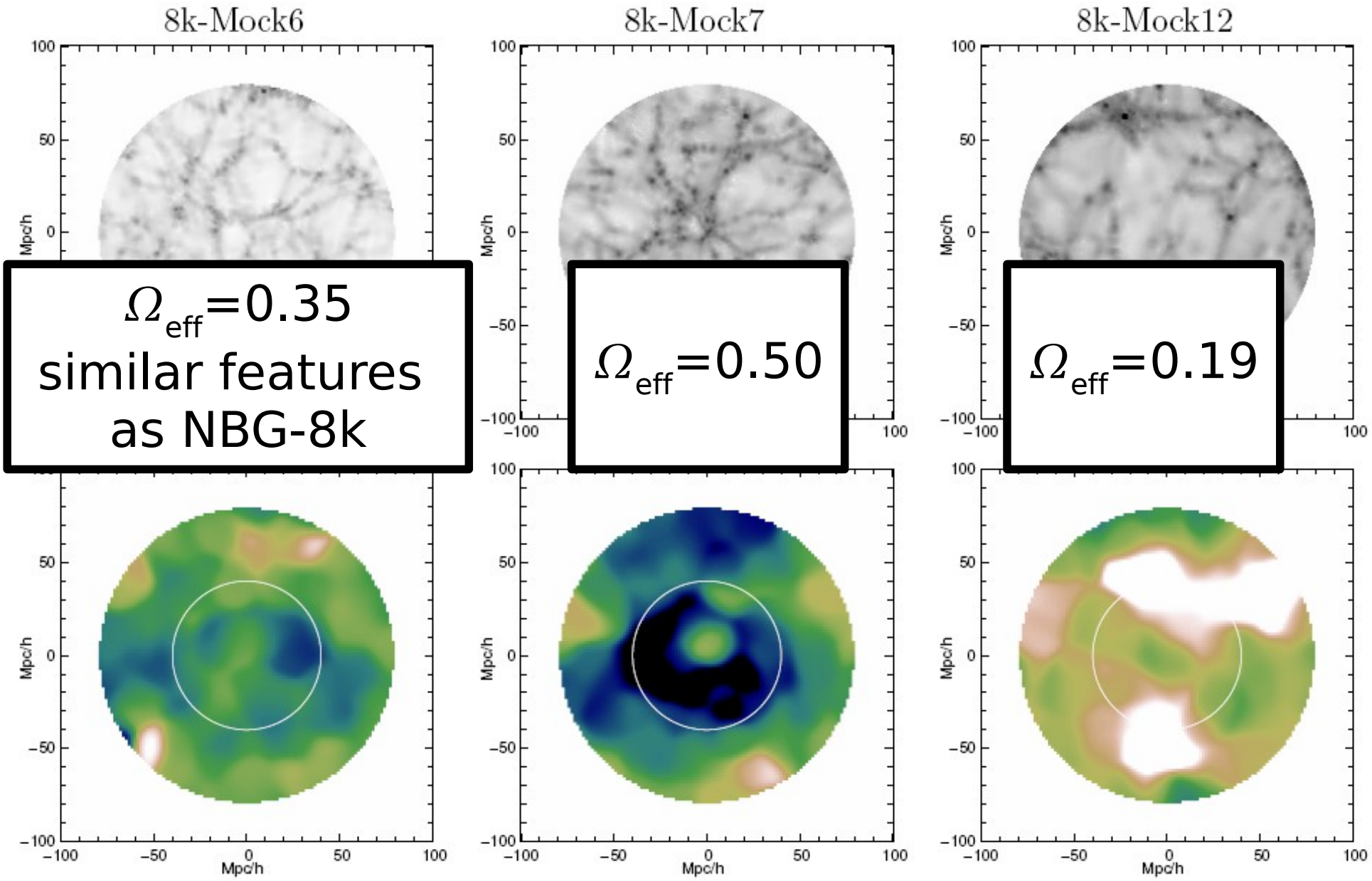




Result (with redshift distortion)



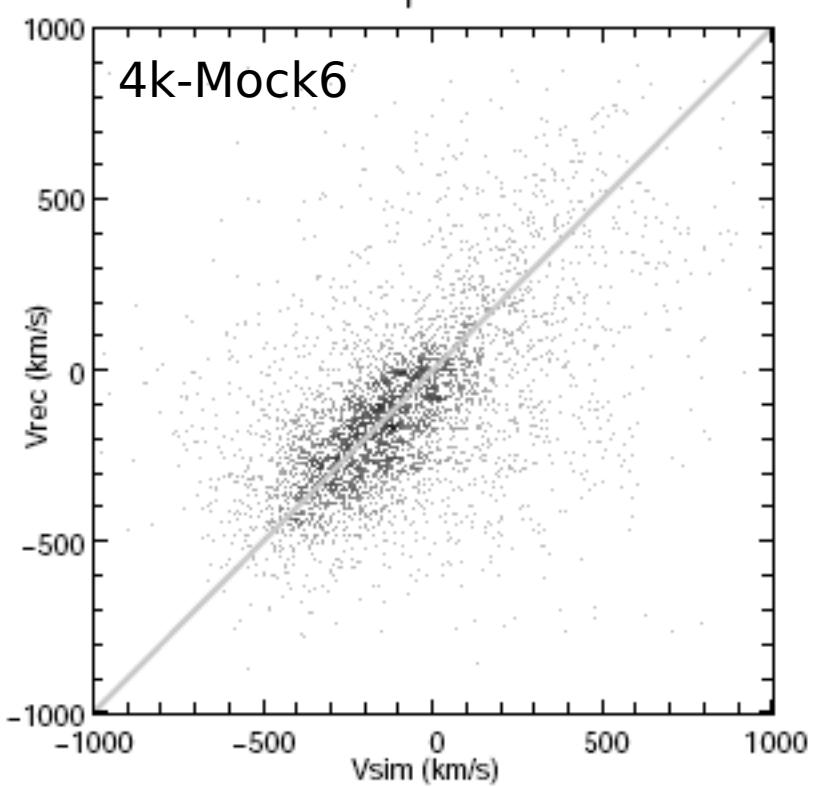
Cosmic variance

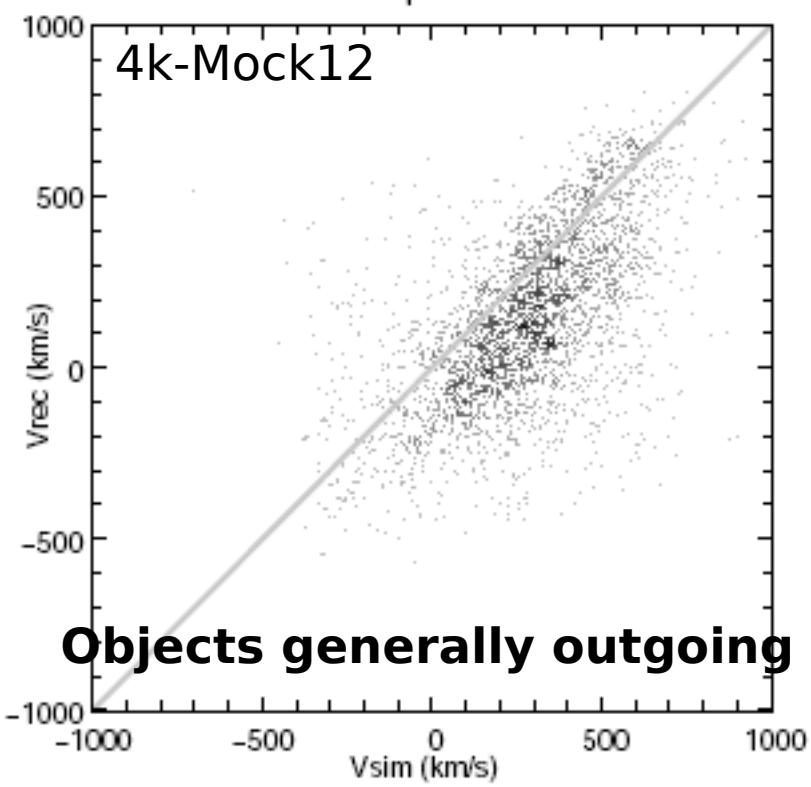


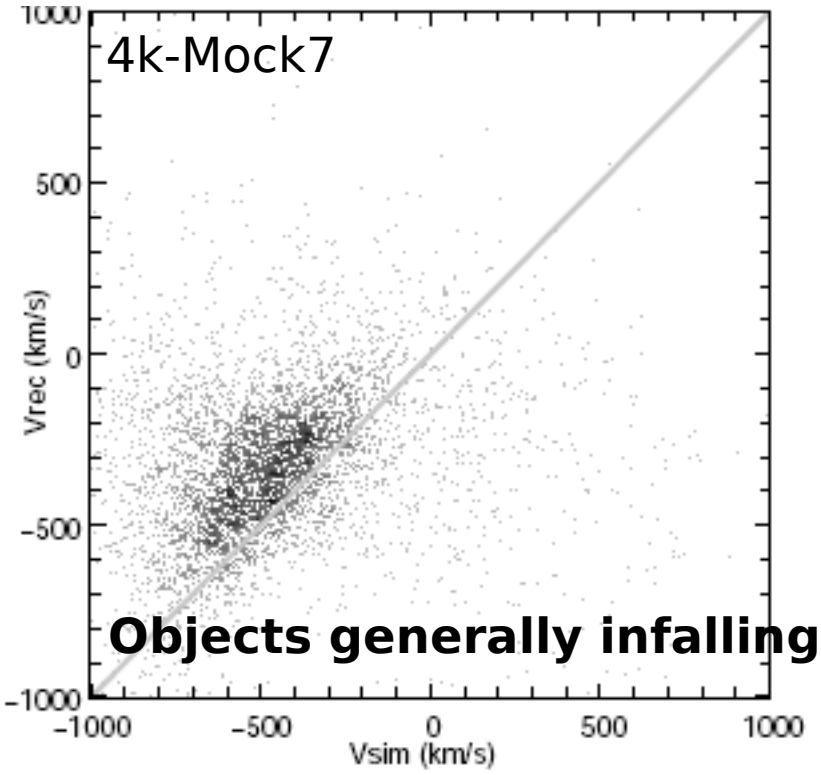
Ω_{eff}=0.35
similar features
as NBG-8k

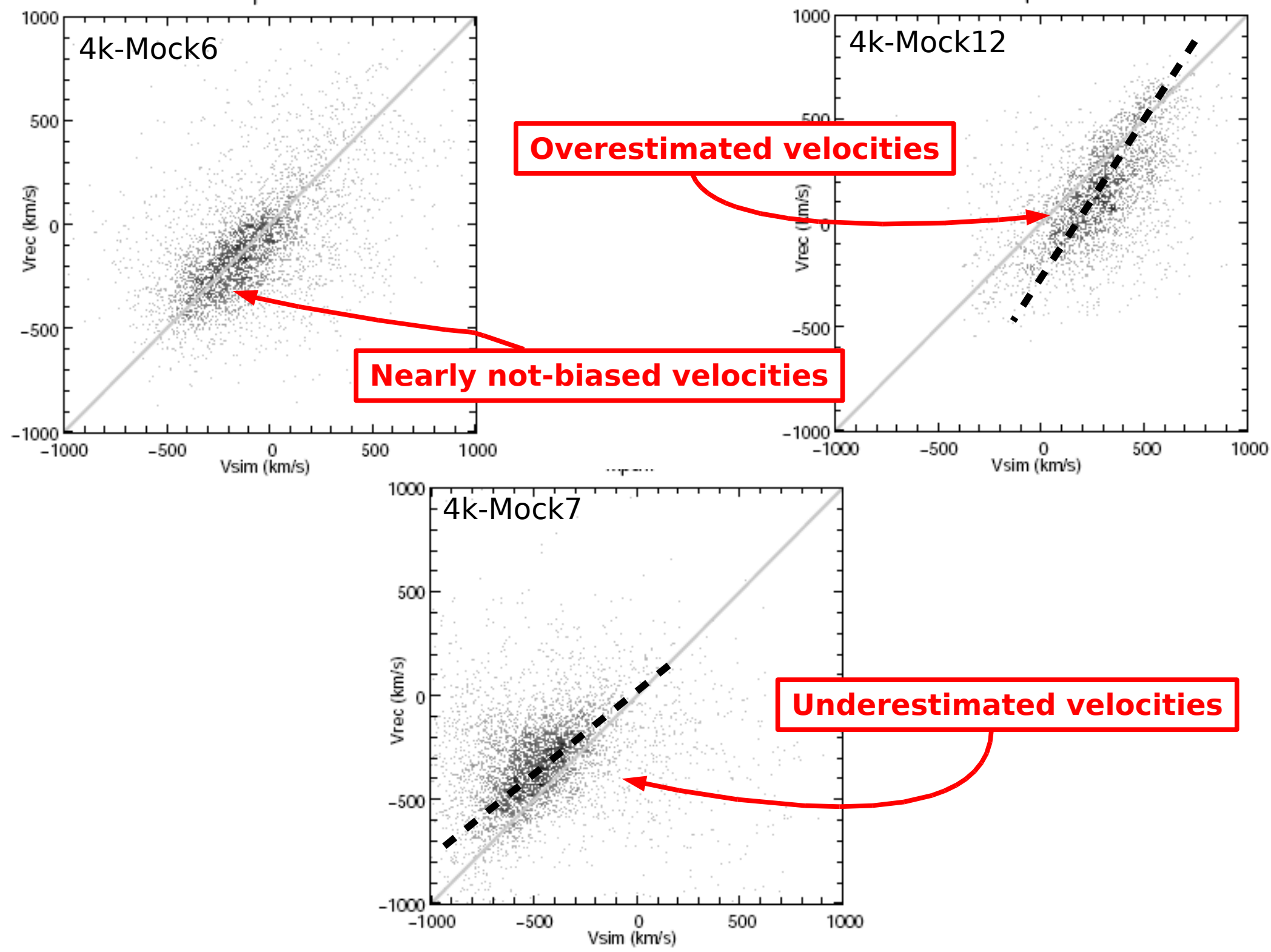
Ω_{eff}=0.50

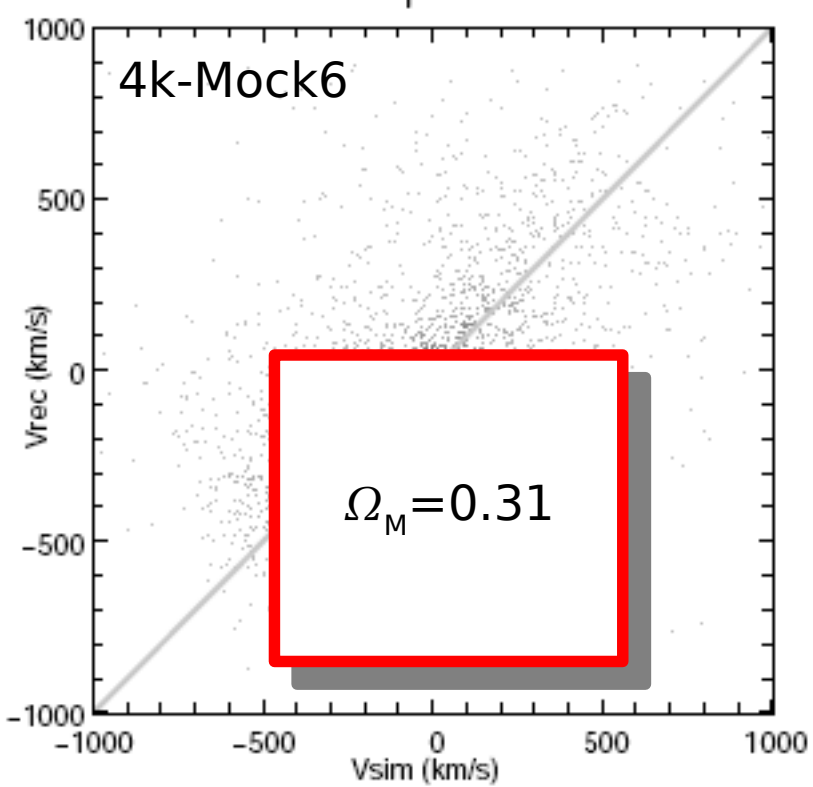
Ω_{eff}=0.19

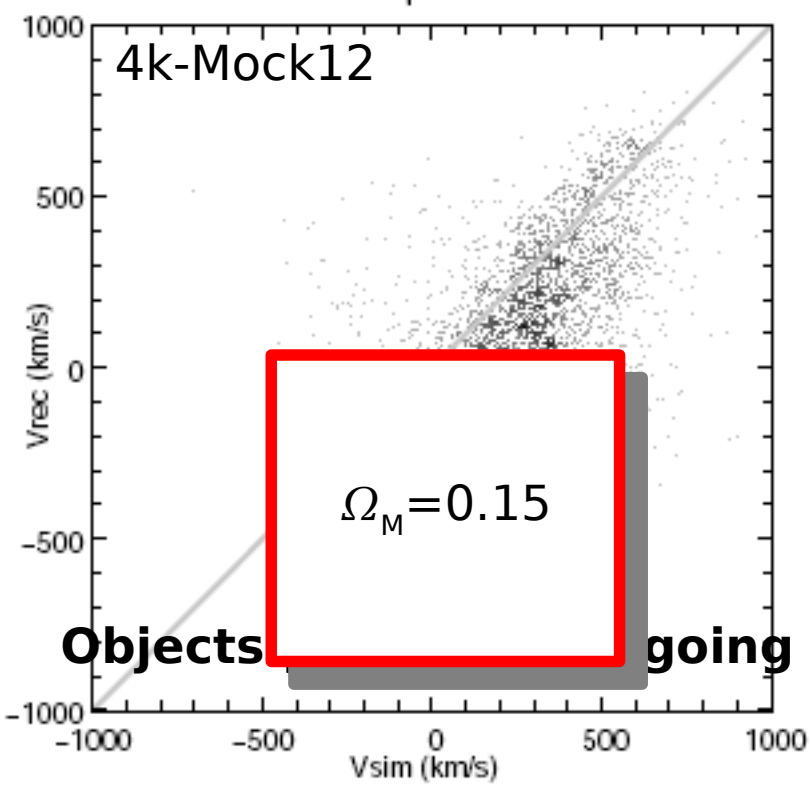

4k-Mock6
Vrec (km/s)
Vsim (km/s)
1000
500
0
−500
−1000
−1000
−500
0
500
1000


4k-Mock12
Vrec (km/s)
Vsim (km/s)
Objects generally outgoing
1000
500
0
−500
−1000
−1000
−500
0
500
1000

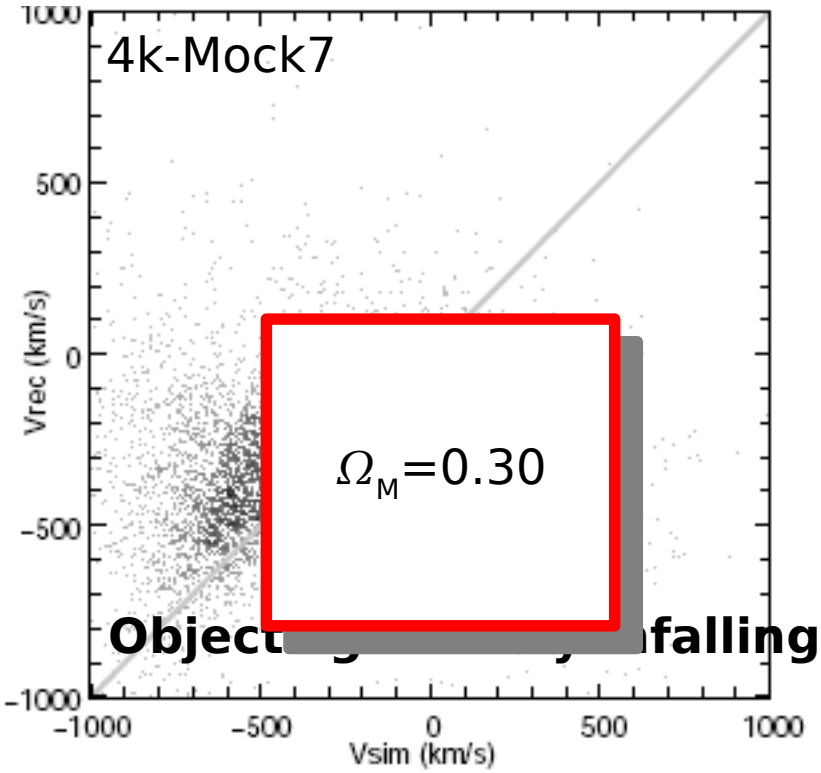

4k-Mock7
Vrec (km/s)
Vsim (km/s)
Objects generally infalling
1000
500
0
−500
−1000
−1000
−500
0
500
1000


4k-Mock6
4k-Mock12
4k-Mock7
Overestimated velocities
Nearly not-biased velocities
Underestimated velocities
Vrec (km/s)
Vsim (km/s)
1000
500
0
−500
−1000

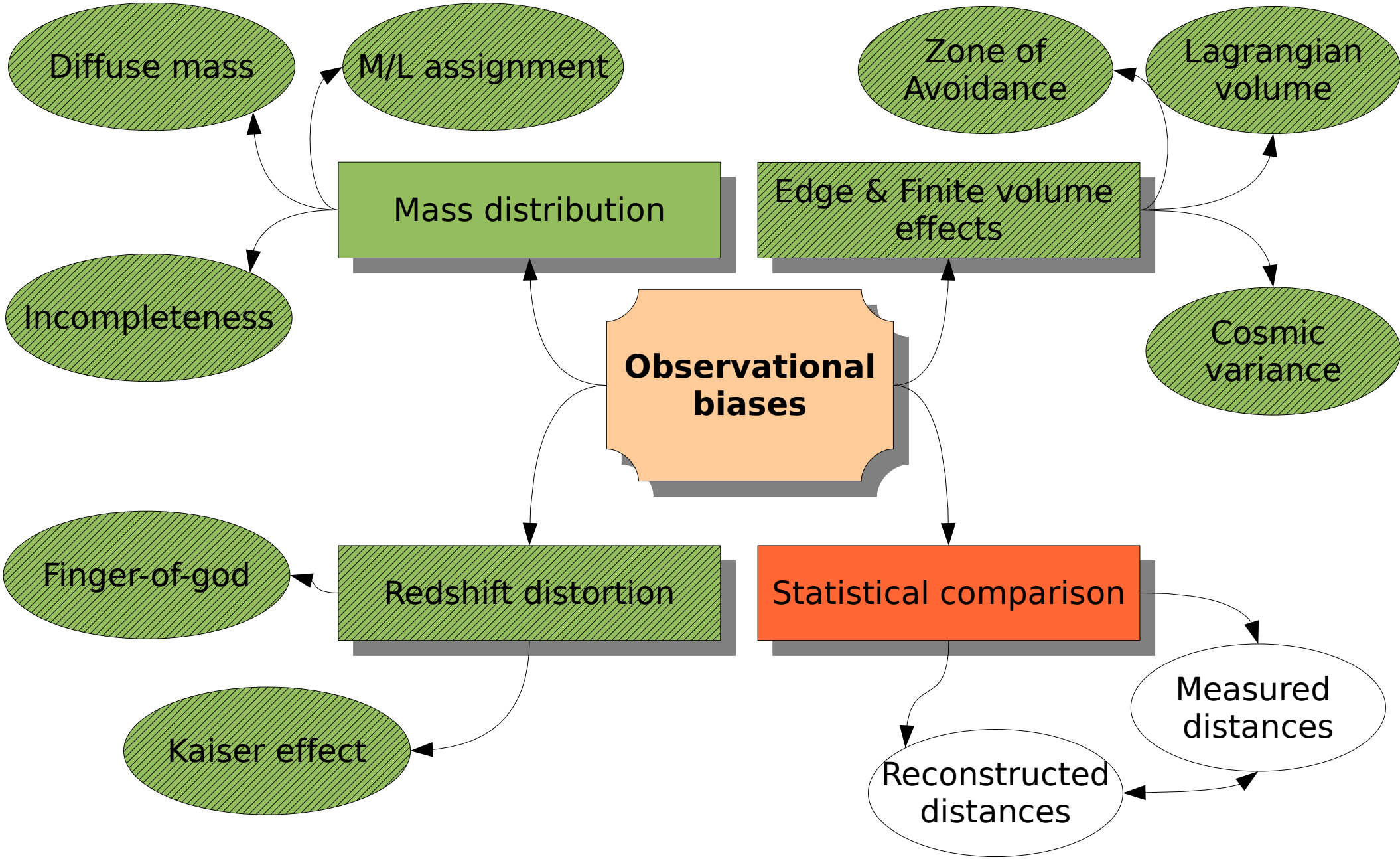




Objects going



Object falling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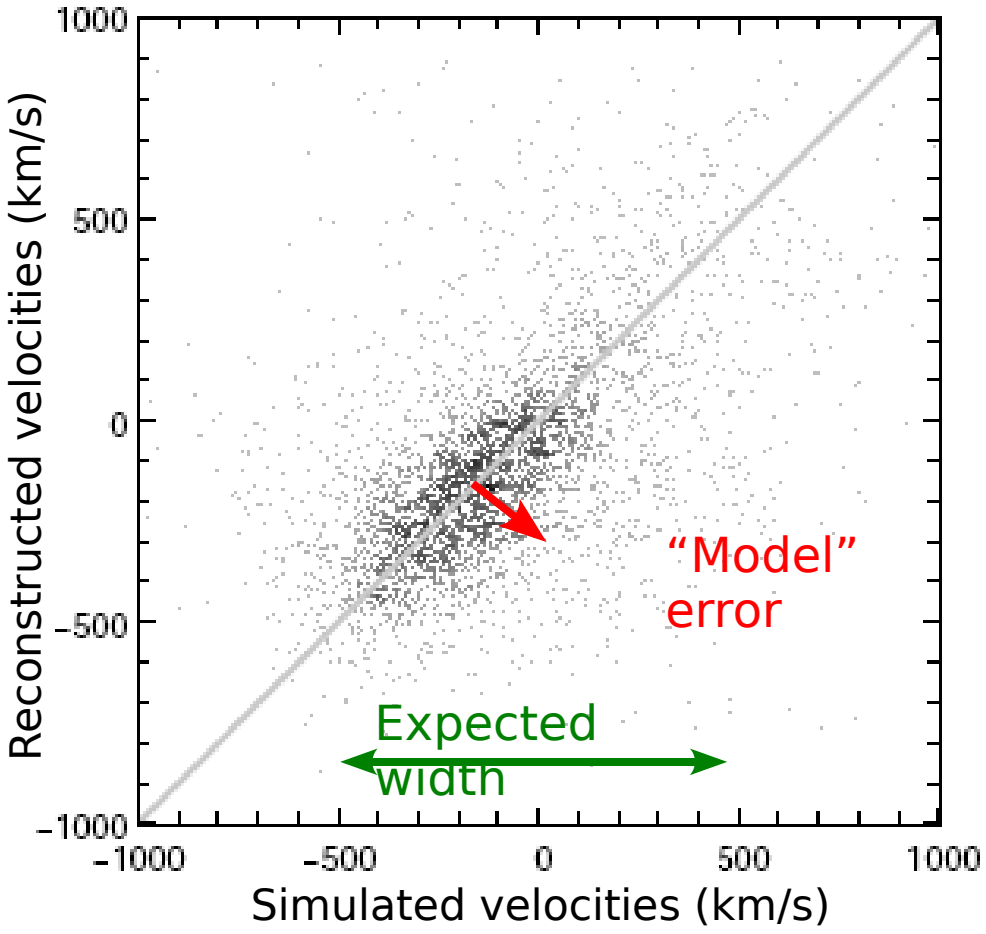
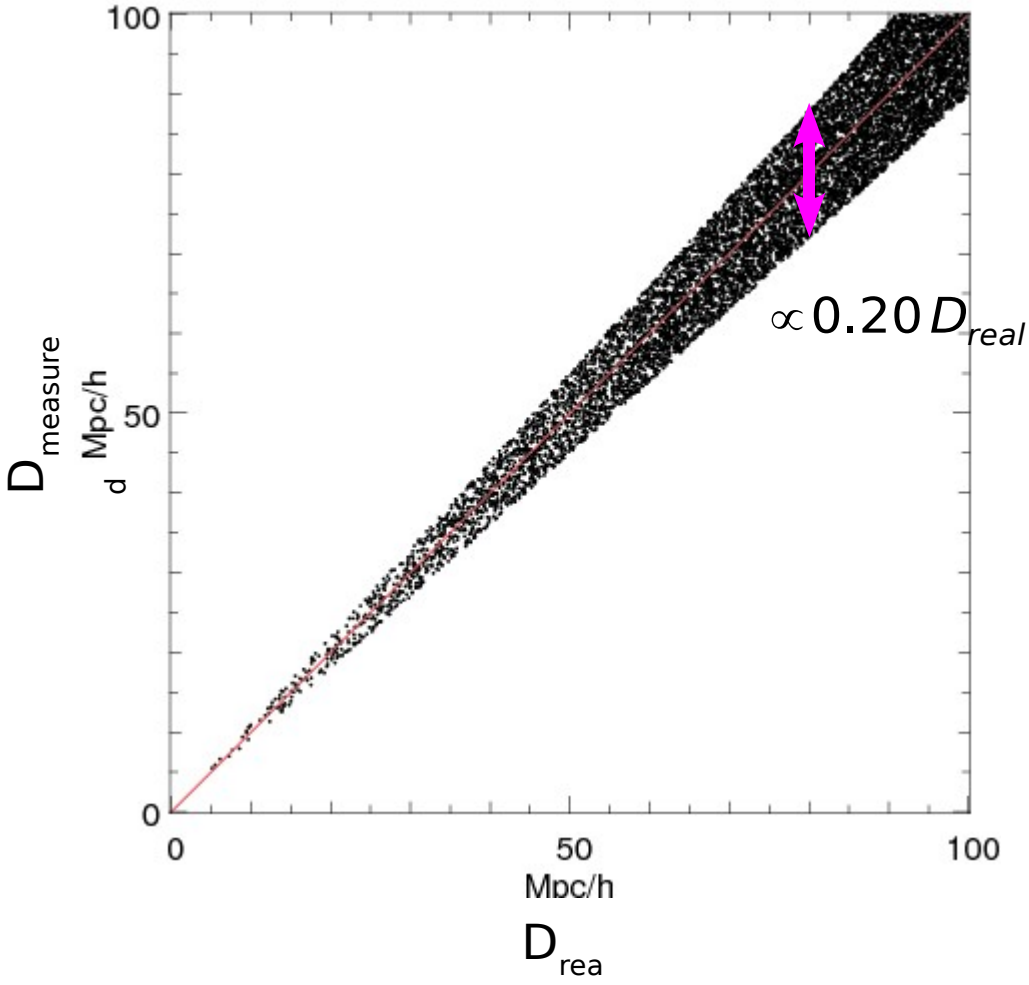
Kaiser effect
Reconstructed distances

Statistical analysis of a scatter

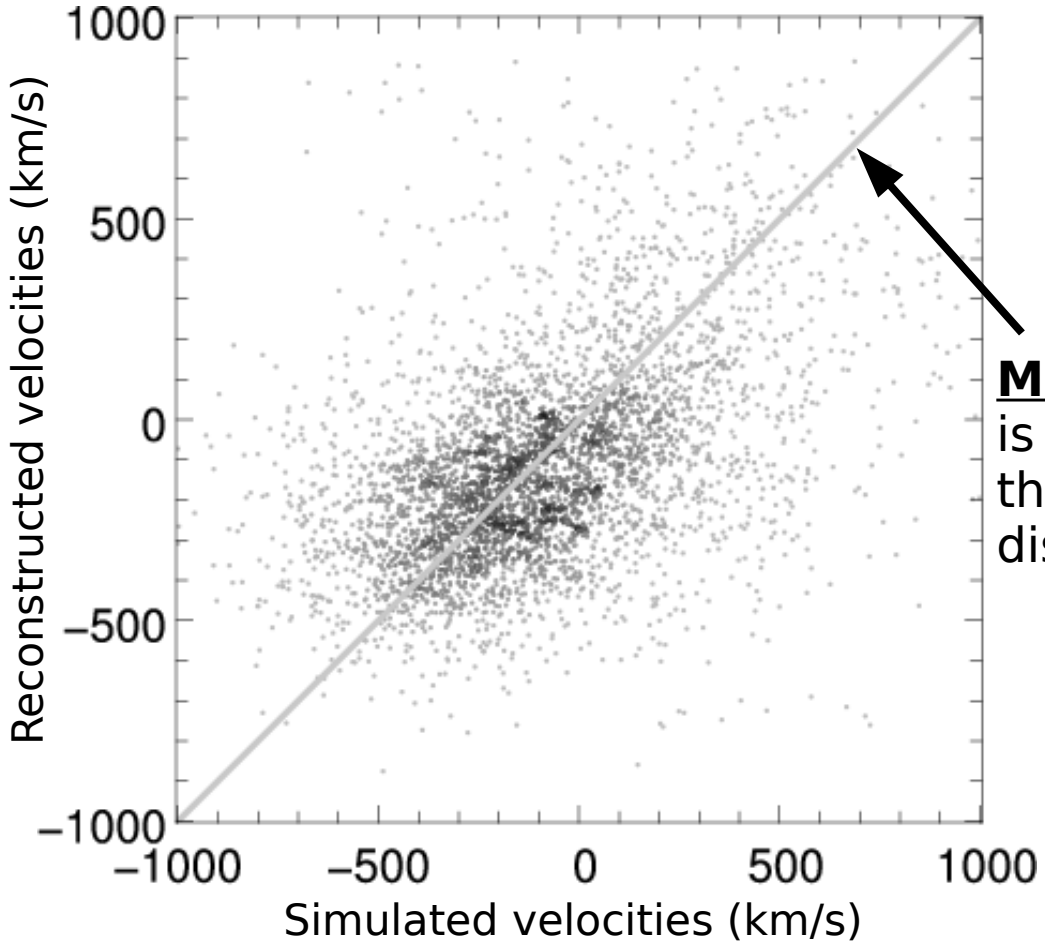
Class 1: “Model” error



Class 2: “Measurement” error

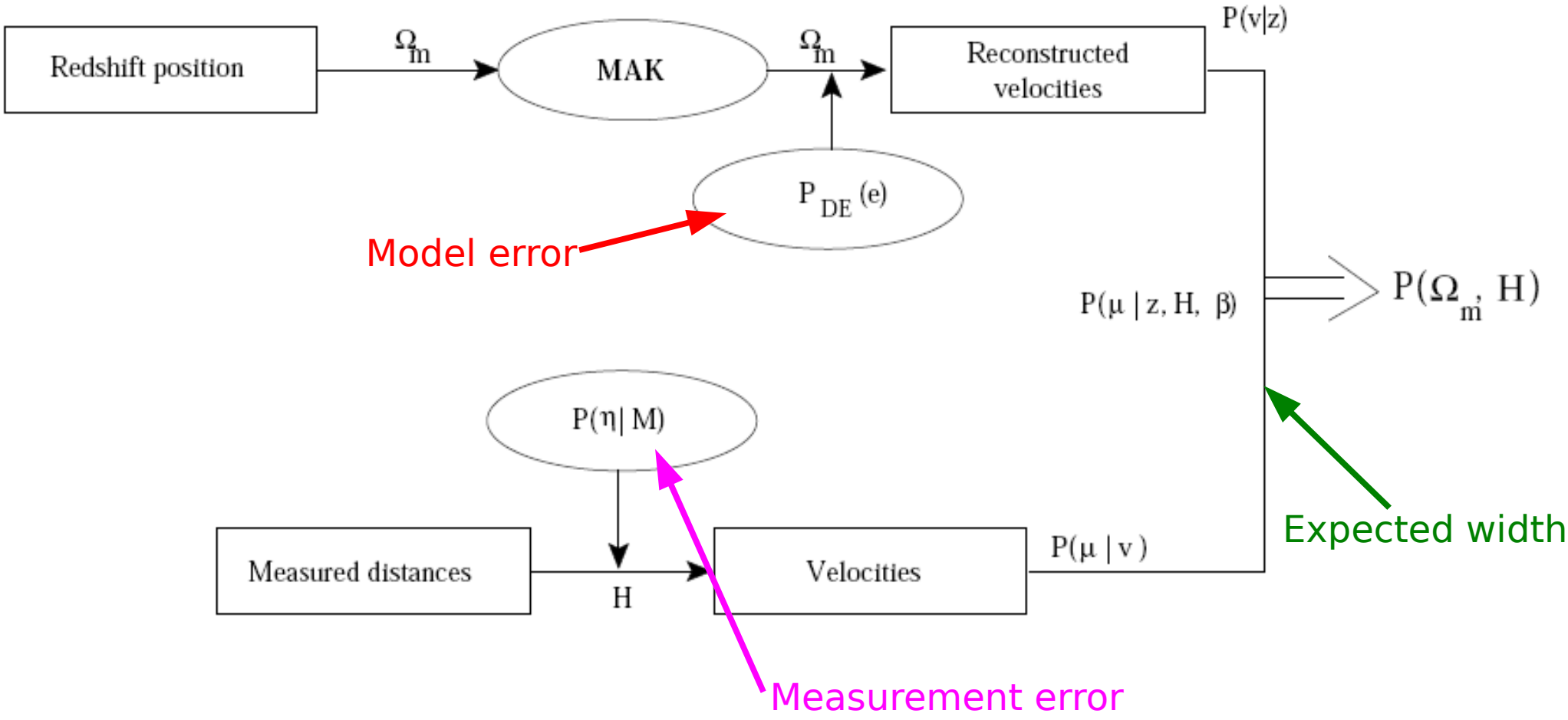


Merging the two problems...



Mission: find that this diagonal is
the real diagonal of the scatter distribution

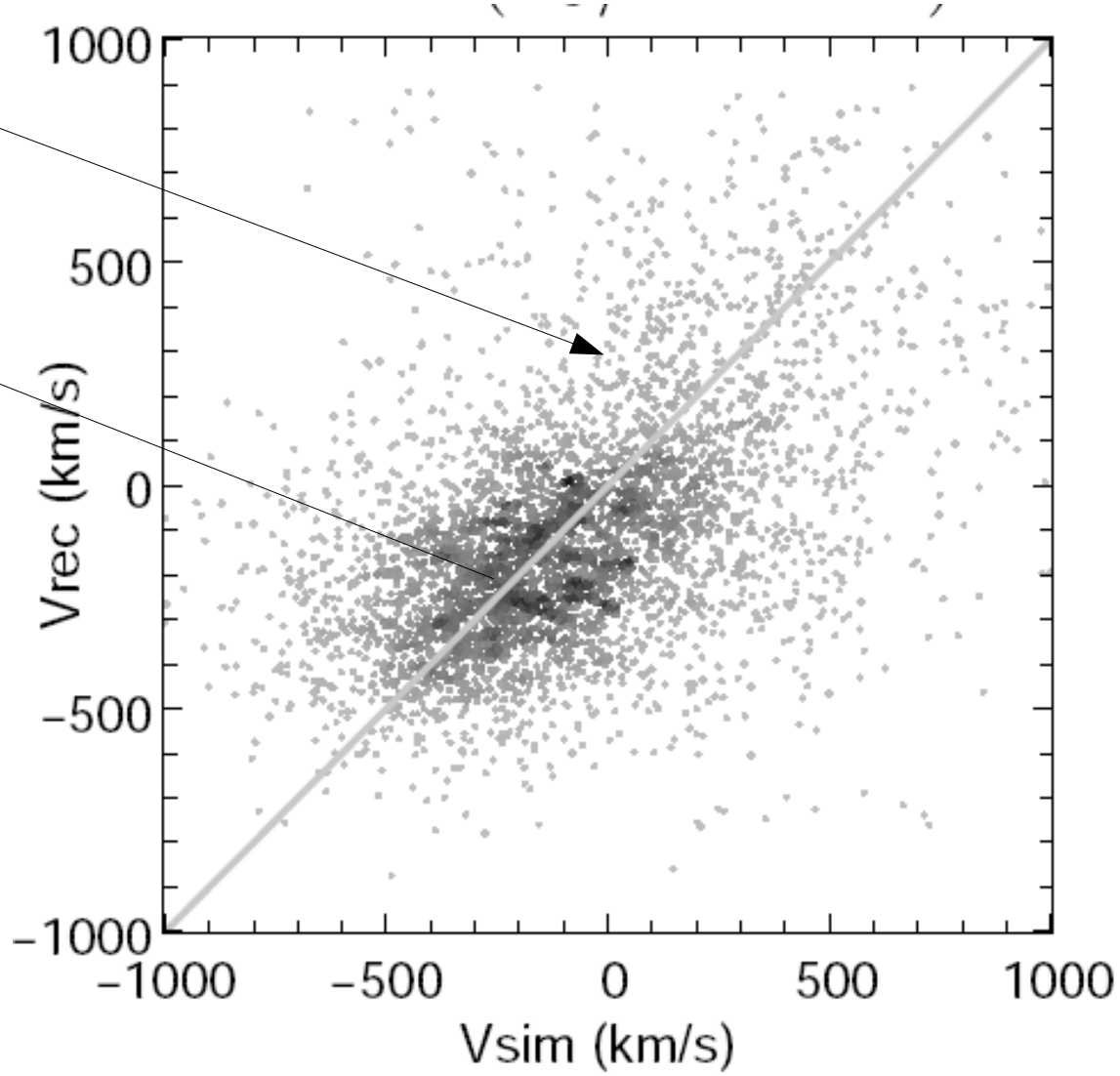
The bayesian chain

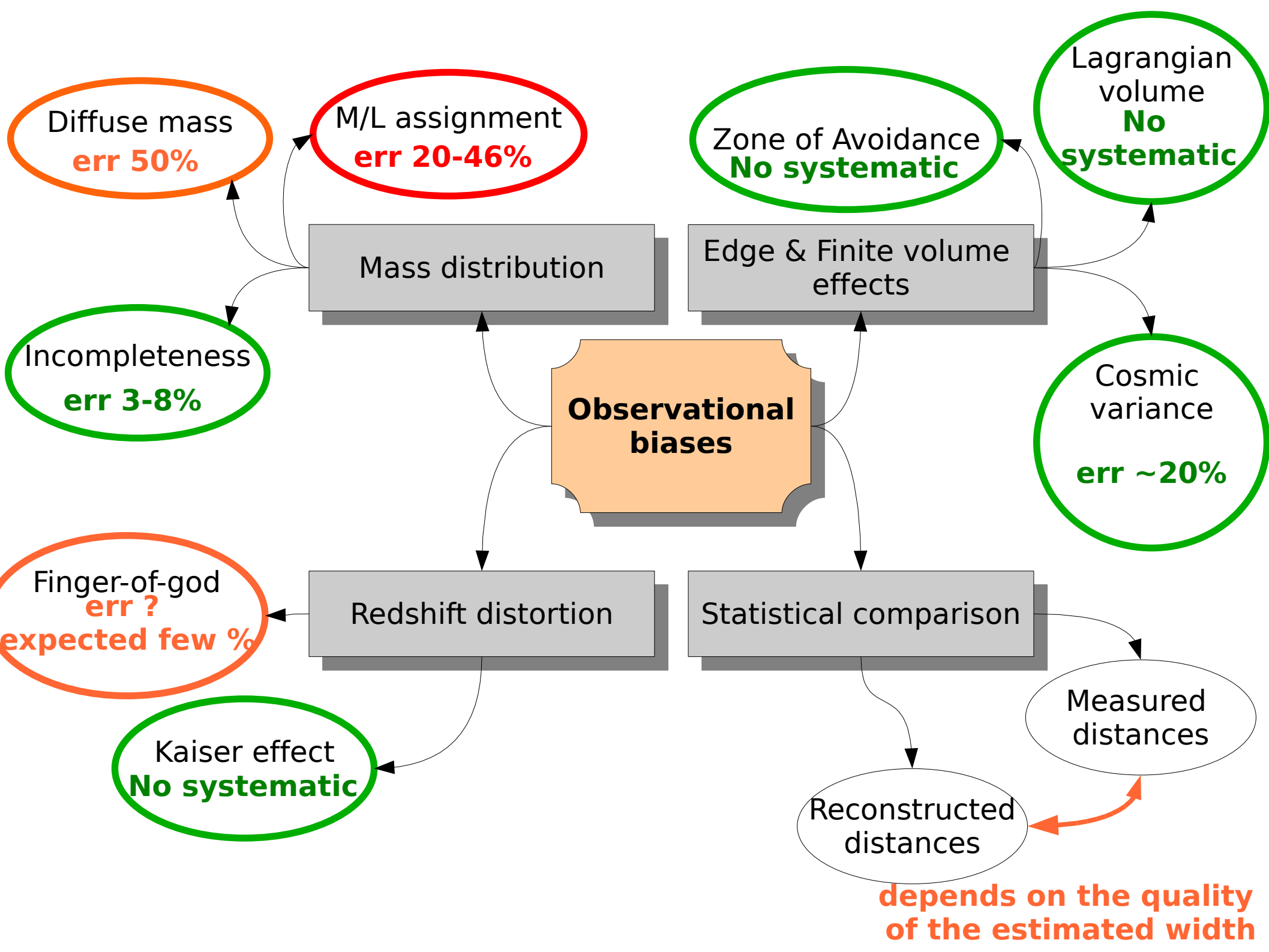


Example

Data points include
typical observational errors
8% distance

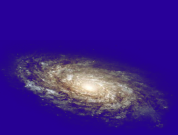
Max of P(Ω_M) yields
- 0.30 when width is known
- 0.10 if width is unknown




Diffuse mass
err 50%
M/L assignment
err 20-46%
Zone of Avoidance
No systematic
Lagrangian volume
No systematic
Mass distribution
Edge & Finite volume effects
Incompleteness
err 3-8%
Observational biases
Cosmic variance
err ~20%
Finger-of-god
err ?
expected few %
Redshift distortion
Statistical comparison
Measured distances
Kaiser effect
No systematic
Reconstructed distances
depends on the quality of the estimated width

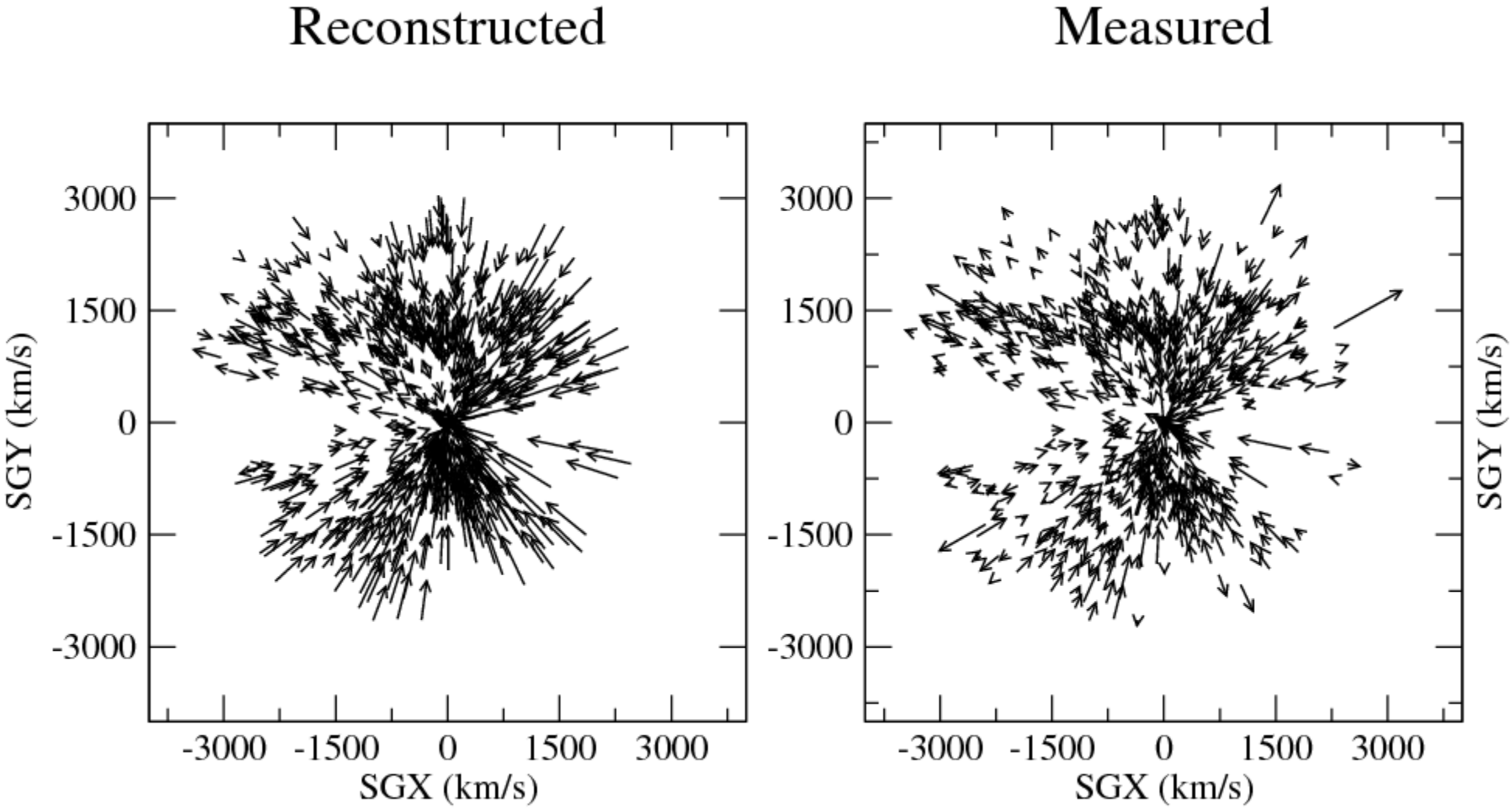
4. Application to NBG-3k

The NBG-3k catalog



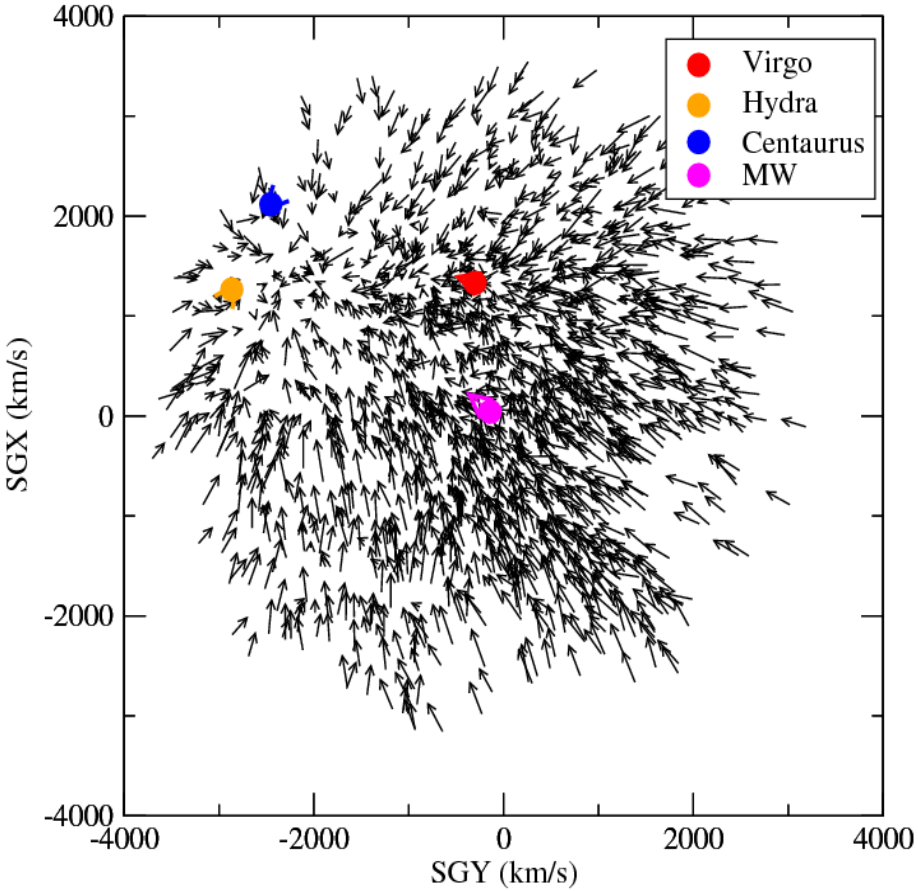
- Nearby Galaxy Catalog (Tully 1987)
- 30 Mpc/h deep
- 743 groups with high quality distances
  (5% < ΔD/D < 20%)
  - Tully-Fisher
  - Tip of the Red giant branch
  - Fundamental plane
  - Surface brightness fluctuation

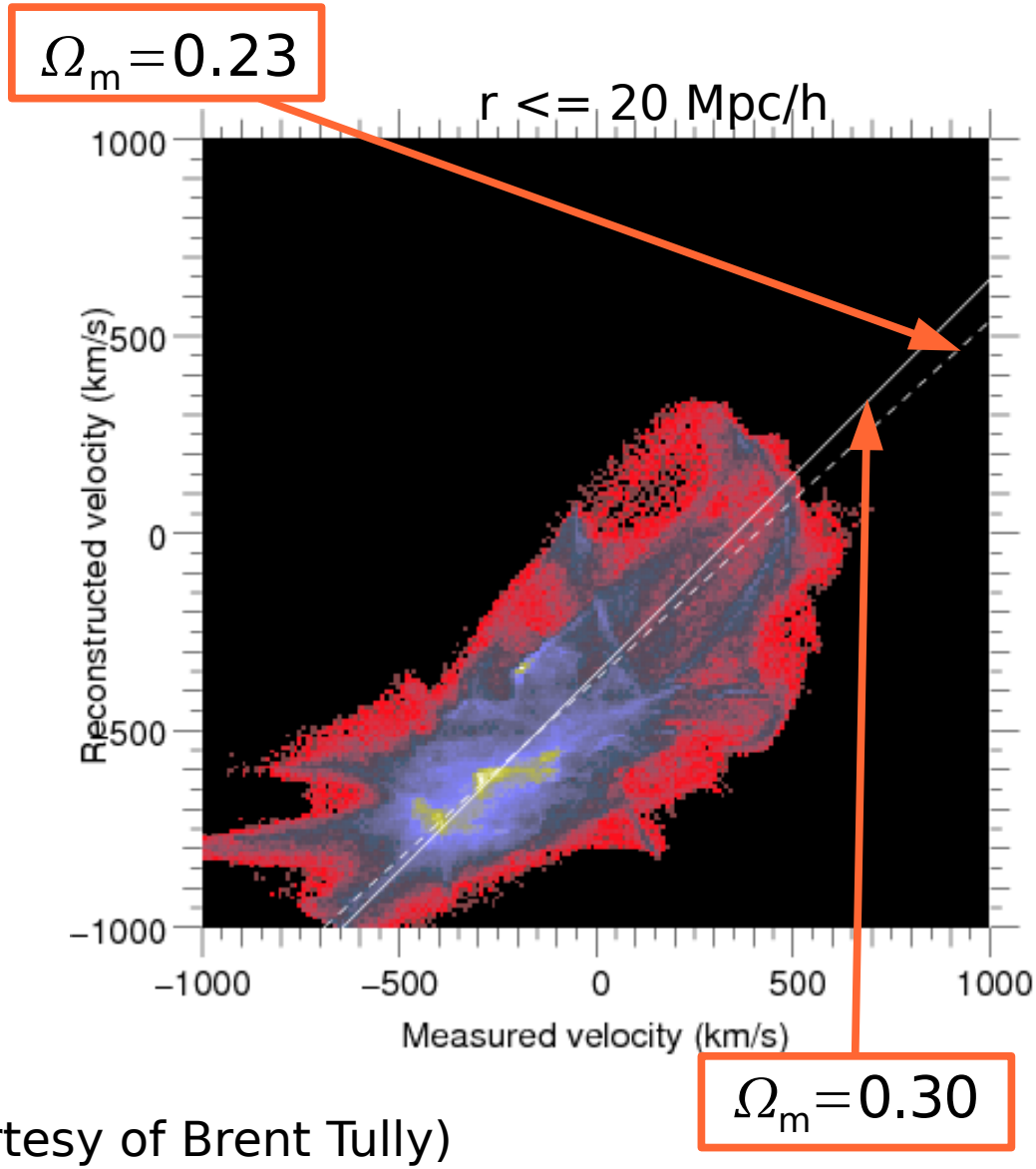
4. Result on observational data



Catalogue redshift/distances NBG-3k (courtesy of Brent Tully)

4. Result on observational data

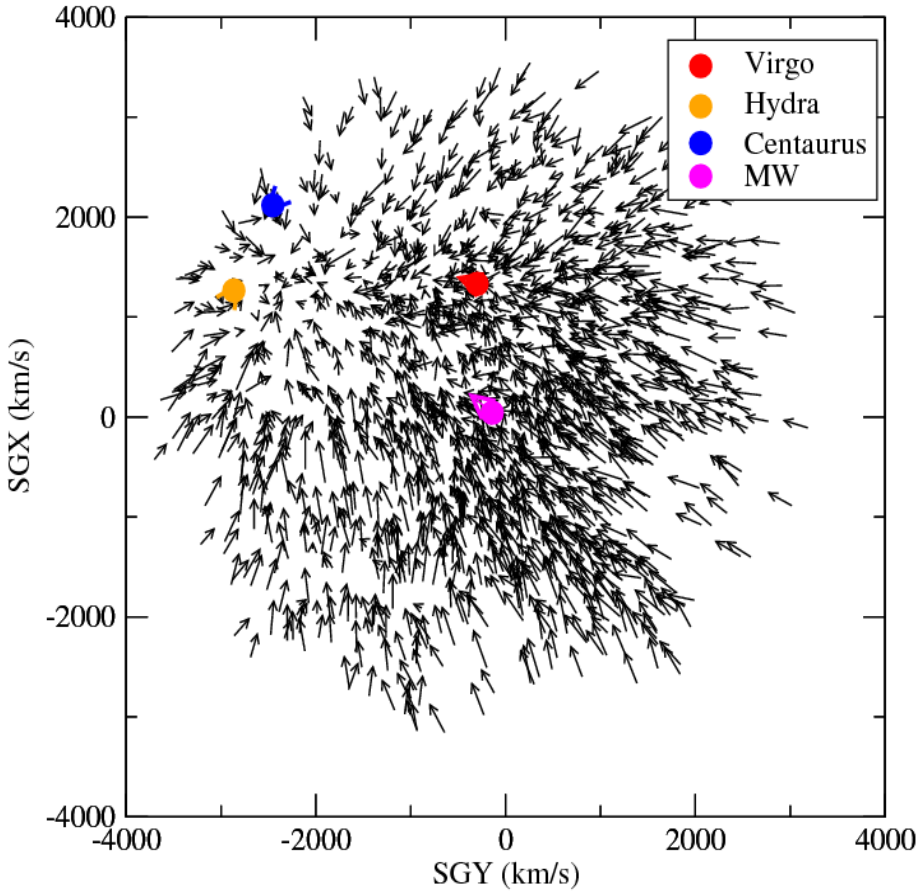


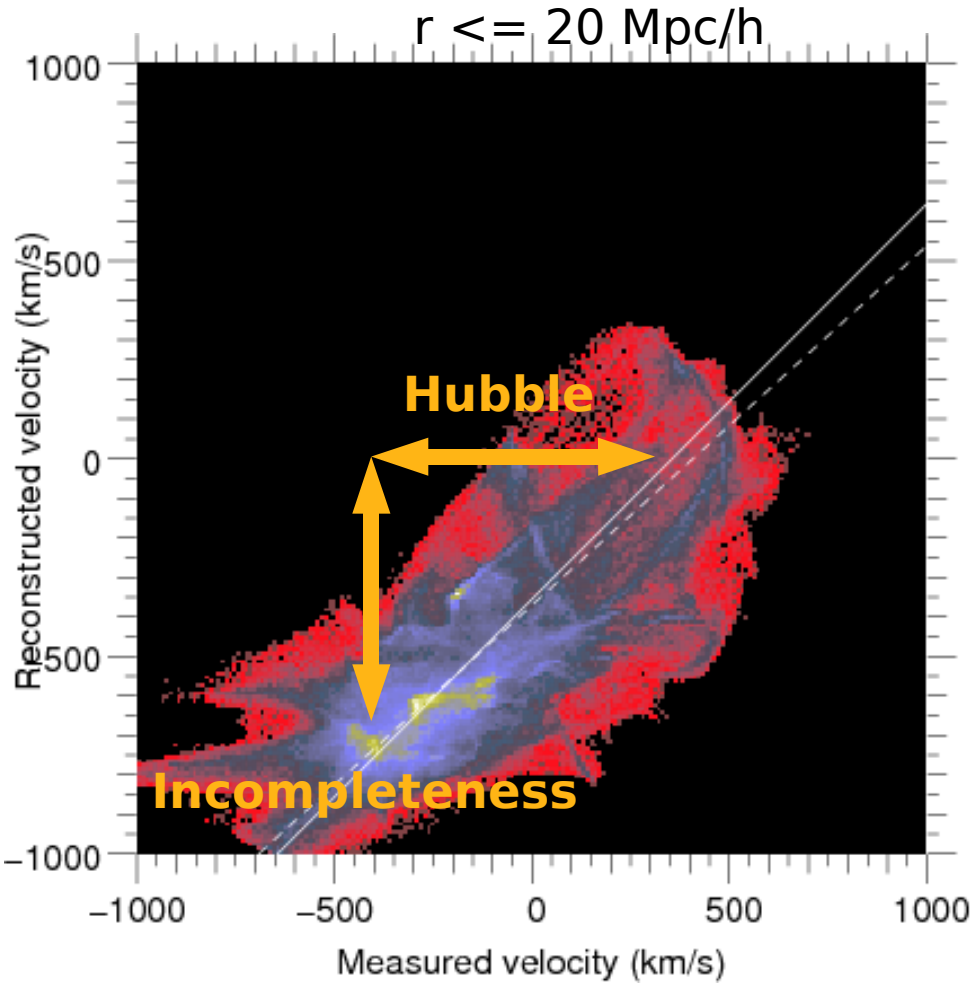


Catalog redshift/distances NBG-3k (courtesy of Brent Tully)

M/L = 300 for ellipticals + M/L = 100 spirals

4. Result on observational data





Catalog redshift/distances NBG-3k (courtesy of Brent Tully)

M/L = 300 for ellipticals + M/L = 100 spirals

Remaining problems

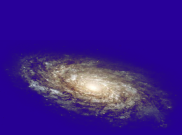
- Missing estimation of the error due to unobserved mass
- Incompleteness correction needs better treatment.
- Use deeper catalog (2MRS and/or NBG-8k) to minimize possible boundary effects.

5. Ongoing work on 2MRS...

Preparation of 2MRS...

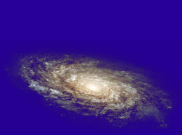
- Post-processing of 2MRS to account for all mentioned effects...

Preparation of 2MRS...



- Post-processing of 2MRS to account for all mentioned effects...
- And some more:
  - ➔ Luminosity corrections (estimation of the real total magnitude, distance estimation)

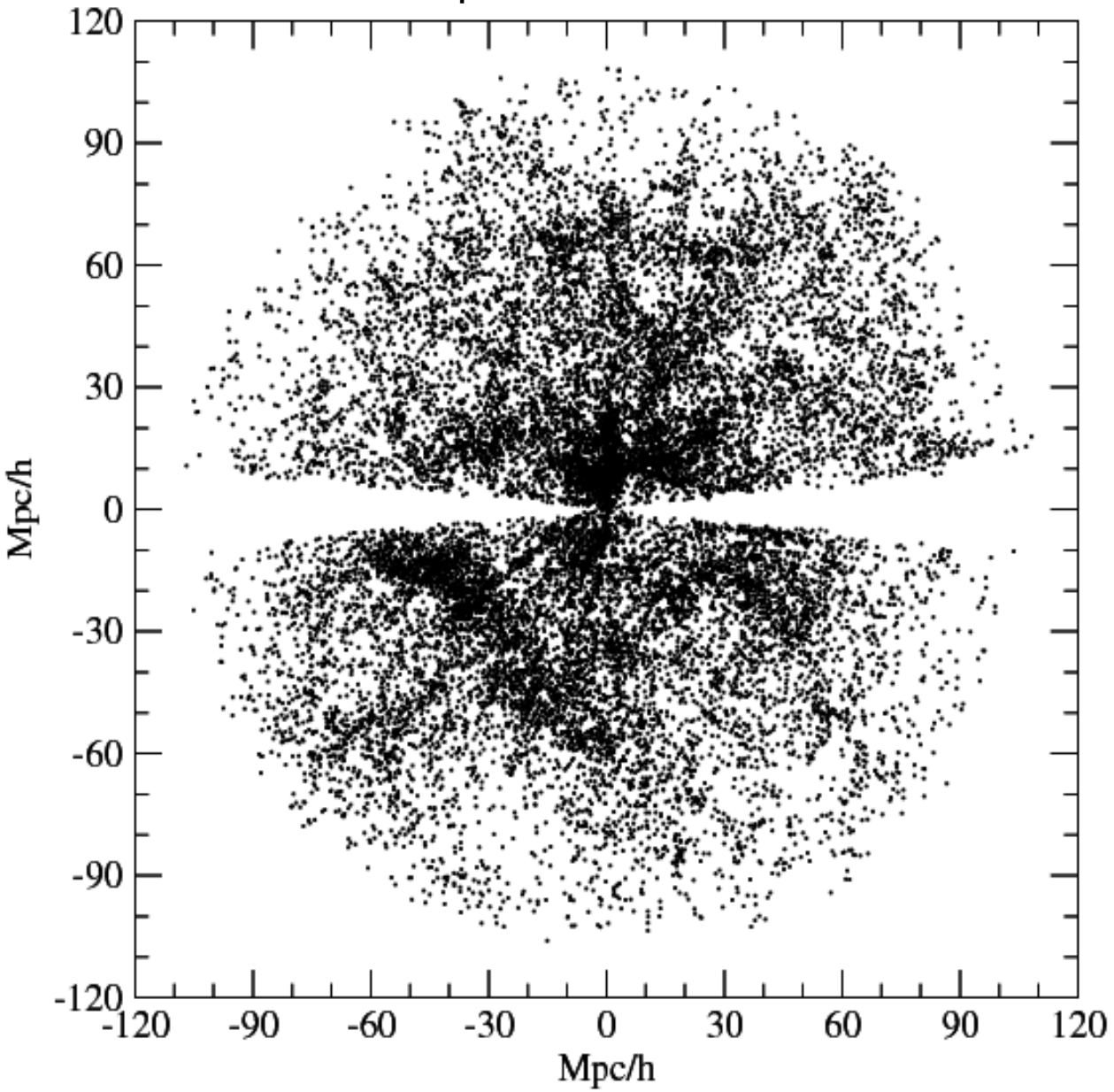
Preparation of 2MRS...



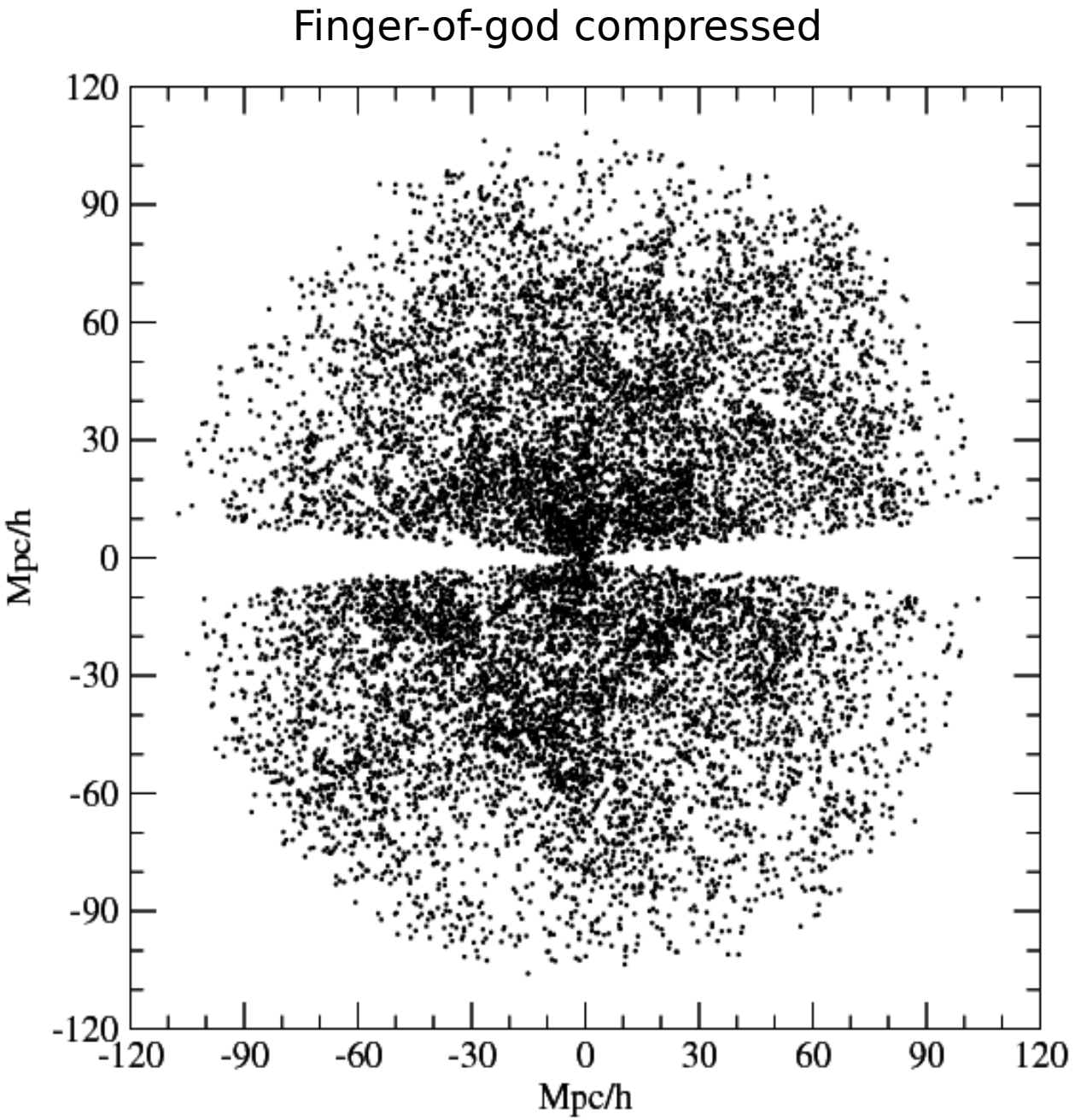
- Post-processing of 2MRS to account for all mentioned effects...
- And some more:
  - Luminosity corrections (estimation of the real total magnitude, distance estimation)
  - parameter adjustment in finger-of-god detection

Finger-of-god compression

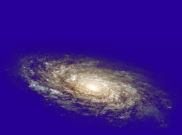
Galaxies at their original position
in a piece of the 2MRS



Finger-of-god compression

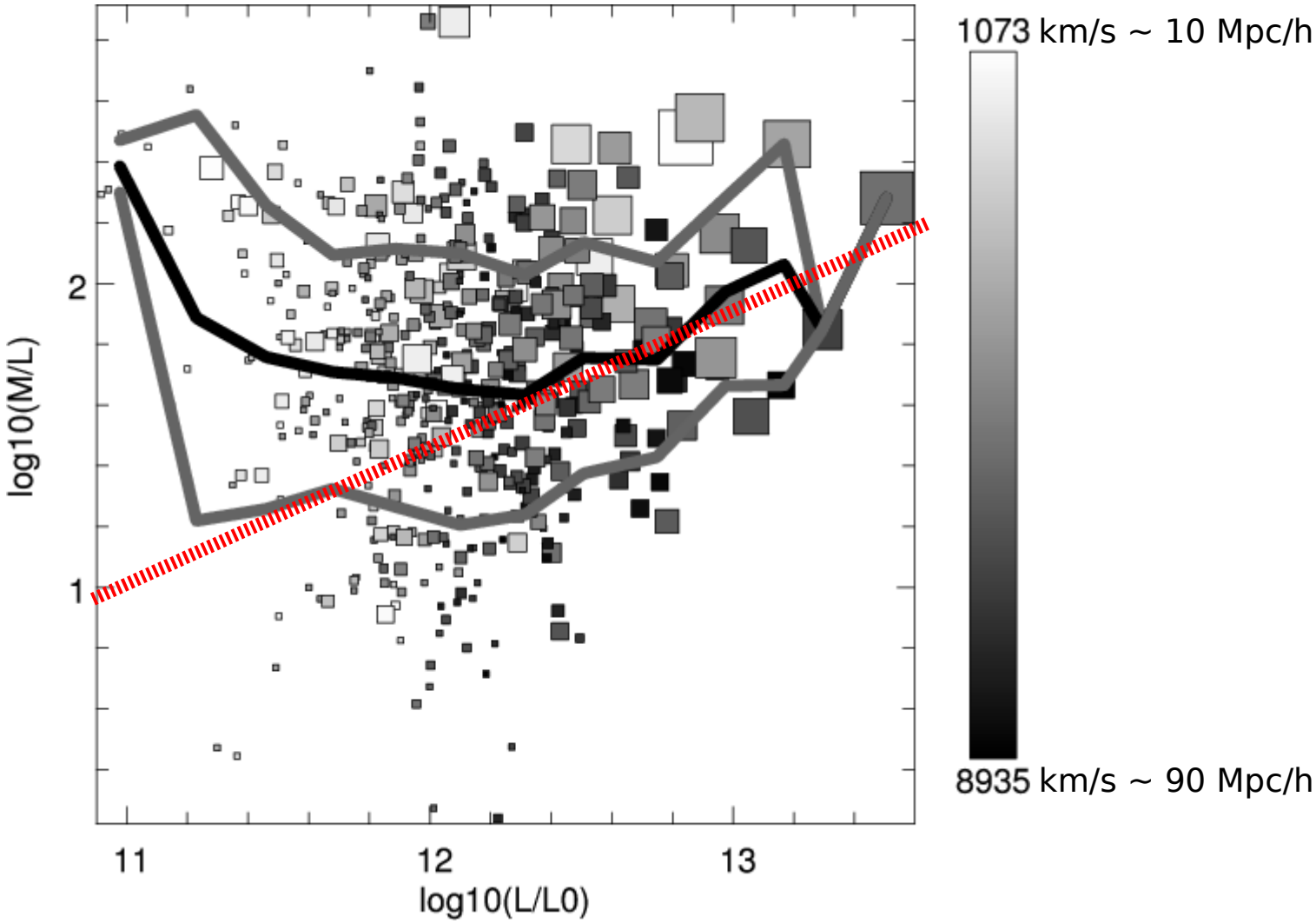


Preparation of 2MRS...



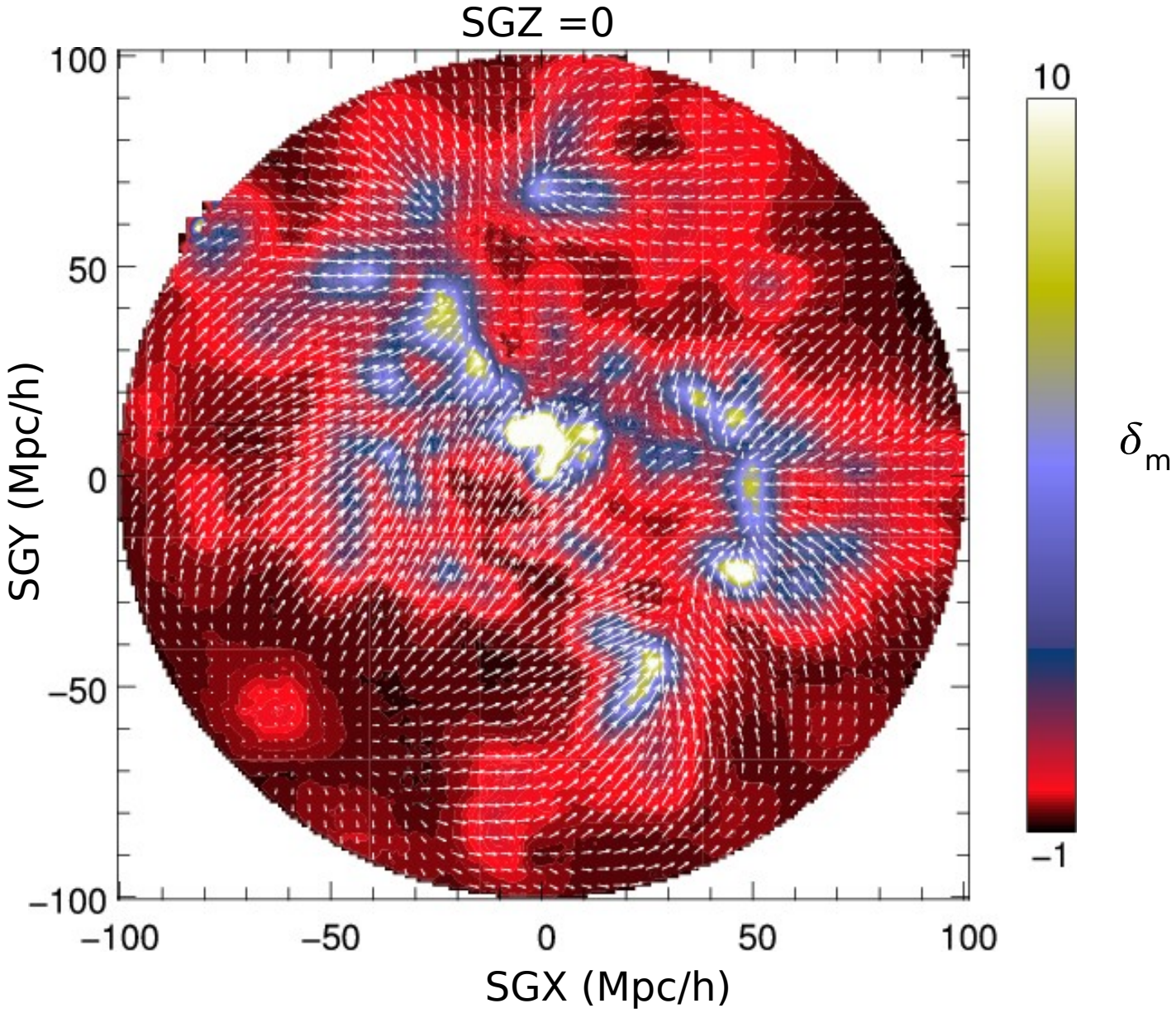
- Post-processing of 2MRS to account for all mentioned effects...
- And some more:
  - Luminosity corrections (estimation of the real total magnitude, distance estimation)
  - parameter adjustment in finger-of-god detection
  - M/L estimation

M/L in 2MRS



slope ≈ 0.27

Density and velocity field in redshift



Conclusion

Conclusion / Perspectives

Extension of MAK to smaller scale (< 4 Mpc/h)

Euler-Poisson
GAIA, SIM, HST

Test on mock catalogues
Study of systematics

NBG-3k

Lagrangian Volume

2MASS, 6DF, SDSS

Better M/L

Application on galaxy catalogs

Displacement field

Initial conditions

Constrained simulations

Comparison to CMB

Statistic
(Power spectrum, cosmological parameters)

THANK YOU !