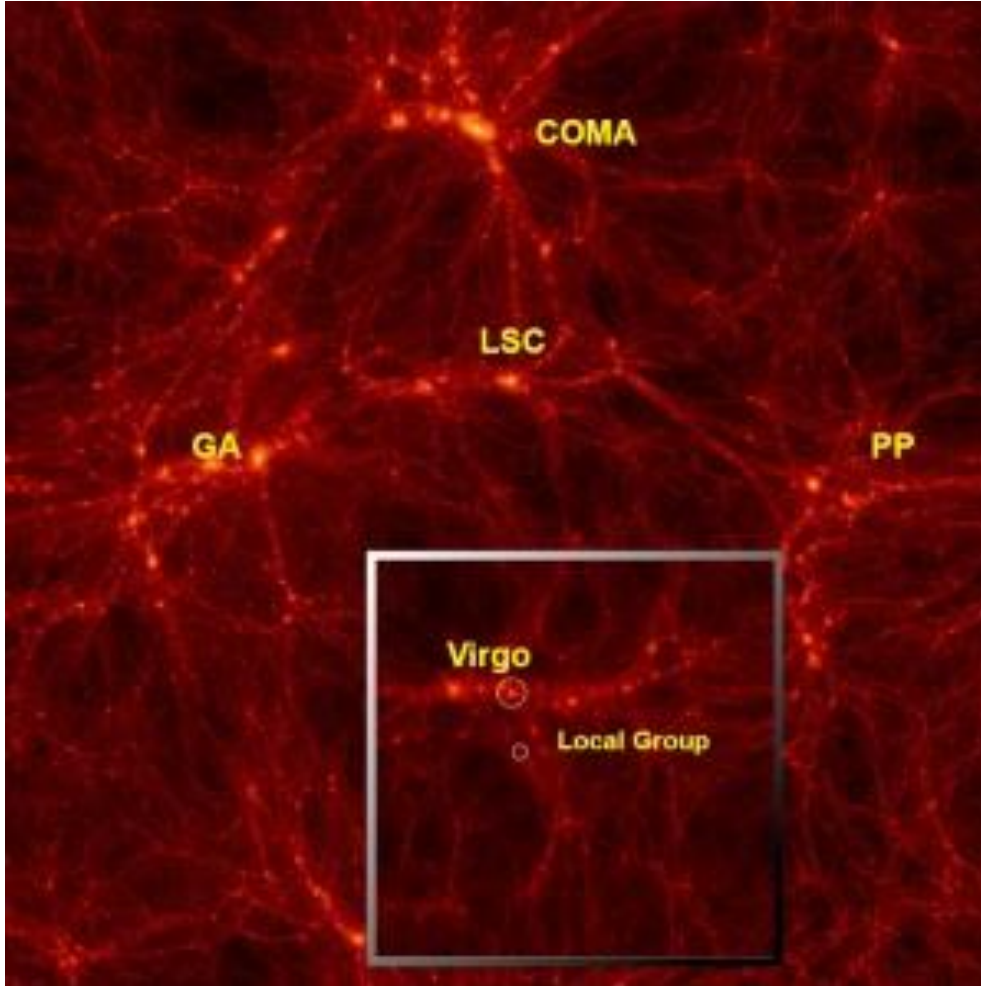


Ginnungagap – a cosmological initial conditions generator

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S. Gottloeber, J. Sorce

¹ Lebedev Physical Institute

Demands

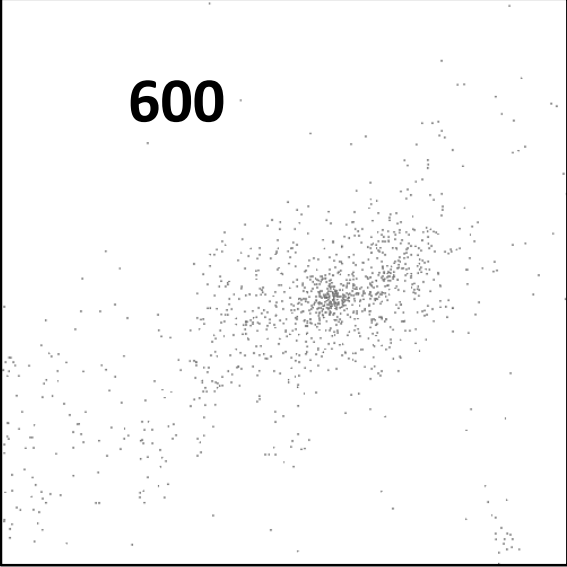


- Box sizes ~ 500 Mpc/h
- Mass resolution
 $< 10^8$ Msun
 $< 10^5$ Msun – reionization

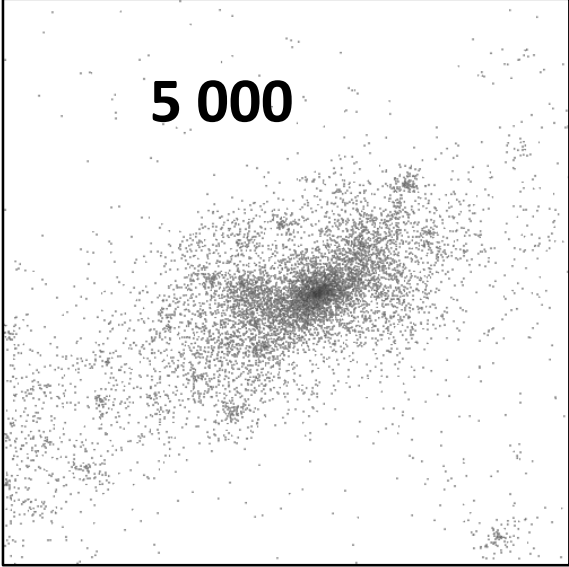
Effective mesh resolution:
 $\sim 8192^3$
 $\sim 65536^3 \dots$

Refinement

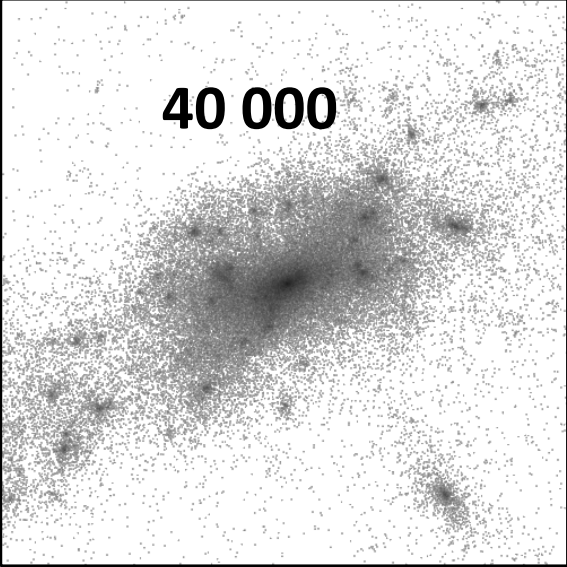
600

A scatter plot showing a very faint, diffuse cloud of points. The points are sparsely distributed, with a slight concentration in the center, but the overall shape is barely discernible against the white background.

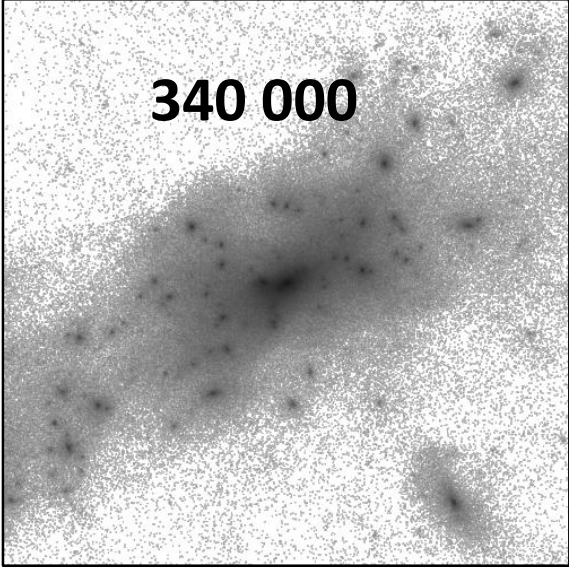
5 000

A scatter plot showing a more defined, elongated cloud of points. The central concentration is more pronounced, and the overall shape is beginning to take form, though some noise remains.

40 000

A scatter plot showing a well-defined, elongated cloud of points. The central concentration is very clear, and the overall shape is more distinct, though some noise remains.

340 000

A scatter plot showing a very dense, elongated cloud of points. The central concentration is extremely high, and the overall shape is very well-defined, with most of the noise removed.

Ginnungagap features

- MPI – parallel
- Density and velocity fields are computed by convolving Transfer Function with White Noise:

$$\delta(x) = TF(x) \otimes W(x)$$

- Not necessarily 2^N grid sizes
- Zoom-in
 - Run low resolution simulation
 - Prepare mask in Lagrangian coordinates
 - Combine velocity fields (including intermediate boundary levels)
- A set of separate tools for extreme flexibility and memory optimization

Methods of WN refinement

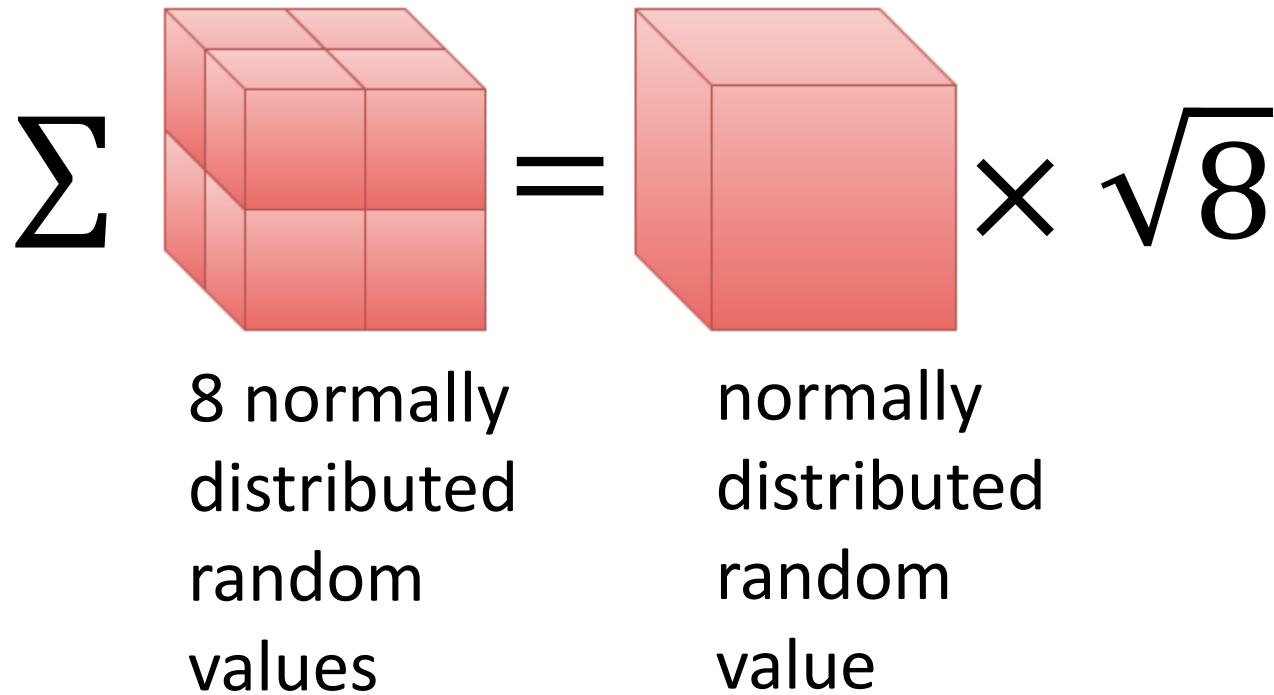
- K-space padding
- Hoffman-Ribak algorithm
- Downscaling of higher resolution velocity field
- MUSIC combined k-space + HR
- Ginnungagap combined k-space + HR

HR algorithm for white noise

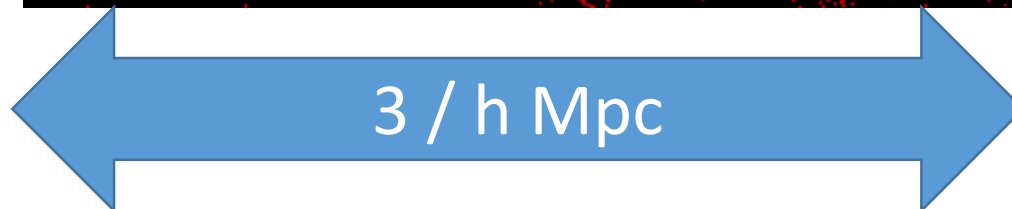
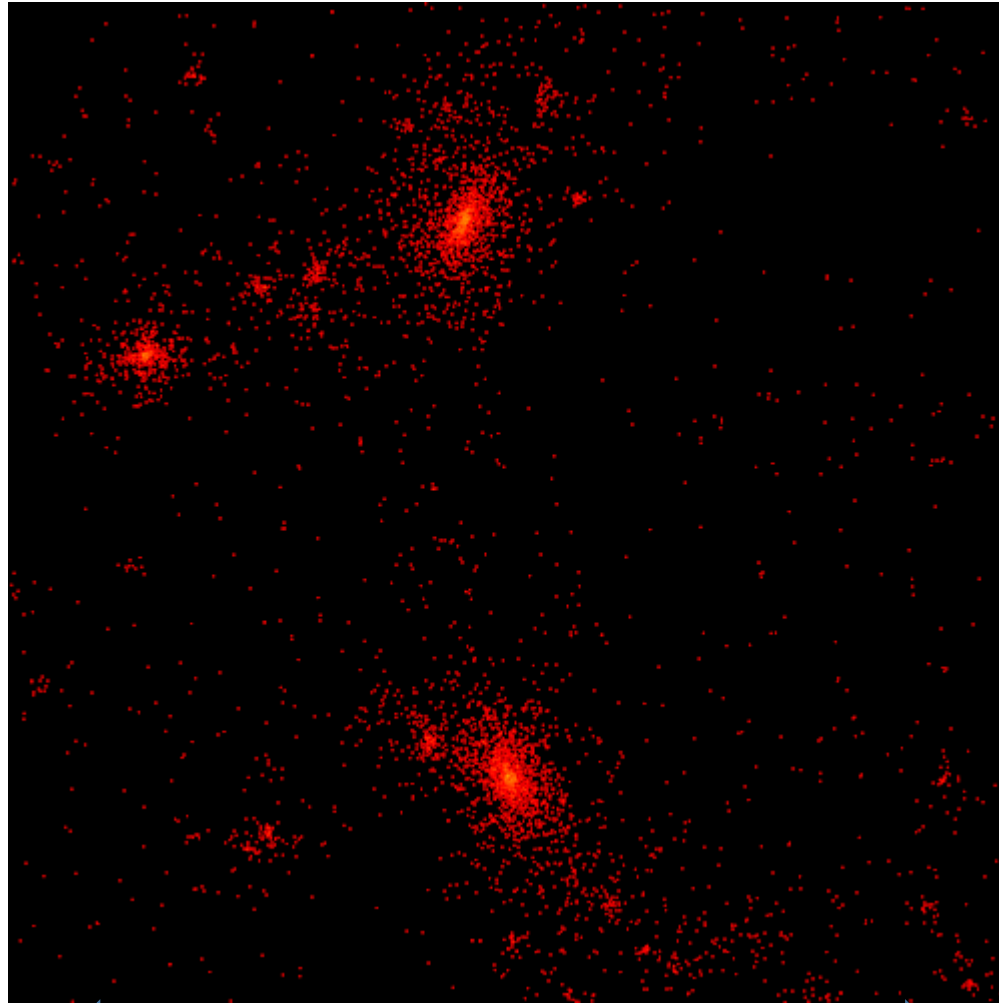
$$\Sigma \text{ [8 small cubes] } = \text{[1 large cube]} \times \sqrt{8}$$

8 normally distributed random values

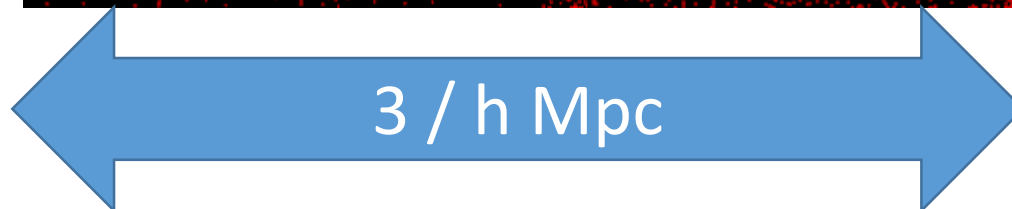
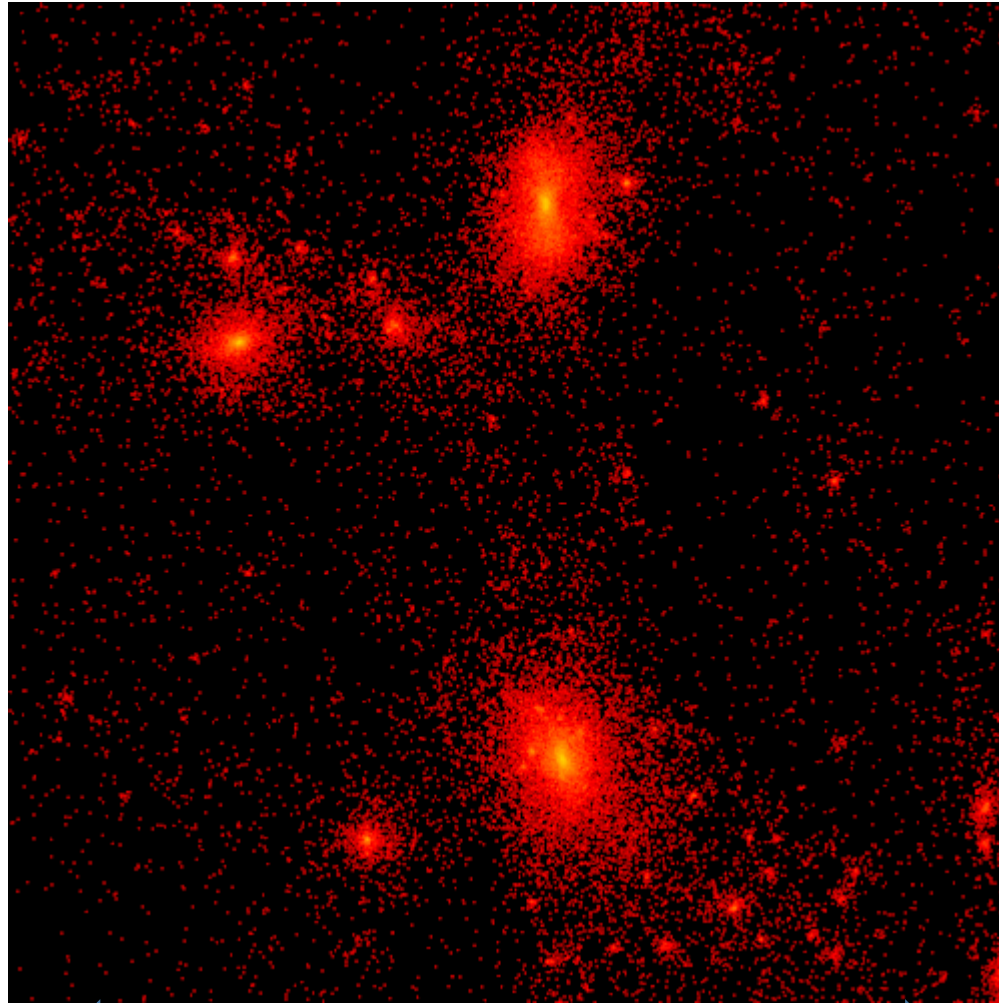
normally distributed random value



Pure HR



Pure HR



Combined method

Use HR to generate new white noise

Filter out low frequencies in the white noise in k-space

Make velocity field

Interpolate low resolution velocity field to new grid

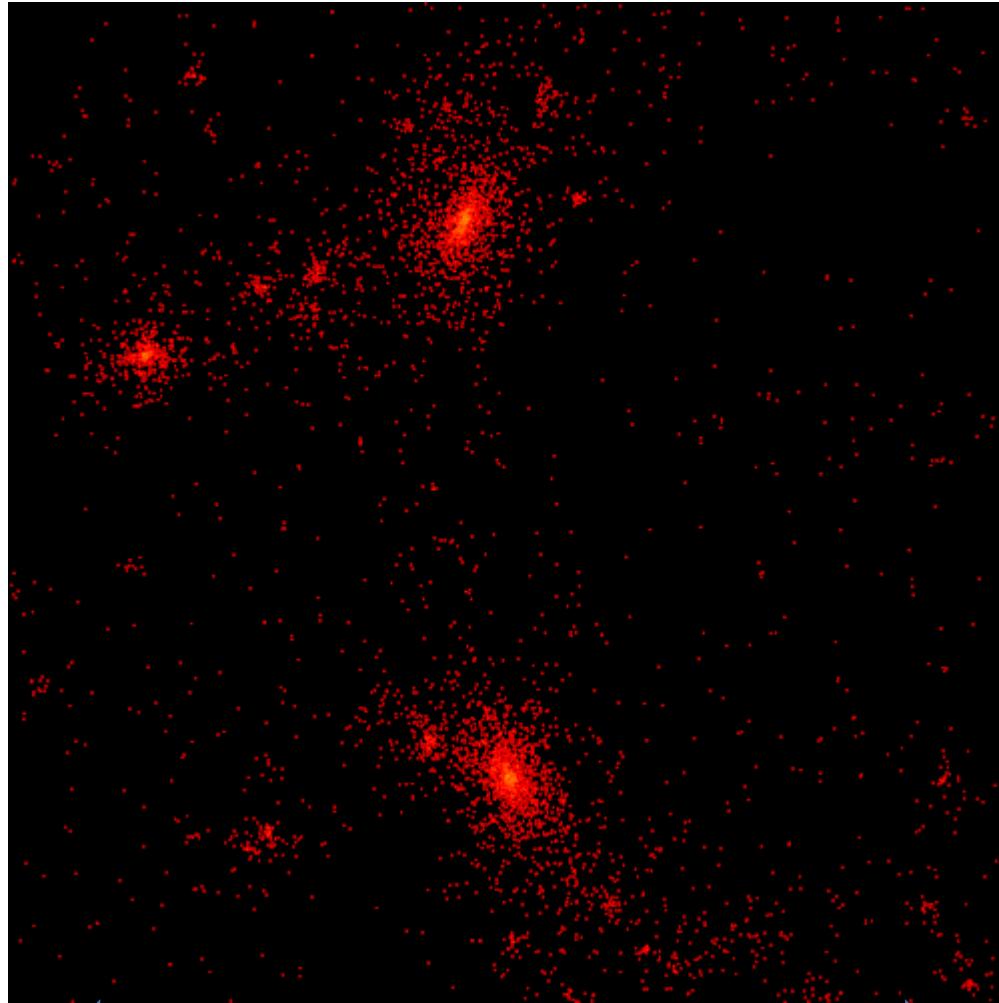
- This requires filtering out shortest modes close to the Nyquist frequency

Add fields

Tests

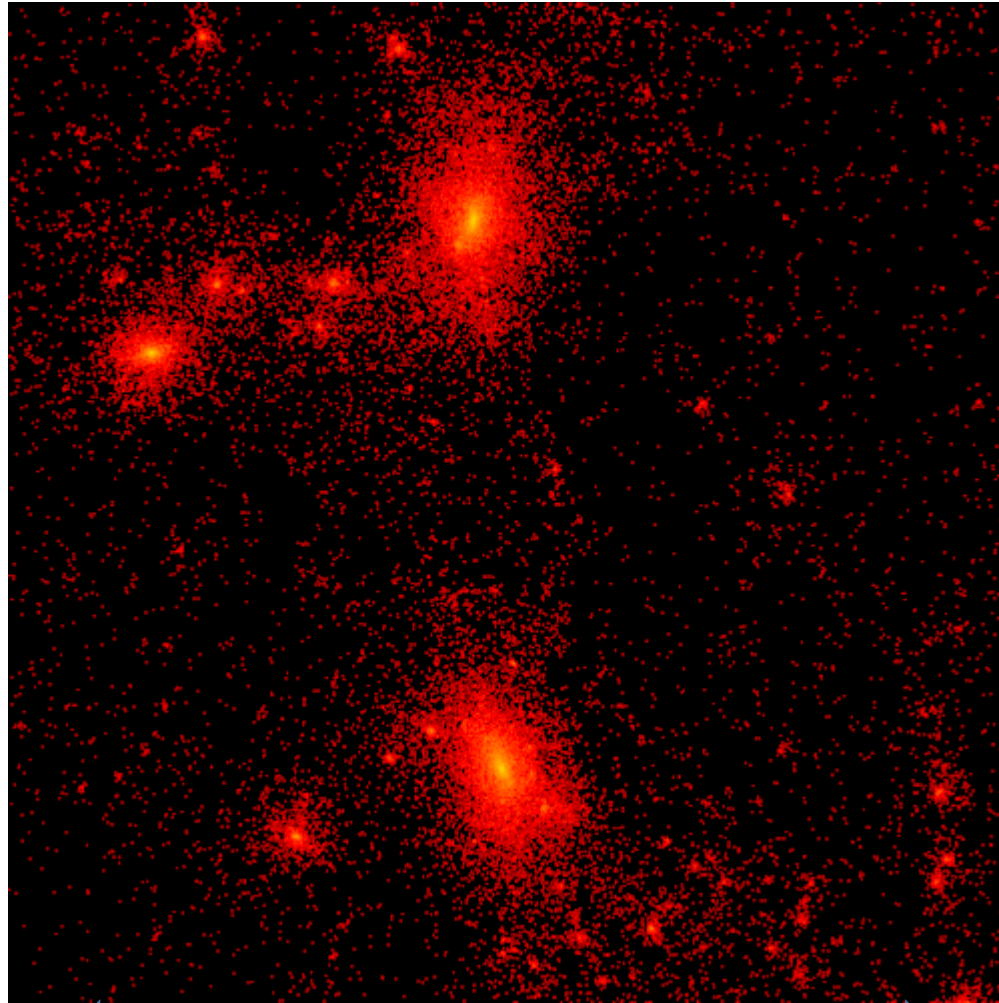
1. Local-group like object in a small box of 64 Mpc/h
 1. Low resolution 256^3 particles (object with 2000 particles)
 2. High resolution 512^3 particles
 3. Zoom simulation 2048^3 particles effectively
2. Cluster-like object in a large box of 500 Mpc/h
 1. Halo selected in full box 512^3 simulation (5000 particles)
 2. Zoom simulations 512^3 , 1024^3 , 2048^3 , 4096^3

Ginungagap



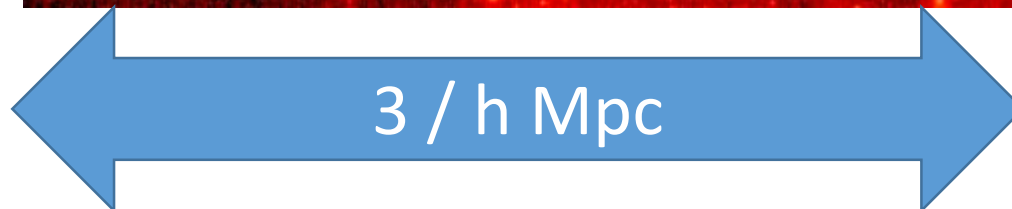
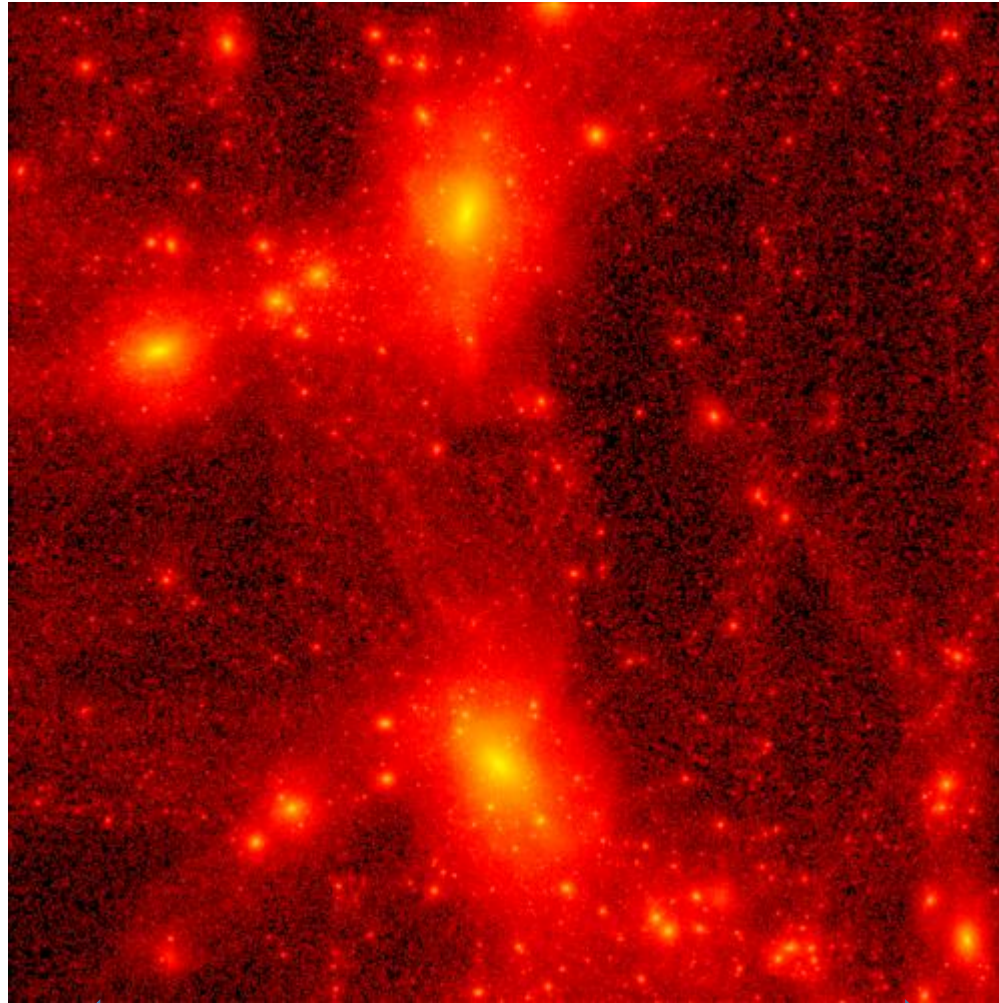
$3 / h \text{ Mpc}$

Ginungagap



3 / h Mpc

Ginungagap zoom to 2048^3



Comparison 1: $1.2 \cdot 10^{12} M_{\odot}$ halo

Method	Coord. Error, kpc	Mass error
K-pad	7	0.08 %
HR	180	11 %
HR + k-space	37	5.9 %
Downscaling	24	2.4 %
Zoom	53	0.8 %

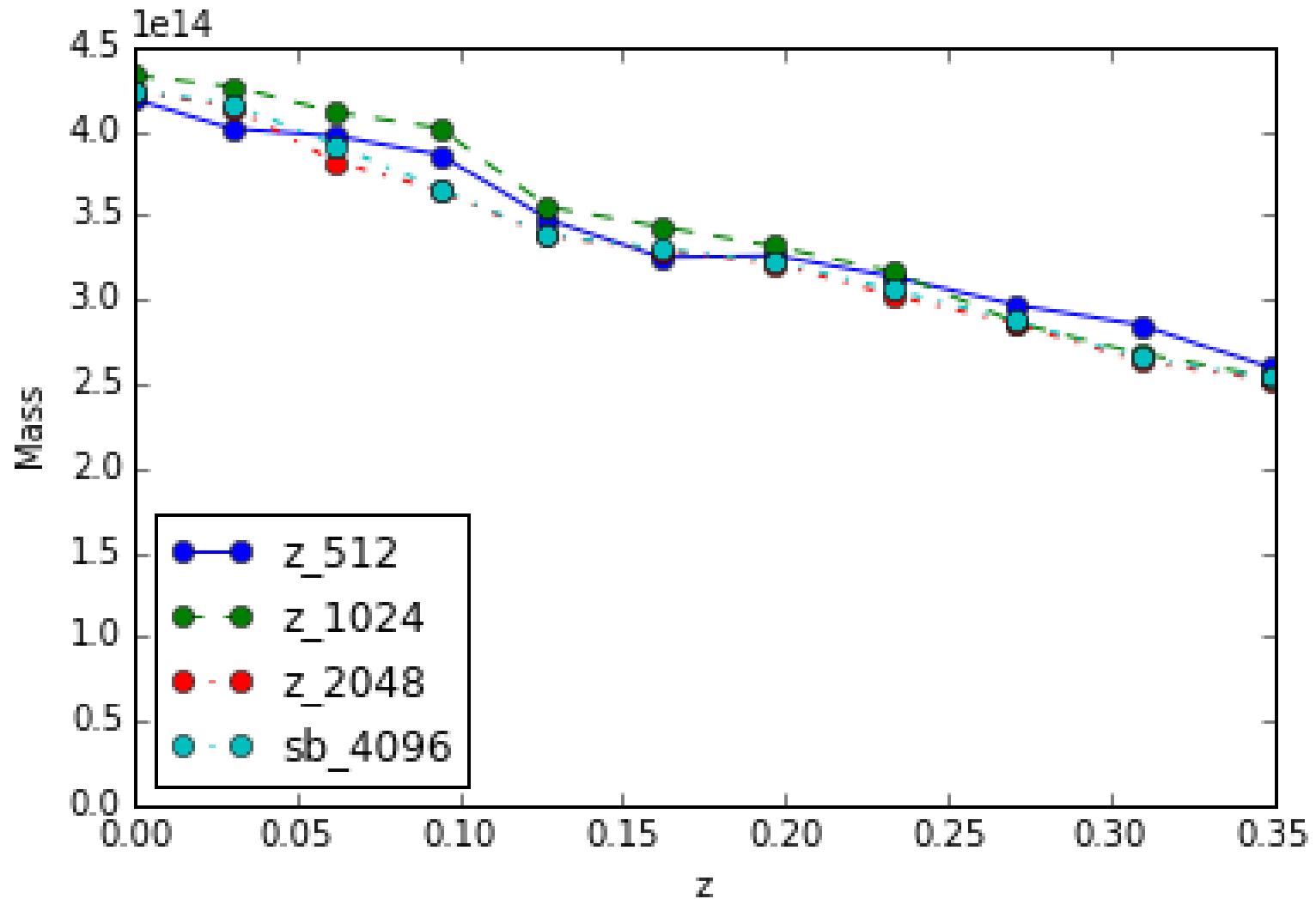
Force resolution: 6 kpc

Comparison 2: another halo

Method	Coord. Error, kpc	Mass error
K-pad	20	3.2 %
HR	250	18 %
HR + k-space	28	5.5 %
Downscaling	24	-1.7 %
Zoom	23	3.0 %

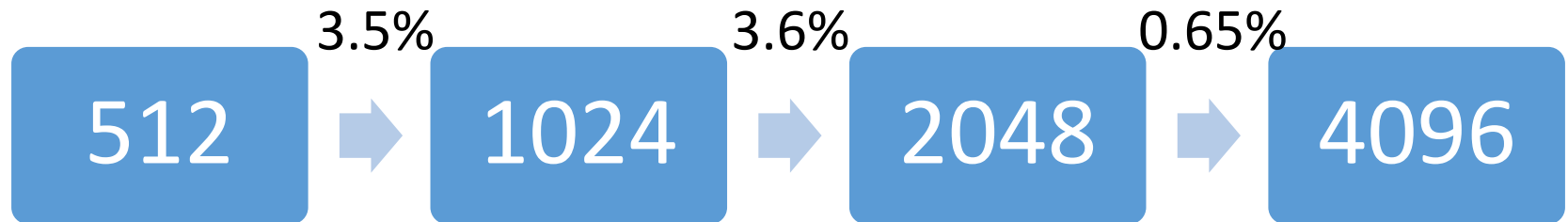
Force resolution: 6 kpc

Evolution of a $4 \cdot 10^{14} M_{\odot}$ halo in 500 Mpc/h box



Convergence (mass change)

Ginnungagap:

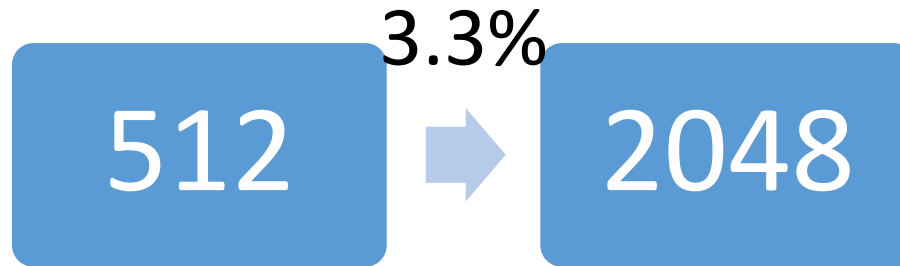


MUSIC:

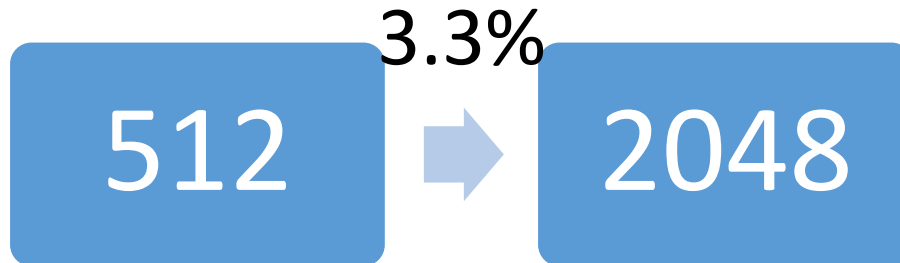


Convergence

Ginnungagap:



MUSIC:



Difference MUSIC-Ginnungagap: 1.6%

Open questions

- Why Fourier space padding is so good?
- Why zoom (refinement 256 -> 2048) is better than no-zoom refinement 256 -> 512?

Conclusions

- Ginnungagap is a code suitable for large zoom-in simulations
- TODO list:
 - Multiple zoom regions optimization
 - 2LPT
 - Multicomponent DM
 - Separate TFs for baryons and DM, velocity offset
- Code is public at <http://ginnungagapgroup.github.io/ginnungagap/>