Ginnungagap – a cosmological initial conditions generator

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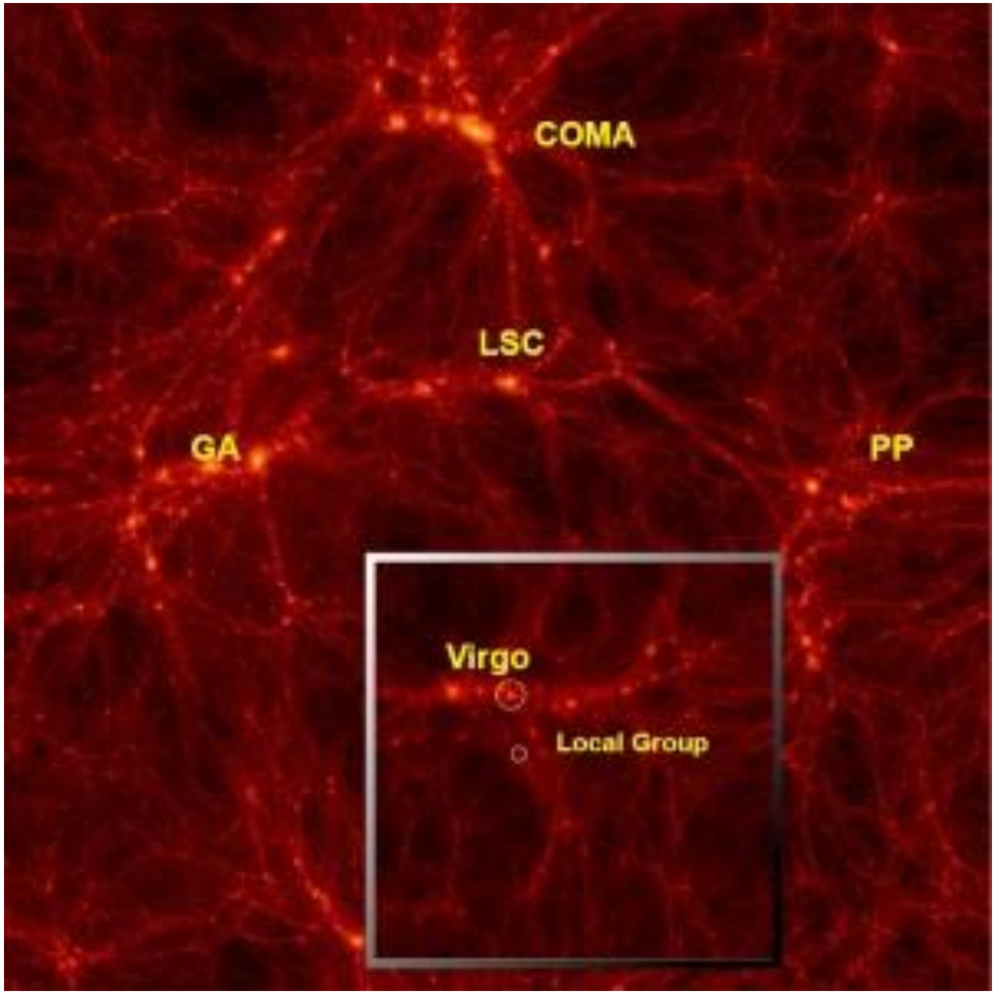
Demands



- Box sizes ~500 Mpc/h
- Mass resolution

< 10^8 Msun

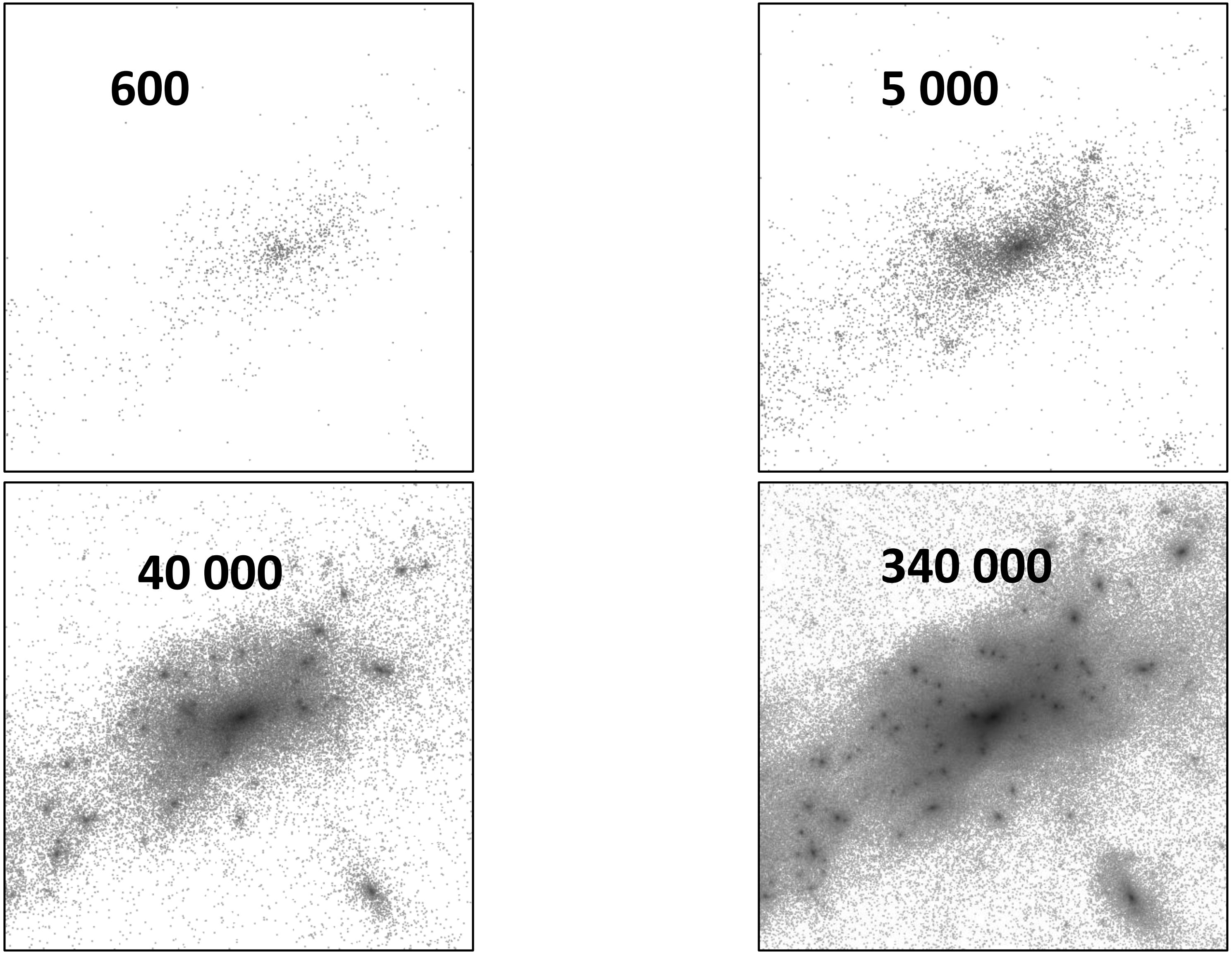
< 10^5 Msun – reionization

Effective mesh resolution:

~ 8192^3

~ 65536^3...

Refinement



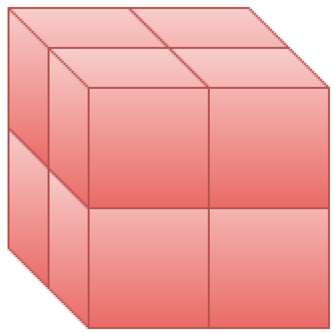
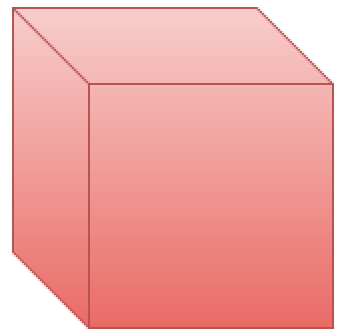
Ginnungagap features

- 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

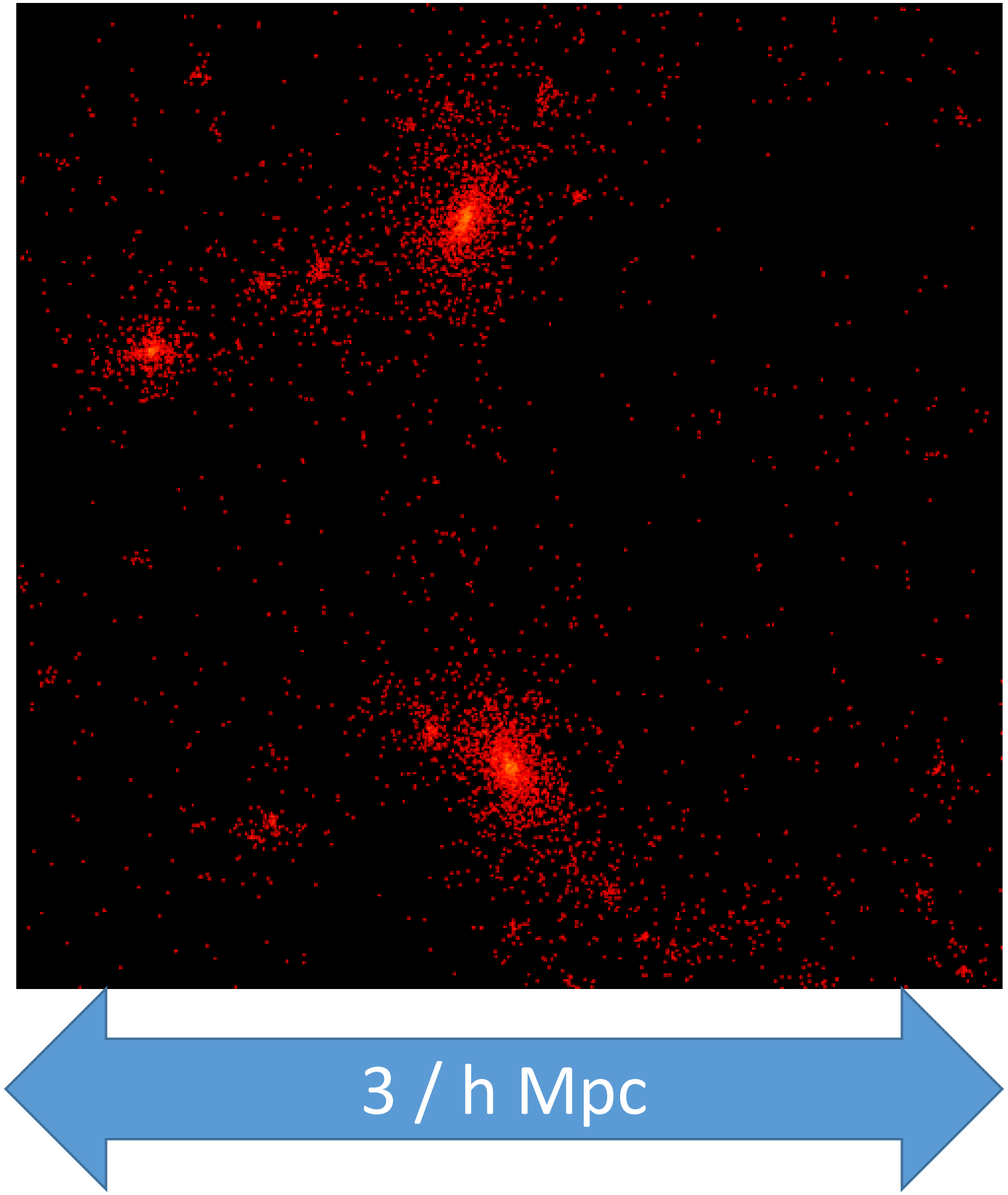
HR algorithm for white noise

$\sum$  $=$  $\times \sqrt{8}$

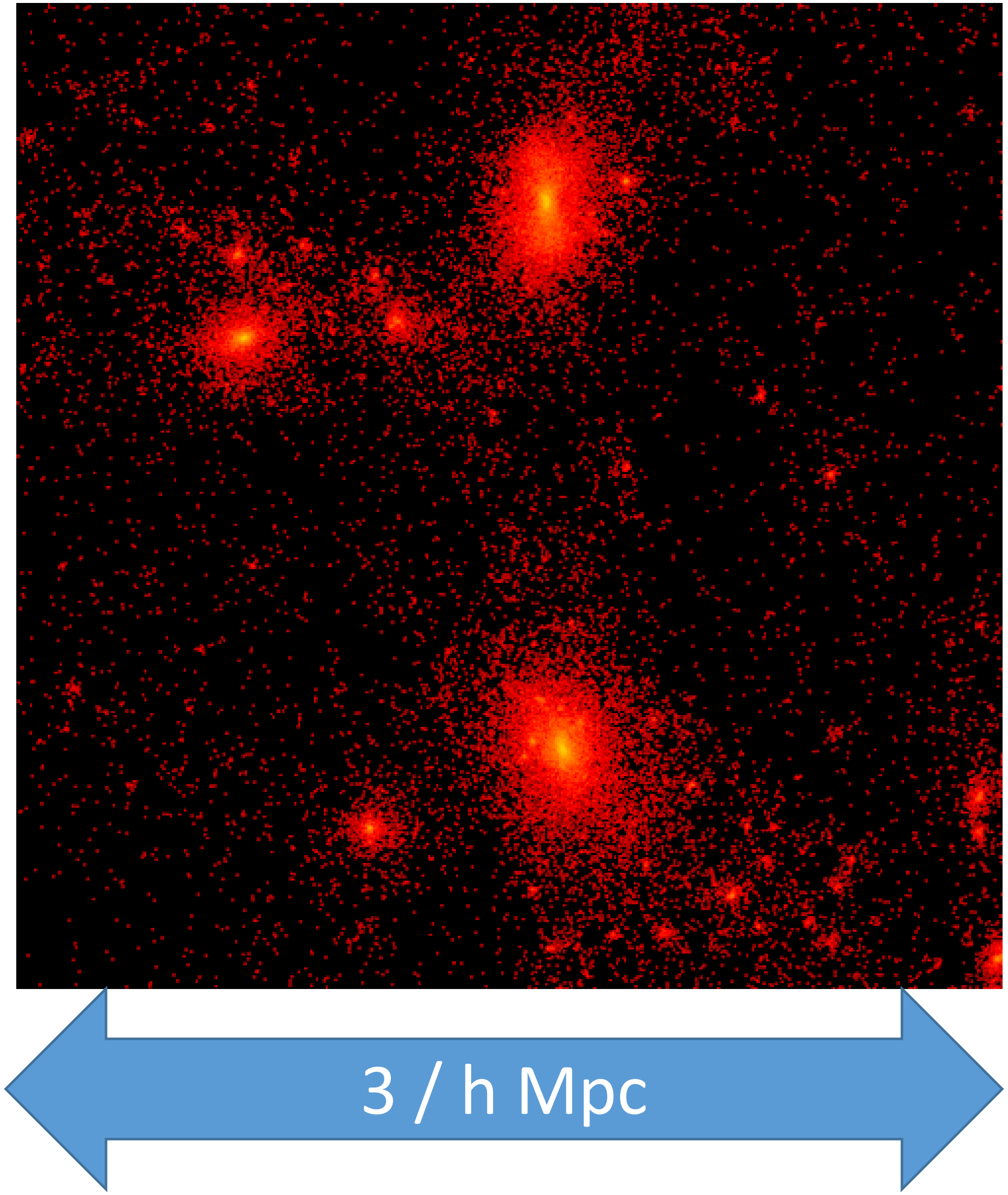
8 normally distributed random values

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

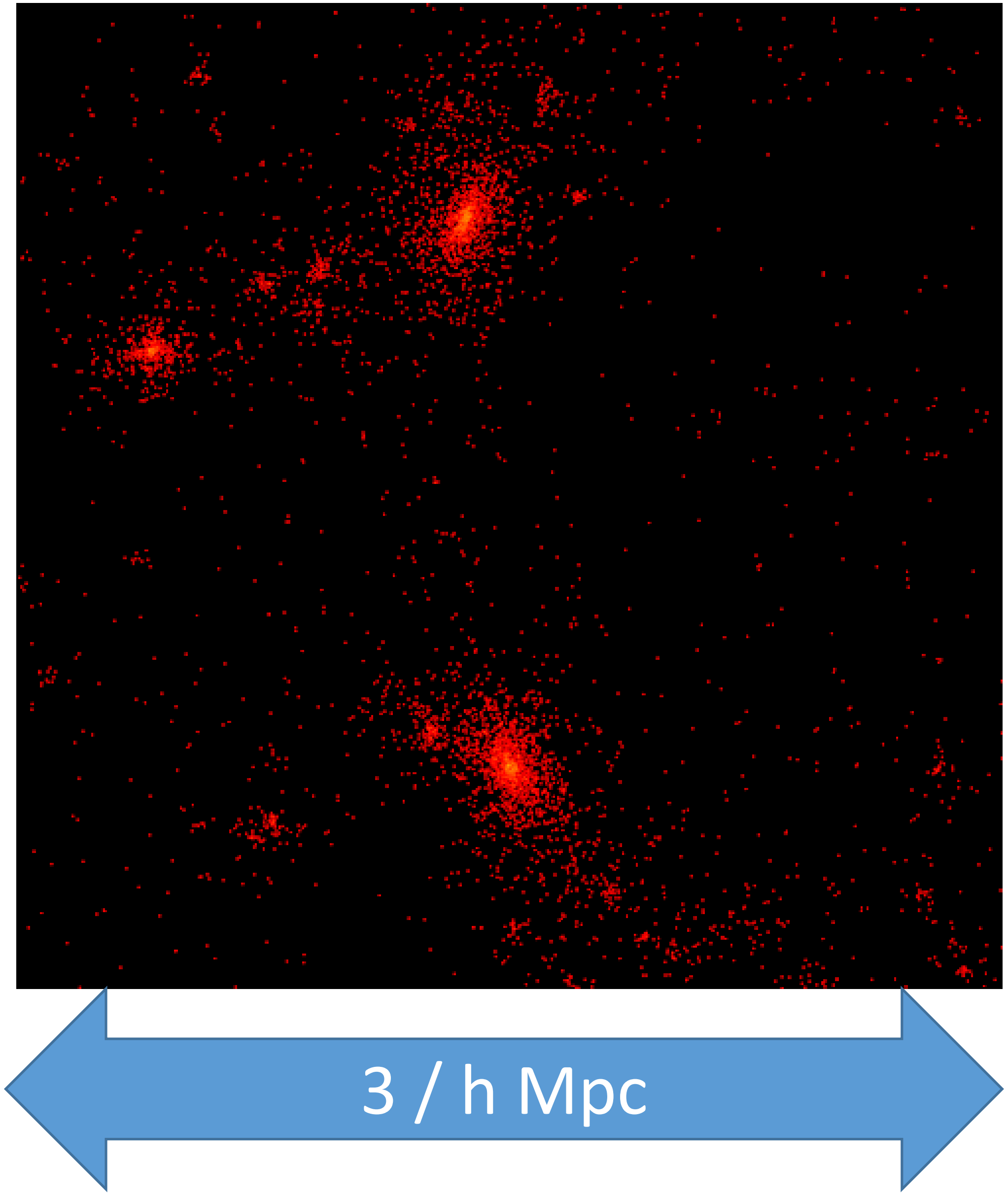
- This requires filtering out shortest modes close to the Nyquist frequency

Add fields

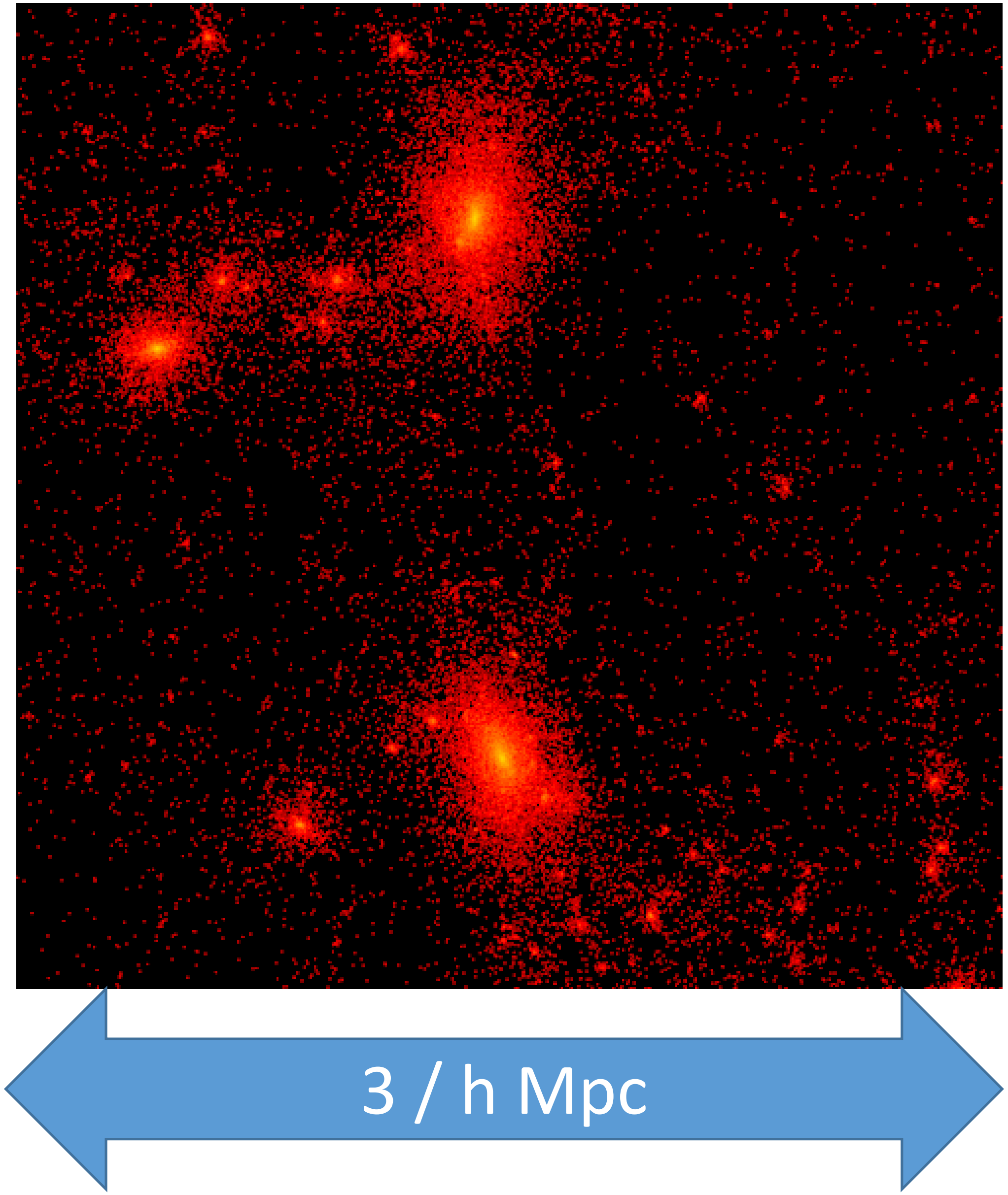
Tests

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

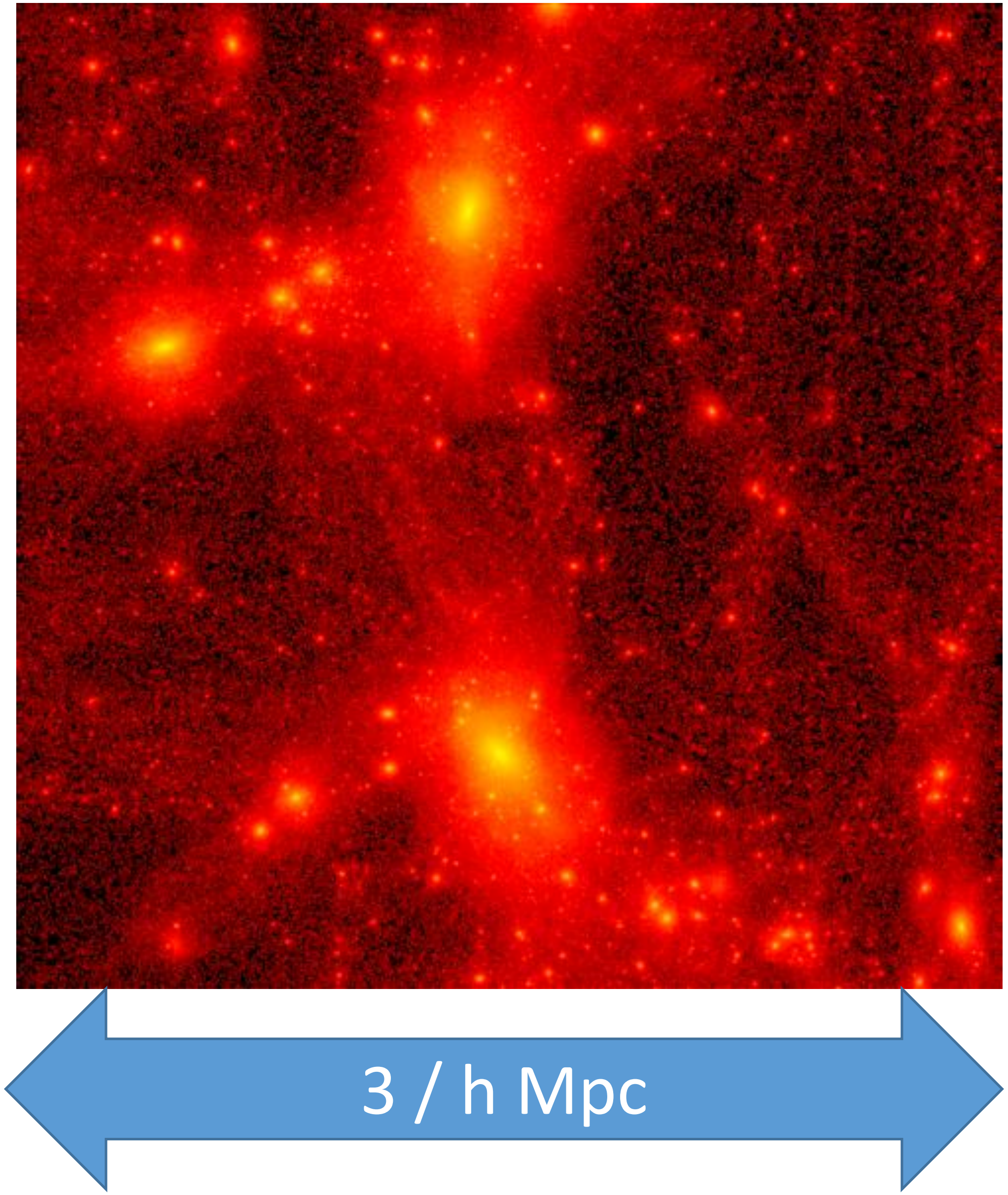
Ginungagap



Ginungagap



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 %

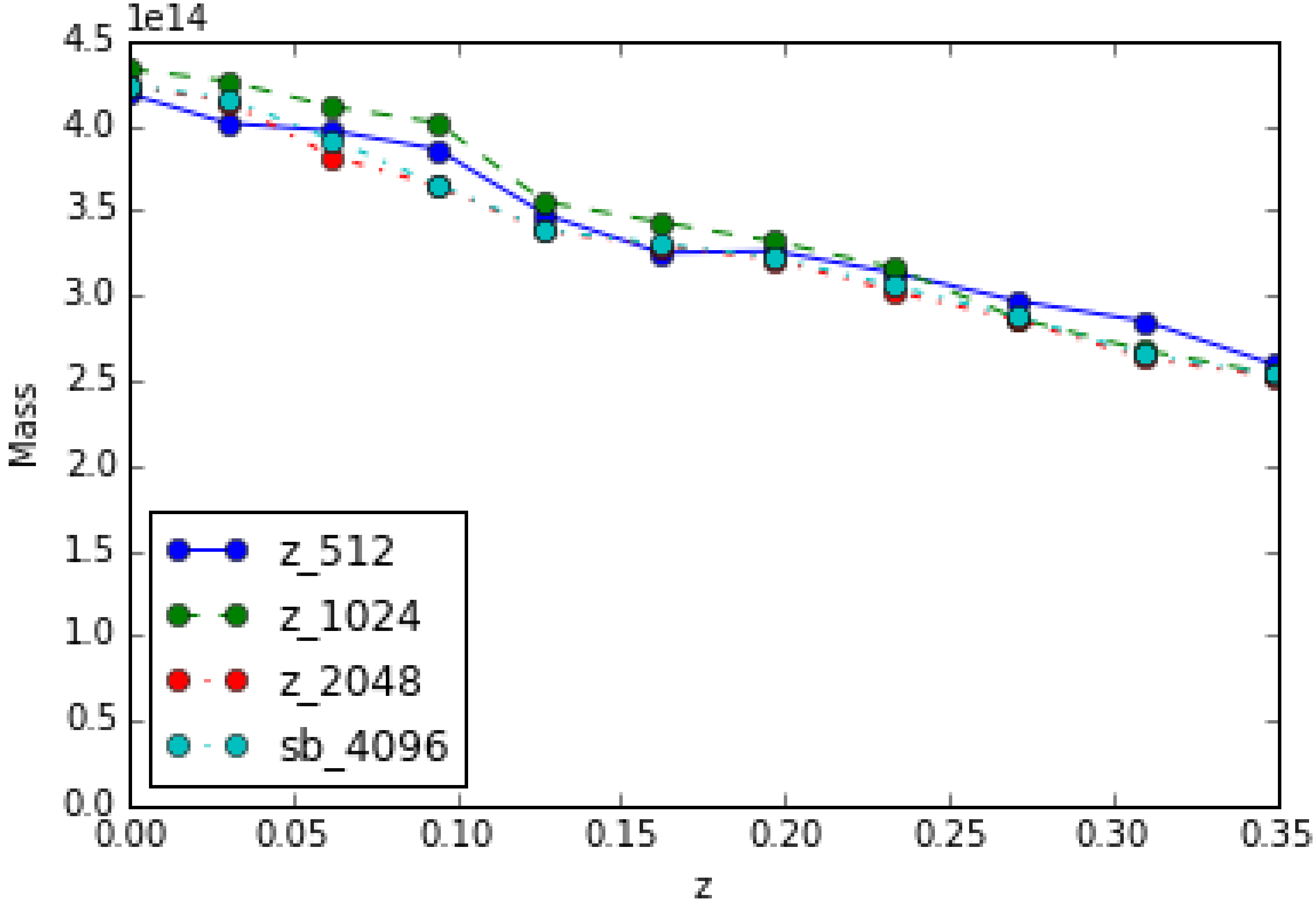
Force resolution: 6 kpc

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 %

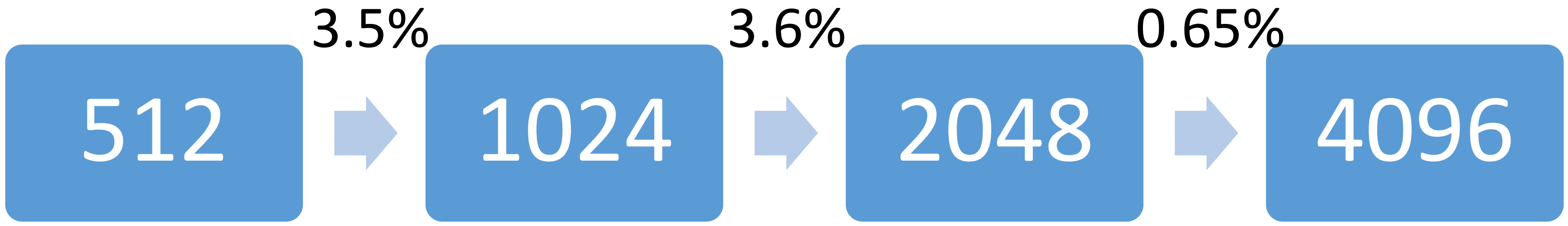
Force resolution: 6 kpc

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



Convergence (mass change)

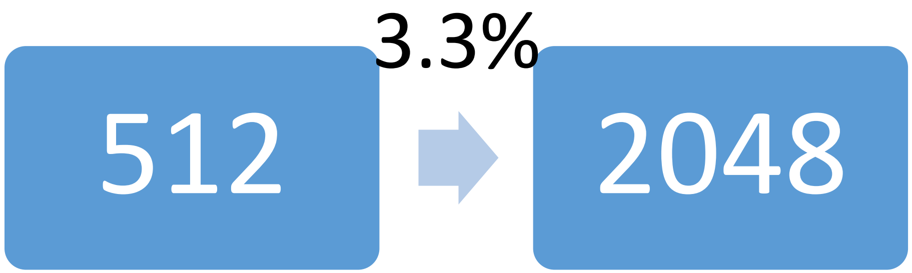
Ginnungagap:



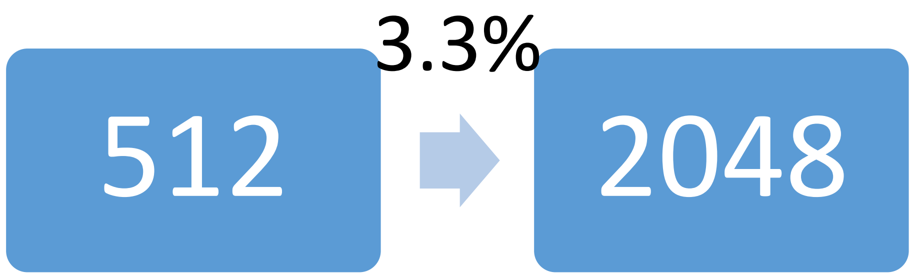
MUSIC:

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/