Ray-Tracing through the Millennium Simulation

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Outline

- Introduction
- Strong lensing
- Weak lensing
- Lensing of pregalactic HI
- Summary and Outlook

Millennium Simulation

- 10^{10} particles in 500 Mpc/h box from z=127 to z=0
- $m_p = 8.6 \times 10^8 \, M_\odot/h$, $l_{soft} = 5$ kpc/h
- dark-matter structures ranging from small galaxy halos to large clusters and LSS
- galaxies from semi-analytic modelling
- 64 snapshots → 20+ TB data

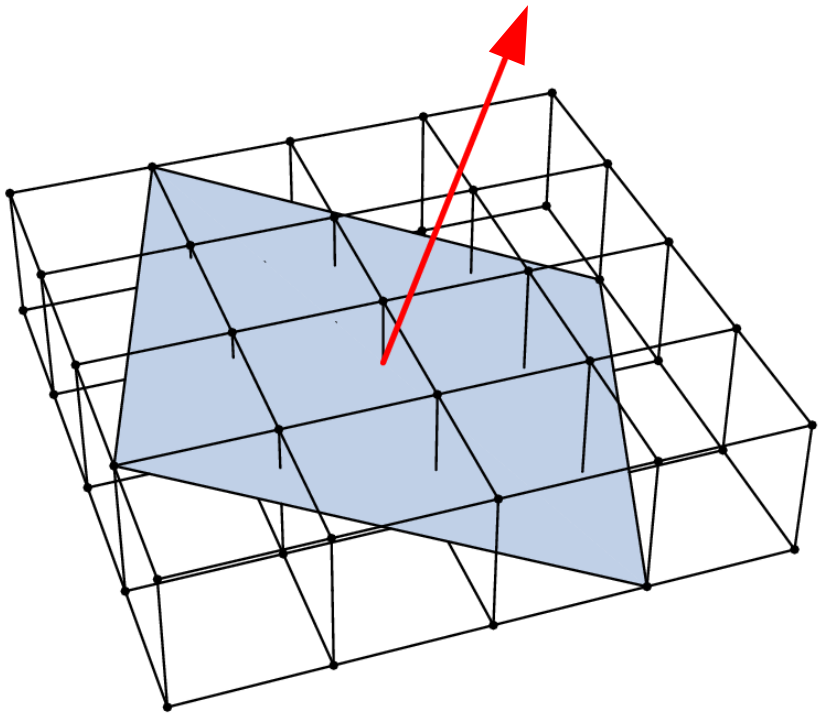
Springel et al., Nature 435, 629 (2005)

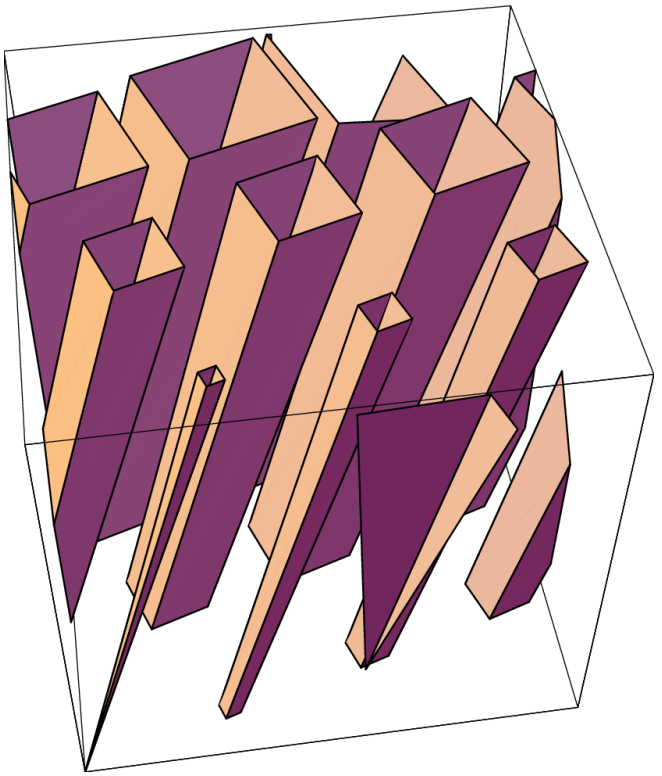
Ray-tracing algorithm

- multiple-lens-plane approach
- one slice / plane per snapshot
- avoid slicing / duplication of halos near boundary
- l.o.s. / slices / planes tilted w.r.t. simulation box
- PM-PM method to obtain potential etc.
- adaptive smoothing (3D)

Implementation details

- tilted l.o.s., slices, planes:





→ large lens planes: 1.55 Gpc/h × 1.65 Gpc/h

Implementation details

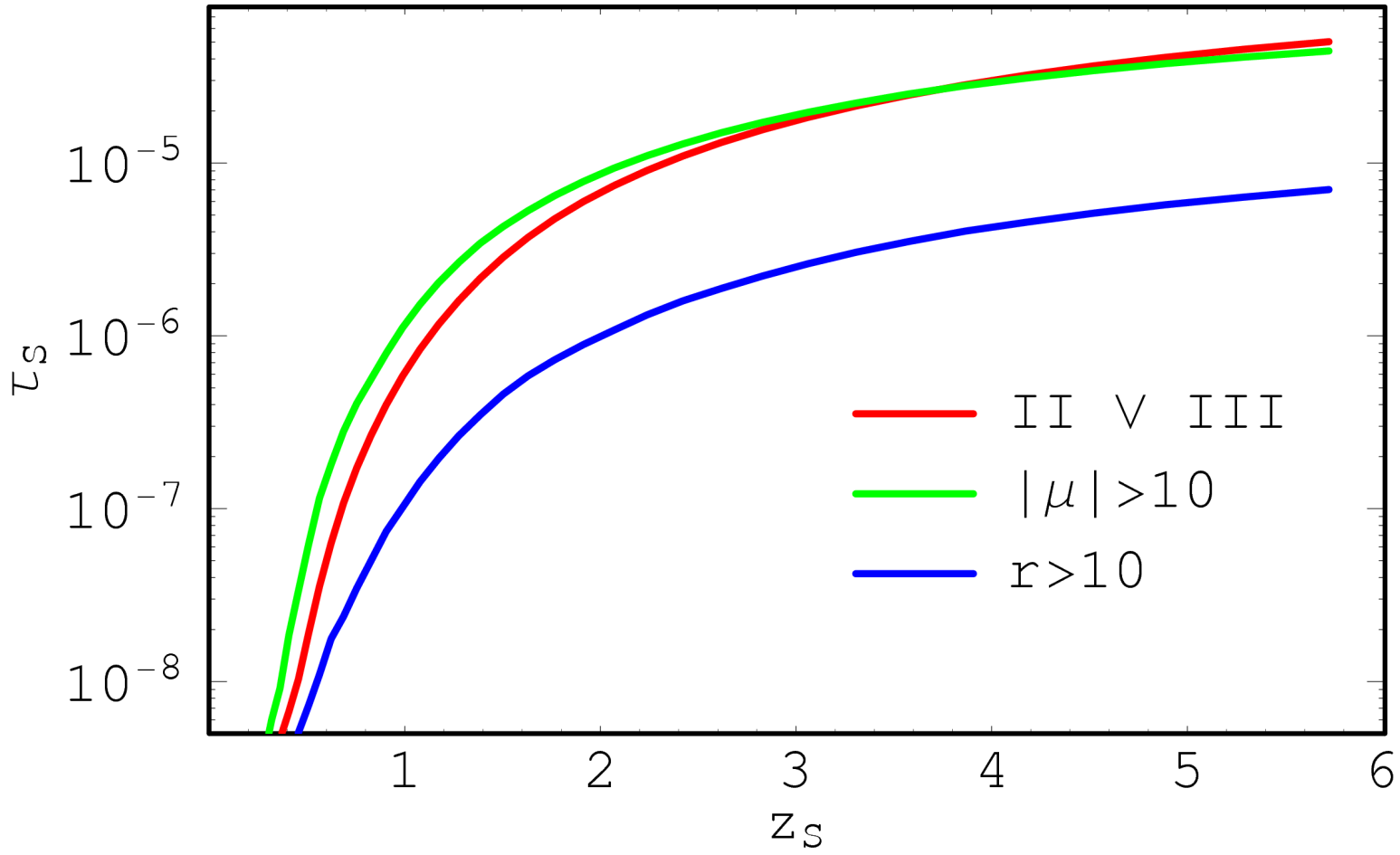
- PM-PM method to obtain lensing potential:
  - project particles onto meshes (adaptive smoothing)
  - Ψ^{long} by FFT on coarse mesh covering whole plane
  - Ψ^{short} by FFT on local fine meshes (2.5 kpc/h)
  - $\Psi = \Psi^{\text{long}} + \Psi^{\text{short}}$
  - finite difference $\rightarrow$ ray deflections / distortions

Strong lensing

- random sample 640 000 000 l.o.s.
- consider l.o.s. with:
  - large magnification $\mu > 10$
  - large length-to-width ratio r > 10
  - of type II or III (multi-image systems)
- identify strong lenses and their properties
- quantify foreground / background

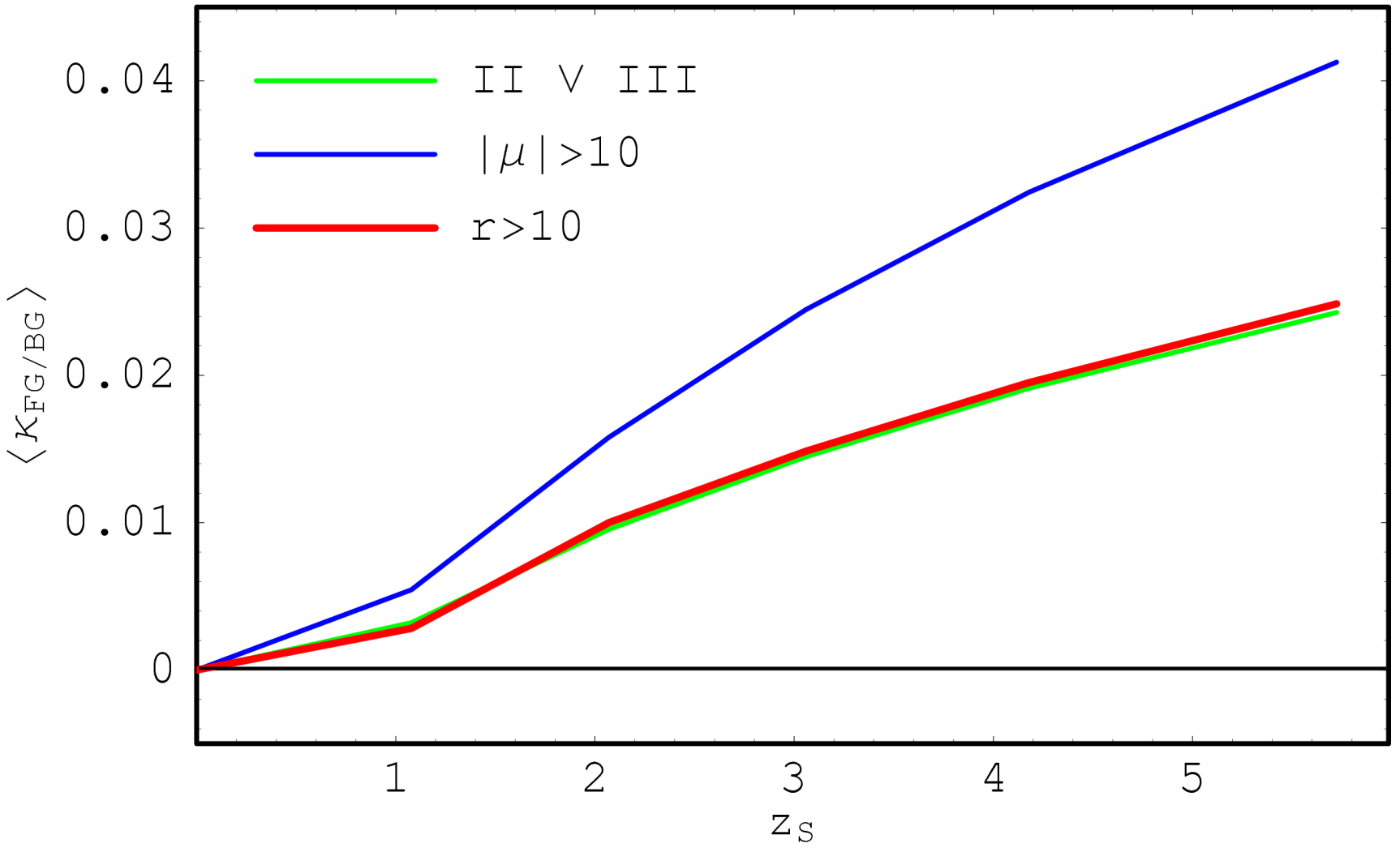
Hilbert et al., astro-ph/0703803

Strong-lensing optical depths



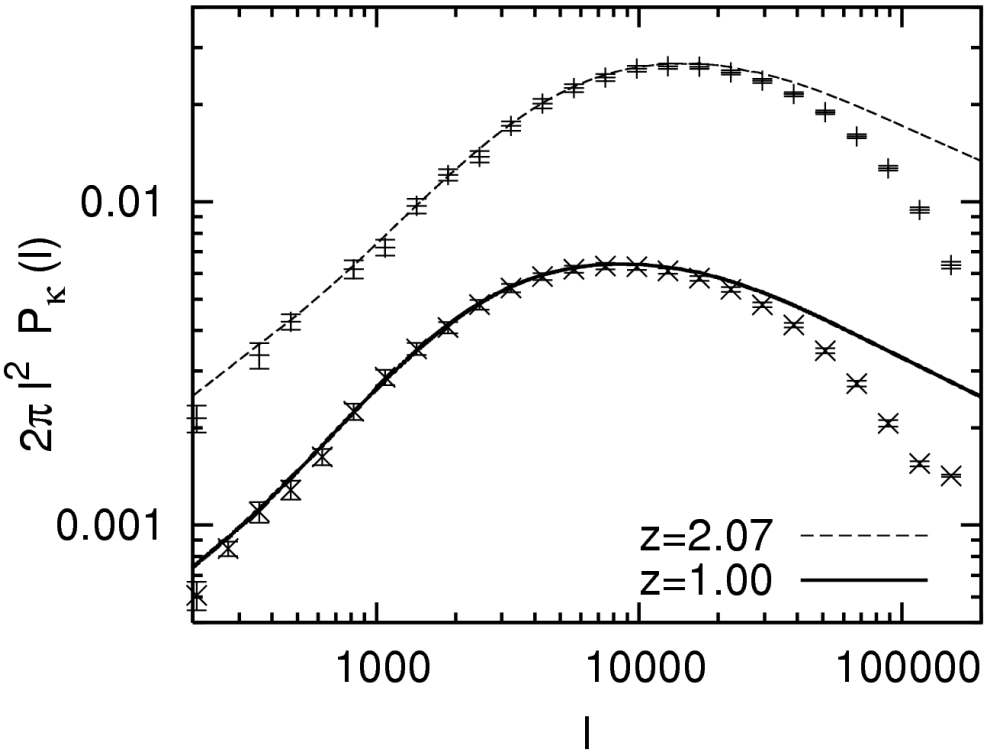
Hilbert et al., astro-ph/0703803

Additional matter along the l.o.s.

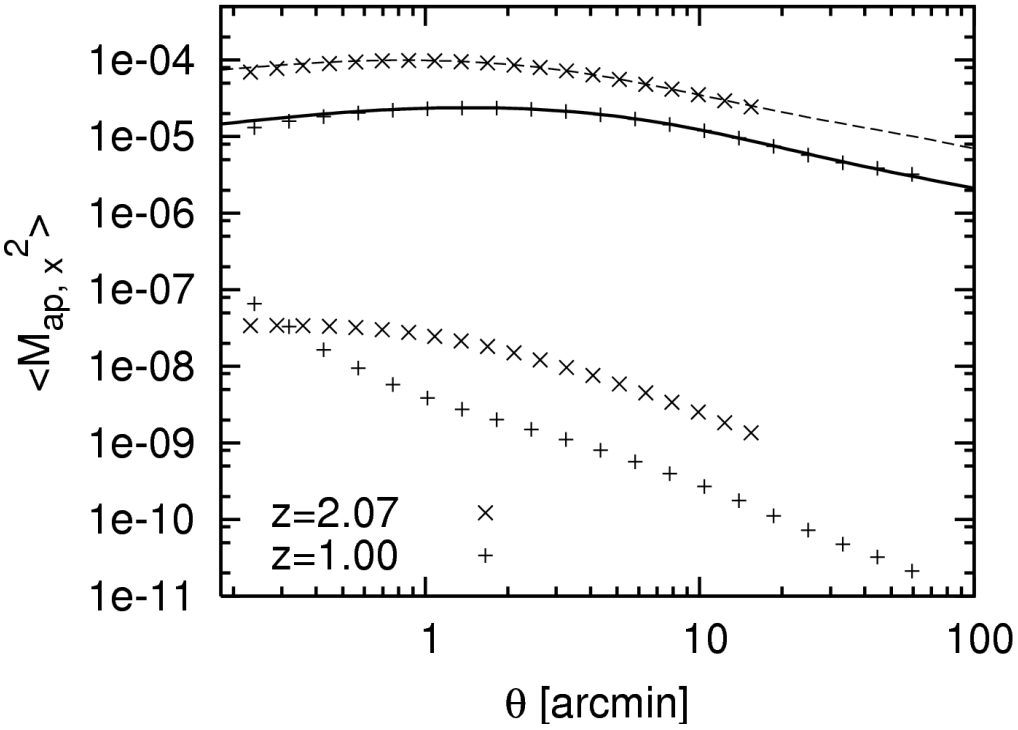


Weak lensing

power spectra



E+B aperture masses



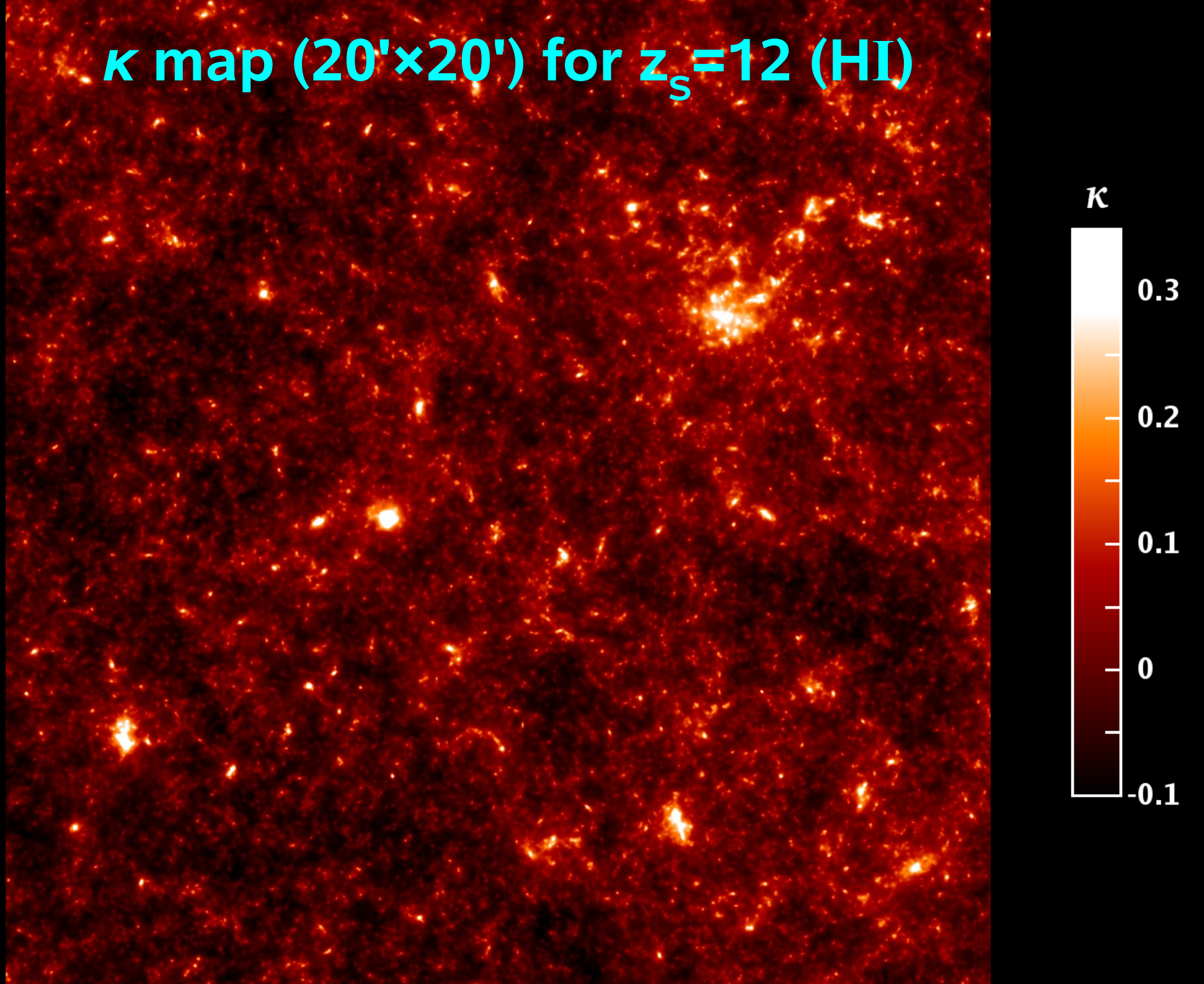
➔Poster “Weak lensing...” by Jan Hartlap et al.

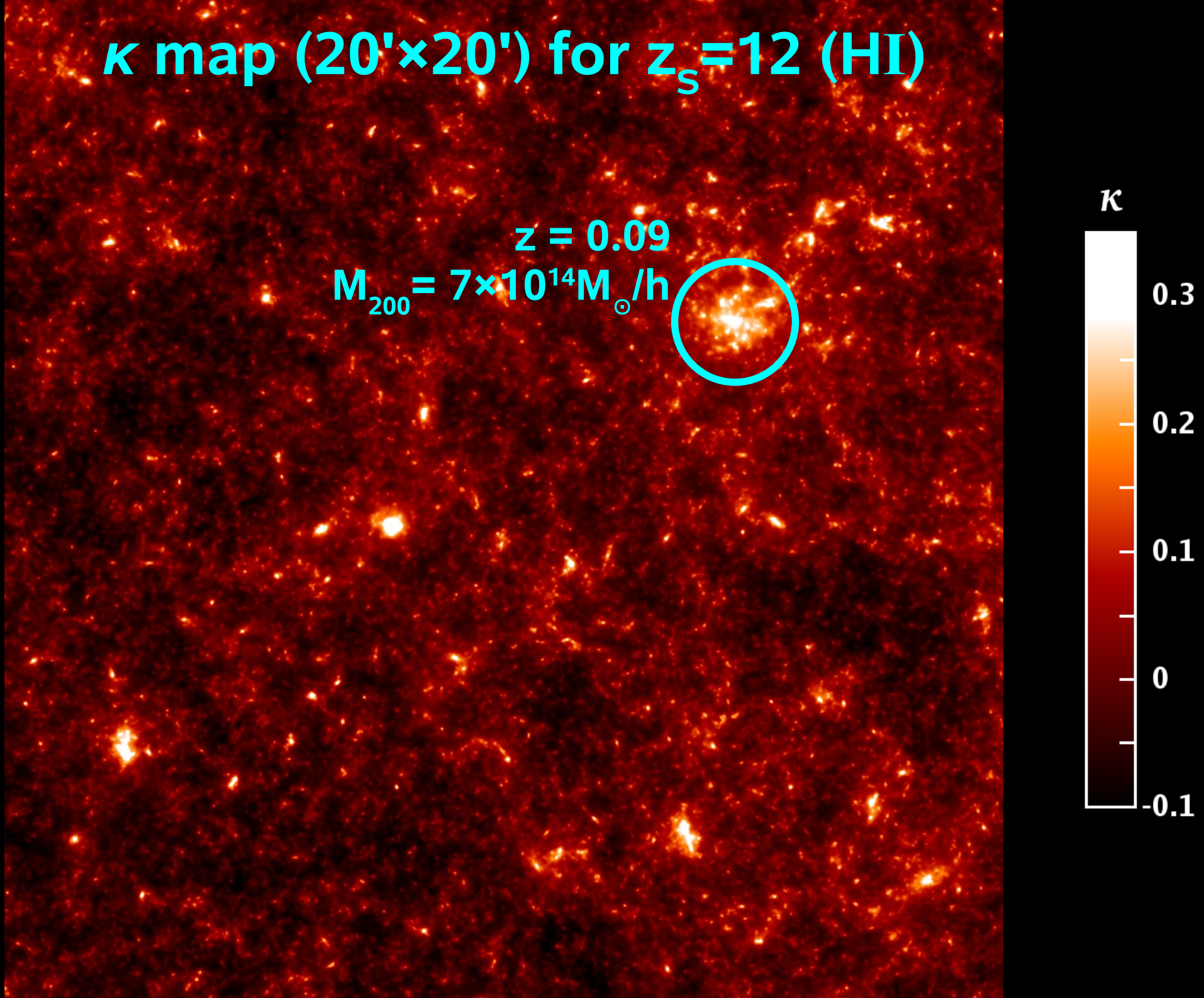
Convergence Maps

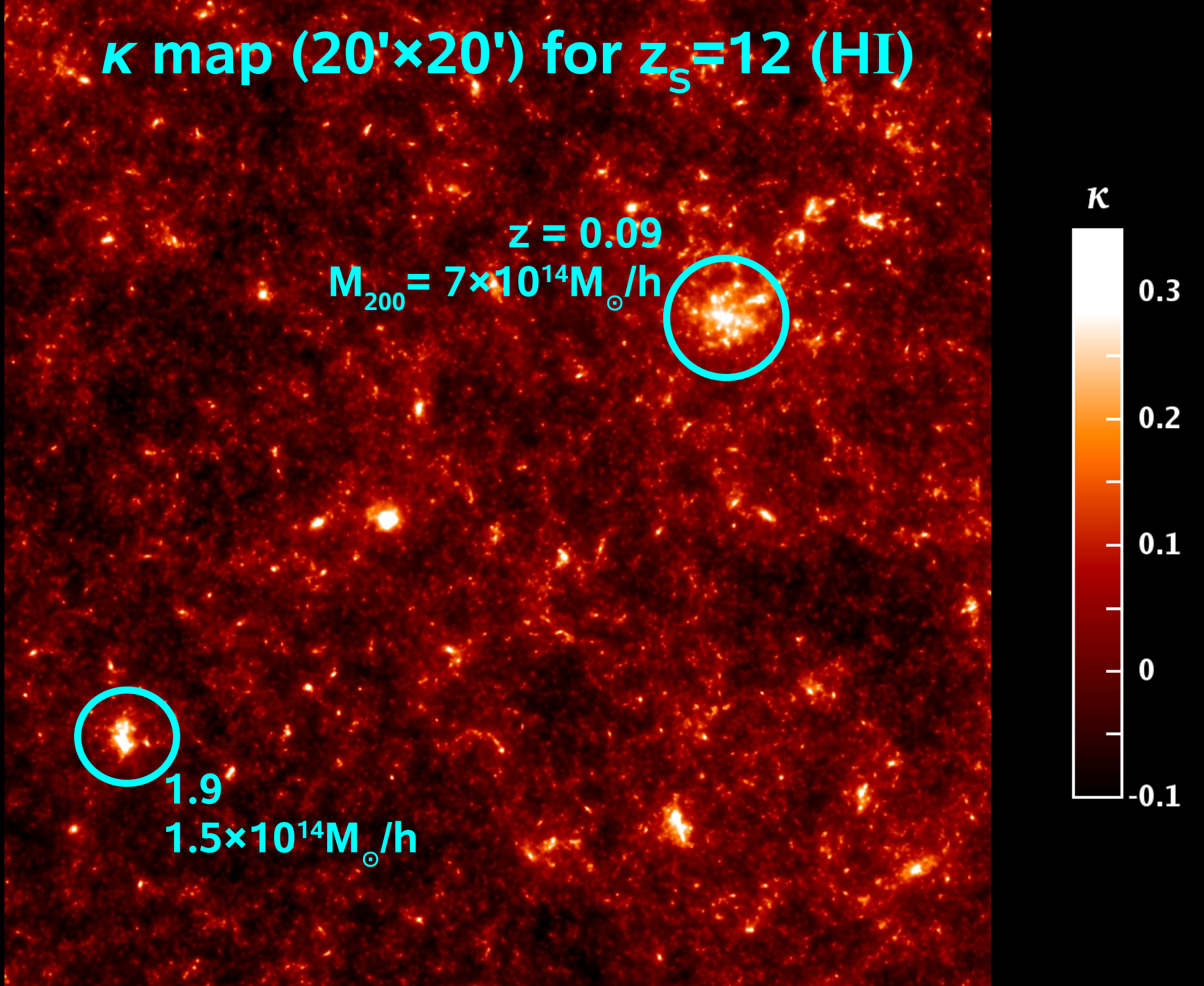
- past and present: distant galaxies used
  - limited sources/area → limited S/N and resolution
  - limited source redshift → only low-z structures
- future (?): use 21cm of pregalactic HI during epoch of reionization:
  - more sources/area and higher source redshift
- simulate convergence maps for 10°×10° fields

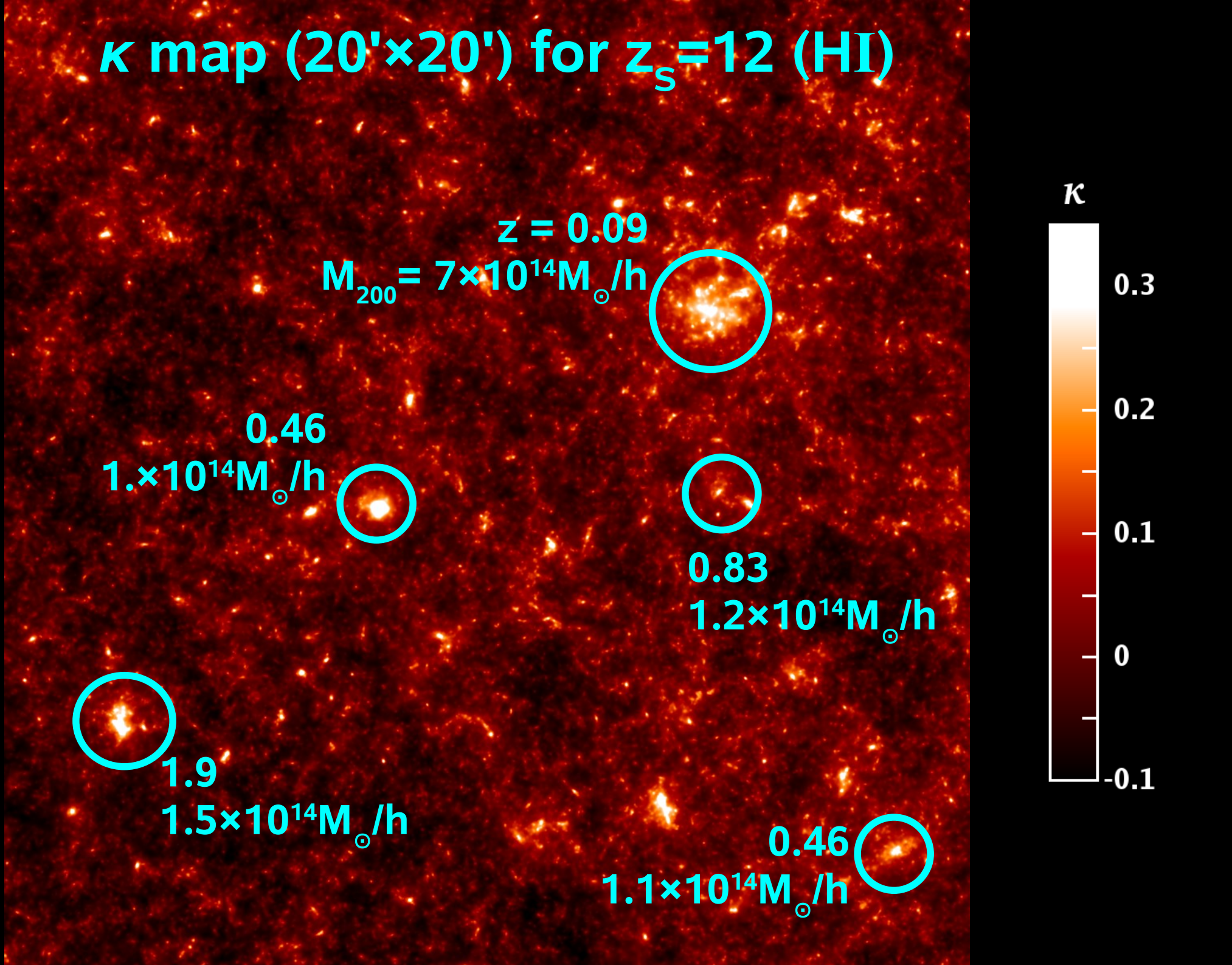
Metcalf & White, astro-ph/0611862

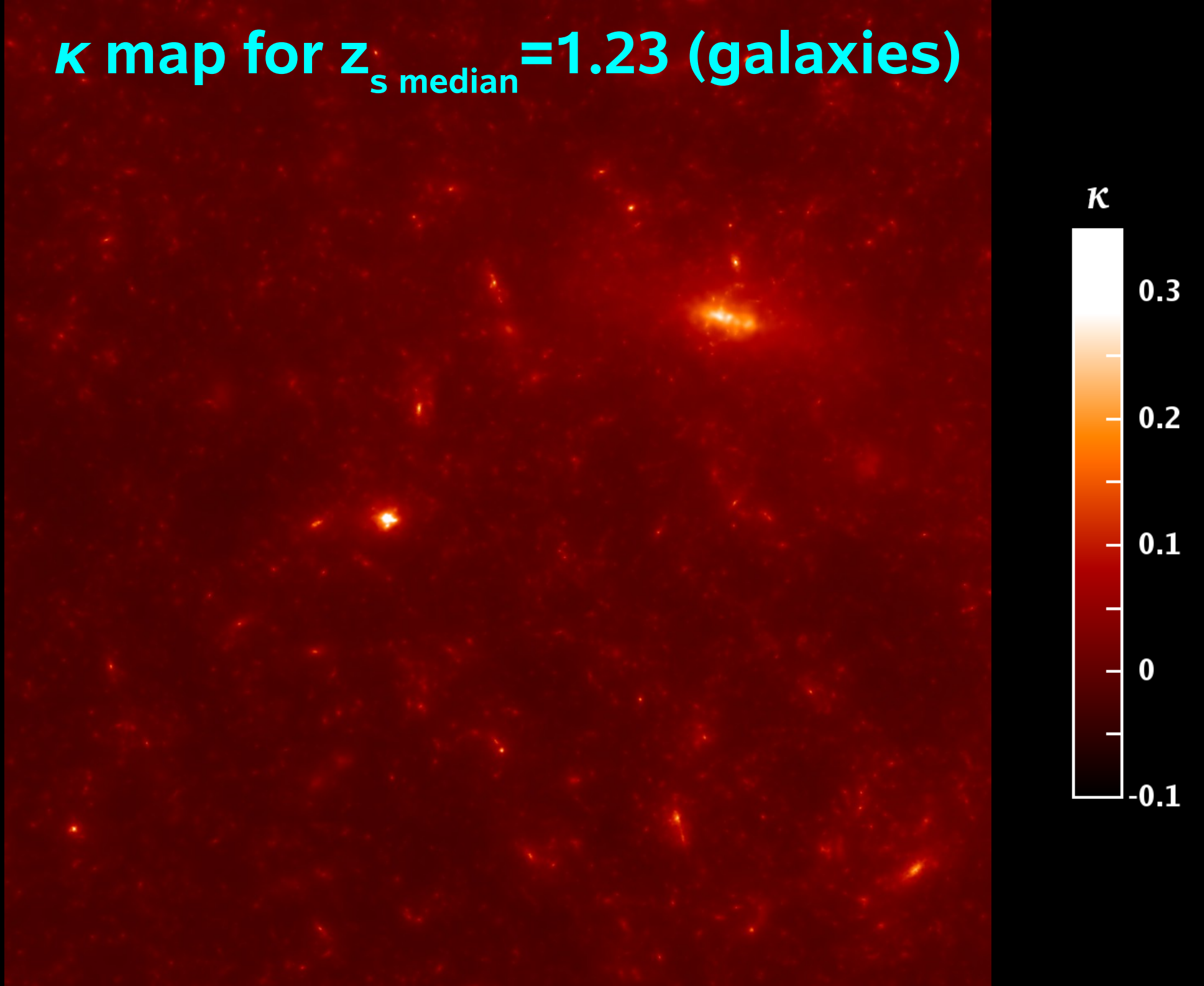
Hilbert, Metcalf & White, arXiv:0706.0849

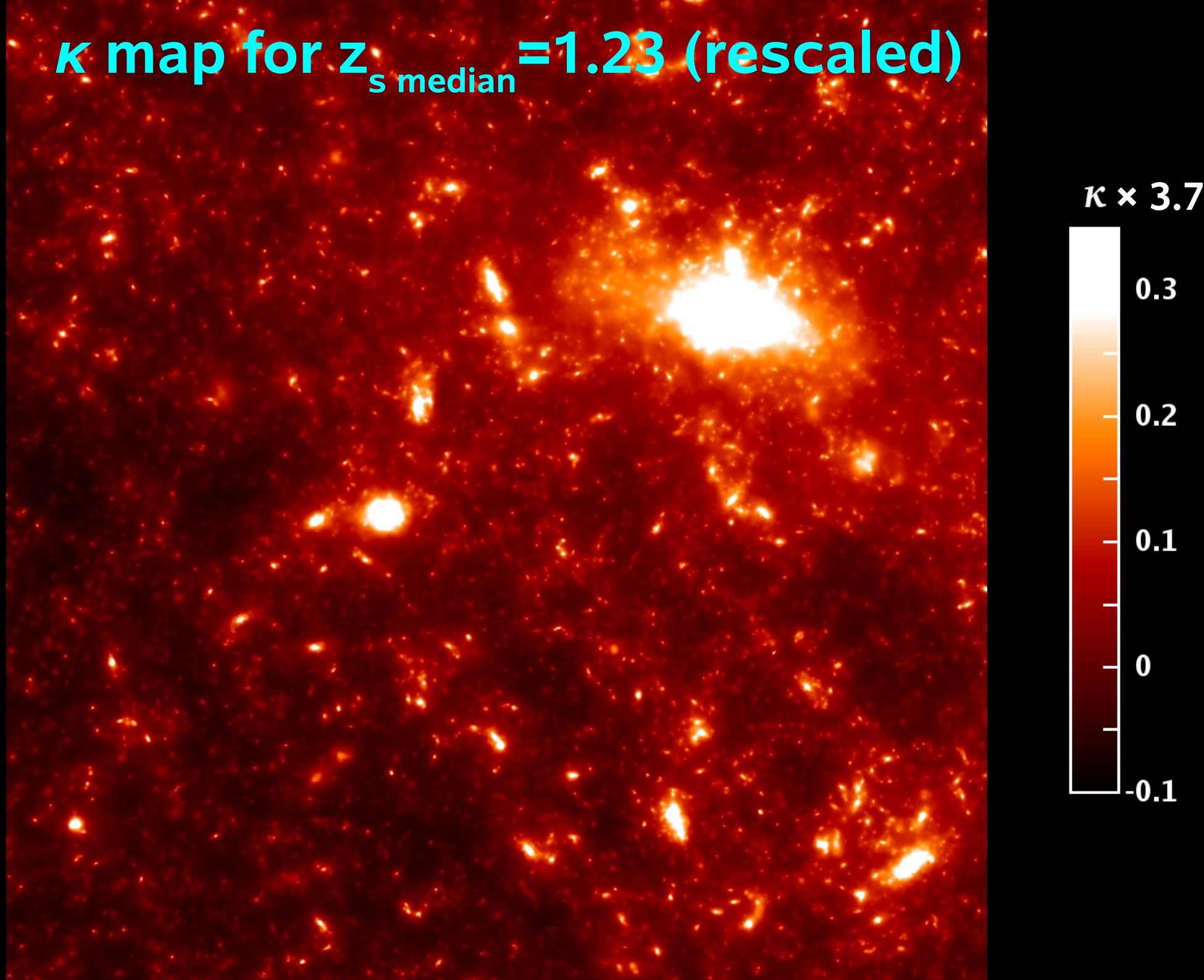

κ map (20'×20') for z_s=12 (HI)
κ
0.3
0.2
0.1
0
-0.1

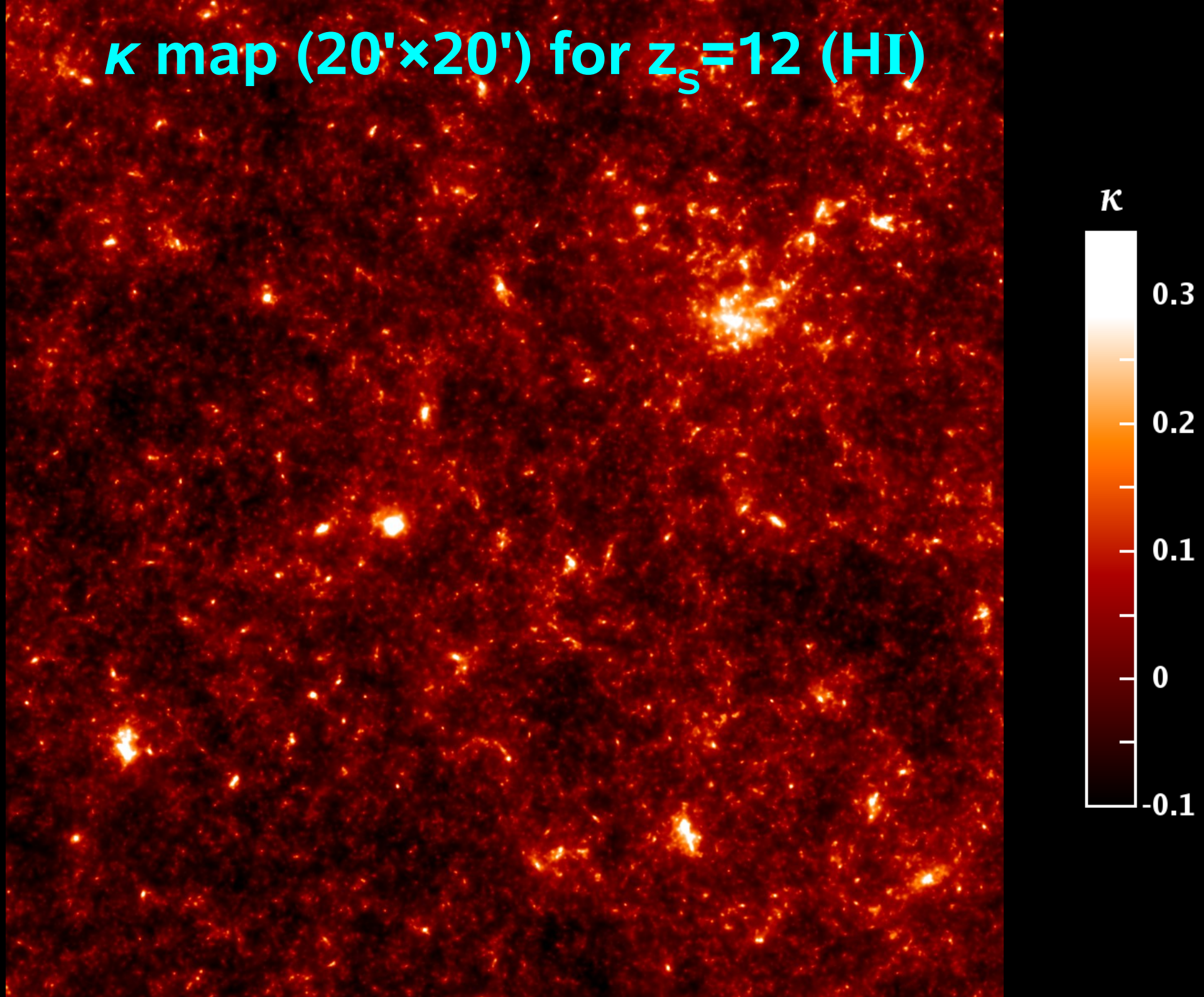

κ map (20'×20') for z_s=12 (HI)
z = 0.09
M_{200}= 7×10^{14}M$_\odot$/h
κ
0.3
0.2
0.1
0
-0.1

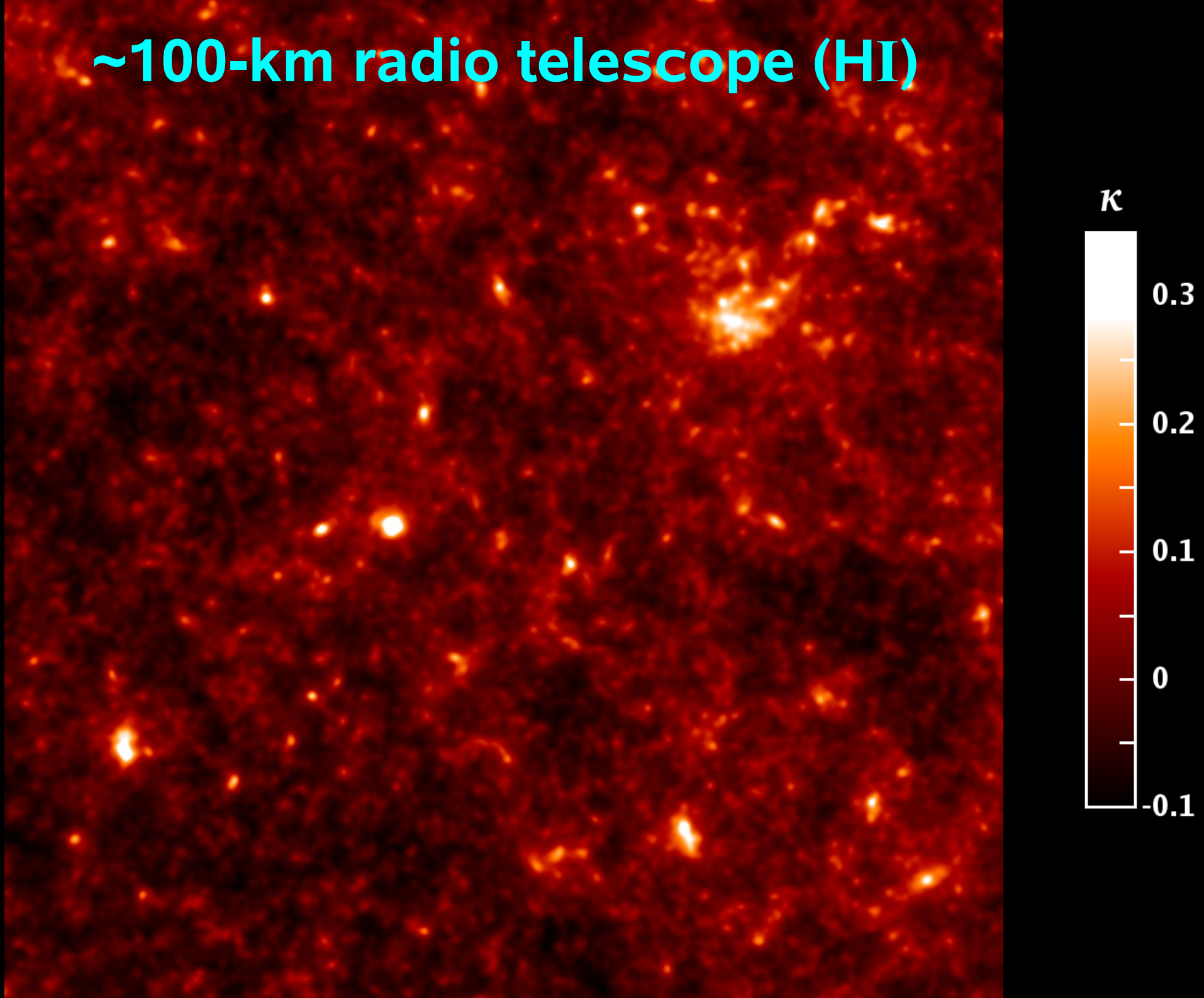

κ map (20'×20') for z_s=12 (HI)
z = 0.09
M_200= 7×10^14M_⊙/h
1.9
1.5×10^14M_⊙/h
κ
0.3
0.2
0.1
0
-0.1

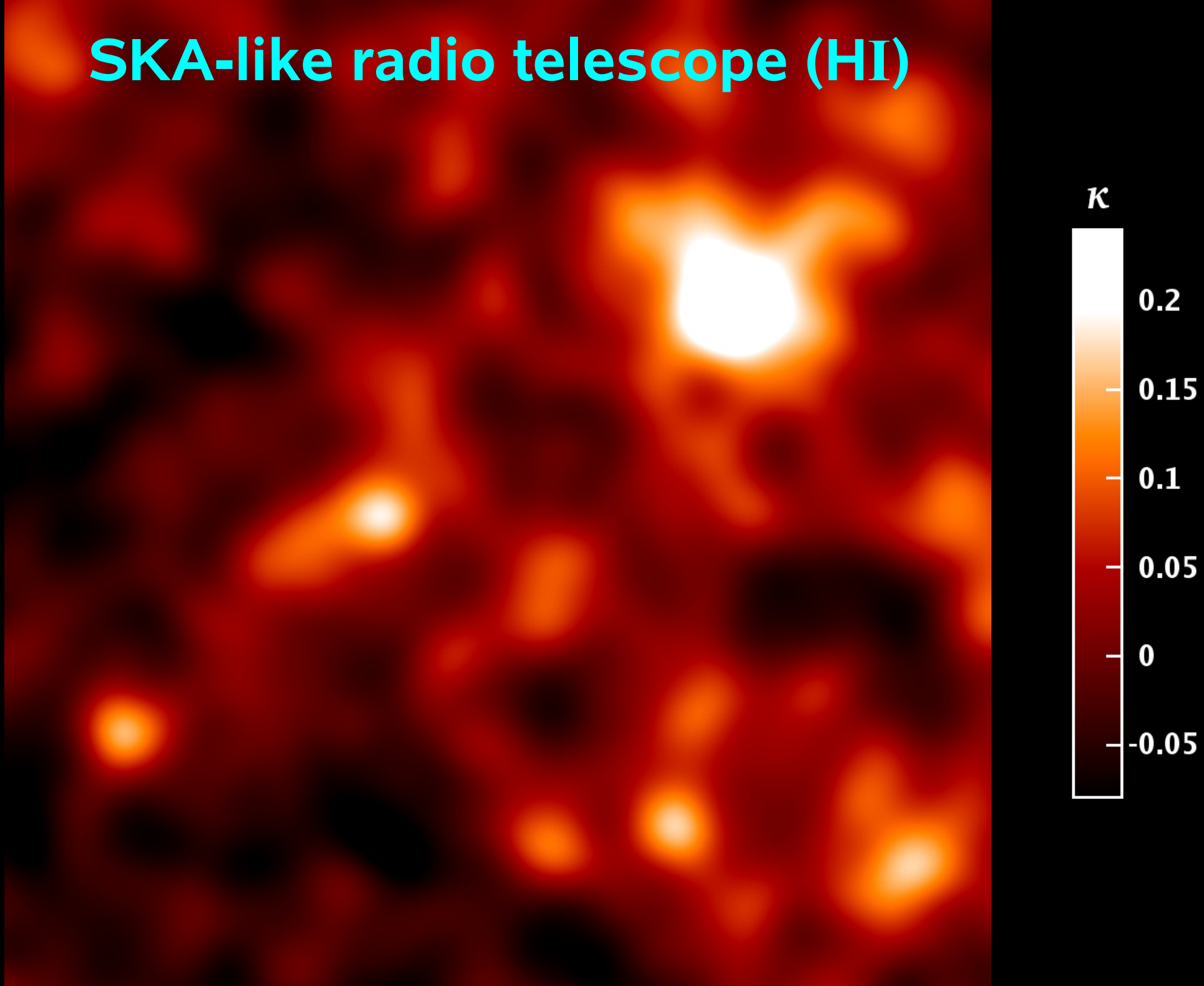

κ map (20'×20') for z_s=12 (HI)
z = 0.09
M_200= 7×10^14M_⊙/h
0.46
1.×10^14M_⊙/h
0.83
1.2×10^14M_⊙/h
1.9
1.5×10^14M_⊙/h
0.46
1.1×10^14M_⊙/h
κ
0.3
0.2
0.1
0
-0.1

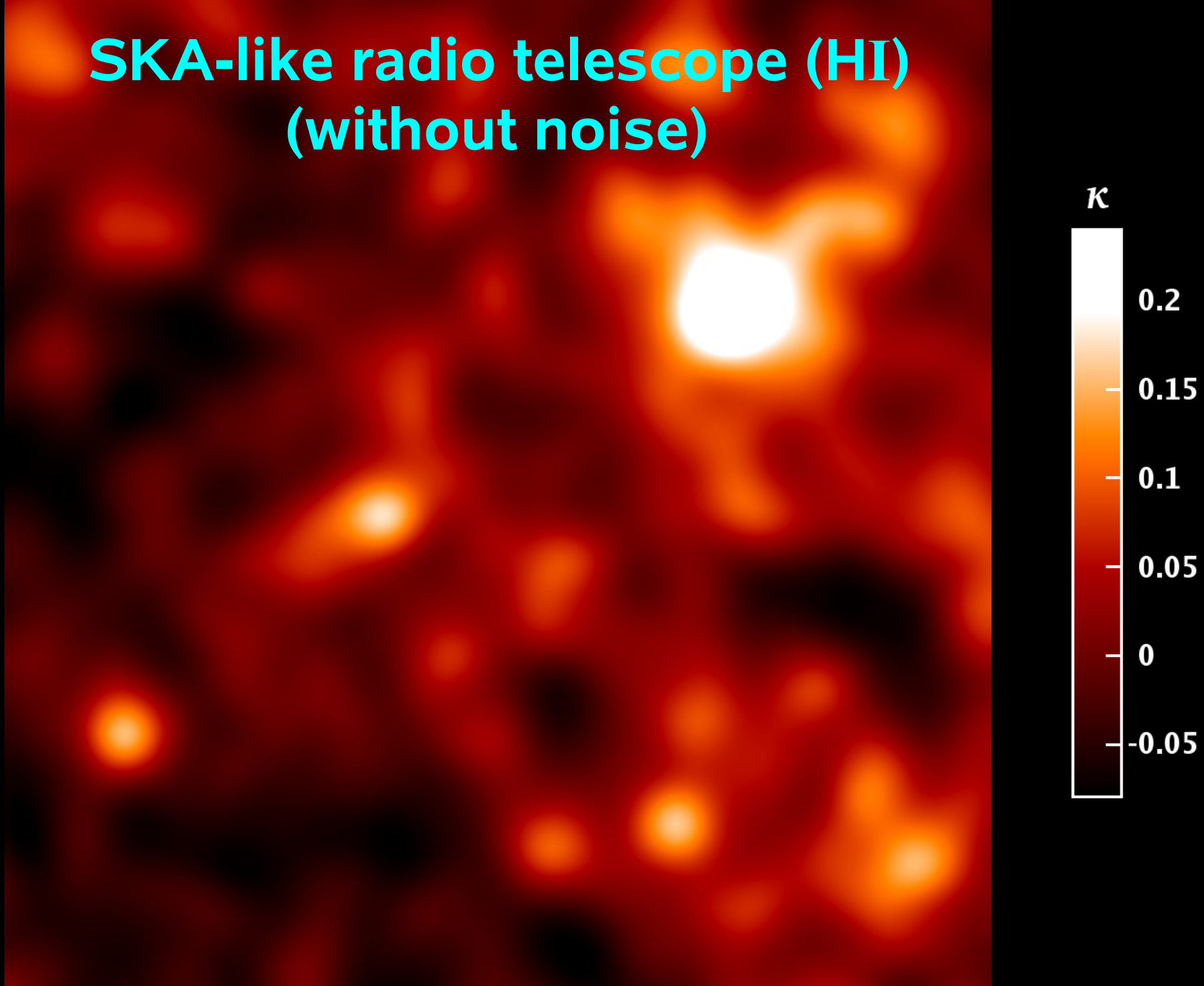

κ map for z s median =1.23 (galaxies)
κ
0.3
0.2
0.1
0
-0.1


κ map for z s median =1.23 (rescaled)
κ × 3.7
0.3
0.2
0.1
0
-0.1

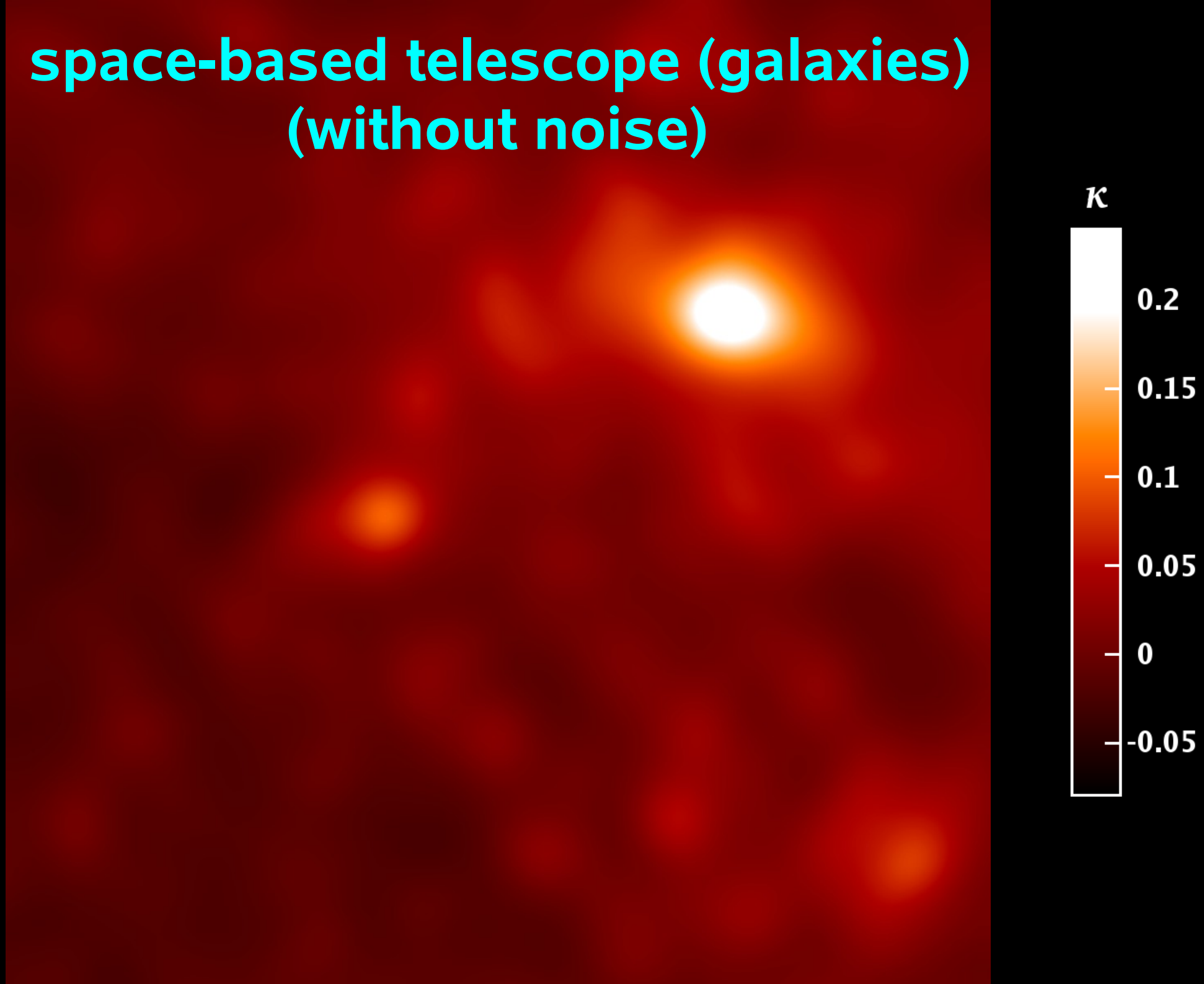

κ map (20'×20') for z_s=12 (HI)
κ
0.3
0.2
0.1
0
-0.1


~100-km radio telescope (HI)
κ
0.3
0.2
0.1
0
-0.1


SKA-like radio telescope (HI)
κ
0.2
0.15
0.1
0.05
0
-0.05


SKA-like radio telescope (HI)
(without noise)
κ
0.2
0.15
0.1
0.05
0
-0.05


space-based telescope (galaxies)
κ
0.2
0.15
0.1
0.05
0
-0.05


space-based telescope (galaxies)
(without noise)
κ
0.2
0.15
0.1
0.05
0
-0.05

Summary

- M.S.: high resolution + large volume
- ray-tracing code adapted to M.S.
- first results:
  - strong lensing: optical depths, lens properties and FG/BG matter contribution
  - weak lensing power spectra and aperture masses
  - convergence maps using lensing of pregalactic HI

Outlook

- inclusion of galaxies from semi-analytic models
- cosmic shear: B modes, selection effects, ...
- galaxy-galaxy lensing: galaxy bias, comparison to halo models, ...
- 3-point statistics (GGGL)
- flexion
- ...

Thanks
for
Your Attention!