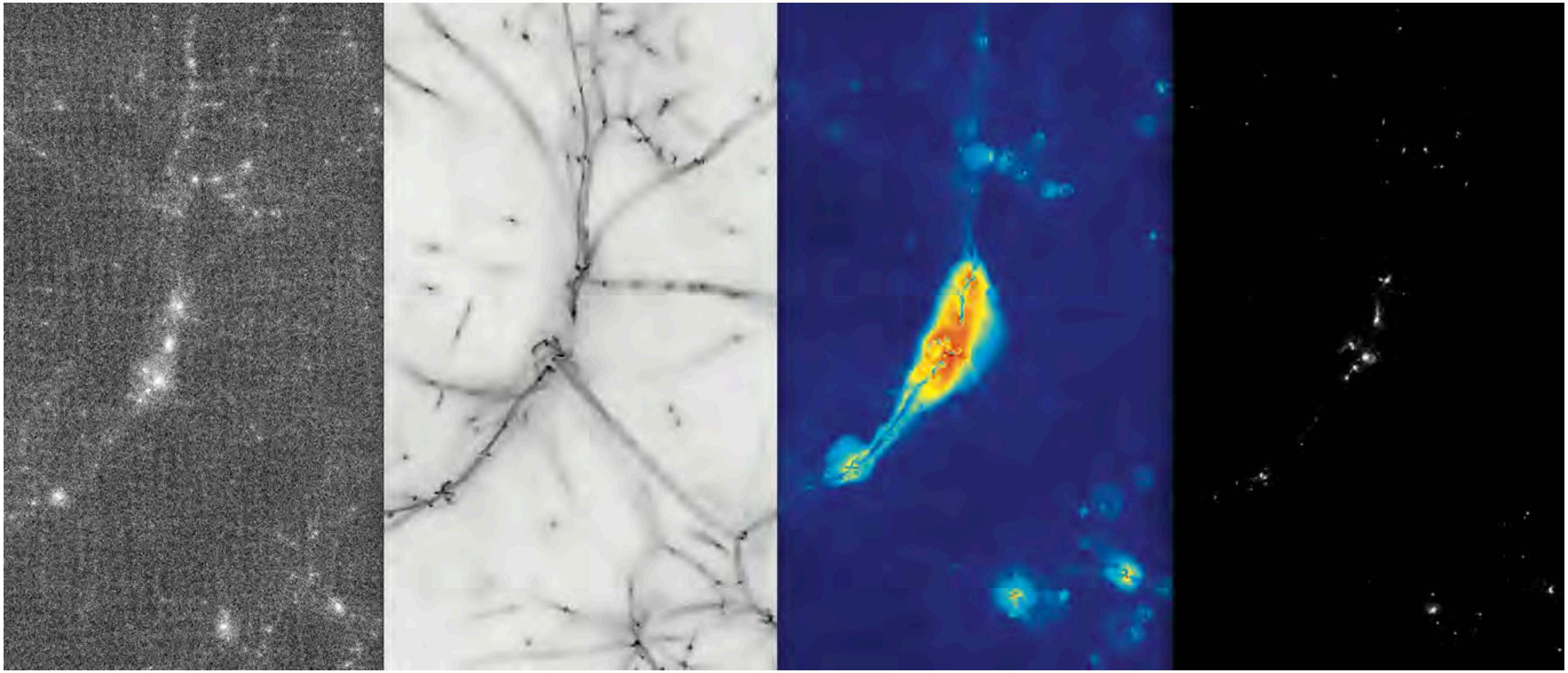


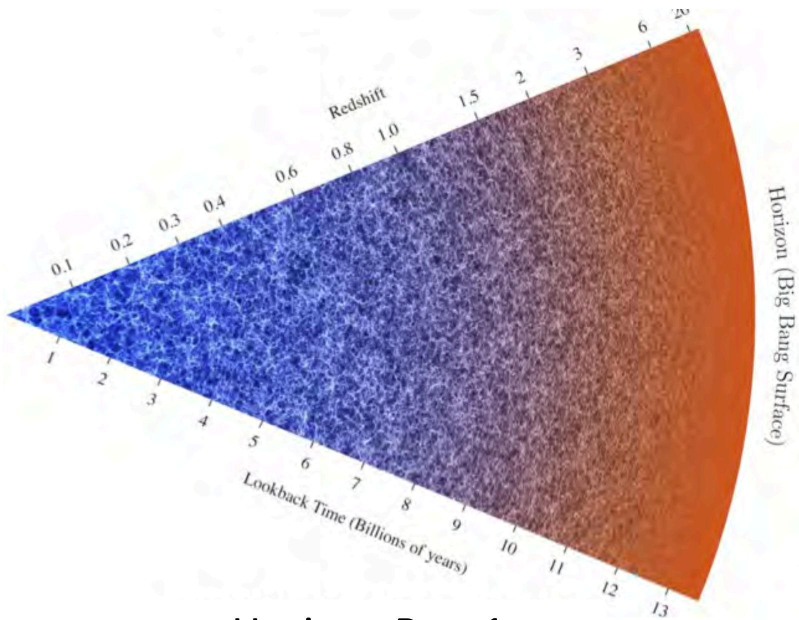
Horizon Run 5 – I. Introduction & Initial setup

Jihye Shin (KASI)

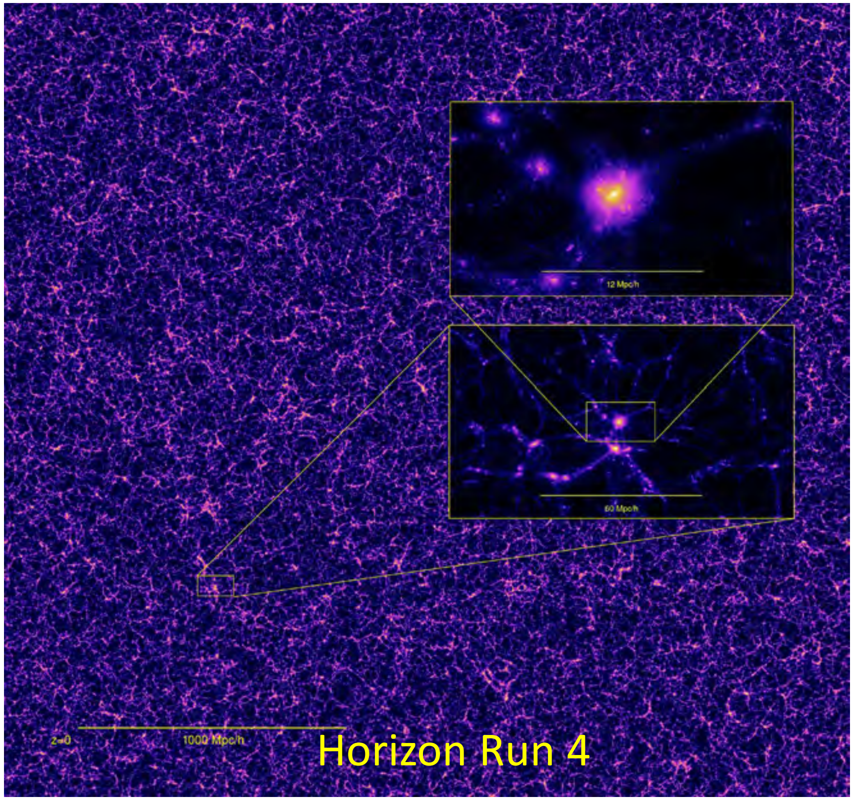
& Juhan Kim, Changbom Park, Owain Snaith, Yonghwi Kim, Jaehyun Lee (KIAS)

Previous simulations by our group

	HR1	HR2	HR3	HR4	HR5
Box size (h^{-1}Mpc)	6592	7200	10815	3150	
# particles	4120	6000	7200	6300	AMR+particles
Reference	Kim et al. (2008)	Kim et al. (2011)	Kim et al. (2011)	Kim et al. (2015)	-
Code	GOTPM (Dubinski et al. 2004)	GOTPM	GOTPM	GOTPM	RAMSES (Teyssier 2002)
Citations (ADS)	73	64	64	22	-

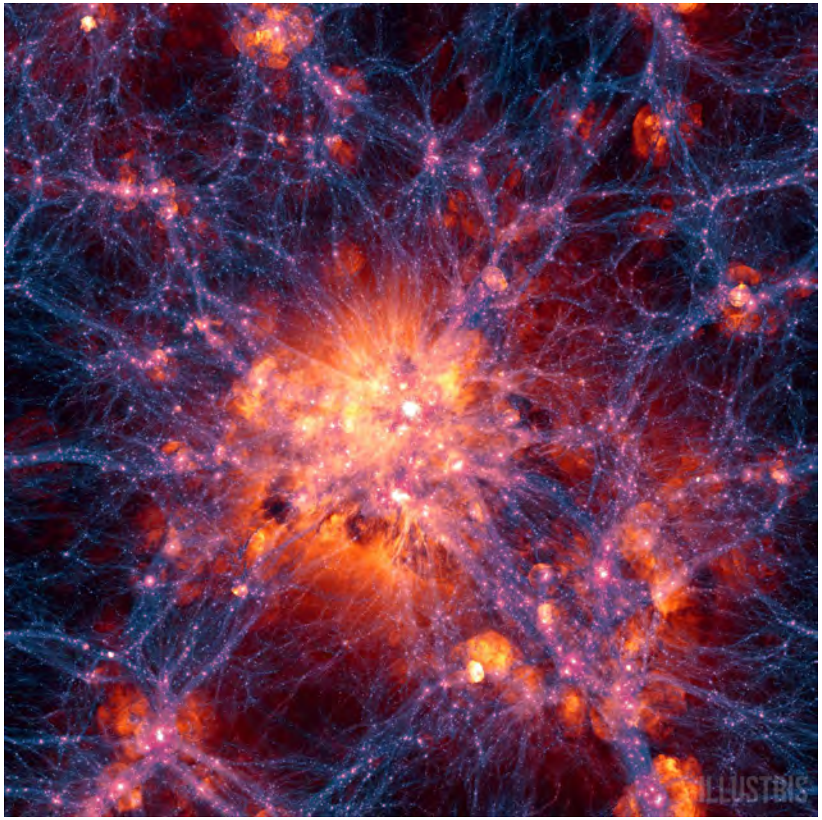


Horizon Run 1



Produced by Juhan Kim

Previous cosmological hydrodynamic simulations



credit: Illustris project team

Recent large-scale simulation projects

Simulation project	Code	Boxsize (Mpc)	M_{gas} (M_{sun})	Epsilon (kpc)
Horizon-AGN (Dobois+2014)	RAMSES	100/h	1.6×10^7 (initial)	1 (Δx)
Illustris (Vogelsberger+2014)	AREPO	110.7	6.3×10^6	0.74
Eagle (Schaye+2015)	Gadget3 +ANARCHY	100	1.81×10^6	0.70
MassiveBlack-II (Khandai+2015)	P-Gadget3	100/h	2.2×10^6/h	1.85/h
TNG Illustris (Pillepich +2017)	AREPO	110.7	6.3×10^6	0.74
		302.6	5.9×10^7	1.48

~100 Mpc-scale structure

~1 kpc resolution

Lack of large-scale perturbation (> 100 Mpc/h)

→ Unable to see the **large cosmic structures** (massive clusters, big voids, etc.)

→ Unable to properly see the large-scale **environmental effects** on galaxies

→ Subject to the **cosmic variance** (wrong statistics)

Rationale of Horizon Run 5

Why a cosmological **hydrodynamic** simulation?

- To directly resolve the galaxy formation and evolution in the cosmological context
- To see the morphological segregation of galaxies under the influence of cosmic environments
- To separate the effect of baryons from that of dark matter on cosmological structures

Why **a big box size** with **1 kpc resolution** is required?

- Small-scale physics are correlated with the large-scale cosmic structures.
- We want to minimize the cosmic variance of simulated galaxies ($L_{box} \geq$ 1Gpc/h, Klypin+18)

<u>Collabaration for HR5 project</u>

KIAS (Changbom Park, Juhan Kim, Owain Snaith, Yonghwi Kim, Jaehyun Lee)

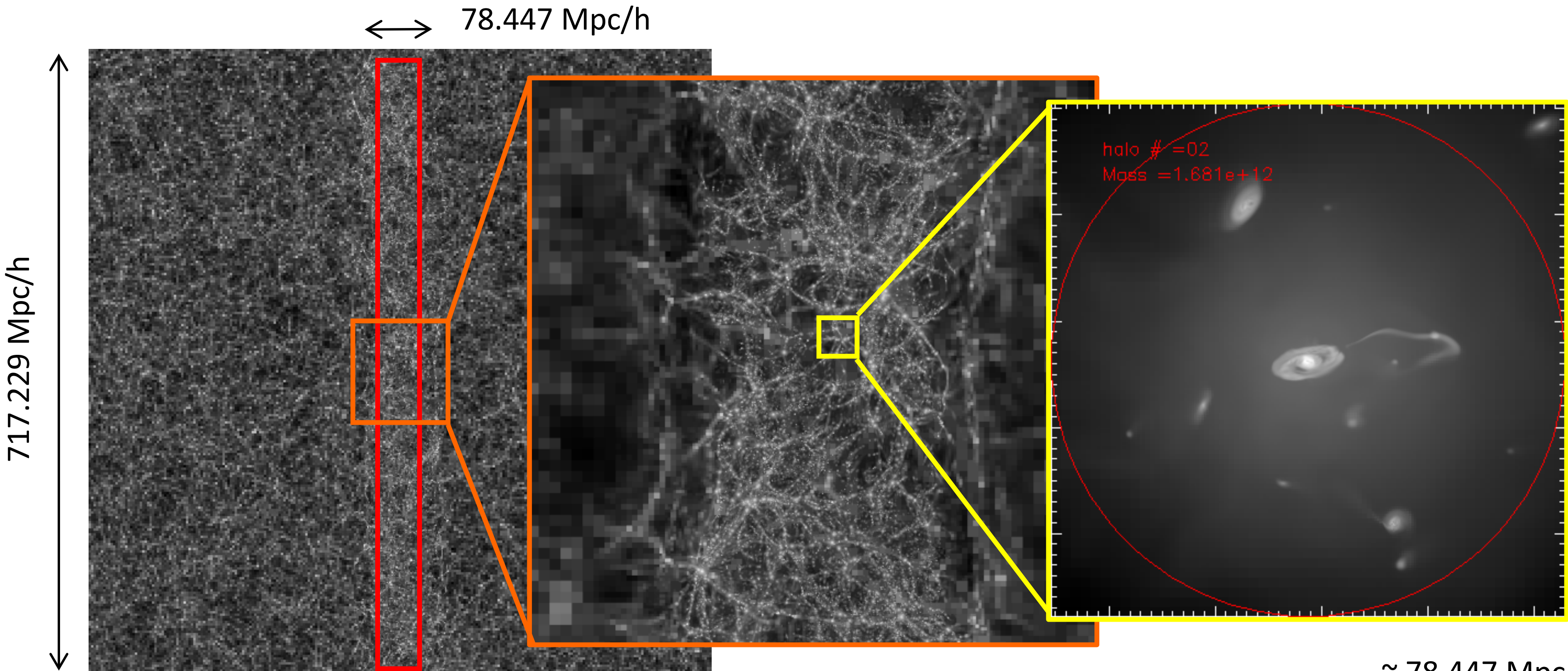
KASI (Jihye Shin)

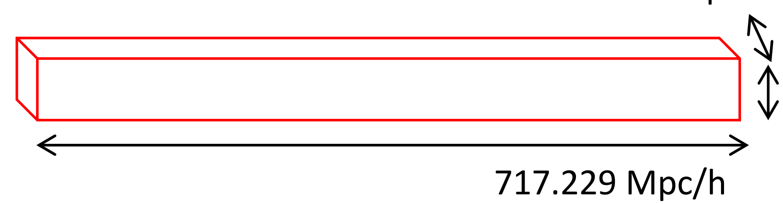
IAP (Christophe Pichon, Yohan Dubois)

University of Hull (Brad Gipson, Gareth Few)

KISTI (Oh-Kyung Gwon, Chan Park)

How to Set HR5





Aim: Large-scale Power + Small-scale Physics

→ Large-scale power in L_{box}= 717.229 Mpc/h

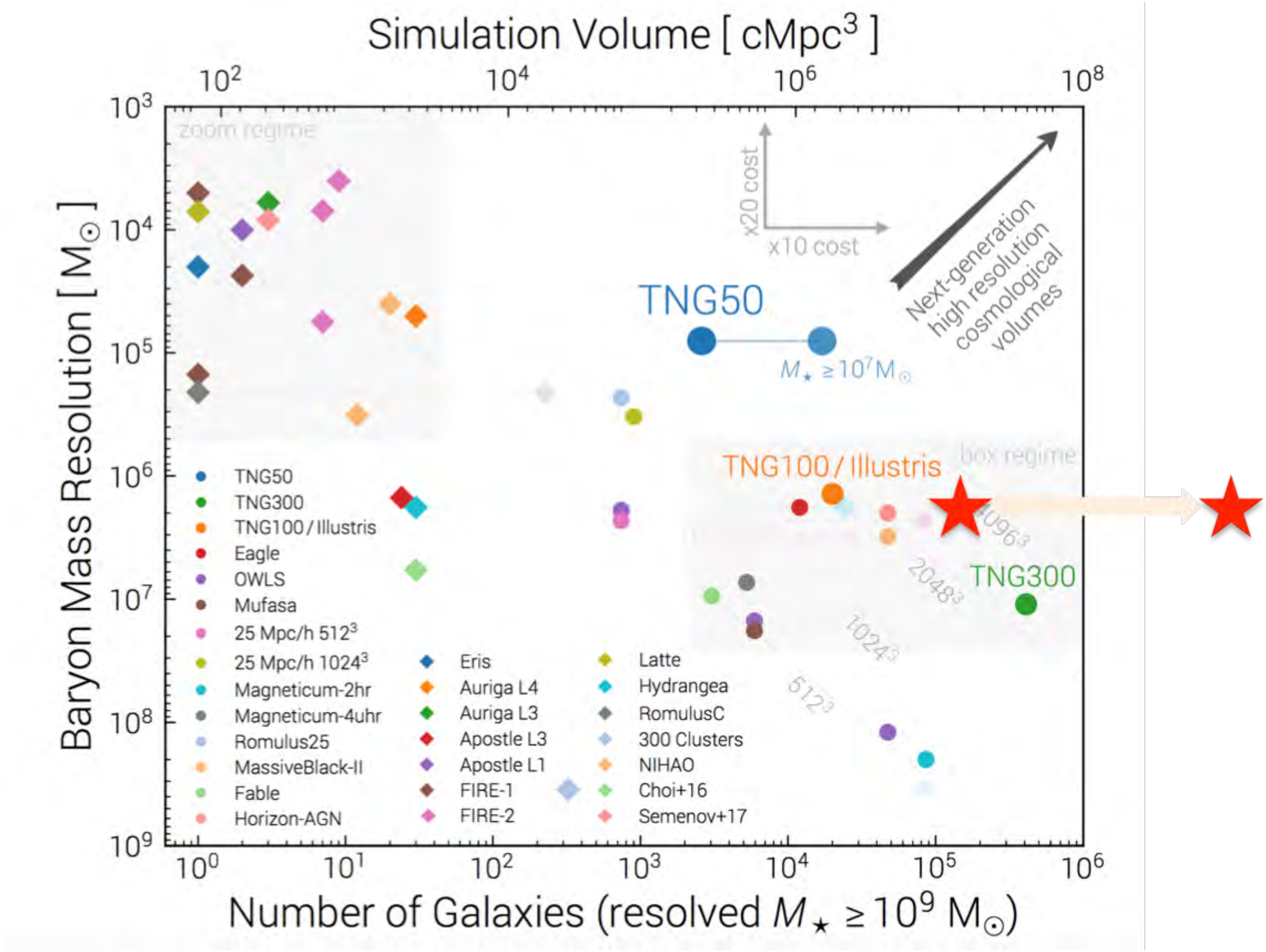
→ Small-scale physics with 1 kpc-resolution

Method: Zoom technique

→ large-scale power in the background and small-scale physics in the target region

717.229 Mpc/h = 1048.58 Mpc = 2^20/1000

Simulation size of HR5



Nelson et al. 2019

Adopted simulation code & cosmological model

- Initial-condition generator: **MUSIC** (Hahn et al. 2011)

- Main simulation code: **RAMSES** (Teyssier 2002)

- RAMSES is an **AMR** (adaptive-mesh refinement) code.
  → Is a hybrid combining Lagrangian particles (DM & star) and Eulerian cells (gas).
  → Incorporates the physics: gas cooling/heating, reionization, star formation, SN feedback, supermassive black holes, AGN feedback, detailed chemistry etc.

- Well developed post-simulation pipelines (e.g. YT, Pynbody)

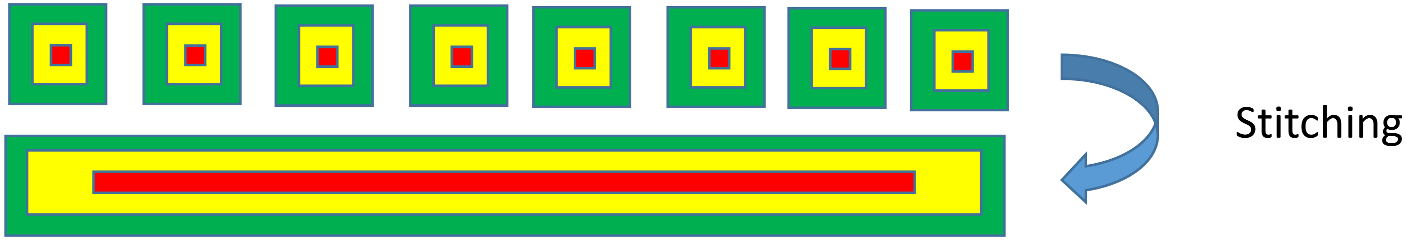
- Using the Concordance LCDM cosmology (Planck 1-year)

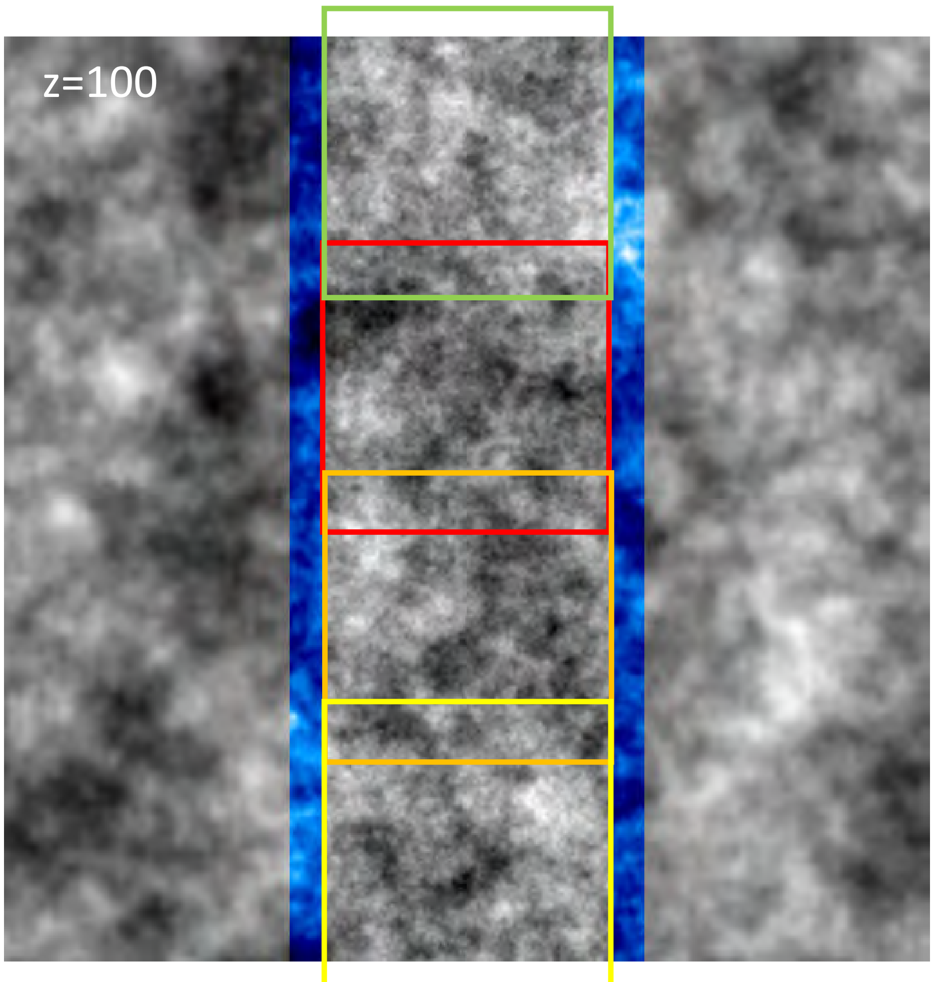
Ω_m	Ω_Λ	Ω_b	H_0	σ_8	n_{spec}
0.30	0.70	0.046	68.4	0.816	0.967

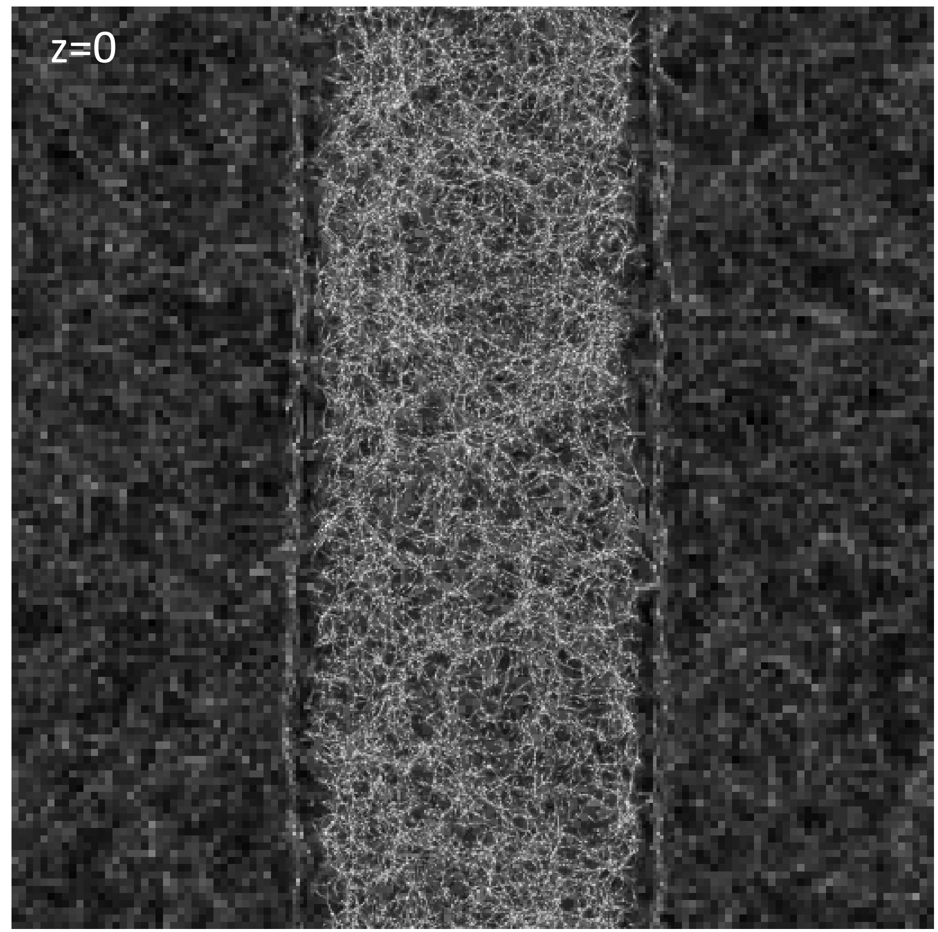
- Resolutions:
  →ICs : ~ 5.2x10^{12} Msun, 87.5h^{-1} kpc
  →**Final : ~ 2.5x10^{6} Msun, 0.684h^{-1}kpc (1kpc)**

7 refinement levels in zoom region

How to generate IC for HR5







How to generate IC for HR5

Random patterns and zoom region **to describe BAO**

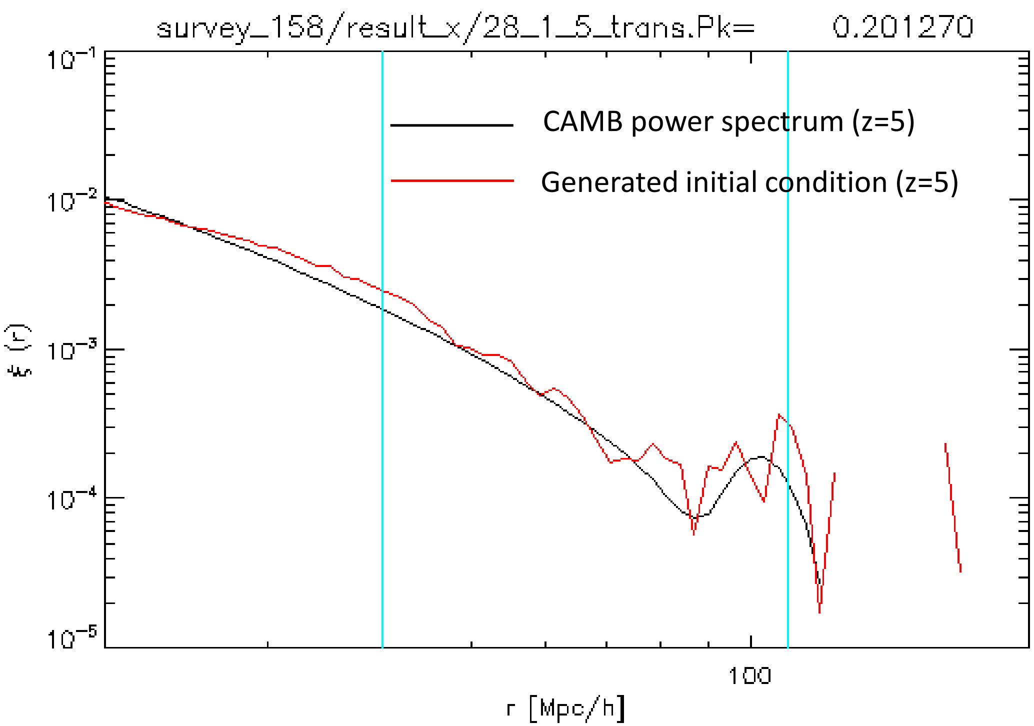
= different **width** (5 values from 72.8436 to 95.2570 Mpc/h)

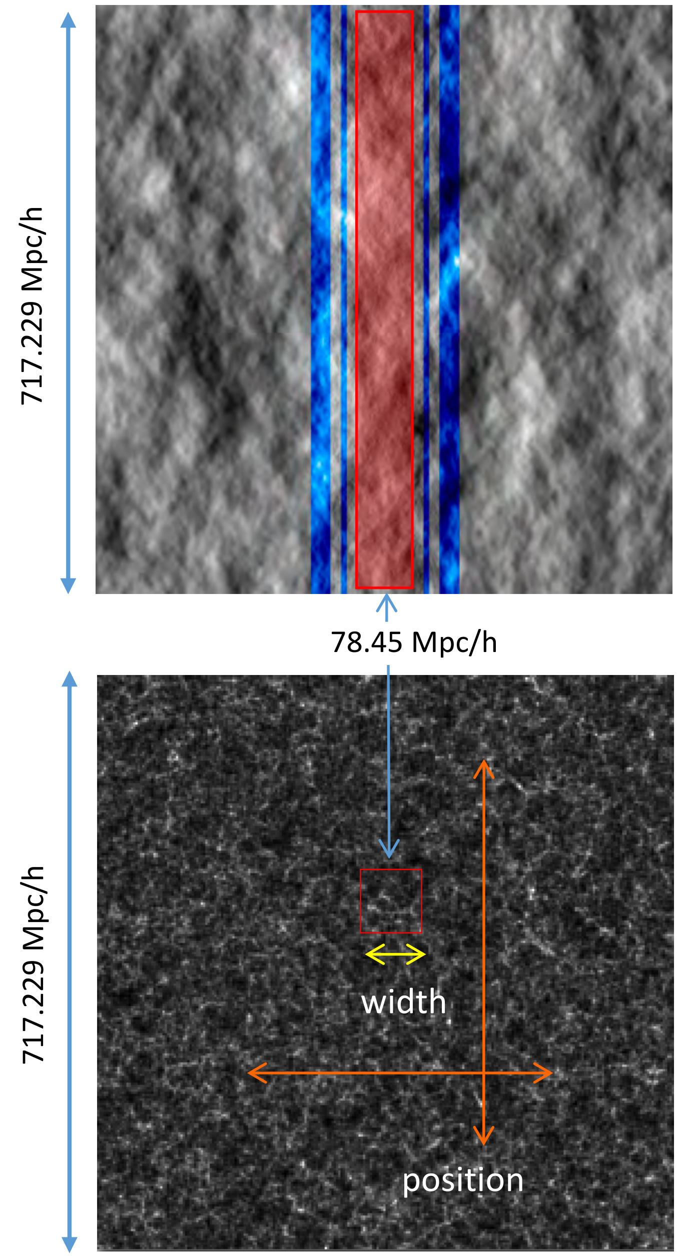
x different **position** (from 7^2 to 9^2 for each width)

x different **direction** (3 values : x, y, and z)

x different **random pattern** (800 patterns)

= ~ 10^6 different zoomed box





HR5 on the 5th KISTI supercomputer

1st Great Challenge program of the 5th KISTI supercomputer (Nurion cluster)

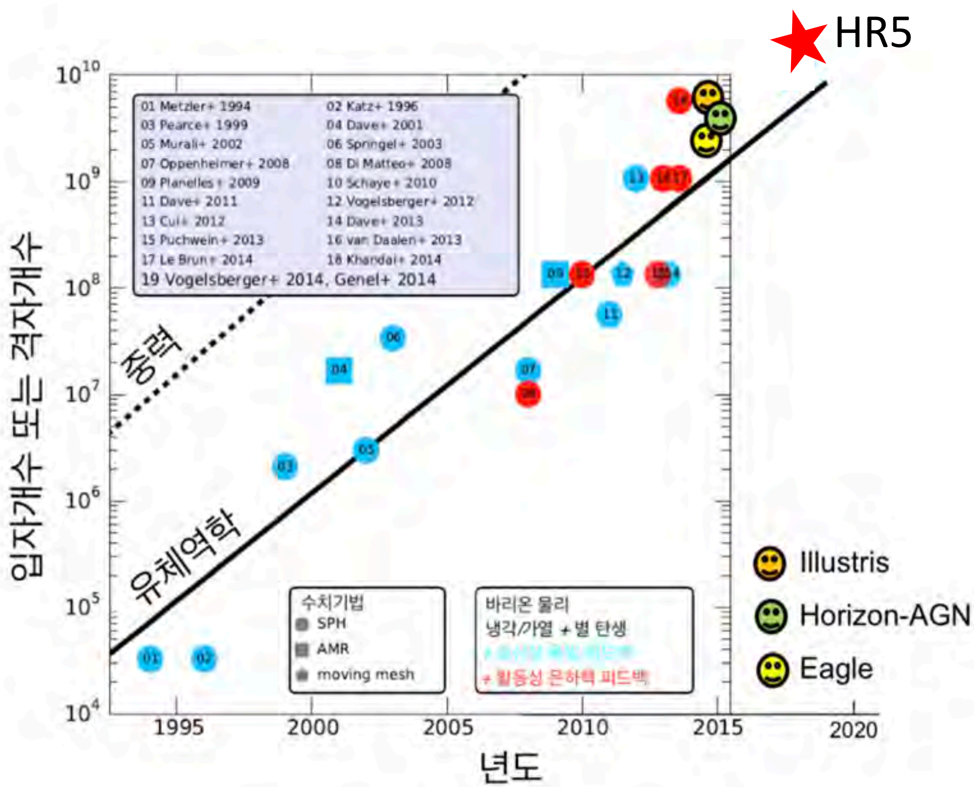
-> 90 days (2018.12.15 ~ 2019.3.15)

-> 2500 node (170,000 cores, 30 % of total system)

-> 68 core/node (many core system, Intel Xeon Phi 7250)

= **36.7 M CPU hours**

Horizon-AGN	Eagle	Illustris	Illustris-TNG	HR5
4 M CPU hours	4.5 M CPU hours	19 M CPU hours	18 M CPU hours	**36.7 M CPU hours**



Original RAMSES

- MPI-only parallelism
- Performance limit around Ncpu≈2,000

OMP-RAMSES

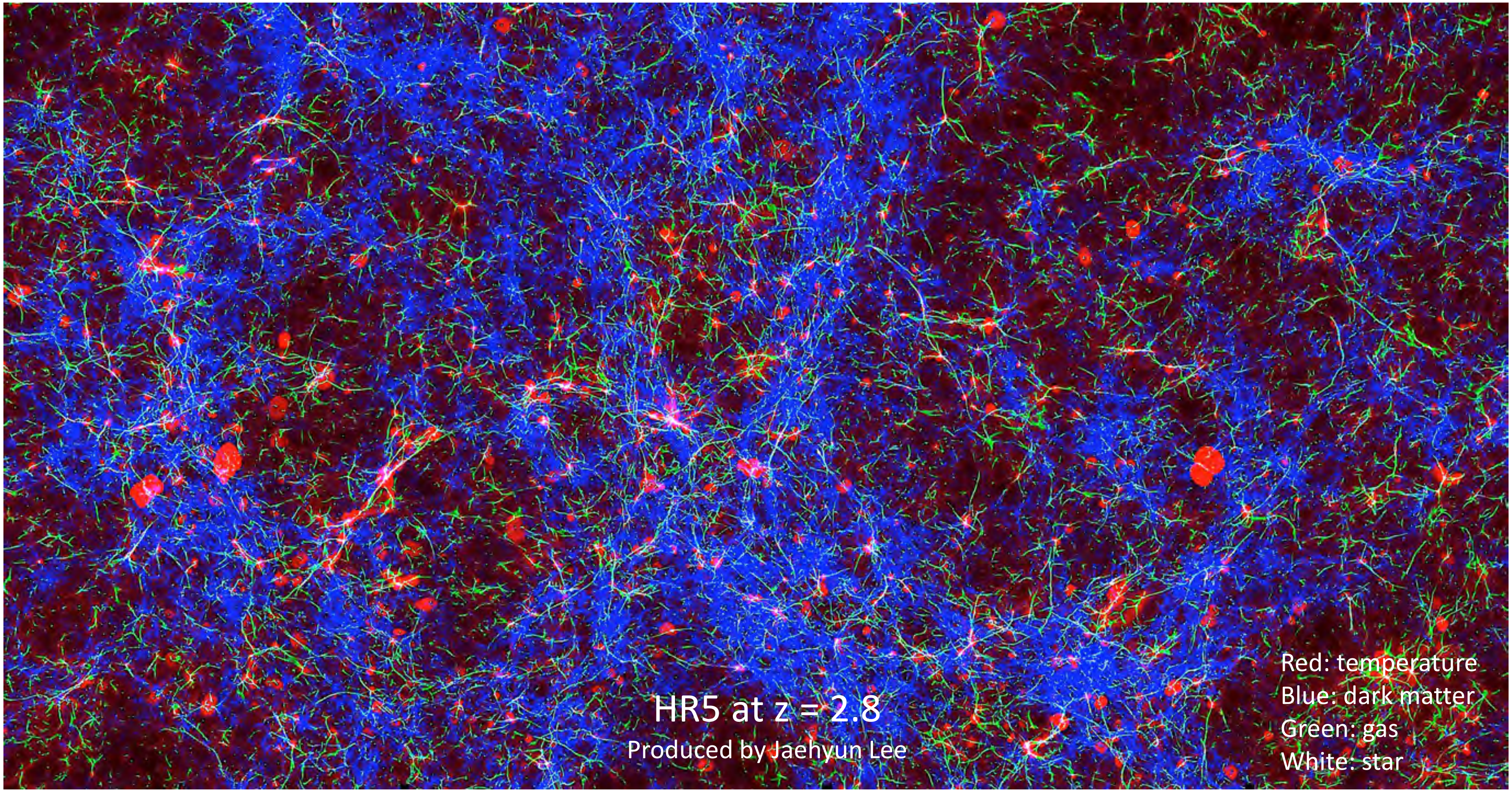
- Hybrid parallelism combining **OpenMP + MPI**
- **mainly by Juhan Kim** (KIAS)

  and Oh-Kyung Kwon, Chan Park (KISTI)
- Well designed for ***"N-core"* systems**
- Well designed for **massive simulations**
- Performance gain of HR5 = more than 10 times?

Running final HR5

Running at Nurion from 2018.12.15 (-> until 2019.3.15)

Current final snapshot at z = 2.7 (-> hopefully to z=0.2)



Science goals - Cluster/Group/Void/Galaxy properties

Dark matter only version of the HR5 volume (HR5-DM)

→ will add extra information about the **role of baryons in the galaxy formation**.

The large volume of HR5

→ will give us access to **a wide range of environments**, including voids/massive clusters.

→ Massive clusters – higher resolution than RHAPSODY-G (Wu et al. 2015),
but fewer clusters expected in high resolution volume

These objects will be simulated in their cosmological context, complete with inflowing filaments etc.

→ Explore the **baryonic processes of galaxies in a range of environments**.

: Galaxy quenching, Impact on galaxy morphologies/color,
Dynamics of gas inflow into halos/galaxies across the Hubble sequence, etc.

Galaxy-galaxy interactions:

→ Satellite alignments (comparison with other simulations/observations)

→ Merger histories of halos/ effect on galaxy properties

→ …