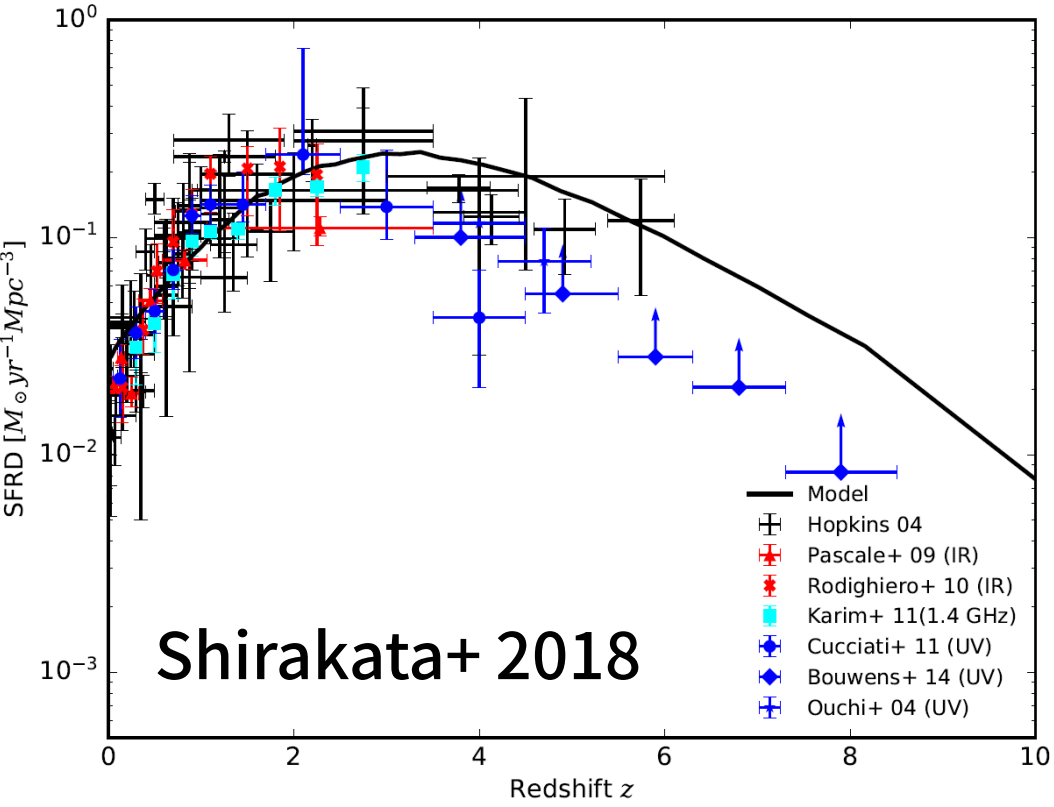
# High Performance Cosmological Simulations for Next Generation Wide and Deep Surveys

**Tomoaki Ishiyama**

Chiba University
(Institute of Management and Information Technologies)

Makiya+ 2016, PASJ, 68, 25, Shirakata+ arXiv:1802.02169

# v²GC: New Numerical Galaxy Catalog




- Successor of Numerical Galaxy Catalog (vGC: Nagashima+ 2005)
  - All basic physics are included
  - MCMC parameter fitting
- Luminosity functions of AGNs at z<6.0 are also reproduced
- Combining with ultralarge simulation
  - Ishiyama+ 2015

Collaboration with
M. Enoki (Tokyo Keizai)
M.A.R. Kobayashi (Kure) R. Makiya (IPMU)
M. Nagashima (Bunkyo)
T. Okamoto (Hokkaido) K. Okoshi (TUS)
T. Oogi (IPMU) H. Shirakata (Hokkaido)

Ishiyama+ 2015, PASJ, 67, 61

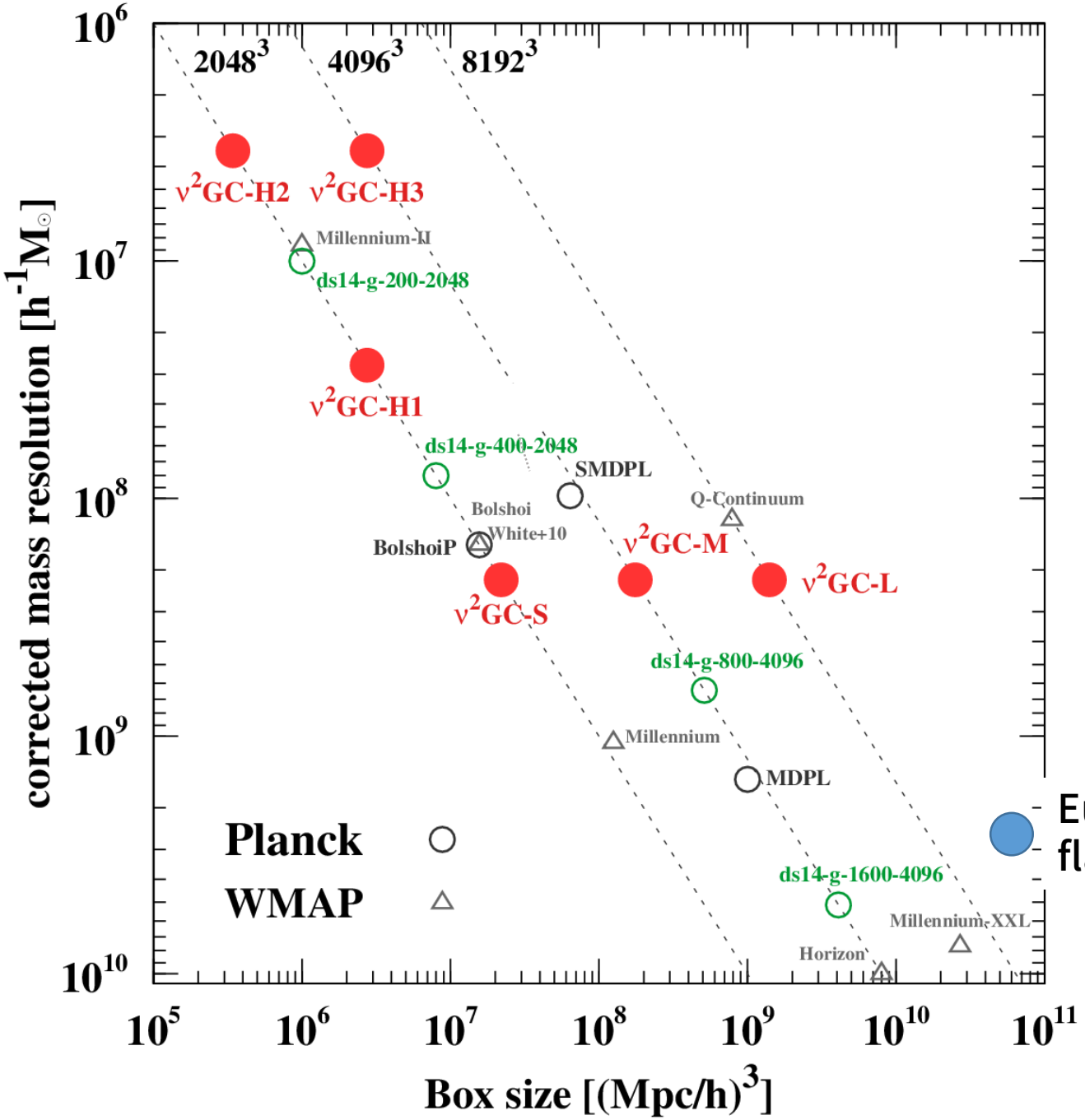
# ν²GC simulation suite

- Compared with Millennium simulation (Springel+05)
  - 11x larger volume, 4x better mass resolution
- Planck Cosmology
- Many runs → **Covering low- and high-z galaxies and AGNs**
- Compared to other large simulations, smaller boxes are used
  - Mass resolution is better

| Name | $N$ | $L(h^{-1}\mathrm{Mpc})$ | $m(h^{-1}M_\odot)$ | $\varepsilon(h^{-1}\mathrm{kpc})$ |
|---|---|---|---|---|
| $\nu^2$GC-L | $8192^3 = 549,755,813,888$ | 1120.0 | $2.20 \times 10^8$ | 4.27 |
| $\nu^2$GC-M | $4096^3 = 68,719,476,736$ | 560.0 | $2.20 \times 10^8$ | 4.27 |
| $\nu^2$GC-S | $2048^3 = 8,589,934,592$ | 280.0 | $2.20 \times 10^8$ | 4.27 |
| $\nu^2$GC-H1 | $2048^3 = 8,589,934,592$ | 140.0 | $2.75 \times 10^7$ | 2.14 |
| $\nu^2$GC-H2 | $2048^3 = 8,589,934,592$ | 70.0 | $3.44 \times 10^6$ | 1.07 |
| $\nu^2$GC-H3 | $4096^3 = 68,719,476,736$ | 140.0 | $3.44 \times 10^6$ | 1.07 |

# ν²GC

- Compare
  - 11x
- Planck C
- Many ru
- Compare
  - Mas

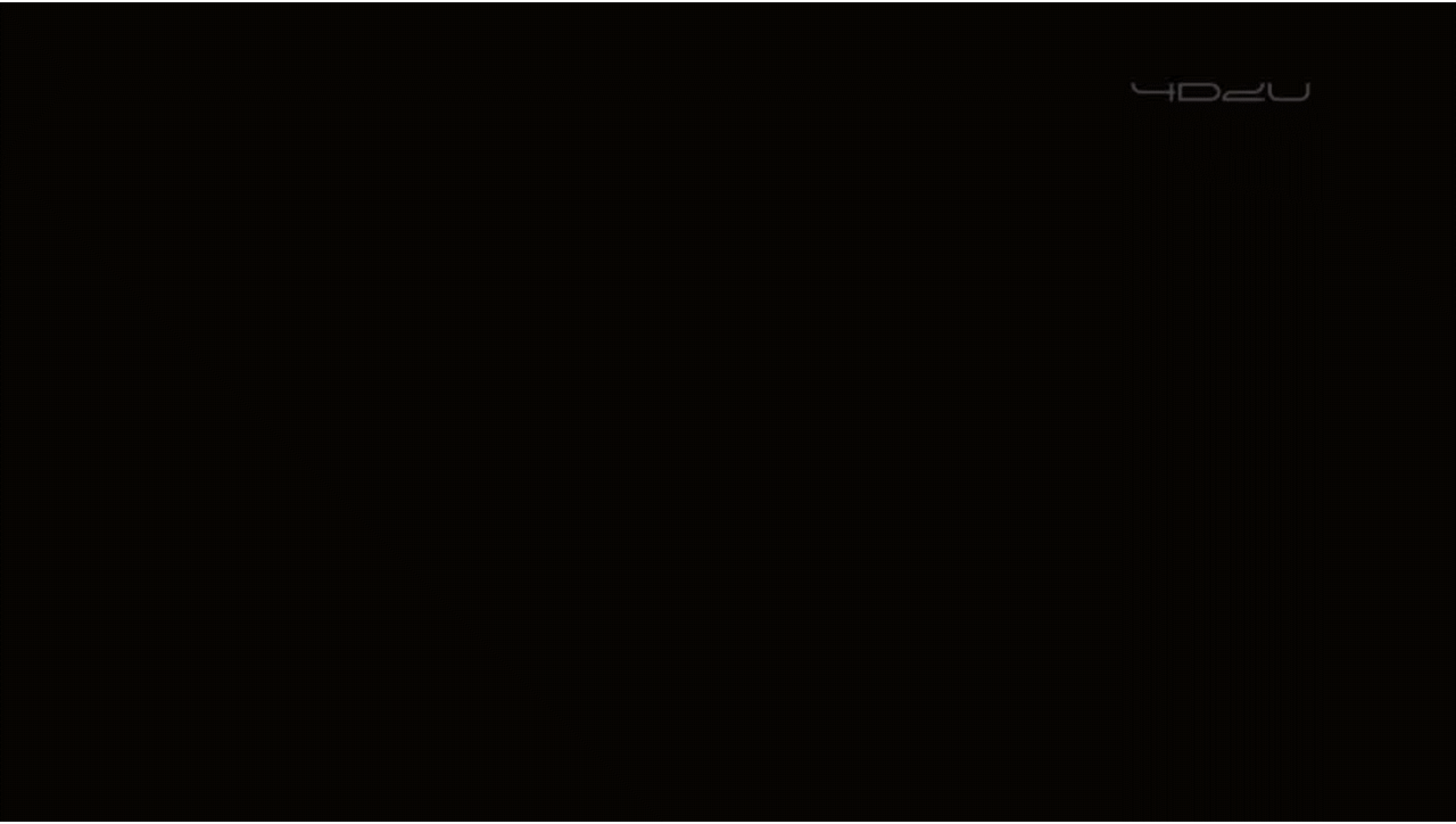



J, 67, 61

Euclid flagship

| Name | $(h^{-1}\mathrm{kpc})$ |
|---|---|
| $\nu^2$GC-L | 4.27 |
| $\nu^2$GC-M | |
| $\nu^2$GC-S | |
| $\nu^2$GC-H1 | 2.14 |
| $\nu^2$GC-H2 | 1.07 |
| $\nu^2$GC-H3 | 1.07 |

# Cosmological simulation ($v^2$GC –H1)



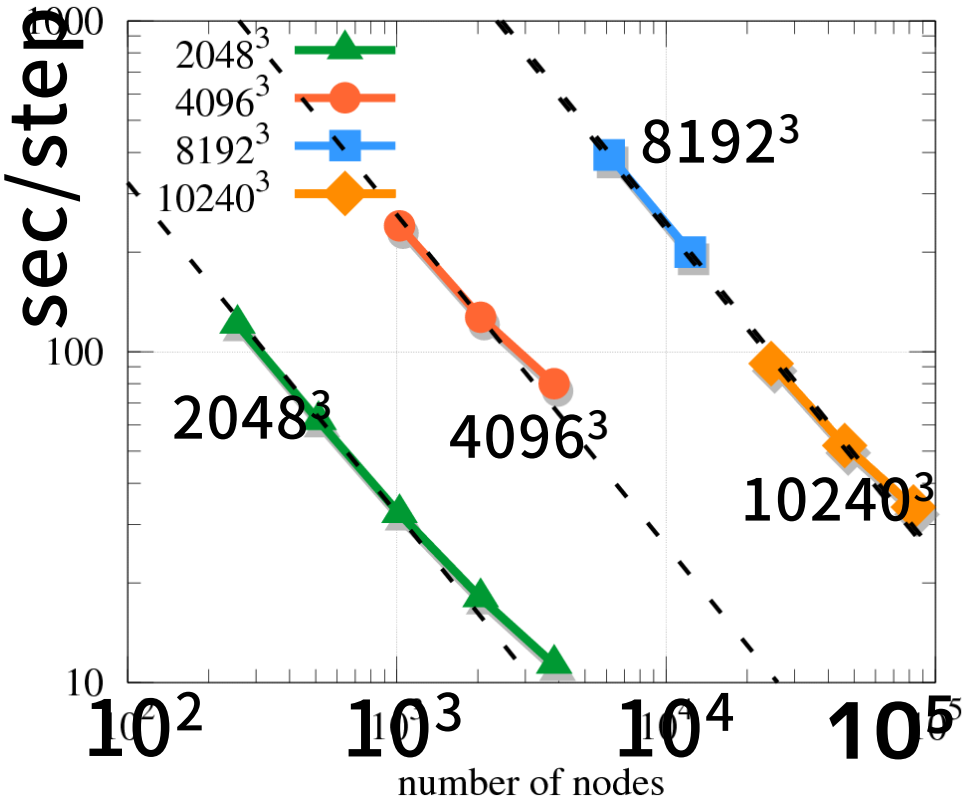
360 degree panoramic video for head mounted display
is available on http://4d2u.nao.ac.jp/English/

# Facilities


- Massively parallel TreePM poisson solver, **GreeM** (Ishiyama+ 2009, 2012)
  - High performance and scalability upto a million CPU cores at least
  - **SC12 Gordon Bell Prize Winner**
  - 2-10 times faster than "Gadget-2" (Springel 2005)
  - ~5 times faster than HACC (Habib+ 2012)

- K Computer at RIKEN, Japan
  - World's eighth fastest supercomputer (10.6 Pflops)
  - Total 0.66 million cores
- Aterui supercomputer at CfCA, NAOJ
  - ~ 1Pflops
  - Astro only

# Performance results on K computer



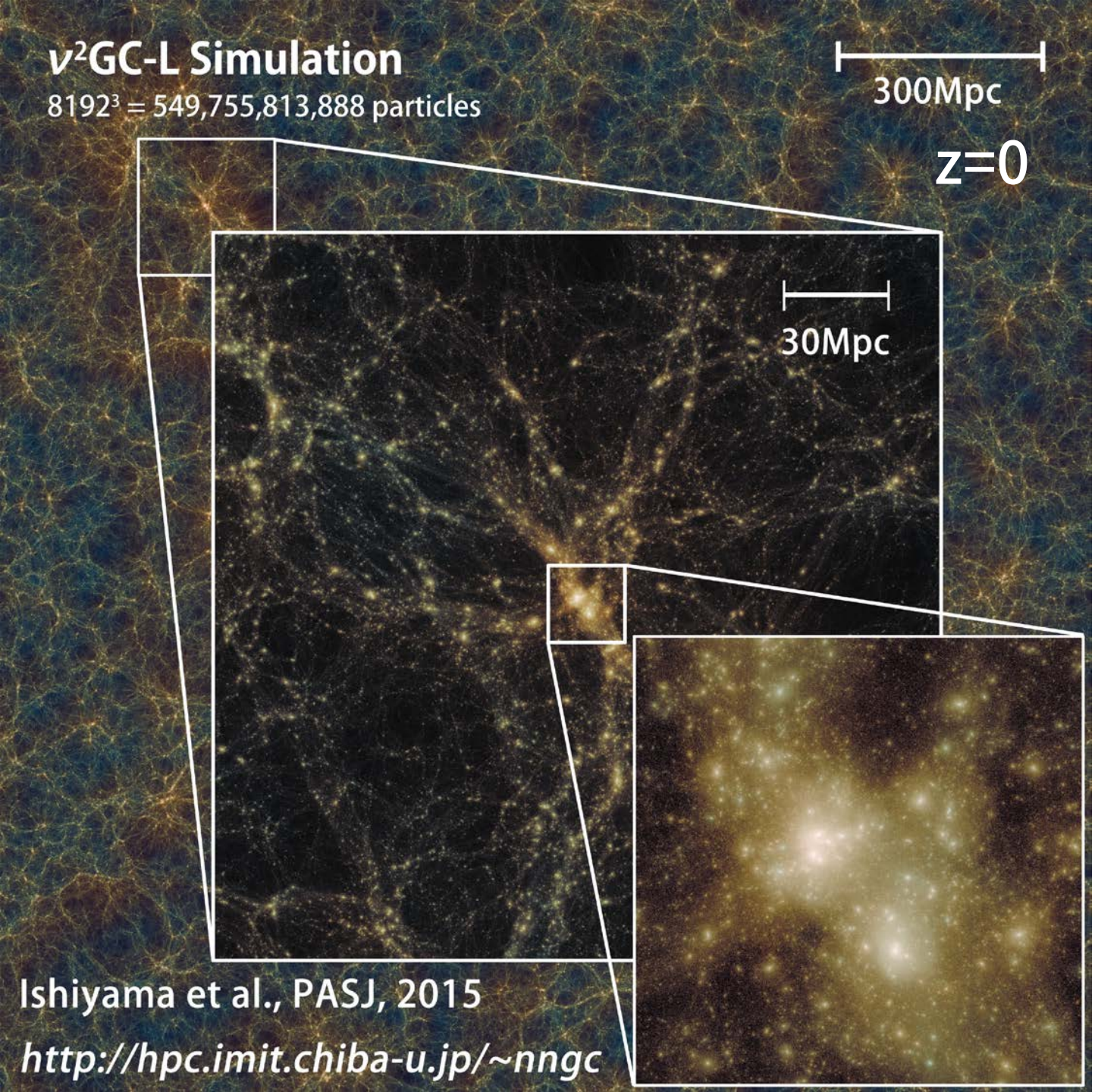

## Scalability ($2048^3$ - $10240^3$)

- Excellent strong scaling
- $10240^3$ simulation is well scaled from 24576 to 82944 (full) nodes of K computer

## Performance ($12600^3$)

- The average performance on
- full system is ~**5.8Pflops**,
  - ~**55**% of the peak speed

Ishiyama et al. 2012
SC12 Gordon Bell Prize Winner




N = $8192^3$ = 549,755,813,888

L = 1.12 Gpc/h
m = 2.2 x $10^8$ Msun/h

Planck Cosmology

11x larger volume,
4x better mass res,
compared to
Millennium Run
(Springel+ 2005)

- N = $2160^3$
- L = 0.5 Gpc/h
- m = 8.6 x $10^8$ Msun/h
- WMAP1 ($\sigma_8$=0.9)

~ 100 hours on
131,072 CPU cores
of K computer

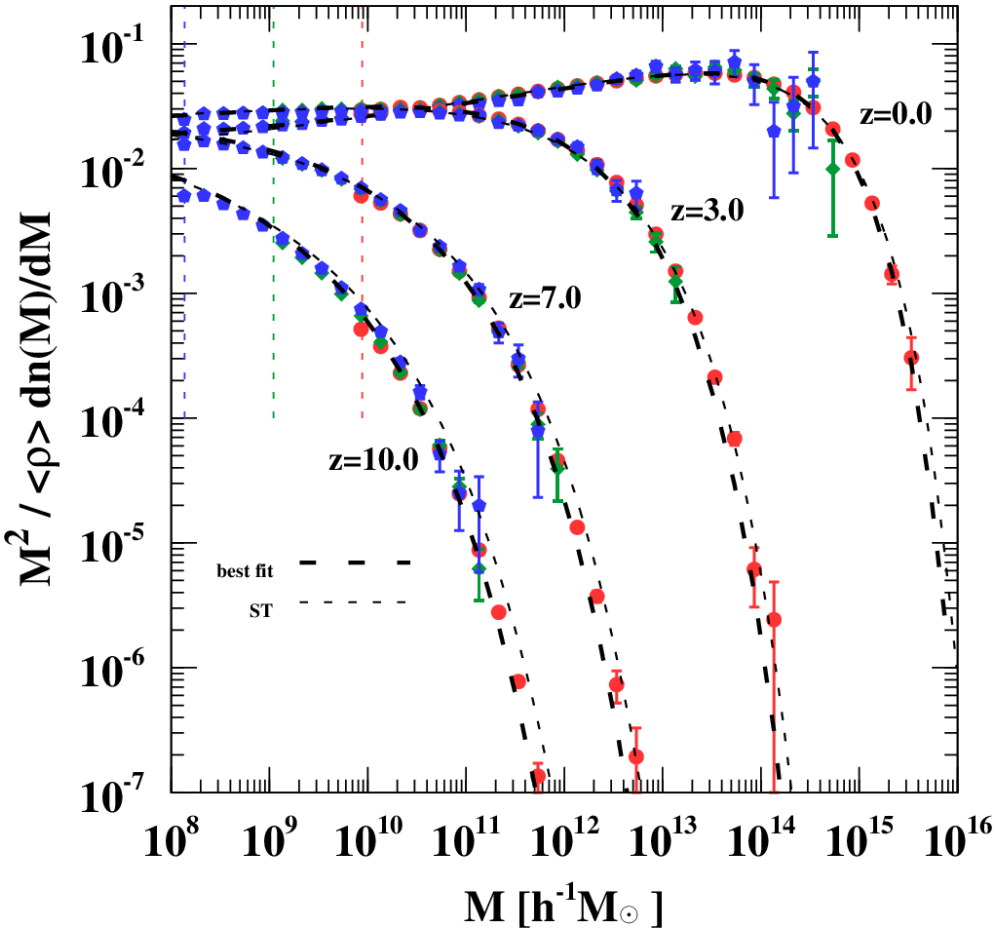
Data size : ~1PB

# Mass functions

$$\frac{dn}{dM} = \frac{\rho_0}{M}\frac{d\ln\sigma^{-1}}{dM} f(\sigma)$$

$$f(\sigma) = A\left[\left(\frac{B}{\sigma}\right)^{C} + 1\right]\exp\left(\frac{-D}{\sigma^2}\right)$$

$$A = 0.193, B = 2.184, C = 1.550, D = \quad 1.186$$




- All mass functions are well converged regardless of redshifts !!!
- Simple single fitting formula describes mass functions of various redshifts pretty much!

# Cosmological N-body simulations databases

Simulation Details  Mock  Publications

## Overview

This site provides halo/subhalo catalogs and merger trees obtained from large cosmological N-body simulations. Management with MySQL enables to access data easily and fast.

link to databases

Username and password are needed to access databases. Please contact to
ishiyama -at- chiba-u.jp
Some data can also be downloaded without databases here.

For the faster access to the databases, redshifts of halos/subhalos are labeled as "Snap_num" (inteager) in consistent tree data. To see look-up tables, please click the "redshifts" columns in the below table.

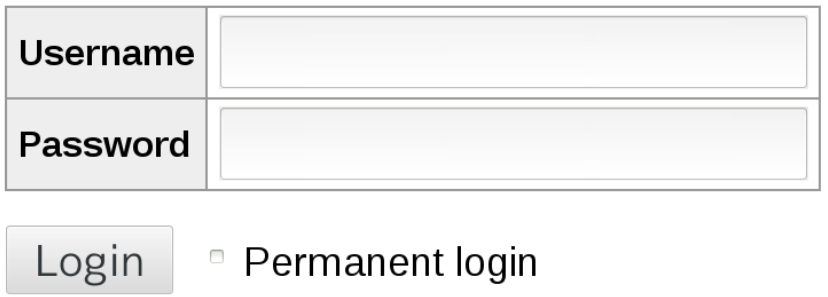
## Simulation Details

The adopted cosmological parameters are based on an observation of the cosmic microwave background obtained by the Planck satellite ( Planck Collaboration, 2014, A&A, 571, A16) , namely, $\Omega_0 = 0.31, \Omega_b = 0.048, \lambda_0 = 0.69, h = 0.68, n_s = 0.96$ , and $\sigma_8 = 0.83$.

Halo/subhalos are identified by Rockstar (Behroozi et al. 2013). Consistent tree (Behroozi et al. 2013) is used for merger tree construction.

**http://hpc.imit.chiba-u.jp/~ishiymtm/db.html**

Cosmological N-body Databases 4.3.1




- Basic authentication + login form
  - Account is anonymous only

  -> unnecessary to make individual user accounts
- Username, password (same)
  - Basic authentication: guest
  - Login form: nbody

**http://hpc.imit.chiba-u.jp/~ishiymtm/db.html**

Login » Server

http://hpc.imit.chiba-u.jp/~ishiymtm/db.html

# Server

Search data in tables: Search

| | Table | Rows |
|---|---|---|
| ☐ | n2gc-h1_lite | 723,237,108 |
| ☐ | n2gc-h2_lite | 700,624,551 |
| ☐ | n2gc-l_z0 | 771,601,092 |
| ☐ | n2gc-l_z1 | 894,523,267 |
| ☐ | n2gc-l_z2 | 867,250,966 |
| ☐ | n2gc-l_z3 | 731,734,992 |
| ☐ | n2gc-l_z4 | 526,296,311 |
| ☐ | n2gc-l_z4p57 | 426,299,082 |
| ☐ | n2gc-l_z6 | 208,425,299 |
| ☐ | n2gc-l_z7 | 108,196,937 |
| ☐ | n2gc-s_lite | 732,136,063 |
| ☐ | n2gc-ss_lite | 11,508,110 |
| ☐ | phi-1_lite | 864,150,468 |

- Rockstar merger trees of all $2048^3$ simulations
- That of a $4096^3$ simulation (560Mpc/h) will be available soon
- Rockstar catalogs of a $8192^3$ simulation
  - z=0, 1, 2, 3, 4, 4.57, 6, 7
  - Other redshifts will be added after file system is upgraded
- FoF merger trees of all simulations will be added

Select: n2gc-s_lite

Select | Search (anywhere) | Limit 50 | Action Select

| Modify | Snap_num | id | desc_id | num_prog | pid | upid | Mvir(Msun/h) | Rvir(kpc/h) | rs(kpc/h) | vmax(km/s) | x(Mpc/h) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| edit | 0 | 43104 | 443013 | 0 | -1 | -1 | 439700000 | 19.007 | 3.377 | 44.77 | 19.8116 |
| edit | 0 | 59834 | 448408 | 0 | -1 | -1 | 439700000 | 19.007 | 3.657 | 44.24 | 14.3188 |
| edit | 0 | 26107 | 452738 | 0 | -1 | -1 | 439700000 | 19.007 | 1.456 | 53.16 | 32.2515 |
| edit | 0 | 67783 | 457769 | 0 | -1 | -1 | 439700000 | 19.007 | 0.593 | 68.6 | 28.5192 |
| edit | 0 | 144574 | 488496 | 0 | -1 | -1 | 439700000 | 19.007 | 2.223 | 48.28 | 40.3644 |
| edit | 0 | 85491 | 500515 | 0 | -1 | -1 | 439700000 | 19.007 | 1.857 | 50.19 | 15.5044 |
| edit | 0 | 89503 | 502348 | 0 | -1 | -1 | 439700000 | 19.007 | 2.726 | 46.41 | 44.3127 |
| edit | 0 | 46443 | 536677 | 0 | -1 | -1 | 439700000 | 19.007 | 3.694 | 44.18 | 44.4611 |
| edit | 0 | 139525 | 469772 | 0 | -1 | -1 | 439700000 | 19.007 | 3.212 | 45.12 | 48.7636 |
| edit | 0 | 84571 | 564281 | 0 | -1 | -1 | 439700000 | 19.007 | 4.093 | 43.57 | 50.9771 |
| edit | 0 | 32631 | 534289 | 0 | -1 | -1 | 439700000 | 19.007 | 3.191 | 45.17 | 76.6841 |
| | | | | 0 | -1 | -1 | 439700000 | 19.007 | 3.006 | 45.62 | 92.599 |

Page: 1 2 3 4 5 ... 14642722 Load more data

# You do not need to know about SQL

**http://hpc.imit.chiba-u.jp/~ishiymtm/db.html**

Select: n2gc-s_lite

Select

Mvir(Msun/h)
x(Mpc/h)
y(Mpc/h)
z(Mpc/h)

Search

Snap_num = 49
Mvir(Msun/h) > 1e13
(anywhere)

| Modify | Snap_num | id | desc_id | num_prog | pid | upid | Mvir(Msun/h) | Rvir(kpc/h) | rs(kpc/h) | vmax(km/ |
|---|---|---|---|---|---|---|---|---|---|---|
| edit | 0 | 43104 | 443013 | 0 | -1 | -1 | 439700000 | 19.007 | 3.377 | 44. |
| edit | 0 | 59834 | 448408 | 0 | -1 | -1 | 439700000 | 19.007 | 3.657 | 44. |
| edit | 0 | 26107 | 452738 | 0 | -1 | -1 | 439700000 | 19.007 | 1.456 | 53. |
| edit | 0 | 67783 | 457769 | 0 | -1 | -1 | 439700000 | 19.007 | 0.593 | 68 |
| edit | 0 | 144574 | 488496 | 0 | -1 | -1 | 439700000 | 19.007 | 2.223 | 48. |
| edit | 0 | 85491 | 500515 | 0 | -1 | -1 | 439700000 | 19.007 | 1.857 | 50. |
| edit | 0 | 89503 | 502348 | 0 | -1 | -1 | 439700000 | 19.007 | 2.726 | 46. |

# You do not need to know about SQL

**http://hpc.imit.chiba-u.jp/~ishiymtm/db.html**

# If you want to download everything anyway

- Most data can be also download from here (bz2 archive)
  - **http://hpc.imit.chiba-u.jp/~nngc/**
  - Some files exceed 100GB
    - Rockstar at one time stamp for the $8192^3$ simulation
  - Rockstar catalogs of $8192^3$ at 40 redshifts (z=0 ~ 7)
- Partially mirrored in “Skies & Universes”
  - **http://skiesanduniverses.org**
- Mock galaxy catalogs (Makiya+ 2016) are available on
  - **http://cdsarc.u-strasbg.fr/cgi-bin/VizieR?-source=J/PASJ/68/2**

# New simulations for next generation wide and deep surveys (2018)

- May 2018, the supercomputer at NAOJ will be upgraded
  - 1PFlops → 3PFlops (40,200 CPU cores,  386 TB memory)
- My proposal for an intensive use has been accepted
  - Access to the full system and use of 1 PB storage
- $8192^3$-$16384^3$,  ~2-10 Gpc/h simulation is possible
  ( ~$10^9$ Msun/h mass resolution)
  - Connection with Euclid and Subaru PFS !!!

- Exascale supercomputer in Japan may start to run in 2020-21
  - ~30 trillion particles simulation will be possible
  - The detail is still unknown, but CPU architecture is announced to be based on ARM ……

# Challenging

- Storage
  - Full particle data for one time stamp: 10-16TB ($8192^3$)
    - With data compression, 100 snapshots can be stored (<1PB)

- Merger tree

  Rockstar runs on distributed memory supercomputers
  - Consistent tree code does not
    - Generating trees for $4096^3$ simulation required **~12 days and maximum 350GB memory**
    - > $8192^3$ ???

  - FoF merger trees are OK
    - Most bounded particle of subhalos are tracked after accretion

# Summary

- Some halo/subhalo catalogs and merger trees are available on
  - **http://hpc.imit.chiba-u.jp/~ishiymtm/db.html**
  - http://hpc.imit.chiba-u.jp/~nngc/
  - **http://skiesanduniverses.org/**

- Mock galaxy/AGN catalogs are available on
  - http://cdsarc.u-strasbg.fr/cgi-bin/VizieR?-source=J/PASJ/68/25

- 360 degree panoramic video for head mounted displays is available on http://4d2u.nao.ac.jp/english/