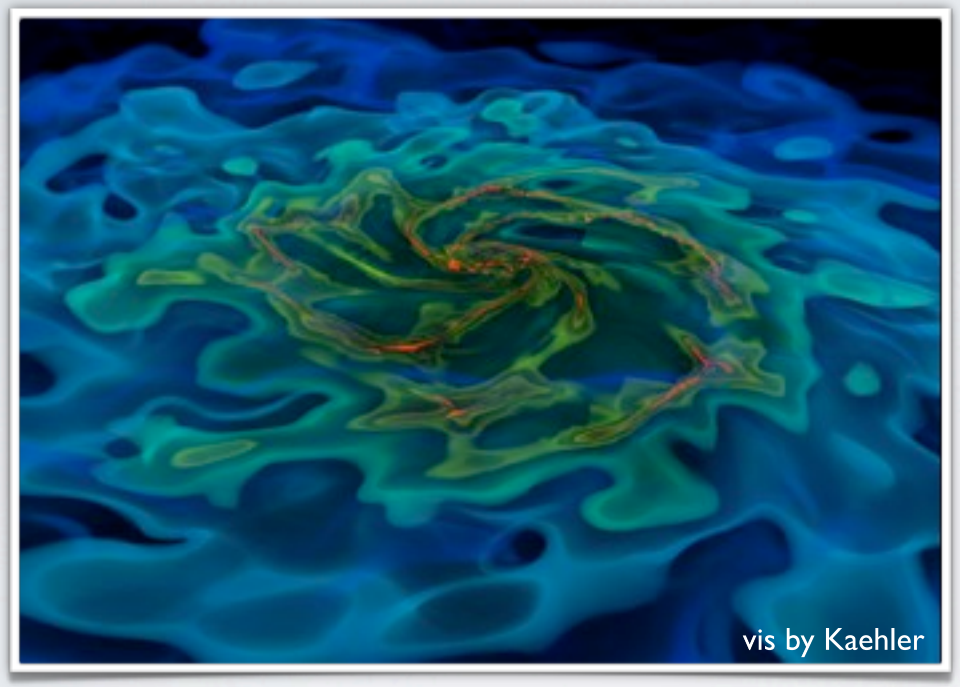
The AGORA Project:
Initial Conditions & Proof-of-Concept Test



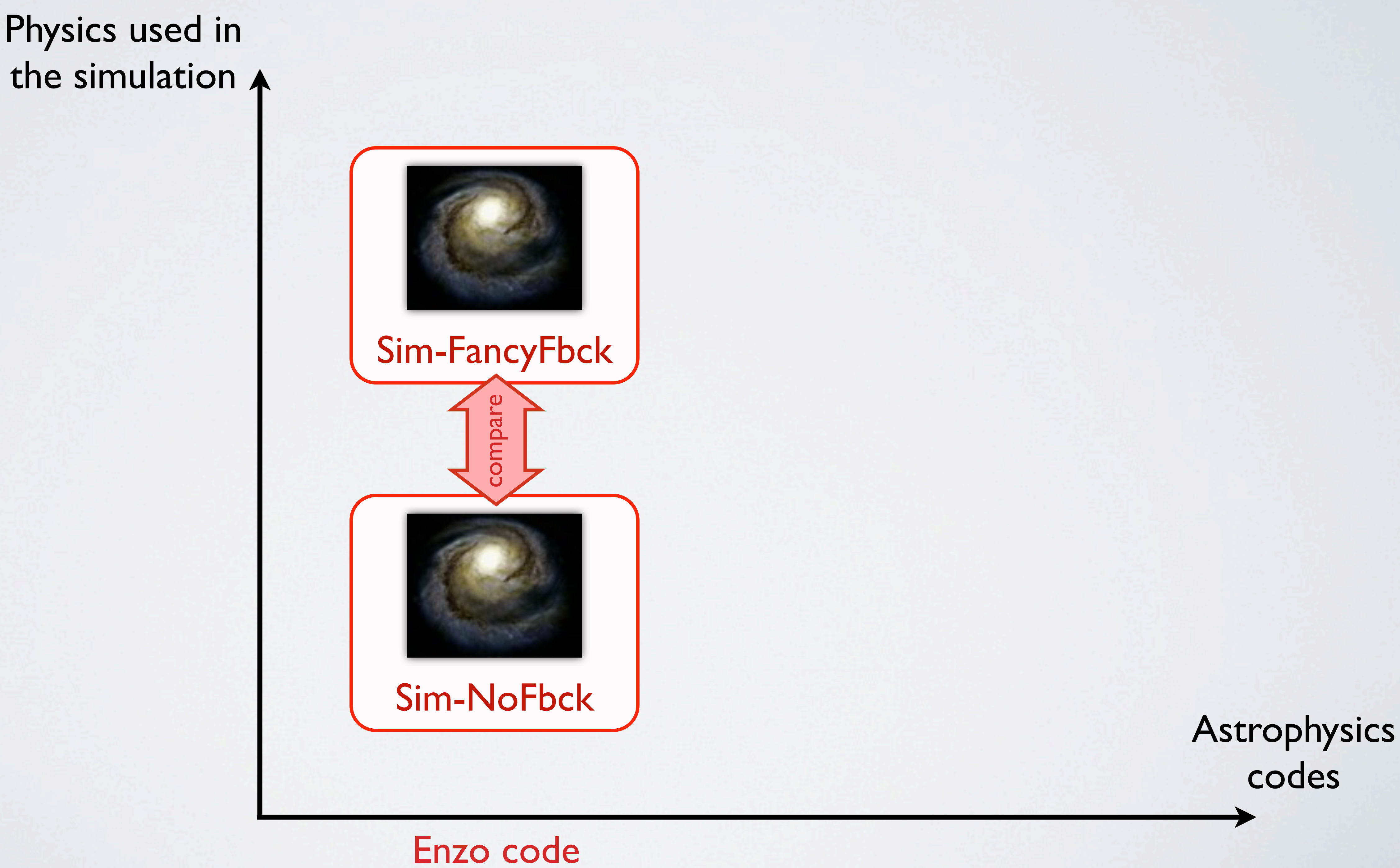
Ji-hoon Kim (UC Santa Cruz)

On behalf of the AGORA Collaboration
Mentors: Mark Krumholz (UCSC), Tom Abel (Stanford)

Speical thanks to: O. Hahn (ETH), M. Turk (Columbia), J. Onorbe (UCIrvine), A. Hobbs (ETH), M. Kuhlen (Berkeley), S. Leitner (Maryland), S. Shen (UCSC), R. Teyssier (Zurich), K. Todoroki (UNLV), members of the AGORA Steering Committee, & many others

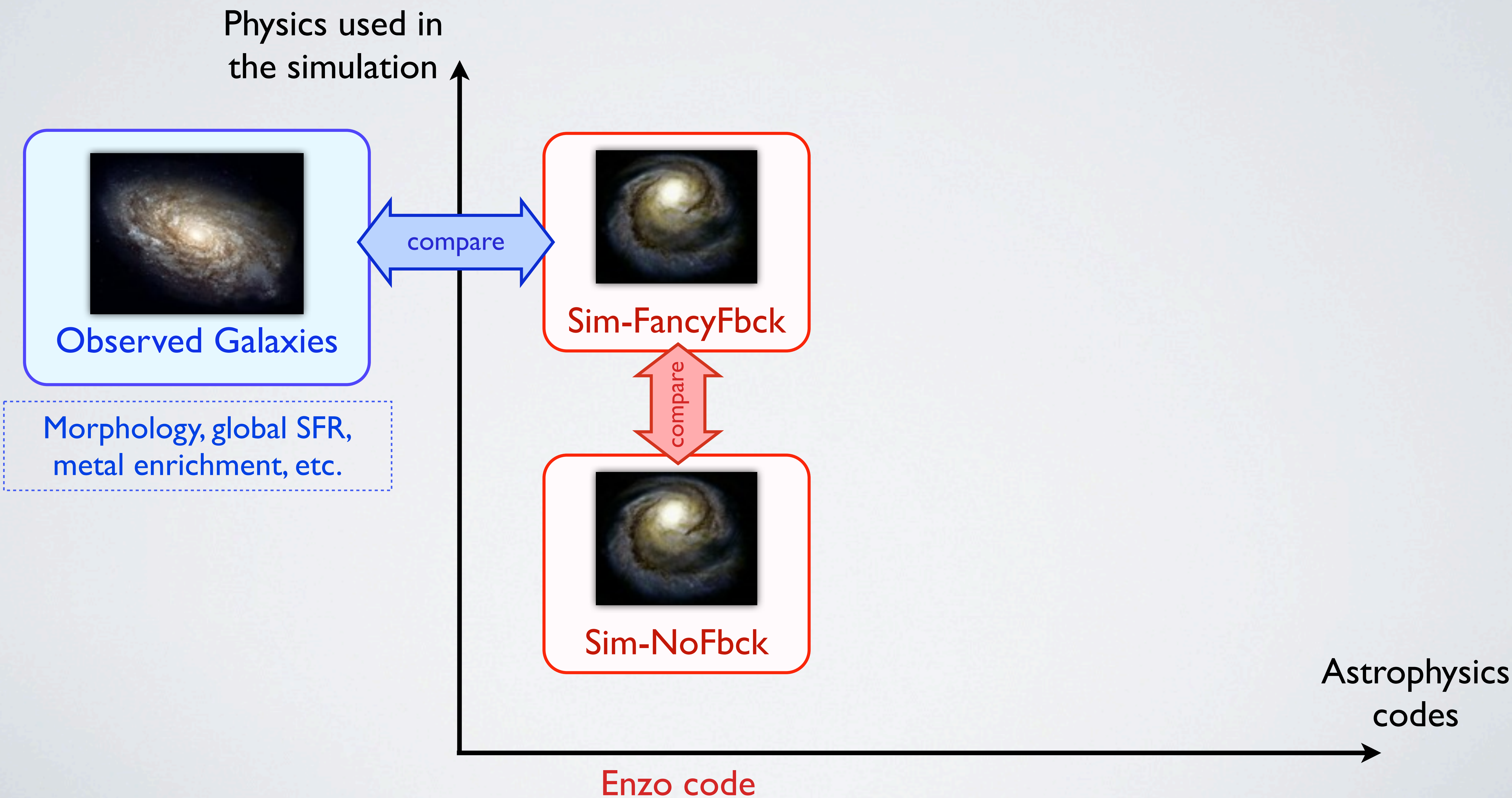
What Galaxy Simulators Do

- Set up a suite with varying physics and compare **within** the suite



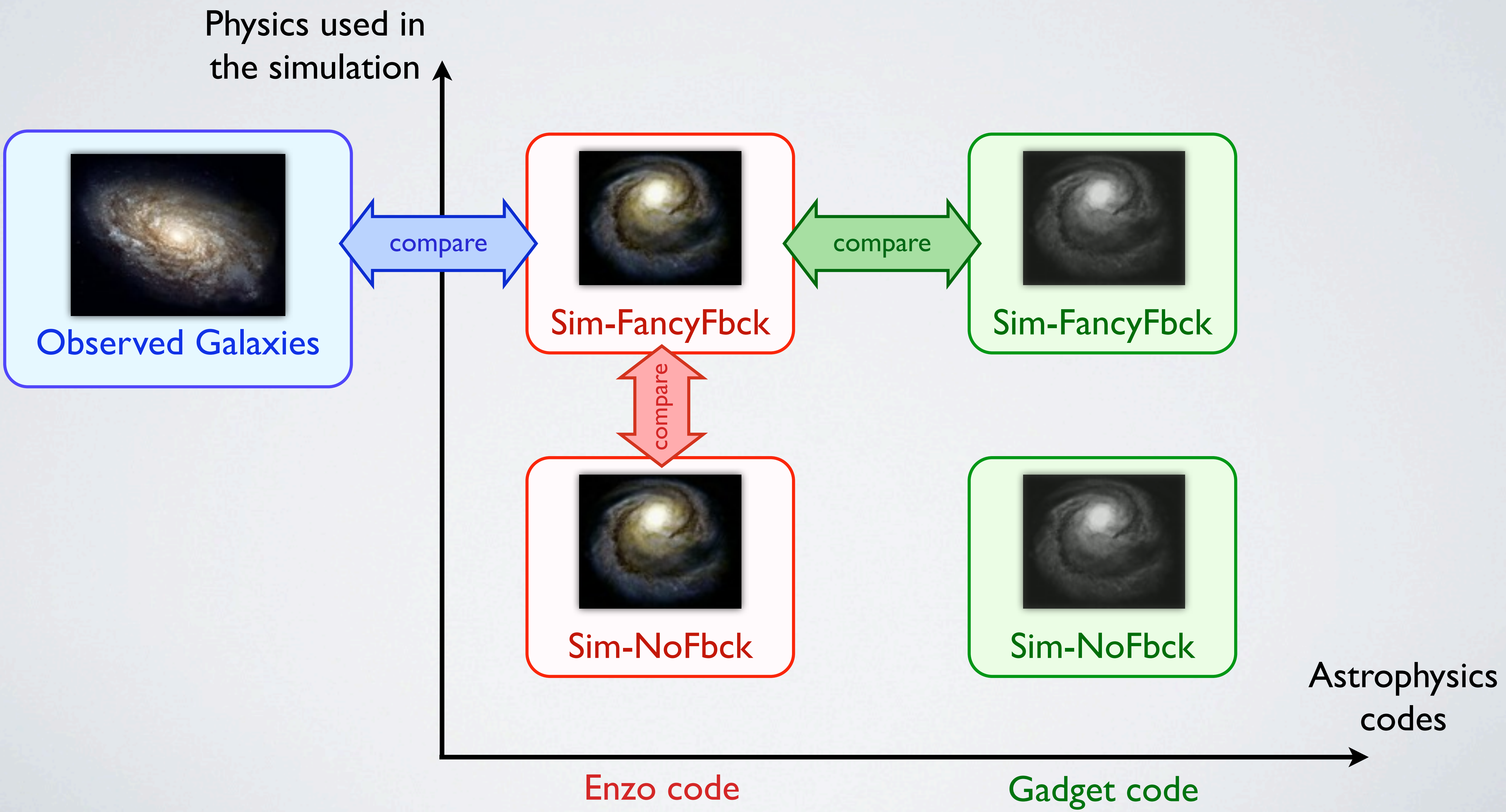
What Galaxy Simulators Do

- To make sure your galaxy is realistic, compare with observations



What Galaxy Simulators Must Do

- To verify that your success is physical, compare across platforms



AGORA Initiative: Multi-platform Approach

- 93 participants from 46 institutions worldwide as of today

[AGORA Flagship paper astro-ph:1308.2269]

- Common ICs for all codes (isolated and cosmological galaxies)

- Cosmological ICs constructed by *MUSIC* (Hahn & Abel 2011)

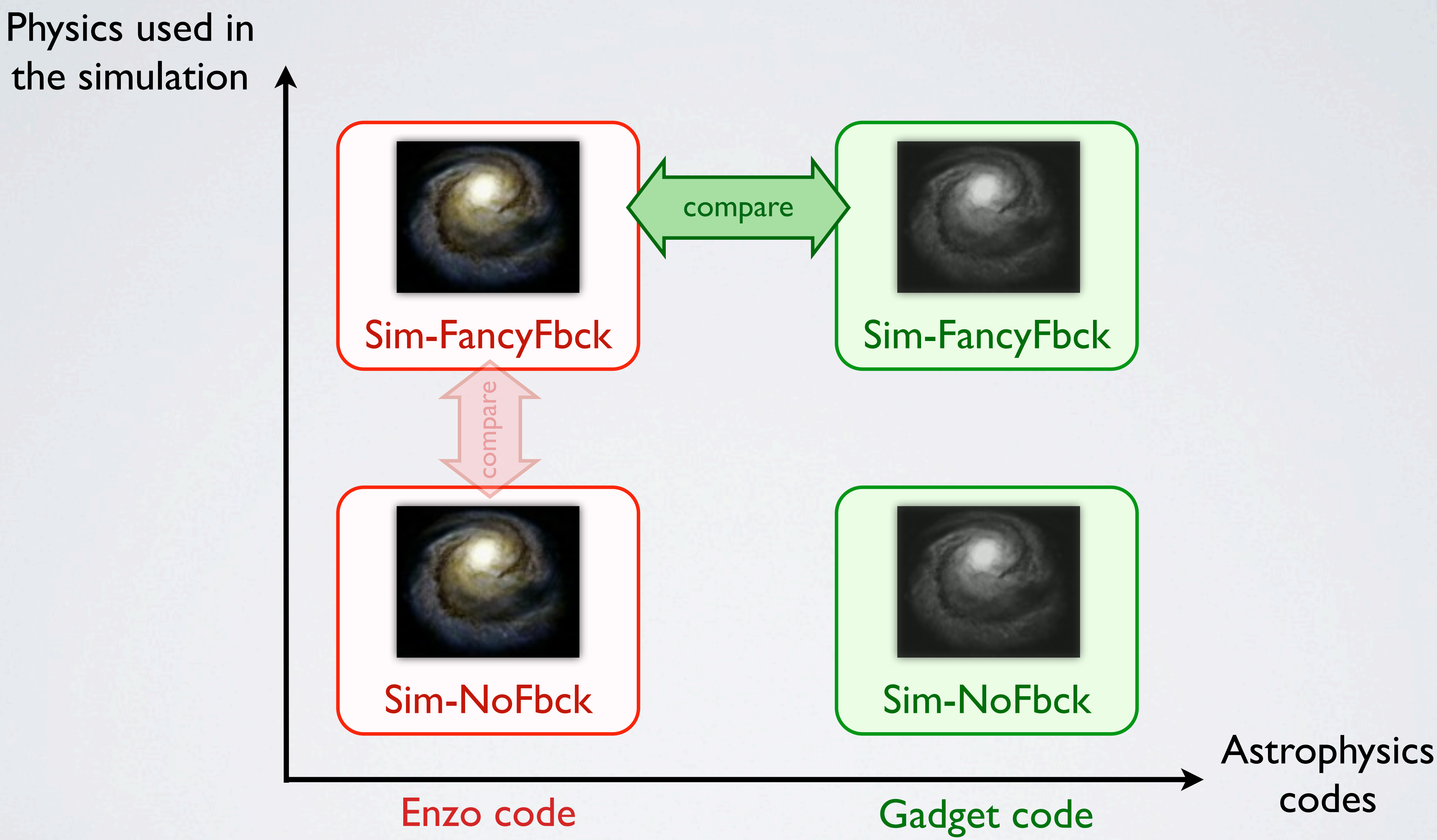
- Common astrophysics all codes will include in high-resolution runs

- Metal-dependent gas cooling, UV background, metal and energy yields and event rates for SNe, etc are defined based on the consensus among the participating code groups

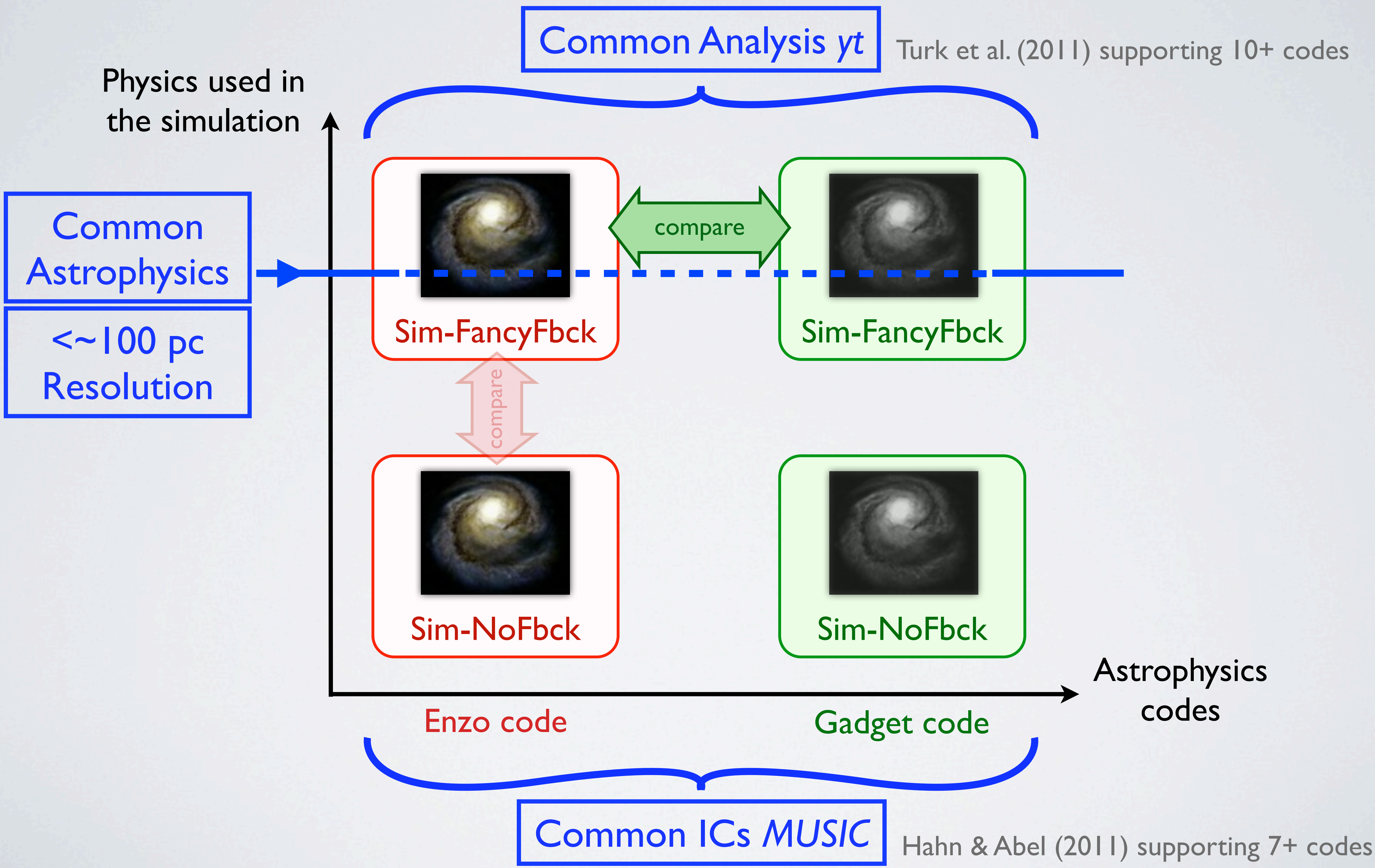
- Common analysis platform for all codes

- Common analysis now possible on the *yt* platform (Turk et al. 2011, Turk 2013)

AGORA Initiative: Multi-platform Approach



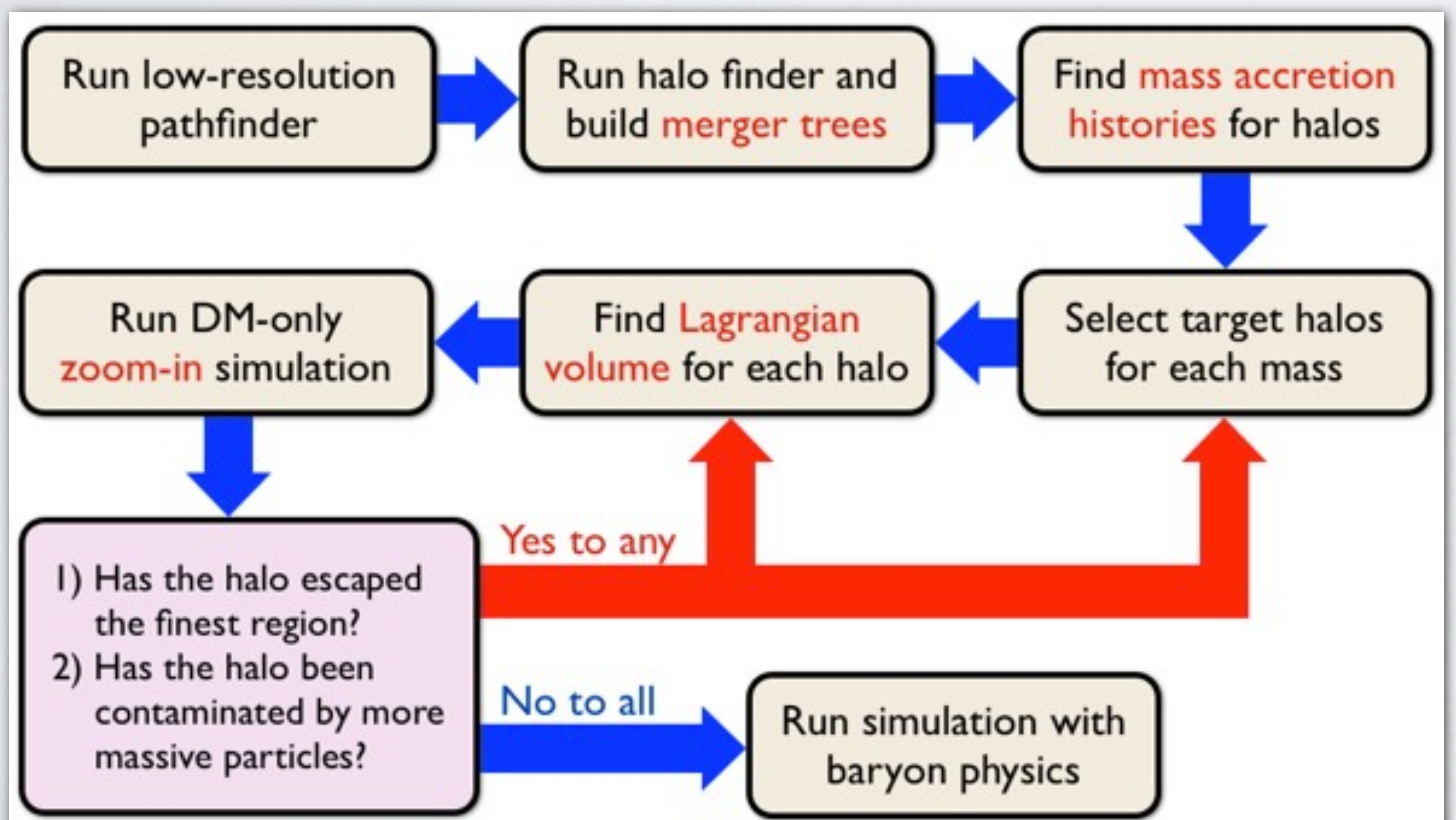
AGORA Initiative: Multi-platform Approach



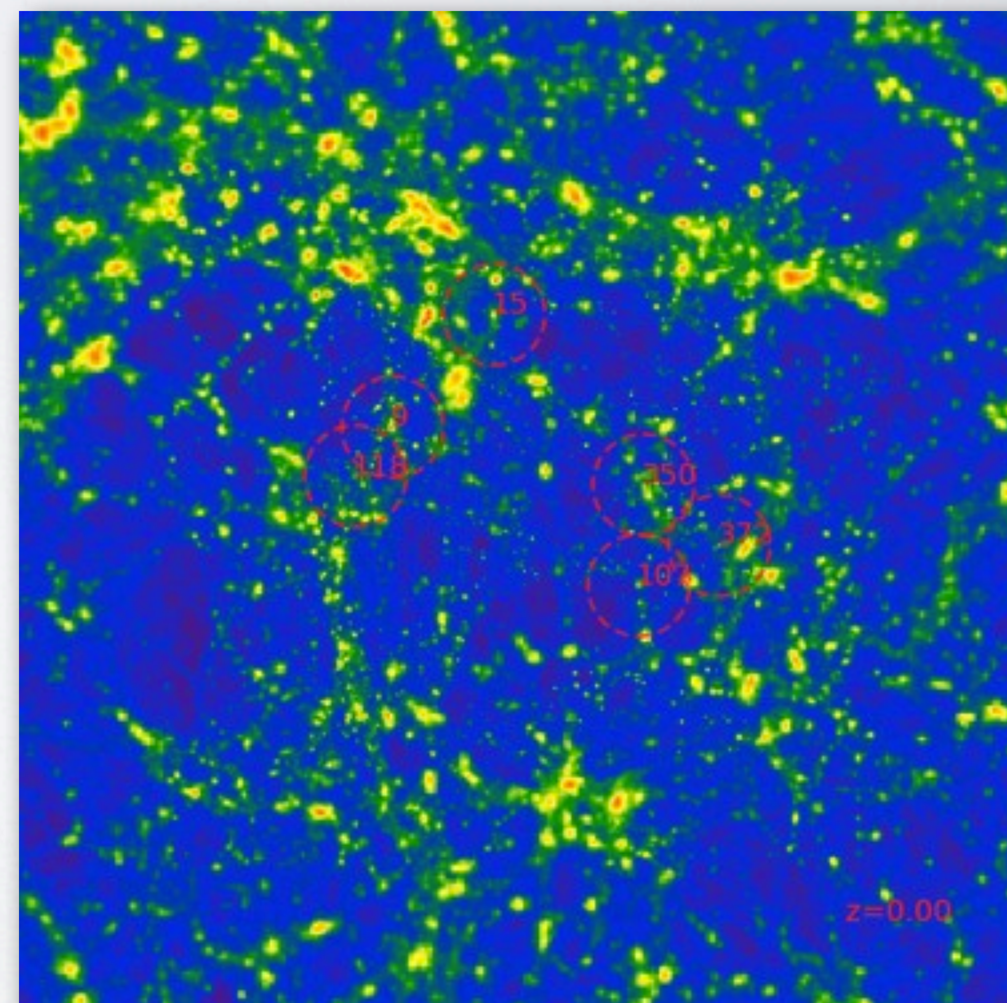
Common ICs for Zoom-in Halos

- Expedited IC generation in *MUSIC* (thanks in great part to O. Hahn and J. Onorbe)
- First run low-resolution pathfinder to identify candidate halos
  - (60 Mpc/h)^3 top box, 512^3 effective resolution in the central (42 Mpc/h)^3 box

Pipeline to generate cosmological zoom-in ICs

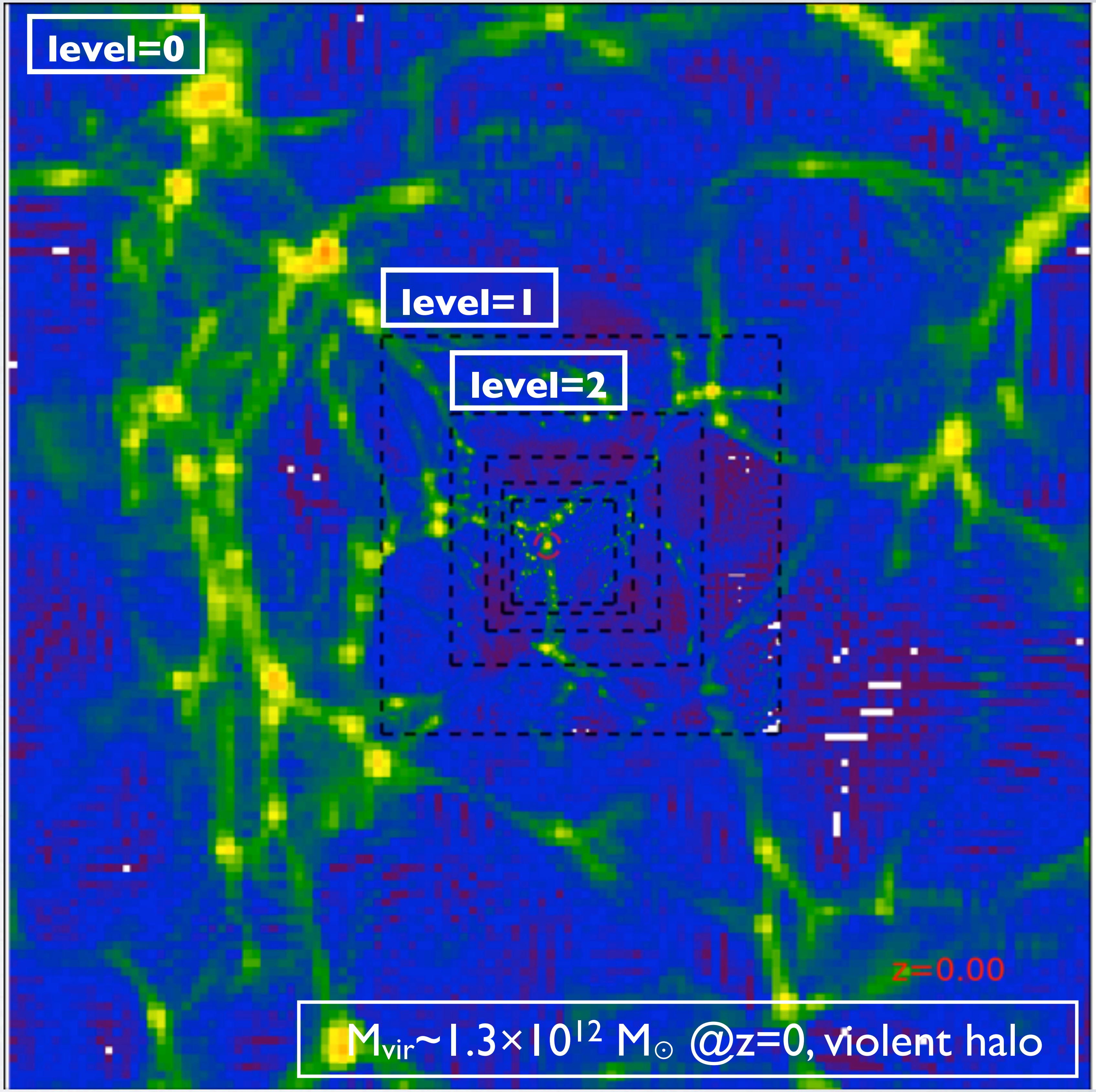


Chosen halos in a pathfinder run



High-resolution Zoom-in ICs

- A nested IC for each of the target halos
  - 128^3 in $(60\ \mathrm{Mpc}/h)^3$ box recentered on target halo
  - For proof-of-concept test: 4096^3 effective resolution in the central $(\sim 2\ \mathrm{Mpc}/h)^3$ box with $2.37\times10^5\ M_\odot/h$ particle resolution
  - 4 types of halo masses: $\sim10^{10,\,11,\,12,\,13}\ M_\odot$ @ z=0
  - 2 types of merger histories: violent vs. quiescent

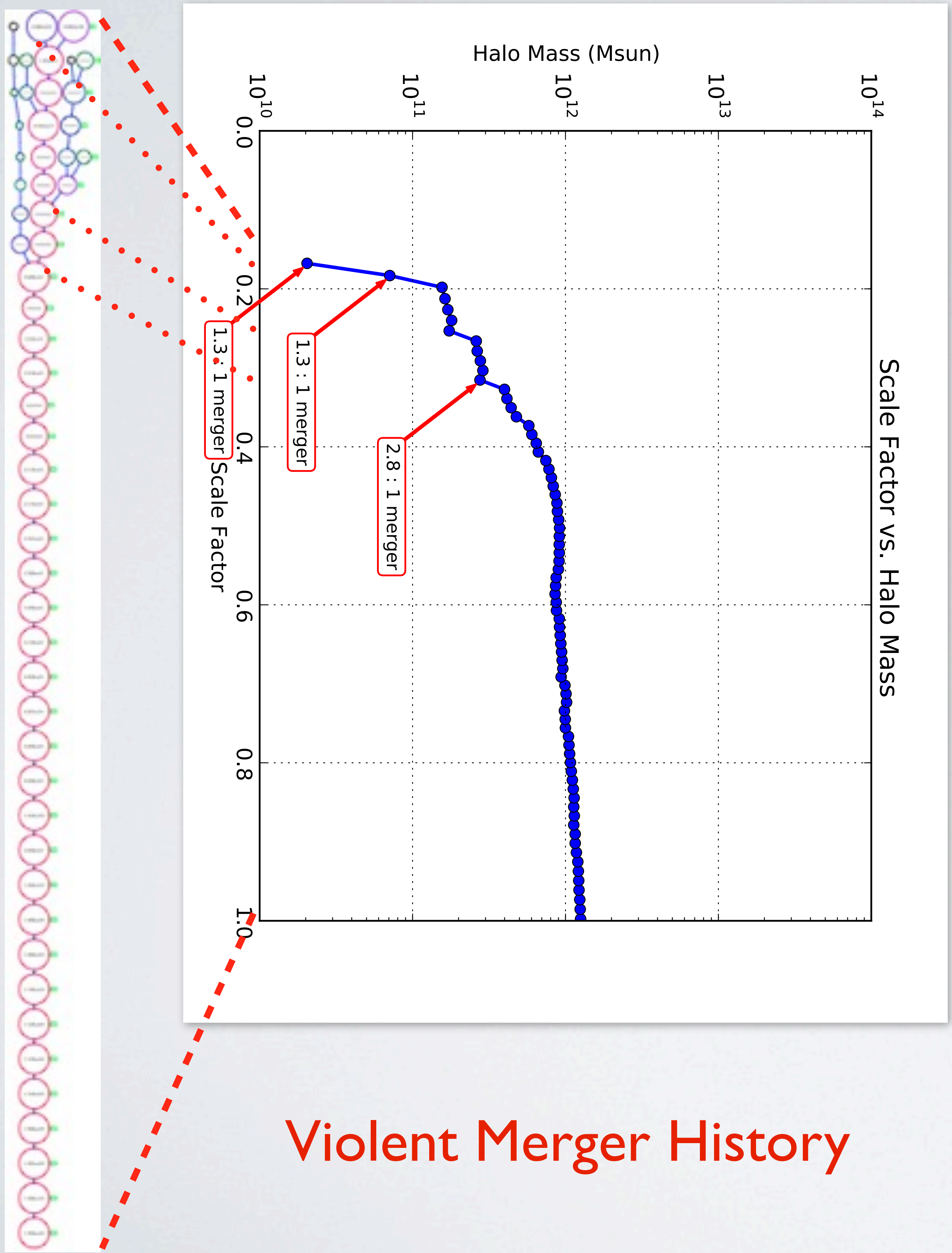


$10^{12} M_\odot$ Halos: Accretion Histories

Merger Tree

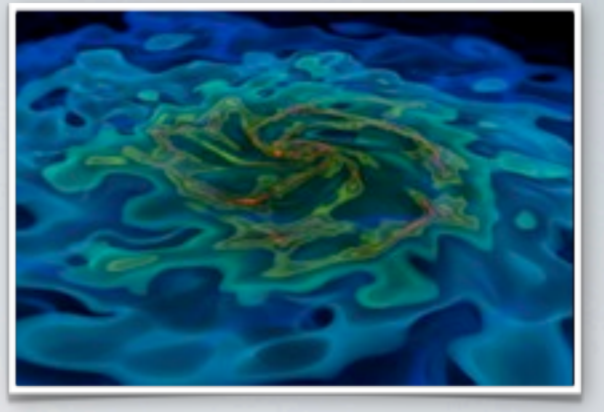
Halo Mass →

Scale Factor ↓



Violent Merger History

Quiescent Merger History



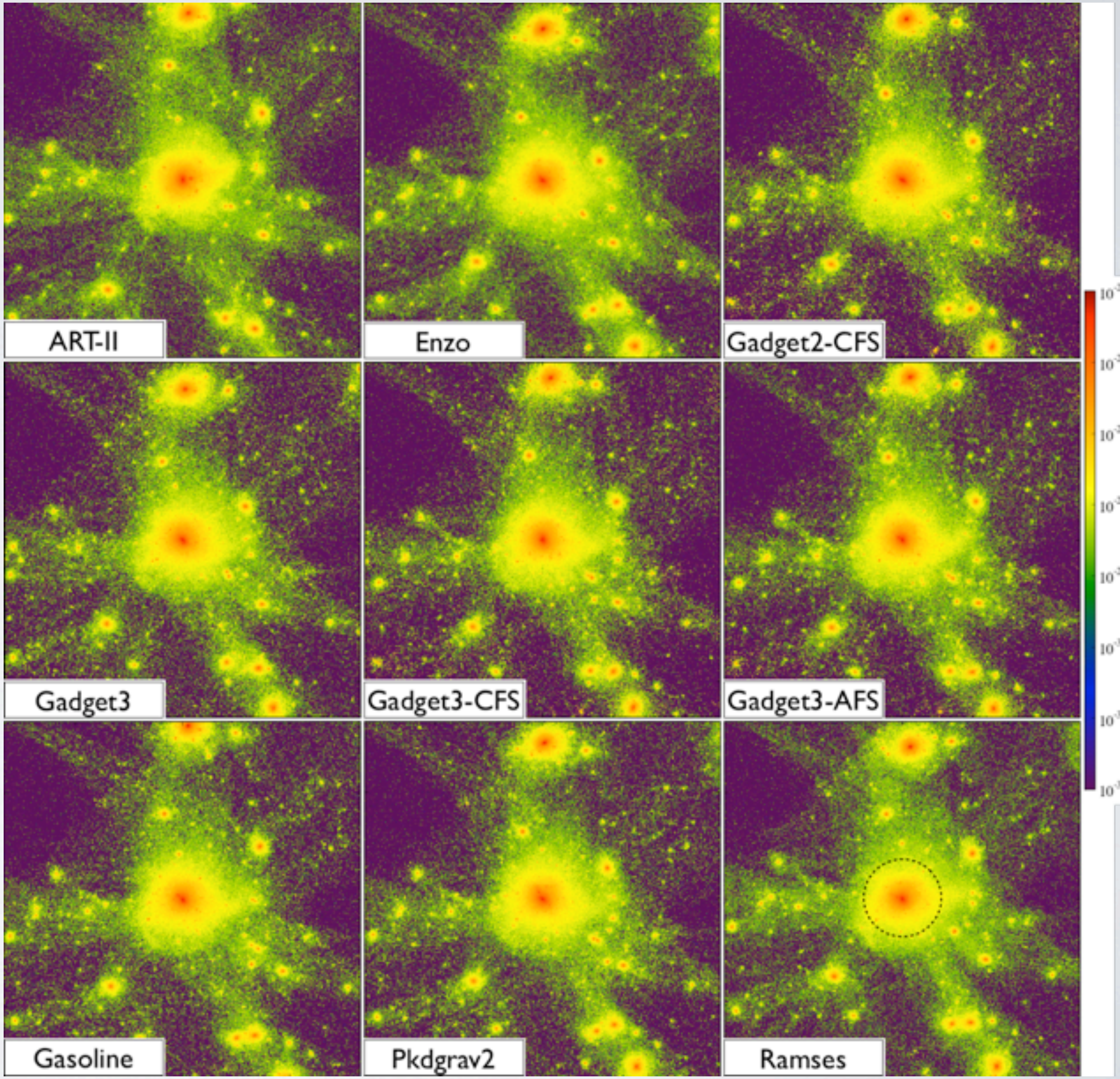
Proof-of-Concept

Dark Matter-Only Test of A Cosmological halo

AGORA Proof-of-Concept Test

- DM-only test run

  - ~300 pc resolution runs by 9 different variations of 6 participating codes on a halo of ~1.7×10^{11} M$_\odot$@z=0



Projected DM density (1 Mpc/h)

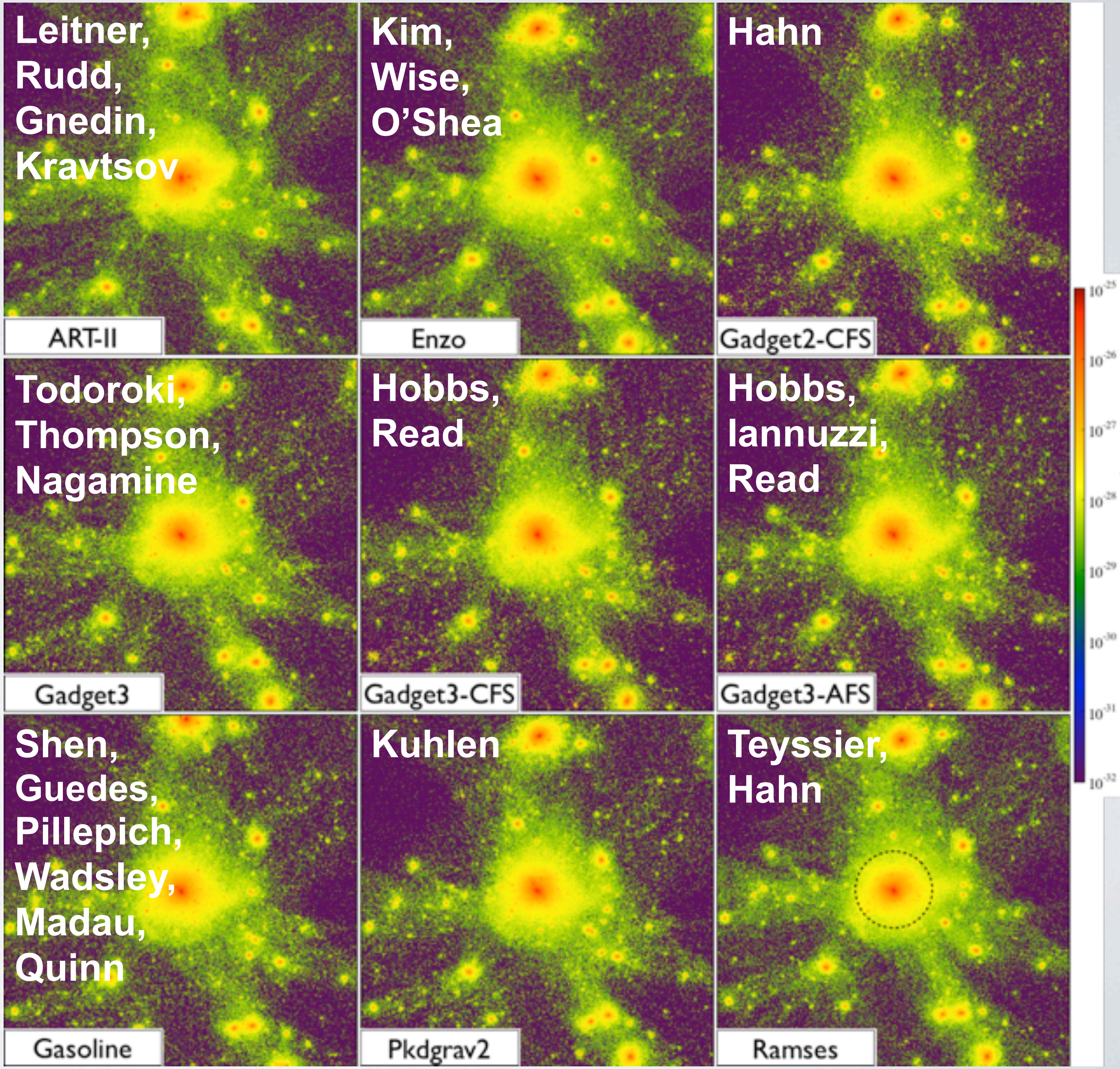
AGORA Proof-of-Concept Test

- DM-only test run

  - ~300 pc resolution runs by 9 different variations of 6 participating codes on a halo of ~1.7×10^{11} $M_{\odot}$@z=0

  - Runtime parameters found which make the code compatible with others

  - Overall structural consistency across codes; mass difference within ~2%

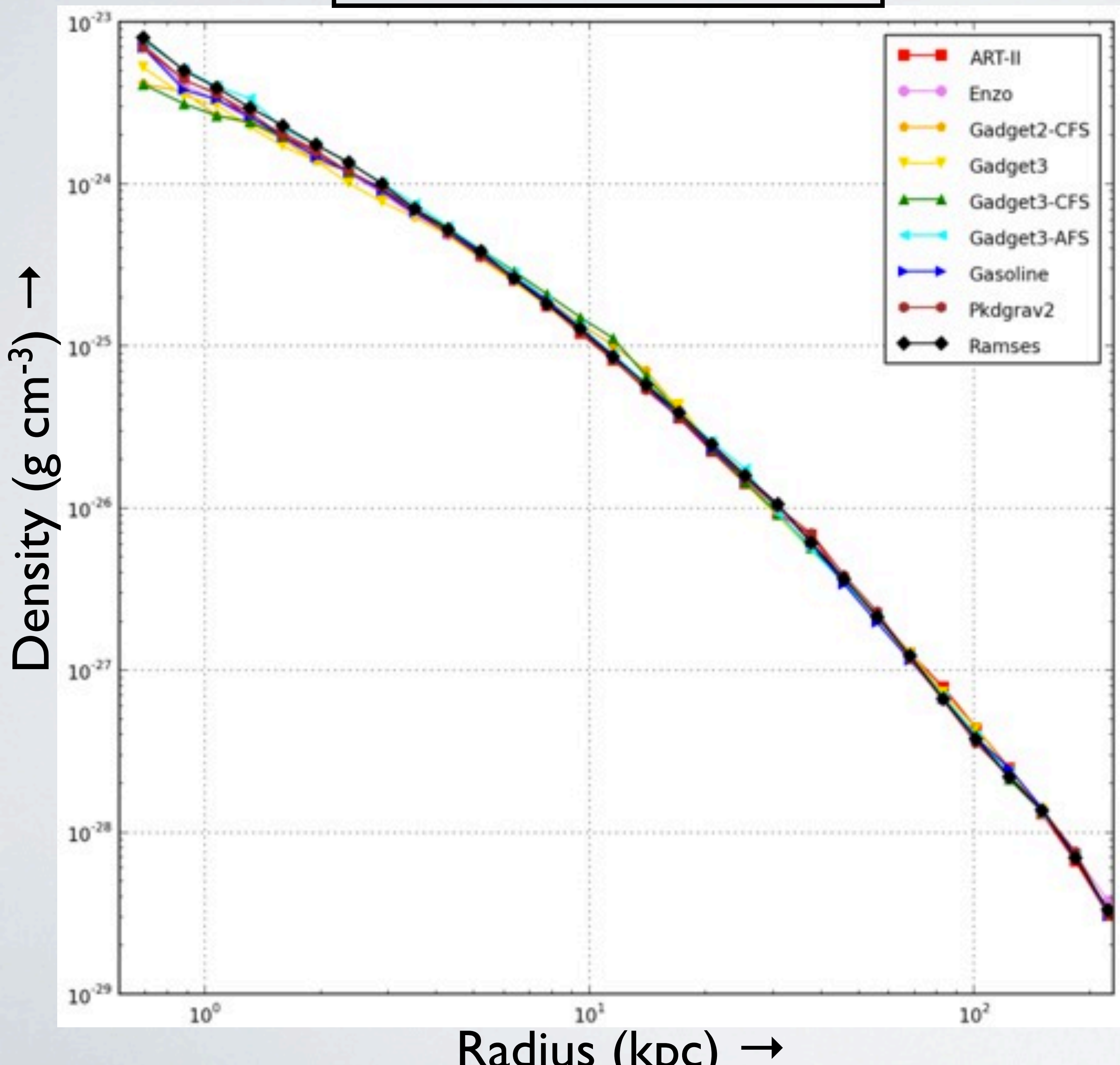


Projected DM density (1 Mpc/h)

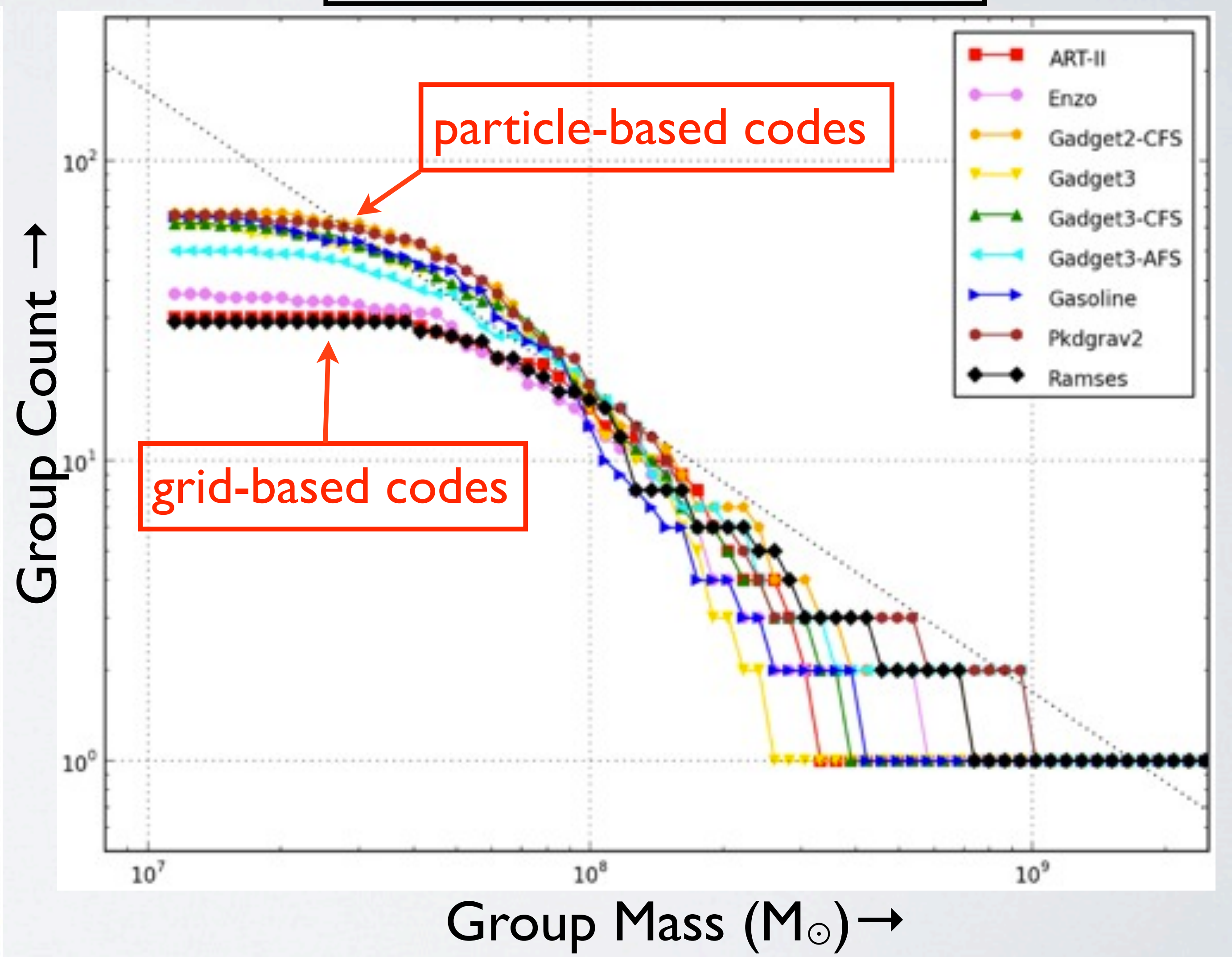
Foundation for Future Comparisons

- Overall density profile and mass function in good agreement
  - Provides solid foundation for future hydrodynamic comparisons

DM Density Profile (<200 kpc)



Mass Function by HOP (<150 kpc)



Improvements in *AGORA* Comparisons

1) Comparison made easy by common analysis platform *yt*

- *Previously:* Often one person tries badly to collect processed data while ensuring that the tests and analyses were identical across platforms.

2) Common ICs open for business via portable *MUSIC* parameters

- *Previously:* Reproducibility of numerical experiments is often ignored.

3) Project specifically designed with astrophysical questions in mind

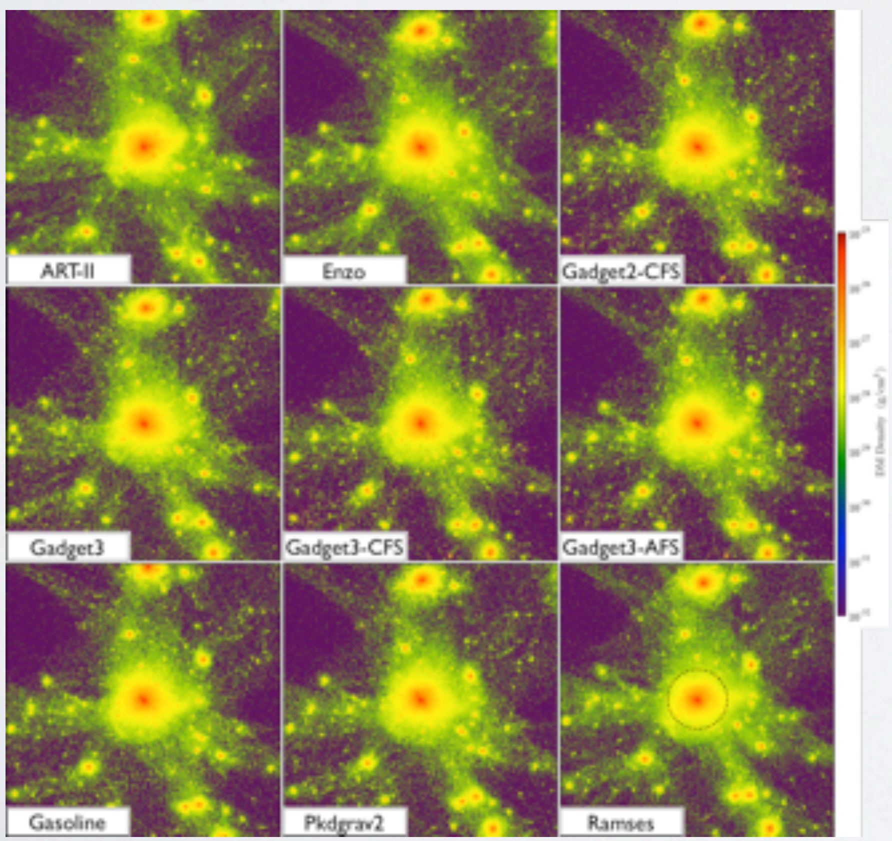
- *Previously:* Comparison projects ended when a single paper was out even though the framework could have been used to explore many problems in galactic astrophysics.

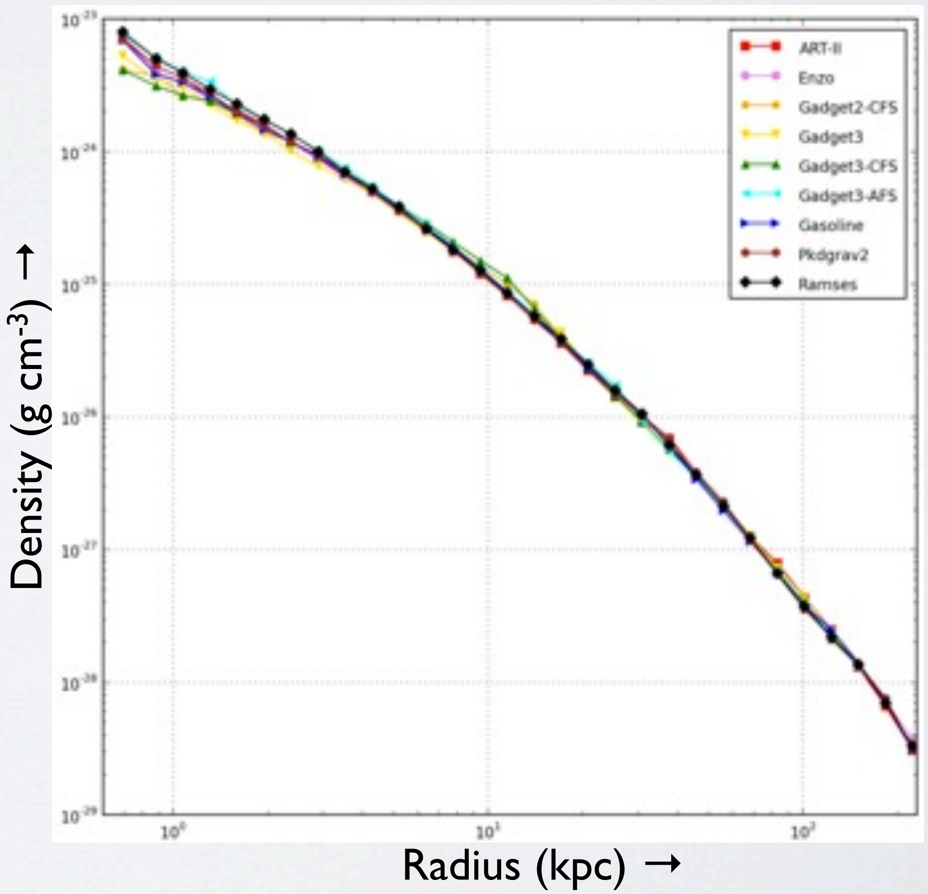
Common Analysis Platform *yt*

- All the analyses in the AGORA Flagship paper performed on *yt*
  - See the talks on Saturday by M. Turk and N. Goldbaum
  - Script as simple as:

```
> ds = load("DD0040/data0040")

> sp = ds.h.sphere([0.5, 0.5, 0.5], (300, 'kpc'))
> prof = BinnedProfile1D(sp, total_bins = 30,  "ParticleRadiuskpc", 0.6, 300)
> prof.add_fields([("all", "ParticleMassMsun")], accumulation=True)
> pyplot.loglog(prof["ParticleRadiuskpc"], prof[("all", "ParticleMassMsun")])
```





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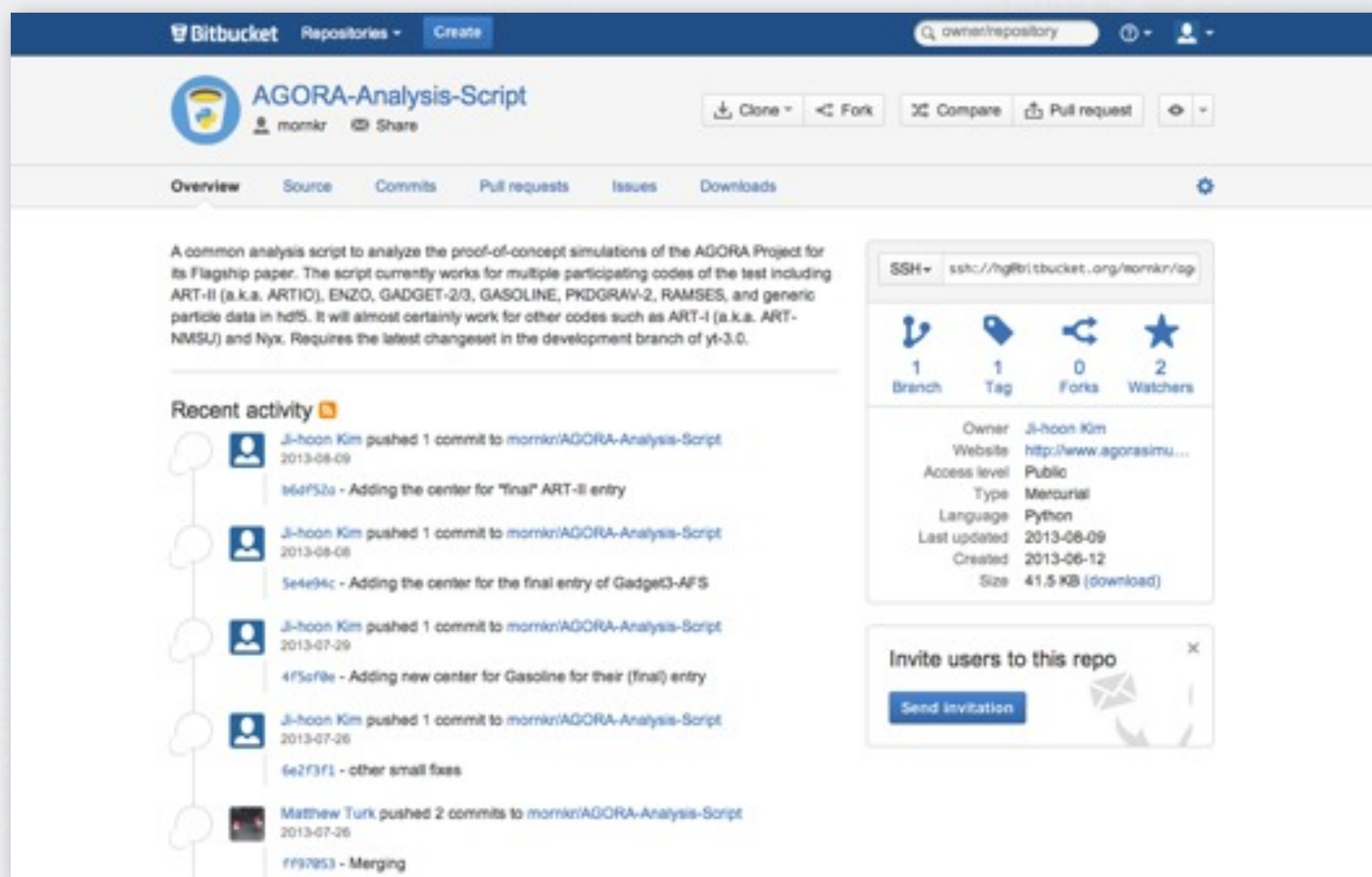
  - AGORA-Analysis-Script initiated on BitBucket:



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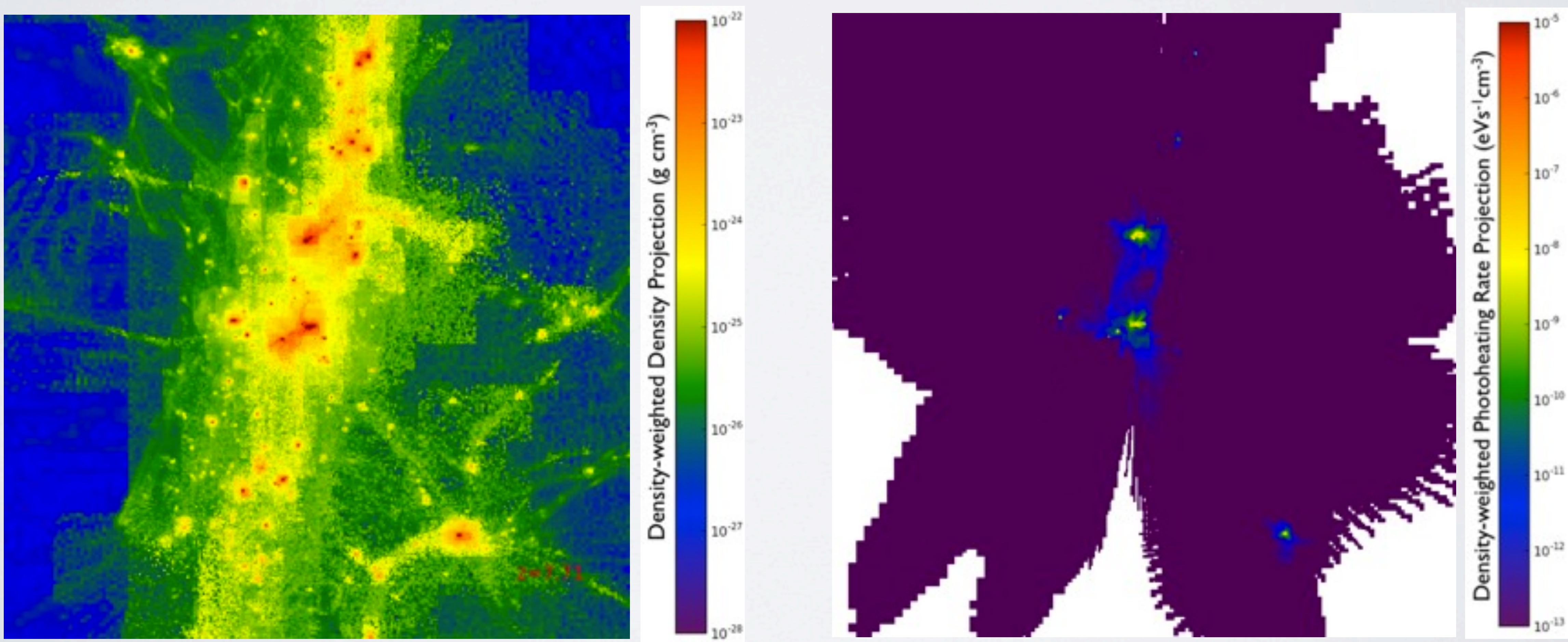
AGORA Initial Conditions: Applications

- Cosmological ICs open for use in any projects (AGORA or not)
  - e.g., Hopkins & Keres (FIRE simulations), Hobbs & Read, Kim & Krumholz, Onorbe
  - Highly portable and public ICs → Starting to build a library of AGORA simulations

$\sim 10^{13}\ M_\odot$ halo @z=0 → $7\times10^{10}\ M_\odot$ halo @z=7.7, radiating star cluster particles, 5pc resolution



Kim, Krumholz, et al., in prep 2013

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AGORA Gearing Up For Science

- Launchpad to initiate a series of science-oriented comparisons

  - 4 task-oriented working groups to establish the framework of the Project

Table 1
Task-oriented Working Groups of the *AGORA* Project

Working Group	Objectives and Tasks†
Common Cosmological ICs	Determine common initial conditions for cosmological high-resolution zoom-in galaxies (Section 2.1)
Common Isolated ICs	Determine common initial conditions for an isolated low-redshift disk galaxy (Section 2.2)
Common Astrophysics	Define common physics including UV background, gas cooling, stellar IMF, energy and metal yields from SNe (Section 3)
Common Analysis	Support common analysis tools, define physical and quantitative comparisons across all codes (Section 4.2)

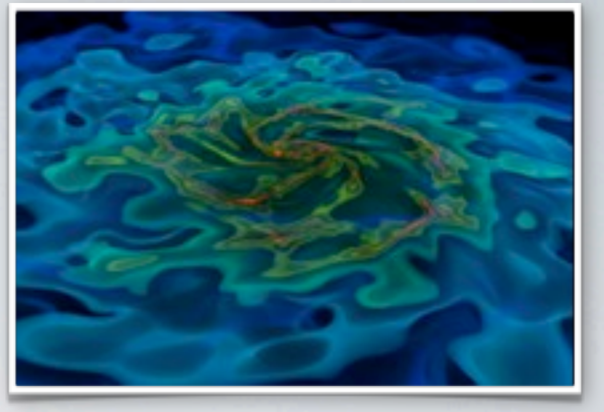
Madau
Teyssier
Hahn & Kim
Turk

  - 9+ science-oriented working groups to perform original research using the framework

Table 2
Science-oriented Working Groups of the *AGORA* Project

Working Group	Science Questions (includes, but are not limited to)†
Isolated Galaxies and Subgrid Physics	Tune subgrid models across codes to yield similar results for similar astrophysical assumptions (Section A.1)
Dwarf Galaxies	Simulate cosmological $\sim 10^{10}$ $M_\odot$ halos and compare results across all participating codes (Section A.2)
Dark Matter	Radial profile, shape, substructure, core-cusp problem (Section A.3)
Satellite Galaxies	Effects of environment, UV background, tidal disruption (Section A.4)
Galactic Characteristics	Surface brightness, disks, bulges, metallicity, images, spectral energy distributions (Section A.5)
Outflows	Galactic outflows, circumgalactic medium, metal absorption systems (Section A.6)
High-redshift Galaxies	Cold flows, clumpiness, kinematics, Lyman-limit systems (Section A.7)
Interstellar Medium	Galactic ISM, thermodynamics, kinematics (Section A.8)
Massive Black Holes	Growth and feedback of massive black holes in a galactic context (Section A.9)

Agertz & Teyssier
Onorbe
Rocha & Kuhlen
Zolotov
Guedes & Hummels
Shen
Ceverino
Leitner
Hobbs



Conclusions

AGORA High-resolution Galaxy Simulations Comparison Project

- The AGORA Project promotes a multi-platform approach to validate answers to long-standing problems in galaxy formation.
- We are at a critical junction in numerical studies of galaxies.
- Thank you for your contribution so far and in the years to come!