New Insights on Stellar Haloes with the Illustris Simulation (and Eris)

ANNALISA PILLEPICH
(ITC Harvard)

MNRAS 2014, 444, 237

Halo mass and assembly history exposed in the faint outskirts: the stellar and dark matter haloes of Illustris galaxies

Annalisa Pillepich,[1⋆] Mark Vogelsberger,[2] Alis Deason,[3†] Vicente Rodriguez-Gomez,[1] Shy Genel,[1] Dylan Nelson,[1] Paul Torrey,[1] Laura V. Sales,[1] Federico Marinacci,[4,5] Volker Springel,[4,5] Debora Sijacki[6] and Lars Hernquist[1]

2015ApJ...799..184P

BUILDING LATE-TYPE SPIRAL GALAXIES BY IN-SITU AND EX-SITU STAR FORMATION

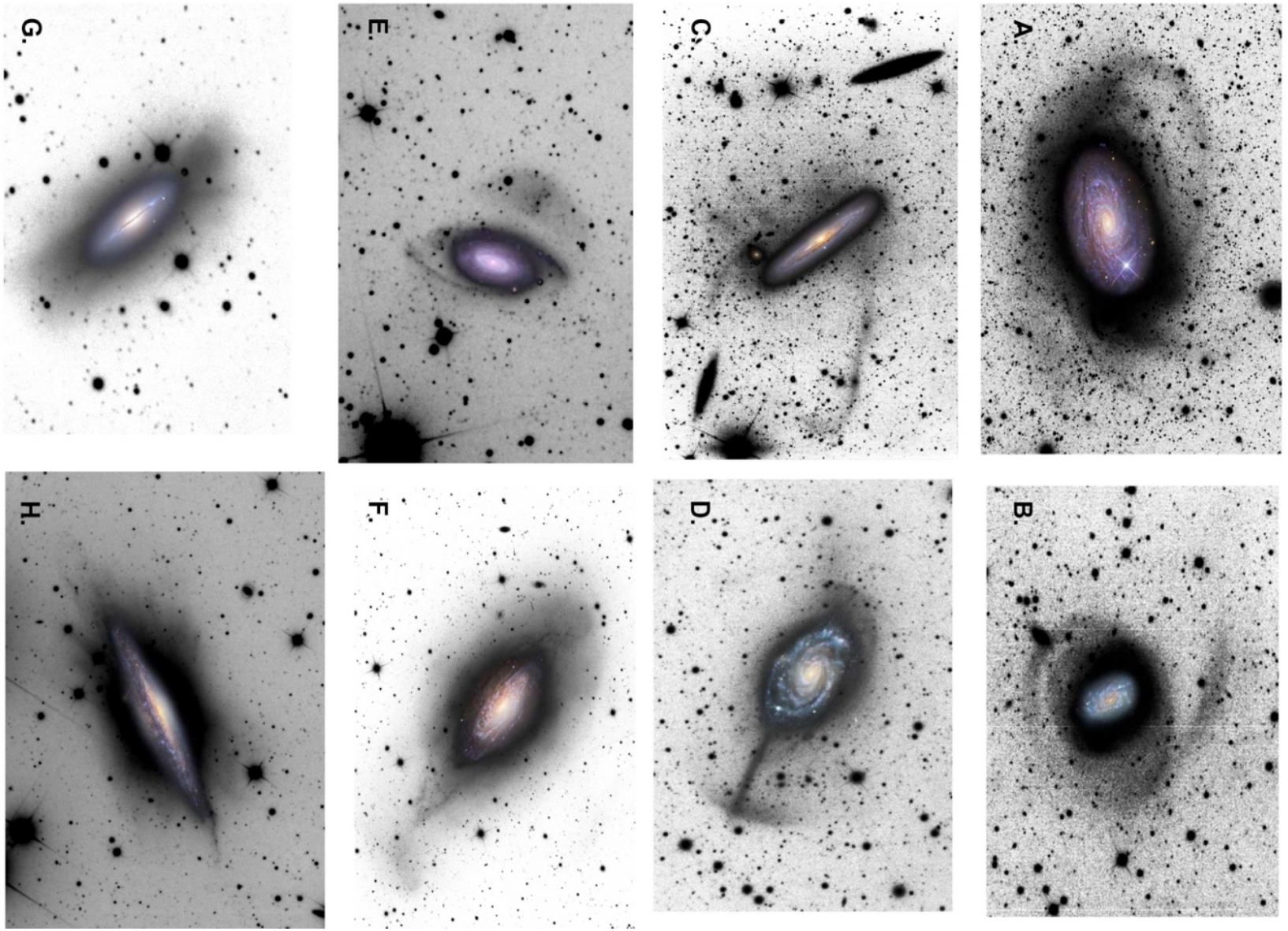
Annalisa Pillepich[1,2], Piero Madau[2], & Lucio Mayer[3]

The Observational Framework

Kaviraj et al. 2010

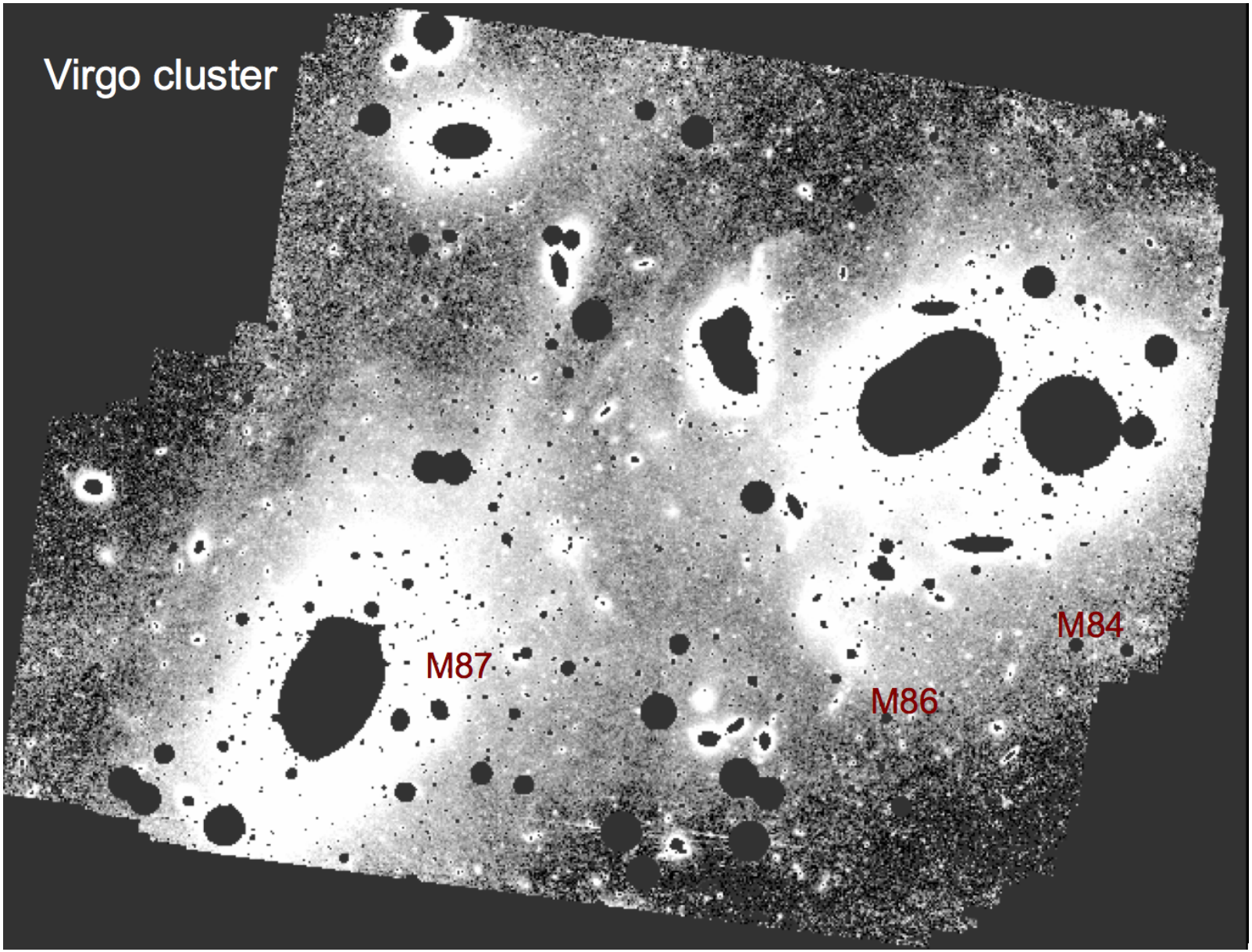
Duc et al. 2014, ATLAS-3D

The Observational Framework



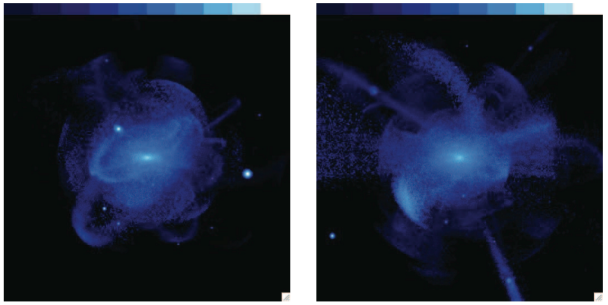
Martinez-Delgado 2010

The Observational Framework



Mihos et at. 2005

From the Theoretical/Numerical Perspective…



0) TOY MODELS,
e.g. N-BODY SIMS in FIXED POTENTIALS

Helmi&White 1999
Bullock&Johnston 2005
Font et al. 2006

I) N-BODY SIMS +

- SEMI-ANALYTICAL MODELS
- STELLAR TAGGING TECHNIQUES

(Aquarius MWs, VLII, Phoenix Clusters)

Cooper et al. 2010, 2013
Lowing et al. 2015
BUT SEE ALSO Bailin et al. 2014

II) N-BODY + GAS DYNAMICS SIMS

- INDIVIDUAL ZOOM-IN GALAXIES (reAquarius MWs, GIMIC, Gasoline zooms & Eris….)
- LARGE SAMPLES OF GALAXIES
- NEW GENERATION OF COSMOLOGICAL VOLUMES

(Illustris & the Eagle Simulations)

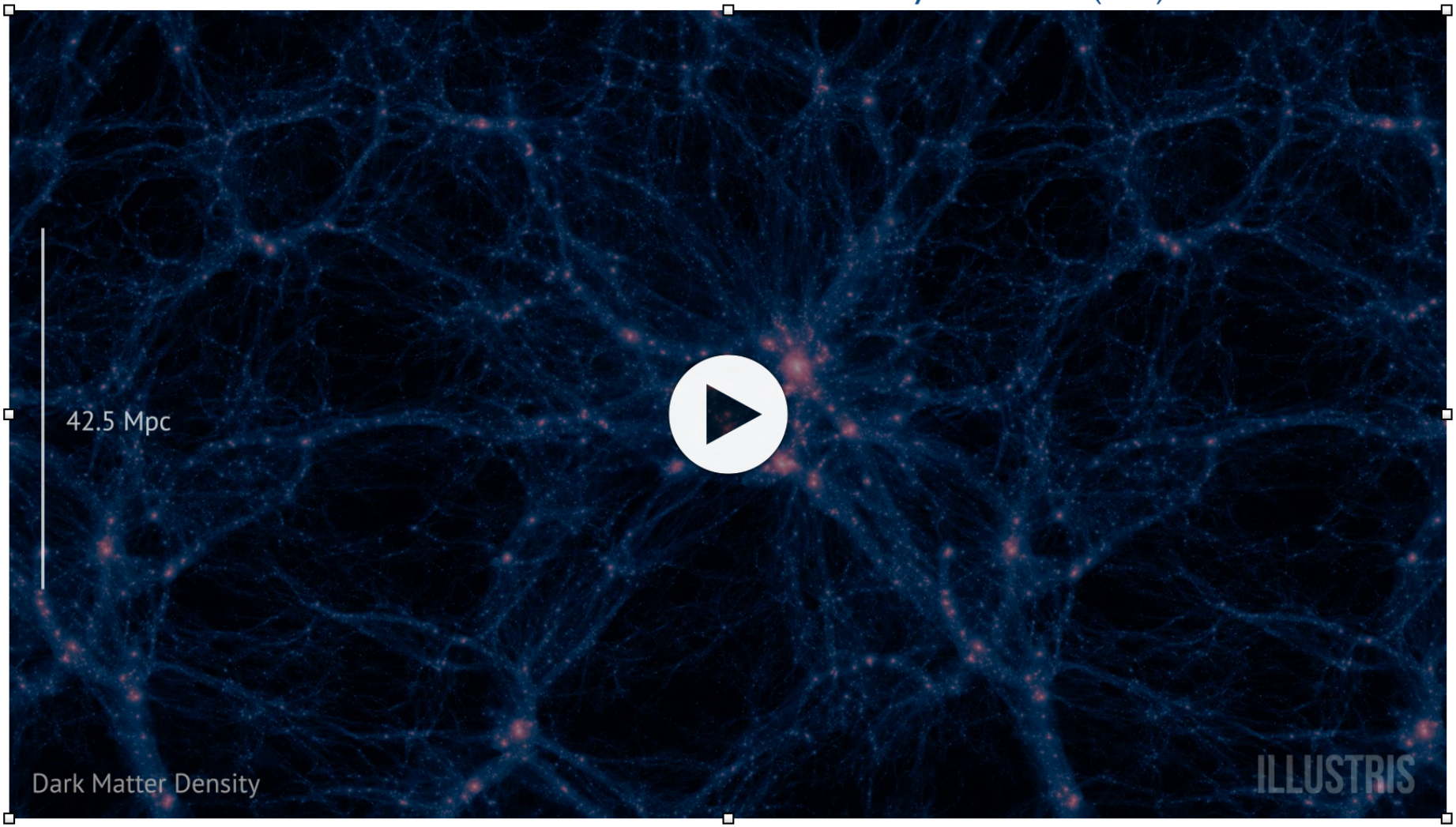
Abadi et al. 2006
Zolotov et al. 2009
Tissera et al. 2012, 2013, 2014

Oser et al. 2010
Font et al. 2011
McCarthy et al. 2012
Lackner et al. 2012

The Illustris Simulation

The Illustris Simulation

Credits: Dylan Nelson (ITC) & the Illustris Team



N-Body+Hydro in a 105 Mpc box at ~1kpc resolution
NEW MOVING-MESH CODE: AREPO

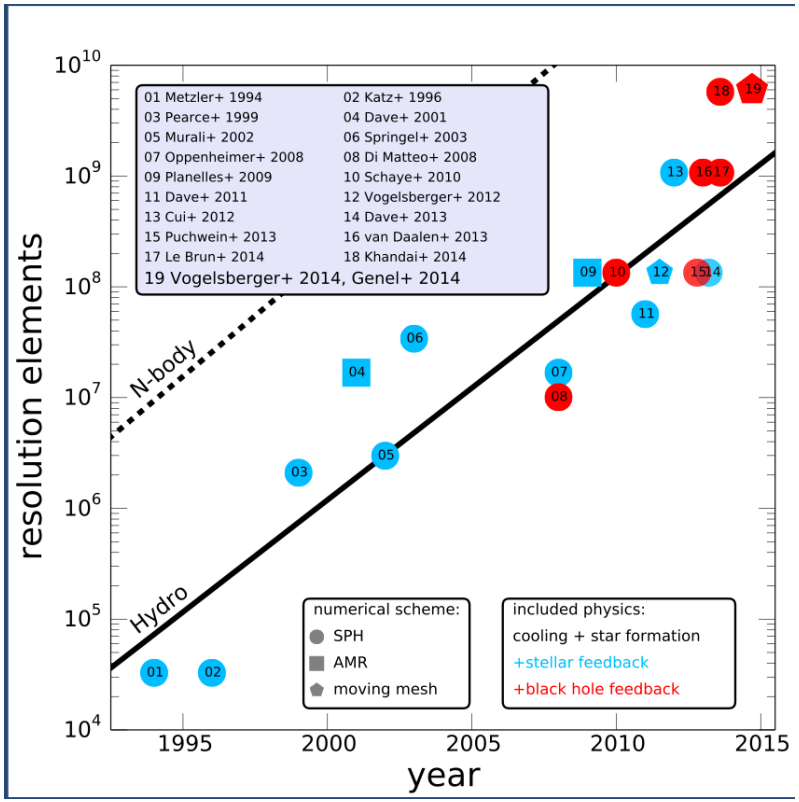
The Illustris Simulation

TECHNICAL DETAILS

CODE: Arepo (moving-mesh)
Lbox = 106.5 Mpc
M_DM = 6.26 x 10^6 Msun
M_BARYONS = 1.26x10^6 Msun
Gravitational Softening = 710 pc (z=0)
Smallest Gas Cell: 50 pc and 1.5x10^4 Msun

It included many of the astrophysical processes which are thought to be relevant for galaxy formation:

a) stellar evolution
b) stellar feedback: winds
c) gas recycling
d) gas cooling (primordial, metal-line)
e) chemical enrichment (nine elements)
f) black holes (seeding and growth)
g) quasar- and radio-mode feedback



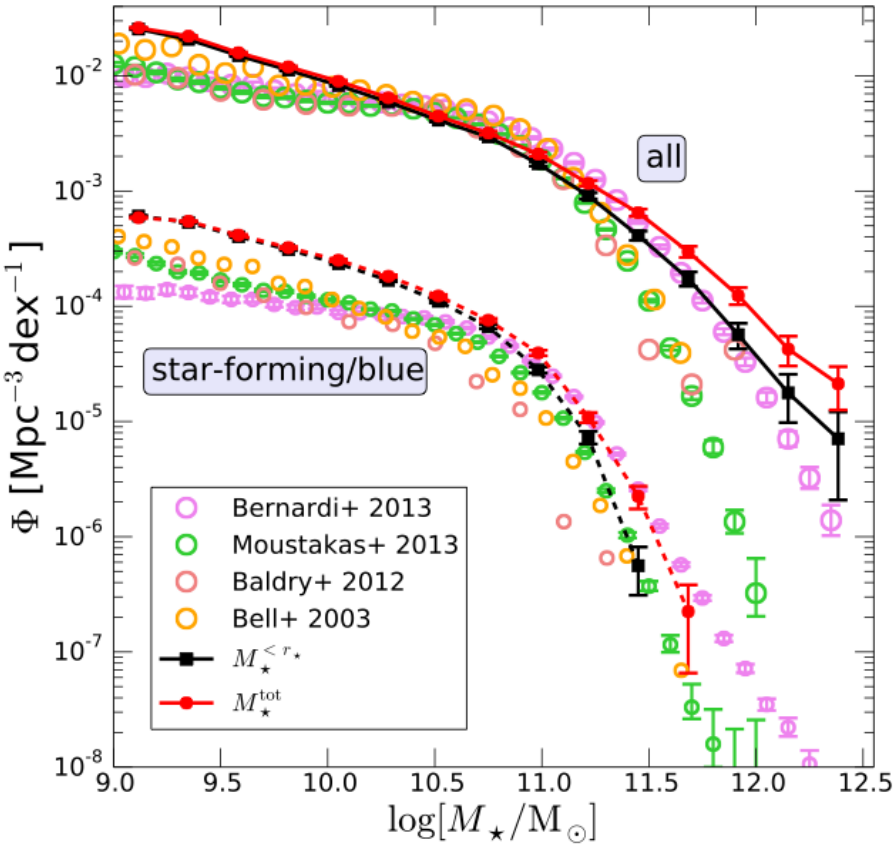
8192 cores, for 19 million CPUhs (3 months net)

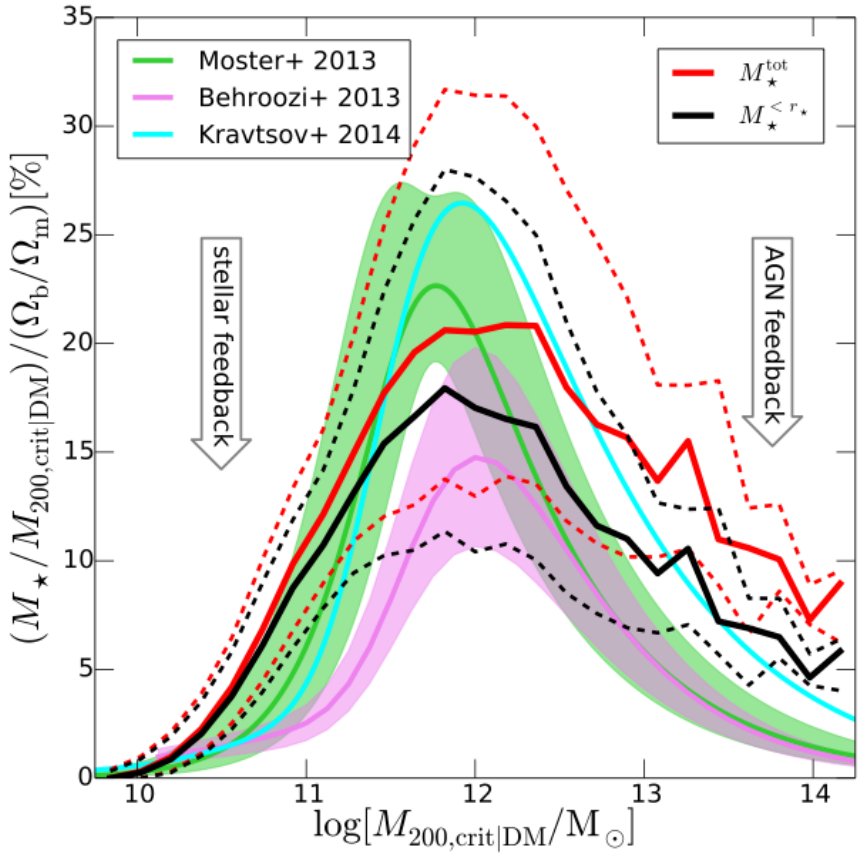
1.4TB per snapshot, 136 snapshots:
Total Disk Volume > 200 TB

Vogelsberger et al. 2014, Nature 509
Vogelseberger et al. 2014, MNRAS 445
Genel et al. 2014, MNRAS 445
Springel 2010, MNRAS 401

The Illustris Simulation

ILLUSTRIS PRODUCES A QUITE REALISTIC POPULATION OF GALAXIES

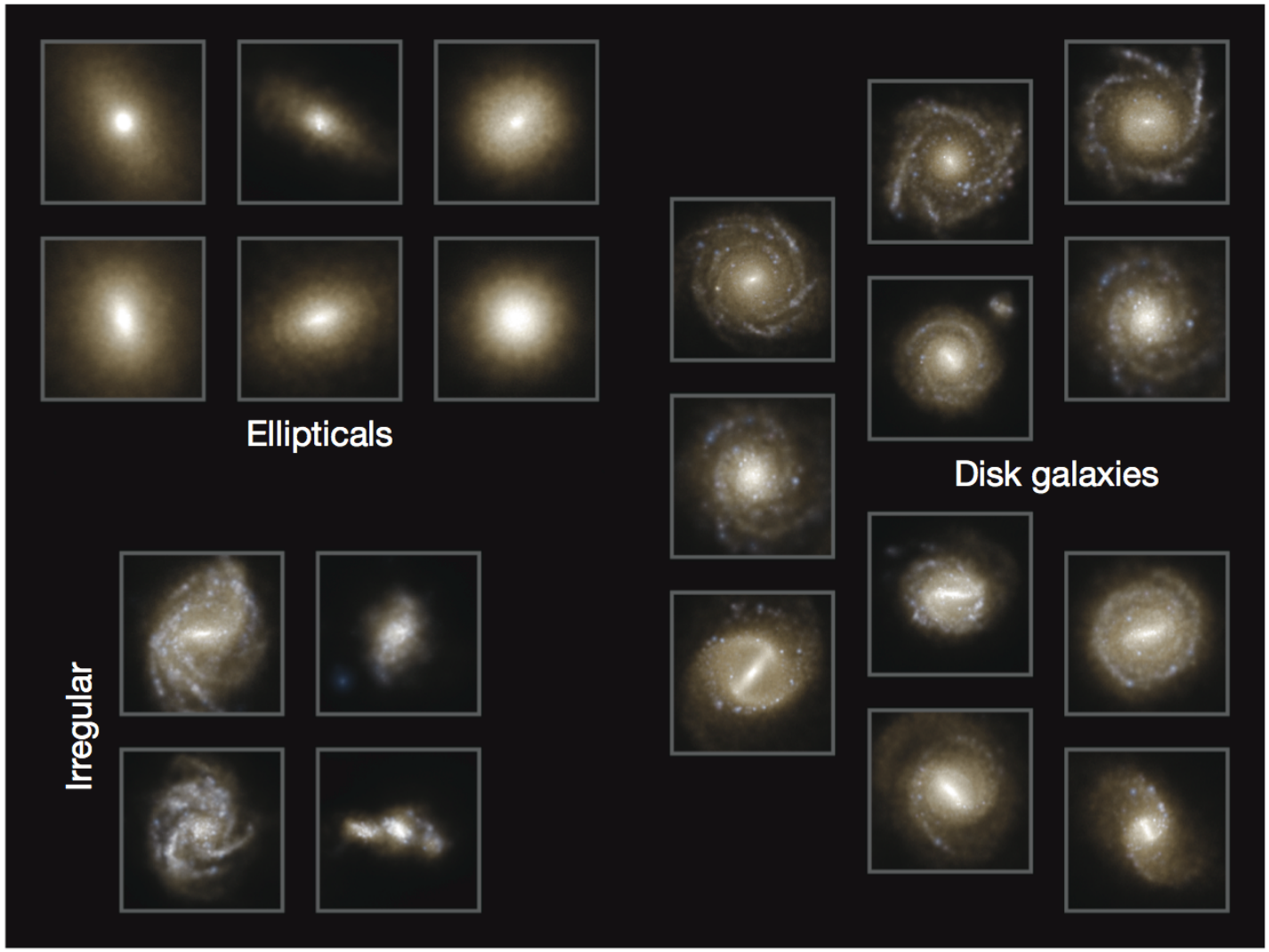




Vogelseberger et al. 2014, MNRAS 445

The Illustris Simulation

THOUSANDS OF WELL-RESOLVED GALAXIES & REASONABLE MORPHOLOGY MIX



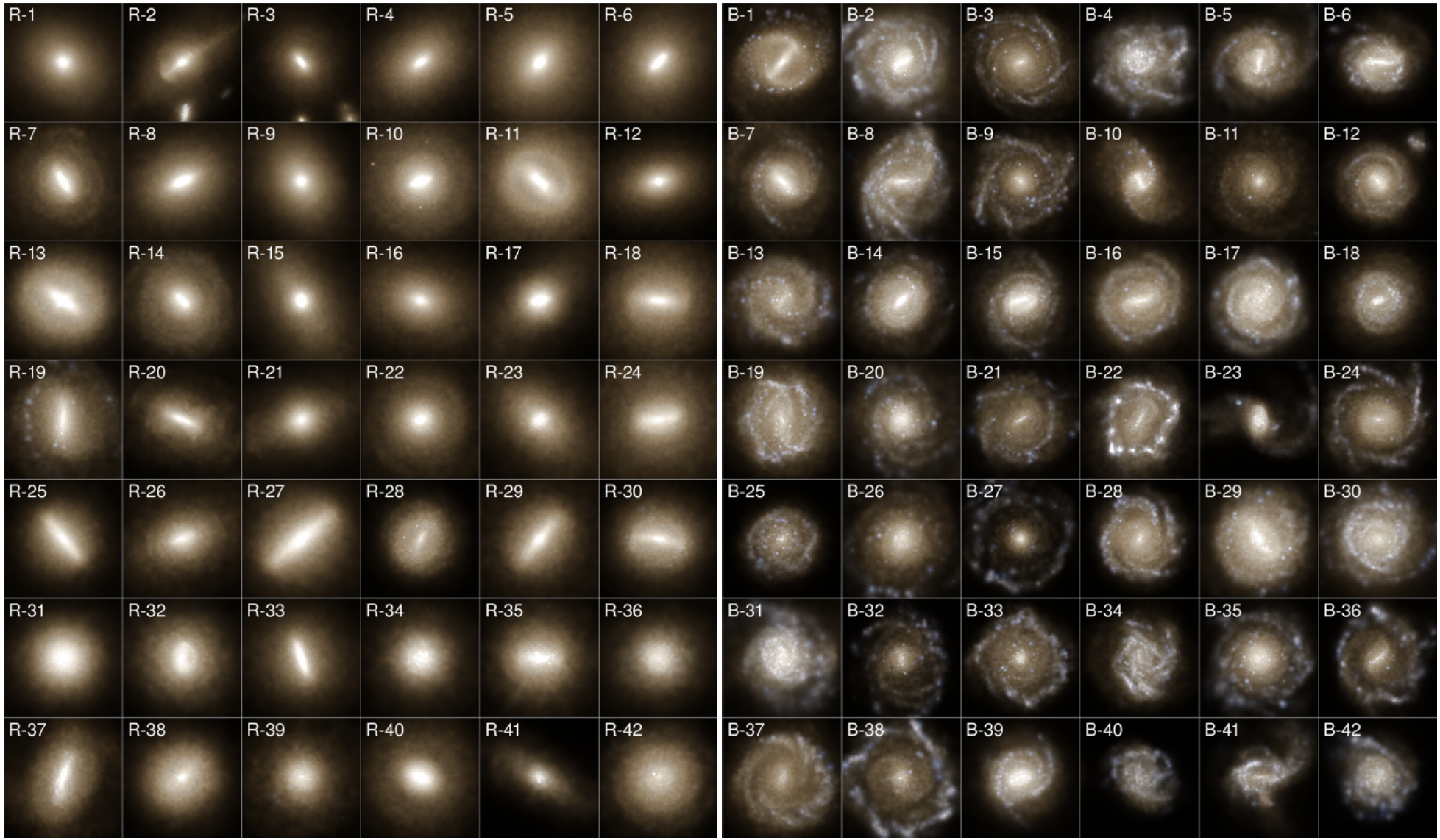
Vogelsberger et al. 2014, Nature 509

The Illustris Simulation

true achievement

e.g. GALAXY BIMODALITY

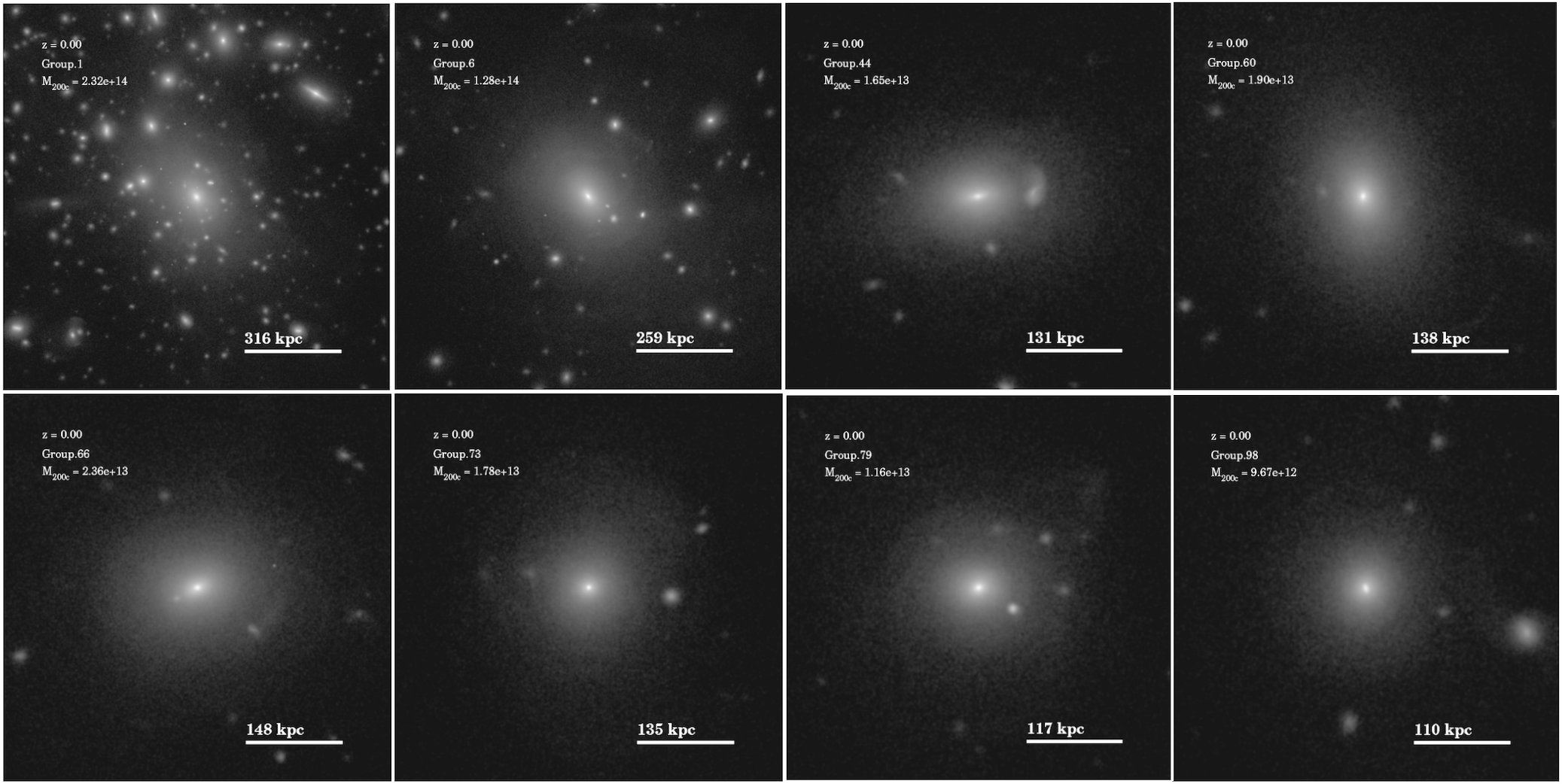
10kpc



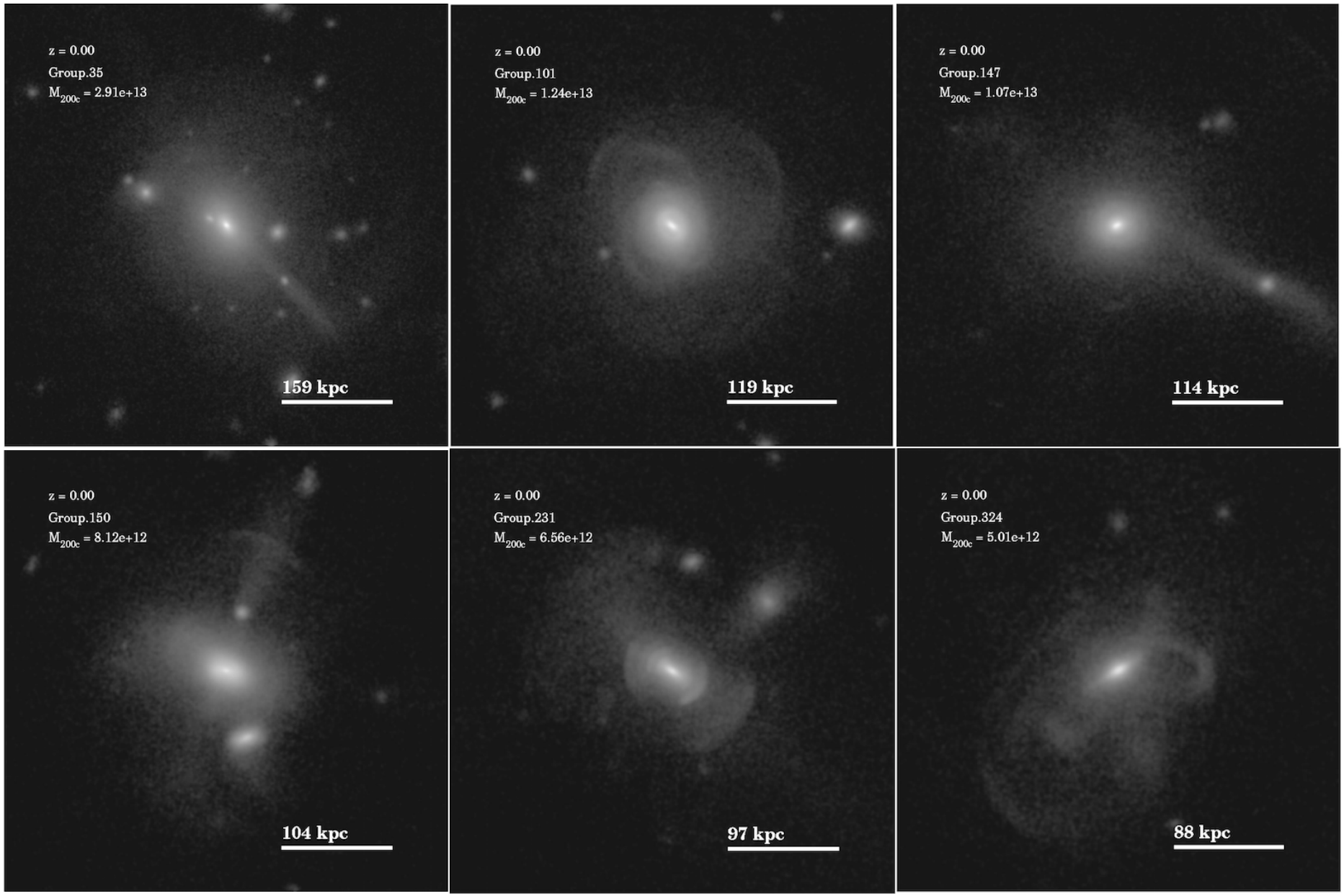
Vogelsberger et al. 2014, MNRAS 445

Zooming out beyond the main body of Illustris galaxies…

Stellar Haloes in Illustris: smooth



Stellar Haloes in Illustris: streams and shells



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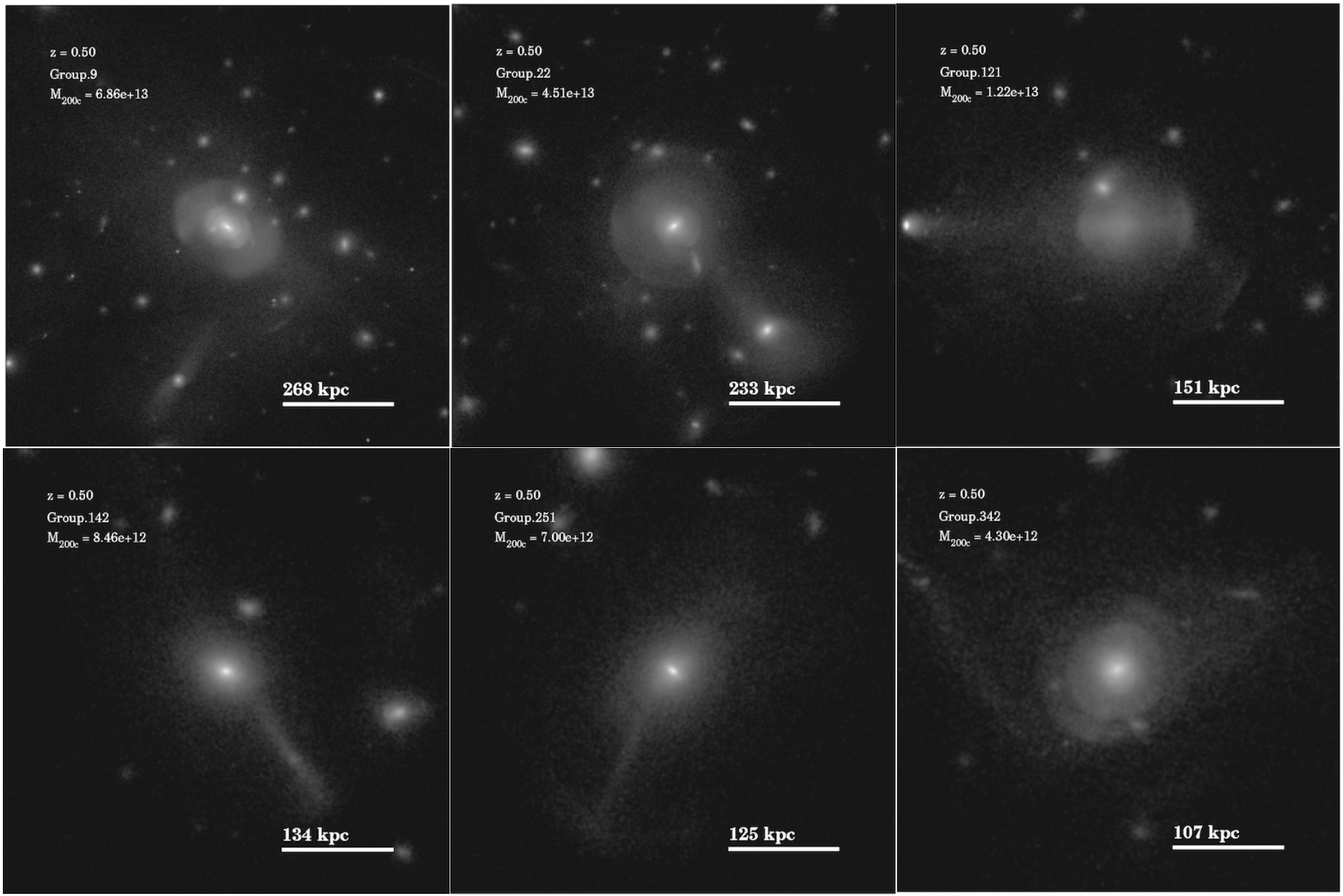
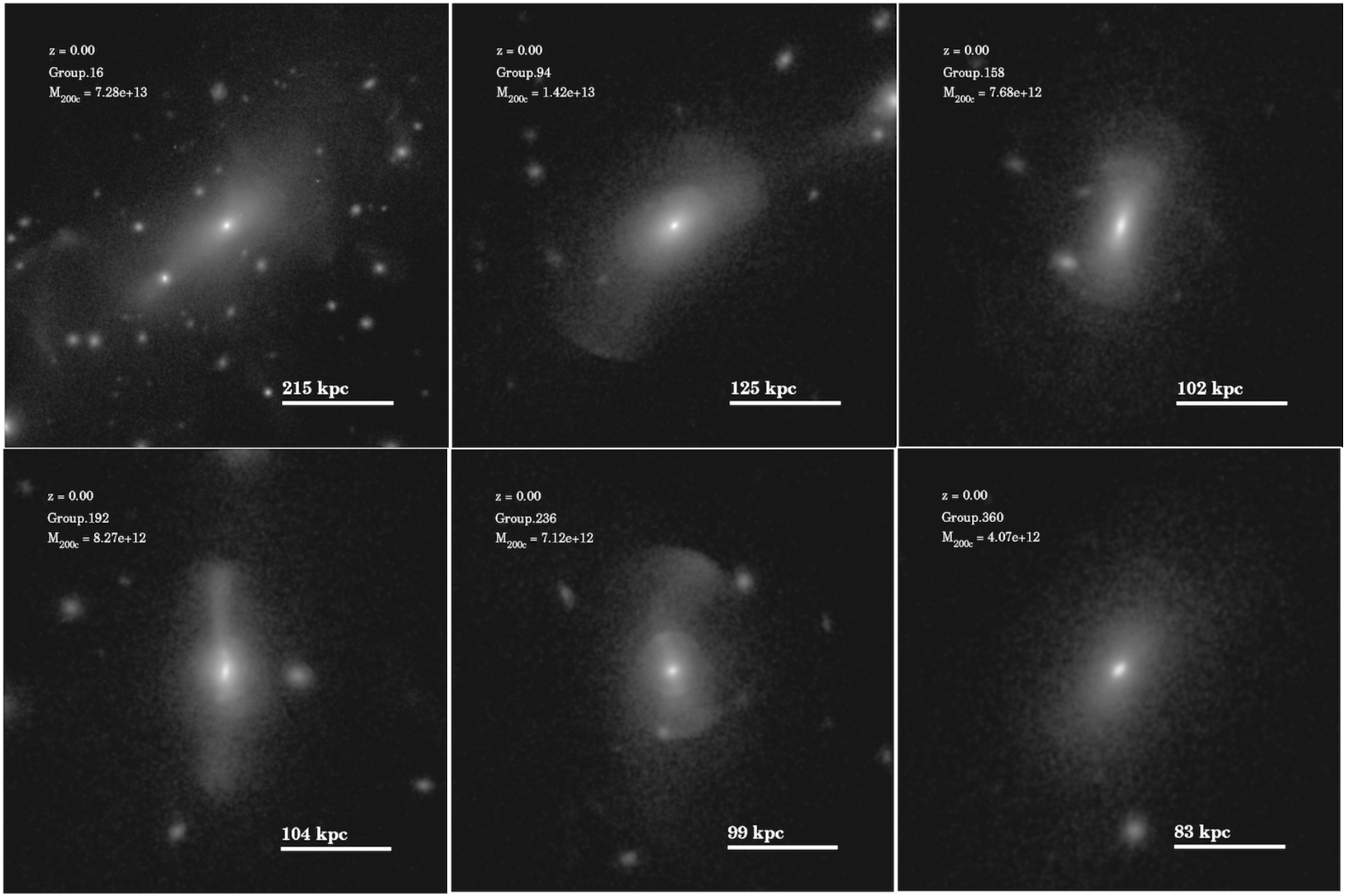
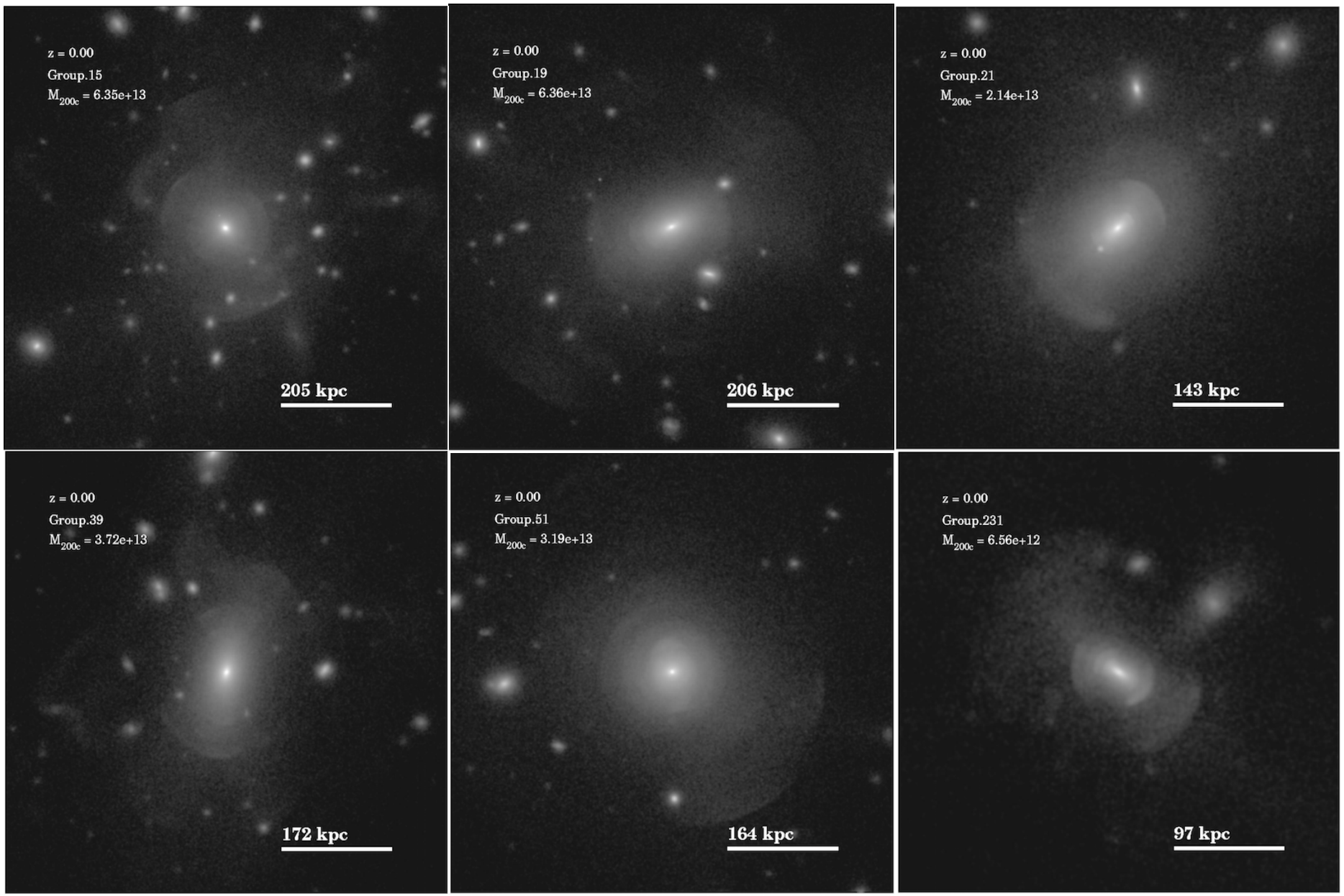


Stellar Haloes in Illustris: not spherically symmetric

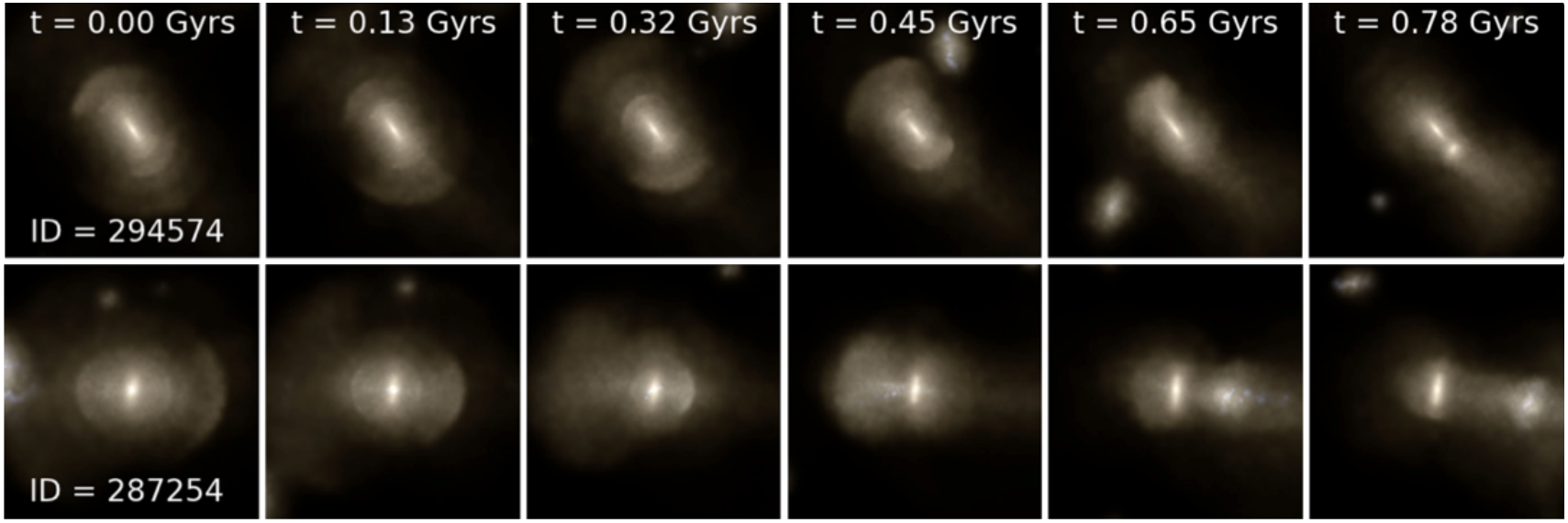


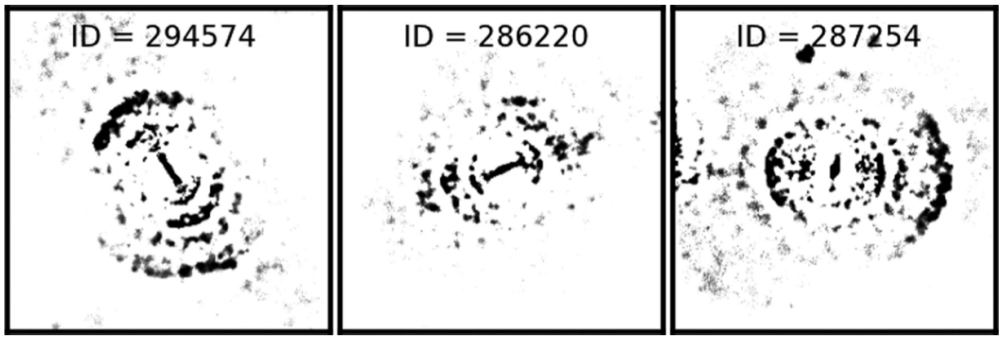
Stellar Haloes in Illustris: merger vestiges



Why are the Stellar Haloes Interesting?

THE STELLAR HALOES ARE THOUGHT TO ENCODE INFORMATION ABOUT THE **ASSEMBLY HISTORY** OF THE HALOES/GALAXIES





Torrey et al. 2015

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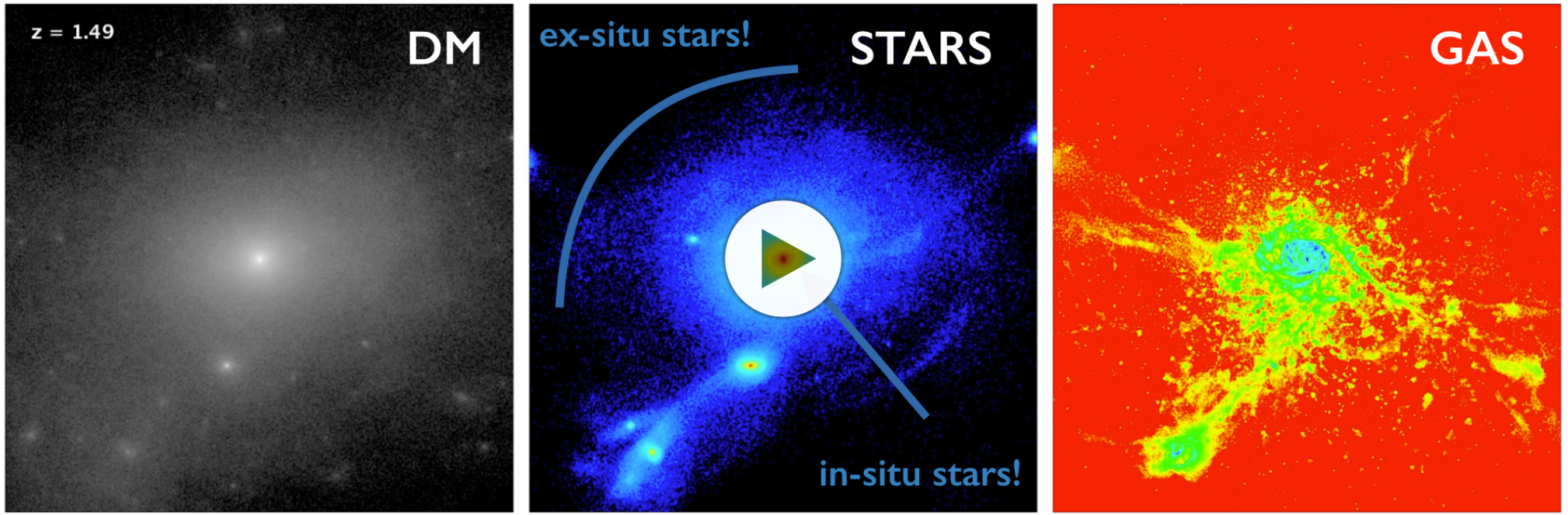
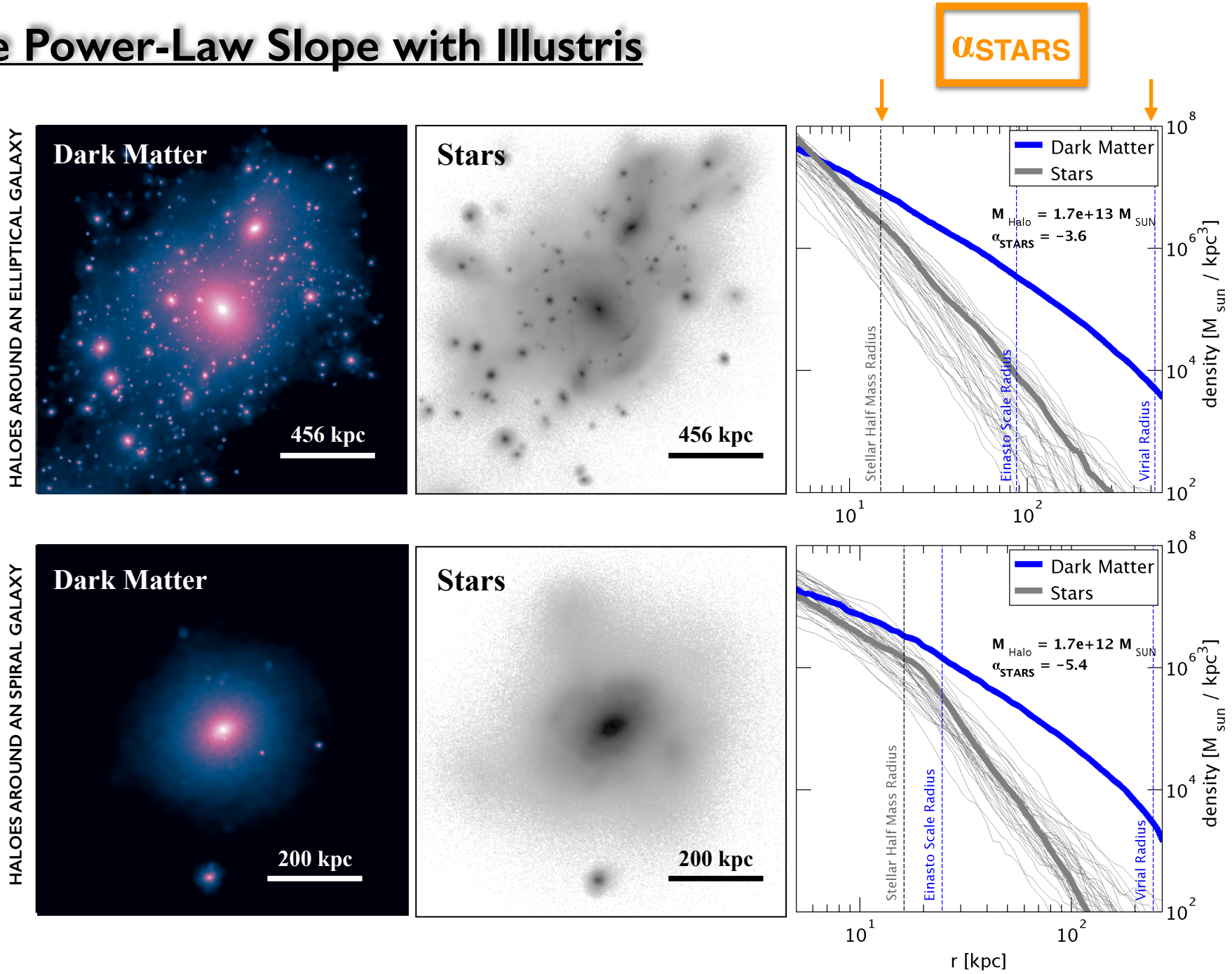


Eris Simulation
Milky-Way -like Galaxy, 8e11 Msun
Guedes et al. 2011, Pillepich et al. 2015

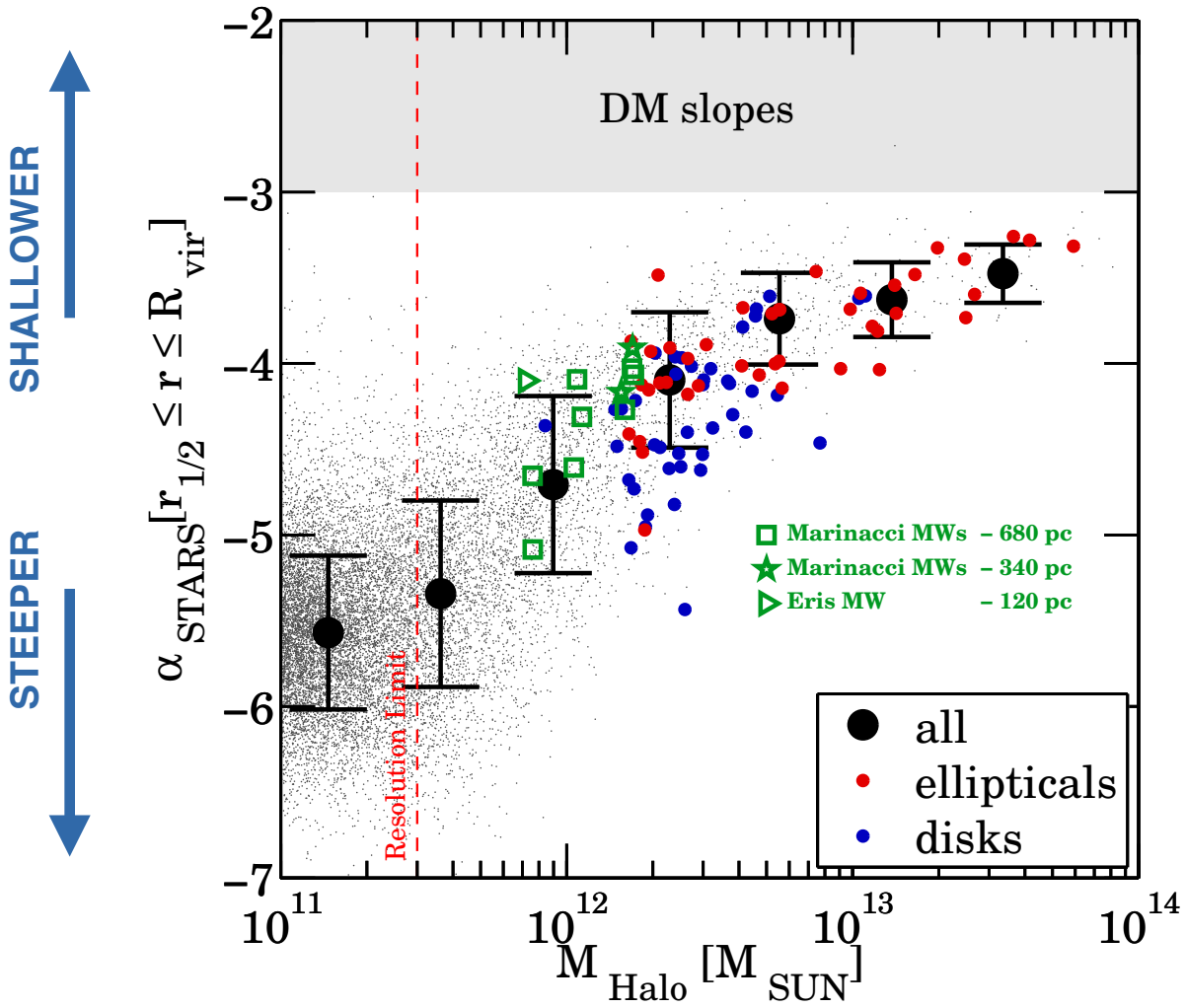
Quantifying the connection between Stellar Haloes and Assembly Histories with Illustris:

αSTARS

The Power-Law Slope with Illustris



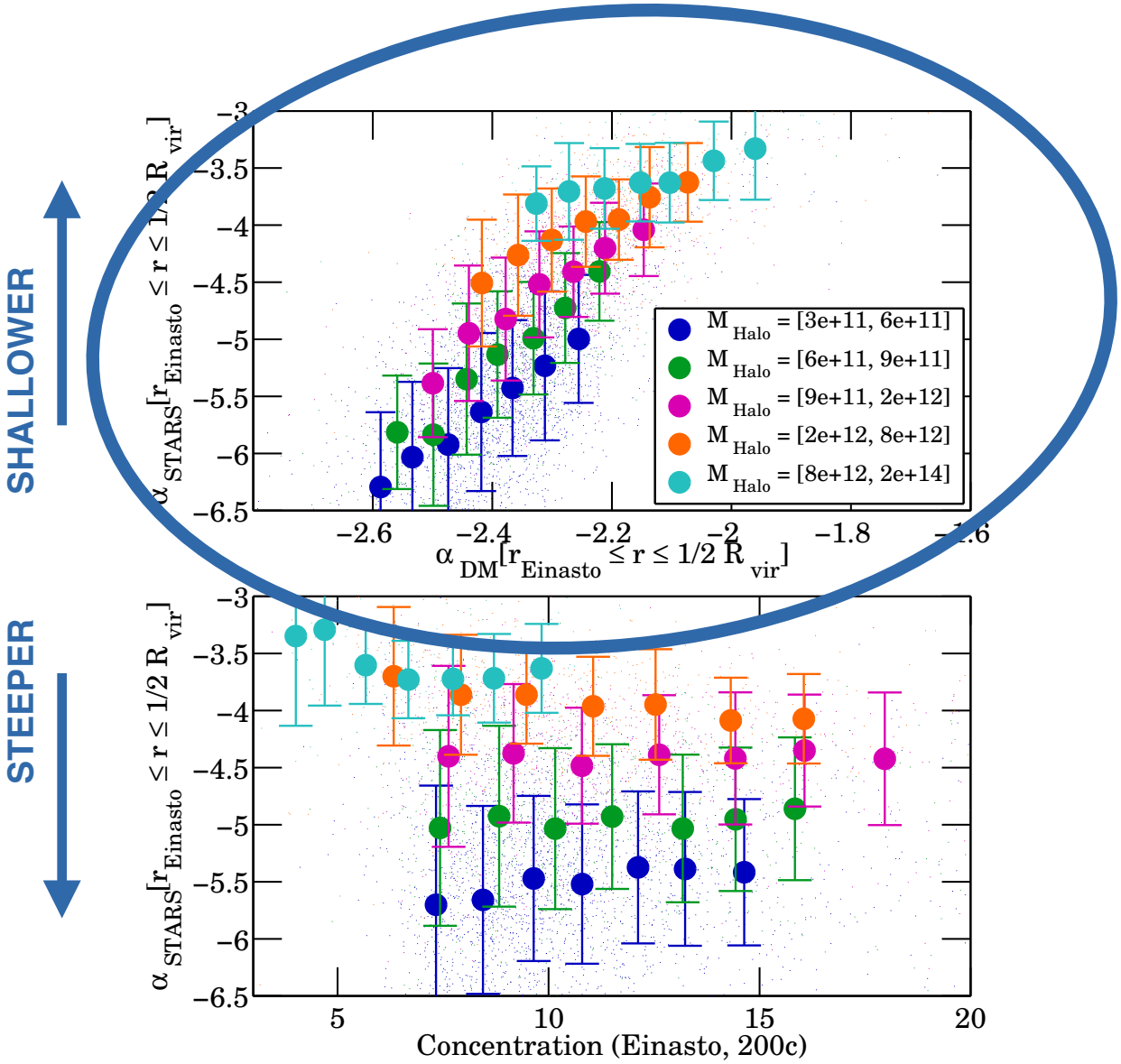
Stellar vs DM Haloes #1: Halo Mass



More massive DM haloes host shallower stellar haloes

MW-like galaxies are characterized by α_{STARS} ~ -4.5 +- 0.5

Stellar vs DM Haloes #2: DM Halo Profiles



The stellar slope is much steeper than the DM slope

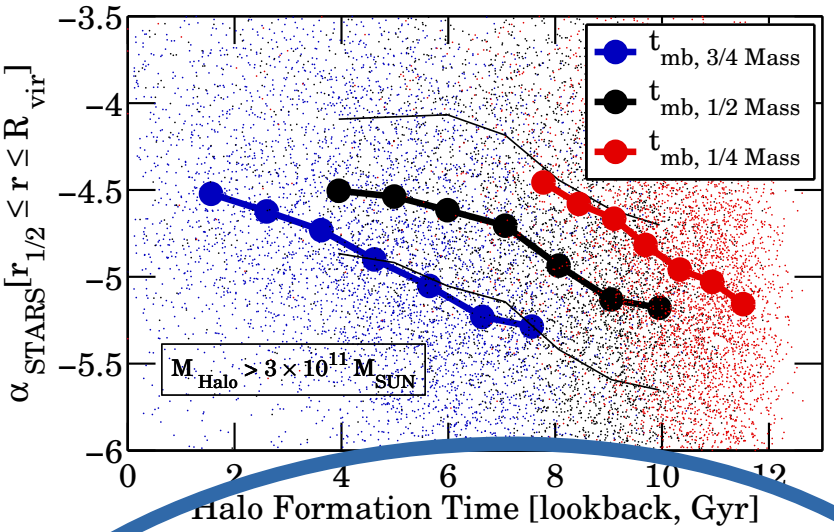
Also the DM slope exhibits a trend with DM Mass!

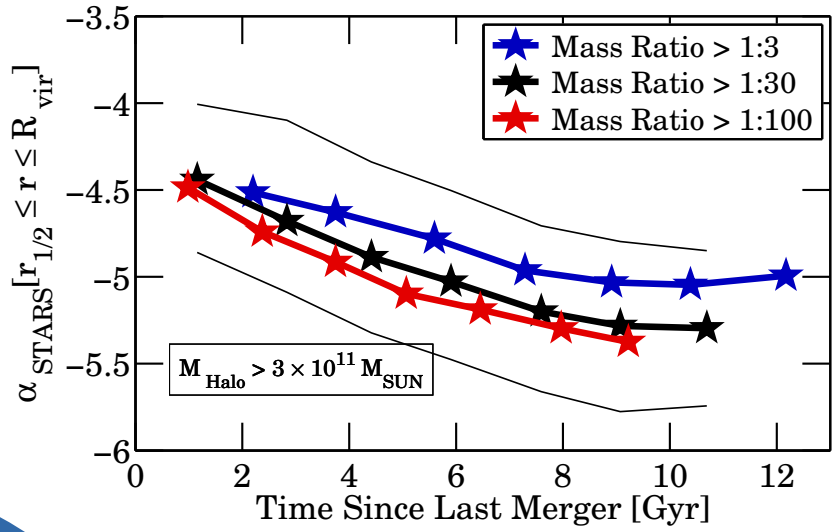
At fixed DM halo mass, there is **no** clear connection between the stellar slope and DM concentration

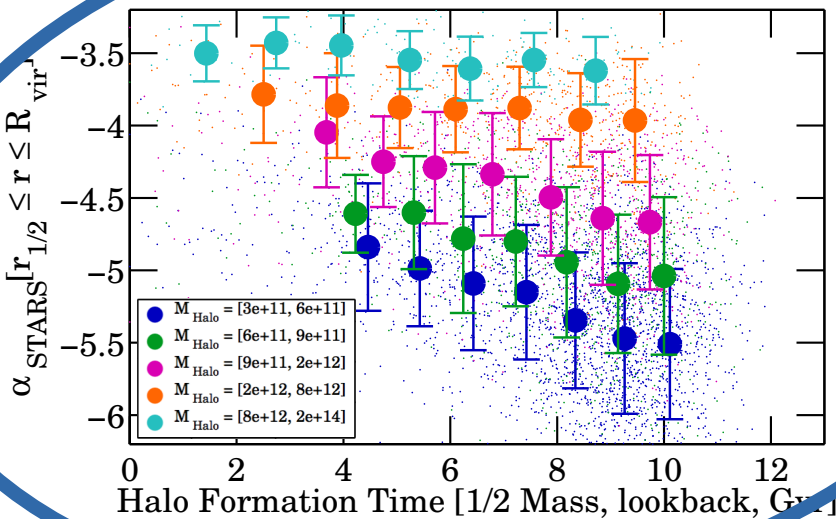
Stellar vs DM Haloes #3: DM Halo Assembly

SHALLOWER

STEEPER

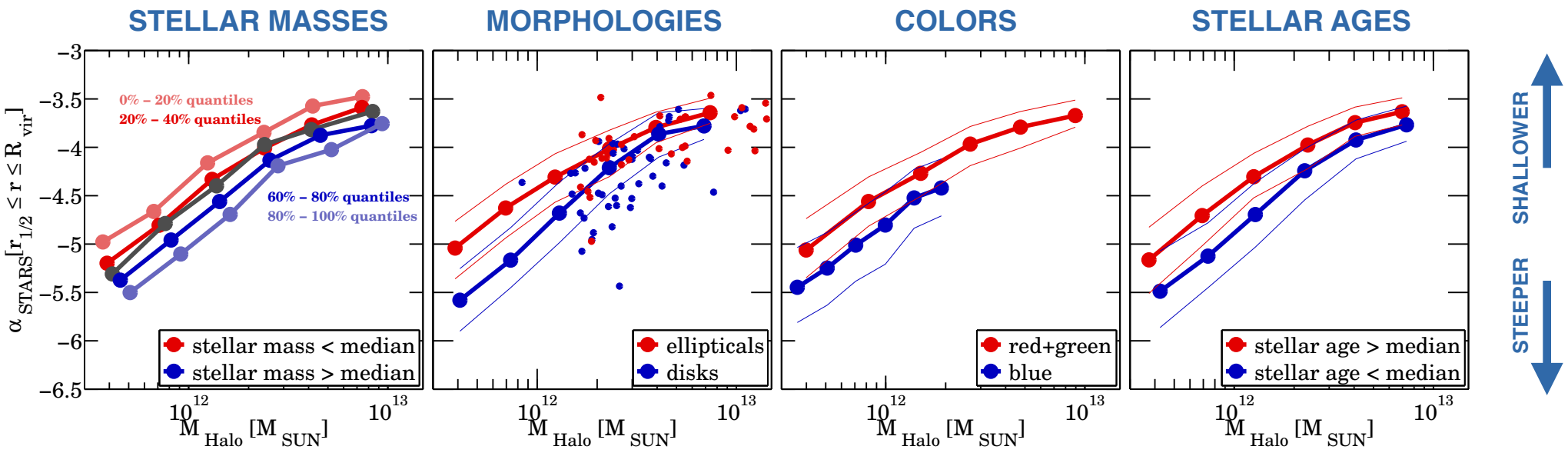






At fixed DM halo mass, DM haloes which formed more recently exhibit shallower stellar haloes!

Stellar Halo Slopes and Galaxy Properties



At fixed DM halo mass,
more massive, disk-like, blue, and young galaxies
are surrounded by steeper stellar haloes than
less massive, elliptical, redder and older counterparts.

Summary (before a real-world application):

α_{STARS} ENCODES A PLETHORA OF INFORMATION!

- HALO MASS
- HALO FORMATION TIME
- GALAXY TYPE

AT FIXED HALO MASS!

(α_{STARS} is more powerful than the Stellar Halo Mass)

Interpretation

more massive haloes accrete more numerous and more luminous satellites than their low-mass companions

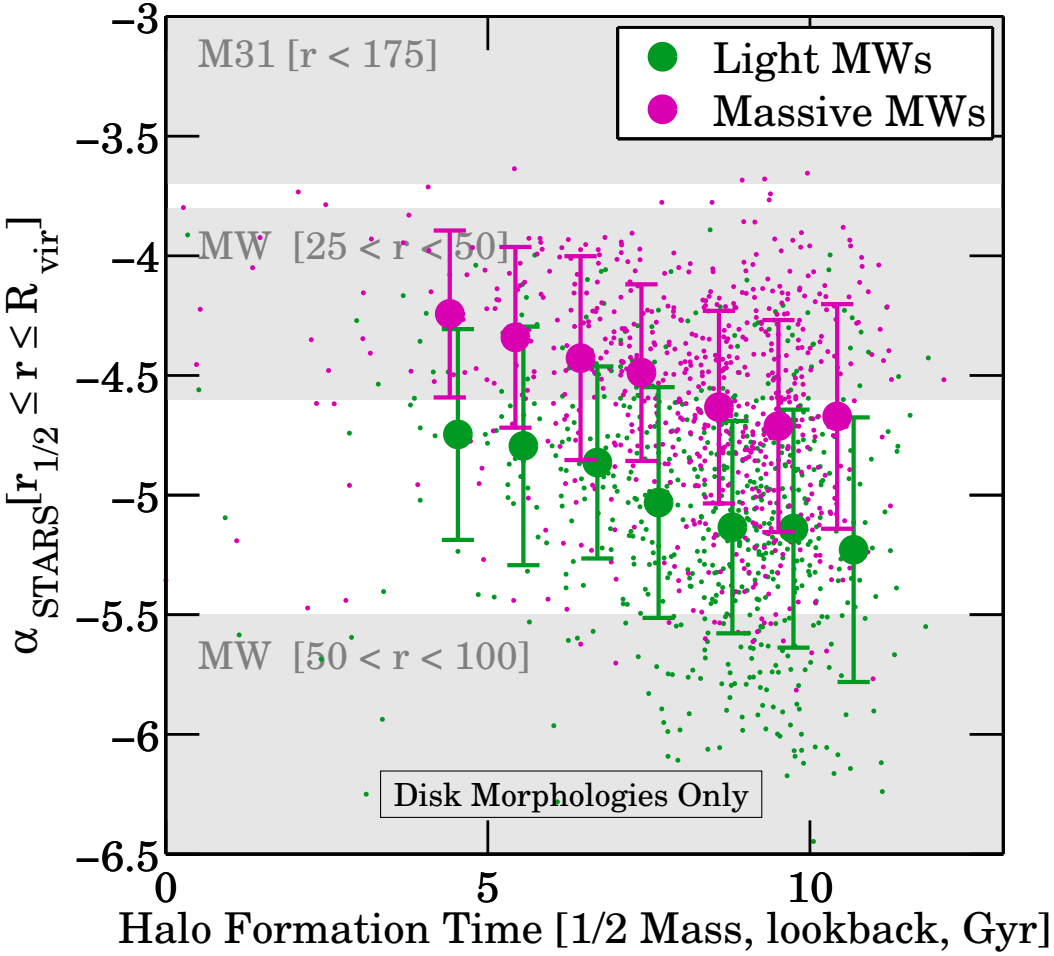
+

more massive haloes accrete their mass more recently and recently accreted satellites have larger apocenters

+

the presence of a disc can enhance the disruption of satellite galaxies in the inner parts of haloes, possibly because of disc shocking or enhanced tidal encounters

Application: Assembly History of MW and M31



Observations

Illustris results seem more consistent with the steep values of the MW than the very shallow values of M31

Illustris Data favors:

1. A **relatively massive M31** (>~2e12 Msun)

2. A **quieter MW** over the last 10 Gyr than M31

Outlook

Illustris is a true laboratory to study Stellar Haloes at intermediate masses

ONGOING PROJECTS:

- mock observations of Illustris Stellar Haloes (A. Pillepich)
- in-situ/ex-situ contributions to Stellar Haloes (V.Rodriguez-Gomez)
- kinematics and angular momenta distributions (B.Motwani)
- metallicity gradients to large distances (B. Cook)

If you are interested in working with the Illustris DataSet or have observationally-motivated ideas to test, come and talk to me!

Public Data Release Coming Soon!

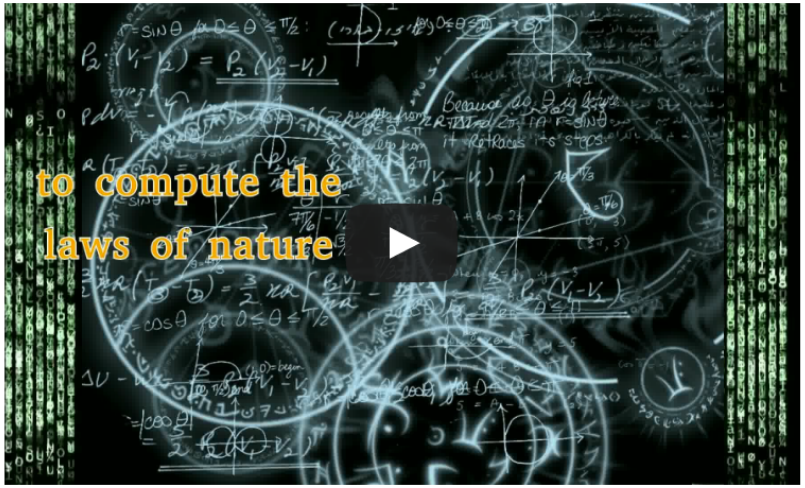
http://www.illustris-project.org/

Welcome

The Illustris project is a large cosmological simulation of galaxy formation, completed in late 2013, using a state of the art numerical code and a comprehensive physical model. Building on several years of effort by members of the collaboration, the Illustris simulation represents an unprecedented combination of high resolution, total volume, and physical fidelity. The About page contains detailed descriptions of the project, for both the general public and researchers in the field.

On this website we present the scientific motivation behind the project, a list of the collaboration members, key results and references, movies and images created from the simulation data, information on upcoming public data access, and tools for interactive data exploration. The short video below is a compilation made from some of the movies available on the Media page.

-The Illustris Collaboration



Recent News

Updates for the simulation and various related projects. Major changes to the website and information about a future public data release will be noted here.

25 December, 2014
Illustris included in Physics Database's Top Physics News of 2014 as the May entry.

17 November, 2014
The first data products are released (synthetic galaxy images at z=0), and user registration has been enabled.

16 July, 2014
Featured on the front page of the New York Times (see Press Page for story and video).

14 June, 2014
The timeframe for the full public data release of Illustris has been set as Q1 2015.

16 May, 2014
The third (and final) introductory paper for Illustris, Genel et al. (2014), is now available under Results.

13 May, 2014
The second introductory paper, Vogelsberger et al (2014b), is now available.

8 May, 2014
Illustris Nature article published.

5 May, 2014
Illustris website launched.

4 April, 2014
First Illustris paper accepted.

19 Oct, 2013
Large run finished on SuperMUC/CURIE.

We gratefully acknowledge support from linode