Joel Primack current research

- **Bolshoi** - best cosmological simulations using the latest cosmological parameters.
- Largest suite of **high-resolution zoom-in hydrodynamic galaxy simulations** compared with observations by CANDELS, the largest-ever Hubble Space Telescope project.
- Dust absorption and re-radiation of starlight in simulated galaxies using my group's **Sunrise** code used to make realistic images from our simulations.
- New methods for **comparison of simulated galaxies with observations**, including new statistical methods. Explain observed **galaxy clumps**, **compaction**, **elongation**.
- Co-leading with Piero Madau the Assembling Galaxies of Resolved Anatomy (**AGORA**) **international collaboration** to run and compare high-resolution galaxy simulations.
- Calculating and measuring **all the light in the universe**.

TASC

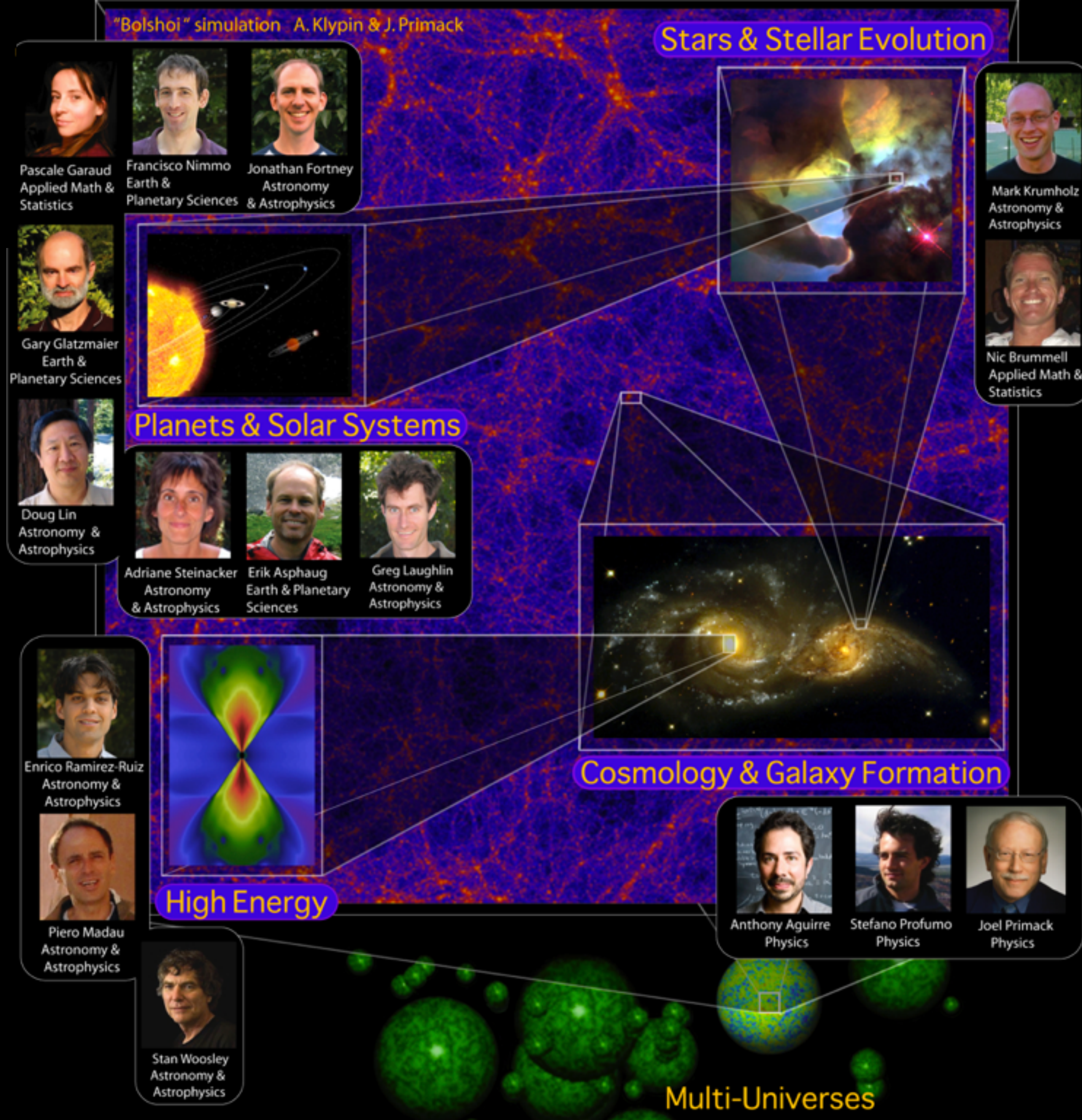
Theoretical Astrophysics Santa Cruz

New Astro Computer "**Hyades**"

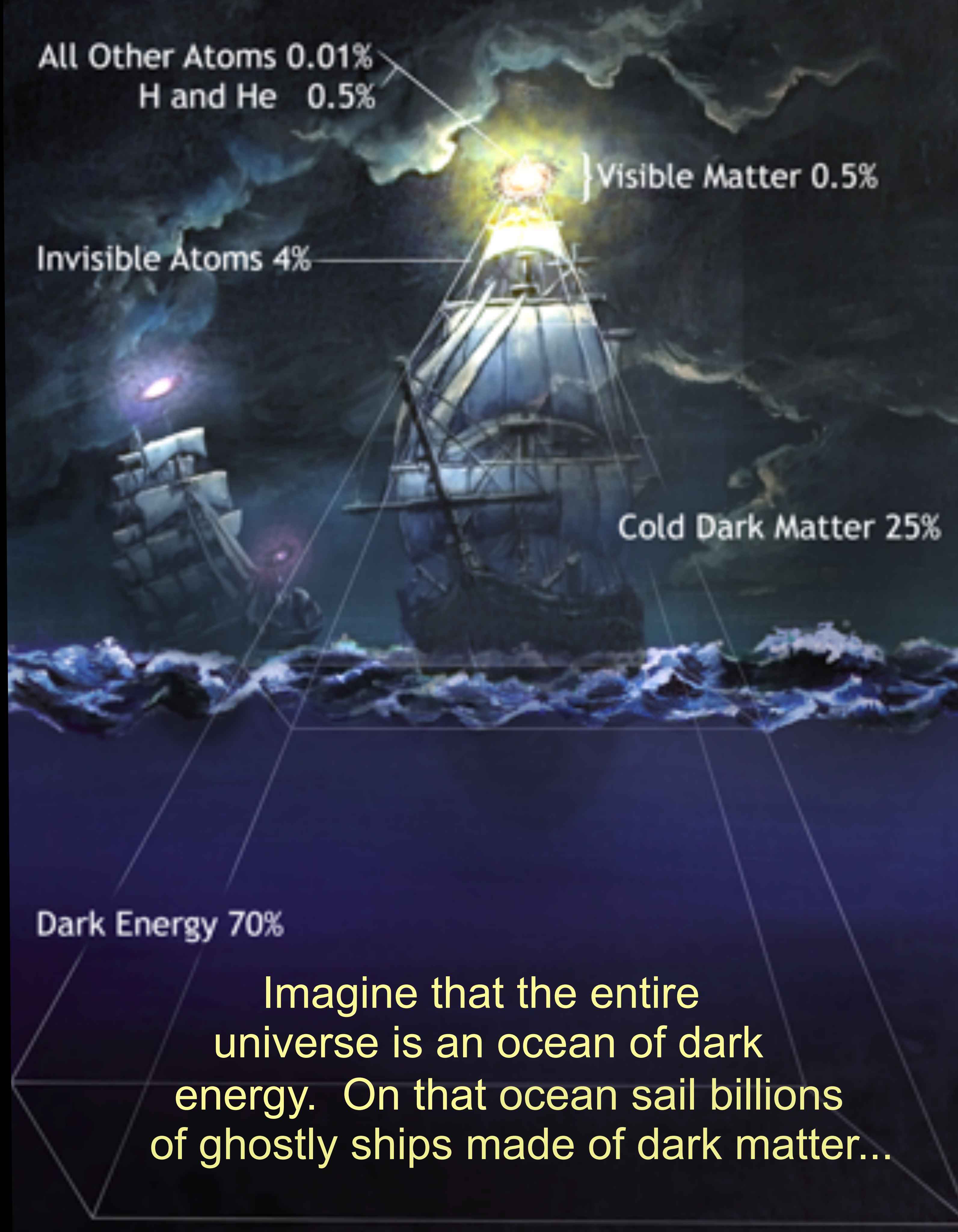
188 compute nodes each with 16 cores and 64 GB ram

+ analysis node w/ 32 cores+ 512 GB

+500 TB working disk
+1 PB online disk



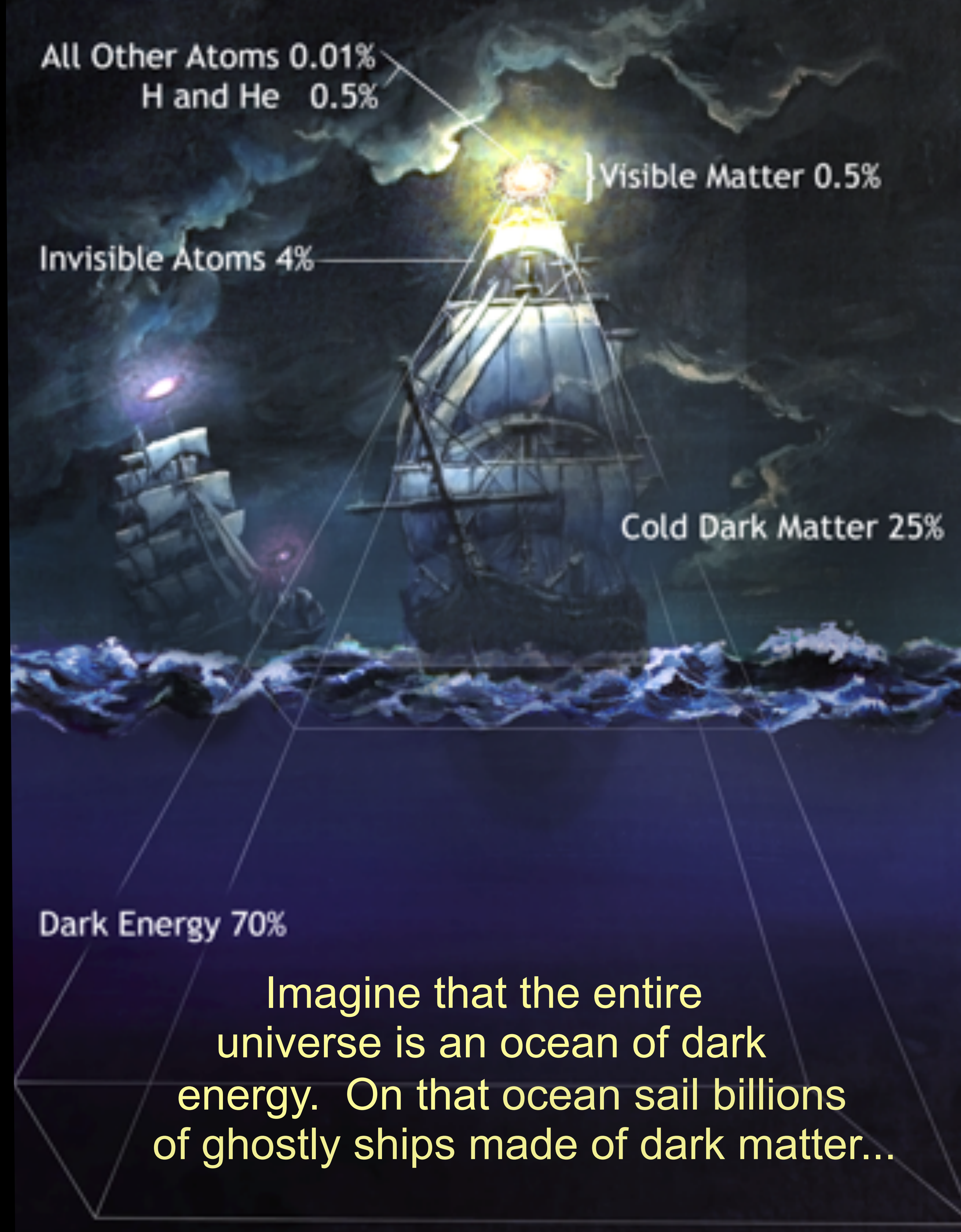
Matter and Energy Content of the Universe



Dark Matter Ships

on a

Dark Energy Ocean

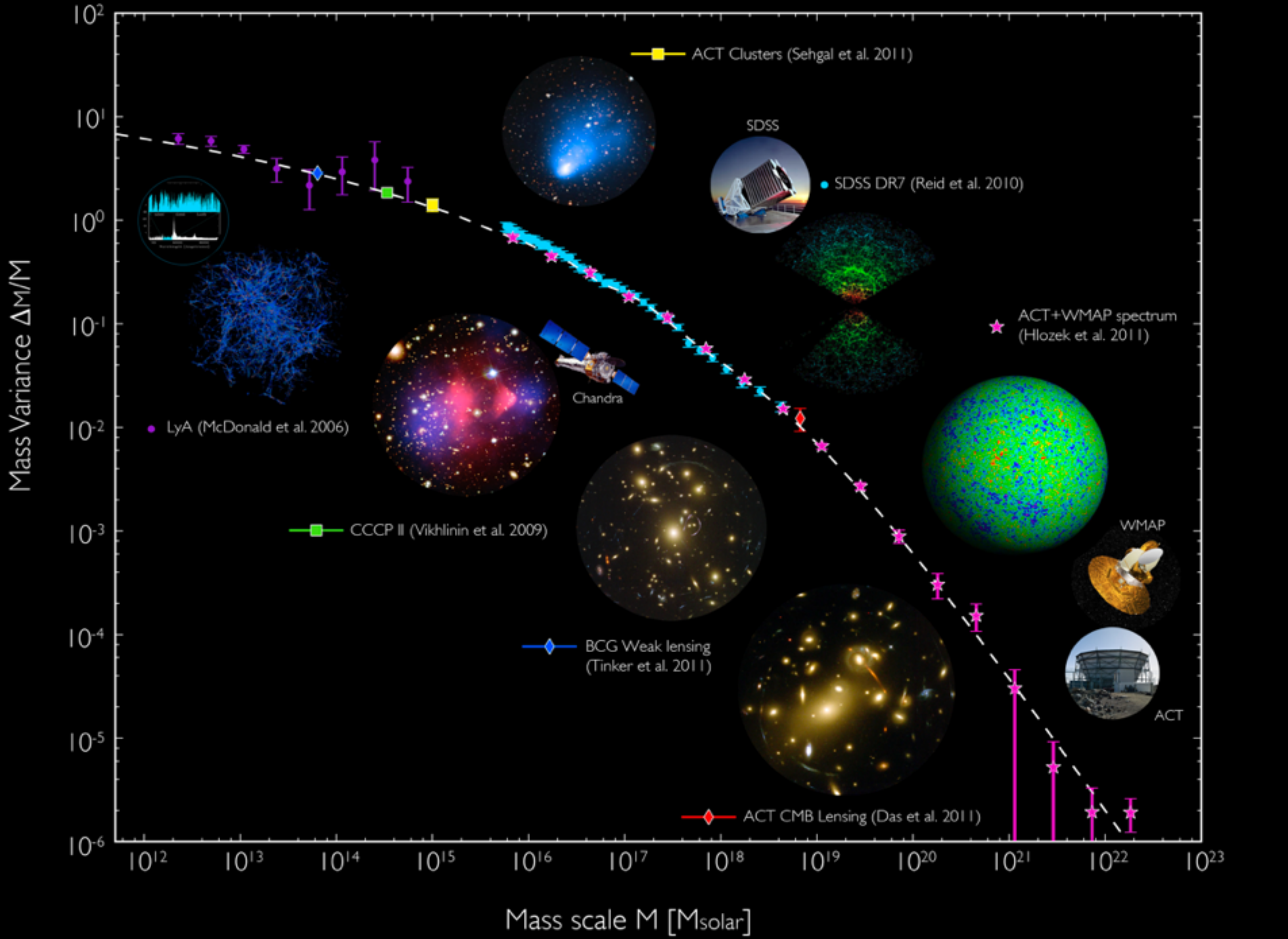


Matter and Energy Content of the Universe

ΛCDM

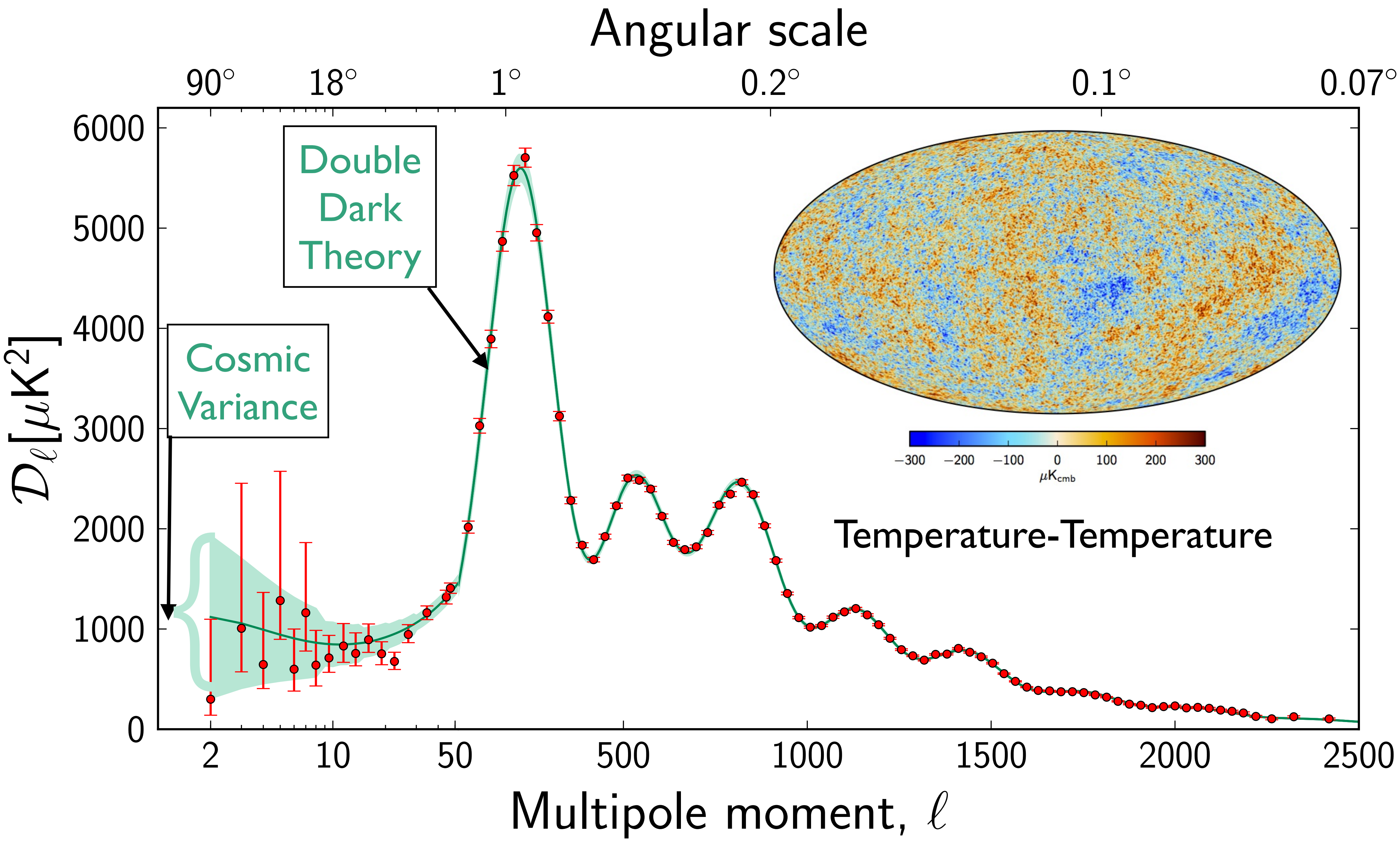
Double Dark Theory

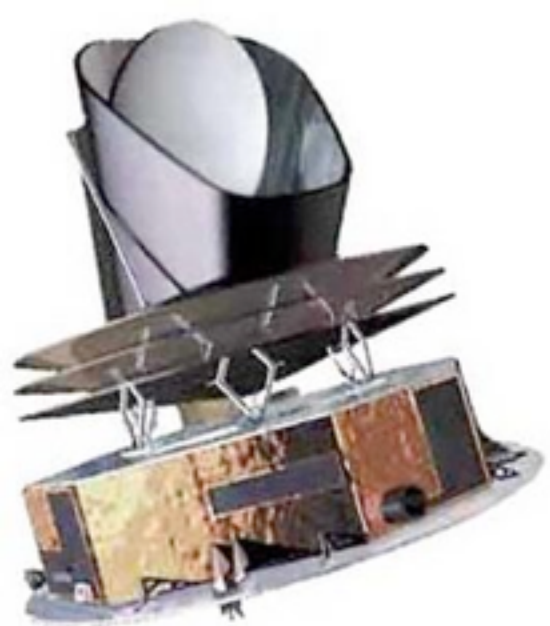
Matter Distribution Agrees with Double Dark Theory!

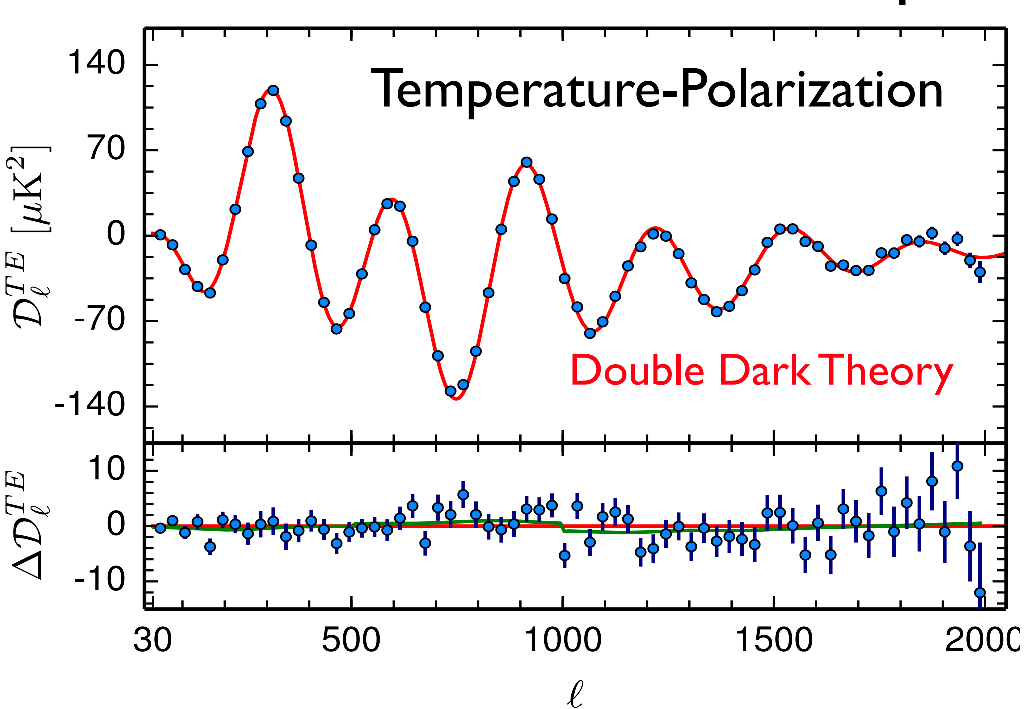


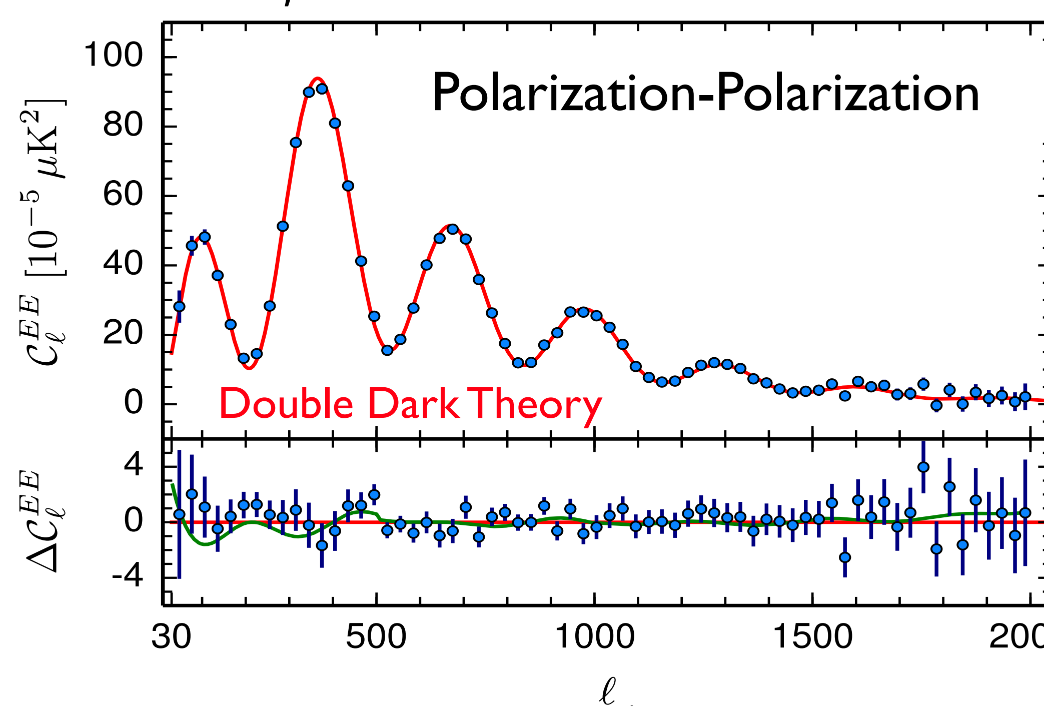
European Space Agency PLANCK Satellite Data

Released February 9, 2015

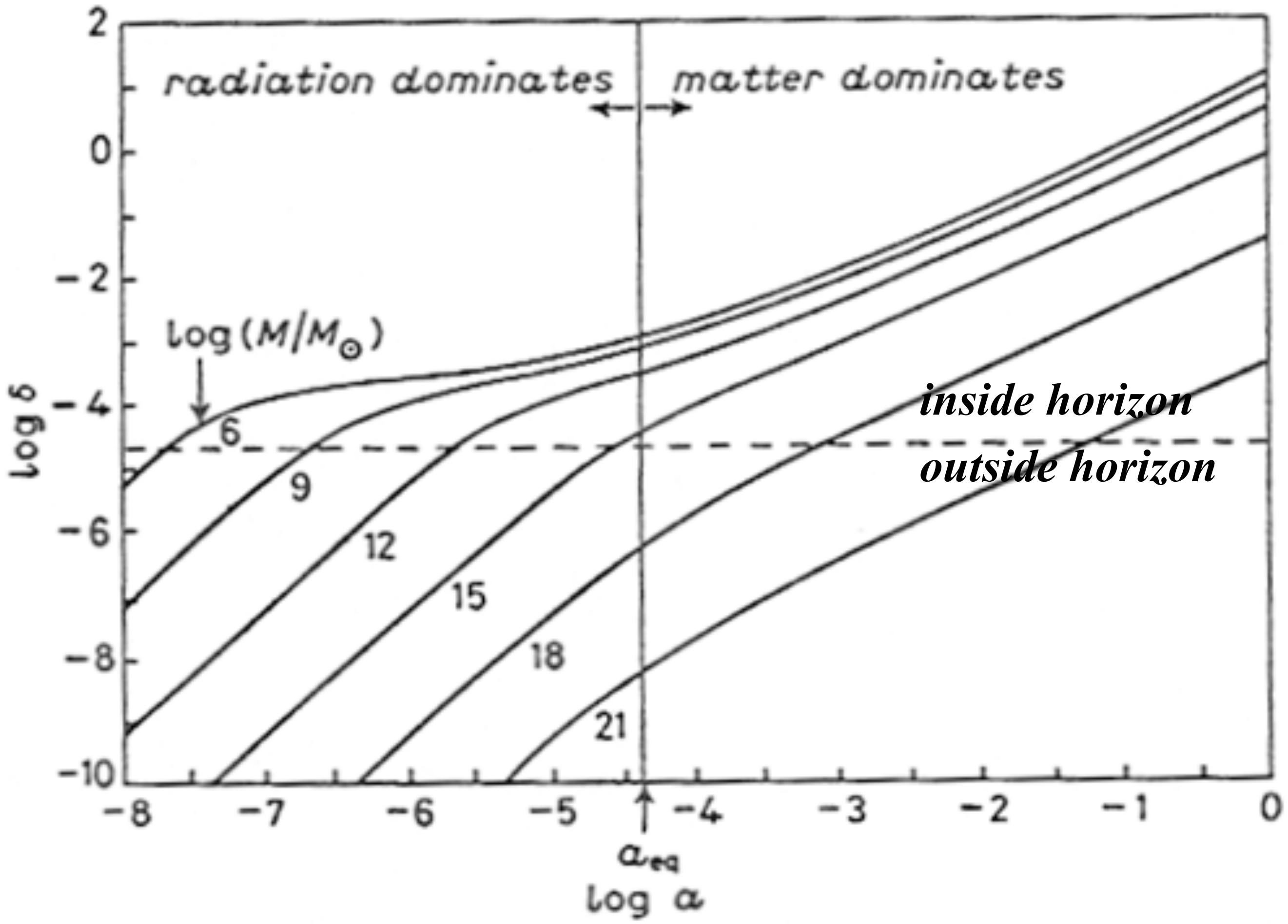






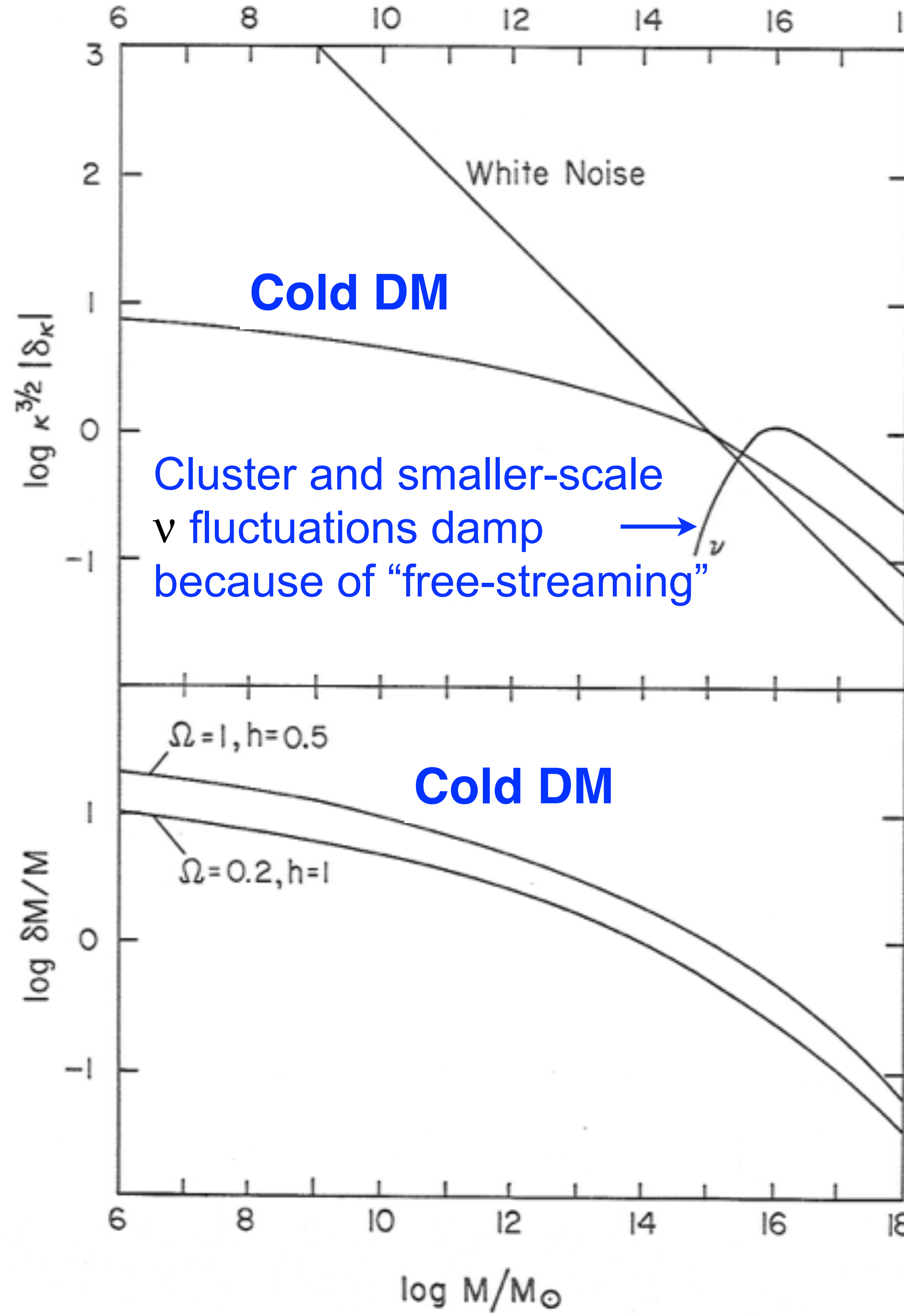


CDM Structure Formation: Linear Theory



CDM fluctuations that enter the horizon during the radiation dominated era, with masses less than about $10^{15} M_\odot$, grow only $\propto \log a$, because they are not in the gravitationally dominant component. But matter fluctuations that enter the horizon in the matter-dominated era grow $\propto a$. This explains the characteristic shape of the CDM fluctuation spectrum, with $\delta(k) \propto k^{-n/2-2} \log k$

Primack & Blumenthal 1983,
Primack Varenna Lectures 1984



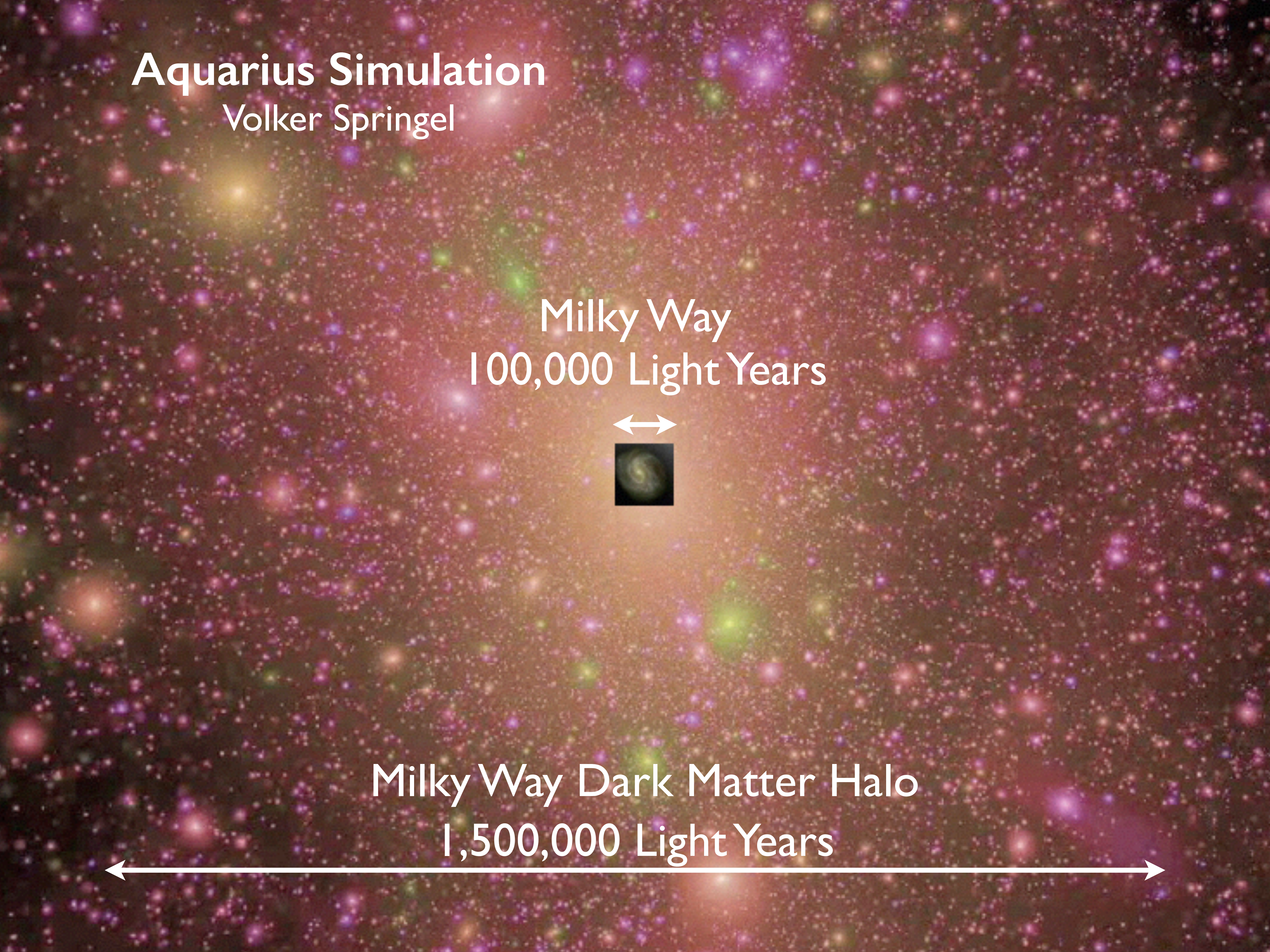
Blumenthal, Faber, Primack, & Rees 1984

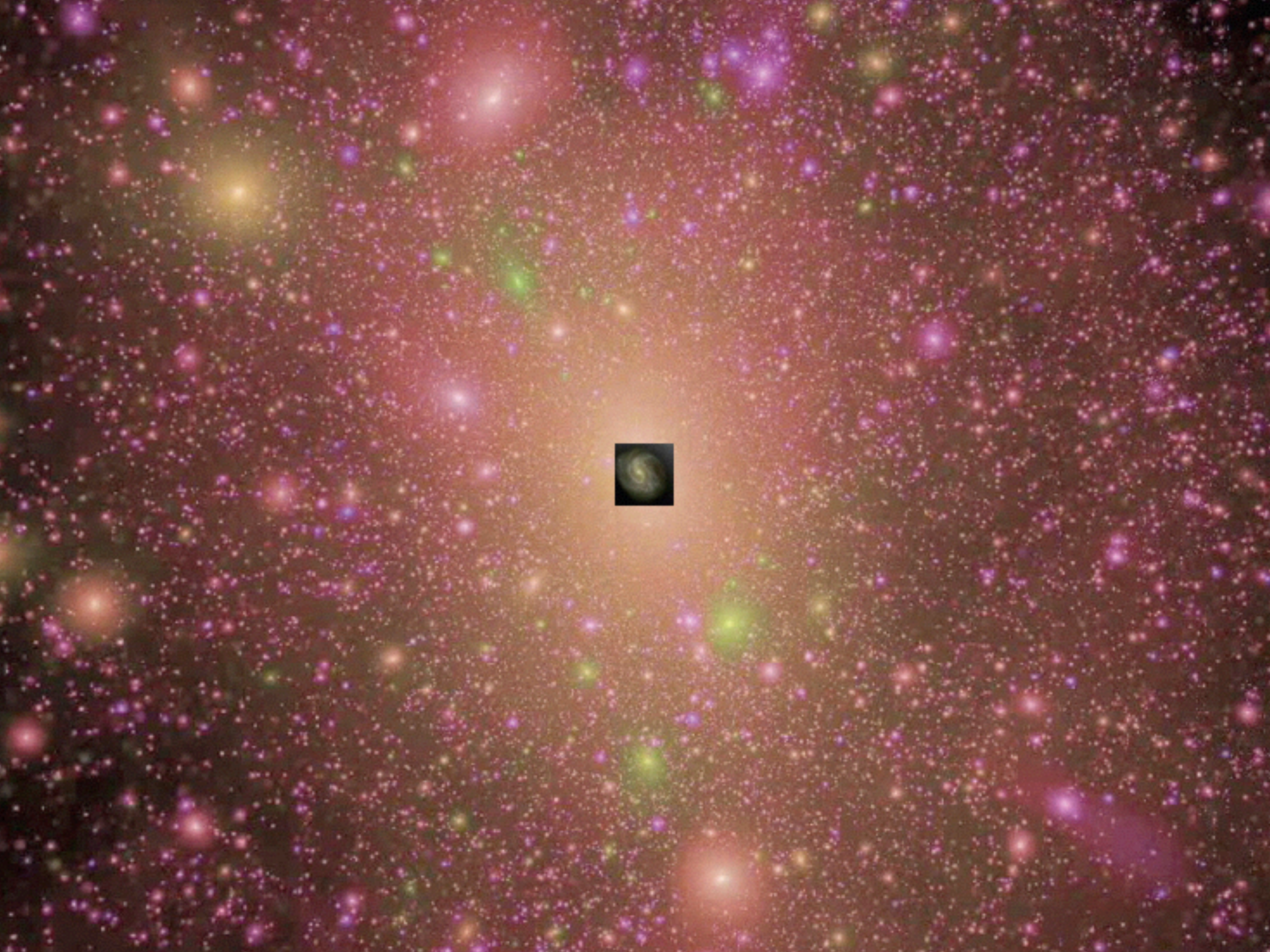
Cosmological Simulations

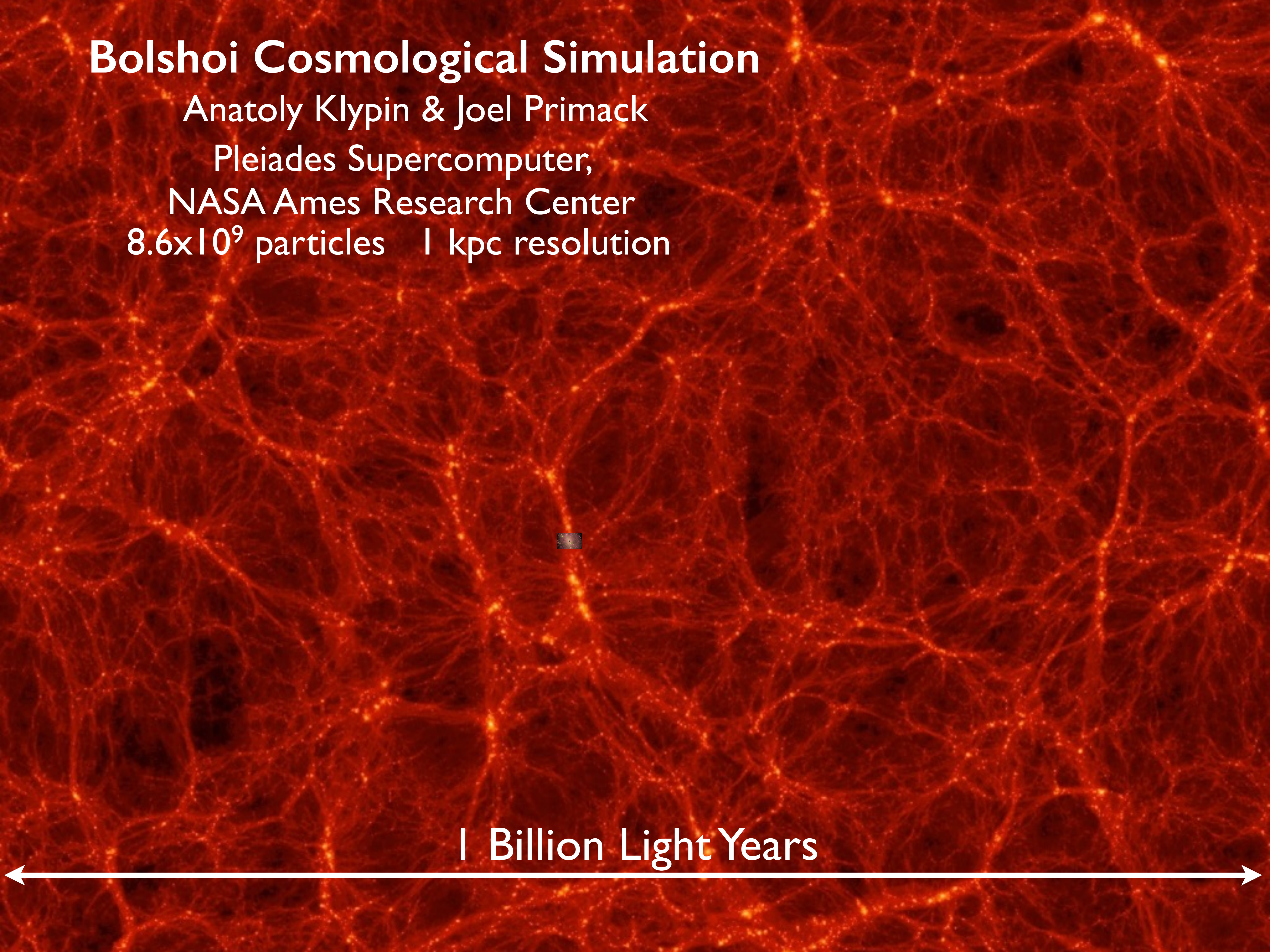
Astronomical observations represent snapshots of moments in time. It is the role of astrophysical theory to produce movies -- both metaphorical and actual -- that link these snapshots together into a coherent physical theory.

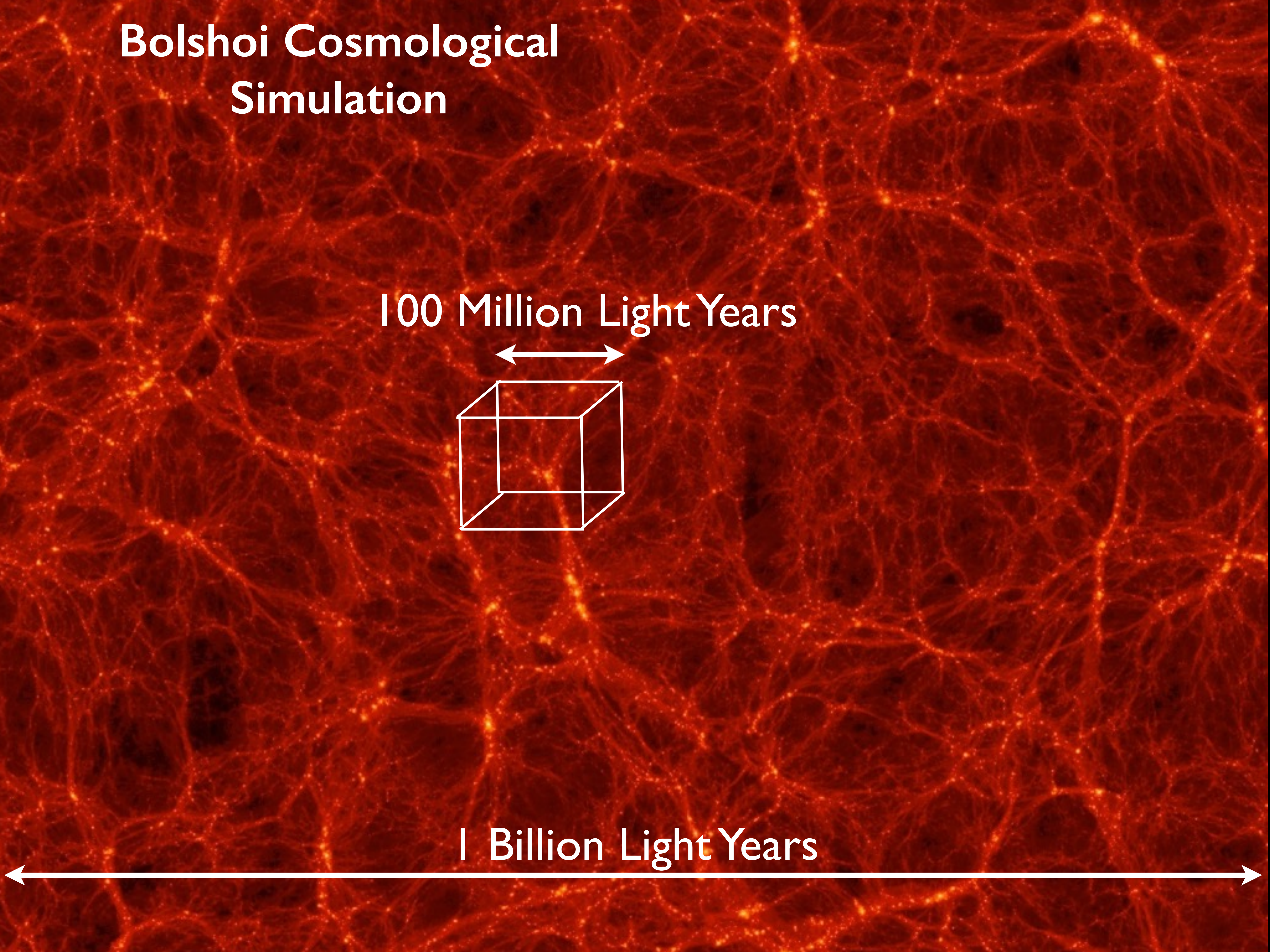
Cosmological dark matter simulations show large scale structure and dark matter halo properties, basis for semi-analytic models

Hydrodynamic galaxy formation simulations: evolution of galaxies, formation of galactic spheroids via mergers, galaxy images and spectra including stellar evolution and dust


Aquarius Simulation
Volker Springel
Milky Way
100,000 Light Years
Milky Way Dark Matter Halo
1,500,000 Light Years



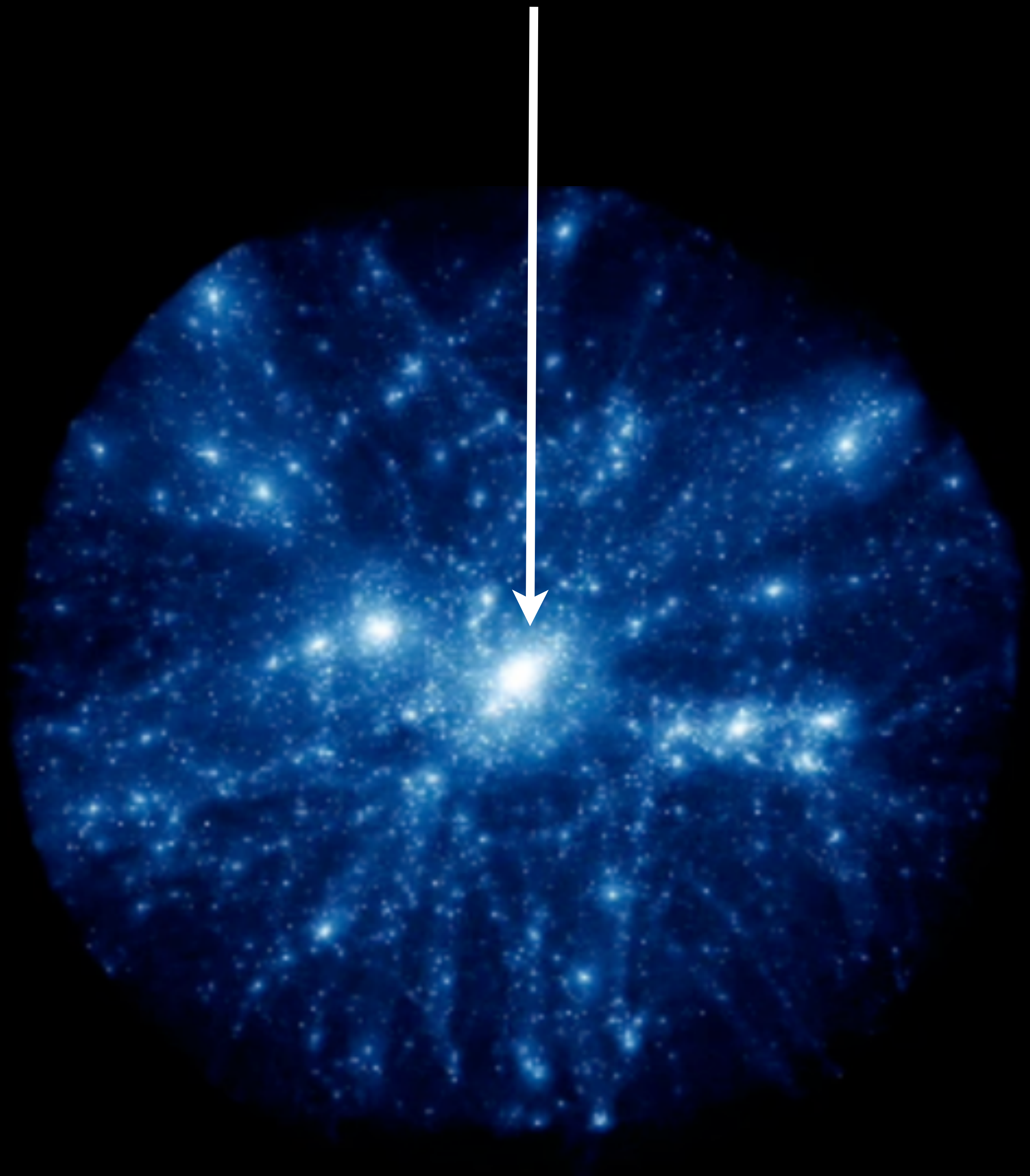

Bolshoi Cosmological Simulation
Anatoly Klypin & Joel Primack
Pleiades Supercomputer,
NASA Ames Research Center
8.6x10^9 particles   1 kpc resolution
1 Billion Light Years


Bolshoi Cosmological Simulation
100 Million Light Years
1 Billion Light Years

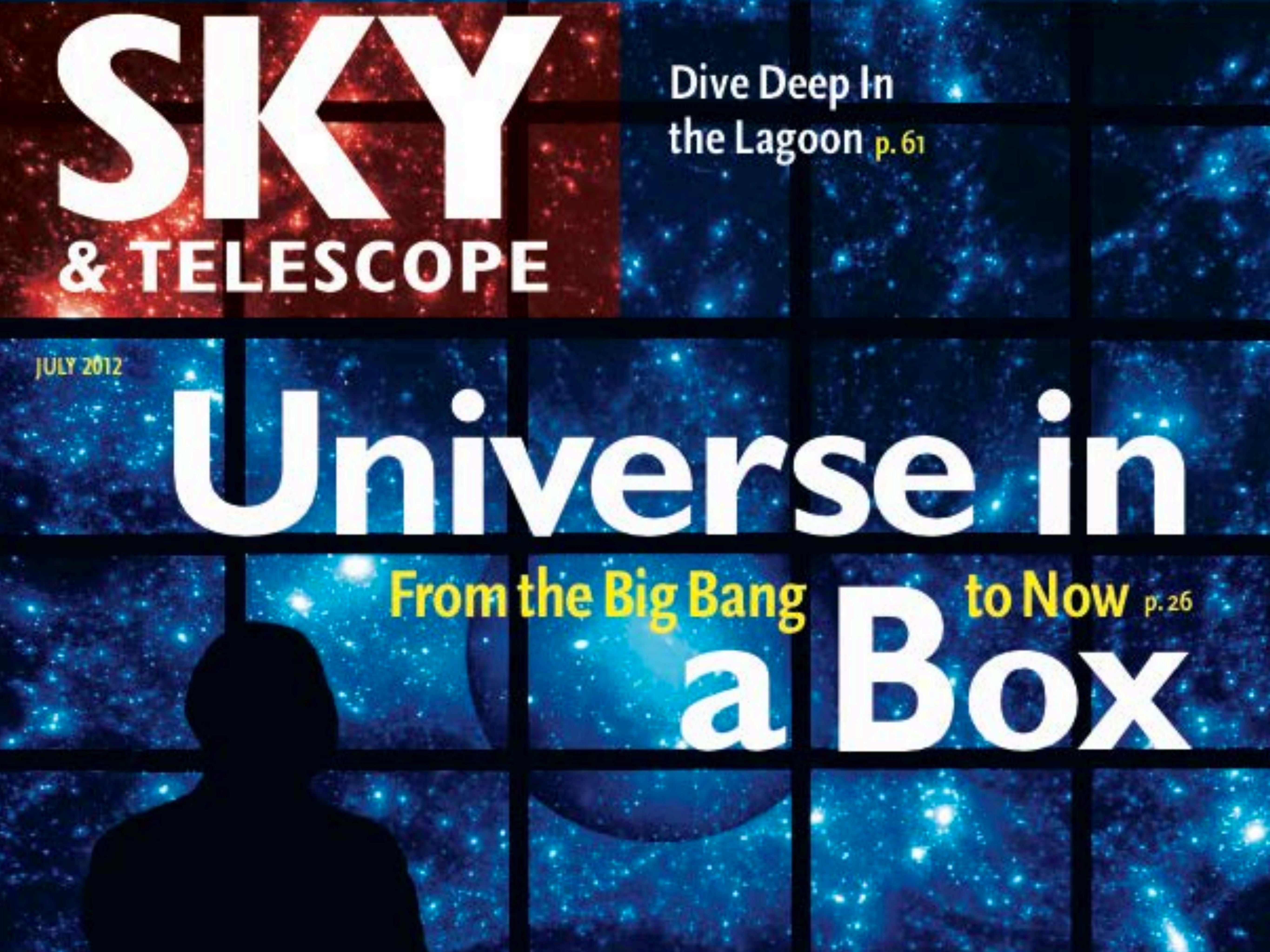
Bolshoi Cosmological Simulation

100 Million Light Years

How the Halo of the Big Cluster Formed



Bolshoi-Planck
Cosmological Simulation
Merger Tree of a Large Halo


SKY
& TELESCOPE
Dive Deep In
the Lagoon p. 61
JULY 2012
Universe in
a Box
From the Big Bang to Now p. 26

Cosmological Simulations

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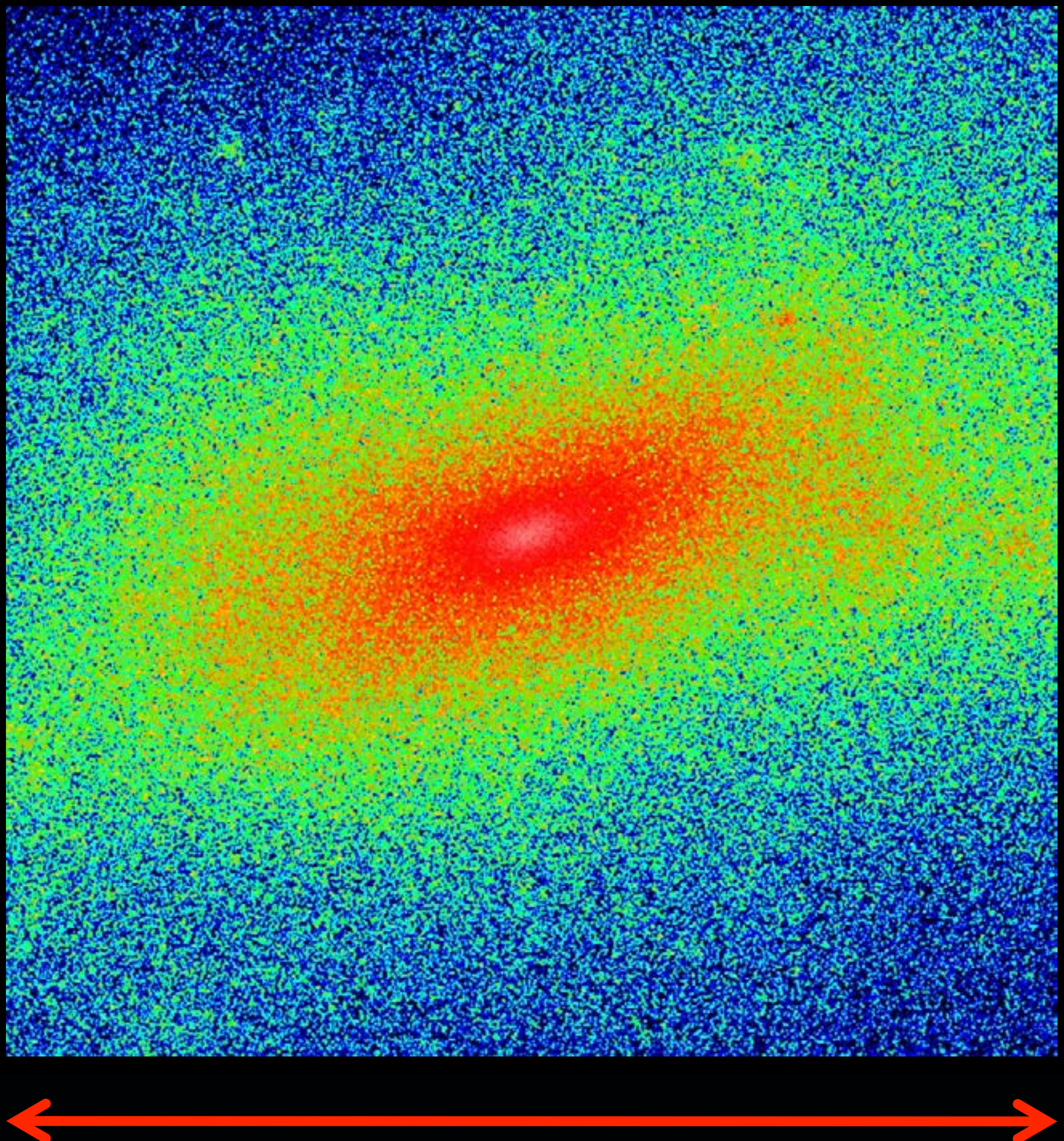
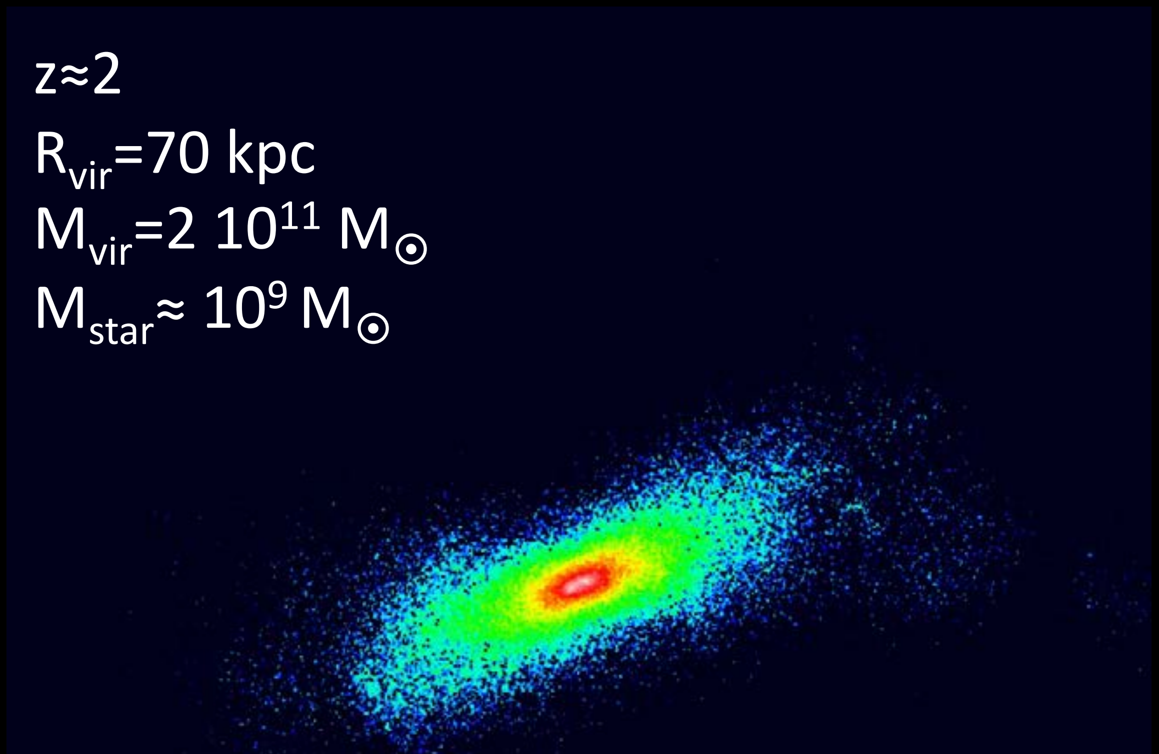
Cosmological dark matter simulations show large scale structure and dark matter halo properties, basis for semi-analytic models

Hydrodynamic galaxy formation simulations: evolution of galaxies, formation of galactic spheroids via mergers, galaxy images and spectra including stellar evolution and dust

Our cosmological zoom-in simulations often produce elongated galaxies like observed ones. The elongated distribution of stars follows the elongated inner dark matter halo.

Prolate DM halo → elongated galaxy

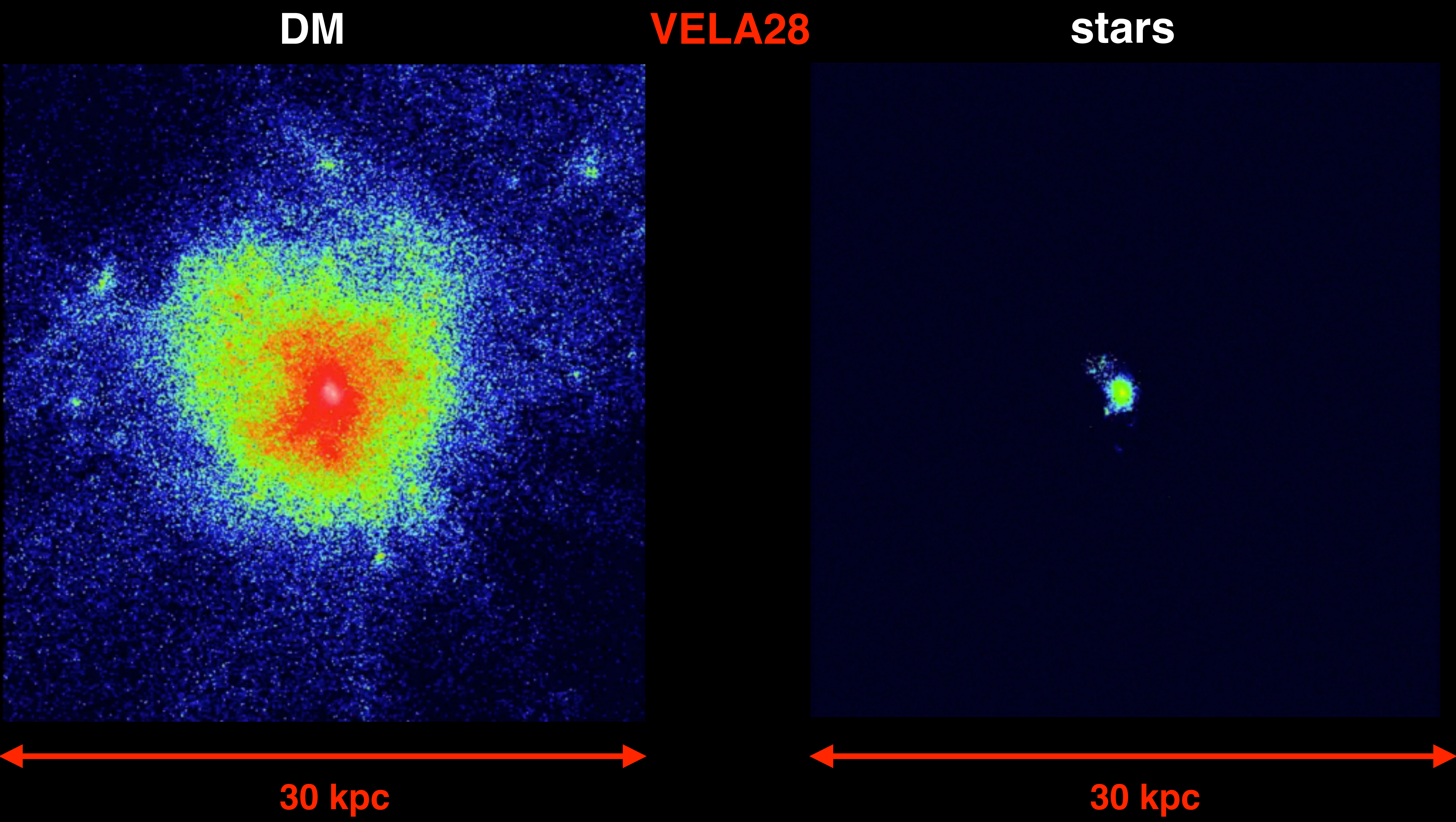




Dark matter halos are elongated, especially near their centers. Initially stars follow the gravitationally dominant dark matter, as shown. But later as the ordinary matter central density grows and it becomes gravitationally dominant, the star and dark matter distributions both become disky — as observed by Hubble Space Telescope (van der Wel+ ApJL Sept 2014).

Our cosmological zoom-in simulations often produce elongated galaxies like observed ones. The elongated distribution of stars follows the elongated inner dark matter halo. Here we show the evolution of the dark matter and stellar mass distributions in our zoom-in galaxy simulation VELA28, viewed from the same fixed vantage point.

VELA28



Most $M_* < 10^{9.5}\ M_\odot$ Star Forming Galaxies at $z > 1$ Are Prolate

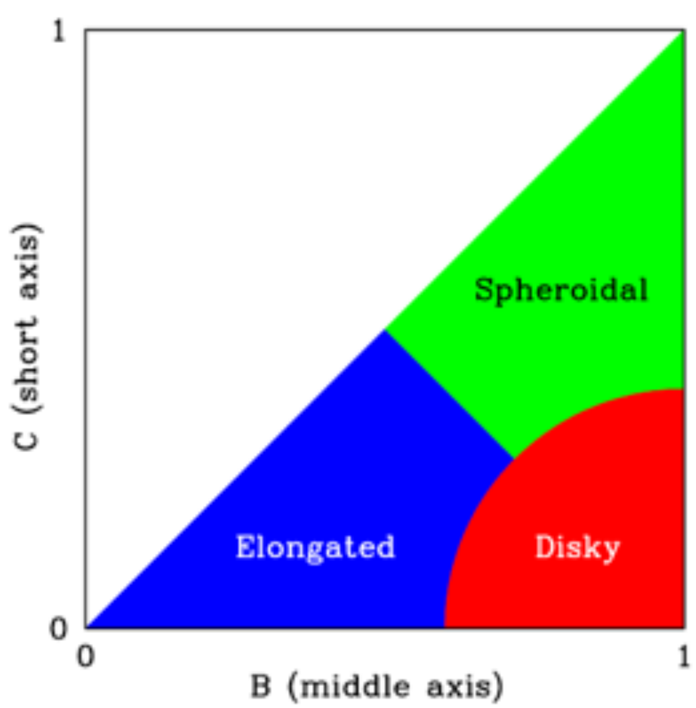
GEOMETRY OF STAR-FORMING GALAXIES FROM SDSS, 3D-HST AND CANDELS

A. van der Wel[1], Yu-Yen Chang[1], E. F. Bell[2], B. P. Holden[3], H. C. Ferguson[4], M. Giavalisco[5], H.-W. Rix[1], R. Skelton[6], K. Whitaker[7], I. Momcheva[8], G. Brammer[4], S. A. Kassin[4], A. Dekel[9], D. Ceverino[10], D. C. Koo[3], M. Mozena[3], P. G. van Dokkum[8], M. Franx[11], S. M. Faber[3], and J. Primack[12]

ApJL 2014

ABSTRACT

We determine the intrinsic, 3-dimensional shape distribution of star-forming galaxies at $0 < z < 2.5$, as inferred from their observed projected axis ratios. In the present-day universe star-forming galaxies of all masses $10^9 - 10^{11}\ M_\odot$ are predominantly thin, nearly oblate disks, in line with previous studies. We now extend this to higher redshifts, and find that among massive galaxies ($M_* > 10^{10}\ M_\odot$) disks are the most common geometric shape at all $z \lesssim 2$. Lower-mass galaxies at $z > 1$ possess a broad range of geometric shapes: the fraction of elongated (prolate) galaxies increases toward higher redshifts and lower masses. Galaxies with stellar mass $10^9\ M_\odot$ ($10^{10}\ M_\odot$) are a mix of roughly equal numbers of elongated and disk galaxies at $z \sim 1$ ($z \sim 2$). This suggests that galaxies in this mass range do not yet have disks that are sustained over many orbital periods, implying that galaxies with present-day stellar mass comparable to that of the Milky Way typically first formed such sustained stellar disks at redshift $z \sim 1.5 - 2$. Combined with constraints on the evolution of the star formation rate density and the distribution of star formation over galaxies with different masses, our findings imply that the majority of all stars across cosmic epochs formed in disks.



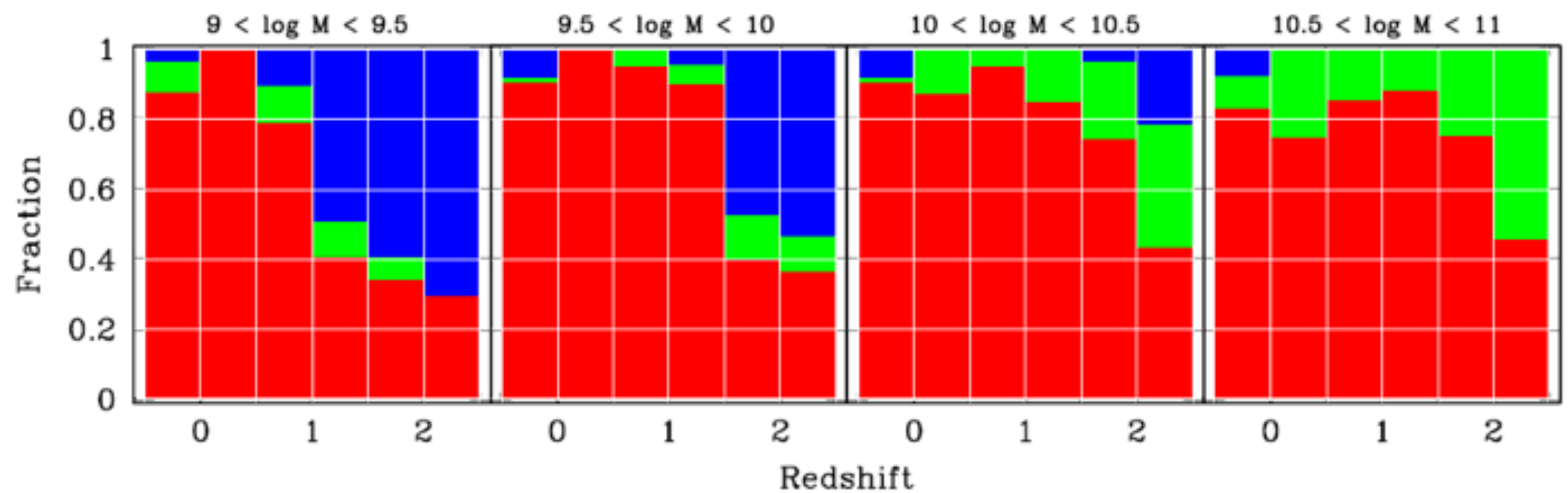
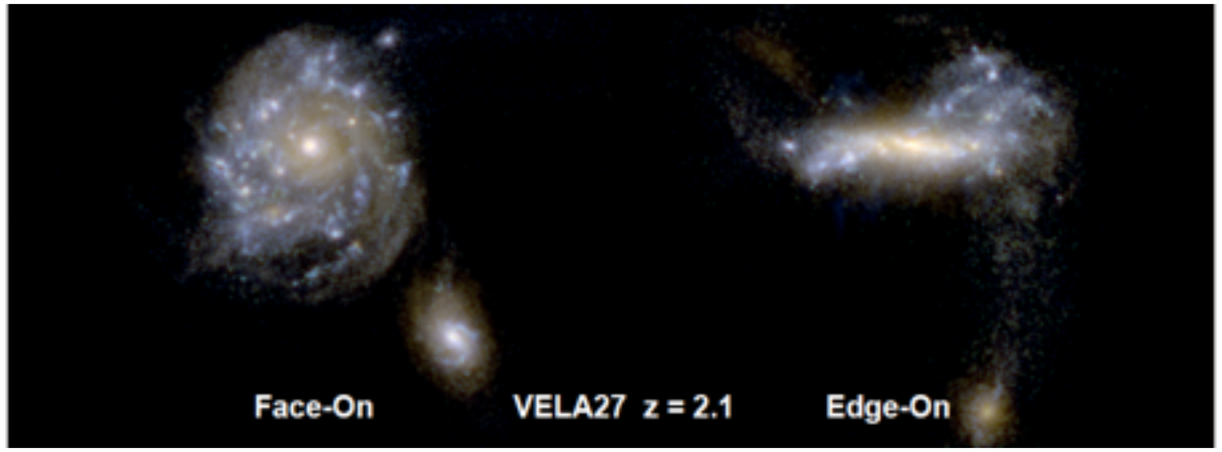
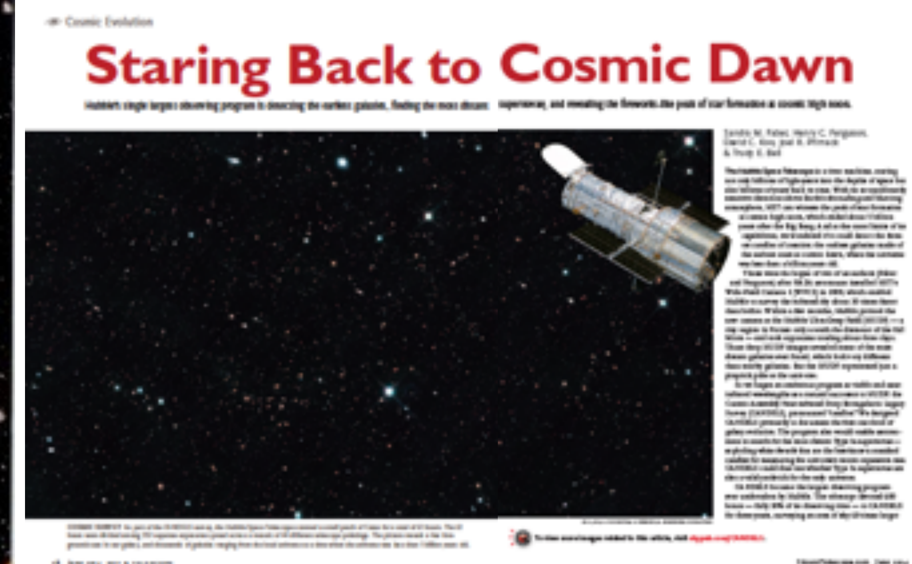


Figure 4. Color bars indicate the fraction of the different types of shape defined in Figure 2 as a function of redshift and stellar mass. The negative redshift bins represent the SDSS results for $z < 0.1$; the other bins are from 3D-HST/CANDELS.

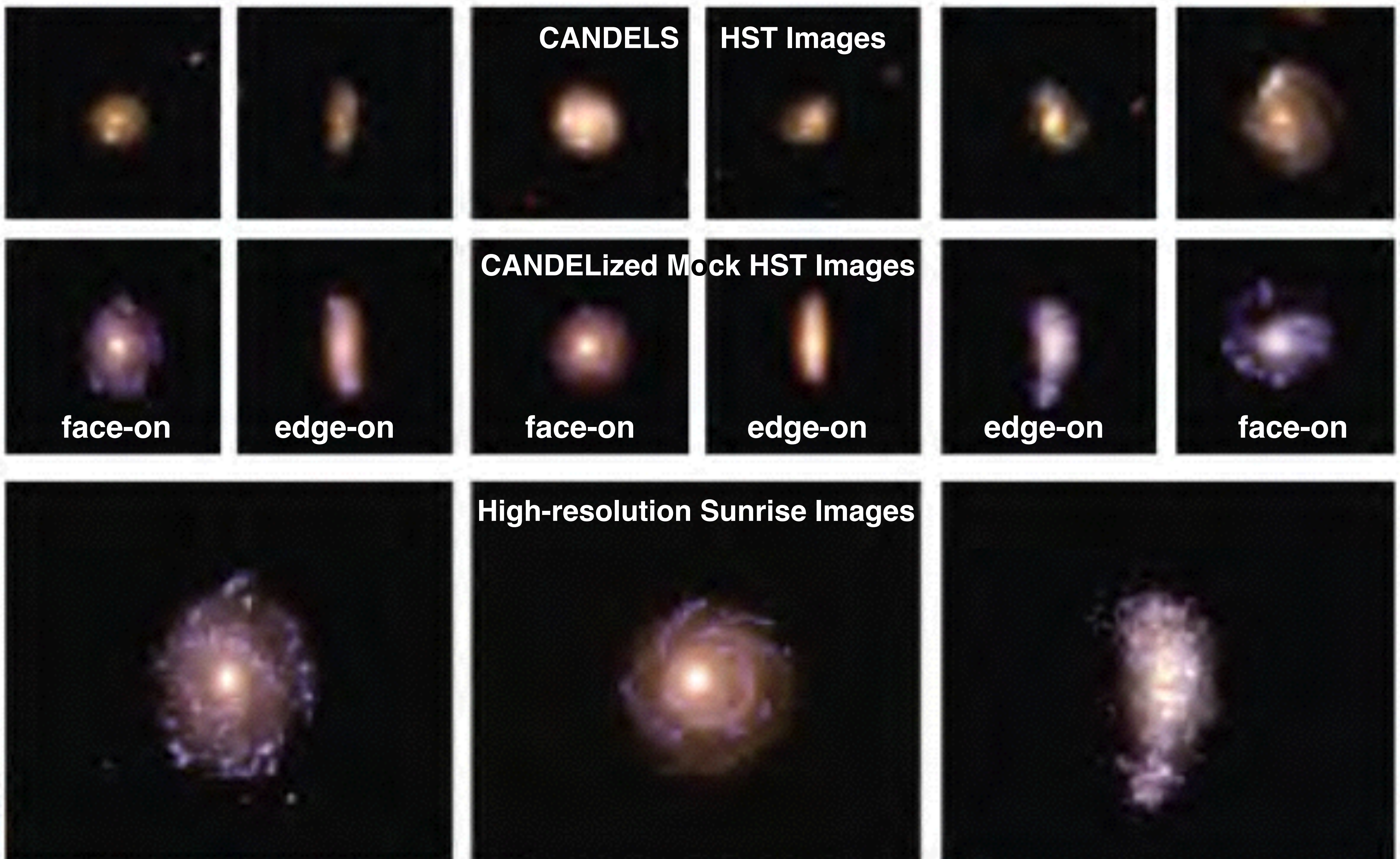
High-resolution Sunrise Images



http://hipacc.ucsc.edu/NewsArchive/June2014-S&T-CANDELS-CoverStory.pdf



From June 2014 *Sky & Telescope* article



CLUMPY GALAXIES
Top row: Six galaxies from CANDELS are seen when the universe was 4 to 6 billion years old. *Middle row:* These computer simulation frames show three disk galaxies as if imaged by CANDELS when viewed roughly face-on (*left of pair*) and edge-on (*right*). *Bottom row:* This is how these galaxies would appear if we could see them closer up from one angle. All three are about 4 billion years old and have large clumps of rapidly forming stars ignited by instabilities in their disks.

Scientific American, June 2015

All the Light There Ever Was . . .

Galaxies in every corner of the universe have been sending out photons, or light particles, since the beginning of time. Astronomers are now beginning to read this extragalactic background light.

By Alberto Domínguez, Joel R. Primack and Trudy E. Bell

Joel Primack RECENT PhD STUDENTS

Rachel Somerville (PhD 1997) Jerusalem (postdoc) – Cambridge (postdoc) – Michigan (Asst. Prof.) – MPI Astronomy Heidelberg (Professor) – STScI/Johns Hopkins – Rutgers (Professor)
Michael Gross (PhD 1997) Goddard (postdoc) – UCSC (staff) – NASA Ames (staff)
James Bullock (PhD 1999) Ohio State – Harvard (Hubble Fellow) – UC Irvine (Professor)
Ari Maller (PhD 1999) Jerusalem – U Mass Amherst (postdoc) – CityTech CUNY (Assoc. Prof.)
Risa Wechsler (PhD 2001) Michigan – Chicago (Hubble Fellow) – Stanford U (Assoc. Prof.)
T. J. Cox (PhD 2004) Harvard (postdoc, Keck Fellow) – Carnegie Observatories (postdoc) – Data Scientist at Voxer, San Francisco
Patrik Jonsson (PhD 2004) UCSC (postdoc) – Harvard CfA (staff) – SpaceX senior programmer
Brandon Allgood (PhD 2005) – Numerate, Inc. (co-founder)
Matt Covington (PhD 2008) – analytic understanding of galaxy mergers, semi-analytic models of galaxy formation – U Minn (postdoc) – U Arkansas (Asst. Prof.)
Greg Novak (PhD 2008) – running and comparing galaxy merger simulations with observations – Princeton (postdoc) – Inst Astrophysique Paris (postdoc) – Data Scientist at Stich Fix
Christy Pierce (PhD 2009) – AGN in galaxy mergers – Georgia Tech (postdoc) – teaching
Rudy Gilmore (PhD 2009) – WIMP properties and annihilation; extragalactic background light and gamma ray absorption – SISSA, Trieste, Italy (postdoc), Data Scientist at TrueCar, L.A.
Alberto Dominguez (PhD 2011) – UCR (postdoc) - Clemson U (postdoc)
Lauren Porter (PhD 2013) – semi-analytic models vs. observations - Data Scientist at Groupon
Chris Moody – analysis of high-resolution galaxy simulations: galaxy morphology transformations (PhD 2014) – Data Scientist at Square, San Francisco

Joel Primack CURRENT PhD STUDENTS

Christoph Lee – galaxy morphology: simulations vs. observations

Here are some projects that I think might work for our SIP students this summer:

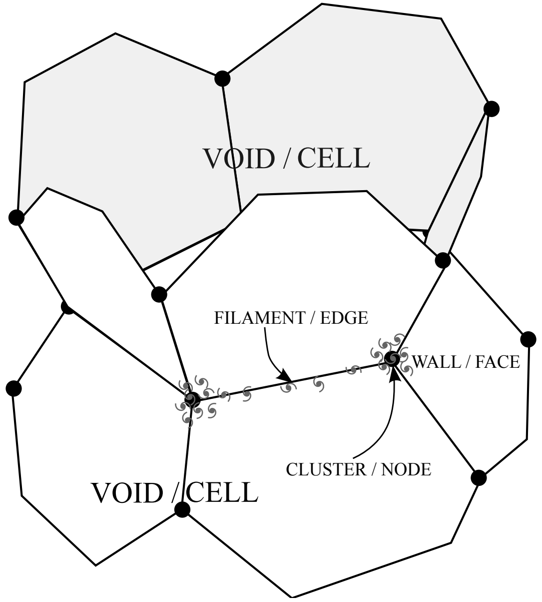
1. **Find the distribution of Oblate (disky), Spheroidal, and Prolate stellar axis ratios b/a that best fit the CANDELS data on b/a vs. a.** In the van der Wel et al. 2014 paper, only the b/a distribution was used. We can do better using the long axis a in addition to b/a. This is basically a geometrical and numerical exercise, so it will not require that the student know much astrophysics. But if we want to include some astrophysics, we can also use the attenuation and Sersic indices that are also measured for all these galaxies.

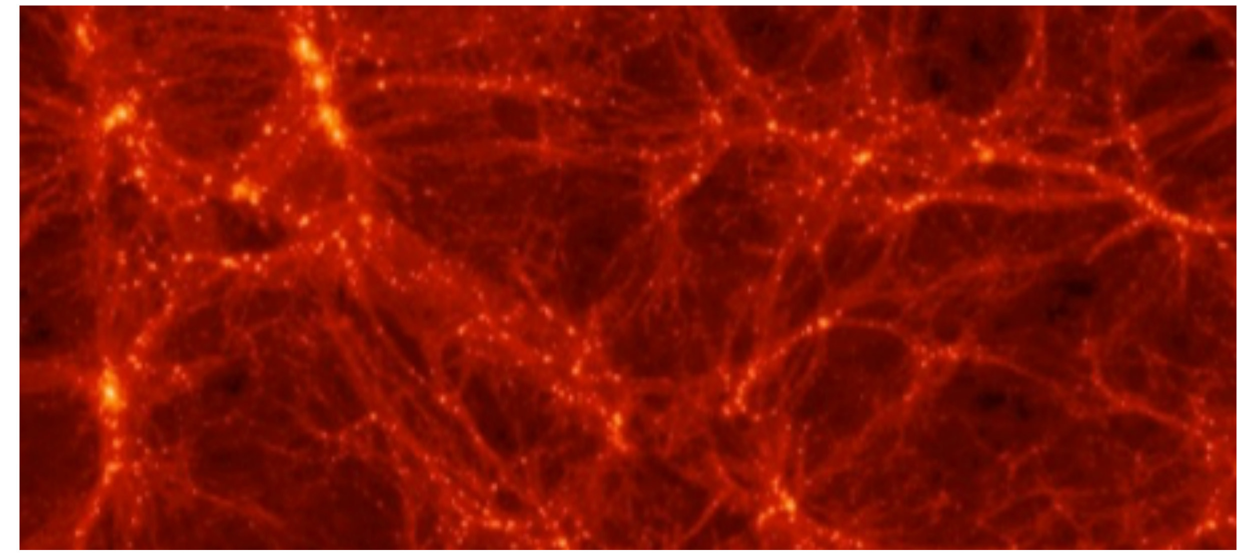
2. **Find the radial distributions of dark matter in stripped dark matter halos**, and determine a good fitting function with presumably a steeper radial falloff than $1/r^3$. See if the radial distribution is different for different NFW concentrations, for backsplash halos (those that were inside a bigger halo) vs. non-backsplash, or in different environments. See if the radial distribution correlates with spin or shape. This is part of Christoph's project on stripped halos. Again, this is essentially a geometrical exercise requiring little knowledge of astrophysics, but with astrophysical implications.

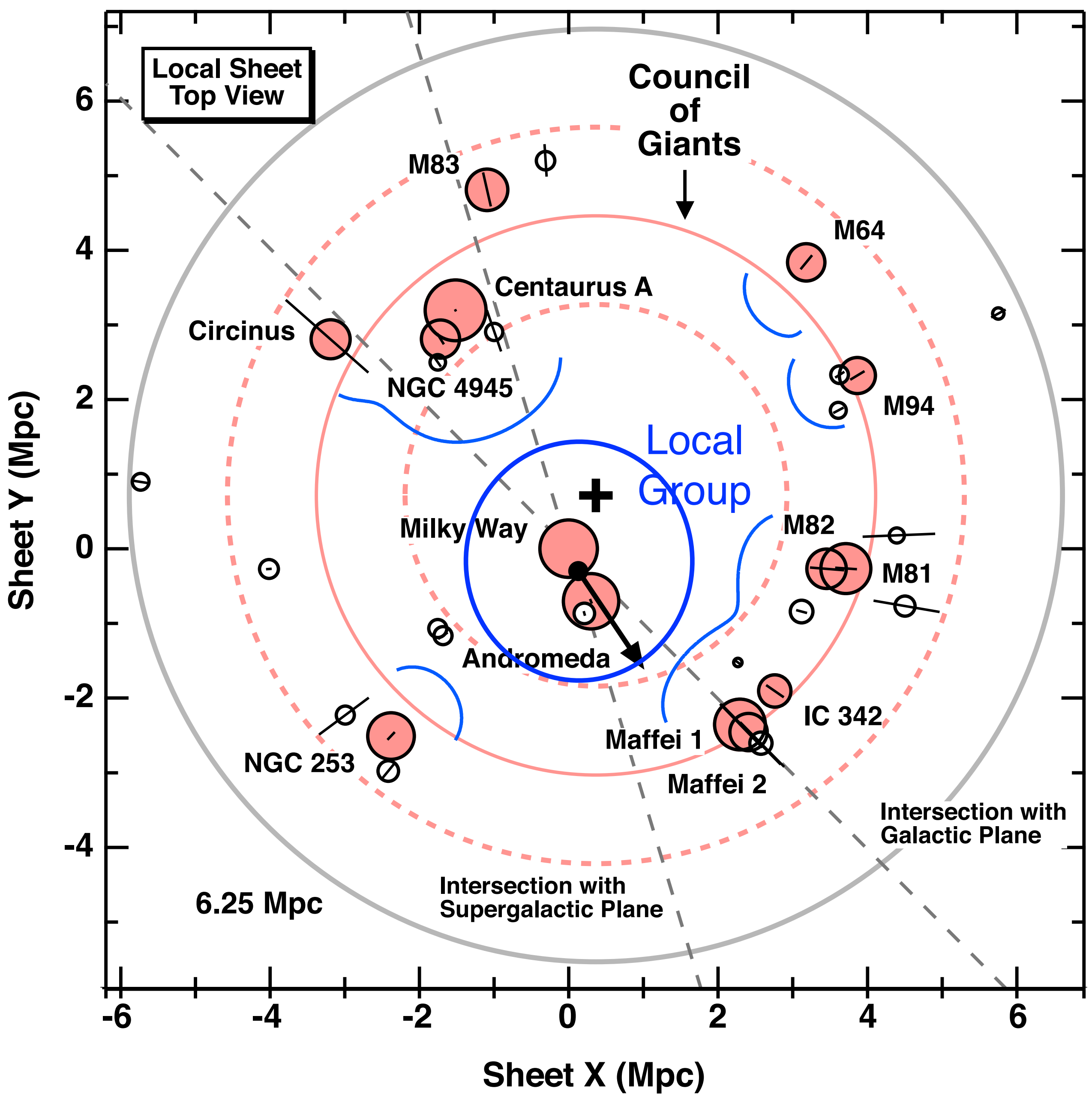
3. Fill Bolshoi-Planck halos with galaxies using abundance matching, age matching, or SAM, and then **work out the angular power spectrum of the light distribution** around points in the simulation that represent possible locations of the Milky Way. This can be compared with the purported detection of what appear to be excess extragalactic light fluctuations at large angular scales up to ~1 degree (e.g., Seo et al. 2015 http://arxiv.org/abs/1504.05681). This is also essentially a geometrical exercise requiring little knowledge of astrophysics, but with astrophysical implications.

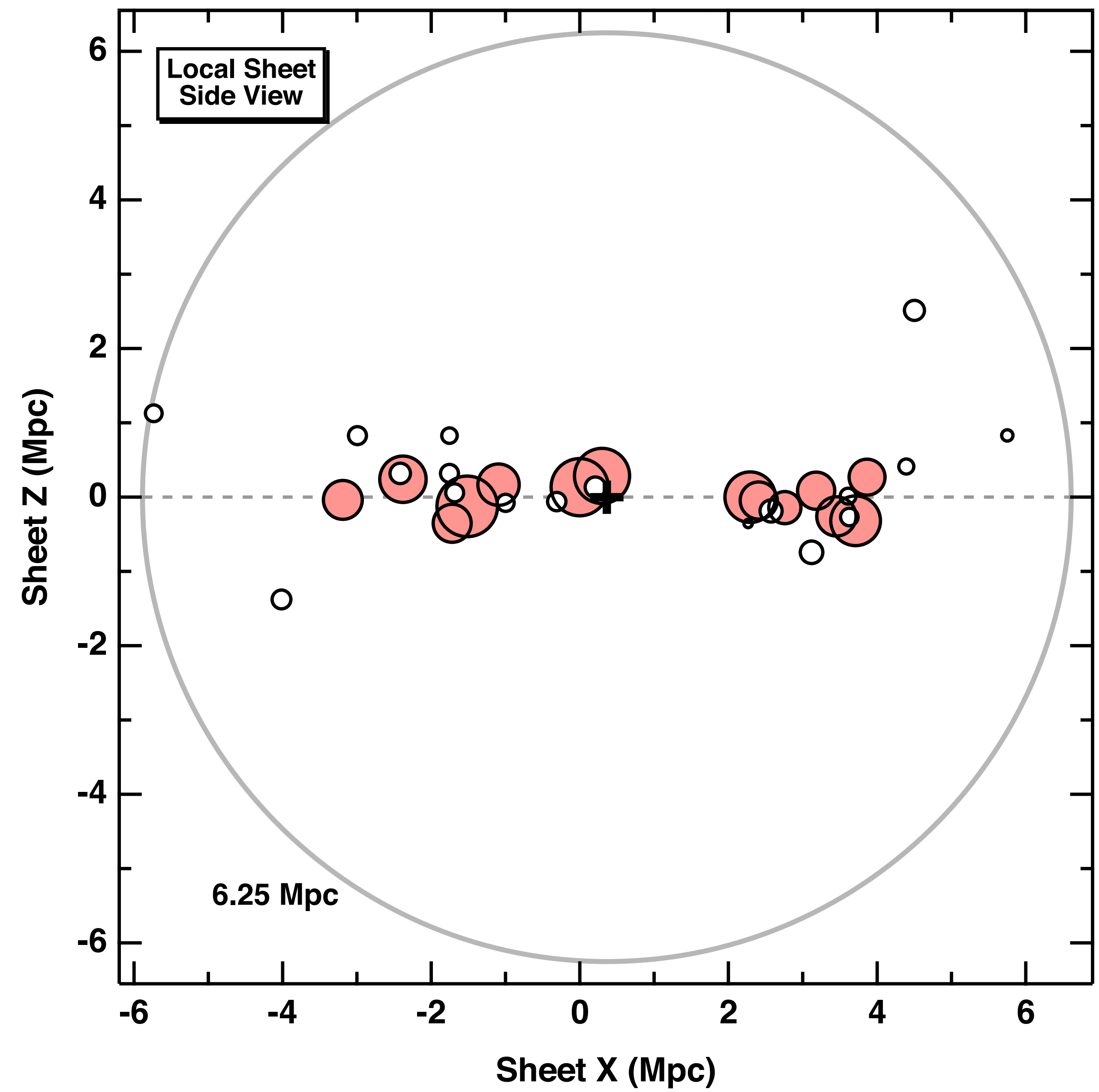
4. **Find sheets in the Bolshoi-Planck simulation using the cosmic web** information from Miguel Aragon, and determine the properties of dark matter halos in the middle of small sheets like the Local Sheet (McCall 2014). See if those halos are in any way distinctive, which will have implications for galaxies like the Milky Way and Andromeda and their satellite populations.

The **Cosmic Web** is composed of Voids, Sheets, Filaments, and Nodes (where filaments cross).









THANKS!