Simulating and Visualizing the Universe

Joel Primack, University of California, Santa Cruz

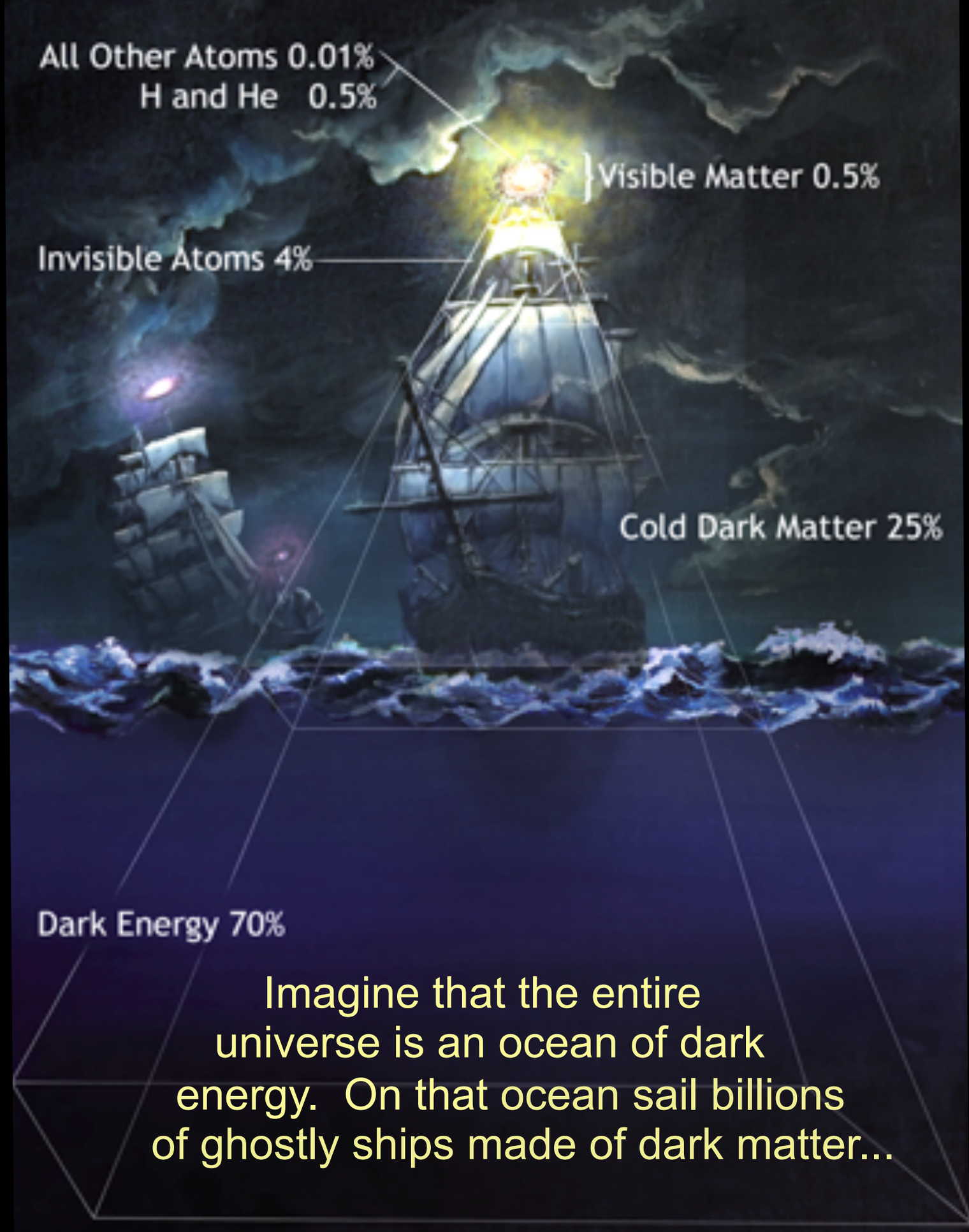
HUAWEI | HCC 2012

Simulating and Visualizing the Universe

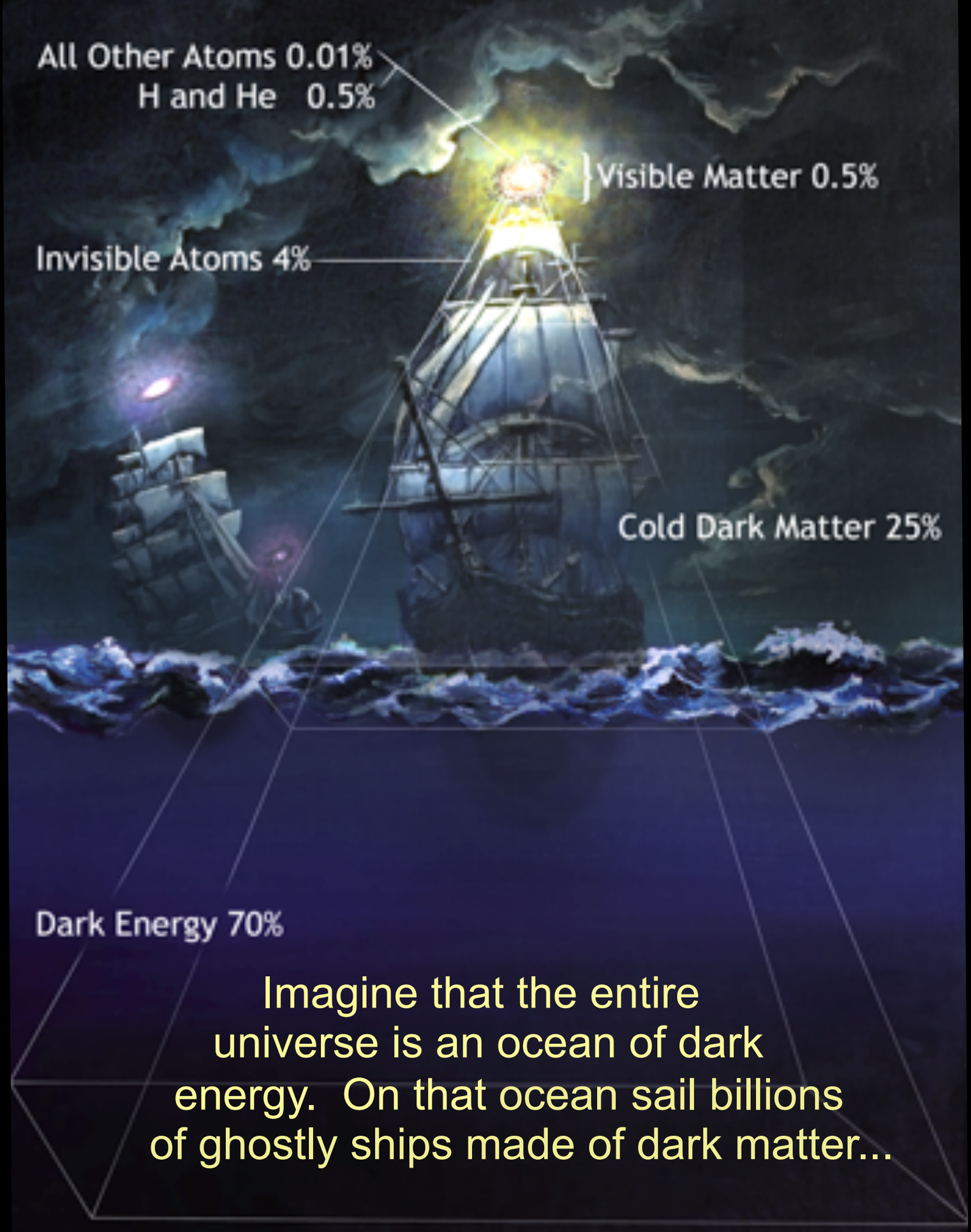
Joel Primack, University of California, Santa Cruz

1. The Double Dark Universe
2. Where We are in the Big Picture
3. The Universe is a Sponge
4. How We Know It's true
5. The Big New Questions Now

Matter and Energy Content of the Universe



Dark Matter Ships on a Dark Energy Ocean



Matter and Energy Content of the Universe

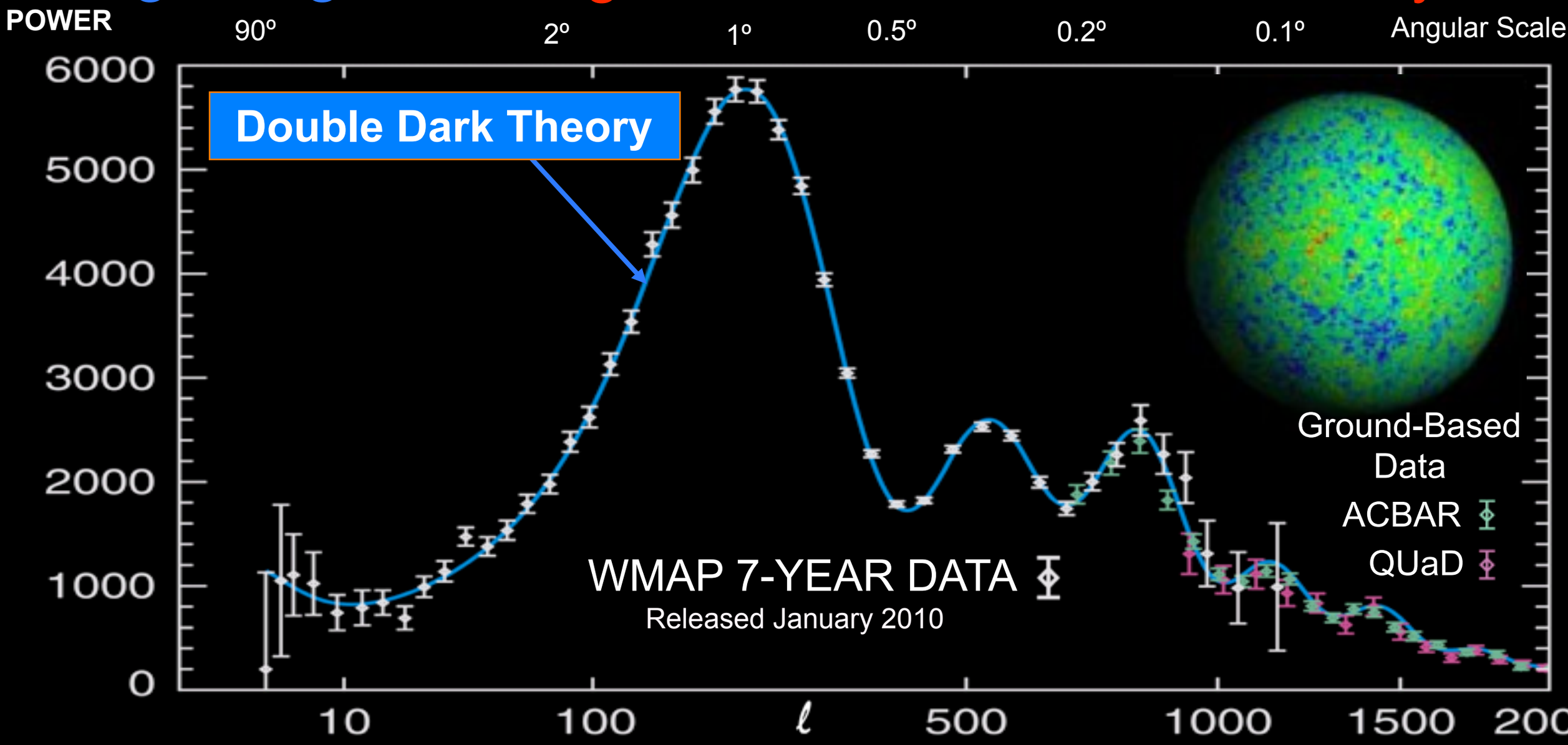
ΛCDM

Double Dark Theory

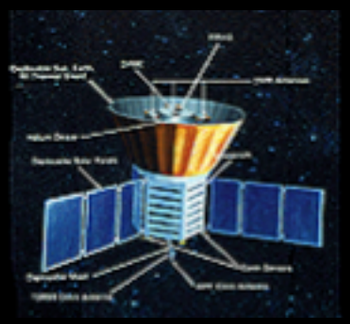
DARK MATTER + DARK ENERGY = DOUBLE DARK THEORY

Technical Name:
Lambda Cold Dark Matter (ΛCDM)

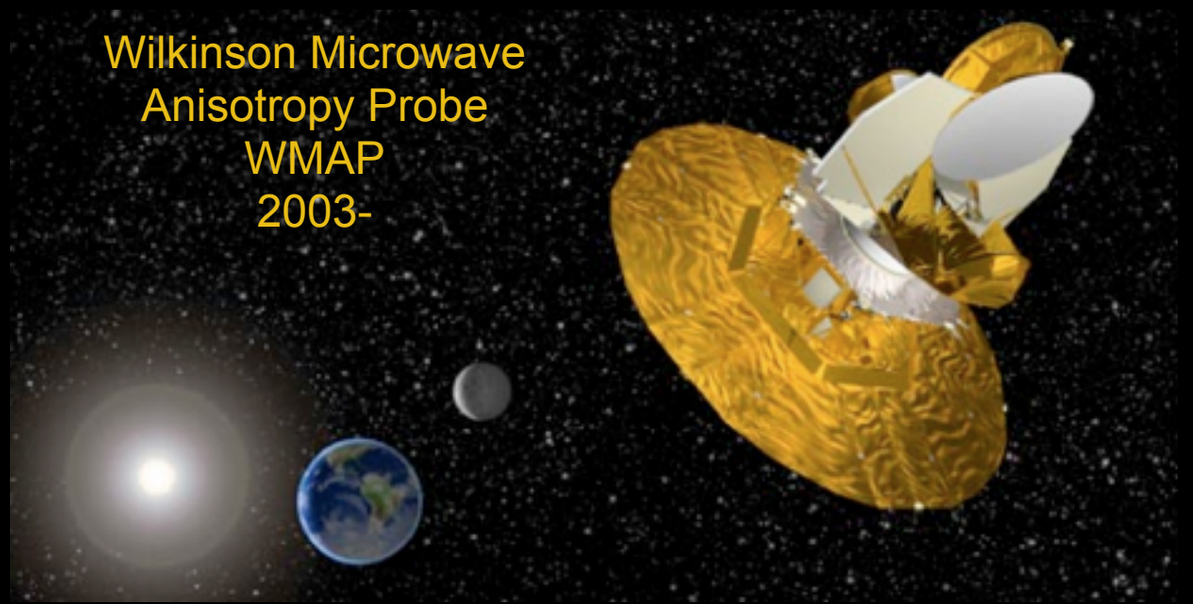
Big Bang Data Agrees with Double Dark Theory!



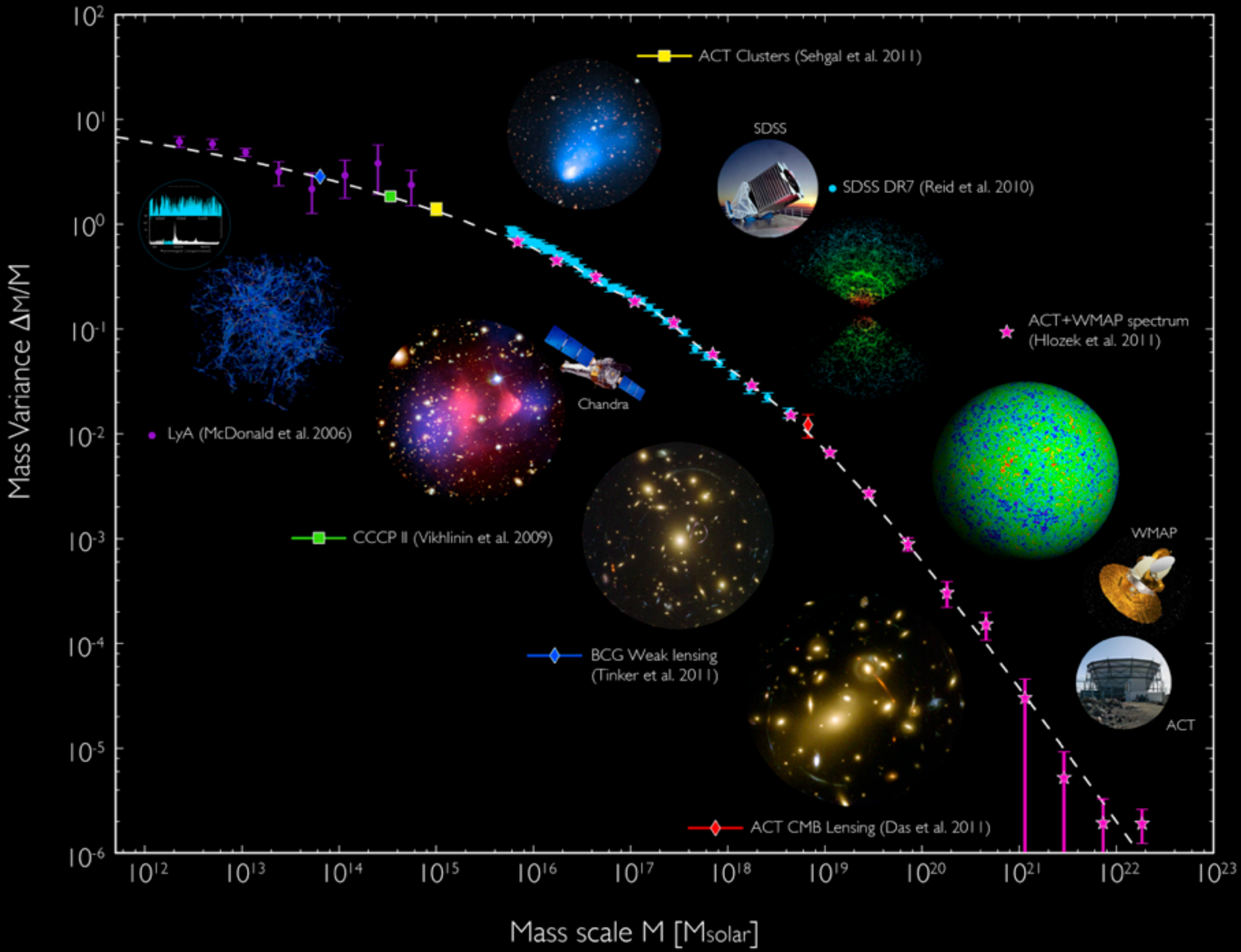
Cosmic Background Explorer
COBE
1992



Wilkinson Microwave Anisotropy Probe
WMAP
2003-



Matter Distribution Agrees with Double Dark Theory!



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, growth of structure, and dark matter halo properties

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

Aquarius Simulation

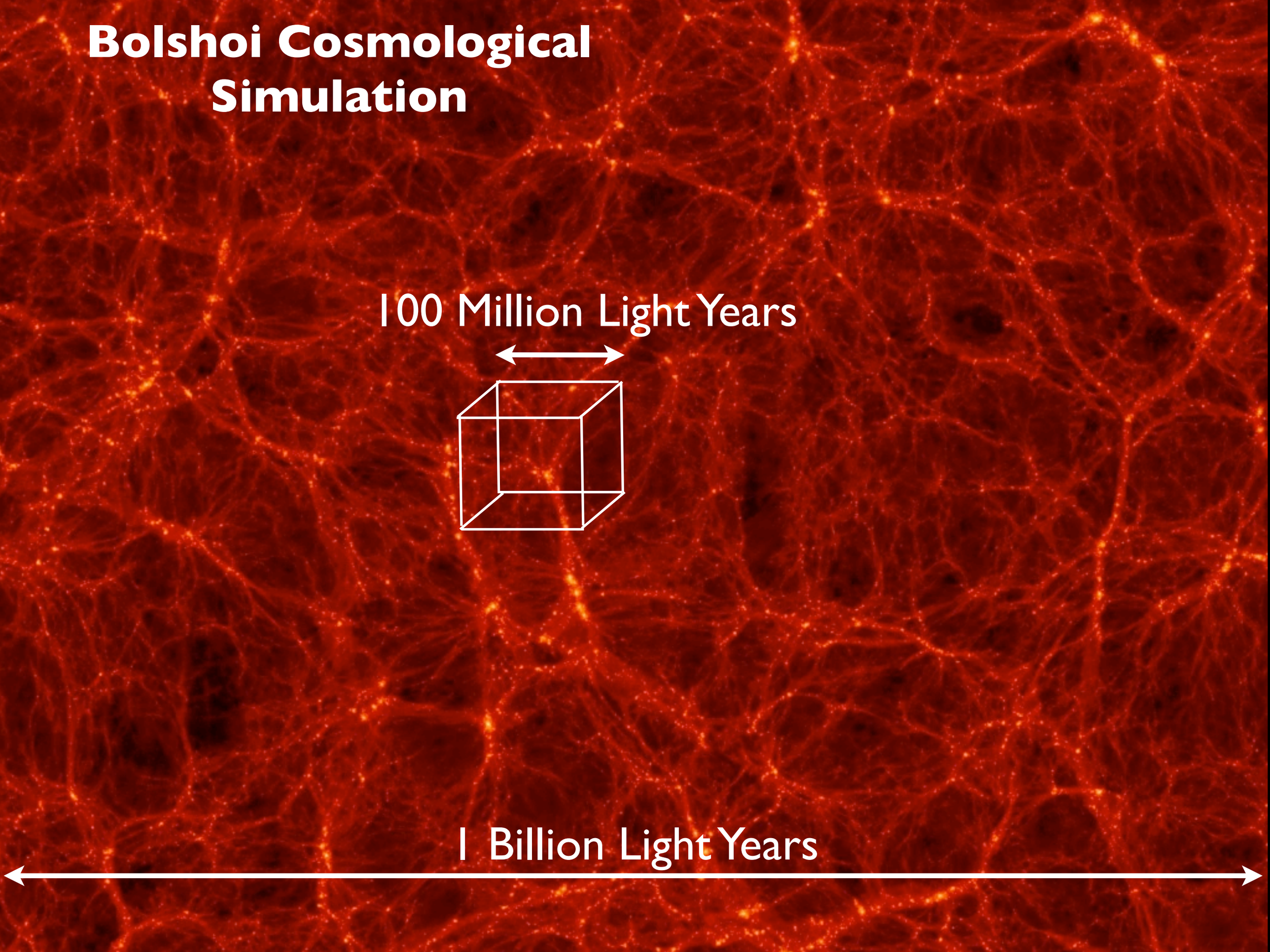
Milky Way
100,000 Light Years

Milky Way Dark Matter Halo
1,500,000 Light Years

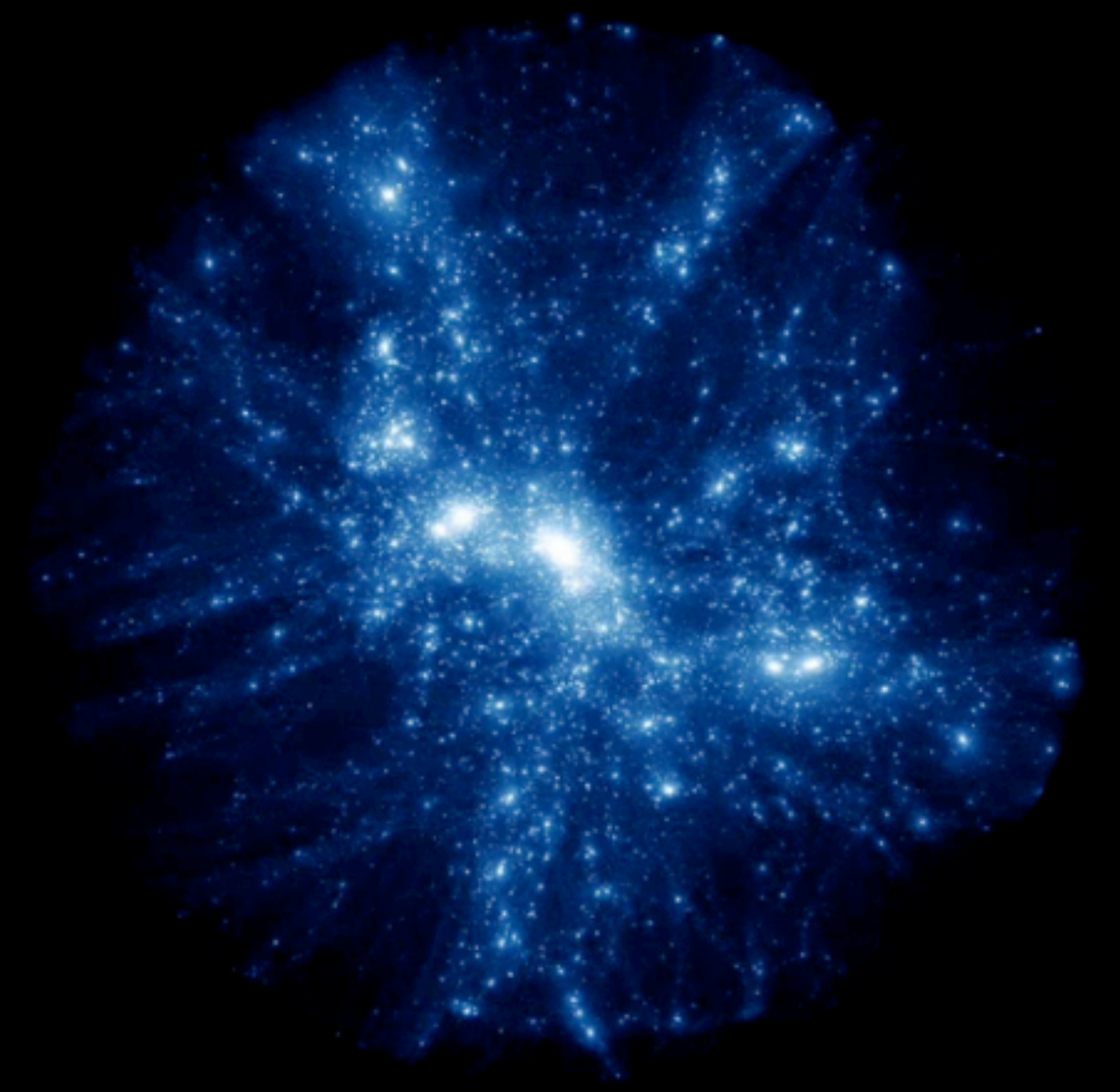
Bolshoi Cosmological Simulation

1 Billion Light Years

Bolshoi Cosmological Simulation



Bolshoi Cosmological Simulation



100 Million Light Years

Bolshoi Cosmological Simulation

100 Million Light Years

Bjork "Dark Matter"
Biophilia

SKY & TELESCOPE

Dive Deep In the Lagoon p. 61

JULY 2012

Universe in a Box

From the Big Bang to Now p. 26

Universe on Fast Forward

STEFAN GOTTLÖBER / LEIBNIZ-INSTITUT FÜR ASTROPHYSIK POTSDAM

Supercomputer modeling is transforming cosmology from a purely observational science into an experimental science.

JOEL R. PRIMACK
& TRUDY E. BELL

https://dl.dropbox.com/u/5495083/Sky%26Telescope%20Bolshoi%20Article.pdf

EVOLVING UNIVERSE
Facing page, left to right: These frames from the Bolshoi simulation depict the universe at redshifts of 10, 3, 1, and 0, which correspond to cosmic ages of 490 million years, 2.2 billion years, 6 billion years, and 13.7 billion years (today). The bright areas have high densities of dark matter. As the far left frame shows, Bolshoi starts off with only a modest degree of lumpiness in the distribution of matter. But the subsequent frames demonstrate how gravity, acting over billions of years, gathered matter into long filaments that surround immense voids. Galaxies are concentrated along the filaments, clusters at the nodes.

Bolshoi Merger Tree for the Formation of a Big Cluster Halo

Time: 13664 Myr Ago
Timestep Redshift: 14.083
Radius Mode: Rvir
Focus Distance: 6.1
Aperture: 40.0
World Rotation: (216.7, 0.06, -0.94, -0.34)
Trackball Rotation: (0.0, 0.00, 0.00, 0.00)
Camera Position: (0.0, 0.0, -6.1)

Peter Behroozi

1000 Mpc/h

BigBolshoi / MultiDark

8G particles

Same cosmology as Bolshoi: $h=0.70$, $\sigma_8=0.82$, $n=0.95$, $\Omega_m=0.27$

7 kpc/h resolution, complete to $V_{circ} > 170$ km/s

4 Billion Light Years

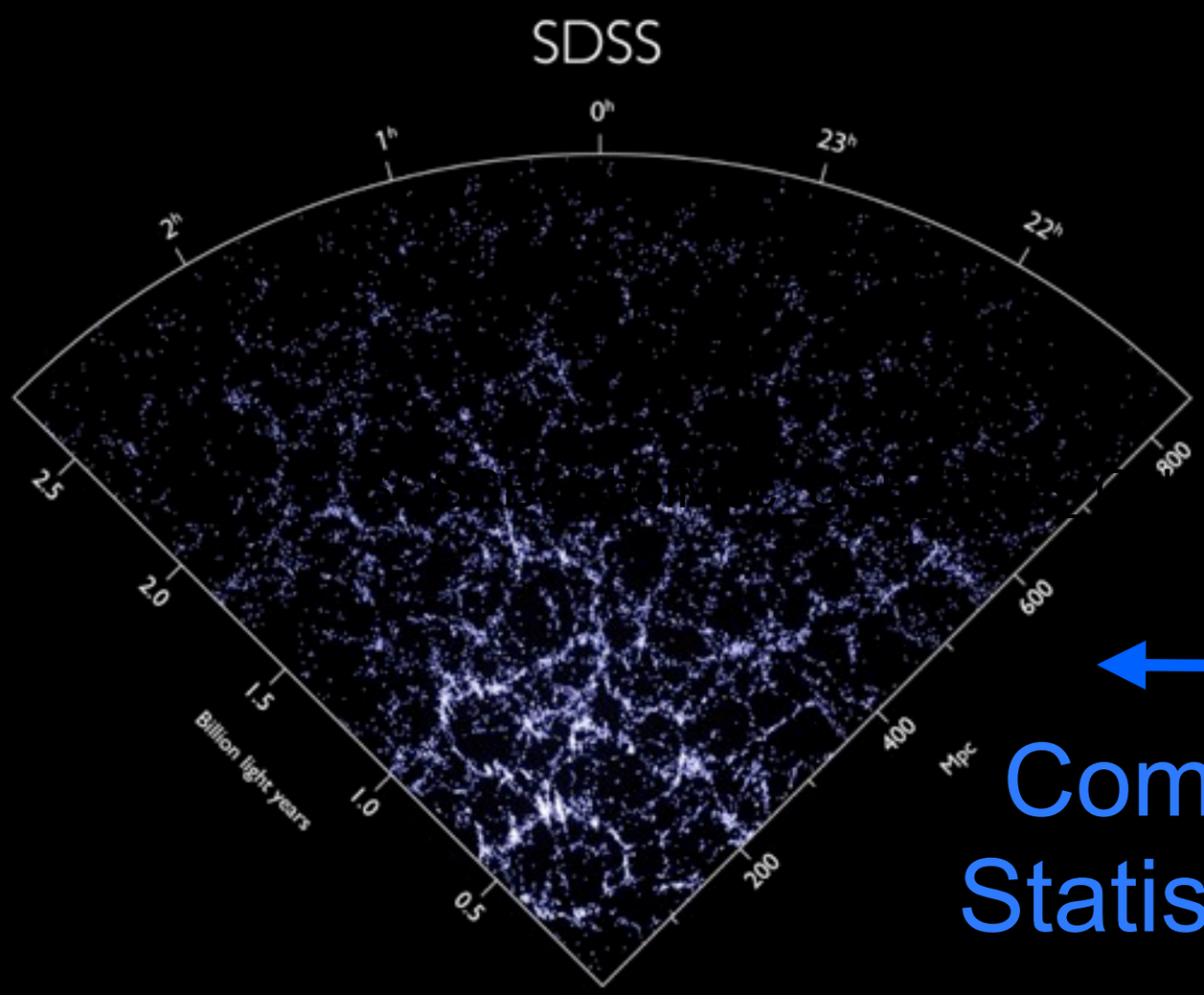
Bolshoi z=0 Dark Matter

Bolshoi z=0 SHAM Galaxies

Wechsler et al.

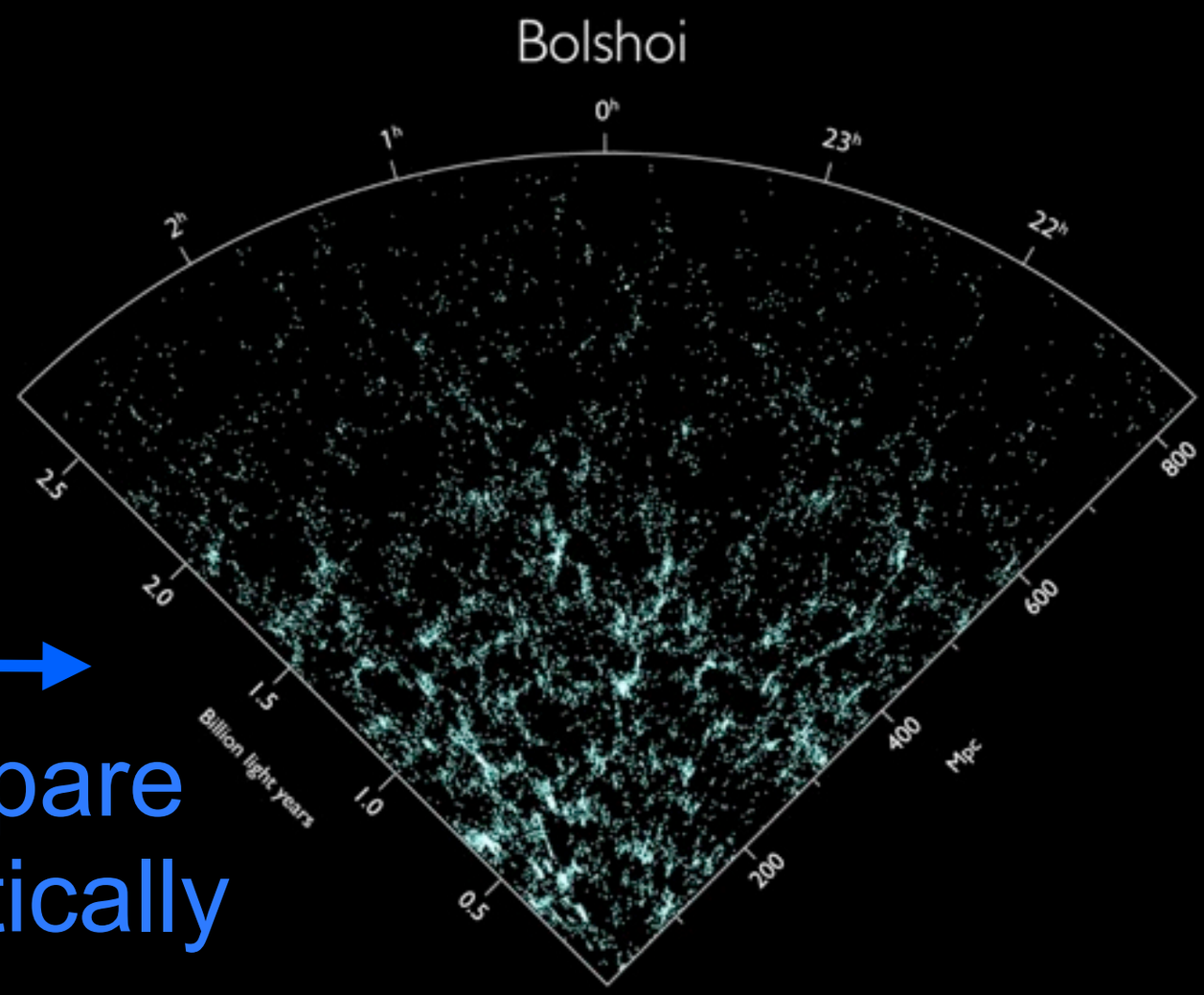
Observational Data

Sloan Digital Sky Survey

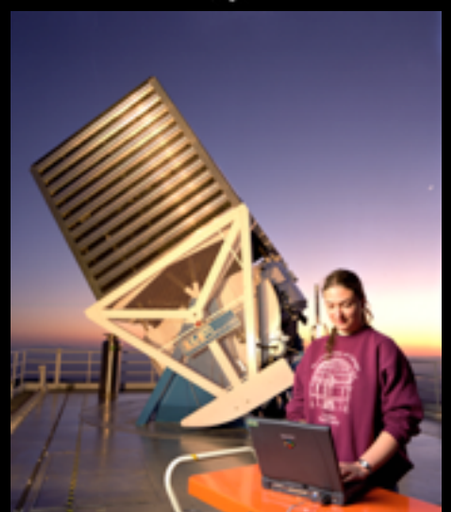


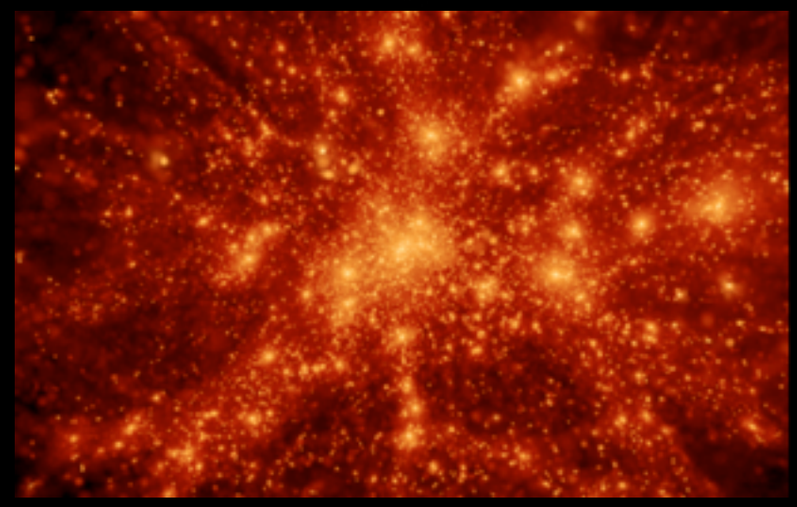
Cosmological Simulation

Risa Wechsler, Ralf Kahler, Nina McCurdy



Compare Statistically



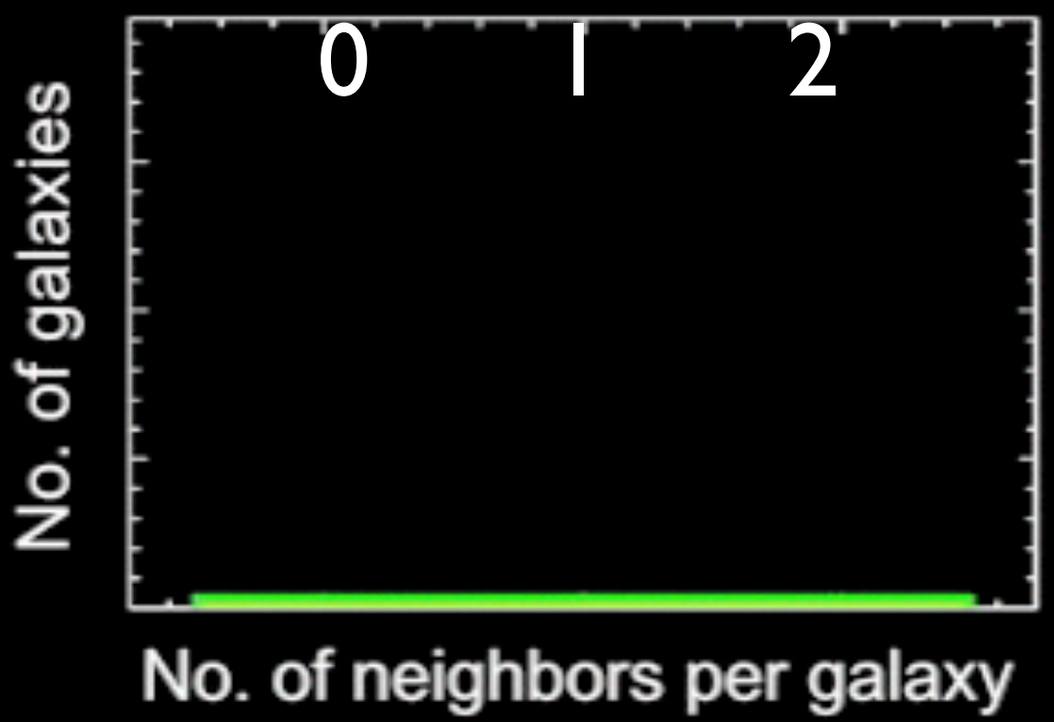


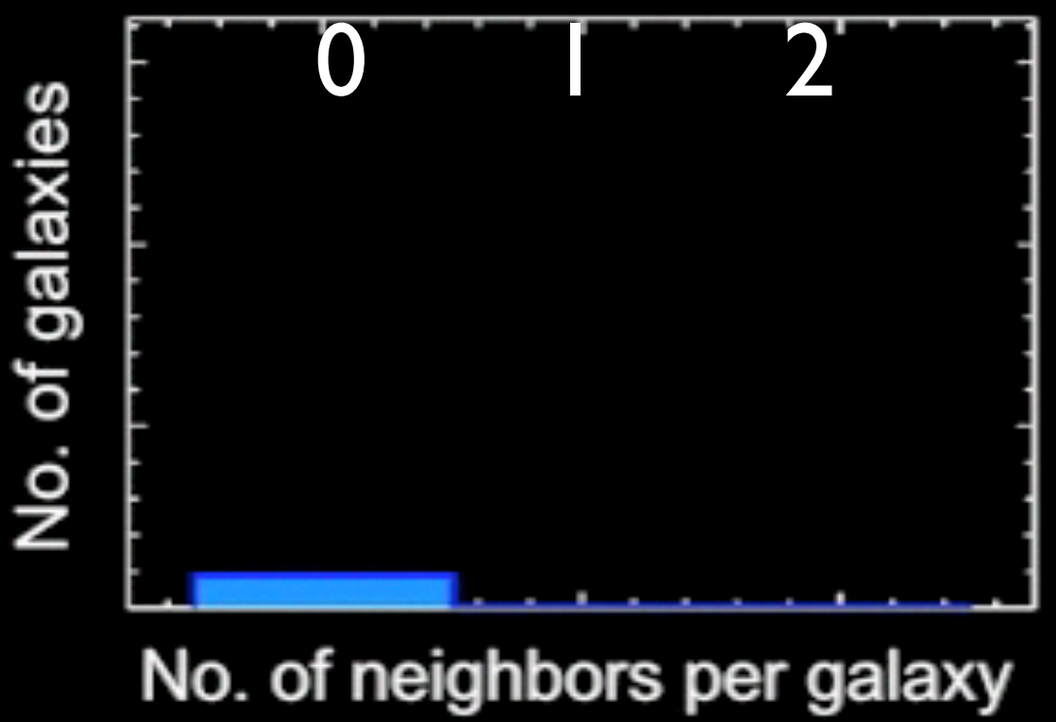
The Milky Way has two large satellite galaxies,
the small and large Magellanic Clouds

The Bolshoi simulation + halo abundance matching
predicts the likelihood of this

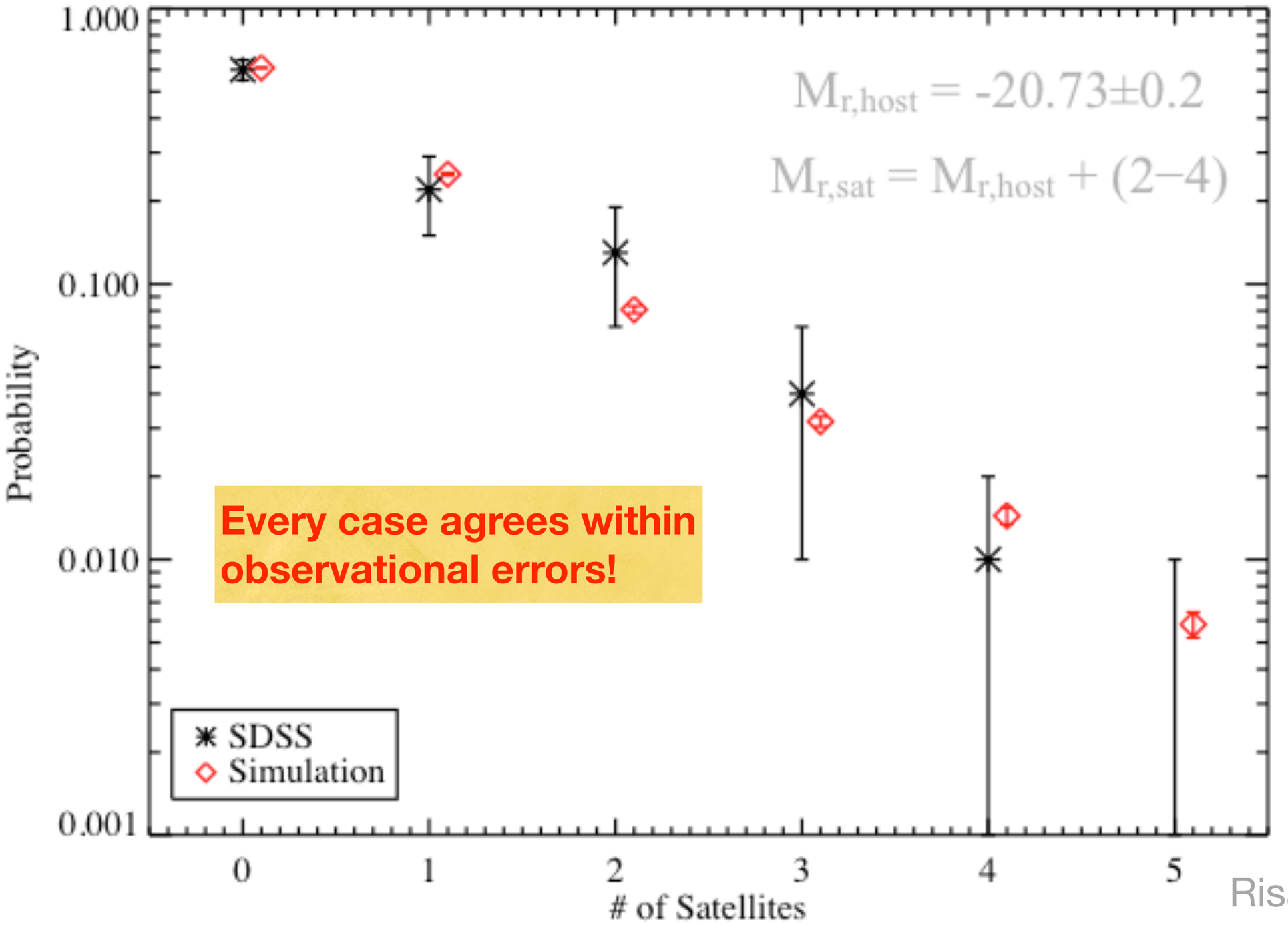
SDSS sky

Bolshoi simulation





Statistics of MW bright satellites: SDSS data vs. Bolshoi simulation



Risa Wechsler

Busha et al. 2011 ApJ
Liu et al. 2011 ApJ

Cosmological Simulations

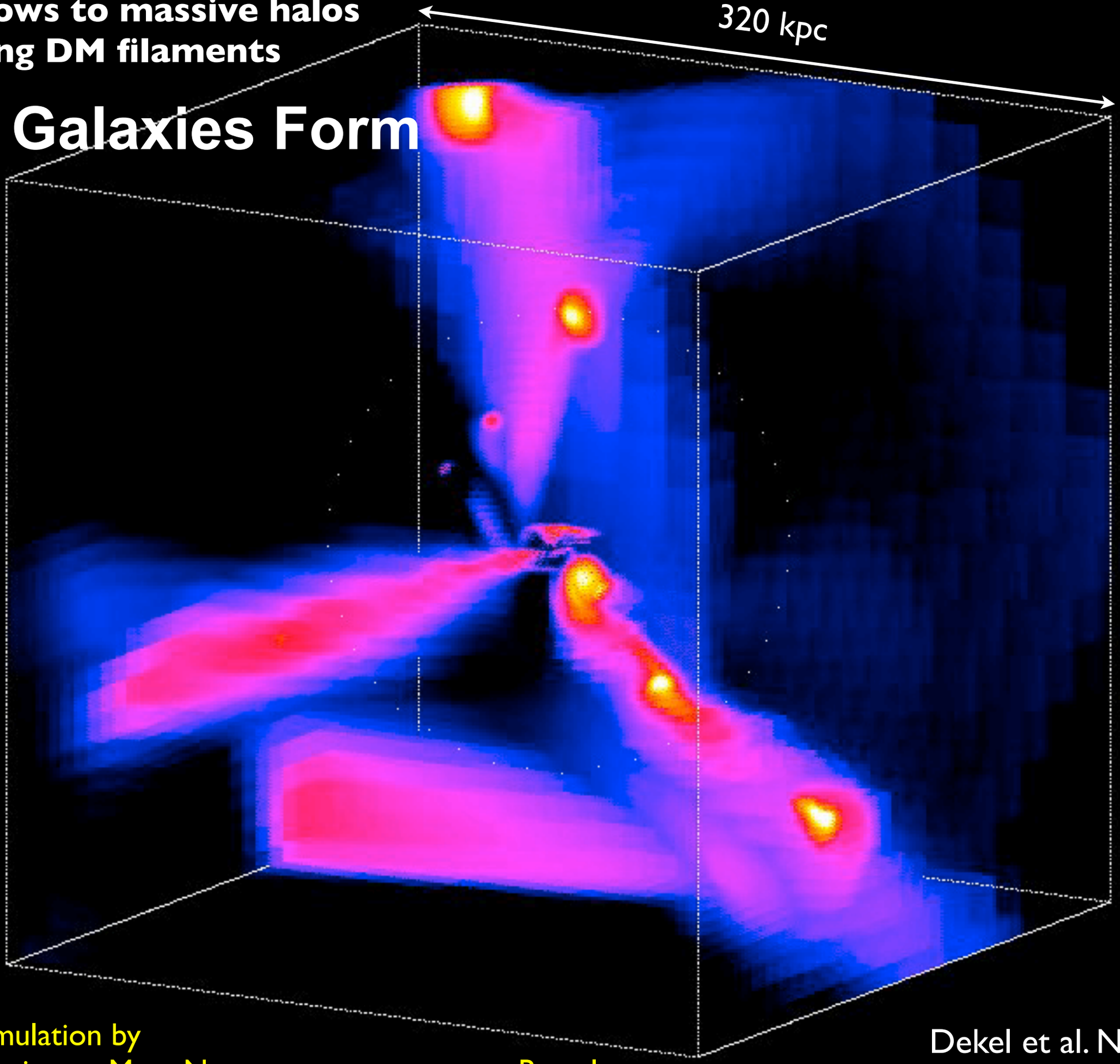
Astronomical observations represent snapshots of moments in time. It is the role of astrophysical theory to produce movies -- both metaphorical and actual -- that link these snapshots together into a coherent physical theory.

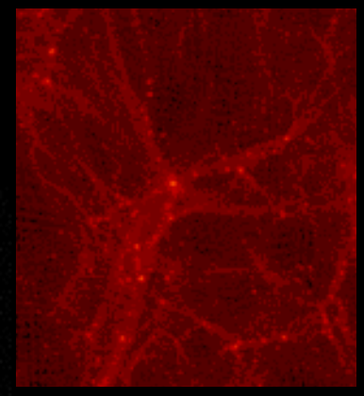
Cosmological dark matter simulations show large scale structure, growth of structure, and dark matter halo properties

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

Gas inflows to massive halos
along DM filaments

How Galaxies Form

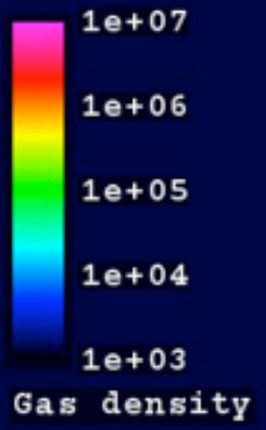




RAMSES simulation by
Romain Teyssier on Mare Nostrum supercomputer, Barcelona

Dekel et al. Nature 2009

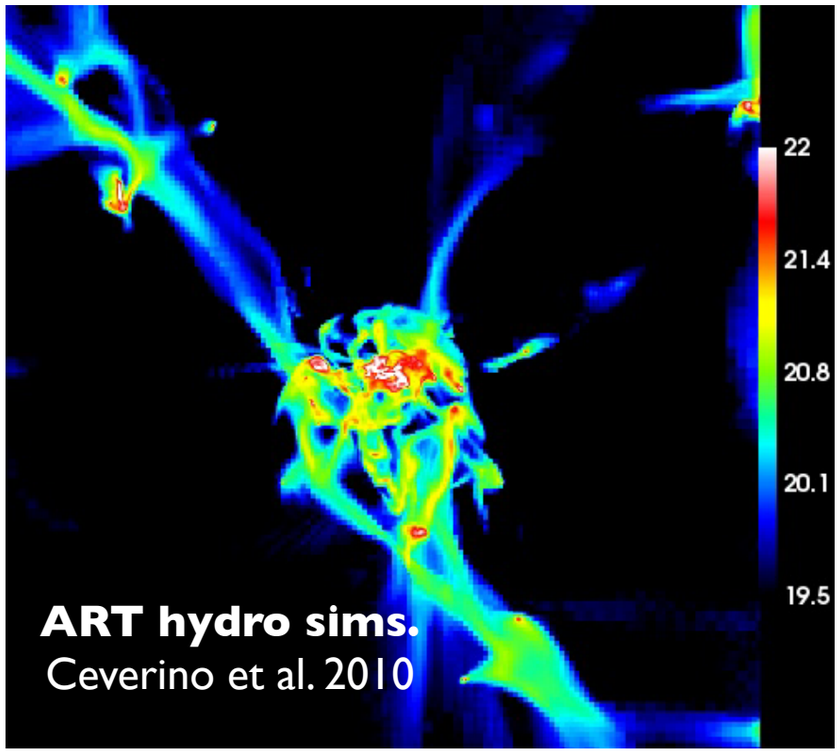
SPIRAL GALAXY FORMATION

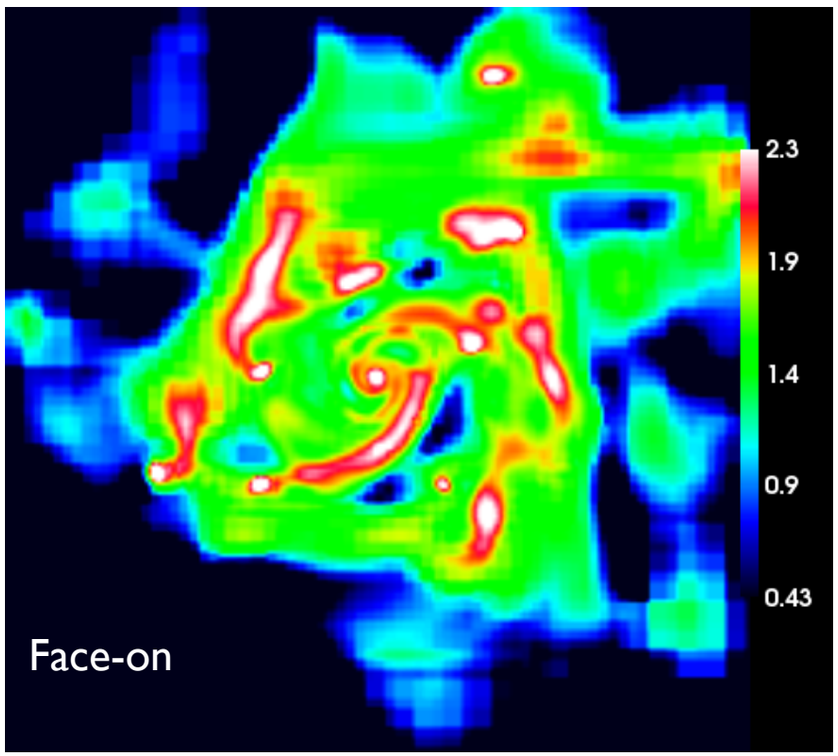


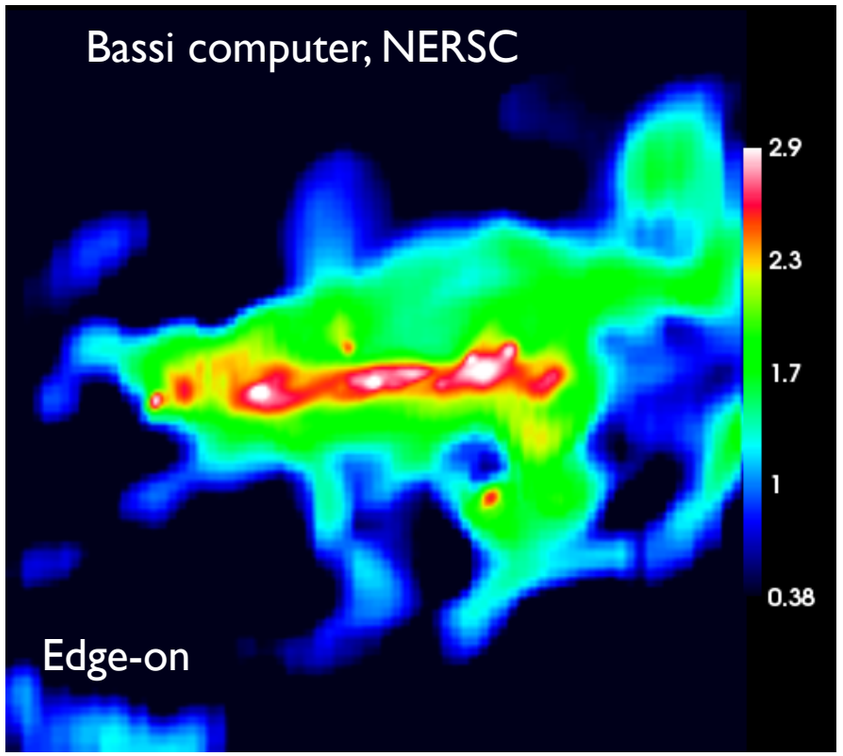
- Stars

time=276

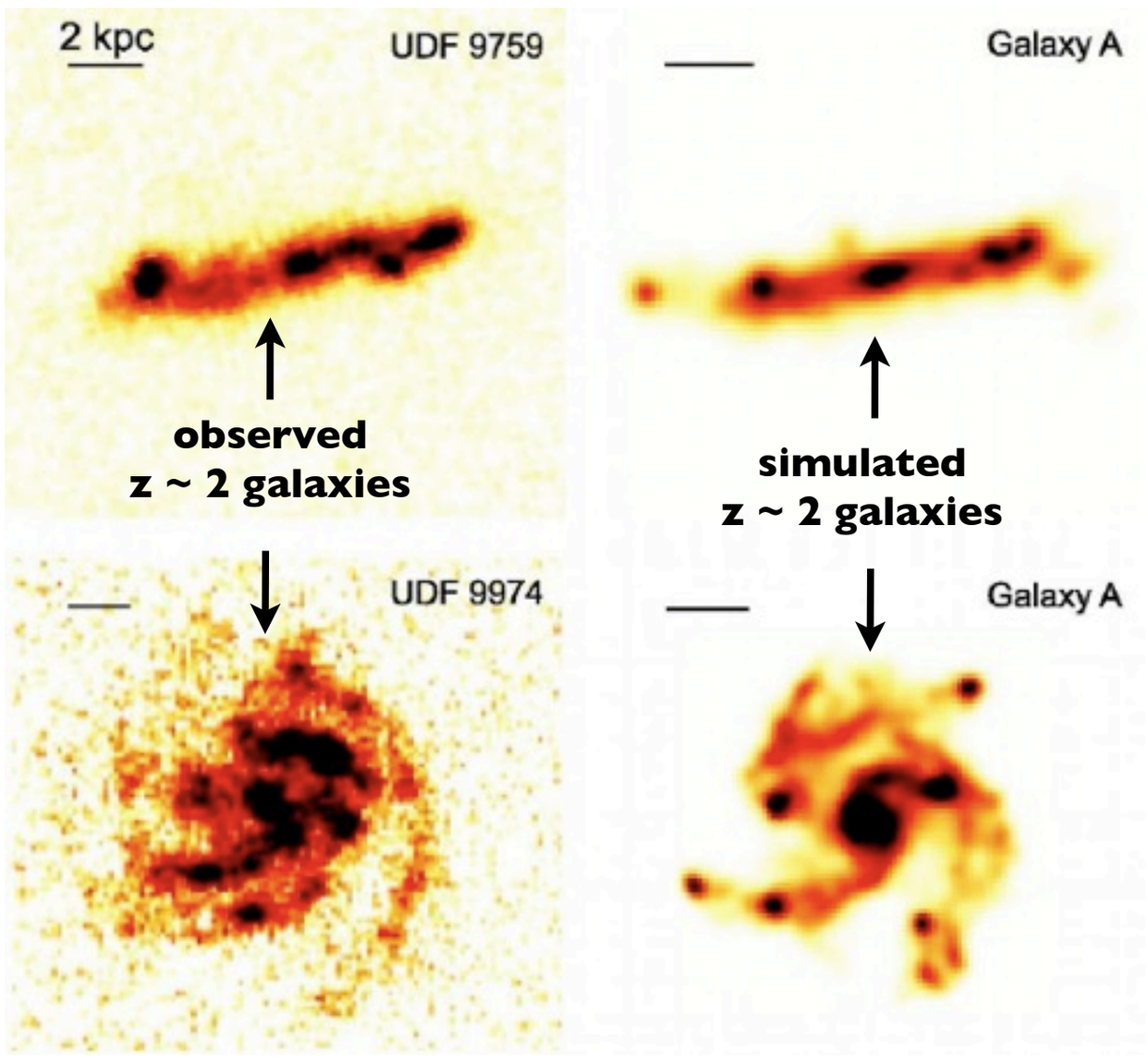
ART Simulation Daniel Ceverino;
Visualization: David Ellsworth



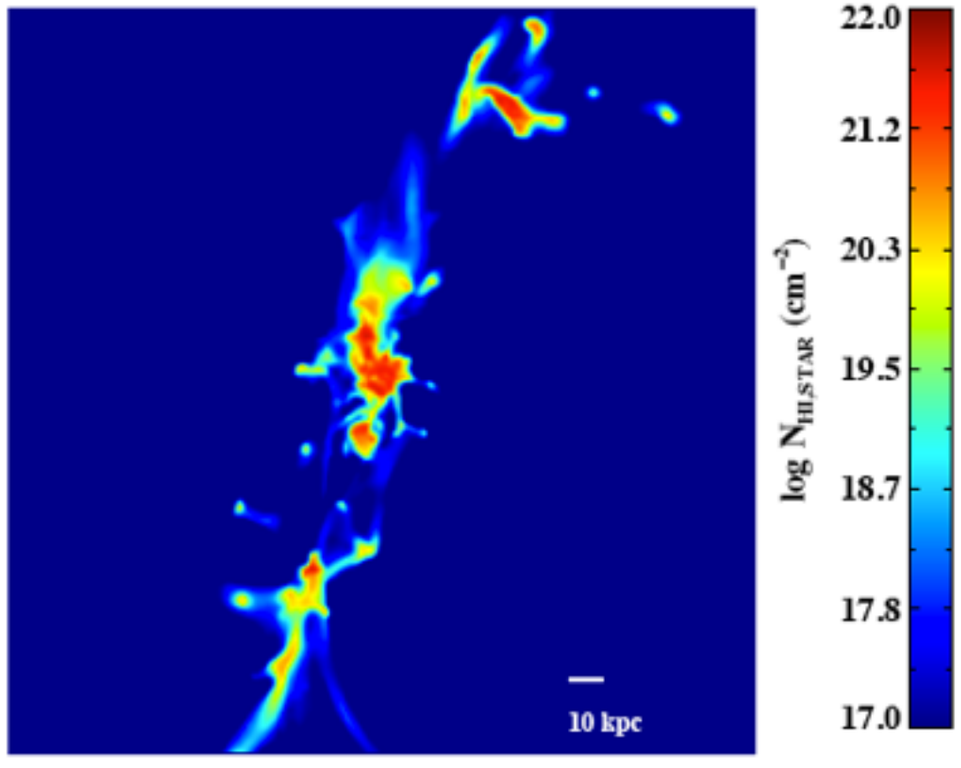




now running on NERSC Hopper-II
and NASA Ames Pleiades supercomputers



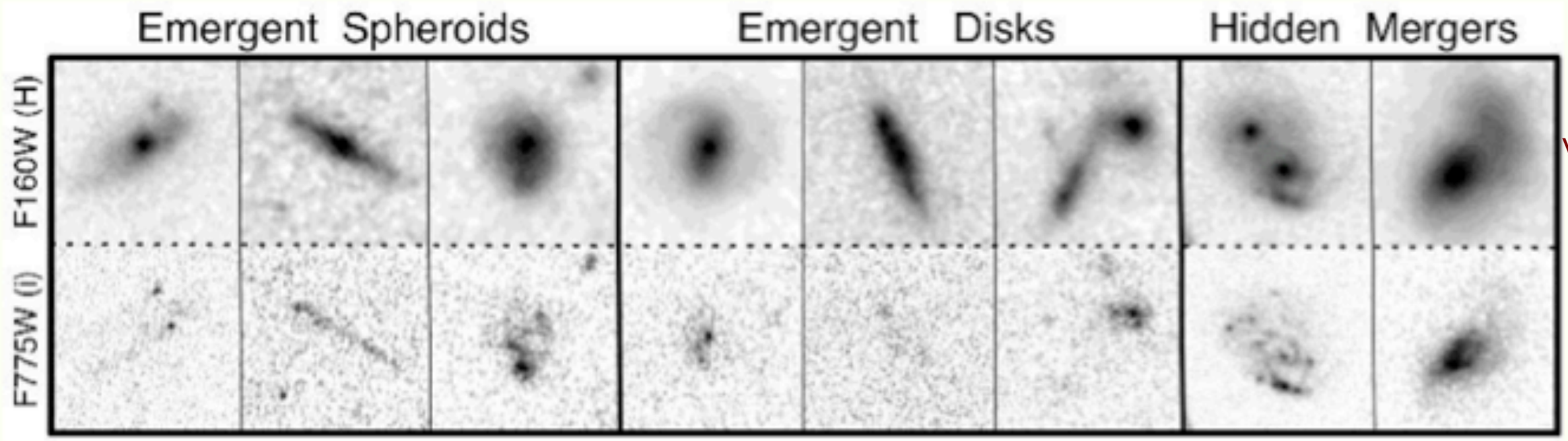
Ly alpha blobs from same simulation



Fumagalli, Prochaska, Kasen, Dekel, Ceverino, & Primack 2011

The CANDELS Survey with new near-ir camera WFC3

GALAXIES ~10 BILLION YEARS AGO



CANDELS makes use of the near-infrared WFC3 camera (top row) and the visible-light ACS camera (bottom row). Using these two cameras, CANDELS will reveal new details of the distant Universe and test the reality of cosmic dark energy.

Hubble Space Telescope

http://candels.ucolick.org

CANDELS is a powerful imaging survey of the distant Universe being carried out with two cameras on board the Hubble Space Telescope.

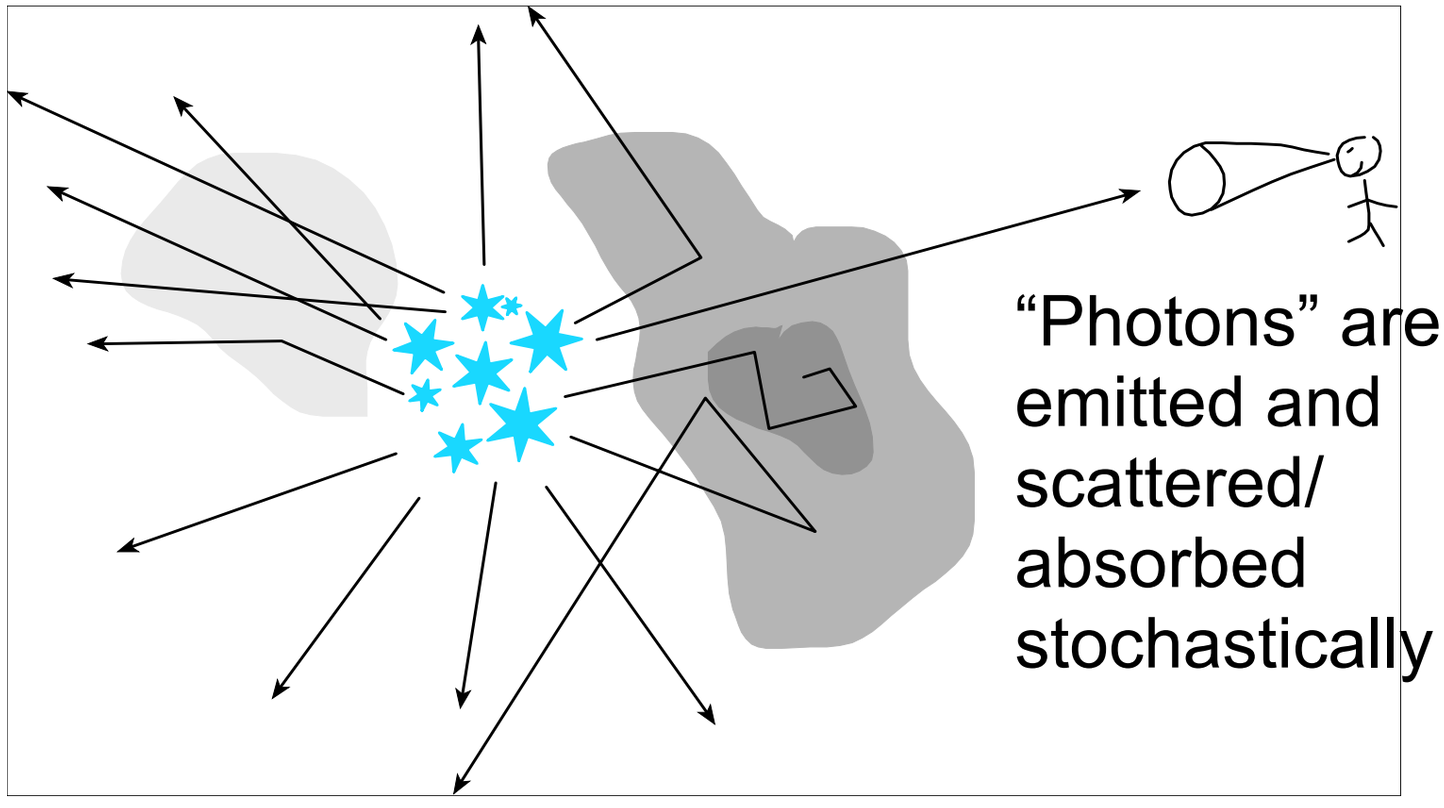
- CANDELS is the largest project in the history of Hubble, with 902 assigned orbits of observing time. This is the equivalent of four months of Hubble time if executed consecutively, but in practice CANDELS will take three years to complete (2010-2013).
- The core of CANDELS is the revolutionary near-infrared WFC3 camera, installed on Hubble in May 2009. WFC3 is sensitive to longer, redder wavelengths, which permits it to follow the stretching of lightwaves caused by the expanding Universe. This enables CANDELS to detect and measure objects much farther out in space and nearer to the Big Bang than before. CANDELS also uses the visible-light ACS camera, and together the two cameras give unprecedented panchromatic coverage of galaxies from optical wavelengths to the near-IR.

Sunrise Radiative Transfer Code

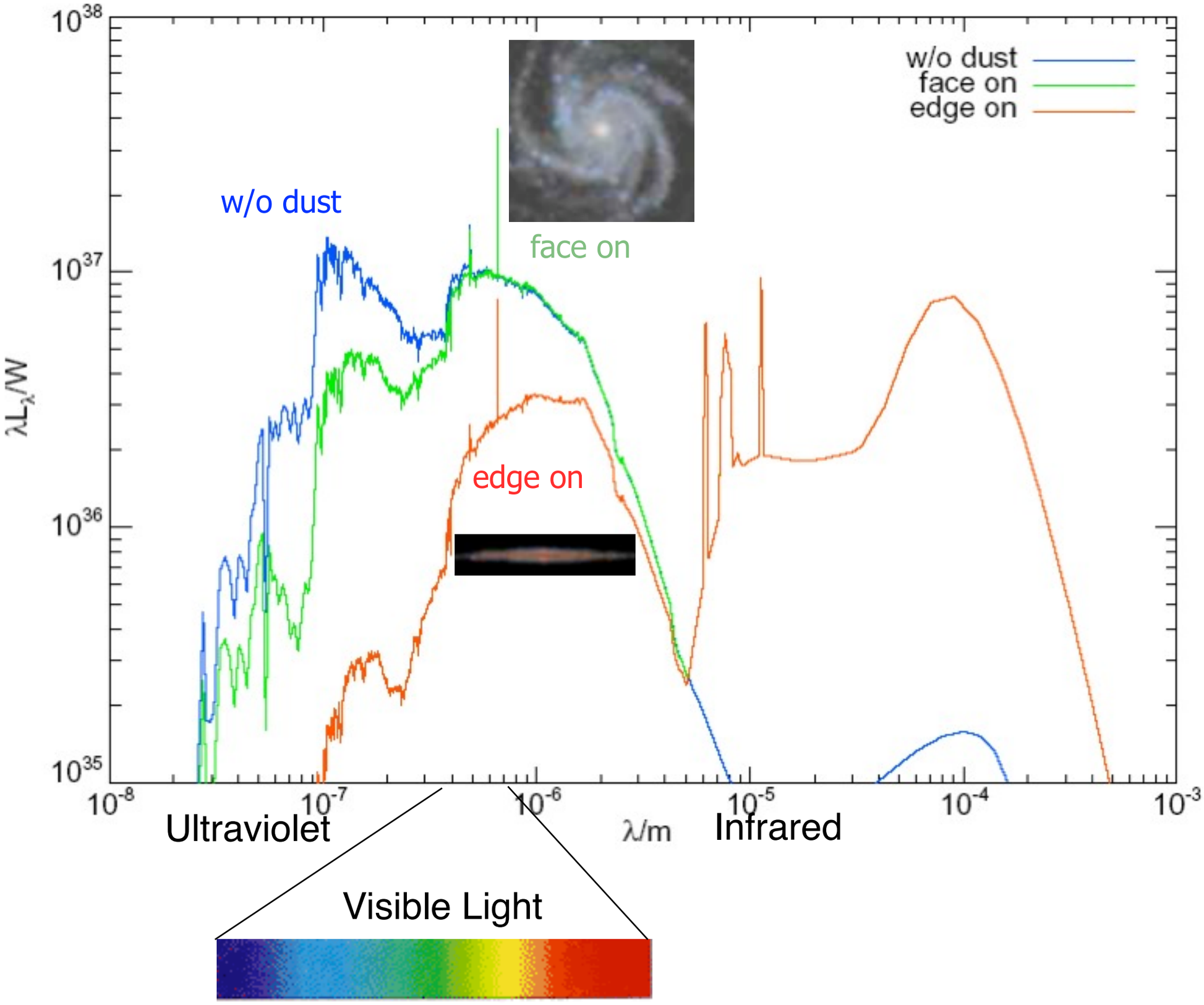
Patrik Jonsson
& Joel Primack

For every simulation snapshot:

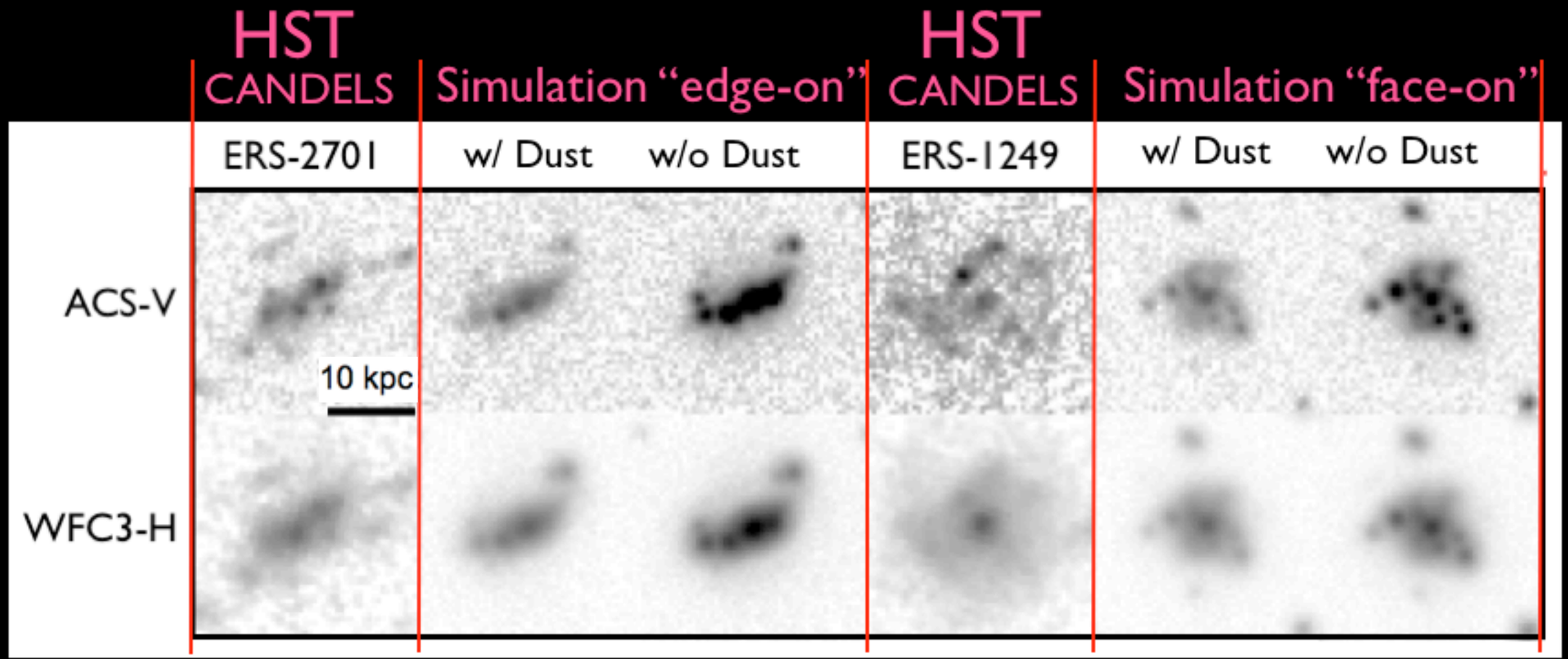
- Evolving stellar spectra calculation
- Adaptive grid construction
- Monte Carlo radiative transfer
- “Polychromatic” rays save 100x CPU time
- Graphic Processor Units give 10x speedup



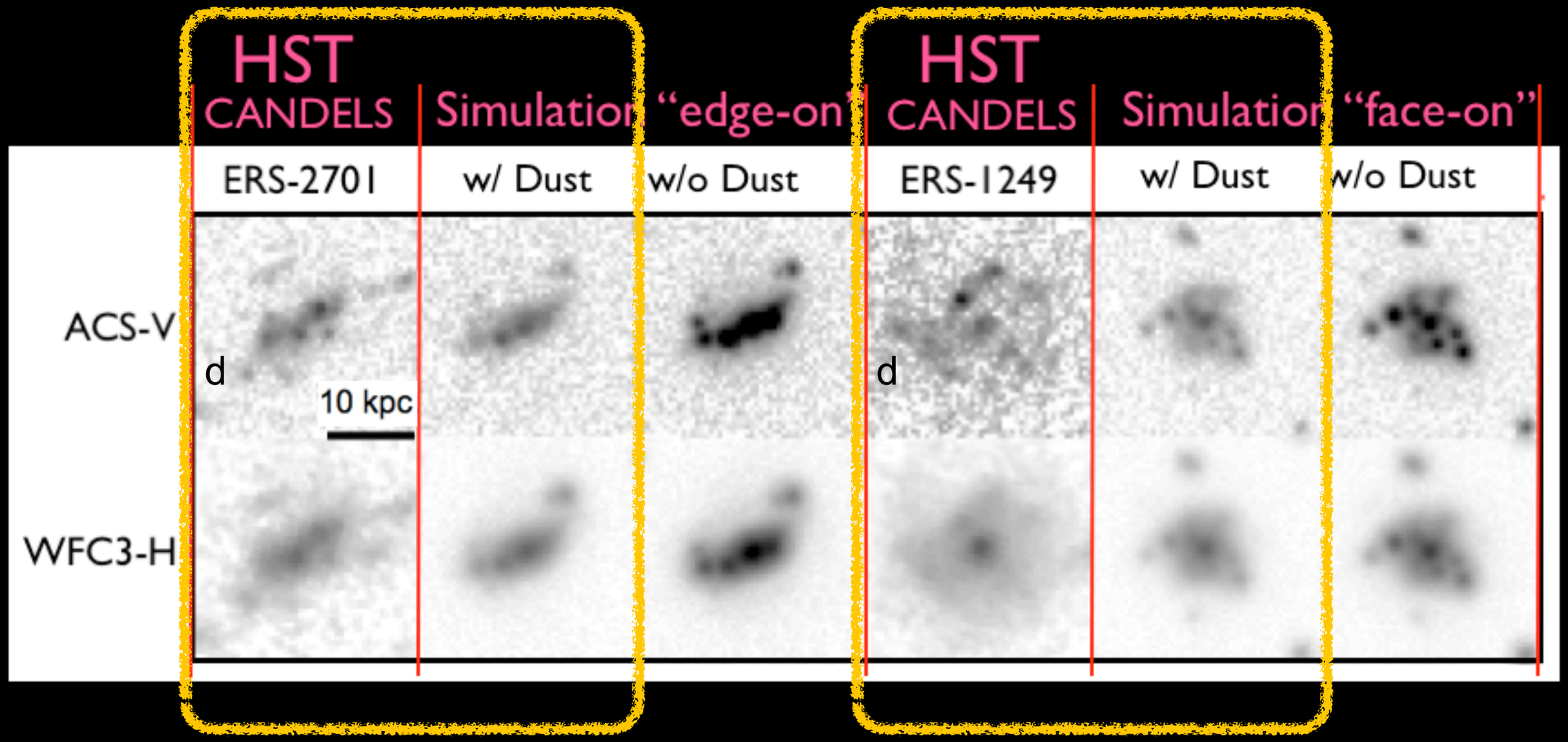
Spectral Energy Distribution



Our Simulations w/ Dust look a lot like galaxies from 10 billion years ago that we see with Hubble Space Telescope



Our Simulations w/ Dust look a lot like galaxies from 10 billion years ago that we see with Hubble Space Telescope



Supercomputing and Petabyte-scale storage have made this research possible, and we expect to benefit greatly from continuing rapid improvements in computation and in data transmission and storage.

Thanks HUAWEI!