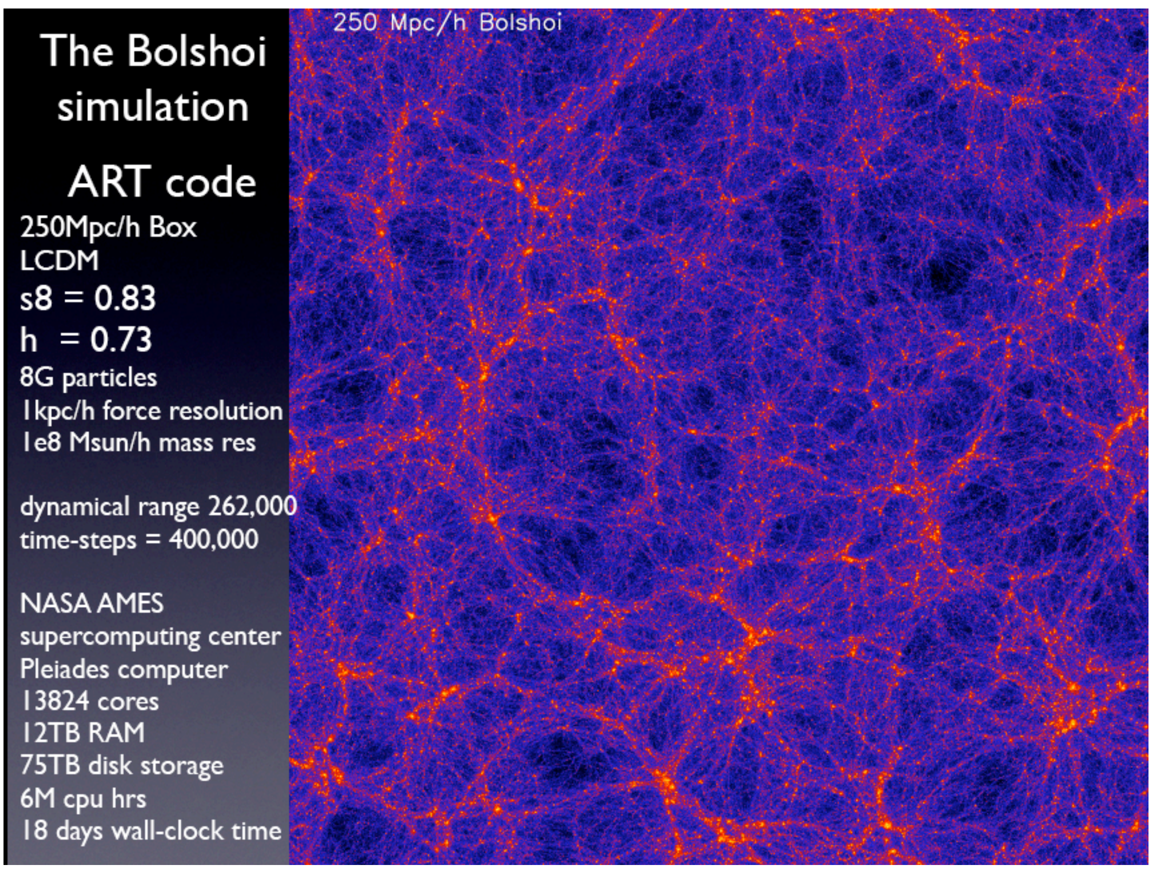
Joel Primack – UCSC – Astrophysics Simulation Visualization Projects

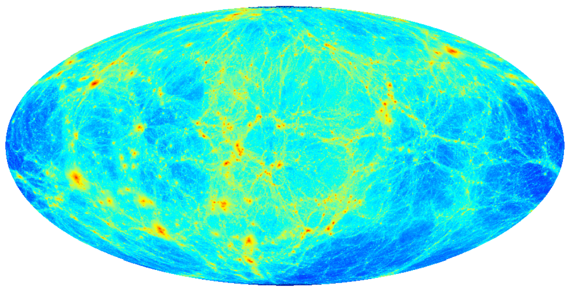
All of these visualizations can be used for videos, digital planetarium shows, and 3D theater presentations. This is a collaboration between Joel Primack's group at UCSC, Chris Henze and the NASA Ames Research Center visualization team, Lucy Fortson, Mark SubbaRao and their colleagues at Adler Planetarium, and Martin Ratcliffe and colleagues at Sky-Skan. Other key collaborators on each project are listed below.

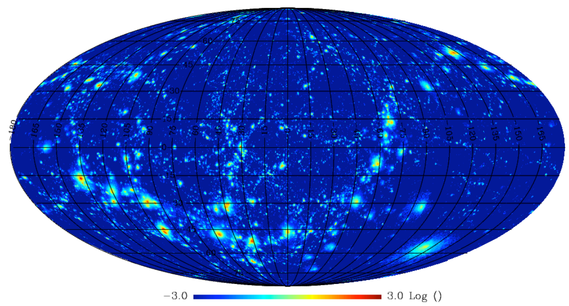
Bolshoi Simulation (cosmological Lambda CDM simulation using 8 billion particles with WMAP5 parameters in a volume 250/h Mpc on a side): **fly-throughs** and **zoom-ins** of the final (redshift $z = 0$) timestep. (This simulation has finished. It used about 6 million cpu-hours of early-user time on the Pleiades supercomputer at NASA Ames Research Center, NASA's most powerful computer. We saved about 150 timesteps, which required ~75 Tb of storage. This is not enough timesteps to smoothly visualize the evolution of the simulation. However, it would be illuminating to visualize the evolution of its merger tree. We have requested additional Pleiades time to simulate subvolumes at 64x better mass resolution, and we could visualize evolution of some of these subvolumes.) Key collaborator: Anatoly Klypin, New Mexico State University.



Bolshoi Semi-Analytic Models. We are working to calculate the halo merger tree from the Bolshoi halo catalog; this is in collaboration with Primack's former PhD student Prof. Risa Wechsler and her group at Stanford University, and based on this to make Semi-

Analytic Models (SAMs) of the evolution of the galaxy population. This would allow us to **paste appropriate pictures of galaxies on the dark matter simulation**, and we could fly though regions of the simulated universe at earlier epochs and at the present epoch. Key SAM collaborators: Rachel Somerville (Space Telescope Science Institute) and Darren Croton (Swinburne University, Melbourne, Australia).



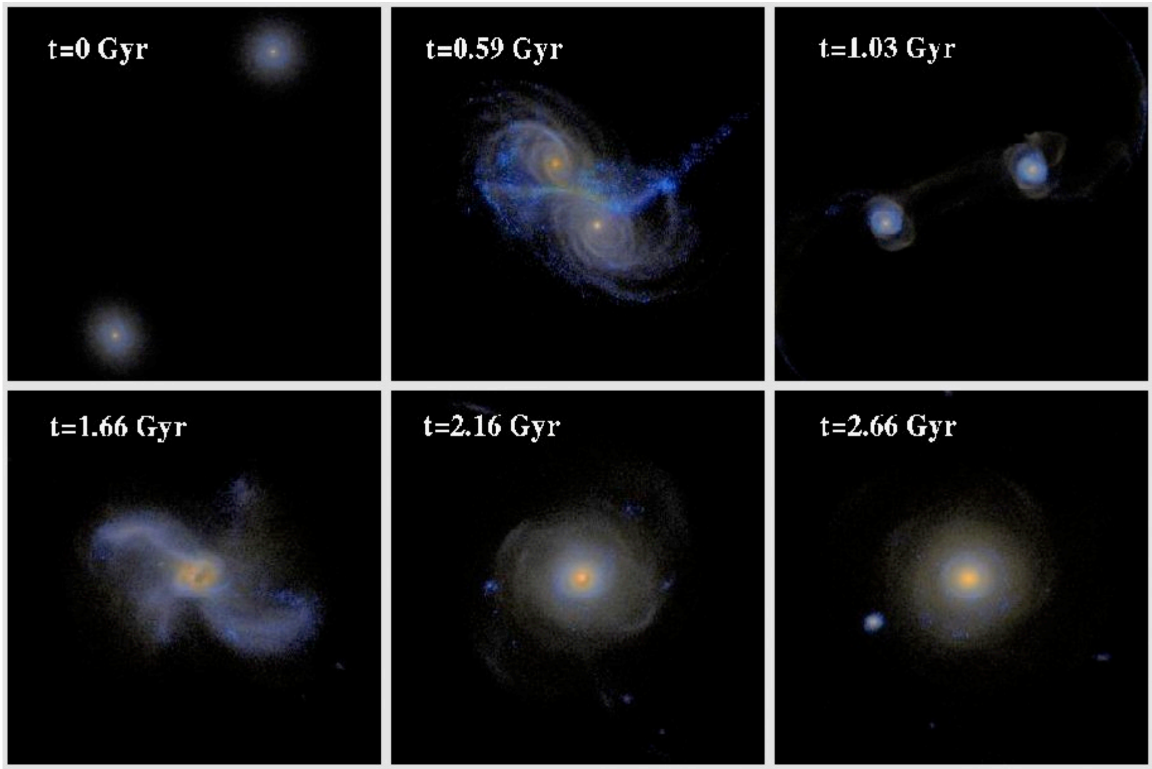


Local Universe Simulation Dark Matter Sky **Annihilation Gamma-Ray Sky**

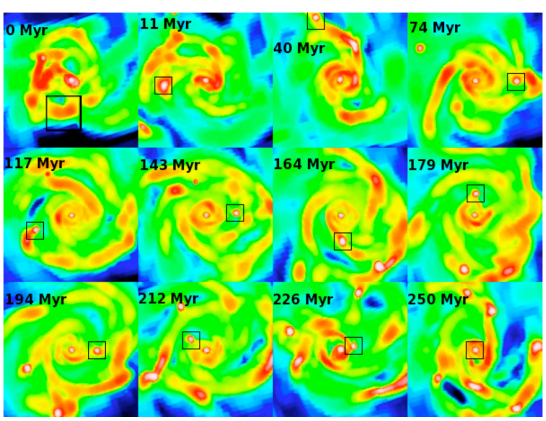
Local Universe Simulation This is a GADGET cosmological Lambda CDM simulation using ~1 billion particles in a volume 64/h Mpc on a side, constrained so that a "Local Group" and "Virgo Cluster" and other nearby structures are near the middle. Thousands of timesteps can be stored so that we can visualize the **evolution of structure to the present**. We can also do **fly-throughs** and **zoom-ins**, both as the simulation evolves and at the present epoch. Although the constraints don't exactly reproduce the local universe, the simulation should be close enough to reality that it would be illuminating to overplot in 3D the local galaxies (e.g., the Tully Catalog) and isodensity **contours representing high and low densities**. The moderately high density regions are the filamentary "cosmic web" and the observed galaxies should lie in the filaments. In addition, we plan to fly through 3D maps of **simulated gamma ray production by dark matter annihilation** (proportional to dark matter density squared). The right panel above is a 2D map (Mollweide projection) of the expected gamma ray sky from annihilation in nearby galaxies projected onto the sphere around us (DM density squared divided by r^2). Compare (left panel) a similar projection of the dark matter distribution (DM density divided by r^2). Key collaborators: Francisco Prada (Institute of Astrophysics of Andalusia, Spain) and his group, and Chris Henze and Pat Moran at NASA Ames.

Future of the Local Universe Simulation (same Local Universe simulation, continued into the future assuming that the dark energy is a cosmological constant). This can be visualized both in **co-moving coordinates** (overall appearance of the volume doesn't change much, but on small scales structures fall together) and in **physical coordinates** (the local region becomes increasingly empty, and in ~100 billion years even the Virgo Cluster leaves the horizon of the Local Group). Key collaborators: same as Local Universe Simulation.

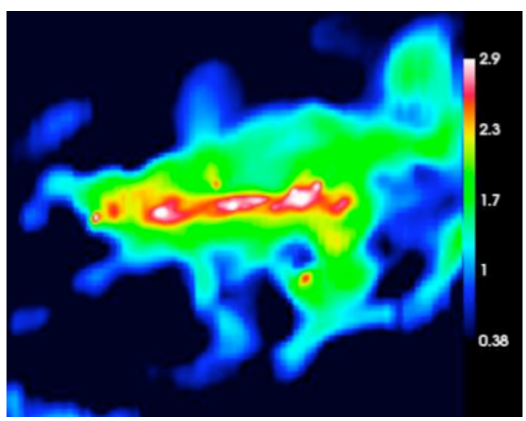
Galaxy Merger Simulations Primack's group has run a wide range of high-resolution GADGET hydrodynamical simulations, including gas cooling and heating, star formation, supernova feedback, and the effects of dust. We have stored thousands of timesteps for some of these simulations, so that we can **visualize the entire process**



from any vantage point including the view from a star in one of the merging galaxies. It will be challenging to visualize all the components: old and newly formed stars, gas density and temperature, metallicity, and dark matter density; also kinematics. Key collaborators: Primack's postdoc (until ~ September 2009) Patrik Jonsson, former grad students T. J. Cox (now at Harvard) and Greg Novak (now at Princeton), and current grad students.



Evolution of gas disk at $z \sim 2$, showing clump merging onto central spheroid.



Side view. Box side is 15 kpc. Color code is log surface density in $M_{\odot}/pc^2$.

Very High Resolution Simulations of Forming Galaxies Daniel Ceverino started these ART-hydro Open MP simulations on the NERSC/Bassi computer as a PhD student with Anatoly Klypin. He is continuing them as a postdoc with Avishai Dekel, now using the

Schirra and Columbia computers at NASA Ames. Visualizations will be crucial to help us understand the formation and evolution of these galaxies in cosmological simulations, and compare the simulations to observations. These are among the highest resolution and most realistic simulations now being done. Key collaborators: Daniel Ceverino, Avishai Dekel, and Anatoly Klypin.

Star Motion in Galaxies – visualizing the motions of stars in high-resolution GADGET simulations of galaxies by tracing their paths in 3D, as time progresses. This will show that most stars in a disk galaxy move in on **nearly circular orbits**, and that a star twice as far from the center as another star takes twice as long to go all the way around. Also that **stars move through the spiral density waves** representing the spiral arms, while the spiral arms rotate as a pattern. These visualizations will also show that stars actually don't move on exactly circular orbits, but rather move in and out radially (i.e., on **epicycles**) and also move above and below the plane of the disk – like horses on a merry-go-round. We might also include stars like the Arcturus group, which have different orbits, perhaps because they originated in another galaxy that was absorbed by the Milky Way. Key collaborator: Marcus Planta, UCSC senior thesis student working with Primack. If his senior thesis project is successful, he could continue work this summer with funding from Joel's NASA Ames-UARC ARP grant.

How Structures Form in the Expanding Universe – visualizing how higher-than-average density fluctuations reach a maximum radius, then stop expanding and undergo **gravitational collapse**, while the rest of the universe continues to expand around them. This is the basis of our modern understanding of the evolution of the universe, and the goal of this project is to devise visualizations that will help both students and the general public to understand this key process. Key collaborator: Nina McCurdy, UCSC senior working with UCSC gamma ray astrophysicist David Williams. Nina visited Adler Planetarium in summer 2008, and could visit again as early as spring 2009 with funding from Joel's NASA Ames-UARC grant. I hope that Nina will help with other aspects of public outreach for this entire project, since that is the field of her planned career.

Examples of Related UCSC Astrophysical Simulation Visualization Projects

Star Formation – Mark Krumholz (UCSC) is doing state-of-the-art hydrodynamical simulations that are answering the question of how stars ~100 times the mass of the sun form, and why most are in binary systems with similar–mass stars.

Supernovae – Stan Woosley (UCSC) is doing state-of-the-art simulations of Type Ia and also core-collapse supernovae, and the formation of long-duration gamma-ray bursts by jets from black holes at the centers of collapsing stars (Type Ic supernovae).