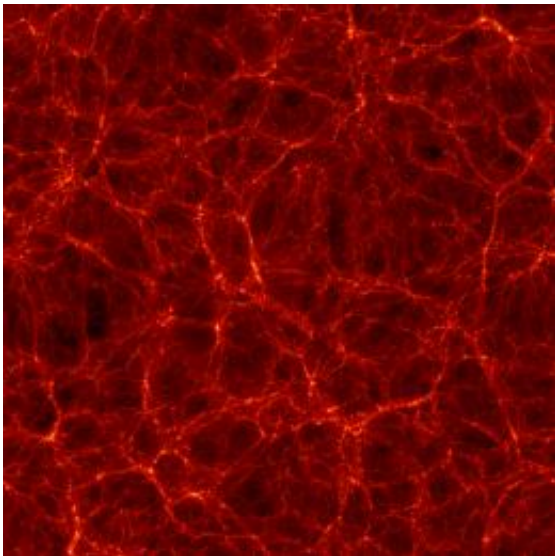


# Scientists release most accurate simulation of the universe to date

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Bolshoi  $z=0$

(PhysOrg.com) -- The Bolshoi supercomputer simulation, the most accurate and detailed large cosmological simulation run to date, gives physicists and astronomers a powerful new tool for understanding such cosmic mysteries as galaxy formation, dark matter, and dark energy.

The simulation traces the evolution of the large-scale structure of the universe, including the evolution and distribution of the dark matter halos in which galaxies coalesced and grew. Initial studies show good agreement between the simulation's predictions and astronomers'

observations.

"In one sense, you might think the initial results are a little boring, because they basically show that our standard [cosmological model](#) works," said Joel Primack, distinguished professor of physics at the University of California, Santa Cruz. "What's exciting is that we now have this highly accurate simulation that will provide the basis for lots of important new studies in the months and years to come."

### *Bolshoi Simulation Visualization*

Primack and Anatoly Klypin, professor of astronomy at New Mexico State University, lead the team that produced the Bolshoi simulation. Klypin wrote the computer code for the simulation, which was run on the Pleiades supercomputer at NASA Ames Research Center. "These huge cosmological simulations are essential for interpreting the results of ongoing astronomical observations and for planning the new large surveys of the universe that are expected to help determine the nature of the mysterious dark energy," Klypin said.

Primack, who directs the University of California High-Performance Astrocomputing Center (UC-HIPACC), said the initial release of data from the Bolshoi simulation began in early September. "We've released a lot of the data so that other astrophysicists can start to use it," he said. "So far it's less than one percent of the actual output, because the total output is so huge, but there will be additional releases in the future."

The previous benchmark for large-scale cosmological simulations, known as the Millennium Run, has been the basis for some 400 papers since 2005. But the fundamental parameters used as the input for the Millennium Run are now known to be inaccurate. Produced by the Virgo Consortium of mostly European scientists, the Millennium simulation used cosmological parameters based on the first release of data from

NASA's Wilkinson Microwave Anisotropy Probe (WMAP). WMAP provided a detailed map of subtle variations in the cosmic microwave background radiation, the primordial radiation left over from the Big Bang. But the initial WMAP1 parameters have been superseded by subsequent releases: WMAP5 (five-year results released in 2008) and WMAP7 (seven-year results released in 2010).

The Bolshoi simulation is based on WMAP5 parameters, which are consistent with the later WMAP7 results. "The WMAP1 cosmological parameters on which the Millennium simulation is based are now known to be wrong," Primack said. "Moreover, advances in supercomputer technology allow us to do a much better simulation with higher resolution by almost an order of magnitude. So I expect the Bolshoi simulation will have a big impact on the field."



Bolshoi predictions agree with Observations

The standard explanation for how the universe evolved after the Big Bang is known as the Lambda Cold Dark Matter model, and it is the theoretical basis for the Bolshoi simulation. According to this model, gravity acted initially on slight density fluctuations present shortly after the Big Bang to pull together the first clumps of dark matter. These grew into larger and larger clumps through the hierarchical merging of smaller progenitors. Although the nature of dark matter remains a mystery, it accounts for about 82 percent of the matter in the universe. As a result,

the evolution of structure in the universe has been driven by the gravitational interactions of dark matter. The ordinary matter that forms stars and planets has fallen into the "gravitational wells" created by clumps of dark matter, giving rise to galaxies in the centers of dark matter halos.

A principal purpose of the Bolshoi simulation is to compute and model the evolution of dark matter halos. The characteristics of the halos and subhalos in the Bolshoi simulation are presented in a [paper](#) that has been accepted for publication in the *Astrophysical Journal* and is now available online. The authors are Klypin, NMSU graduate student Sebastian Trujillo-Gomez, and Primack.

A [second paper](#), also accepted for publication in the *Astrophysical Journal* and available online, presents the abundance and properties of galaxies predicted by the Bolshoi simulation of dark matter. The authors are Klypin, Trujillo-Gomez, Primack, and UCSC postdoctoral researcher Aaron Romanowsky. A comparison of the Bolshoi predictions with galaxy observations from the Sloan Digital Sky Survey showed very good agreement, according to Primack.

The Bolshoi simulation focused on a representative section of the universe, computing the evolution of a cubic volume measuring about one billion light-years on a side and following the interactions of 8.6 billion particles of [dark matter](#). It took 6 million CPU-hours to run the full computation on the Pleiades supercomputer, recently ranked as the seventh fastest supercomputer in the world.

A variant of the Bolshoi simulation, known as BigBolshoi or MultiDark, was run on the same supercomputer with the same number of particles, but this time in a volume 64 times larger. BigBolshoi was run to predict the properties and distribution of galaxy clusters and other very large structures in the universe, as well as to help with dark energy projects

such as the Baryon Oscillation Spectroscopic Survey (BOSS).

Another variant, called MiniBolshoi, is currently being run on the Pleiades supercomputer. MiniBolshoi focuses on a smaller portion of the universe and provides even higher resolution than Bolshoi. The Bolshoi simulation and its two variants will be made publicly available to astrophysical researchers worldwide in phases via the MultiDark Database, hosted by the Potsdam Astrophysics Institute in Germany and supported by grants from Spain and Germany.

Primack, Klypin, and their collaborators are continuing to analyze the results of the Bolshoi simulation and submit papers for publication. Among their findings are results showing that the [simulation](#) correctly predicts the number of galaxies as bright as the Milky Way that have satellite [galaxies](#) as bright as the Milky Way's major satellites, the Large and Small Magellanic Clouds.

"A lot more papers are on the way," Primack said.

**More information:** [hipacc.ucsc.edu/Bolshoi/](http://hipacc.ucsc.edu/Bolshoi/)

Provided by University of California - Santa Cruz

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