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HIGH-PERFORMANCE ASTROCOMPUTING CENTER

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FOR IMMEDIATE RELEASE

THREE "BOLSHOI" SUPERCOMPUTER SIMULATIONS OF THE EVOLUTION OF THE UNIVERSE ANNOUNCED BY AUTHORS FROM UNIVERSITY OF CALIFORNIA, NEW MEXICO STATE UNIVERSITY

Accepted for Publication in the *Astrophysical Journal*

Major Cosmological Simulations Are Anticipated to Become New Benchmark Standard

Two research articles describing the most accurate cosmological simulation of the evolution of the large-scale structure of the universe yet made—named "Bolshoi" (the Russian word for "great" or "grand")—have been accepted for publication in the *Astrophysical Journal.* The results calculated by the Bolshoi simulation and saved for later analysis—spectacular visualizations of what the universe was like at 180 different times from the Big Bang to the present epoch—are being made publicly available to the world's astronomers and astrophysicists.

The first two of a series of research papers describing the Bolshoi simulation have been accepted for publication in the *Astrophysical Journal*. The first paper was coauthored by Prof. Anatoly Klypin and Sebastian Trujillo-Gomez of New Mexico State University and Prof. Joel Primack of the University of California, Santa Cruz (UCSC); the second paper additionally included Aaron Romanowsky of UCSC.

Large cosmological simulations run on supercomputers are now the basis for much current research on the large-scale structure of the universe and the evolution of galaxies. Due to significant advances in the power and speed of supercomputers and computer codes over the past half-decade, "the Bolshoi simulation is better in every respect" than any previous simulation, explained Primack, who is also director of the University of California High-Performance AstroComputing Center (UC-HiPACC). Klypin wrote the computer code for the Bolshoi simulation, which took 6 million CPU hours to run on the Pleiades supercomputer—recently ranked as seventh fastest of the world's top 500 supercomputers—at NASA Ames Research Center.

The Bolshoi simulation is based on WMAP5, a data set that collates the most accurate data from ground-based observations plus a five-year run of cumulative data from the highly successful NASA Explorer mission WMAP (the Wilkinson Microwave Anisotropy Probe). The cosmological parameters of WMAP5 are measurements of the detailed structure of the cosmic microwave background radiation—radiation left over from the Big Bang that formed the universe 13.7 billion years ago—observed and catalogued by the WMAP science team in 2008. The WMAP science team produced high-resolution maps of the entire sky, meticulously plotting the anisotropy (the unevenness) of the temperature and other characteristics of the cosmic microwave background radiation in great detail, revealing a wealth of information about the history, structure, and composition of the early universe.

In addition, the Bolshoi simulation is based on Lambda Cold Dark Matter cosmogony (abbreviated ΛCDM), now accepted as the standard modern theoretical framework for understanding the formation of the large-scale structure in the universe. It is now known that ordinary matter —known to physicists as "baryonic" matter because most of the mass of ordinary atoms comes from its baryons, the protons and neutrons in atomic nuclei—makes up less than 5 percent of the universe. About five times that much—about 23 percent—of the density of the universe is made of invisible, transparent "cold dark matter," whose existence is felt through its gravitational influence. The remaining 72 percent of the cosmic density is dark energy. Every galaxy, including our own Milky Way, resides at the center of a giant halo of dark matter roughly ten times larger in radius and mass. The ΛCDM cosmogony makes detailed predictions for the way structure in the universe grows hierarchically through gravitation: specifically, it predicts that repeated mergers of smaller things ultimately end up creating bigger things

Thus, the Bolshoi simulation models not just how the minority of the *visible* universe of stars, gas, and dust evolved—but also how the vast majority of the *invisible* universe evolved. Indeed, one principal purpose of the Bolshoi simulation is to compute and model the evolution of dark matter halos—thereby rendering the invisible visible for astronomers to study, and to predict structures that astronomers could then seek to observe.

Just as many sciences seek to understand large populations by analyzing a smaller representative sample of a population, the Bolshoi simulation focused on modeling a hypothetical representative volume of the universe. Specifically, it computed the evolution of a cubic volume measuring about 1 billion light-years on a side, a volume that would contain over a million galaxies.

Subsequently, a lower-resolution simulation called BigBolshoi or MultiDark was run on Pleiades to predict the properties and distribution of galaxy clusters and other very large structures in the universe in a volume 4 billion light years across, thus 64 times larger. Currently, a higher-resolution miniBolshoi simulation of a smaller region is now being run on Pleiades, to model the formation and distribution of the tiniest galaxies. Results from all Bolshoi variants are being made publicly available via the MultiDark Database, hosted by the Leibniz-Institute for Astrophysics Potsdam (AIP) in Germany and supported by grants from Spain (MultiDark Consolider Project) and Germany.

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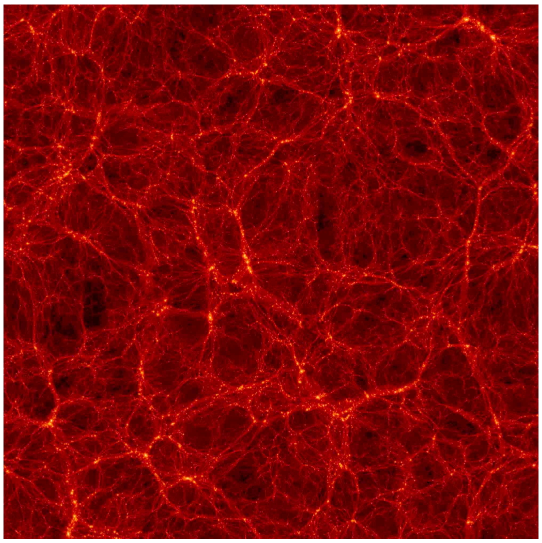

CAPTION: Snapshot from the Bolshoi simulation at a red shift z=0 (meaning at the present time), showing filaments of dark matter along which galaxies are predicted to form.
CREDIT: Anatoly Klypin (New Mexico State University), Joel R. Primack (University of California, Santa Cruz), and Stefan Gottloeber (AIP, Germany).
More images and videos appear at http://hipacc.ucsc.edu/Bolshoi/ , including high-resolution versions suitable for print publication.

For more information:

Links to research papers on the Bolshoi and BigBolshoi/Multidark cosmological simulation are posted at http://hipacc.ucsc.edu/Bolshoi/Papers.html .

For more information about the Bolshoi simulations, see: Bolshoi Cosmological Simulation at http://hipacc.ucsc.edu/Bolshoi/ and http://astronomy.nmsu.edu/aklypin/Bolshoi/ and the BigBolshoi/MultiDark Database http://www.multidark.org/MultiDark/ . The MultiDark Database is a project of the German Astrophysical Virtual Observatory (GAVO), hosted by the Leibniz-Institute for Astrophysics Potsdam (AIP), and supported through the MultiDark collaboration supported by the Spanish Ministry of Science and Innovation's Consolider-Ingenio 2010 Program.

See also the UCSC news story "Scientists release most accurate simulation of the universe to date" at http://news.ucsc.edu/2011/09/bolshoi-simulation.html .

See also the New Mexico State University press release "NMSU professor co-authors astronomical paper on Bolshoi supercomputer simulations" at http://newscenter.nmsu.edu/news/article/8043/ .

For more information about the Pleiades supercomputer at NASA Ames Research Center, visit: + http://www.nas.nasa.gov/Resources/Systems/pleiades.html ; also see the NASA press release on the role of Pleiades in computing the Bolshoi simulations at http://www.nasa.gov/centers/ames/news/releases/2011/11-77AR.html

For information on the University of California High-Performance AstroComputing Center (UC-HiPACC), visit: http://hipacc.ucsc.edu/

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