

New map of the universe reveals its history for the past six-billion years

January 13 2012, By Michael Wood-Vasey



This image shows the positions of the 900,000 luminous galaxies used in four Sloan Digital Sky Survey studies described during the 2012 annual meeting of the American Astronomical Society. Each green dot represents one galaxy. The image covers a redshift range from 0.25 to 0.75, a time when the universe was between 7-billion and 11-billion years old. Credit: David Kirkby (University of California, Irvine) and the SDSS-III Collaboration

The scientists of the Sloan Digital Sky Survey (SDSS), including astronomers at Penn State, have produced a new map of the universe that is in full color, covers more than one quarter of the entire sky, and is full of so much detail that you would need five-hundred-thousand high-definition TVs to view it all. The map consists of more than one-trillion

pixels measured by meticulously scanning the sky with a special-purpose telescope located in New Mexico. This week, at the annual meeting of the American Astronomical Society in Austin, Texas, the SDSS scientists announced results of four separate studies of this new map that, taken together, provide a history of the universe over the last six-billion years.

"This [map of the universe](#), constructed from observations over the past decade, is an unprecedented view of the distribution of stars, galaxies, and quasars, and allows us to trace the evolution of the constituents of the [universe](#) over vast swaths of cosmic time," said Donald Schneider, head of Penn State's Department of [Astronomy and Astrophysics](#), the SDSS survey coordinator, and a coauthor on all four studies. Two additional department members, Distinguished Professor Niel Brandt and Assistant Professor Suvrath Mahadevan, are participants in the SDSS.

The final version of the SDSS map was published online last year and has been viewed more than a million times by astronomers, students, and citizen scientists from all over the world, and it has been studied in depth by international teams of scientists from the SDSS collaboration.

The scientific results announced this week are based on an investigation of the clustering of galaxies all over the sky. "The galaxies we see today give us clues to the history of our universe," says Shirley Ho, an astrophysicist at Lawrence Berkeley National Laboratory (LBL) and the Bruce and Astrid McWilliams Center for Cosmology at Carnegie Mellon University, who was the lead author of one of the papers. "The way galaxies cluster together today can tell us two things. First, galaxy clustering can provide a measuring stick to see how the universe has expanded over time. Second, we can use that information to calculate exactly how much matter the universe contains, and what fraction consists of ordinary matter, dark matter, dark energy, and neutrinos."

The other three papers explore various pieces of the universe in more detail. A team led by Hee-Jong Seo of the Berkeley Center for Cosmological Physics at LBL and the University of California Berkeley compared the observed clustering of nearby galaxies to those in the early universe to obtain a detailed picture of the universe's expansion, while a team led by Roland de Putter of the University of Barcelona used the clustering data to determine the mass of the neutrino, a subatomic particle that only recently was proven to have any mass at all. None of these results would have been possible without the work of a team led by Ashley Ross of the University of Portsmouth (UK), who carefully studied how other effects, such as the presence of stars in our galaxy, affect these conclusions.

The first step in the research was to identify 900,000 "luminous galaxies" seen by the SDSS -- so-called because they shine much brighter than typical galaxies, meaning that they can be seen at great distances across the universe. "By covering such a large area of sky and working at such large distances, these measurements are able to probe the clustering of galaxies on incredibly vast scales," says Martin White, a member of the research team based at Lawrence Berkeley National Laboratory and the University of California Berkeley.

The luminous galaxy measurements were used by Ross's team to determine what additional factors needed to be taken into account. "Because we are looking out at the universe from one place -- the Earth -- we don't always get a clear picture of what the universe as a whole looks like," says Ross. "We have to carefully consider what that means, to make sure that we don't mistake an accident of our Earthbound view for the true structure of the universe."

Armed with the proper estimates of how luminous galaxies cluster, the researchers compared the estimates for the clustering of nearby galaxies with those much farther away. "This analysis is one of the most

trustworthy ways to measure dark energy," Seo says. "The imprint of sound waves in the early universe leaves a clear signature on the clustering of galaxies known as baryon acoustic oscillation. By comparing the size of this feature, seen in the cosmic microwave background just 300,000 years after the Big Bang, to that measured by SDSS-III for galaxies 7-11 billion years later, we can measure how the universe has expanded over that time and can learn about the nature of dark energy."

By comparing the distances to galaxies with how much the universe has expanded since light left those galaxies, astronomers can learn more about the nature of the mysterious dark energy currently driving the increasing rate of that expansion. "These studies allow us to look back six-billion years, to a time when the universe was almost half as old as it is now," said Antonio Cuesta of Yale University, a key member of all four research teams. Among the results: assuming the most widely accepted and likeliest cosmological model, the researchers found that dark energy accounts for 73 percent of the universe, with a margin of error of only two percent.

The SDSS's map covers almost unimaginably large scales but, amazingly, it also offers insights into the almost unimaginably small. The universe is full of tiny particles called neutrinos, the by-products of the nuclear reactions that make stars shine. Many trillions of the tiny particles pass harmlessly through the Earth every second. When initially discovered, it was believed that neutrinos were massless. Recent work by particle physicists have demonstrated that the neutrino has a small mass, but they have been able to place only an upper limit on this value.

Astronomy offers another approach to determining the mass of this ubiquitous subatomic particle. A team led by Roland de Putter of the University of Valencia in Spain examined the SDSS's map to estimate the largest neutrino mass consistent with the universe we see. "One of

the greatest laboratories for particle physics is the universe itself," de Putter says. The team's study pinpointed the largest possible neutrino mass at less than a millionth of the mass of an electron -- a better constraint by a factor of ten than can be offered by traditional particle-physics methods.

The four papers announced this week fit together to help in understanding the history of the universe in unprecedented detail. But even more detail is still to come. Later this year, the SDSS will publish Data Release 9, which will include highly accurate distance measurements to many galaxies, substituting these accurate measurements for the estimates used in the four new studies.

"For each and every one of our million [galaxies](#)," Cuesta says, "we will replace its estimated distance with a very precise measure. Our upcoming map will bring the universe into sharp focus." Seeing the universe in sharp focus will almost certainly help advance our understanding of the whole universe -- from the very large to the very small.

More information: Ross et al. (2011): "[Ameliorating Systematic Uncertainties in the Angular Clustering of Galaxies: A Study using SDSS-III](#)" 2011, MNRAS, Vol 417, pp. 1350-1373.

Ho et al. (2012): "[Clustering of Sloan Digital Sky Survey III Photometric Luminous Galaxies: The Measurement, Systematics and Cosmological Implications](#)"

Seo et al. (2012): "[Acoustic scale from the angular power spectra of SDSS-III DR8 photometric LRGs](#)"

de Putter et al. (2012): "[New Neutrino Mass Bounds from Sloan Digital Sky Survey-III Data Release 8 Photometric Luminous Galaxies](#)"

Provided by Pennsylvania State University

Citation: New map of the universe reveals its history for the past six-billion years (2012, January 13) retrieved 20 March 2024 from <https://phys.org/news/2012-01-universe-reveals-history-six-billion-years.html>

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