What will Webb see? Supercomputer models yield sneak previews

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As scientists and engineers work to make NASA's James Webb Space Telescope a reality, they find themselves wondering what new sights the largest space-based observatory ever constructed will reveal. With Webb, astronomers aim to catch planets in the making and identify the universe's first stars and galaxies, yet these are things no telescope -- not even Hubble -- has ever shown them before.

"It's an interesting problem," said Jonathan Gardner, the project's deputy senior project scientist at NASA's Goddard Space Flight Center in Greenbelt, Md. "How do we communicate the great scientific promise of the James Webb Space Telescope when we've never seen what it can show us?"

So the project turned to Donna Cox, who directs the Advanced Visualization Laboratory (AVL) at the National Center for Supercomputing Applications (NCSA). Located at the University of Illinois in Urbana-Champaign, NCSA provides enormous computing resources to researchers trying to simulate natural processes at the largest and smallest scales, from the evolution of the entire universe to the movement of protein molecules through cell walls.

Cox and her AVL team developed custom tools that can transform a model's vast collection of ones and zeroes into an incredible journey of exploration. "We take the actual data scientists have computed for their research and translate them into state-of-the-art cinematic experiences," she said.

Armed with an ultra-high-resolution 3D display and custom software, the AVL team choreographs complex real-time flights through hundreds of gigabytes of data. The results of this work have been featured in planetariums, IMAX theaters and TV documentaries. "Theorists are the only scientists who have ventured where Webb plans to go, and they did it through complex computer models that use the best understanding of the underlying physics we have today," Cox said. "Our challenge is to make these data visually understandable -- and reveal their inherent beauty."

The new visualizations reflect the broad science themes astronomers will address with Webb. Among them: How did the earliest galaxies interact and evolve to create the present-day universe? How do stars and planets form?

"When we look at the largest scales, we see galaxies packed into clusters and clusters of galaxies packed into superclusters, but we know the universe didn't start out this way," Gardner said. Studies of the cosmic microwave background -- the remnants of light emitted when the universe was just 380,000 years old -- show that the clumpy cosmic structure we see developed much later on. Yet the farthest galaxies studied are already more than 500 million years old.

"Webb will show us what happened in between," Gardner added.

Cox and her AVL team visualized this epoch of cosmic construction from a simulation developed by Renyue Cen and Jeremiah Ostriker at Princeton University in New Jersey. It opens when the universe was 20 million years old and continues to the present-day, when the universe is 13.7 billion years old.

AVL team members Robert Patterson, Stuart Levy, Matthew Hall, Alex Betts and A. J. Christensen visualized how stars, gas, dark matter and

colliding galaxies created clusters and superclusters of galaxies. Driven by the gravitational effect of dark matter, these structures connect into enormous crisscrossing filaments that extend over vast distances, forming what astronomers call the "cosmic web."

"We worked with nine scientists at five universities to visualize terabytes of computed data in order to take the viewer on a visual tour from the cosmic web, to smaller scales of colliding galaxies, to deep inside a turbulent nebula where stars and disks form solar systems like our own," Cox said. "These visuals represent current theories that scientists will soon re-examine through the eyes of Webb."

Closer to home, Webb will peer more deeply than ever before into the dense, cold, dusty clouds where stars and planets are born. Using data from models created by Aaron Boley at the University of Florida in Gainesville and Alexei Kritsuk and Michael Norman at the University of California, San Diego, the AVL team visualized the evolution of protoplanetary disks over tens of thousands of years.

Dense clumps develop far out in a disk's fringes, and if these clumps survive they may become gas giant planets or substellar objects called brown dwarfs. The precise outcome depends on the detailed makeup of the disk. "Dr. Boley was interested in what happened in the disk and did not include the central star," Cox said, "so to produce a realistic view we worked with him to add a young star."

This is astrophysics with a pinch of Hollywood sensibility, work at the crossroads of science and art. "The theoretical digital studies that form the basis of our work are so advanced that cinematic visualization is the most effective way to share them with the public," Cox said. "It's the art of visualizing science."

"What AVL has done for the Webb project is truly amazing and

inspiring," Gardner noted. "It really whets our appetites for the science we'll be doing when the telescope begins work a few years from now."

More information: www.jwst.nasa.gov/

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