The Formation of First Stars and Galaxies
Simulation data from John H. Wise of Georgia Institute of Technology's Center for Relativistic Astrophysics

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yt rendering software: Matt Turk, Sam Skillman

The AVL worked with astrophysics data scientists to create a narrative journey through the dynamic processes of the sun in a digital fulldome production titled "Solar Superstorms", narrated by Benedict Cumberbatch, as part of the CADENS NSF ACI-1445176 grant. This visualization looks back to a time in the early universe when ionized gas was becoming widespread. This visualization represents the part of the story that describes the life cycle of the stars, and introduces the notion of plasma - ionized gas - which is crucial in presenting the sun and its magnetism.

John Wise's simulation of the early universe (from ~20 million - 500 million years after the Big Bang) shows formation of the first generations of stars, as their light ionizes much of the space around them. Three features were targeted in this visualization: the dense filaments along which stars form (measured by "baryon overdensity", blue-whitish where density of ordinary matter much exceeds the average); the large regions of gas which become ionized and heated as new stars begin emitting lots of ultraviolet light, and later cool off after those stars' lives end (measured by temperature, in orange/yellow/white); and the heavier elements mixed into the gas after those dying stars explode as supernovae, forming small bubbles of high "metallicity density". A second ("supernova") simulation examines the life and death of a single first-generation ("Population III") star, looking in detail at the processes that mix the heavy elements into their environment. Those "metals" in turn make it easier for later generations of stars to form. John Wise computed both simulations using the Enzo code, on Blue Waters at NCSA.

Combining these fields in the previsualization environment, and in the final renders was a challenge. Another persistent challenge was the non-uniform cadence of the simulation output which made the visualization stutter when mapping data files directly to successive movie frames.

To create interactive previews of scientific datasets, the AVL uses an original open-source software tool called Partiview, which was primarily authored by AVL programmer Stuart Levy. Partiview is able to render particles, lines, triangle meshes, and star-like data and interactively update their visual attributes based on data attributes. To flexibly navigate through these Partiview environments, explore 3D data topology, and develop complex camera choreography in an immersive stereoscopic 4K environment, the team links Partiview with another original software tool called Virtual Director, authored by past AVL programmer Matt Hall and Marcus Thiebaux. Virtual Director is a remotely collaborative camera control and design tool capable of performing or keyframing path splines and editing them during interactive data playback.

A Partiview scene was created for the shot by visualizing the particles in John's data, which gave the team a general idea where the large scale structure would be. The team relied heavily on low-resolution render tests to perfect the camera view.

Because of the size of John Wise's data, the AVL team chose to engineer a new pipeline using the Blue Waters supercomputer to facilitate higher parallelism than their dedicated visualization cluster was capable of, to take advantage of the high speed network between the data storage location and the compute nodes, and to develop a method of cinematic production rendering of restrictively large data directly on a supercomputer.

This new supercomputer-based pipeline relied upon a supercomputation data analysis and visualization software package called "yt", and the AVL interfaced closely with founding developers Matt Turk and Sam Skillman to ensure that the image output would be as high quality and data-accurate as possible. AVL employed this experimental volume renderer and adapted this into the development pipeline. These tasks included integrating color transfer functions and Virtual Director camera path data into yt, integrating a fish-eye lens shader for digital fulldome rendering, and coordinating OpenMP functionality to take advantage of the parallelism on the Blue Waters supercomputer.

As mentioned above, integrating three data fields into a single image render was a challenge, as multi-field rendering is not a feature of yt. The AVL achieved this multi-field look through two different methods. In the supernova shot, they built a combined color ramp that represented the color transfer functions of two fields, baryon overdensity and temperature, and adjusted the combined transfer function to write the first half of the color ramp to the temperature field, and the second half to the density field. At render time, the color of the higher-normalized magnitude field was chosen. Because the multi-field colormap method did not allow for the accumulation of color in voxels shared among fields, a 2D image compositing method was preferred for the galaxy evolution shot where that limitation was apparent. This same compositing method was used to add a metallicity layer to the supernova shot. Using a consistent camera path, each of the three fields was rendered on its own and then layered with the others. This compositing method also provided the flexibility to adjust color, contrast, and optimize visibility of the features after the time-consuming data rendering process was complete.

To compensate for the irregular cadence of the data output, the AVL used a script to arrange timesteps based on their relative position in the predetermined frame length. Data files with a low redshift were discarded, and files with high redshift were aligned to their correct spot along the timeline. To fill in the gaps, an image interpolation technique called "motion flow" was employed in the compositing software Nuke on a per layer basis. This technique was then used to create more in-between frames throughout the sequence to achieve a slow-moving embodied experience for digital fulldome audiences.

Using these techniques, the AVL was able to iteratively produce high quality cinematic renders of thousands of John Wise's multi-gigabyte datasteps in approximately 71,500 compute-node hours on the Blue Waters supercomputer.