Data-Driven VR/AR 3D Models: Walking Among the Stars

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In conjunction with scientists observing with *Chandra* and other telescopes, the Public Outreach program at the *Chandra* X-ray Center has pioneered two programs that enable scientists and the public to visualize dimensionally, touch, and even walk through astronomical sources.

Our initial example, Cassiopeia A (Cas A), was the first supernova remnant to be modeled in 3D based on observational data. In 2009, PI Tracy Delaney (then at MIT) analyzed data from *Chandra*, *Spitzer* and ground based telescopes. The data set was ported to unique brain imaging software that had been modified for use in astronomy by the Astronomical Medicine Project run at the CfA to create a 3D model. Initially the model was primarily accessible only in on-line video and via a special online video viewer developed by the Smithsonian to showcase its collections.

Since 2013 we have seen the rapid development and proliferation of 3D printers for mass use, and we worked with experts at the Smithsonian in Washington to convert the Cas A 3D files into a printable format. Cas A was not the easiest object to start with. The turbulent details of the explosion are difficult to print and the tendril-like jets have a habit of breaking off, even with careful handling. Having failed to find a commercial printer willing to deal with the intricacy of the model, we have printed a limited number of copies using in-house 3D printers while we continue to search for a commercial option.

Figure 1: Testing the Oculus Rift version of Cas A VR in the Brown YURT. Photo: E.Jiang

The models were used with great success over the summer at the National Federation for the Blind Youth Slam. Modifications suggested by the Youth Slam participants, such as sturdier jets and a version made in halves to provide access to the interior structure, have been implemented. See *http://chandra.si.edu/photo/2013/casa/* and *http://chandra.si.edu/deadstar/deadstar.html*.

Achieving success with a 3D printed Cas A sparked a search for other sources with 3D potential. The 30th anniversary of SN1987 A in 2017 offered such an opportunity. Based on models by Salvatore Orlando that were constrained by *Chandra* observations we developed a printable 3D model of the important threshold that SN 1987A has just passed: the shock wave moving beyond the dense ring of gas produced late in the life of the pre-supernova star and into the poorly known medium beyond. Orlando's visualization is based on a sophisticated 3D simulation that incorporates the complex interaction among radiation, matter and relativistic effects, reproducing the observed properties of the supernova. See *http://chandra.si.edu/deadstar/sn1987a.html*.

Also using simulations developed by Orlando, we have printed a 3D model of the latest outburst (2014) from the binary system V745 Sco. The printed model was made in two pieces to allow exploration of the shapes of the blast wave and the ejecta morphologies. See *http://chandra.si.edu/photo/2017/v745/* and *http://chandra.si.edu/deadstar/v745.html*.

The downloadable files and instructions for printing the three astronomical sources as well as a 3D *Chandra* spacecraft can be found at *http://chandra.si.edu/resources/illustrations/3d_files.html*.

We have used these models at AAS meetings and also with the public and at educational events. The physical representation of the astronomical data generates both interest and increased learning capacity in the public, and scientists report that it increases their understanding of the physical attributes of sources. We urge anyone with an interest in developing 3D models of astrophysical sources that they are working with to contact us to talk about what additional data or simulations would be necessary to turn that data into a physical representation. There is no single approach: each source has different requirements.

Simultaneously with the growth of 3D printing, software and hardware developments also spurred the dissemination of virtual reality (VR) and augmented reality (AR) into new content areas. VR is computer technology that simulates a user's physical presence in a virtual environment.

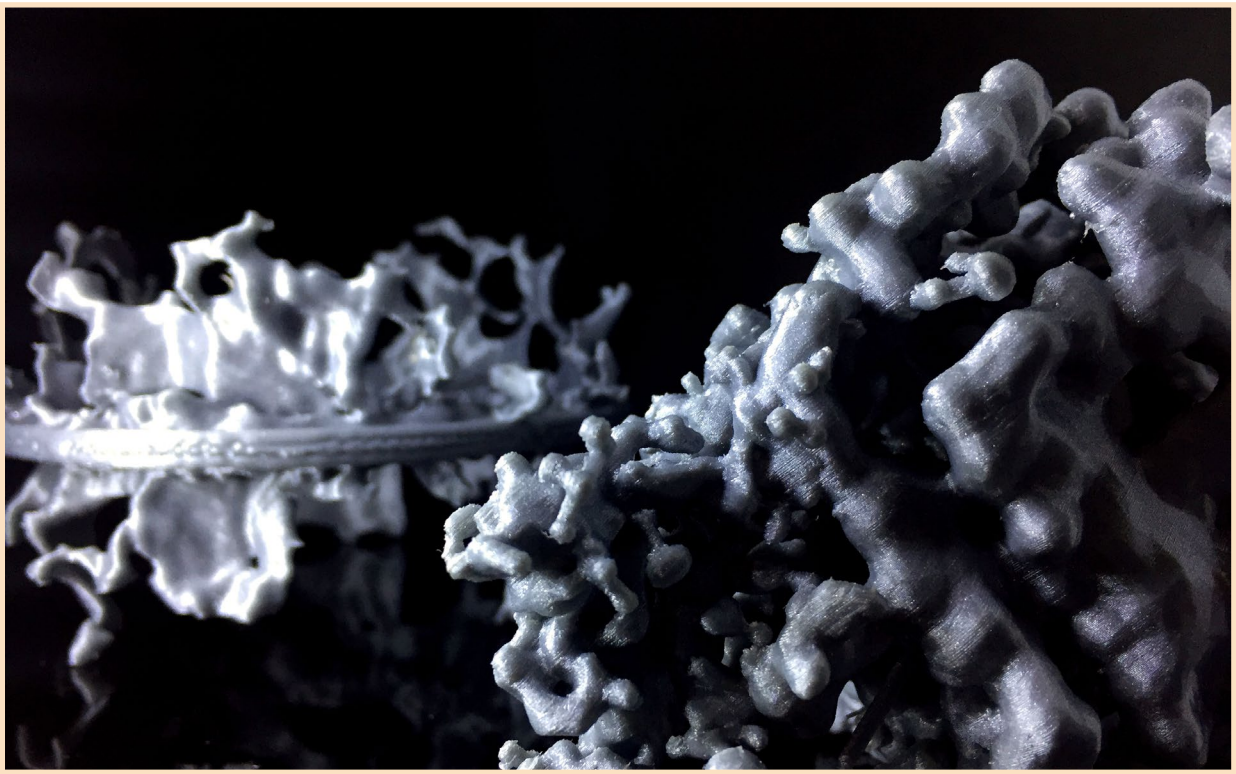

Figure 2: 3D prints of SN1987a (left) and Cas A (right). Photo: K.Arcand

AR adds elements, such as text, overlays, audio—essentially informational interactivity—to enhance that experience with sensory input and additional information about the virtual environment.

We were excited by the technological advances in the VR and AR realms and realized that we could expand the applications of our 3D models. For example, instead of our telling people where and what to look at in Cas A, VR/AR lets people explore the object themselves by, for the first time, navigating through the physical representation of the real data from the remains of an exploded star. The Cas A 3D VR/AR project is a collaboration between the *CXC* and Brown University's Center for Computation and Visualization in Providence, RI, and provides opportunities for public communications, informal education, and research.

Additionally, the *CXC* has worked with the Smithsonian Learning Lab to broaden the reach of *Chandra*'s Cas A 3D model. We collaborated to create a browser-based interactive 3D application that includes a 360 degree video playable in YouTube and also compatible with VR viewers such as Google Cardboard. The application has related educational resources and activities that can be explored at *http://s.si.edu/cas-a*.

Chandra has repeatedly observed Cas A since the telescope was launched into space in 1999. Each exposure has added new and important data to the growing bank of information that astronomers use to study this object. This deep reservoir of data also allows astronomers and visualization specialists to take the Cas A data set far beyond the two-dimensional imagery that exists for most astronomical objects. The latest release of a two-dimensional Cas A image shows the locations of the various elements produced in the explosion. This information is incorporated into the interactive VR/AR activity with color-coding and labels for enhanced visual interpretation.

The 3D visualization and VR/AR also have scientific applications. The 3D visualization shows that there are two main components to this supernova remnant: a spherical component in the outer parts of the remnant and a flattened (disk-like) component in the inner region. The insight into the structure of Cas A gained from the 3D visualization is important for astronomers who build models of supernova explosions.

The VR project is being made available in an open access format suitable for VR caves as well as on the Oculus Rift platform. More information on Cas A in VR is available at *http://chandra.si.edu/vr* or one can contact Kimberly Arcand for more information about accessing those files (*kkowal@cfa.harvard.edu*). Additional data-driven 3D astronomical objects are also in the works for the *Chandra* VR/AR experience. Again, we strongly encourage any scientist who is interested in using their data in 3D or VR/AR experiences to contact Kimberly Arcand. ■