An accessibility case study incorporating rich visual descriptions for *Chandra's* high-energy universe

Kimberly Arcand
Center for Astrophysics | Harvard & Smithsonian
kkowal@cfa.harvard.edu

Megan Watzke
Center for Astrophysics | Harvard & Smithsonian
mwatzke@cfa.harvard.edu

J.J. Hunt
Consultant
jj@jjhunt.com

Christine Malec
Consultant
christine.malec@gmail.com

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The nature and complexity of various kinds of astronomical data visualisations can be challenging to communicate with non-experts. The obstacles can become even larger for people who are blind, low vision or learn best via non-visual methods since much of the messaging in astronomical communication hinges on the visual imagery created from these data. In consultation with members from blind and low-vision communities, we present an overview of the 3D print and sonification projects and an in-depth discussion of the visual description project at NASA's *Chandra X-ray Observatory*. We offer a case study of how the 3D prints, sonifications, and visual descriptions are currently being used for mission and programme communications. We focus on how we integrate verbal explanations of the scientific phenomena along with descriptions of what the visual viewer sees in the presented imagery, sonification or 3D model to create a more accessible, cohesive package. We suggest that this process of creating content for blind or low-vision audiences can be scaffolded and applied to other types of astronomy content and a wide range of science communication.

Introduction

The *Chandra* 3D modelling and printing, sonification, and visual description programme is a set of accessible digital projects created to help communicate with communities, particularly those who are blind, have low vision, or have different learning needs. These programmes connect our target communities with the science of NASA's *Chandra X-ray Observatory* and other astronomical missions. The 3D modelling and printing project was launched about a decade ago (Arcand et al., 2019), the sonification project was launched in 2020[1], and the visual description project was launched in 2021[2]. Many of the results communicated with the public from *Chandra* science involve other telescopes that are capable of detecting light across the electromagnetic spectrum and even multi-messenger astronomy. As a result, these accessible projects also typically cover science results and images from other missions, telescopes, and instruments beyond *Chandra*.

The 3D printing project began in 2009 with the first 3D data model released of the supernova remnant Cassiopeia A (*Chandra X-ray Observatory*). By combining X-ray data from *Chandra* with infrared data from another orbiting NASA observatory, the *Spitzer Space Telescope*, and visible light from telescopes on the ground, we created the first 3D reconstruction of a supernova remnant. That 3D model was eventually improved with input from students at the National Federation of the Blind (*Arcand et al., 2019*) before being printed as a 3D print. Since then, we have added other objects, ranging from galaxies to interacting stars, to this growing 3D print collection[3].

Sonification was the next phase of our accessibility programme. Generally, sonification uses non-speech audio to provide information to listeners (*Kramer et al., 2010*). This project uses sonification to translate astrophysical data into sound, bringing cosmic objects and environments observed by *Chandra* and other telescopes to listeners by creating soundscapes of the image, spectrum, or other data. The sonifications are provided as audio-only files and in video/audio compilations. We have had a very positive response to these sonifications in blind and low-vision communities (*Arcand et al., in preparation*) as well as traditional popular and social media. For the former, workshops, talks and a research survey have been completed with the community. The workshops in particular provided time for feedback from blind and low vision community members which was positive overall. And the research survey showed high engagement and learning with the sonifications (*Arcand et al., in preparation*). In the press, recent *Chandra* sonifications of the black hole in the Perseus galaxy cluster in May 2022 led to huge spikes in our Chandra.si.edu web traffic (e.g.,15,240,111 hits in May compared to an average of about 8-10,000,000 in more typical months) and social platforms (e.g., 19,000,000 views of the Perseus sonification on Twitter (5/2022 -12/2022) compared to fewer than 1,000,000 views for most *Chandra* videos similarly shared on the platform.), as well as articles in the *New York Times* (*Overbye, 2022; Engle, 2022*) and other major outlets such as National Public Radio (*Simon, 2022*) and *Popular Science* (*Woodall, 2022*).

The visual description project creates detailed verbal descriptions of *Chandra* and multiwavelength data, which primarily take the form of 2D images, timelapse movies or sonifications, and illustrations as needed. Visual descriptions, also sometimes referred to as alternative (or “alt”) text, are text-based assets that provide written information to accompany an image to describe it for a user who cannot see it (*Mack, 2021*). Working with experts in visual descriptions, including an expert who is blind, we developed rich text descriptions of the images created from astronomical data that are released simultaneously with the traditional package of press release text and images. These rich visual descriptions differ from typical image captions in that they provide extended detail of what is shown, are written in a style more suitable to listening rather than reading (e.g., shorter sentences and the frequent use of proper names), and with commonplace analogies when possible. The visual description information is created as text[4] and recorded in audio[5] format, and published as alternative texts in both web and social media platforms (shortened to the appropriate character length as needed for the latter). In response to user feedback, we now also package audio recordings of the rich texts into an XML podcast feed[6].

Visual description techniques

How can we best describe images or videos of cosmic objects constructed from light mostly invisible to the human eye to people who are blind or have low-vision? Some of the common reference points frequently used in traditional caption writing can be of low value to those who have not been able to experience certain phenomena firsthand.

We have, therefore, developed three main strategies to create visual descriptions of complex astronomical objects. The first is to weave the scientific meaning throughout the text, instead of simply describing the image or video only as it appears. Our blind and visually impaired (BVI) testers reported that this method enhanced understanding of both the visual structure and the scientific significance behind it when we integrated these information tracks.

The second strategy is adapting the writing style. Quite frequently, captions for astronomical images can include longer sentences that contain a good deal of information. While this can be effective for some sighted users, it can be challenging for someone receiving the information audibly. Our solution has been to provide shorter sentences with multiple commas that allow for natural pauses in the description. We also use proper nouns more frequently than in other settings. For example, replacing “it” with “the black hole” in a sentence may seem like a trivial change, but it can help anchor a BVI user in following along with the discourse. These changes can also have a secondary benefit by boosting the search engine optimisation (SEO) results for websites (*Ltd, Innovation Visual, n.d.*). These user-tested techniques have also been informing how other *Chandra* captions or descriptions for non-experts are written to improve accessibility and inclusion generally, with similar incorporation of more proper nouns, fewer complex structures, and so on.

Our third strategy has been to insert this process of creating descriptions into the pre-existing pipeline of communications products we produce for every publicly released result. Rather than having a separate process, we have made it an adaptation of text already being written and vetted. This is important for missions and telescopes with more limited staff and resources. By adapting existing reviewed text rather than creating it from scratch, we have been able to absorb this project into the workload without significant additional time allocations from staff. Of course, adding rich descriptions is extra work and must be considered by those who would like to implement this step in their communications. Ideally, organisations should identify staff or contractors who can write, or learn to write, in this specific style and members of the blind or low vision community who can collaborate to help adapt and verify the meaning-making of the product.

In our pilot programme we have found that using the regular caption or release text as a starting point does not require an exorbitant amount of additional research. In other words, we can improve access for an underserved community by re-writing and adapting what is already being prepared. We purport that any effort in this area is an important step in better serving these audiences that have long been overlooked by astronomical communication.

Case study examples

The following examples demonstrate elements of the accessibility scaffolding: 3D printing, sonifications, and visual descriptions. By offering such products, we hope to provide users with a suite of options that they can select based on their interests, needs and abilities. Indeed, as there is no “one size fits all” mode of accessible science communication, we work directly with members of different communities to develop, refine, and innovate to help meet the needs of multiple non-expert audiences.

Videos provide content across time, so often, there is more involved in providing such descriptions than a still image alone requires. However, it is also possible that an image can be particularly complex or nuanced and need more text to assist users in understanding the content.

Eta Carinae 3D model (video)[7]

3D Print:
https://chandra.si.edu/deadstar/eta.html

Sonification:
https://chandra.si.edu/sound/index.html#etacar

Visual Description
(*Chandra X-ray Observatory, 2022a*):

Today's release features a visualisation of a massive star, Eta Carinae, which expelled about 10% of its mass in an event known as the Great Eruption observed in the 1840s. This eruption created a small nebula around the star, the Homunculus Nebula. Images taken in different wavelengths of light by the *Hubble Space Telescope*, *Chandra X-ray Observatory*, and *Spitzer Space Telescope* have helped visualisation specialists create a digital 3D model that can be rotated 360 degrees. This visualisation is presented in a short video that shows the digital model being constructed layer by layer.

The video begins with static images of each layer: Visible, Ultraviolet, Hydrogen, and X-ray, as well as an image combining all of the above wavelengths. When frozen in time, the Great Eruption resembles a peanut in the shell. The bulbous, knobby shapes at either end represent the erupting nebula, while the star itself occupies the tapered space between them.

In the 2D image and 3D model of the Great Eruption in visible light, Eta Carinae is presented in mottled and veiny browns and tans. This 3D rendering is the base image onto which subsequent layers are added. As the model rotates, cloudy columns shooting out of the glowing core become evident.

As the 3D model continues to rotate, bright blue ultraviolet light is added to the visualisation. This light blankets the peanut shape in a soft neon blue cloud. Thin shafts of blue light burst from the core, extending beyond the cloudy brown columns.

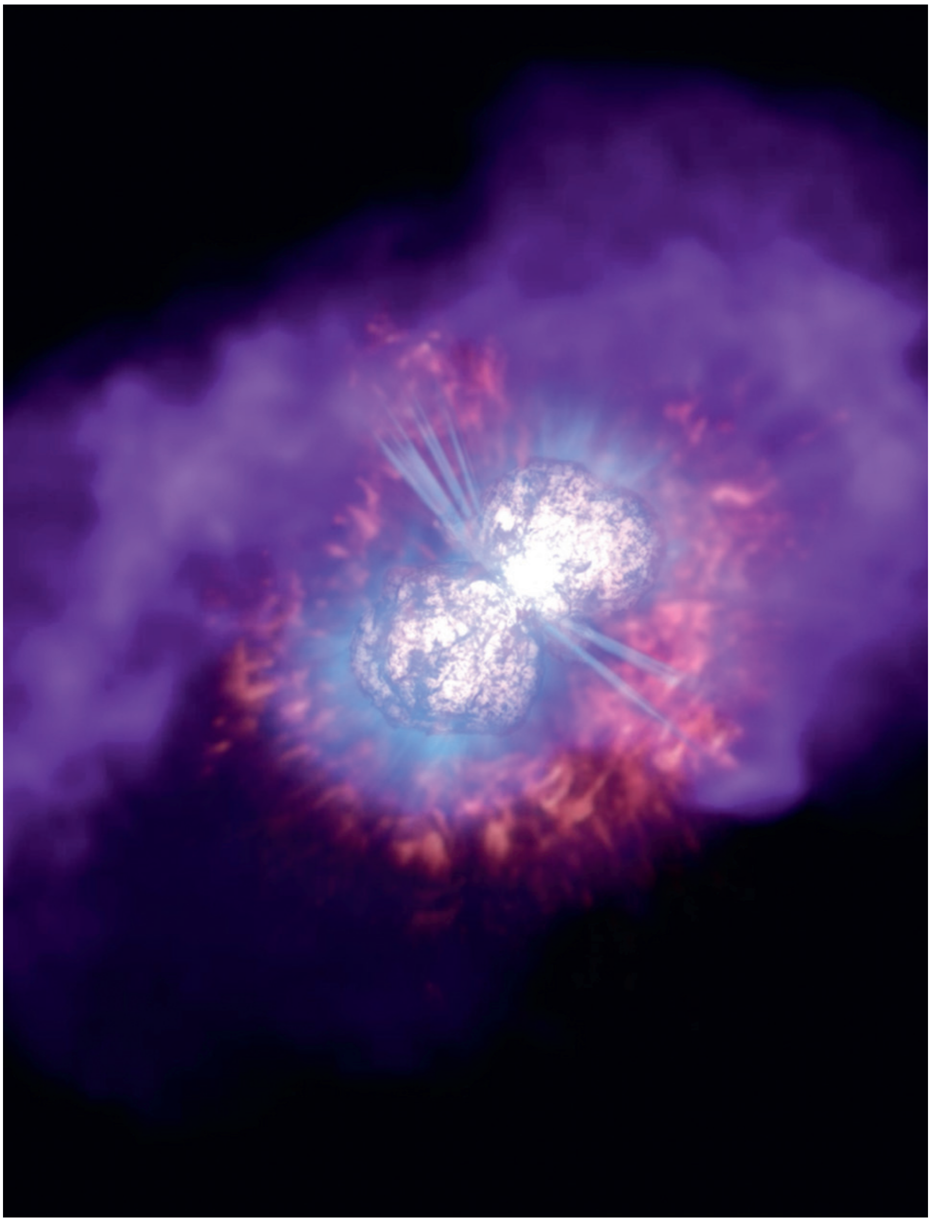

Figure 1 *A 3D visualisation of a massive star, Eta Carinae, which expelled about 10% of its mass in an event known as the Great Eruption observed in the 1840s. Image Credit: J. Olmsted, D. Player, L. Hustak, A. Pagan, J. DePasquale, G. Bacon, F. Summers (STScI), R. Hurt (Caltech/IPAC), NASA, ESA*

Next, the emission from hydrogen atoms is added to the still-rotating model. This resembles a translucent ball of red flames encircling the peanut shape and the blue ultraviolet light. Inside the cloud, the visual layer appears to glow.

Finally, an irregular cloud of purple X-ray light surrounds the red hydrogen emission. This cloud appears soft in texture and is longer than it is wide, similar in shape to the glowing eruption at its core.

Cat's Eye Nebula (sonification)[8]

3D Print:
https://chandra.si.edu/tactile/3d_printing.html

Sonification:
https://chandra.si.edu/sound/index.html#ngc6543

Visual Description
(*Chandra X-ray Observatory, 2021*):

The Cat's Eye video features a static image of an ethereal shape surrounded by concentric circles. The shape is the Cat's Eye nebula, a huge cloud of gas and dust blown off of a dying star. The concentric circles are bubbles expelled by the star over time. The dust cloud resembles a translucent pastry pulled to golden yellow points near our upper right and lower left, with a blob of bright purple jelly inside the bulbous pale blue core. The jelly-like centre represents X-ray data from Chandra.

The outer cloud and translucent circles represent visible light data from the Hubble Space Telescope. As the video unfolds, a white line emanating from the centre of the nebula scans the image in a circle, like the second hand on a clock, or the radial arm on a radar screen. The more of the nebula that's in its path, the richer the accompanying sound. Light that is farther from the core has a higher pitch than light that is close to the core. X-rays are represented by a harsher sound, while visible light data sound smoother. The concentric circles create a constant hum interrupted by a few sounds from spokes in the data. Additional videos feature Cat's Eye images and audio from separated X-ray and optical data sets.

Figure 2 *When a star like the Sun begins to run out of helium to burn, it will blow off huge clouds of gas and dust. These outbursts can form spectacular structures like the one seen in the Cat's Eye nebula. Image Credit: X-ray: NASA/CXC/RIT/J.Kastner et al.; Optical: NASA/STScI; Sonification: NASA/CXC/SAO/K.Arcand, SYSTEM Sounds (M. Russo, A. Santaguida)*

Cassiopeia A (image)[9]

Related 3D Print:
https://chandra.si.edu/tactile/3d_printing.html

Related Sonification:
https://chandra.si.edu/sound/index.html#casa

Visual Description
(*Chandra X-ray Observatory, 2022b*):

This image resembles a disk of electric blue light, purple clouds, glowing white fog, and red and yellow flames, dotted with glowing orange specks. This is Cassiopeia A, a supernova remnant. Here, elements of the exploded star are cast into space. The red and yellow flames are silicon and sulfur. The light purple within the cloud is iron, and the blast wave is blue. All were observed by the *Chandra X-ray Observatory*. The electric blue-purple light, which appears in ripples throughout the disk and around the outer rim, is radio data from the National Science Foundation's Very Large Array. This also shows the blast wave from the explosion. A layer from the *Hubble Space Telescope* adds orange to the flames and the glowing specks.

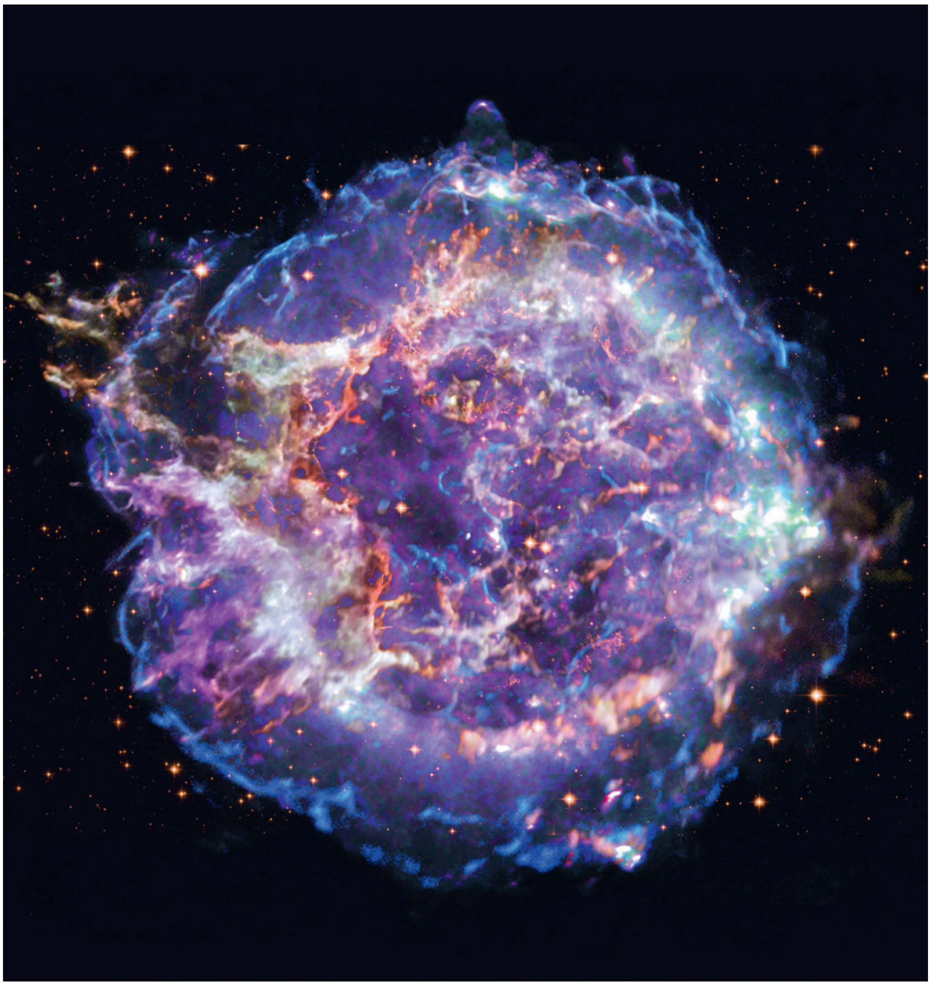

***Figure 3** Cassiopeia A is a supernova remnant observed by the Chandra X-ray Observatory. The X-ray image has been combined with radio data from the National Science Foundation's Very Large Array and optical information from the Hubble Space Telescope. Image Credit: X-ray: NASA/CXC/SAO; Optical: NASA/STScI; Radio: NSF/NRAO/VLA*

Discussion

Since the *Chandra* Communications group began implementing these accessibility programs, we have continued to survey the results among the audiences we are trying to reach. We have presented the projects at numerous events, from webinars and workshops to radio shows and podcasts, particularly for participants who are blind or low vision, with highly positive feedback. As we learn more about the needs and wants of these communities, we will adapt further to refine our best practices. We intend to submit a paper on the sonification project's quantitative data and conduct a more formal qualitative and quantitative user study on the visual descriptions programme soon. Moreover, we have shared what we have learned so far with other NASA missions, other groups at the Center for Astrophysics | Harvard & Smithsonian, as well as with other professional astronomy and science communications organisations, and have developed a "master class" workshop to help other groups apply these techniques for their own programs. This type of program is a small but important step towards being more responsive to and inclusive of what have traditionally been underserved audiences in astrophysics.

Notes

1 *Chandra* X-ray Center, Sonification page: https://chandra.si.edu/sound

2 *Chandra* X-ray Center Visual description page: https://chandra.si.edu/tactile/visual.html

3 *Chandra* X-ray Center, 3D print page: https://chandra.si.edu/3dprint

4 *Chandra* X-ray Center, Text example: https://chandra.si.edu/photo/2021/kpd0005/kpd0005_description.txt

5 *Chandra* X-ray Center, Audio example: https://chandra.si.edu/photo/2021/kpd0005/kpd0005_description_audio.mp3

6 *Chandra* X-ray Center, URL for XML feed: https://chandra.si.edu/resources/podcasts/description_audio.xml

7 *Chandra* X-ray Center, Eta Carinae 3D model page: https://chandra.harvard.edu/photo/2022/etacar/

8 *Chandra* X-ray Center, website for example sonification: https://chandra.si.edu/photo/2021/sonify3/

9 *Chandra* X-ray Center, website for example sonification: https://chandra.si.edu/photo/2021/v404cyg/

10 NASA's Universe of Learning -Accessible Resources: https://www.universe-of-learning.org/resources/projects/accessible-learning-resources

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Conflict of Interest Statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Biographies

Kimberly Arcand is an expert in astronomy visualization and has been a pioneer in 3D imaging, printing, and extended reality applications with high-energy astrophysics data.

Megan Watzke is the press officer for the Chandra X-ray Observatory at the Center for Astrophysics | Harvard & Smithsonian.

J.J. Hunt is an innovative Audio Describer and storyteller who co-founded with Malec the podcast Talk Description to Me.

Christine Malec is an arts consultant, sonification consultant and member of the blind community. She's been a lifelong space enthusiast and advocate of accessible astronomy.