Touch the Universe: Developing and Disseminating Tactile Telescope Models Created with a 3D Printer

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We initiated a project to develop tactile models of telescopes from the National Astronomical Observatory of Japan (NAOJ) to explain cutting-edge technologies of the telescopes and how they work. The goal was to develop models that could be understandable for blind and visually impaired (BVI) and sighted people and to make the data for these models freely available in a format compatible with commercially available 3D printers. As a first step, we created a 1/110th scale model of the Subaru Telescope, NAOJ's large optical-infrared telescope on Maunakea, Hawai'i. Based on comments from people who are BVI and a science teacher of special needs, we created two types of model: A detailed model for sighted people and people who are BVI who have excellent haptic observing (touch interaction) skills and a simplified model for students at special needs schools for the visually impaired who are learning how to touch samples and need tactile models in science classes. With these models and other tactile models of celestial bodies, the special exhibit Touch the Universe was held at the tactile museum of the Japan Braille Library.

Introduction: Why Tactile Telescope Models

Astronomy is a gateway science which arouses the curiosity of people regardless of age, nationality, ethnicity, or disability. Nobody should be left behind when enjoying and experiencing the wonders of the Universe. However, many people with disabilities do not have enough opportunities to "touch" the Universe probably due to a lack of resources (e.g., Mineshige et al., 2009). In order to improve such situations, astronomers and astronomy communicators have developed various resources to reach more diverse people such as people who are blind or visually impaired (BVI) over the last decade. For example, an astronomy book in braille and a planetarium show with a tactile hemisphere were developed in Spain (Ortiz-Gil et al., 2011), a braille astronomy textbook has been published in the United States[1], and a tactile and braille exhibit of astronomy images were also presented in the United States (Arcand et al., 2010).

In Japan, Dr Shin Mineshige and Mr Jun Takahashi have published multimodal astronomy textbooks (Mineshige et al., 2009) for three different knowledge levels: undergraduate students in science courses, secondary school students, and children who are elementary school-aged or younger. These books were published in multiple media: a print version, a printed version in braille, an audio version, and a PC version for people to read with larger letters and with bright white letters on a black background. The braille versions included many tactile images of celestial bodies developed by the authors with people who are BVI. At NAOJ headquarters in Mitaka, Tokyo, the visitors' area is open daily except for the New Year's holidays. At the headquarters, visitors can enjoy exploring historical telescopes, the Solar System Walk (a to-scale model of the Solar System), and an exhibition room introducing current NAOJ projects. A printed guidebook of the Mitaka campus is written in Japanese braille and large gothic font, in addition to Japanese, English, Chinese, Korean, and Spanish, so visitors can select their preferred version (Usuda-Sato et al., 2018). With a smartphone or a tablet, an audio guide in English and Japanese, as well as a Japanese sign language movie, can also be accessed at each facility through scanning a two-dimensional barcode (QR code) linked to an audio guide website[2].

In the 2010s, the three-dimensional (3D) modelling and printing technology has become cheaper and more accessible in science communication and education (e.g., Arcand et al., 2017). In astronomy, the A Touch of the Universe project[3] (e.g., Pérez-Montero 2019) in Spain and other countries developed a tactile sphere of the Moon and the rocky planets. The Tactile Universe project[4] (Bonne et al., 2018) in the United Kingdom created 3D-printed tactile images of galaxies. NASA's Chandra X-ray Center (CXC)[5] developed the 3D models of supernova remnants such as Cassiopeia A and other objects (Arcand et al., 2017, Arcand et al., 2019). On the official website of these projects, printable 3D files (STL and sometimes OBJ files) can be downloaded. The printable 3D and other tactile resources are being developed in many countries, and NASA opened a repository website[6] of a collection of printable 3D models. The International Astronomical Union (IAU) Astronomy for Equity and Inclusion Working Group [7] also has various resources and activities on its website. In the new IAU Strategic Plan 2020-2030[8], the IAU set one of the five goals (Goal 2) to promote the inclusive advancement of the field of astronomy in every country, and astronomy activities are expected to become more inclusive in the next decade.

Although many tactile 3D models of celestial bodies and astronomical data have been developed and disseminated in the world, few telescope models have been introduced. A telescope is an essential tool for studying the Universe and for understanding how a cutting-edge telescope works. It is a fundamental component of astronomical observations. In the visitors' area of NAOJ headquarters, many old, retired telescopes and some telescope models of the current projects can be seen. However, the old existing telescopes are too large for people who are BVI to understand the whole telescope with their arms and fingers, and the new telescope models are inside glass cases and, thus, not accessible. For these reasons, it is challenging to answer simple questions from people who are BVI such as "How does the telescope enclosure open?" and "How does the telescope move?", so we initiated a project to create 3D tactile models of telescope, starting with a model of the Subaru Telescope. Just like the 3D models of celestial bodies, the telescope models are helpful not only for people who are BVI but also for people who are sighted to better understand the telescope.

Figure 1. The detailed version (left) and the simplified version (right) of the 3D models of the Subaru Telescope. Credit: NAOJ

Subaru Telescope Models: What Is a Good Model?

The Subaru Telescope is a Japanese optical-infrared telescope constructed near the summit of Maunakea on the Big Island of Hawai'i. It is operated by NAOJ and started observations in 1999. The diameter of its primary mirror is 8.2 metres, making it one of the largest monolithic mirrors in the world. To develop a tactile 3D model of the Subaru Telescope we listed its distinguishing features to be communicated with the public: (1) it is one of the largest monolithic mirrors in the world, (2) with a wide field-of-view, prime focus camera mounted at the top of the telescope, and (3) has various observing instruments mounted at four foci. We also wanted to show (4) a telescope without a telescope tube structure and (5) the motion of the telescope as a giant optical-infrared telescope. The 3D model was designed by Hirotaka Nakayama using Autodesk Maya, a commercial 3D computer graphics application. Nakayama based the model off information on the entire form and size of the Subaru Telescope collected from the official website[9]. He then finalized its specific individual parts with photos of the telescope he took inside of the enclosure on Maunakea.

For the initial 3D model with detailed features, we consulted the following three people: Mr Naoto Shibata, Dr Kojiro Hirose and Mr Sadao Hasegawa. Shibata, a science teacher at the Special Needs Education School for the Visually Impaired, University of Tsukuba, Japan checked the prototype model and requested we make it simpler. In science classes, students who are BVI learn how to observe samples and models using their haptic sense. They may not understand the essential features of a highly detailed model. On the other hand, Hirose, a blind researcher at the National Museum of Ethnology in

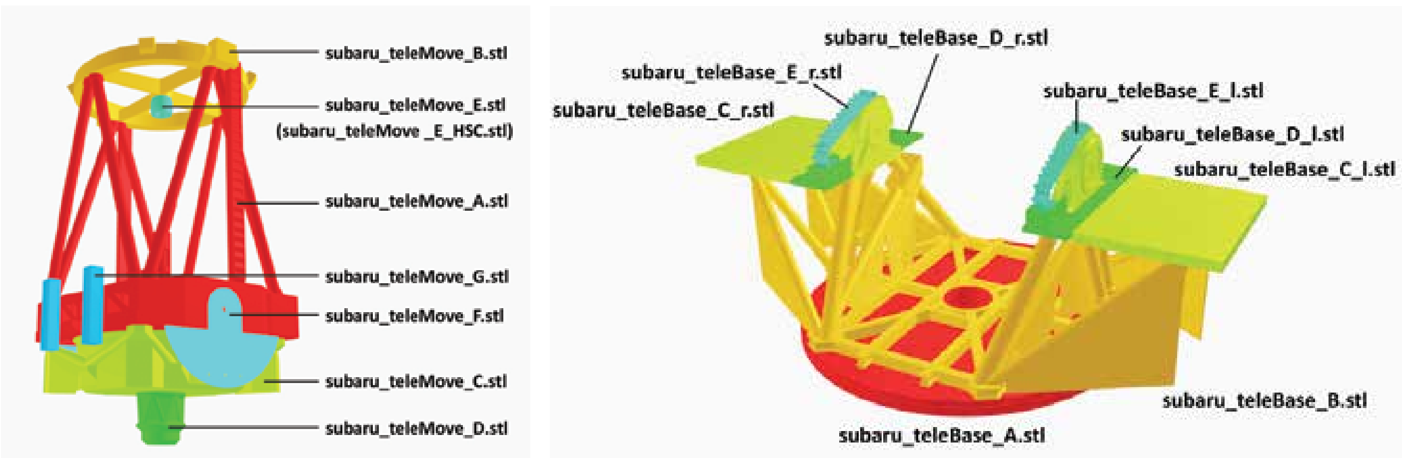

Figure 2. The parts of the movable section (left) and the base section (right) of the detailed model. The movable section the secondary mirror (subaru_teleMove_E.stl) can be exchanged with the Hyper Suprime-Cam or HSC (subaru_teleMove_E_HSC.stl) part, which is an extremely wide field-of-view camera mounted on the prime focus. In the base section, the "C", "D", and "E" parts have a left ("l") and right ("r") version, both of which are needed to construct the telescope. Credit: Hirotaka Nakayama/ NAOJ

Japan with excellent haptic observing skills enjoyed touching it and told us not to simplify the model. Therefore, we decided to develop both simplified and detailed models (Figure 1)[10]. Hasegawa, another blind person, asked us many questions about the Subaru Telescope when he was touching the model. He said that he had a great time getting to learn about the telescope, and this conversation showed us the importance of having detailed explanations of the model.

Each model consists of the movable and base sections, and each section is divided into as many as ten parts. All parts are designed for sizes that can be easily printed using a 3D printer without any support materials, and all STL files can be downloaded from the official NAOJ 3D-models website[11]. After assembling the two sections individually, they are bolted together. The rough dimensions of the approximately 1/110th scale models are 27-cm width × 17-cm depth × 25-cm height, and the diameter of the primary mirror is 7.4 cm, which is large enough for everyone to touch with one's fingers and to recognize the concave shape (the curvature of the mirror is not to scale and exaggerated on the model). The model can be printed smaller, but this will lessen a user's ability to touch certain details of the telescope, like the mirror.

Figure 3. Mr Naoto Shibata (farthest left) explains the structure of an amateur refractor telescope as three students try to understand it by touching the telescope. Credit: Lina Canas/IAU Office for Astronomy Outreach

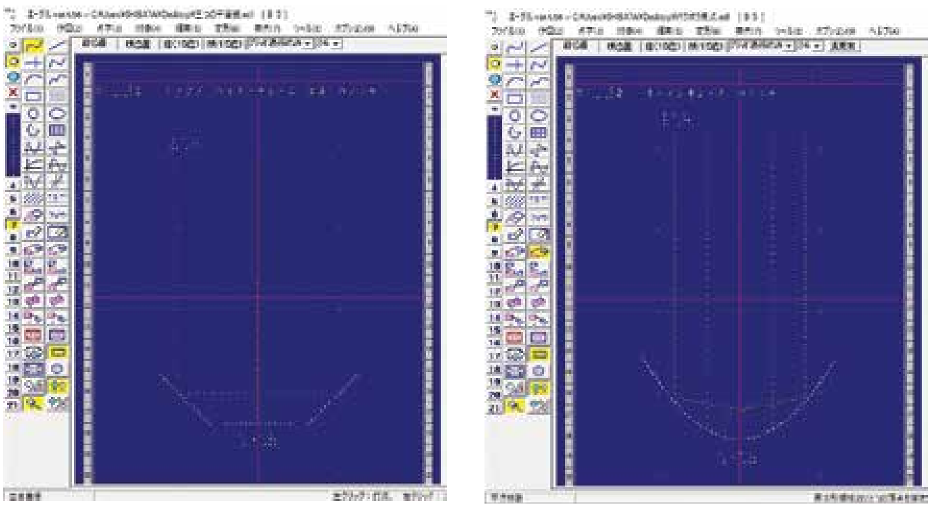

Figure 4. Two tactile diagrams displayed with EDEL software show how parallel light from outer space is collected with three flat mirrors (left) and with a concave mirror (right). The flat and concave mirrors at the bottom of the diagrams were designed with larger dots, and the light rays were designed with smaller dots. Credit: Naoto Shibata

The models used ABS (acrylonitrile butadiene styrene) thermoplastic as the printing material. PLA (polylactic acid) is another popular thermoplastic material for 3D printing. Compared with ABS, PLA is easier to handle, especially when printing a flat surface as PLA is less sensitive to temperature and does not warp like ABS. On the other hand, ABS is stronger when printed at a sufficient temperature (210-250˚C) and can bounce back when dropped whereas PLA can chip or break. For the Subaru Telescope models, the parts need to be assembled, and the two sections need to be bolted. To avoid breaking any parts, ABS is a better material.

In general, people who are BVI are curious about textures, and they ask questions about smoothness and roughness. The smoothness of the primary mirror, the heart of the Subaru Telescope, is one of the essential features that need to be explained. However, it is challenging to make a smooth curve with a 3D printer and ABS materials because concentric rings are printed to make the primary mirror. Therefore, we decided to use a different material for the primary mirror. A 7.4-cm diameter "mirror" was cut out with a compass cutter from a 20-cm diameter transparent vinyl-chloride half-sphere and pasted on the subaru_teleMove_C part in Figure 2 using an ABS adhesive bond before assembling the movable section. The curvature of the subaru_teleMove_C part is designed to fit the curvature of a 20-cm half-sphere. The smooth mirror is easy to find for people who are BVI with their fingers. For sighted people, the mirror part looks shiny like a real mirror.

For both models, STL files and a manual can be downloaded from the official NAOJ 3D-models website. The detailed instructions are explained on the website. The website also has a page explaining key points of the structure of the Subaru Telescope to

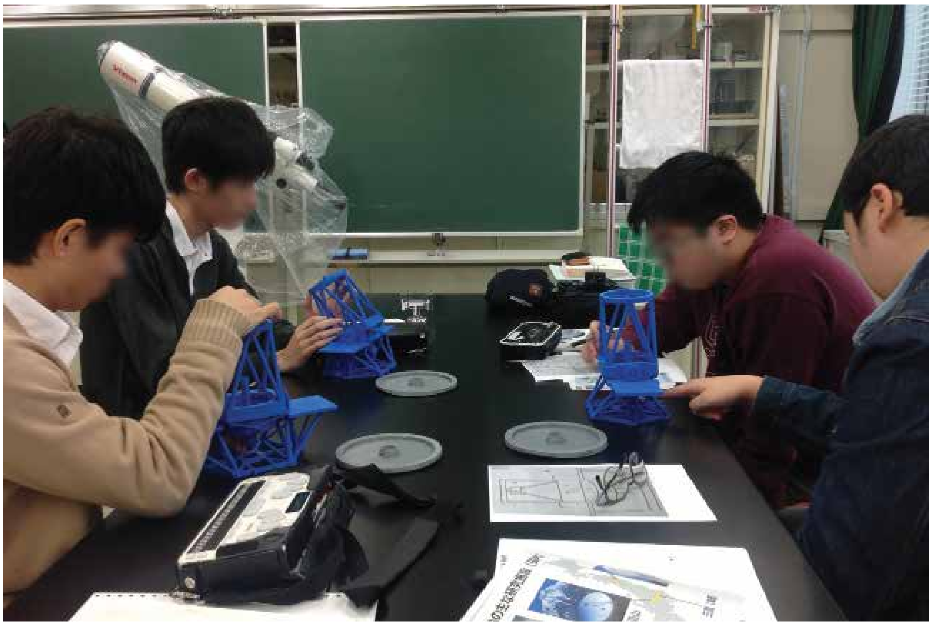

Figure 5. Students observe Subaru Telescope models. Two students with total blindness (on the left) observed the model individually while two students with low vision (on the right) shared one model. Credit: Lina Canas/ IAU Office for Astronomy Outreach

be used by teachers and educators in conjunction with the 3D models.

Communicating With People With BVI: Additional Tactile Images

The first presentation of the models was made in Shibata's science class. The Grade 11 class consisted of three students with total blindness and four students with low vision. In the first half of the 90-minute class, each student learned about the structure of a refractor telescope (convex lens, telescope tube, and mount) by touching a real amateur refractor telescope (Figure 3). Using a light probe, a simple device which converts light into sound, Shibata explained that the light collected with the objective lens goes through the telescope tube to the eyepiece. Some low-vision students looked through the eyepiece and saw the light. In the second half of the class, Dr Kumiko Usuda-Sato explained the difference between a refractor and a reflector telescope, and then introduced the Subaru Telescope. Linking to light reflection, which is included in the school curriculum guidelines (Science Standard of Japan), she explained using two tactile diagrams of how telescopes utilize reflection (Figure 4). The first diagram explained the concept of collecting parallel light rays from outer space with three flat mirrors, and this concept was extended to a concave mirror in the second diagram.

These diagrams were designed with EDEL[12] software for drawing tactile diagrams and then printed on white paper with a braille printer. EDEL was developed at Tsukuba University of Technology in Japan and can be downloaded for free onto a Windows computer. Diagrams made with EDEL can be converted into image data such as a jpeg file.

When the seven students observed the 3D Subaru Telescope model, five simple models were provided (Figure 5) as Shibata requested: one model for each fully-blind student and one for two low-vision students. Using their haptic sense, students needed enough time to observe the model and understand its structure and motion.

After the presentation, the students sent thank you letters, writing, "I had never studied the detailed structure of a telescope before. After this class, I could understand how a telescope works", "I have touched a real telescope (refractor) for the first time, and could feel its size and the weight of the lens", "By touching the models, I could understand the telescope better than by just listening to the lecture. Thanks to the model, I can imagine the telescope in my mind." Many students also mentioned the cutting-edge technologies and accuracy of the Subaru Telescope, which means that a tactile model can be a catalyst for communicating astronomy and technology, and that related stories and facts can enrich students' understanding of the model.

Usuda-Sato also gave presentations to other BVI groups in Tokyo. Compared to the classroom, a bigger group was more challenging. Enough time was needed to touch the model by each BVI person, but, on the other hand, six models were the maximum number that could fit in a large suitcase to bring them to the location. Therefore, each model was used by a group of up to five people of both BVI and sighted ability, and limited the maximum number of participants to 30 in total. During the presentation, sighted people were asked to repeat information to BVI people what Usuda-Sato and other presenters explained. It was different from a classroom as there was no teacher, so asking sighted attendees to be interpreters helped enhance the understanding of BVI participants. Additionally, at these meetings, two tactile diagrams of the cross-section of simple refractor and reflector set-ups, along with the Subaru Telescope (Figure 6) were shown. Attendees learned about the structure of the telescope with the images and then enriched their understanding by touching the 3D models. The tactile diagrams were made with the PIAF Tactile Image Maker[13] manufactured by Hapro. Hapro is a Polish company with a global reach, and PIAF products can be purchased in many countries, including Japan. Each diagram was copied onto heat-sensitive capsule paper and heated with the PIAF Tactile Image Maker, which made the black lines and areas swell up.

Some of the attendees had BVI networks. An editor of a BVI journal asked us to write an article about developing the tactile models, and another attendee introduced us to the director of the Japan Braille Library (JBL). The presentations resulted in the special exhibition at JBL reported in the next section.

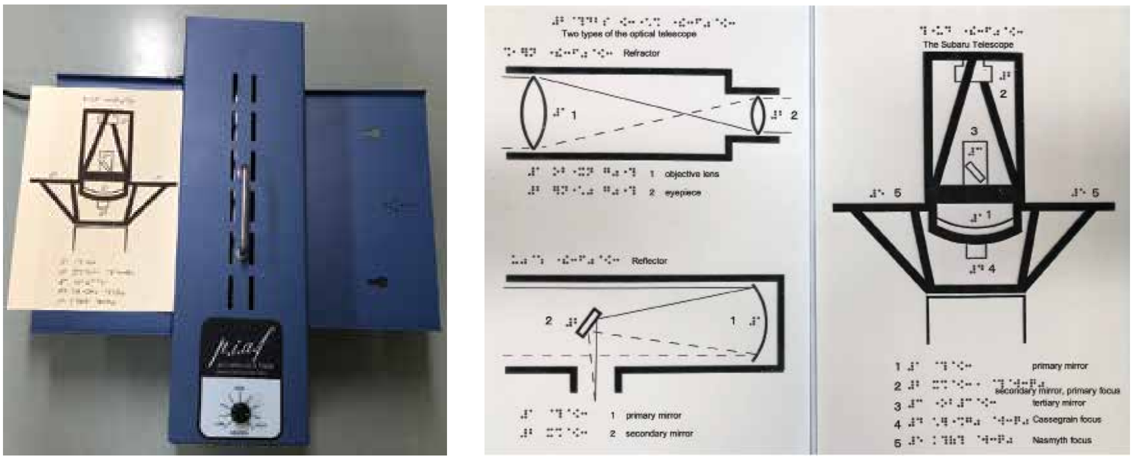

Figure 6. On the left, the tactile diagram of the Subaru Telescope comes out of the PIAF Tactile Image Maker. On the right are two diagrams printed on heat-sensitive capsule paper. A free Japanese braille font created and distributed by Japan Lighthouse, a social welfare corporation[15], was used to note parts of the telescope. On these images, an English translation is shown. Credit: NAOJ

Special Exhibit at Japan Braille Library

The Japan Braille Library (JBL) opened Tactus Museo[14], a tactile museum on the second floor of its annexe building, in 2018. The museum is open three days a week to everyone for free, and each visitor signs up at the entrance and then receives antibacterial wipes to be ready to touch the exhibits. The special exhibit Touch the Universe was held from 17 August 2018 to 22 December 2018, and it was co-hosted by the Educational Materials Library Seen with Hands and Eyes in collaboration with NAOJ. The Educational Materials Library provided tactile models of rockets and spacecraft, and NAOJ provided models of telescopes and celestial bodies with supervision from Usuda-Sato on the content. The layout of the museum is shown in Figure 7. The exhibit consisted of four sections: (1) going into outer space, (2) studying outer space, (3) a scale model of the Solar System by distance, and (4) a scale model of the Solar System by size.

At the elevator exit area, an existing tactile Moon created for the A Touch of the Universe project[3] was displayed. In Section 1 with the rockets and spacecraft models, a tactile model of asteroid Itokawa was displayed, printed from STL files downloaded from the NASA 3D Resources website[6]. A blind visitor shouted, “It is not spherical!” when he touched the Itokawa model. This episode shows that most information on celestial bodies is only sent to the public through images, and even a simple tactile model helps people with BVI understand celestial objects more precisely. Later on during the exhibit run, a tactile model of the asteroid Ryugu was added, which was created with the latest data taken with the Japanese spacecraft Hayabusa2 (Watanabe et al. 2019). At that time, the data had not been published or released to the public[16], and Dr Hiroshi Arai, an NAOJ researcher working with Hayabusa2, created the 3D model. The addition of the Ryugu model was immediately announced on the official site of Tactus Museo, and some visitors to the museum said, “I read the website and came to touch the Ryugu model.”

On the first display panel of Section 2, people learned that it is challenging to send spacecraft outside of the Solar System and that telescopes are an essential tool for studying the Universe. With this panel, people recognized the gap in the distance between Section 1 (where a probe can be sent) and Section 2 (beyond the reach of a probe). A simple model of Galileo’s rudimentary refractor telescope and an amateur reflector telescope were displayed with the Subaru Telescope tactile models. A human fig-

Figure 7. The layout of Tactus Museo. In front of the elevator exit (image 1), the tactile globe and the Moon model were displayed. At the entrance with the title of the exhibition (2), a braille block was on the floor. After people signed up at the reception, they started touching the exhibit in the following order: Section 1. “Going to the outer space” (Image 3), Section 2. “Studying outer space” (Image 4), Section 3. “A Scale Model of the Solar System I. Distance” (Image 5), and Section 4. “A Scale Model of the Solar System II. Size” (Image 6). Credit: Kumiko Usuda-Sato/NAOJ

Figure 8. The Subaru Telescope model (detailed version) with a human figure centred at the bottom of the model. A tactile map of Hawaiian islands created by Tactus Museo was displayed. On the map, a transparent braille label was overlaid onto each printed label. Credit: Kumiko Usuda-Sato/NAOJ

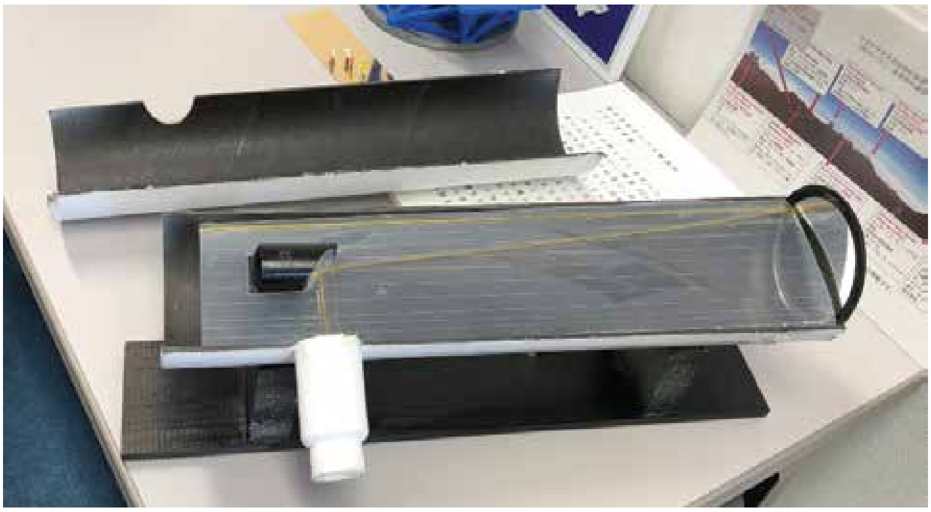

Figure 9. The tactile 3D model of a reflector. The primary and secondary mirrors and the eyepiece were shown, and a light path in the telescope tube is shown with a string. Credit: Kumiko Usuda-Sato/NAOJ

ure was added as a scale indicator so that people realised the actual size of the telescope by touching it (Figure 8). Additional tactile materials were added to enhance visitors' understanding. In addition to the tactile diagrams shown in Figure 6, a 3D diagram of a reflector was displayed, which was created by the Educational Materials Library (Figure 9). An old amateur reflector was also displayed for people who are BVI to touch it.

In Section 3, a one-trillionth scale model of the Solar System was displayed on the wall. This scale was chosen to fit the length between the Sun and Neptune in the nine-metre-long exhibition room. In Section 4, we used the 1.4-billionth scale planet balls in the "Universe in a Box" educational kit distributed by Leiden University in the Netherlands for the EU Universe Awareness project[17]. The Mercury, Venus, Earth, Mars, Uranus, and Neptune balls were individually put in transparent plastic bags, and a braille label was placed on the bag. The existing educational materials evolved into tactile ones with the braille labels.

During the 54 open days of the Touch the Universe special exhibition, a total of 545 people visited, which is on average of about 10 people per day. About half of the visitors were sighted people not accompanying BVI persons. Irrespective of visual impairment, a tactile museum with haptic experiences captures attention. An editor of another BVI journal was one of these visitors. He directly contacted Usuda-Sato and she wrote a series of articles based on the contents of the exhibition. Planetarians outside of Tokyo also visited the Tactus Museo, and they are now planning to hold a similar exhibition with the same tactile materials. The exhibition was also exported to National Astronomical Research Institute of Thailand (NARIT) in collaboration with IAU Office for Astronomy Outreach (OAO) located at NAOJ, to hold Inspiring Stars[18], an inclusive exhibition which commemorates the 100th anniversary of IAU, in Thailand.

Discussion: Tips

Collaboration with people who are BVI and an expert of special needs education is essential to developing a tactile model that is understandable through the haptic sense. A good relationship with BVI communities would also be helpful when developing and disseminating the model. A good, understandable model depends on their haptic observing skills, so two types of the Subaru Telescope models of different levels of detail were developed. Related stories or technological facts are also necessary to engage people in the 3D model. In the case of the Subaru Telescope, people were impressed by stories such as why the telescope

Box 1: Tips for Developing a Tactile Model

1. Modelling
- Feedback from visually-impaired and related people is essential.
- A good model can be made to different levels of detail for students versus people with excellent haptic skills.
- An appropriate (not too large, not too small) size should be considered so the primary mirror can be touched with a finger.
- Considering texture is important, such as a smooth primary mirror for explaining some specific features.

2. Presentation
- Haptic observing takes time. One model per one visually impaired person is ideal.
- In a classroom, try to connect the model to some items in the school curriculum guidelines.
- Additional tactile images can be helpful.
- Show the scale using a figure of an adult/human.
- Related stories and technological facts can help the audience understand the model.
- Develop a webpage about how to understand the model for future communicators.

was built outside of Japan, the surface accuracy of the primary mirror, the cutting-edge technologies used to achieve excellent tracking accuracy, and a giant epoch-making digital camera.

The special exhibition at Tactus Museo was an extension of the presentations of the telescope models to BVI groups and a collaboration between astronomy professionals and braille and tactile materials experts. For JBL staff members, answering astronomy questions from visitors was challenging, so a retired astronomy educator of NAOJ helped with the exhibition. Training museum staff members or assigning an astronomy expert should be considered for tactile exhibitions. Tips for developing and presenting a tactile model are summarised in Box 1.

Despite our growing network with BVI communities, dissemination of the telescope models is challenging. Even though STL files can be downloaded from the official site with detailed explanations, most people do not have a 3D printer nor the skills to use it. As a next step, building a circulation system for the models among domestic planetariums and science museums is being planned. Additionally, establishing a website in which tips of planning a tactile exhibition is being considered and more 3D models of other telescopes are planned for the future based off of this project.

Conclusion

As reported in previous works (e.g. Bonne et al., 2018; Pérez-Montero 2019), a tactile model is a useful communication tool for both people who are BVI and sighted. When developing a model, feedback from people who are BVI and experts of special needs education are necessary, and a good, understandable model sometimes depends on their haptic observing skills. In addition to developing a tactile model, how to present the model to BVI people is a key component to disseminating it.

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Notes

[1] You Can Do Astronomy LLC: http://www.youcandoastronomy.com

[2] NAOJ Mitaka Audio Guide: https://www.nao.ac.jp/study/mitaka-guide/

[3] A Touch of the Universe: https://astrokit.uv.es/

[4] Tactile Universe: https://tactileuniverse.org

[5] NASA Tactile Universe: http://chandra.cfa.harvard.edu/tactile/

[6] NASA 3D Resources: https://nasa3d.arc.nasa.gov

[7] IAU Astronomy for Equity and Inclusion Working Group: http://sion.frm.utn.edu.ar/iau-inclusion/

[8] IAU Strategic Plan: https://www.iau.org/administration/about/strategic_plan/

[9] Subaru Telescope: https://subarutelescope.org

[10] Simplifications included removing details from the top ring of the telescope and the protective case of the mirror. These details were not necessary for the overall explanation of the telescope.

[11] Making Tactile Models with a 3D Printer: http://prc.nao.ac.jp/3d/index_e.html

[12] EDEL software (in Japanese): http://www.ntut-braille-net.org/EDEL-Web/index.html

[13] PIAF (Picture in a Flash): http://piaf-tactile.com/piaf/

[14] Tactus Museo at Japan Braille Library (Japanese): https://www.nittento.or.jp/about/fureru/index.html

[15] Braille font created and distributed by Japan Lighthouse (in Japanese): http://www.lighthouse.or.jp/tecti/tecti/br-font.html

[16] Japan Planetarium Society, 3D data of Ryugu (Japanese): https://planetarium.jp/ryugu/

[17] Universe Awareness, Universe in a Box: https://www.unawe.org/resources/universe-box/

[18] Inspiring Stars: https://www.iau-100.org/inspiring-stars

References

Arcand, K.K., et al., CAPjournal, 8, 2010, p.15-17, https://www.capjournal.org/issues/08/08_15.pdf

Arcand, K.K., et al., CAPjournal, 22, 2017, p.14-20, https://www.capjournal.org/issues/22/22_14.pdf

Arcand, K.K., et al., JCOM, 18 (04), 2019, A01, https://jcom.sissa.it/archive/18/04/JCOM_1804_2019_A01

Bonne, N.J. et al., Astronomy and Geophysics, 59 (1), 2018, p. 1.30-1.33, https://doi.org/10.1093/astrogeo/aty028

Mineshige, S., et al., The Astronomical Herald, 102, 2009, p. 543-551 http://www.asj.or.jp/geppou/archive_open/2009_102_09/102_543.pdf

Ortiz-Gil, A. et al., CAPjournal, 11, 2011, p.12-15, https://www.capjournal.org/issues/11/11_12.pdf

Pérez-Montero, E., Nature Astronomy, 3, 2019, p.114-115, https://www.nature.com/articles/s41550-019-0693-3

Usuda-Sato, K. et al., Nature Astronomy, 2, 2018, p.692-694, https://www.nature.com/articles/s41550-018-0567-0

Watanabe, S. et al., Science, 364, 2019, p.268-272, https://science.sciencemag.org/content/364/6437/268

Biographies

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Hirotaka Nakayama is a visualisation expert of scientific data at the NAOJ Four-Dimensional Digital Universe (4D2U) Project. His virtual reality (VR) movie A Journey Through the Milky Way won the Best VR Science Experience at the Lumiere Awards, promoted by the US Headquarters of the Advanced Imaging Society.

Hideaki Fujiwara is an astronomer in charge of public information at the Subaru Telescope. His research speciality is astro-mineralogy and infrared astronomy, particularly to investigate planets and their formation processes.

Tomonori Usuda is the project manager of the TMT (Thirty Meter Telescope)-J Project. Previously, he worked at the Subaru Telescope as the associate director and the chief of the telescope engineering division.