Think outside the booth: An immersive virtual exhibit for discussing science and technology with an audience from around the world

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Exhibition booths provide a platform for organisations to showcase their specialities but are often limited by space and prohibitive costs for transporting large or fragile equipment. To address this, we developed a three-dimensional virtual exhibit that allows visitors to explore the technology and research behind the ASKAP radio telescope through interactive models of antennas and other components of the telescope array, including 360-degree visuals and animations. People can meet inside the virtual space regardless of their physical location to tour the exhibit and engage in discussions. The exhibition can be accessed through nearly any internet-accessible device, including a virtual reality (VR) headset, computer, or smartphone. The virtual exhibit was demonstrated at three in-person conferences by using a VR headset to access the exhibit from a conference booth, with both in-person and online team members to support the space. Participants were markedly impressed by the sense of presence in the 3D space and the ability to meet with experts who were not attending the conference. Such virtual spaces can be constructed relatively simply and have the potential to bridge online and in-person participants, as well as demonstrate facilities impossible to carry to event locations.

Introduction

As international borders reopened in the wake of the COVID-19 pandemic, we have witnessed a resurgence of in-person meetings and events. However, the marginalisation of online formats for these gatherings risks losing the very real benefits they offer to the astronomy community. Surveys of conferences during the height of the pandemic have demonstrated that the number and diversity of attendees greatly increase when events go online (*Skiles et al., 2022; Wu et al., 2022*). There is also a rising awareness of the environmental impact of frequent travel, with calls to the astronomy community to explore pathways to reduce the field's carbon footprint (*Burtscher et al., 2020; Frost et al., 2021; Rector, 2024; Gokus et al., 2024*). Combined with additional factors such as political unrest and the recently experienced rising travel costs, this suggests that a traditional in-person format suits a relatively small fraction of potential participants, which may decrease further as we go into the future.

However, online events have frequently been found to be a less satisfactory experience than those conducted in person (e.g., *Guetter et al., 2022*). In particular, difficulties in achieving natural interactions between people have been considered a major weakness of the online experience (e.g., *Brucks & Levav, 2022*). It is true that the most commonly utilised platforms, such as Zoom or YouTube, excel at the one-to-many format in which a single speaker shares a presentation but struggles to enable casual conversations that are credited for important connections and idea generation at meetings. Yet this problem can be tackled through emerging immersive technologies that improve online social experiences through the use of 3D digital spaces that have a significantly improved sense of presence.

In most cases, participants joining a virtual immersive platform enter as an avatar that provides a location within the space, allowing directional audio and audio fall-off (sound that decreases with distance). This enables groups to meet together and engage in simultaneous and overlapping conversations in the same manner as an in-person meeting.

Conversations can be overheard as you move through the space, encouraging groups to form and change organically rather than in the forced interaction style of a breakout room. Moreover, the virtual environment offers opportunities that cannot be leveraged at in-person events, such as the potential for large event spaces, digital copies of bulky or delicate equipment that can be safely examined and handled, or virtual representations of inaccessible or difficult-to-reach locations. These assets can be used for education, outreach and research, as well as providing points of interest to facilitate conversation at online gatherings.

While requirements vary between platforms, many virtual spaces can be entered through a virtual reality (VR) headset, desktop computer, or smartphone, either through a web browser or an app that is usually free to download. Unsurprisingly, the most immersive experience is through a headset, allowing users to feel most like they are physically present in the virtual world. However, cross-platform compatibility ensures a low entry requirement, and users can meet and chat with one another independently of the device they are using.

Exploring these technological solutions to online meeting interactions is the driving force behind The Future of Meetings (TFOM) community (*Moss et al., 2021; Moss et al., 2023*). The TFOM community has organised and advised on events such as online and hybrid conferences, science communication workshops, and public talk series (e.g., *Frost et al., 2022; Moss et al., 2023*). This article describes the development of a virtual exhibition space designed in collaboration with CSIRO, Australia's national science agency. The exhibit was demonstrated at three primarily in-person conferences: the 2023 Astronomical Society of Australia Annual Science Meeting in Sydney, Australia (ASA2023), the 2023 Asia Pacific Regional International Astronomical Union Meeting in Koriyama, Japan (APRIM2023) and the 2023 Union Radio-Scientifique Internationale General Assembly and Scientific Symposium in Sapporo, Japan (URSI2023). Alongside the main goal of communicating ASKAP science and technology to these relevant audiences in an impactful and innovative way, additional key goals were to demonstrate the strength of virtual platforms to connect and meet with people and to show creative ways in which virtual spaces can supplement both in-person and online events by offering an experience that goes "beyond being there" through extending what is possible to achieve in person.

The virtual exhibit itself showcased research and engineering from ASKAP, a radio telescope operated by CSIRO that is located at Inyarrimanha Ilgari Bundara, the CSIRO Murchison Radio-astronomy Observatory, in Western Australia (*Hotan et al., 2021*). ASKAP consists of 36 parabolic antennas that are 12 metres in diameter, each equipped with an innovative phased-array feed (PAF) that greatly increases each antenna's field of view. The exhibit space introduced ASKAP through interactable models of the antennas and components, written and audio explanations, a holographic animation, a 360-degree view of the Murchison site, Indigenous artwork capturing each survey, and posters describing the telescope's operations model and astronomical survey data. Inside the virtual exhibit, visitors could explore alone or chat with team members who are experts on radio astronomy research and engineering, or on the virtual space itself. Since the exhibit was hosted online, the in-person conference booth was staffed by one or two people, with the exhibit guides joining from elsewhere in the world.

The design of the virtual exhibit was a mixture of readily available prefabricated components and bespoke assets explicitly developed for this project. Creating a simple virtual space is not overly complex and could be replicated by any group wishing to explore these kinds of spaces for their own event. While the exhibit space was accessible from computers and smartphones, VR headsets were brought to the in-person conferences to allow visitors to try the most immersive way to experience the exhibit space.

Projects to develop virtual spaces have been previously used in astronomy, for example, the virtual tour of the ALMA Observatory (*Hiramatsu et al., 2021*) and the Frontiers of Space exhibit experience developed by the University of Arizona (*Impey et al., 2022*). In contrast to those experiences, this project focussed on demonstrating the social side of virtual spaces by meeting people not physically in the same location to tour the exhibit and seeing places and instrumentation that would usually be inaccessible. These abilities are particularly relevant to workshops, conferences and networking events where an accessible space is needed to freely exchange and develop ideas.

In this article, we describe the development of the virtual exhibit space and the set-up of the in-person exhibit booth counterpart before moving to a walk-through of the exhibit and reception received at the conferences.

Developing the virtual exhibit

The exhibit was hosted on the virtual social platform *Spatial*[1]. From the *Spatial* website, users can create a new virtual area by utilising several pre-fabricated spaces or constructing a template for an entirely customisable world. A web link to a newly created area can be shared to invite other people to the same space to meet and explore. Spatial has a free-use tier that includes most key features for development. A paid *Spatial+* tier is also available for $25 USD per month, offering additional event host controls.

Spatial is similar to virtual platforms such as *VRChat, Mozilla Hubs* and *EngageVR*, which have been popular for organising virtual events. Spatial was selected for this project due to the cross-platform compatibility that allowed visitors to enter the space on a VR headset, a computer running either Windows or Mac OS, or a smartphone. Fifty people can enter a space at once; parallel instances (identical copies) of the space are automatically created once a space reaches capacity. Access from a computer via a web browser offers faster entry during an event than a dedicated application that would have to be downloaded. *Spatial* also includes the ability to easily design your own avatar, utilising the *Ready Player Me*[2] character creation tool that allows a wide variety of human attributes and clothing. This allows visitors to easily generate individualistic but still professional options for appearance in the social space. At the time of writing, *Spatial* was being actively developed with frequent updates and a large user base. This can be valuable if help is needed on a new project.

For this project, we made use of a new template for the exhibit space rather than using one of the designs available within the *Spatial* platform. The template design was created with *Unity*, a cross-platform game engine with a free licence for users who generate an annual revenue of less than $200,000 USD per annum. *Spatial* includes a *Unity* plugin that allows designed spaces to be easily uploaded.

The base (the virtual building) of the exhibit space was chosen to resemble a small museum, with a series of rooms containing models, posters and animations (see Figure 1). The familiarity of this design was intentional so visitors could quickly feel comfortable in the space. The area was sized so that it could be fully explored within about ten minutes, a time frame easy to accommodate during the coffee breaks and lunch hour of the conferences. The base layout was purchased as a pre-fabricated asset pack, an easy way to acquire high-quality construction and design elements for a virtual space when bespoke items are not required.

The models displayed in the exhibit were developed specifically for this project. These included an ASKAP antenna, a 3D map of the inner 25 antenna positions on the Murchison site, the key Phased Array Feed (PAF) receiver – which increases the antennas' field of view by a factor of 36 – the PAF electronics package – known as a "domino" – and a "rocket PAF" element from the next generation PAF design. The domino, rocket PAF and PAF were presented as full-scale models, while the antenna was approximately 1:10 scale to allow visitors to view comfortably.

Information about these models was presented as an audio explanation that automatically triggered as you approached each model, as well as written descriptions displayed on boards on the room's walls. This enabled visitors to learn about the different components of the radio telescope through their preferred medium. The models were fixed to a plinth to prevent anyone from dropping or moving away with a model. However, the smaller domino and rocket PAF models had duplicates that visitors could handle and resize.

Model development was based on the engineering CAD (Computer Aided Design) model provided by CSIRO collaborators. As CAD models are used for manufacturing, they are typically intricate with prohibitively large file sizes for displaying in a virtual environment, which needs to be rendered rapidly in 360 degrees. The models were, therefore, adapted in the software packages *Blender* and *Autodesk Maya*. Both packages are 3D computer graphics applications; *Blender* is an open-source, freely available option. The models were simplified through steps that included stripping out hidden interior components and reducing the number of polygons used to form each shape.

The model of the ASKAP antenna was animated so that the dish slowly rotated to demonstrate its innovative sky mount that allows three axes of motion. A main feature piece of the exhibit was a more advanced animation developed for the PAF, which expanded when approached to reveal the interior components. A holographic animation of a CSIRO staff member appears next to the model and describes the now visible components of the PAF (Figure 1c). The hologram was created by filming against a green screen and projected into the virtual space using a video player that always faced the visitor, with a chroma key shader to remove the background.

Although the models displayed here were individually developed for the exhibit, it is worth noting that many useful models for astronomy are freely available. NASA and

Figure 1: *Scenes from inside the virtual exhibit space.* ***(A)*** *The virtual team meet a visitor. This is the hallway close to where a visitor first enters the exhibit. The open space lets people practise moving around and chatting with the team.* ***(B)*** *The model room inside the virtual exhibit. The plinth at the front of the photo shows the position of the inner 25 ASKAP antennas at the Murchison site* ***(i)****. Behind this plinth and to the left is the domino* ***(ii)****, and behind that is the rocket PAF* ***(iii)****.* ***(C)*** *Visitors gather around the animated PAF, which expands as you approach to reveal the interior layers. A holographic animation of a CSIRO staff member describes the different components.* ***(D)*** *A visitor admires the radio sky above the ASKAP antennas in a spherical projection of data from the telescope's first large-area survey, RACS. Image Credit: TFOM.*

ESA provide models of many of their spacecraft suitable for virtual spaces, and sites such as *Sketchfab*[3] have models created by individuals that can be downloaded for free or for a small fee.

Visitors could also step into a spherical ball that provides a 360-degree view of the ASKAP site at Inyarrimanha Ilgari Bundara, the CSIRO Murchison Radio-astronomy Observatory (Figure 1d). The antennas are located in a remote area with restricted access to protect the telescope from radio interference. Therefore, a virtual space is the best way to allow people to see what the site is like without creating any radio interference. Real data from ASKAP was also projected onto the background sky of the spherical projection, showcasing the radio sources seen in the telescope's first large-area survey, RACS (Rapid ASKAP Continuum Survey: *McConnell et al., 2020*).

In addition to the written description of the models, research posters describing the work done with ASKAP were displayed around the exhibit. These included an introduction to radio astronomy and the importance of radio-quiet sites, the history of the PAF development, and the autonomous operations model of ASKAP. Several of these were interactable, with either an audio summary or slides the visitor could advance independently. Artwork commissioned by CSIRO from members of the local Indigenous Wajarri Yamaji community in collaboration with the Survey Science Teams was also on display.

Combined, the exhibit hall had a choice of media to explore radio astronomy with ASKAP, designed to appeal to different levels of interest and learning preferences. Notably, using a virtual platform with smartphone and web-based access did introduce tighter restrictions on the file size of the individual displays. In particular, models had to be around 10 MB to import and render well, a limit that would be higher if we had used a platform that required a PC or access through a VR headset connected to a PC. However, a primary goal of our exhibit was accessibility, and we wanted to minimise the chance of visitors being limited by hardware.

Figure 2: *Photos from the in-person booths and team members at the three conferences. Image Credit: TFOM*

Hardware and booth design

The exhibit was demonstrated at three primarily in-person conferences via an exhibition booth space reserved by CSIRO. Access to the virtual exhibit space was offered at the booth through a Meta Quest 2 VR headset, providing the most immersive way to explore the experience. Visitors were also free to access the space from their own devices, either at the booth with the help of our staff or independently.

The Meta Quest 2 is a standalone headset that does not require a connection to a PC, nor any cables beyond that to recharge the battery. It is one of the most popular personal VR headsets on the market, costing substantially less than most smartphones. The headset was selected for its portability and for demonstrating what could be easily achieved at home institutes after the conference. The headset can be seen held and in use in Figure 2.

The booths were a standard size for an astronomy conference, with sufficient space for a table to seat two people with a small area behind. For ASA2023, there was the opportunity to also use a small amount of space directly in front of the booth. Due to space constraints, conference attendees were encouraged to sit for the APRIM2023 and URSI2023 meetings, whereas, with the extra area during ASA2023, people could stand if they preferred. For first-time users, staying seated with a VR headset can help prevent nausea. However, very few attendees reported this as an issue. Two headsets were brought to the meetings, but due to lack of space and a small number of booth staff, only one headset was usually in use at a time, with the other plugged into the power outlet at the booth to ensure the battery was fully charged.

One or two people were at the booth to run the session in person, helping conference attendees enter the virtual exhibit. For those using the VR headset, booth staff ensured that the headset was adjusted comfortably and provided basic instructions for using the controls. As a person wearing a headset cannot see the physical space around them, booth staff stayed next to attendees while they were visiting the virtual exhibit. After use, the silicon facemask on the headset and the controllers were cleaned with antibacterial wipes.

Once inside the virtual space, attendees were met by team members from TFOM and CSIRO, who offered guided tours around the space and further directions on the controls for movement and interaction with the displays. Since most people were unfamiliar with virtual reality, often just one of the headset's two hand controllers was used to make the necessary controls simpler to learn.

The booth and virtual staff communicated via Slack and within the virtual exhibit itself, with booth staff occasionally joining the exhibit via the VR headset or on a laptop. Booth staff informed their virtual counterparts when a meeting delegate entered the space, and both teams shared feedback from the exhibit visitors.

As the virtual exhibit required a wireless internet connection, a portable Wi-Fi router was brought to each conference. This avoided any potential issue should the conference internet become overloaded.

The in-person booth also included the traditional material for an in-person event, with postcards and stickers advertising CSIRO activities. A physical model of the domino was also brought to the exhibit, as this is small enough to fit into a suitcase. During the URSI2023 conference, a *Looking Glass* holographic display that can show a 3D image was included at the booth, showing a projection of the virtual exhibit space. Although the projection was too small to study the virtual exhibit in detail in the *Looking Glass*, the visualisation helped orient visitors before entering via the VR headset. It also assisted in explaining the concept of the virtual exhibit to groups of people at a time. All three conferences used printed images from inside the virtual exhibit to facilitate this further.

The final experience

Putting on the VR headset for the first time places you in an open space at one end of the virtual exhibit. This area resembles a lobby, with seating and images on the walls. Content is intentionally low in this area, allowing you time to practice moving around, listen to the spatial audio, and meet the exhibit virtual team. There is also a mirror where you can wave at yourself and see your avatar.

During the brief chat with the virtual team, you might explain your main interests and highlight anything you particularly want to see (Figure 1a). Hopefully, this will convince you that your guides are real people, not AI-generated avatars!

On the far side of the lobby are posters describing the observatory site, including its scientific advantages and the associated radio quiet zone. This sets the scene for ASKAP, offers background to visitors less familiar with radio science, and displays a map showing the location of the ASKAP site in Australia.

Moving forward from the lobby brings you to a room on your left, inside of which you can see the layout models of the central ASKAP antennas, the animated antenna rotating on its sky mount, the domino, and rocket PAF (Figure 1b). Entering the room and approaching the models triggers the short audio explanations while moving to the edge of the room allows you to read the descriptions on the walls or ask one of the virtual team members a question. The virtual team will also demonstrate how to pick up the domino and rocket PAF models and resize these for a better view.

Exiting through the room's second doorway at its far end brings you back into the hallway, close to a gallery showing the works of art by Wajarri artists local to the Murchison region that celebrate ASKAP and the radio telescope's surveys. You can also see smaller astronomical images on the facing wall representing research utilising ASKAP data.

Turning right at the hallway end brings you to an open area with a blue carpet. A poster on autonomous telescope scheduling is on one side of the wall and offers an audio explanation as you approach. On the opposite wall, an embedded presentation lets you click through slides outlining the science behind the PAF.

Stepping onto the carpet causes the full-sized model of the PAF to appear, which expands outwards towards you as the holographic image of the CSIRO team member talks through the different components (Figure 1c). You can walk around the PAF and examine the interior design as the animation plays. If you are an engineer, you might want to step off the carpet and back on, retriggering the animation to play again!

Turning your back on the PAF leaves you facing the final room of the virtual exhibit, whose curved walls display a wraparound image of the radio sky as seen by ASKAP, with several objects of interest highlighted. In the centre is the sphere that you can step inside to see the same image projected around you in 360 degrees (Figure 1d). Standing at the sphere centre, your view is now that of an ASKAP antenna, looking out into the Universe from the perspective of one of the best instruments in the world for mapping the radio sky.

Reception

The visitors to the virtual exhibit had a broad range of interests, from experts in radio astronomy and engineering to family members of conference attendees with no scientific background. This diversity was a surprising positive that emerged from offering the virtual experience, bringing people with interests beyond radio astronomy to the CSIRO booth. There was a similar demographic at each conference, although the Australian-based ASA2023 attendees were more familiar with ASKAP, whereas those at URSI2023 were more likely to be experts in radio engineering but not necessarily in astronomy.

The exhibit successfully catered to the wide interest range, with most visitors spending ten to fifteen minutes in the space regardless of their background. Field professionals spent more time examining the component models, such as the PAF and domino, and discussing the details of the instruments with the team members. In contrast, those with more general interests enjoyed the 360-degree visual experience of the Murchison site and spent time listening to the short audio descriptions of the models. Perhaps the most satisfying response came from our youngest visitor, who, upon removing the headset, sat for a few minutes before quietly saying, “Wow!” and returning to their accompanying family.

The headset at the booth provided most visitors with their first experience of wearing a VR headset. The feedback received was very positive, with surprise being expressed both at the capabilities of the portable headset and the quality of the interactions with the virtual team. Visitors particularly noted that the ability to ask questions and discuss with the virtual team produced a far more personalised experience than watching a video or presentation.

Introductions to the virtual team were made in a quiet area of the exhibit directly after entering the space, and visitors were encouraged by both the booth and virtual team to test their microphones by saying “hello”. This was a trigger for the virtual team and visitor to begin to chat, after which the visitor’s attention usually focussed completely on the virtual space, and interactions felt very comfortable. On several occasions, the visitor had to be reminded they could call out to the in-person booth team member for help with tasks such as removing the headset at the end of their visit.

Communication between the in-person and virtual team via the Slack channel was effective but occasionally difficult to maintain when the booth became busy. An extra person to exchange messages between the two teams would have been helpful when the booth staff were chatting with visitors.

Unfortunately, due to the limited capacity at the booth, more detailed feedback was beyond this exploratory project. In particular, an extra team member would have been needed to manage the personal data collected in a questionnaire, and ethics approval would need to be obtained from CSIRO. Future events that build on this format will hopefully provide the opportunity for a more detailed analysis.

Due to the structure of the conference, visitor numbers were clustered during coffee breaks and the lunch hour. About 10-15 visitors typically entered the virtual exhibit through the headset each day, totalling approximately 170 across the three conferences (Table 1). This number was capped by the capacity of the in-person booth, as there was only the staff and hardware to accommodate one person at a time comfortably. However, the virtual space can accommodate up to fifty visitors together, with parallel copies of the space automatically created by the *Spatial* platform if this capacity is exceeded. The number of visitors could, therefore, be easily expanded with more space and support personnel. Overall, the number of visitors and level of interest was considered a success, as the booth was popular during the conference breaks and remained so throughout the week for each of the three meetings.

Conference	Exhibition hours	In-person team	Virtual team	Visitors	Avg. time spent per visit
ASA2023	Mon, Tue*, Thurs: 10:30-17:00 *online-only Total = 19.5 hr Total break = 6.5 hr	~4 (2 headsets)	~3	~50	~10 min
APRIM2023	Mon 14:00-17:00 Tue 10:00-17:00 Wed 10:00-12:00 Thu 10:00-17:00 Fri 10:00-13:00 Total = 22 hr Total break = 7 hr	~1 (1 headset)	~5	~50	~10 min
URSI2023	Mon -Fri 10:00-17:00 Sat 10:00-12:00 Total = 37 hr Total break = 10.3 hr	~2 (1 headset)	~3	~70	~15 min

Table 1: *Summary of the virtual exhibit availability and uptake across the three conferences. The team numbers are indicative on average because they varied throughout the time period and similarly so with the time spent in the exhibit by attendees. The number of attendees is approximate, as we only roughly kept track of the number of visitors (sometimes due to staffing); we estimate the true number in each case is ±5 attendees. The exhibition hall and booths were typically available all day, but visitors mainly came to the booth during breaks in the programme content. The total duration of the break time is estimated for each meeting.*

Although one headset was typically used at a time due to the restricted physical space, there were a few opportunities to use multiple headsets during ASA2023, where slightly more space and assistance were available. On those occasions, two people could enter the virtual exhibit together. This was effective for initiating conversations inside the virtual space, including chatting with the virtual team, and for the pair of visitors to support one another in operating the platform.

Relatively few technical problems occurred over the conference period. Issues were alleviated by having a second headset on standby, which allowed one headset to be charged or rebooted if needed. Rebooting the headset was often the solution to problems with sound, either that the microphone was not working or there was difficulty hearing others within the virtual exhibit. The background noise from the conference exhibition hall occasionally became sufficiently loud that it was difficult for exhibit visitors to hear the virtual team. This issue could be addressed by using noise-cancelling headphones with the headset. When problems did arise, visitors were usually very understanding and happy to wait a few minutes or – more rarely – leave and return at the next opportunity.

While most visitors could quickly manage the controls and move around the exhibit space, host controls on the *Spatial* platform also allowed the virtual team to assist. For example, if a visitor could not comfortably move between displays, an option exists for a virtual space host to bring everyone in the exhibit to their location. A tour could, therefore, be easily conducted, even for visitors new to virtual spaces.

Future prospects

The virtual exhibit significantly extends what can be presented at a conventional exhibition event booth and allows visitors to connect easily with experts not attending the event. This social aspect allows for greater networking opportunities and enables organisations to showcase a wider variety of their expertise. Delegates at events with virtual exhibits can meet an organisation's in-person delegation and those joining the virtual exhibit online from anywhere in the world.

The potential for interaction also applies to connections between the event participants, especially in hybrid meetings where only part of the audience has travelled to the venue. Bridging the gap between in-person and online participants is a long-standing problem, with online attendees at risk of feeling excluded. Virtual exhibits offer an avenue to address this issue, with unique content that cannot be created in physical exhibition halls due to prohibitive size or fragility. This creates an opportunity for inviting the in-person participants to come online, see creative displays and, interact with the online audience. The virtual exhibit hall provides a natural way to facilitate this interaction, with a sense of presence in the virtual space that feels similar to in-person spaces and displays that are icebreakers to conversation.

While the exhibit presented here was for a single institute, the concept would be relatively easy to expand to a full expo hall with interconnected virtual spaces. The virtual expo could be accessed from multiple devices, as presented here, including devices carried by most event delegates, such as laptops and smartphones. Still, a conference area dedicated to using VR headsets could also offer the opportunity to try the full immersive experience and engage with online attendees. The *Spatial* platform allows up to fifty visitors in a single space, with the ability to expand this by creating copies of the space to accommodate more people. This allows a large group of people to meet and chat simultaneously and can be scaled up to accommodate large events. Our future work will explore these aspects as applied to academic meetings, conferences and communication.

In addition to exhibits focussed on hardware and scientific research, virtual visits to remote sites are a creative use of virtual spaces that can bring together in-person and online event audiences and provide opportunities to chat and network. Digital replications of astronomical sites have already been created, such as ALMA (*Hiramatsu et al., 2021*) and the "Cosmoria: VR Museum of Space", which includes a wide variety of space-related visitable locations such as the International Space Station and the Super-Kamiokande neutrino observatory (*えんでばー, 2023*). These virtual spaces provide a unique "field trip" to see locations very difficult to reach in person and offer the chance of a live guided tour by the professionals who use the instruments.

The three-dimensional aspect of virtual spaces also allows informative displays of objects or data that are difficult to understand in 2D representations such as pictures or movies. Astronomy is inherently three-dimensional and can often be more easily understood if visualisation is possible from multiple angles. Immersive 360-degree videos for outreach and education designed by organisations such as NASA and the Space Telescope Science Institute (STScI) are available on YouTube and display brilliantly inside virtual spaces where the full 360-degree view is available by turning your head. These have recently been used for teaching classes on astronomy and space science in virtual spaces[4]. Standalone VR apps have also been designed to exploit this feature for astronomy, such as the "Galactic Center VR" (GCVR) that displays supercomputer simulations of the region around our supermassive black hole, Sagittarius A[5], and a walkthrough of the supernova remnant, Cassiopeia A (*Arcand et al., 2018*).

Looking further into the future, virtual spaces have the potential to further aid accessibility with tools such as automatic language translation which is now being tested on a few virtual platforms. Facial tracking to allow people to see expressions and steadily improved graphics are also under development.

Virtual spaces and virtual reality have traditionally been associated with the gaming community but are now becoming more widely used as unique opportunities for work, education and outreach. Unlike a conventional exhibition booth that needs to be assembled and disassembled within the short period of a single event, the virtual exhibit can be used multiple times and is accessible from anywhere in the world. It is worth noting that while the virtual exhibit presented here was intentionally cross-platform to facilitate a low barrier for access through computer and smartphone, the cost of a VR headset is low compared to that associated with even domestic conferences and can be used for years. Therefore, this immersive option for connecting to virtual spaces is worth serious consideration by institutes wanting to expand their international presence and share their work innovatively.

From here, our team plans to expand the virtual exhibit experience to a multi-exhibit space as part of the hybrid experience of international conferences. One of our main interests is the quality of the experience when visiting the exhibitions via a smartphone and laptop, versus a more immersive headset. We hope to be able to collect this feedback in the future to explore how online meetings and events can be improved wherever you are in the world.

Conclusions

We developed a virtual exhibit showcasing the scientific research and technology behind the CSIRO ASKAP radio telescope. The exhibit was accessible from a computer, smartphone, and VR headset and formed a social space where people could meet and discuss the displays. The exhibit was presented at three primarily in-person conferences by bringing a VR headset to an exhibition booth, as well as providing a web link to the virtual space. The exhibit was visited regularly during the coffee and lunch breaks of each of the three conferences and successfully demonstrated that virtual additions can enhance the in-person experience as well as for online attendees.

The virtual exhibit was designed to demonstrate an experience that cannot be easily created at in-person-only events and provide a gateway to connect event attendees with experts and participants at other geographical locations. The exhibit was well received, enjoyed and explored by conference attendees from a wide range of backgrounds who met with remote team members to tour the exhibit.

The main strengths of such virtual exhibits are the ability to display places and instruments that are usually inaccessible and provide a location where people can chat and meet in natural conversation, regardless of their location. For hybrid events, virtual exhibits could provide a place where online and in-person attendees can easily meet and connect to colleagues and experts who are not on location.

Most of the exhibit was created with freely available software or pre-fabricated assets that could be purchased at a very low cost. This enables similar experiences to be constructed relatively easily, with the potential for greater customisation depending on available resources. With an exhibit unrestricted by space or even physical laws of nature, very little cannot be achieved.

Notes:

[1] spatial.io
[2] https://readyplayer.me
[3] https://sketchfab.com
[4] New experiences through Virtual Reality education: OAE's 5th Shaw-IAU Workshop: https://www.youtube.com/watch?v=4UnbcHGH7UY
[5] The Galactic Center VR: https://store.steampowered.com/app/1240350/Galactic_Center_VR/

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Biography

Elizabeth J. Tasker is an astrophysicist and science communicator at JAXA's Institute of Space and Astronautical Science. She is a member of the international outreach team for the Hayabusa2 asteroid exploration mission and the upcoming Martian Moons eXploration (MMX) mission, and is interested in using virtual space to explore environments that cannot be reached by humans.

Vanessa A. Moss is a Senior Experimental Scientist at CSIRO and oversees science operations for the ASKAP radio telescope. After chairing the original symposium in 2020, she has led "The Future of Meetings" community to advocate for improved online practices across astronomy and beyond, collaborating with like-minded groups and organisations worldwide.

Glen A. Rees is a Data Scientist doing machine learning and data analysis for clients in a wide range of industries. With broad expertise in technology and virtual reality applications for online interaction, he leads and coordinates many of the technical activities of TFOM.

Aidan W. Hotan is a senior system scientist working to support radio astronomy national facilities. He has worked on a wide range of science and instrumentation projects and has an interest in building effective collaborations across widely distributed teams.

Ronald D. Ekers is a radio astronomer and a CSIRO fellow (retired) based at CSIRO Space and Astronomy. During his career he has been director of radio observatories in the US and Australia and is a past president of the International Astronomical Union. He is an internationalist and has always been motivated by the use of technological innovations to pursue our science and facilitate our ability to collaborate.

Rika Kobayashi is a High-Performance Computational Chemist. Her main area of expertise is in the development, implementation and support of computational chemistry packages. More recently her interests have taken her into the area of exploring better ways of working virtually, especially with respect to best practice in remote teaching.

Emily F. Kerrison is a PhD candidate at the University of Sydney where she is on the hunt for the youngest supermassive black holes. Through The Future of Meetings she has developed an interest in how more sustainable and inclusive meeting practices can improve opportunities for EMCRs.

Katrina V. H. Amos is a freelance 3D artist with an Arts/Science degree from the University of Sydney and a diploma in 3D game art and animation from the Academy of Interactive Entertainment. Her specialty is in stylised art and character art and is familiar with the Maya software suite and Unity platform.