CAP journal

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Communicating Astronomy with the Public

Community engagement across Africa

and the plans for public engagement before, during and after the XXXII IAU General Assembly

The benefits of immersive technology

Explore new ways to engage audiences.

Fact or fiction

Discover the rise of pseudoscience and how to combat it.

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IAU

In Côte d’Ivoire, learners explore the planets and their properties with the National Outreach Coordinator, Aziz Diaby.

Kassamba Abdel Aziz Diaby

Editorial

Shortly after this issue's publication, the XXXII General Assembly (GA) of the International Astronomical Union (IAU) will take place on the African continent for the first time. This is an important milestone for African astronomy research and communication. Leaders of the GA Education and Public Outreach Team share their plans for public engagement with astronomy before, during, and after the conference. To underscore the breadth of astronomy communication already underway across Africa, we highlight the contributions of select National Outreach Coordinators (NOCs) from Africa. The NOCs are national points of contact that represent the Office for Astronomy Outreach in their communities. The OAO owes its success to the tireless efforts of the NOCs, and we are proud to honour their work in this issue of CAP Journal.

As we become more globalised through media of various forms, understanding how mis- and disinformation spread becomes vitally important. In *The truth is out there: Tracking the rise of pseudoscience*, the author explores how pseudoscience has grown through printed and digital media.

Often, our authors approach astronomy communication through innovative means. *Dark sky educational outreach through art and collaboration* provides a best practices guide for how to approach dark sky protection from an interdisciplinary perspective. In *Think outside the booth: An immersive virtual exhibit for discussing science and technology with an audience from around the world,* you will find an example of how to expand the reach of spaces typically used for conference exhibition booths. This exciting application of virtual reality provides an excellent framework for how to engage global audiences without having to travel across the world.

In *Pioneering research on the contribution of astronomy to the needs of older adult learners,* the authors describe a topic that often goes neglected: older adults and their intersection with astronomy communication. The article *Expanding access: The effectiveness of online science events in attracting a wider audience* similarly examines who is missing from public events. This work seeks to understand the impact of online events on the demographics of audiences.

As a note to our readers and potential authors: all articles in this issue follow our new guidelines for submission. As with Issues 31 and 32, each article has been reviewed by a member of our Editorial Board and an external Peer Reviewer. We welcome submissions on a rolling basis and invite everyone to learn about our new Submission Guidelines on our website, www.capjournal.org.

Kelly Blumenthal

Editor-in-Chief and Managing Editor

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Cover: This photograph was taken with a smartphone near Keetmanshoop, Namibia. It was a first-prize winner of the International Astronomical Union Office of Astronomy for Education's Astrophotography Contest in the smartphone and mobile devices category. The image shows the arc of the Milky Way, the two Magellanic Clouds, and many other naked-eye objects behind a silhouette of quiver trees. Overlaid on the image is an outline of the African continent.

Image Credit: Jianfeng Dai/IAU OAE (CC BY 4.0)

Column

Explained in 60 seconds: Community engagement at the XXXII IAU General Assembly

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Keywords
Public Engagement, Science Communication, Cultural Astronomy, Development, Community, Conference

In August 2024, the International Astronomical Union General Assembly will take place on the African continent for the first time in the organisation's 105-year history. To celebrate this historic event, the National Organising Committee's education and public outreach team is planning a series of events to encourage students and the general public across the continent to explore and engage with astronomy. This article describes how we will engage the African public before, during and after the conference.

Introduction

The International Astronomical Union (IAU) holds its largest conference, the General Assembly (GA), every three years. Throughout the IAU's history, General Assemblies have occurred in Asia, North and South America, Europe, and Oceania. This year, the IAU GA will occur on the African continent for the first time in the institution's 105-year history.

With each GA, the host country works hard to ensure that not only the scientists who attend benefit but also the surrounding communities. This typically includes organising a wide range of astronomy-related outreach activities, such as public lectures, workshops and observing nights.

This year, the Education and Public Outreach team for the XXXII IAU GA is planning a suite of activities for students across the African continent before, during, and after the conference. An important factor of our model is to build impactful and sustainable programmes, ensuring that the GA's societal benefits will not end in August 2024.

Leaning on previously established networks of astronomy communication volunteers across Africa, the team focuses on the Cascade Model of astronomy communication. The Model, first coined and developed by Professor Carolina Ödman-Govender, describes the generative and impactful process of training young people to train their peers, who then train others in turn. This powerful Model uses relatable role models to explain concepts, breaking the cultural and language barriers often experienced in other outreach methods. Applied to astronomy communication, this produces a wide network of involved and empowered youth who are inspired to continue engaging their communities with astronomy. By implementing this Model, the GA Education and Public Outreach Team will reach a continent-wide audience, particularly amongst the future generations of astronomers and astronomy communicators.

Before

In the lead-up to the GA, the #AfricaLookUp Campaign will highlight the rich cultural and historical connection that people all over Africa have to astronomy and the night sky. This Campaign, which approaches astronomy engagement from a creative lens, will celebrate global Indigenous knowledge systems, our shared humanity, and the connections we have made with the cosmos over millennia of observations. This will be achieved through the #AfricaLookUp to the Arts Open Nights held at the South African Astronomical Observatory. During these events, the public can engage with astronomers while merging their experience with various forms of artistic expression.

The Beauty of Astronomy Art Competition was launched earlier this year to motivate youth to create artwork inspired by their love for astronomy. The competition has since received over 100 submissions from students of all ages across Africa, and the winning artwork will be showcased at the IAU GA in August.

During

During the conference, scientists are encouraged to participate in the various planned activities, such as public lectures by astronomers, astronauts and a Nobel Prize winner, talks at local pubs and restaurants, possible radio connection to the International Space Station and even a hike: unique and engaging ways to interact with the public. These opportunities are often a chance for astronomers and astronomy communicators to make vital connections in new and sometimes unusual places, perhaps leading to future collaborations. As one outstanding example, the South African National Science Week will take place during the first week of the conference, providing a natural venue for astronomers' public engagement to have a broader impact nationwide. To show the human side of science and scientists, there will be a talent show where astronomers are encouraged to sign up to showcase their talents with the public in attendance.

A cultural exchange evening featuring Indigenous knowledge will take centre stage to encourage knowledge exchange and deeper connections. This unique event will celebrate the rich tapestry of cultures and their historical relationship with the skies through storytelling, music, dance, and poetry, providing captivating insight into the timeless wisdom of Indigenous traditions.

Additionally, a diverse and multi-layered education programme will be offered during the GA. Learners and teachers will be invited to the conference venue to encourage everyone, especially underrepresented groups in science, technology, engineering and mathematics (STEM), to engage with astronomy in new ways and be exposed to authentic experiences in science. Astronomers in attendance at the conference are encouraged to sign up to visit local classrooms and discuss their work, their careers, and the process of science. Scientists will also be able to engage with learners online in a series of virtual meet-ups throughout the conference.

During the GA, teacher training sessions will be held, focusing on specific content covered in their curricula. These sessions aim to help teachers better understand the material while providing guidance on the most effective teaching methods. Specific curriculum outcomes will be shared with participants to allow them to properly prepare and deliver accordingly.

As an exciting and innovative first for international astronomy conferences, Radio Astro will be an online pop-up radio station designed to leave a lasting legacy in the hearts and minds of Cape Town's at-risk youth and listeners from vulnerable communities across the developing world. The primary goal is to train aspiring science communicators to broadcast highlights from the GA in an accessible and conversational radio format, providing them with valuable on-the-job training. Moreover, this platform aims to ignite the dreams of the next generation of astronomers and space scientists, helping them realise that their aspirations are achievable.

Figure 1: *Learner engagements during the National Science Week Launch in 2023. Image Credit: Zodwa Tiki (AfAS Junior Media and Outreach Coordinator)*

Figure 2: *The iThemba Youth Choir performed as part of the celebrations of African culture and Indigenous astronomy during the #AfricaLookUp festivities at the African Regional SHAW-IAU Workshop on Astronomy for Education. Image Credit: Lusanda Tamesi (African Science Stars Stakeholder Engagement Officer)*

After

The Cascade Outreach Project extends well beyond the GA, with students and young professionals from across Africa engaging in outreach and education activities within their local communities. This initiative promotes diversity, inclusivity, and relatable role modelling while training a new generation of scientists in communication and leadership skills.

The celebration of astronomy in Africa will continue throughout August as part of Africa Astro Month. This collaboration involves outreach professionals, amateur astronomers, and astronomy organisations across the continent, who will participate in additional astronomy outreach and education activities. Participants will also be able to visit organisations in other parts of Africa, volunteering and contributing to the outreach efforts.

Looking Forward

In modern times, it is no longer sufficient to continue to host massive global conferences as we have before. It is essential that "tried and trusted" methods make way for innovative and adaptable solutions if we are to ensure sustainable and meaningful impact for the benefit of all. Therefore, this year's IAU GA, and by extension its outreach and education programme, has established three key pillars: worldwide impact, increased accessibility through open-access hybrid means, and eco-conscience sustainability. It is with these goals in mind that all of our outreach and education projects were devised.

As the first GA on the African continent, participants, learners, and the public alike will undergo a unique experience. Not only will they be able to engage in the typical offerings of a scientific conference and its outreach programme, but they will also get to experience a proudly African innovation: an event that is not afraid to push the limits. Indeed, participants will be able to gain a glimpse into the future of conferences, with a global impact that will be felt long after the conference doors are closed.

Biography

Duduzile Kubheka is the BRICS Astronomy project coordinator at the South African Astronomical Observatory (SAAO). She oversees BRICS Astronomy initiatives, including the BRICS Intelligent Telescope and Data Network (BITDN), and leads activities aimed at societal benefits. Additionally, she co-chairs the Outreach and Education Committee of the African Astronomical Society (AfAS), implementing astronomy outreach and educational programs across Africa. Duduzile is also pursuing a Master of Philosophy in Science and Technology Studies (Science and Public Engagement) at Stellenbosch University's Centre for Research on Evaluation, Science and Technology (CREST).

Sally Macfarlane is the associate director for Development and Outreach at the Inter-university Institute for Data-Intensive Astronomy (IDIA). She is also co-chair of the Outreach & Education Committee for the African Astronomical Society (AfAS) / IAU GA 2024 and chair of the African Planetarium Association (APA). When not busy with these responsibilities (and sometimes during), she is an avid birdwatcher, a newly minted professional nature field guide, and a planetarium presenter.

Astronomy Communication Across Africa: The IAU National Outreach Coordinators

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The International Astronomical Union National Outreach Coordinators (IAU NOCs) serve a vital role in their communities. As the tie between the IAU and local public engagement activities, they are responsible for disseminating materials and resources into their communities, broadening the IAU's reach, and leveraging astronomy communication to move toward a better and more equitable future. The NOCs and their teams truly embody the IAU Office for Astronomy Outreach motto - Astronomy for Everyone. In 2024, the OAO is excited to join the rest of the IAU community at the XXXII IAU General Assembly in Cape Town, South Africa. In celebration of this event, we asked the IAU NOCs from across the African continent to describe their work, demonstrating the diversity of astronomy communication taking place in these communities.

Algeria

Mourad Hamdouche (NOC), Chaima Amine-khodja (Incoming NOC), Jamal Mimouni (Former NOC)

Figure 1: *Amateur astronomers from the Sirius Astronomy Association in Constantine gather for a field mission in the Hoggar mountain range in Algeria's Sahara Desert. Image Credit: Mourad Hamdouche*

Algeria has a thriving community of amateur astronomers engaged in outreach, mainly at the local level. Most large and medium cities have an astronomy club or association, though they need a unifying structure. These groups convene at regional astronomy gatherings, the most notable being the annual National Festival of Popular Astronomy in Constantine. The Algerian astronomy community participates regularly in leading international events like Global Astronomy Month, 100 Hours of Astronomy, World Space Week and more. The National Outreach Coordinator (NOC) and National Astronomy Education Coordinator (NAEC) teams are addressing the substantial needs by engaging with various public and local

Figure 2: *The Cameroon Astronomy and Space Research Organization (CASRO), headed by its CEO and Founder, Mbonteh Roland Ndunge, leads community members as they look through a telescope provided by IAU OAO partners Sterren Schitteren Voor Iedereen (Stars Shine for Everyone; SSVI) and Bresser. Image Credit: Mbonteh Roland Ndunge*

actors to integrate astronomy into national educational structures. Notably, a high-level public magazine produced by a dedicated team of amateurs and professionals, Echiheb el-Ilmi (The Scientific Meteor), has gained good recognition in the Arabic-speaking world. However, the academic program in astronomy is limited in scope and media exposure, sustained mainly at one research centre and two universities.

Figure 3: *Learners at a primary school in Cape Verde engage in activities about the Solar System. Image Credit: Ivanilda Maria Cabral*

Cameroon

Mbonteh Roland Ndunge (NOC), Williams Tchaptchet (Vice NOC; Incoming NOC), Dinka Williet (Deputy NOC)

The NOC Cameroon Team, driven by a deep curiosity about the Universe, has brought astronomy activities to Cameroon communities. This initiative has allowed people to think beyond their horizons and study with a higher perspective, thereby contributing to preserving our planet - our only home. Over the years, the NOC Cameroon Team has touched the lives of thousands of people, from young students to adults. In collaboration with the Cameroon Astronomy and Space Research Organization (CASRO), the Team has visited numerous schools, inspiring students in science through access to astronomy communication and providing them with the resources necessary to start their own astronomy clubs. Through programmes like ActInSpace, the NOC Cameroon Team fosters the country's development by promoting the technology and data used in the space sector to impact the next generation of astronomers and space entrepreneurs. The Team has also provided theoretical and practical training on satellite construction and using satellites to boost community development, improve agricultural practices, and address climate change.

Cape Verde

Ivanilda Maria dos Santos Cabral Semedo (NOC)

In Cape Verde, the National Outreach Coordinator Team has been developing several activities linked to teacher training, practical workshops and lectures with students from schools nationwide, day and night observation sessions with the general population, and art-science collaborations alongside other Portuguese-speaking NOCs. Through their efforts, the NOC Cape Verde Team reaches hundreds of teachers and thousands of students annually. The Team has a strong connection with Portuguese-speaking communities worldwide and leverages this common ground to promote astronomy. As participants in the OruMbya project, funded by the Office of Astronomy for Development, the NOC Cape Verde Team aims to build bridges between communities through a shared understanding of Indigenous cultures and their connection to the stars. They try to cement this sense of astronomical connection in the next generation of scientists and astronomy enthusiasts by engaging local students in the Dark Sky Rangers Light Pollution contest. Based out of Portugal, this contest encourages young learners to understand the consequences of light pollution on our night skies and environment and seek to define light pollution initiatives that might lead to change they can actualise in their lifetimes. With a dedication to collaboration and communal understanding, the NOC Cape Verde Team provides the island nation with valuable access and appreciation of the multifaceted nature of the Universe.

Côte d'Ivoire

Diaby Kassamba Abdel Aziz (NOC)

In Côte d'Ivoire, the NOC is involved in several activities to promote astronomy through the Ivorian Astronomy Association. This association was set up to promote science in general and space science in particular, and at a time when there were fewer people studying science. Since its creation in February 2021, the Ivorian Astronomy Association has carried out many activities in schools and for the general public. It has set up five astronomy clubs nationwide, reaching over 10,000 people. However, the Association is encountering enormous difficulties in implementing its action plan, as it is supported solely by the membership fees of its 50 members. Despite these difficulties, the Association has obtained support from associations in France with donations of telescopes and supplementary funding.

Egypt

Somaya Saad (NOC), Morcos Abd El Fady (Former NOC)

In Egypt, astronomy is vital in raising society's awareness of science and promoting the country's socioeconomic development. As astronomy is closely connected to many sciences and technical disciplines, it intersects with many aspects of society in and outside Egypt. The National Outreach Coordinator Team for Egypt leverages these features of astronomy to promote the uptake of science, technology, engineering, and mathematics among the nation's children and increase awareness of astronomy among the general public. Egypt is lucky to have multiple observational facilities that regularly communicate with the public, students, and children; through the rich historical and cultural context of Egypt, the NOC Team can draw many people to learn about their astronomical heritage. The Team regularly holds talks, workshops, interactive events, astronomy camps and more to enrich the lives of their communities. In particular, the NOC Egypt Team co-organises the Cairo International Book Fair, a two-week-long festival held every year featuring lectures and demonstrations of astronomical models.

Figure 4: *Each year in late February and October, the Sun is orthogonal to the Holy of Holies in the Temple of Abu Simbel, producing one of the most stunning examples of hierophany in the world. Image Credit: Mahmod Ismail/NRIAG*

Through this event alone, the Team can reach more than two million people. The National Outreach Coordinator Team in Egypt is a leader in making astronomy accessible to all nationwide.

Ethiopia

Alemiye Mamo Yacob (NOC), Kirubel Menberu (Deputy NOC; Incoming NOC)

Over the past decade, Ethiopia's National Outreach Coordinator Team has played a central role in advancing astronomy outreach efforts. Through close collaboration with the Ethiopian Space Science Society (ESSS), a non-governmental and non-profit organisation dedicated to outreach and capacity building, as well as the Space Science and Geospatial Institute (SSGI), the governmental space agency, NOC Ethiopia has effectively utilised ESSS's extensive network within schools and universities, along with SSGI's specialised expertise. Together with these local organisations, NOC Ethiopia has organised outreach activities, including school visits and public lecture events. This collaboration has enabled NOC Ethiopia to actively participate in and disseminate numerous projects initiated by the International Astronomical Union's Office for Astronomy Outreach (IAU OAO). These initiatives have included impactful projects such as NameExoworlds 2019, which achieved nationwide reach, and regional endeavours like the Dark Sky and Astro-tourism Outreach project involving five East African NOCs, funded by the OAO. Furthermore, NOC Ethiopia received a telescope courtesy of Stars Shine for Everyone (Sterren Schitteren voor Iedereen, SSVI) for its involvement in the 2018 and 2022 editions of the OAO project, 100 Hours of Astronomy - a pivotal instrument for future outreach endeavours. Beyond the OAO projects, NOC Ethiopia has collaborated extensively with the broader IAU community in Ethiopia, contributing significantly to initiatives led and funded by the Office for Astronomy Education and the Office of Astronomy for Development.

Ghana

Naomi Asabre Frimpong (Co-NOC), Albert Kuntu Forson (Co-NOC)

Under the leadership of Dr Naomi Asabre Frimpong, the National Outreach Coordinator (NOC) for the International Astronomical Union (IAU), alongside her dedicated team, astronomy outreach in Ghana witnessed a remarkable surge in 2023. Through innovative events like the 100 Days of Astronomy celebration on April 10th, where 40 students

Figure 5: *Families and staff from the Ghana Space Science and Technology Institute come together for an online viewing of the April Total Solar Eclipse at the Ghana Radio Astronomy Observatory. Image Credit: Naomi Asabre Frimpong*

from St. Martha's Catholic School Basic B engaged with a Galileo telescope, and SpaceJam 2023 on October 6th, hosted by the Ghana Space Science and Technology Institute (GSSTI) to mark World Space Week, engaging over 400 school children and 100 university students, the passion for space science among Ghanaians, especially the youth, was ignited. These efforts were amplified through national media coverage, with Dr Emmanuel Proven-Adziri and Dr Naomi Asabre Frimpong appearing on UTV and GBC television stations, advocating for astronomy education's significance in STEM and national development. Additionally, the Ghana Radio Astronomy Observatory hosted over 600 schoolchildren throughout the year for educational tours, introducing them to various observatory facilities and hands-on astronomy activities, further fostering their interest in STEM education. These strategic actions, coupled with the dedication of Dr Asabre Frimpong and her team, have laid a solid foundation for inspiring the next generation of scientists and innovators in Ghana. For young astronomers in Ghana, the journey to explore the Universe is only just beginning, and endless possibilities lay among the stars.

Libya

Amjed Khurwat (NOC), Abbas Endaisha (Former NOC)

In Libya, astronomy outreach is forging connections, from educating the locals about the desert's night sky to establishing the first space camp in historically rich sites like Cyrene, which aimed to promote peace and cultural exchange through astronomy education and communication. By using dynamic mediums such as podcasts, educational videos, and captivating sky camps, the National Outreach Coordinator Team for Libya and Roaya for Astronomy Foundation are breaking down barriers, fostering unity, and igniting curiosity across communities. In Libya, astronomy is not just about stargazing but building bridges that transcend borders, uniting us beneath the boundless sky.

Madagascar

Zara Randriamanakoto (NOC), Deralaza Rafieferantsoa (Vice NOC; Incoming NOC)

Making astronomy accessible to all has its own challenges, especially for communities in developing countries such as Madagascar. With support from local volunteers and various key stakeholders, the National Outreach Coordinator Team in Madagascar has been running several projects and initiatives to promote astronomy among the public since its appointment in 2017. This covers a wide range of activities, such as regular school visits, stargazing parties, and the use of social media for community digital outreach. In particular, the annual national Astro Quiz, Le Rendez-vous des Astrophiles, one of the Team's flagship projects, has been ongoing since 2020, with the 5th edition scheduled in September 2024. The competition, which targets school learners and the public at large, aims to improve awareness, interest, and knowledge of basic astronomy. The NOC Madagascar Team has also recently completed a successful project named Orion Astro Lab, in collaboration with the NOC Senegal Team, thanks to the financial support of the Office for Astronomy Outreach NOCs Funding Scheme. The project aims to build a strong network of astronomy club leaders who will work together to promote science, including astronomy, to the local community.

Morocco

Meriem El Yajouri (NOC), Hassane Darhmaoui (Vice NOC), Bani Abdelhafid (NOC Committee), Belhaj Zakaria (NOC Committee), Boskri Abdelkarim (NOC Committee), Chennaoui Hasnaa (NOC Committee), El Azhari Youssef (NOC Committee), Nail Naima (NOC Committee), Talibi Hassan (NOC Committee), Zouhair Benkhaldoun (Former NOC)

In Morocco, the NOC Team aims to uplift the work of local astronomy associations nationwide. At the African Astronomical Society Meeting 2024, the Team showcased these efforts at a dedicated exhibition space, allowing them to present their activities and introduce their initiatives to the international scientific and outreach community. The Team also engages the public through stargazing events, workshops for school children, and more, bringing participation from many associations across Morocco. Through the IAU OAO's partnerships, members of the broader NOC Morocco network have won telescopes, using them to bring astronomy into their own communities. One programme in particular - SpaceBus Morocco, designed to support earthquake-affected communities - highlights NOC Morocco's commitment to using astronomy as a tool for community wellness and rebuilding, addressing local needs while promoting science education.

Mozambique

Claudio Moises Paulo (NOC), Yara Herminia Simango (NOC Committee), Francisco Fenias Macucule (NOC Committee), Ramiro Caisse Saide (NOC Committee), Toivo Samuel Mabote (NOC Committee), Victoria Da Graça Gilberto Samboco (NOC Committee), Bívar Garcês Felizardo Chavango (NOC Team)

Mozambique is one of the African countries partnering with South Africa to implement the Square Kilometre Array (SKA) initiative in Africa. Since 2004, local scientists have tried to introduce Astronomy in the country, where outreach has played a crucial role. Here, we share the struggles and happiness of conducting outreach in a country with limited resources and present the successful results and future aspirations that can be used as a model for Africa's astronomy development. By using amateur telescopes in public places, schools and universities for almost 20 years, it was possible to motivate young people to pursue their careers in Astronomy, which brought Mozambique PhD students studying abroad and some people with MSc and PhD degrees as well as a post-doctoral fellow in the country. This opened a new environment at Eduardo Mondlane University, an important academic centre in

Figure 6: *Aligning with the International Day for Women and Girls in Science and the beginning of the OAO's Women and Girls in Astronomy Global Project, the NOC Mozambique, Claudio Paulo, helped to organise a lecture on women's contributions to science and astronomy that was attended by nearly 450 girls. Image Credit: Claudio Moises Paulo*

Mozambique. This attracted external funding that was used to establish the Computer Laboratory for Astronomy, Space Science and Artificial Intelligence at the UEM and the High-Performance Computing Facility at a Park of Science and Technology, paving the way for future astronomy development in Mozambique.

Figure 7: *Participants eagerly gather for a Moon sighting event, with the telescope aimed at the glowing Moon. The atmosphere is filled with anticipation and wonder as celestial enthusiasts marvel at the detailed craters and shadows on the lunar surface. Image Credit: Peter Okagu*

Nigeria

Peter Okagu (NOC), Timothy C. Egbuim (NOC Committee), Ojima Ocheni (NOC Committee), Onyeuwaoma Nnaemeka (Former NOC)

The National Outreach Coordinator Team in Nigeria is gradually transforming the current state of astronomy and space science, focusing on combating misinformation and motivating the next generation of space scientists in Nigeria and beyond. The Team has made substantial efforts to provide quality lectures, workshops, and hands-on sessions in astronomy and space sciences across varying levels of education, including special events for girls to learn about telescopes and astronomy, as well as events aimed at young children to expose them to the wonders of the Universe through activities, planetarium shows, and applications of astronomy in their daily lives. The NOC Nigeria Team engages schools in regular events through various channels, especially those in remote areas. As a result of the Team's intervention, there is increased knowledge and interest in astronomy, with the formation of new astronomy clubs demonstrating the Team's impact in schools. Of course, the Team's outreach activities extend beyond schools; they engage with the general public, non-scientific institutions, and space enthusiasts, inspiring awe and curiosity about the vastness of space in all individuals in Nigeria. Looking toward the future, the NOC Nigeria Team hopes to extend its work into more remote regions, correctional facilities, and internally displaced persons camps.

Figure 8: *School children gather around a solar telescope at a local primary school to observe and learn about the Sun. Image Credit: Salma Sylla*

Senegal

Salma Sylla (NOC), Abdoulaye BA (Vice NOC; incoming Co-NOC), Cheikh Tidiane Bop (Deputy NOC), Mariama Balde (Assistant NOC)

In Senegal, even if astronomy teaching in schools and universities is slow to take off, there are several activities promoting astronomy in the country. This is done primarily through associations and science clubs in secondary schools. In 2009, during the International Year of Astronomy, one of our universities had the opportunity to host astronomy lecturers, which sparked an interest in astronomy and astronomy outreach nationwide. Since then, we have been organising outreach activities to encourage the younger generation to take an interest in and learn about astronomy. In 2019, Salma Sylla joined the Office for Astronomy Outreach network as part of Senegal's National Outreach Coordinator Team. Together, this team of four planned and carried out many activities. For example, we worked with Madagascar on a project funded by the OAO to train future astronomy club leaders in both countries, which led to the formation of 20 new astronomy clubs.

We have additionally held events with telescopes provided by Stars Shine for Everyone (Sterren Schitteren voor Iedereen, SSVI), online workshops for teachers in collaboration with the Network for Astronomy School Education, and participated in OAO Global Projects, such as 100 Hours of Astronomy and NameExoWorlds. Recently, for the first time in Senegal, we have organised astronomy workshops at an inclusive school with deaf and mute children, demonstrating the inclusive role of astronomy. This was initiated in a collaborative program between Senegal and Belgium, "SeneSTEM," to promote science through astronomy. We want to expand it at a national scale, reaching the most disadvantaged areas of the country.

Sudan

Mohammed Yahya Alradi Eldaw (NOC), Banona Osman (Vice NOC), Abubakr Yagob (Deputy NOC), Eshraga Adel Altyp Abdelsalam (Assistant NOC), Hozyfa Ahmad Brima (NOC Committee), Abubkr Mastor (NOC Committee), Ismail Abdallah (NOC Committee), Nasreldin Adam (NOC Committee), Hoyam Abubaker Yousif (NOC Committee), Yassir Abbas (NOC Committee), Anwar Osman (NOC Committee), Elnazir Ishag (NOC Committee), Khalid Omer (NOC Committee), Magdi Elfadil (NOC Committee), Abdallah Osman (NOC Committee), Omer Souliman (NOC Committee), Mohammed Mahgoub Hussain (NOC Committee), Mohammed Hussain (NOC Committee)

The National Outreach Coordinator Team in Sudan is a leader in promoting astronomy nationwide. Through monthly lunar observations to inform local religious institutions, inner city and rural outreach events, television programmes, and nationwide astronomy campaigns, the NOC Sudan has continued to engage their communities in astronomy despite ongoing political unrest. Armed with the knowledge that a truly dark sky is an ideal way to pique the public's interest in astronomy, the NOC Sudan leads trips to rural areas of the country to give inner-city inhabitants the opportunity to experience the night sky without the intrusion of city lights and discuss the culture and history of astronomy. Another project aims to encourage students to pursue astronomy as a career by showcasing STEM's sustainability and business potential. Together, these activities aim to promote capacity building throughout Sudan for future generations and encourage today's researchers to go into their communities and help them understand and appreciate the night sky.

Togo

Doh Koffi Addor (NOC)

The amazement and questions that come from observing a starry sky or participating in practical demonstrations with the simple equipment we have at our disposal is an extraordinary opportunity to communicate science in general, and astronomy in particular, to a Togolese population that does not have access to scientific knowledge and concepts about the Universe. In our first actions to promote astronomy in Togo in 2017, we set up a simple telescope directly on the streets, in schoolyards and public squares, inviting passers-by to look through the eyepiece at the Moon and the Sun. Through these initiatives, the public could talk with experts, tell stories, learn, and explore their imaginations as they unravelled the mysteries of our Universe. The National Outreach Coordinator and National Astronomy Education Coordinator teams work in tandem to popularise and promote astronomy in Togo. We have organised many activities, such as Astronomy Days in Togo, Togolese Astronomy Olympiads, Teacher Training Workshops, and more. We have carried out these activities in different formats to reach as many people as possible and popularise astronomy among the population. Though we have faced challenges through patience, determination, and passion for astronomy, we have continued to promote astronomy nationwide. Our efforts have resulted in a significant milestone for Togo: negotiations are underway with the Togolese educational authorities to officially introduce astronomy to secondary school and university-level curricula.

Tunisia

Mayssa El Yazidi (NOC), Moslem Hassiki (Vice NOC), Imen Titouhi (Deputy NOC), Farah Hani (Assistant NOC), Sana Ayari (NOC Committee), Khaled Segni (NOC Committee), Tayssir Ennafti (NOC Committee), Jamel El Jeri (NOC Committee), Ranya Hamdeni (NOC Committee), Riadh Ben Nessib (NOC Committee), Lina Jardak (NOC Committee), Wael Jomni (NOC Committee), Asma Bdhief (NOC Committee), Ahlem Loudhaief (NOC Committee), Yassine Tahri (NOC Committee), Samaher Ben El hadj Slimene (NOC Committee), Lassad Akrout (NOC Committee), Olfa Mannai (NOC Committee), Sami Elouati (NOC Committee), Ahmed El Fadhel (NOC Committee), Zayneb Jouini (NOC Committee), Amine Zribi (NOC Committee), Taha Basly (NOC Committee), Amjed Bachtobji (NOC Committee), Zied Mejri (NOC Committee)

One of the main goals of the NOC Tunisia Team is to promote astronomy nationwide and ensure all Tunisians understand its importance to everyday life and society. Since 2018, the NOC Tunisia Team has worked alongside the IAU Office for Astronomy Outreach, Sterren Schitteren Voor Iedereen (Stars Shine For Everyone), and NOCs from around the world to provide many projects and initiatives, both in person and online. We have organised astronomy training sessions, open days, summer schools, solar and deep sky observation sessions, and workshops in collaboration with several astronomy clubs and associations in Tunisia. For example, the programme AstroTalk aims to deliver online lectures to students and amateur astronomers. This project has been in operation since

Figure 9: ***(a)*** *The NOC Morocco Team, co-organisers of the Festival of Ifrane, engaged the public through astronomy through innovative hands-on exhibits, like the one shown here. Image Credit: Meriem El Yajouri* ***(b)*** *In collaboration with the physics department at Misurata University, the NOC Libya Team helped to raise awareness of astronomy and space in society among all participants in the 2022 International Children's Exhibition. Image Credit: Amjed Khurwat* ***(c)*** *In Tunisia, the NOC Team gathered young children to learn about astronomy and space through art during the IAU OAO 100 Hours of Astronomy celebration 2021. Image Credit: Mayssa El Yazidi* ***(d)*** *The Ethiopian NOC Team regularly engages its communities in accessible activities. Here, the NOC Ethiopia presents a series of tactile models aimed at conveying astronomical topics to people with blindness or low vision. Image Credit: Alemiye Mamo* ***(e)*** *Despite the challenges faced by their communities, Mohammed Yahya Alradi Eldaw and Anwar Osman of the NOC Sudan Team find ways to bring new experiences to local children, such as their programme entitled Astronomy for Children and Students, shown here. Image Credit: Mohammed Yahya Alradi Eldaw*


A
B
C
D
E

2020, and in 2021, it won first prize in the OAO Astronomy@Home Awards in the Outstanding Online Events category. In 2019 and 2022, the NOC Tunisia Team successfully named an exoplanet and its star in the NameExoWorlds competition: in 2019, Chechia (star) and Khomsa (exoplanet); in 2022, Zembra (star) and Zembretta (exoplanet). The Team has also been awarded a telescope from SSVI and BRESSER, equipped with a complete set of optics and a CCD, which has been used to support many communities, including astronomy clubs, amateur astronomy societies, and universities. From its foundation, the NOC Tunisia Team has reached thousands of people across Tunisia, helping and supporting them to learn more about the Universe and the planet on which they live.

Biography

Jamal Mimouni is an Algerian astrophysicist involved with the scientific, societal, and cultural dimensions of the contemporary scientific debate in the Arab-Muslim world. He has developed a keen interest in the philosophy of contemporary science and in advancing scientific culture, and astronomy in particular, in the Arab World and Africa. He is also the past president of the African Astronomical Society (AfAS).

Mbonteh Roland Ndunge is a Cameroonian astronomer and astrophysicist. He is dedicated to promoting astronomy education in Cameroon and is the founder of the Cameroon Astronomy and Space Research Organization (CASRO).

Ivanilda Maria dos Santos Cabral Semedo has a PhD in Statistics and Risk Management, a master´s degree and a degree in Mathematics. She is a Professor at the University of Cabo Verde, member of the National Statistics Council, Coordinator of the PLOAD (Portuguese Language Office of Astronomy for Development) in Cabo Verde, statistics consultant and science communicator. Her research focuses on extreme statistics.

Kassamba Abdel Aziz Diaby is an Ivorian space physicist holding a PhD in geomagnetism and aeronomy. His research work is about the interaction between the Sun and the Earth. He studies the variations of the Earth magnetic field due to solar activity, the estimation of the ionosphere daytime equatorial vertical drift and the Earth magnetosphere. In addition to his researche, Aziz is highly involved in astronomy outreach in his country. He is the founder and president of the Ivorian Astronomy Association and he has set up many astronomy clubs in secondary schools. All of his efforts have enabled him to become the National Outreach Coordinator for Côte d’Ivoire at the IAU Office for Astronomy Outreach (OAO).

Somaya Saad is an Egyptian astrophysicist at the National Research Institute of Astronomy and Geophysics (NRIAG). Her main interest is studying the physics of hot massive stars and she collaborated globally in this direction. As one of the pioneers in this field, she leads a research group studying variable stars at the Kottamia Astronomical Observatory. In addition to her scientific interests, she is highly involved in the IAU, AfAS and AfNWA activities, and she strives to achieve the SDGs in supporting women, girls and marginalised groups in Egyptian and Arab societies through the concepts of diversity, inclusion and equity.

Alemiye Mamo Yacob is an astronomer and science communicator by profession. He works as a researcher and Regional Partnership Lead Executive at the Space Science and Geospatial Institute (SSGI) in Ethiopia, and is also the Coordinator of the East Africa Regional Office of Astronomy for Development (EA-ROAD). He is among the few individuals who have laid the foundation for space science development in Ethiopia.

Kirubel Menberu is pursuing an MSc in Space Engineering and holds a BSc in Electromechanical Engineering. He is a dedicated advocate for space science and a science communicator, currently serving as the Program Manager at the Ethiopian Space Science Society (ESSS), the National Point of Contact for Ethiopia at the Space Generation Advisory Council (SGAC), and National Outreach Coordinator for Ethiopia at the IAU Office for Astronomy Outreach (OAO).

Naomi Asabre Frimpong is a research scientist at the Ghana Space Science and Technology Institute and Head of Science Communication at Ghana Space Science and Technology Institute. Her research interests include the evolution of massive young stellar objects using complex organic molecules. She is very active in outreach to young people - especially girls - and mentoring other African students.

Amjed Khurwat is a science communicator and civil society activist from Libya, focusing on media and information literacy and the impact of science on sustainable community development.

Zara Randriamanakoto is a research staff astronomer at the South African Astronomical Observatory. She mainly studies the most massive star clusters in the local universe. She is passionate about science engagement, the promotion of Girls and Women in STEM, and especially the advancement of astronomy in all its aspects in her home country (Madagascar) and Africa.

Meriem El Yajouri is an astronomer and an ambassador of astronomy for outreach and development. She leads scientific communication as president of Spacebus Morocco and co-founder of TITRITLAND, Morocco’s first astro-tourism company. She also served as the vice president of the Atlas Dark Sky Foundation and chaired the 4th AfAS annual conference. Her research focuses on interstellar matter in star-forming regions through major astronomical programs, including those by the JWST.

Claudio Moises Paulo is an Assistant Professor of astrophysics at Eduardo Mondlane University and the Coordinator of the Astrophysics, Space Sciences & Artificial Intelligence Group. In his free time, he dedicates himself to the dissemination of science using Astronomy.

Peter Okagu is a scientific officer, a Science Communicator, and the Head of the Outreach Unit of the NASRDA Centre for Basic Space Science and Astronomy Nsukka. I am dedicated to promoting astronomy education and outreach in Nigeria. I am active in popularising science and astronomy among young people and the general public, promoting girls in STEM, and mentoring young amateur astronomers in Nigeria.

Salma Sylla is an astrophysicist and computer engineering technologist with a background in atomic and nuclear physics. In addition to her research, she is involved in popularising science and astronomy and promoting girls in STEM. She is a board member of the African Network for Women in Astronomy (AfNWA) and a member of the Organisation for Women in Science for the Developing World (OWSD).

Mohammed Yahya Alradi Eldaw is a Sudanese astronomer whose research focuses on space weather and climate action regarding astronomical activities and phenomena and Indigenous peoples’ knowledge of Astronomy.

Doh Koffi Addor is a geological engineer and amateur astronomer. He is passionate about everything concerning Earth and Space, and he founded the ONG Science Géologique pour un Développement Durable -SG2D (Geological Science for Sustainable Development NGO) and the Association Togolaise d’Astronomie (Togolese Association of Astronomy) for the development of Earth and Space Sciences in Togo. He is very active in outreach and education in Astronomy and Space Sciences in Togo, especially for young Togolese.

Mayssa El Yazidi is a planetary geologist. Her research focuses on surface geology, geomorphology, and tectonic and structural analysis of Mars, Mercury, and Venus.

At the Kottamia Astronomical Observatory in Cairo, Egypt, stargazers are routinely met with breathtakingly clear skies. This image, taken in December 2021, prominently features constellations such as Orion, Taurus, and Canis Major.

Mohamed Aboushelib

"The truth is out there": Tracking the rise of pseudoscience

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Keywords
Public Understanding of Science, Science and Society, Science Literacy, Website, Book, History of Astronomy

The rising tide of misinformation is compromising civic discourse, and the pervasiveness of pseudoscience threatens rational decision-making on scientific issues. This paper uses Google Books and Google Trends data to report on several types of astronomical pseudoscience in English language books since 1800 and English language online searches since 2004, with a particular focus on the United States regarding Internet searches. These tools can be unreliable for diagnosing subtle or short-term trends, but they are robust for major trends over long timescales. *Astrology*, *UFO* and related terms have increased in occurrence in books over the past half-century and in web searches since 2004. In the 21st century, there is a striking rise in the occurrence of the word *horoscope* in books and its use in web searches. Mention of *UFO* has increased steadily in books since 1950, and spikes in web searches in the 21st-century track with a national UFO reporting database. Three aspects of the "culture" of UFOs have appeared much more frequently in books since the 1990s: alien abduction, crop circle, and ancient astronauts. For web searches since 2004, the first two dominate, with the search peaks generally correlated with the release of related movies. By all these measures, pseudoscience is on the rise.

Introduction

The modern world is awash in misinformation on subjects ranging from politics to science (*Scheufele & Krause, 2019*). A pernicious form of misinformation is pseudoscience: beliefs, statements, or practices that claim to be factual and whose proponents claim are scientific but which are incompatible with the scientific method. Pseudoscience is a hybrid word from the Greek *pseudo* and the Latin *scientia*, meaning "false knowledge." For an extensive and rigorous discussion, see *Hansson (2021)*. Over half a century ago, the science writer Martin Gardner was the first to thoroughly debunk pseudoscience (*Gardner, 1957*). Differentiating pseudoscience from science matters because many legal, medical, and public policy decisions depend on understanding the natural world. The National Science Foundation has used belief in astrology, the quintessential pseudoscience related to astronomy, to demarcate the public's ability to distinguish science from pseudoscience (*National Science Board, 2016*). Astrology might be considered a harmless belief system, but in the health arena, misinformation and anti-scientific mindsets are dangerous and can be fatal (*Hotez, 2021*).

Drawing the boundary between science and pseudoscience is not always straightforward, and there is no litmus test for distinguishing them (*Pigliucci, 2010; Pigliucci & Boudry, 2013*). This was referred to as the "demarcation problem" by Karl Popper, who argued that science is marked by statements that can be falsified (*Popper, 1959*). He used the examples of Einstein's theory of general relativity, verified by tests of gravitational lensing, and Freud's theory of human behaviour, which Popper claimed ignored many cases that did not support the theory. However, falsehood as a sole criterion is problematic. String theory is a legitimate scientific framework but is not currently falsifiable (e.g., *Villavicencio, 2019*). Meanwhile, the hypothesis that intelligent extraterrestrials exist is scientifically plausible, but falsifying it would require inspection of the billions of habitable exoplanets beyond the Solar System (e.g., *Cockell, 2014; Perryman, 2018*). Philosophers have explored these demarcation and definition issues (e.g., *Grodin, 2021; Hansson, 2021*).

This paper focuses on pseudoscience topics related to astronomy, particularly astrology and unidentified flying objects, or UFOs. A practical criterion for pseudoscience will be used (*Shermer, 2011*), based more on what scientists do than on what science is. Science is concerned with testing hypotheses and building testable theories. Research that propagates in a community of scientists and produces useful knowledge has the attributes of science. It has been argued that pseudoscience is becoming more pervasive as part of the rising tide of misinformation and "fake news," particularly online (e.g., *Iammorino & O'Rourke, 2018*).

The title of this paper refers to a catchphrase from *The X-Files*, a science fiction television show featuring paranormal phenomena ran from 1993 to 2002 (*Lowry, 1995*). Most people now seek information from unvetted corners of the Internet rather than reputable sources. This percentage has grown from 9% in 2001 to 57% in 2018 (*National Science Board, 2020*). This paper focuses on books written in English and web pages searched for in English (with a particular focus on the United States). The era of the Internet is defined as starting around 1990. The most rapid rate of growth in Internet users in North America was from 1995 to 2005, when the share of the population using it rose from 9% to 68%, with a similarly steep rise 5–15 years later in other parts of the world (*Roser et al., 2022*).

Surveys of beliefs

At the University of Arizona, we have been surveying undergraduate non-science majors for thirty years, with a sample size of

13,000. Pseudoscience beliefs run high. About 40% think that the positions of the planets affect everyday life, and the same percentage think some people are psychic. A quarter believes in faith healing and a similar fraction trust in lucky numbers. Strikingly, these beliefs correlate poorly with science literacy (*Impey et al., 2011*). Beliefs and attitudes were measured with 24 Likert-scale items subject to factor analysis (*Impey et al., 2012*). One factor included pseudoscience items on astrology, psychic powers, and lucky numbers. Another item included the belief that UFOs are alien spacecraft visiting Earth and the belief that aliens visited ancient civilisations, often called the alien astronaut idea. The strength of these beliefs did not change significantly over 27 years (*Impey et al., 2017*).

A benchmark on pseudoscience beliefs in the United States comes from biennial reports called *Science and Engineering Indicators* (*National Science Board, 2020*). In surveys conducted by the National Science Foundation (NSF) spanning forty years, the public has been polled about ten topics: extrasensory perception, haunted houses, ghosts and spirits, telepathy, clairvoyance, astrology, channelling, communicating with the dead, witches, and reincarnation. Among these items, only a quarter of Americans believed in none, 32% believed in four, and 22% believed in five or more. These beliefs rose throughout the 1990s (*Newport and Strausberg, 2001*). It can be argued from data in the NSF surveys that pseudoscience beliefs show a widespread misunderstanding of how science works and how scientists judge evidence (*Losh et al., 2003*). Similar results were found in surveys by Chapman University of seven paranormal beliefs (*Chapman University, 2018*). Only a quarter believed in none, a third believed in four or more, and the belief levels in all seven have risen in recent years. The paranormal has become a firmly rooted strain of modern American culture (e.g., *Bader et al., 2017*).

In what follows, pseudoscience terms appearing in digitised books and used for web searches will be analysed to diagnose public interest in various topics. Word counts in books may only measure the topic's popularity among authors, and web searches may only measure awareness of the topic. Each of the two metrics has its quirks and biases. This exploratory analysis is, therefore, only a starting point, with the goal of deciding whether this approach has merit for a deeper investigation.

References in books

Google Books is a project that scans many books, converts the data into text using optical character recognition, and stores it in a digital database. Analysis of this corpus allows cultural trends to be tracked quantitatively (*Michel et al., 2011*). The database holds over 40 million books going back five hundred years, including nearly two trillion words and a third of the titles ever published. All book editions are included, and all instances of a particular word are counted. Google also provides a tool called the Ngram Viewer, which counts the occurrence of strings of up to five words, including wildcards and searches of parts of speech (*Google Books, 2022*). Only matches found in 40 or more books are returned, and the data are normalised by the total number of books published each year. This strategy attempts to avoid the problem of sparse data and the increasing publication rate over time. The Ngram viewer was set up in such a way that capitalisation did not affect the results.

It was quickly recognised that Google Books could provide cultural insights by tracking trends in word usage across decades and centuries (*Bohannon, 2010*). The tool has led to research in diverse fields like economics, medicine, political science, and literature (e.g., *Zieba, 2018; Richey & Taylor, 2019; Sheffer et al., 2021*). However, there are caveats and significant limitations. The early data are sparse. From 1500 to 1800, there are very few published titles. By 1800, the corpus grows to 100 million words per year, then it rises rapidly, by 1900 to two billion words, and by 2000 to 11 billion words. Additionally, the Google Books corpus is essentially a library. A single, prolific author can have disproportionate weight; any book appears once, regardless of whether it has been read once or a million times. With the growth of science in the 20th century and the fact that many scanned books are from academic libraries, scientific terms have become an increasing part of the database (*Pechenick et al., 2015*). With care, these effects and biases can be understood, controlled for, and mitigated (*Younes & Reips, 2019*). This paper is exploratory and should not be considered a definitive analysis.

Astrology is an over 5,000-year-old practice (*Tester, 1990*) that claims to learn information about human affairs by studying the movements and relative positions of celestial objects (*Allum, 2010*). The word comes from the Greek *astron* and *logia*, meaning "a telling of the stars," and the European etymology dates to the late 14th century (*Online Etymology Dictionary, 2022a*). If astrology is the practice, a horoscope is a tool astrologers use, with their interpretation or predictions given as text, found in many newspapers, magazines and, increasingly, online. The fraction of Americans who thought that astrology was at least partly scientific grew from a quarter to a third in the first decade of the 21st century (*National Science Board, 2014*), with a burst of popularity since then as a loosely held belief that is comforting in stressful times (*Beck, 2018*). This booming industry is worth over $2 billion annually (*Kaplan & Stenberg, 2020*). Nonetheless, astrology is definitively classified as a pseudoscience (*Thagard, 1978*).

Figure 1 shows the incidence of the words astronomy, astrology, and horoscope in the Google Books database over the past 200 years. The use of the term astronomy relative to the size of the corpus fell for most of the 19th century, hit a low in 1918, peaked in 1964, and then fell by 40% until now. The astronomy trend maps to societal trends in science. Universities grew globally after World War II (*Frank & Meyer, 2007*). Federal funding for physical science grew rapidly in the 1950s and peaked in 1965 before falling by 50% in constant dollars (*American Association for the Advancement of Science, 2022*). The use of the term "astrology" in books fell through the 19th century to a low in 1916 but has since risen by a factor of three. Although there is the potential for word confusion between astronomy and astrology, a Pew Survey found that three-quarters of Americans could distinguish the two definitions, and NSF surveys use an item to control for word confusion (*Funk & Goo, 2015; National Science Board, 2018*). In the 21st century, as the Internet has become ubiquitous, the incidence of *astrology* has not changed substantially, while the incidence of *horoscope* has doubled. The rise of this pseudoscience in books is most clearly seen by comparison with its scientific parent term, *astronomy*. At the beginning of the Internet age in 1995, *astrology* occurred at 27% of the frequency of *astronomy*, similar to its occurrence in the

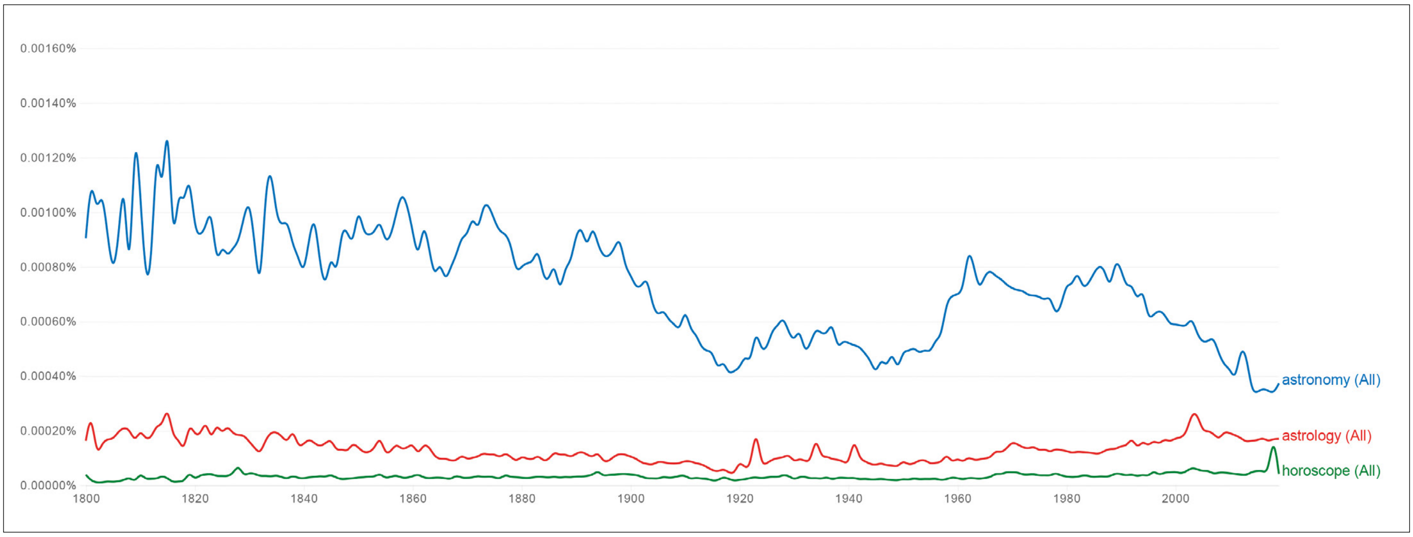

Figure 1: *The incidence of the words astronomy (blue), astrology (red), and horoscope (green) in Google Books since 1800. By contrast to astronomy, which is near its lowest level in two centuries, astrology and horoscope are near their all-time highs. Image Credit: Google*

19th century, and horoscope occurred at 10% of the frequency of astronomy. Now, the percentages are 52% and 30%, relative rises of a factor of two and three, respectively.

Unidentified Flying Objects have migrated from being a fringe belief to the mainstream of modern American popular culture (*Pasulka, 2019*). The many Earth-like exoplanets being discovered make it statistically likely that there is intelligent life beyond the Solar System, and it is plausible that some of these creatures could have surpassed our technical abilities to achieve interstellar travel. The subject is even getting scholarly attention (e.g., *Andresen & Chon Torres, 2022*). However, scientists consider reports of extraterrestrials visiting the Earth lacking verifiable evidence and unconvincing (*Fraknoi, 2010*). The UFO acronym dates to 1953, in a book by an American aviator (*Keyhoe, 1953*), and 1956, when Air Force officer Edward Ruppelt claimed he invented it to replace the earlier term *flying saucer* (*Clarendon Press, 1989*). The phrase *flying saucer* originated in 1947 when pilot Kenneth Arnold reported saucer-shaped objects flying in formation, and reporters coined *flying saucer* even though Arnold himself never used the phrase. Within six weeks, 90% of Americans had heard the term *flying saucer*. The contemporary idea of UFOs dates back to that time (*Eghigian, 2021*).

The top panel of Figure 2 shows the incidence of the term *UFO* since 1920, along with *extraterrestrial*. The word comes from the Latin *extra* and *terrestris*, which means “outside the Earth.” *Extraterrestrial* used as a noun dates back to 1956, contemporaneous with the origin of the acronym *UFO* (*Online Etymology Dictionary, 2022b*). Usage of *UFO* in books begins in the early 1950s, a few years after the 1947 Arnold sighting and the 1947 Roswell incident (*Saler et al., 2010*). It rose steadily until 2000 and has flattened since then. While likely a coincidence, it is amusing that the strongest rise is during the nine-year run of *The X-Files*. The use of *extraterrestrial* rose strongly until 1964 and has been relatively

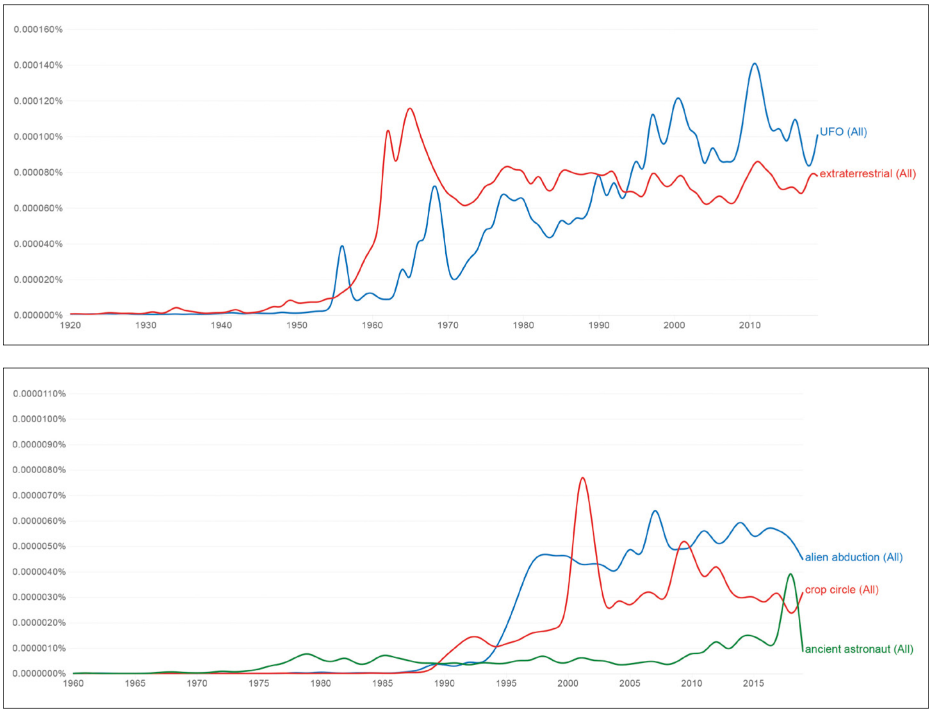

Figure 2: *Top: Incidence of the acronym UFO (blue) and the word extraterrestrial (red) in Google Books since 1920. Both show a rise after the 1947 Roswell incident. Bottom: Incidence of the phrases alien abduction (blue), crop circle (red), and ancient astronaut (green) in Google Books since 1960. All three rose after 1990 as the Internet became more widespread. Image Credit: Google*

flat for over half a century. The rise in references to UFOs in books tracks publicly reported sightings in the United States (*National UFO Reporting Center, 2022*). Reported sightings began at the time of the Roswell incident, climbed to dozens of reports per month in the 1970s and 1980s, grew to several hundred per month at the end of the 1990s, and have plateaued at 300–500 per month in the past few decades. The all-time peak of 1050 UFO sightings occurred in April 2020, when the Pentagon officially released three U.S. Navy videos showing UAPs (Unidentified Aerial Phenomena; *U.S. Department of Defense, 2020*). Despite intense public interest and speculation, most military UFO reports show no evidence of visits from aliens (*Barnes, 2022*).

UFOs are part of a broad ecosystem of beliefs, including other manifestations of advanced alien life forms visiting Earth. The bottom panel of Figure 2 shows the incidence of three of these since 1960; before that, the terms rarely appear in any book. Ancient astronauts are an extension of the UFO hypothesis: the claim that intelligent extraterrestrials visited Earth in ancient or prehistoric times and the idea that some religious deities were extraterrestrial in origin. The occurrence of this term started in the late 1960s. The rise is associated with the bestselling novel *Chariots of the Gods* (*von Daniken, 1968*) and nine sequels that came out between 1970 and 1984, selling over 60 million copies (*Feder, 2010*). After a decline in the 1980s, there has been a more recent rise to its current highest level, which may be associated with the proliferation of UFO religions (*Pasulka, 2019*). Crop circles have been claimed to be created by visiting aliens. Ironically, the incidence of this phrase in books took off in the early 1990s, soon after two self-professed English pranksters confessed to inventing the phenomenon 25 years earlier (*Irving & Brookesmith, 2009*). Crop circles then proliferated worldwide, including some of dizzying complexity (e.g., *Physics World, 2011; Stables, 2021*). Alien abduction is the claim of direct interaction with aliens and often removal from Earth. While the phenomenon is psychologically fascinating, no evidence suggests it is real (*Appelle et al., 2000*). References to alien abduction in books grew rapidly in the 1990s, soon after it started getting scholarly attention, particularly from Harvard psychiatrist John Mack (*Matheson, 1998*).

Searches online

Google Trends is the quintessential tool for measuring the 21st-century zeitgeist. It parses the popularity of queries made in Google Search across many geographical regions and languages and presents the data as graphs over time (*Google Trends, 2022*). Coverage started in 2004, and the relative popularity of two or more search terms can be compared. Dynamic range is limited as the numerical scale goes from 1 to 100, which is the peak popularity for a given region and time. A growing amount of research has been published using Google Trends. The data can illuminate human behaviour (*Mavragani et al., 2018*), track interest in the environment (*Nghiem et al., 2016*), and forecast economic indicators (*Choi & Varian, 2012*) and financial markets (*Preis et al., 2013*). Another important application is analysing searches on health topics. Such data has been used to track and predict outbreaks of diseases (*Mavragani & Ochoa, 2019*). In fact, Google Trends often outperforms some survey-based indicators (*Vosen & Schmidt, 2011*).

However, search engine data must be used with caution. Inconsistencies can arise when considering intervals of less than a year (*Behnen et al., 2020*). Over short intervals, searches for the same term and period at different times can yield very different results. Another study found statistical variations in a long-interval search when the identical search was repeated weekly (*Cebrian & Domenech, 2022*). The cause of the inaccuracies is unknown and lies deep within Google's sampling algorithms. This does not invalidate Google Trends as a data source but suggests it should only be used to look for large-scale effects. Unlike Google Books, where scientific content has been increasing, the fraction of all Google searches for scientific terms has decreased as the Internet is used increasingly to track leisure and politics and explore popular culture (e.g., *Ficetola, 2013*). For example, from 2004 to 2022, searches for *coffee* and *weather* increased by factors of 12 and 8 relative to searches for *science*. Similarly, one of the National Science Foundation's biennial reports (*National Science Board, 2016*) found that searches for *science*, *engineering*, and *technology* declined from 2004 to 2014. However, little has been published using Google Trends to track interest in science and pseudoscience (*Baram-Tsabari & Segev, 2009*).

Analogous to Figure 1, Figure 3 shows the relative frequency of the search words *astronomy*, *astrology*, and *horoscope* from Google Trends data since 2004 in the United States. In 2004, relative to *astronomy*, searches for *astrology* were twice as frequent, and searches for *horoscope* were 2.5 times as frequent: the reverse trend we see in the relative order of occurrence of

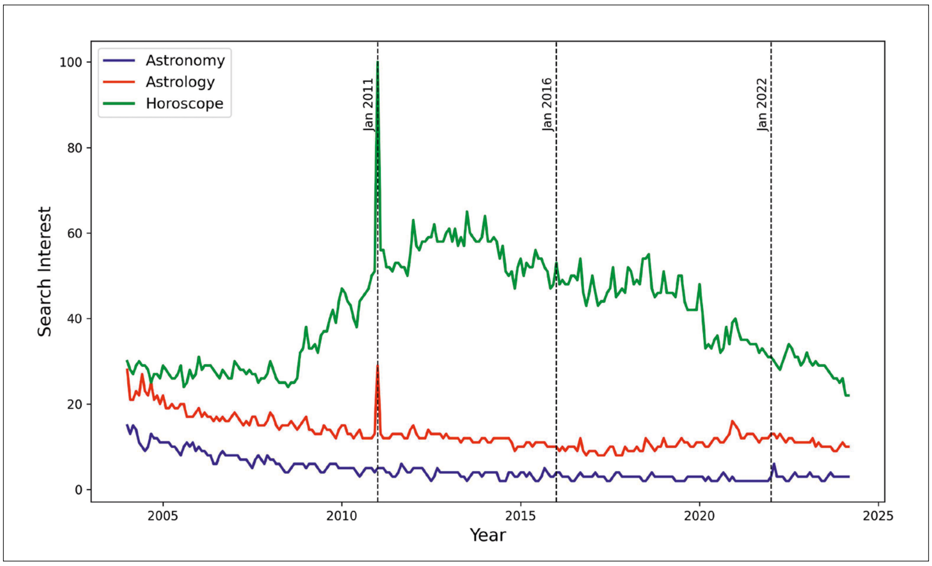

Figure 3: *The relative occurrence of the search terms astronomy (blue), astrology (red), and horoscope (green) in Google Trends shows a decline for astronomy relative to the other terms. Dates with dashed vertical lines correspond to improvements in Google search methodology. Image Credit: Google*

these terms in books. The disparity in Internet searches for these terms has increased over the past two decades. In 2013, *astrology* searches were three times as frequent as *astronomy* searches, and *horoscope* searches were 15 times as frequent. Early in 2022, the ratios grew to factors of five and 15. Google Trends can be used to look at searches in the U.S. by state. From 2004 through 2022, Hawai'i had the most *astronomy* searches per capita, which is plausibly explained by the many large telescopes concentrated there. The states with the most *astrology* and *horoscope* searches were Hawai'i and New York, a result with no obvious explanation. As mentioned earlier, word confusion between astronomy and astrology may be a factor. It is noted that state-level search results involve much smaller samples, so results can be variable. A state-by-state analysis is outside the scope of this work. Anonymous Google searches for *astrology* and *horoscope* return around 200 million unique web pages. The rise of astrology in the 21st century can be seen as a reflection of New Age thought and its pervasive influence on Western culture (e.g., *Campion, 2012*). The rapid rise of searches for *horoscope* before 2010 matches when the fraction of the American public thinking astrology was at least partly scientific grew significantly (*National Science Board, 2014*). As people increasingly believe in astrology, acting on that belief means looking up your horoscope. The rise of the Internet and social media has led to more horoscopes online (e.g., *Smallwood, 2019*).

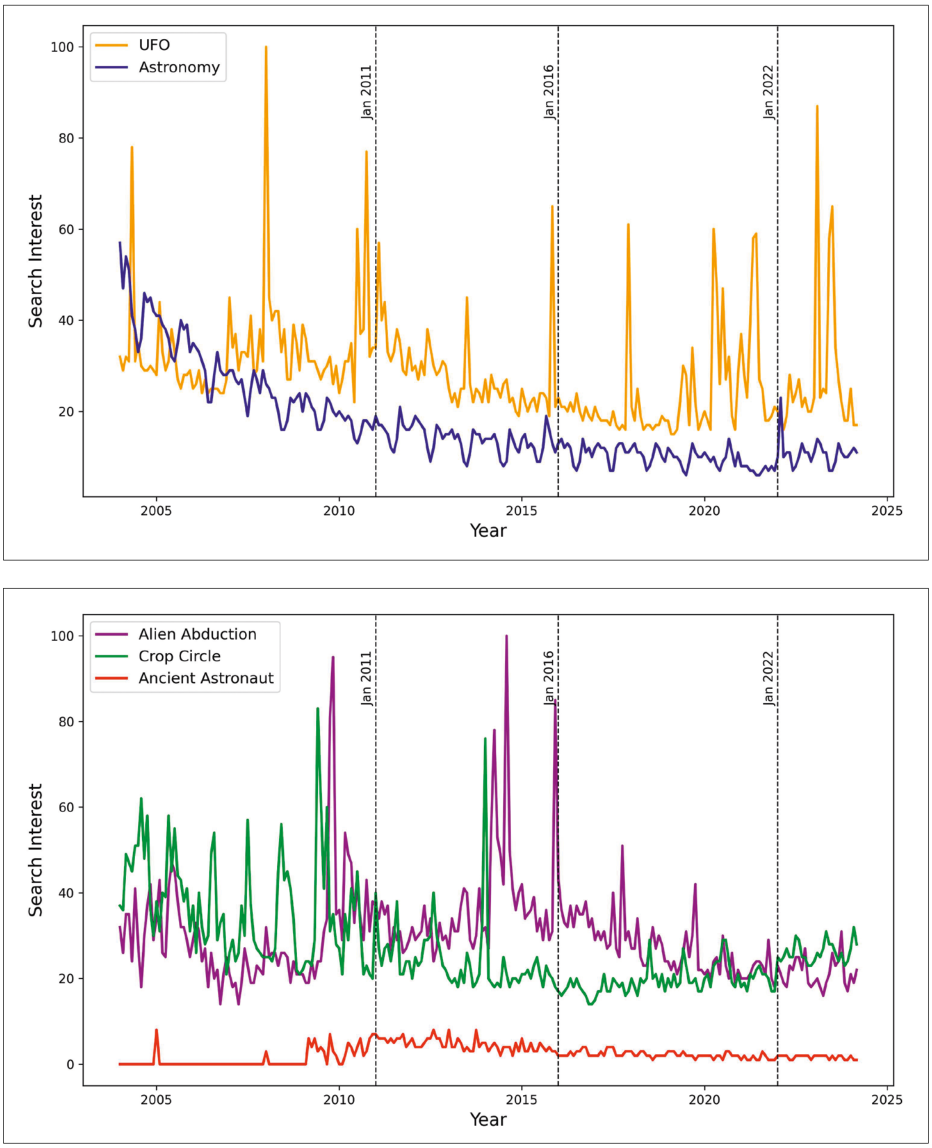

Figure 4: *Top: The relative occurrence of the search terms UFO (yellow) and astronomy (blue) in Google Trends shows a stronger decline for astronomy. Bottom: The relative occurrence of searches for the phrases alien abduction (purple), crop circle (green) and ancient astronaut (red) in Google Trends. Sharp peaks are often associated with news reports online in the case of UFO and movies in the case of alien abduction and crop circle. Dates with dashed vertical lines correspond to improvements in Google search methodology. Image Credit: Google*

The search frequency of *UFO* relative to *astronomy* is shown in the top panel of Figure 4. Unlike the case for books in the Google corpus (Figure 2), web searches for *extraterrestrial* are relatively rare. As they are about 20 to 30 times less frequent than searches for *UFO,* searches for this term are not displayed in Figure 4. Though searches for *astronomy* rivaled those for *UFO* around 2004, searches for *astronomy* have declined, the relative frequency dropping to 20%–25% in recent years. Searches for *astronomy* show a dip every summer in the Northern Hemisphere, an effect seen in other science searches, perhaps indicating student activity in the United States. By contrast, *UFO* searches show sharp peaks correlating with media coverage of a single sighting. In the top panel of Figure 4, the four highest search peaks between 2008 and 2017 correspond to months when the numbers of UFO reports were 25–100% higher than in adjacent months. A recent surge in searches in 2020 and 2021 is tied to the highly publicised release of three U.S. Navy videos of UFOs (*National UFO Reporting Center, 2022*). The states with the most UFO searches per capita are New Mexico, Arizona, and Nevada, all located in the desert Southwest with mostly dark skies. The relative search frequencies for the terms *alien abduction*, *crop circle*, and *ancient astronaut* are also shown in the bottom panel of Figure 4. Comparatively, searches for *ancient astronaut* are sparse. However, all of these phrases are much less common than *UFO* searches, and the peaks do not align with the *UFO* peaks or obvious news stories. However, there may be a tie-in with movies. The highest *alien abduction* peaks correspond to the release of movies on the topic: *The Fourth Kind* in 2009, *Alien Abduction* in 2014, and *The True Story of Travis Walton* in 2015. The highest *crop circles* peaks correspond to the release of *Crop Circles: The Enigma* in 2009 and *The Ultimate Crop Circles* in 2014 (*Internet Movie Database, 2022*). However, searches for *alien abduction* and *crop circle* have increased by a factor of four relative to *astronomy* since 2004, showing the enduring fascination of these exotic forms of pseudoscience.

As another example showing how media-driven pseudoscience can lead to a surge in online searches: in 2012, there was a spike in searches for the term *Nibiru*, which refers to a planet that was supposed to collide with the Earth and wipe out civilisation. It was tied to an erroneous interpretation of the Mayan calendar predicting the end of the world on December 21, 2012 (*Sitler, 2006; NASA, 2011*). This heavily debunked conspiracy theory resurfaced in 2017 with an even stronger spike in online activity. Additionally, the idea that the Earth is flat has persisted for millennia after ancient Greeks presented arguments that the Earth is round. Flat Earth searches online climbed by an order of magnitude from 2015 to 2018, declined, and then recently has settled at a level twice as high as before 2015. Much, but not all, of this activity was driven in 2017 by the high-profile basketball player and social media influencer Kyrie Irving, who came out publicly to say that the Earth was flat, but subsequently recanted his belief in 2018 (*Reuters, 2018*). Social scientists have analysed the propagation of pseudoscience beliefs and find that it is like a "contagion" spread by media (*Schiele, 2020*), where intuitive appeal outweighs intellectual integrity (*Boudry et al., 2015*). A journey down the "rabbit hole" of these and other astronomy-related conspiracy theories would make a rich subject for future investigation.

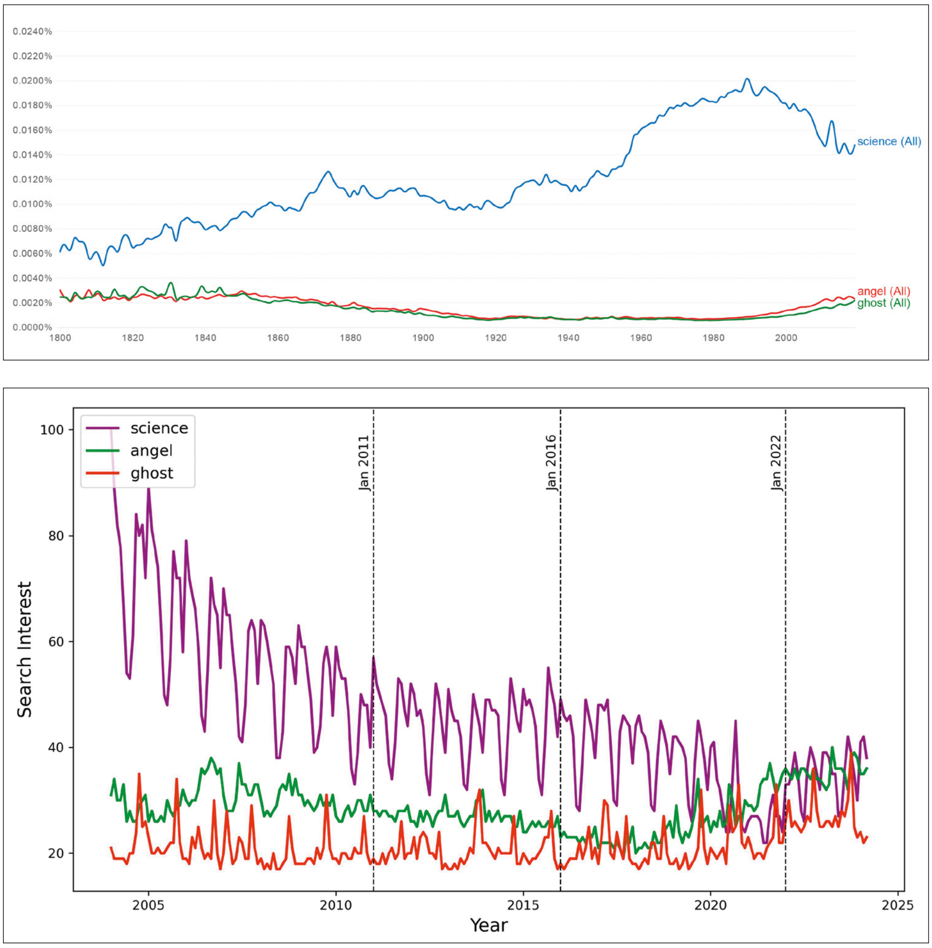

Figure 5: *Top: The relative occurrence of the words science (blue), ghost (green), and angel (red) in Google Books shows a strong rise for ghost and angel in the past forty years. Bottom: The relative occurrence of the search terms science (purple), ghost (red), and angel (green) in Google Trends data. Dates with dashed vertical lines correspond to improvements in Google search methodology. Image Credit: Google*

Discussion

Despite its limitations, Google Books is a unique resource for parsing the occurrence of words in print, and Google Trends is unrivalled for tapping into the gestalt of the Internet age. The other social media giants like Meta (Facebook) and X (formerly Twitter) zealously guard their data because they use it to target advertising. Third-party developers have added functionality to Google Books by allowing users to execute more complex searches and copy data into other applications (*English Corpora, 2024*). Interestingly, English Corpora also operates a free tool called iWeb that does for the Internet what Google Books does for books: counts words, in this case, 14 billion words in 22 million web pages from 100,000 top-ranked websites. It is a powerful resource for studies like this one.

The rise of pseudoscience concerns scientists, educators, and policymakers. Book references and web searches show the persistence and rise of astrology and UFOs in modern culture despite a lack of evidence that they have scientific explanations or bases in verifiable facts. However, other beliefs eclipse the astronomy-related topics explored in this paper. Figure 5 compares the frequency of *science* relative to *ghost* and *angel* using the Google Books corpus (top) and Google Trends web searches (bottom). Books referencing angels became rarer through the 19th century, but references to angels and ghosts have soared by more than a factor of four in the last forty years while references to science have been steady. Since 2004, online searches for angels and ghosts have risen by a factor of three relative to searches for science. Three-quarters of Americans think angels are real (*CBS News, 2011*). The word *angel* is predominantly a religious term and, therefore, is often a matter of faith and not necessarily anti-scientific; however most non-Christians also think angels exist. A third of Americans believe in ghosts, similar to the belief level for UFOs (*Ipsos, 2021*). In the bottom panel of Figure 5, web searches for *ghost* seasonally spikes by 20-30% around Halloween, but most searches occur throughout the year.

The caveat of this analysis is that book references and web searches are imperfect proxies for interest and belief. A particular term might occur in a book on an entirely different topic, and a web search might occur for various reasons. A follow-up study is required to connect data like this to belief systems and the reasons for those beliefs. Finally, a fascinating counterpoint to this study of astronomy-related topics in pseudoscience comes from a textual analysis of sentiment and rationality (e.g., *Scheffer et al., 2021*). Words related to rationality, like *determine* and *conclusion*, rose after 1850, while words related to human experience, like *feel* and *believe*, declined. This century-long trend reversed around 1980, as measured by Google Book Ngrams, web searches, and articles in the *New York Times*. The rise in pseudoscience tracked in this paper has been accompanied by a more general decline in rationality in language. We live in a world where major societal decisions depend on an understanding of science, but the pervasiveness of pseudoscience may threaten our ability to move forward as a society.

This study has illustrated the growing popularity of pseudoscience terms related to astronomy at the expense of conventional scientific terms. Educators and science communicators must operate in a world where they are not the gatekeepers of information. A seminal report from the Rand Corporation, *Truth Decay,* highlighted four trends underlying the declining importance of truth in American society: (1) increasing disagreement in evaluating facts; (2) blurring of the line between opinion and fact; (3) increase in the volume and influence of opinion over facts; and (4) declining trust in formerly respected sources of factual information (*Kavanagh & Rich, 2018*). Studies have shown that young people are particularly impacted by misinformation. In one study of high school students, a climate change denial website misled 97% of the students, and in tasks to evaluate the veracity of social media, 90% scored at a beginning level, and only 3% scored at a mastery level (*Breakstone et al., 2021*). For astronomy educators and outreach specialists, the archetype of a growing and erroneous belief system is astrology (*Das et al., 2022*).

Teaching information literacy is an essential strategy in combating science misinformation. Strategies for improving information literacy must accommodate the fact that we live in a dynamic ecosystem of digital information (*Howell & Brossard, 2021*). In academia, librarians are key allies in this effort (*Goodsett, 2020*). A useful resource is the *Debunking Handbook*, which is the current consensus on the science of debunking pseudoscience and misinformation for engaged citizens, policymakers, journalists, and science communicators (*Lewandowski et al., 2020*). This manual explains why misinformation is "sticky," and it presents strategies for inoculating against it and debunking it. Combating scientific misinformation starts with a clear demarcation between legitimate science and pseudoscience (*Gerges, 2022*). In practice, debunking a piece of misinformation or a myth creates a gap in people's mental models, so the myth has to be replaced with factual information, keeping in mind the cognitive mechanisms that drive misinformation in the first place. Moreover, the new facts have to be "sticky," able to grab attention and stick in the memory (*Cook, 2015*). Communicators can use books and internet search data to present pseudoscience case studies to their audiences. The ecosystem of UFO beliefs is a particularly rich example since it ranges from straightforward sightings, which are innocuous, to outlandish abduction reports. The goal would be to reduce credulity and increase scepticism and critical thinking.

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Biography

Chris Impey is a university distinguished professor in the Department of Astronomy at the University of Arizona. He researches active galaxies and observational cosmology and has written 240 refereed papers and a dozen popular books on astronomy. He has won 11 teaching awards and has taught 350,000 adult learners in four massive open online courses, or MOOCs.

Dark sky educational outreach through art and collaboration

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Keywords:
Dark Skies, Interdisciplinary, Light Pollution, Public Engagement, STEAM

Contemporary assessments reveal the widespread repercussions of light pollution, impacting 99% of the population in the United States and Europe (*Falchi et al., 2016*). In Pakistan, a study employing satellite remote sensing and GIS techniques exposed the challenges posed by artificial light sources, impeding the nation's potential to establish Dark Sky Places (*Butt, 2012*). Over the seven-year period from 2012 to 2019, the city of Lahore witnessed a nearly 25% escalation in light pollution, affecting more than 50% of the city, emphasising the importance of government and public initiatives for mitigation (*Nisar et al., 2022*). This article asserts the critical need for effective measures to mitigate light pollution, positioning Pakistan as a distinguished destination for Dark Sky Places. Regrettably, a deficiency in awareness exacerbates light pollution in the region (*Stare, 2022*). Urgent and robust awareness initiatives are imperative to underscore the value of preserving natural darkness. This interdisciplinary examination delves into methodologies fostering public awareness of dark sky protection, emphasising their substantial impact on conveying the severity of light pollution, engaging diverse audiences, and garnering support for policies safeguarding the dark sky (e.g., *Sleigh & Craske, 2017*).

Introduction:

Light pollution, characterised by the excessive use of artificial light that disrupts natural light patterns, has become a pressing global issue with far-reaching consequences. It affects human health and well-being and significantly impacts wildlife and astronomy (e.g., *Morand & Lajaunie, 2019*). The issue is particularly pronounced in megacities like Karachi, Pakistan, with approximately 17 million people (*Zia et al., 2022*). Figure 1 compares the population density with the distribution of light pollution in Karachi, Pakistan. This reveals the interplay between human settlement and artificial light emissions. The population density map of Karachi showcases dense concentrations of people in areas like the city centre, along major transport corridors, and in residential clusters. The effects of light pollution include disruptions to ecosystems, alteration of natural habitats and migration patterns, interference with circadian rhythms in humans and animals, and hindrance to astronomical observations (e.g., *Falchi et al., 2016*).

Addressing light pollution requires effective public engagement strategies that can capture the attention of diverse audiences and raise awareness about its implications (e.g., *Nisbet, 2009*). However, traditional methods often struggle to reach broad segments of the population due to the complexity of the topic and competing priorities for public attention (e.g., *Offe, 2019*). This necessitates exploring innovative approaches that combine scientific knowledge with artistic creativity to engage and educate the public (e.g., *Gauntlett, 2007*).

Interdisciplinary collaborations between science and art have emerged as a powerful tool for public engagement on complex scientific issues such as light pollution (*Pérez et al., 2021*). These collaborations leverage the strengths of both disciplines to create impactful experiences that resonate with people on an emotional and intellectual level (e.g., *Lasker & Weiss, 2003*). By integrating creative storytelling, visual arts, and interactive experiences, artist-scientist collaborations can communicate scientific concepts in accessible and engaging ways (e.g., *Wynne, 2006*).

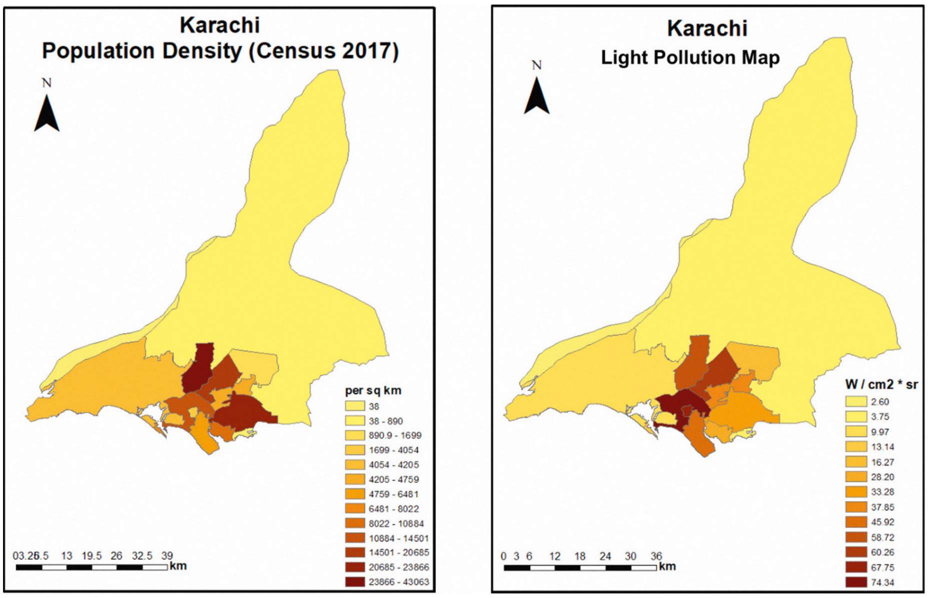

Figure 1: *(Left) A map of the population density of Karachi. (Right) A map of the light pollution distribution in Karachi. Image Credit: Muhammad Aly Gajani*

One of the key benefits of interdisciplinary public engagement initiatives is their ability to foster dialogue and trust between scientists and the public. By providing opportunities for interaction and discussion, these initiatives empower individuals to ask questions, express concerns, and contribute to informed decision-making processes (e.g., *Pace et al., 2010*). These collaborative approaches enhance public understanding of scientific issues and strengthen the foundation of democratic societies by promoting transparency and accountability in science communication (e.g., *Stilgoe et al., 2014*).

This article delves into the need for innovative approaches, particularly interdisciplinary collaborations between art and science, to effectively engage the public on light pollution issues. Through three distinct examples of art/science collaborations, this article explores the power of such initiatives in raising awareness and advocating for dark sky preservation.

This article will discuss three specific examples of interdisciplinary collaborations integrating art and science to address light pollution. These examples showcase the diverse strategies and creative approaches that can be employed to engage and educate the public on the importance of preserving natural darkness.

Dark Sky Superhero: A Collaborative Journey Toward Dark Sky Advocacy
This initiative introduces a superhero character, the Light Pollution Fighter, designed to raise awareness and initiate discussions on light pollution using creative storytelling and sustainable art practices.

Unveiling the Dark Sky Defender: Bridging Art and Science to Combat Light Pollution
Drawing inspiration from the real-life Light Pollution Fighter, we created the 3D animated character, the Dark Sky Defender. This represents a fusion of art and science to communicate the harmful effects of light pollution and promote sustainable lighting practices. Inspired by a physical costume designed for the Dark Sky Superhero character, this animated representation extends the impact of interdisciplinary collaboration in raising awareness about light pollution and advocating for environmental conservation.

Collaborative Storytelling with Luke Korns
A collaborative travelogue project with Luke Korns, a prominent YouTube influencer, showcases Pakistan's landscapes while highlighting the impact of light pollution and advocating for dark sky preservation.

These initiatives demonstrate the power of interdisciplinary collaborations in conveying complex scientific concepts and fostering public understanding and action.

Enhancing public scientific literacy via imaginative collaborations.
As *Owen et al. (2013)* assert, adopting an interdisciplinary framework for public engagement with science offers numerous advantages. Such an approach helps to clarify and explain intricate subjects, including light pollution, for individuals lacking specialised expertise while concurrently fostering a bilateral exchange of ideas between scientists and the public. Additionally, it introduces novel perspectives on research and potential resolutions.

Nevertheless, *MacLeod (2018)* articulated that interdisciplinary methodologies are not without challenges. Striking an equilibrium between diverse disciplines can be difficult, and divergent viewpoints regarding the optimal means of communicating scientific concepts to the general public may arise. However, these should not dissuade communicators from pursuing innovative methods in science engagement.

Figure 2 visually explains the inherently intersectional nature of light pollution based on the framework outlined in *Hölker et al. (2010)*. Their article describes the intrinsic value of collaborations extending beyond scientific domains involving policy and

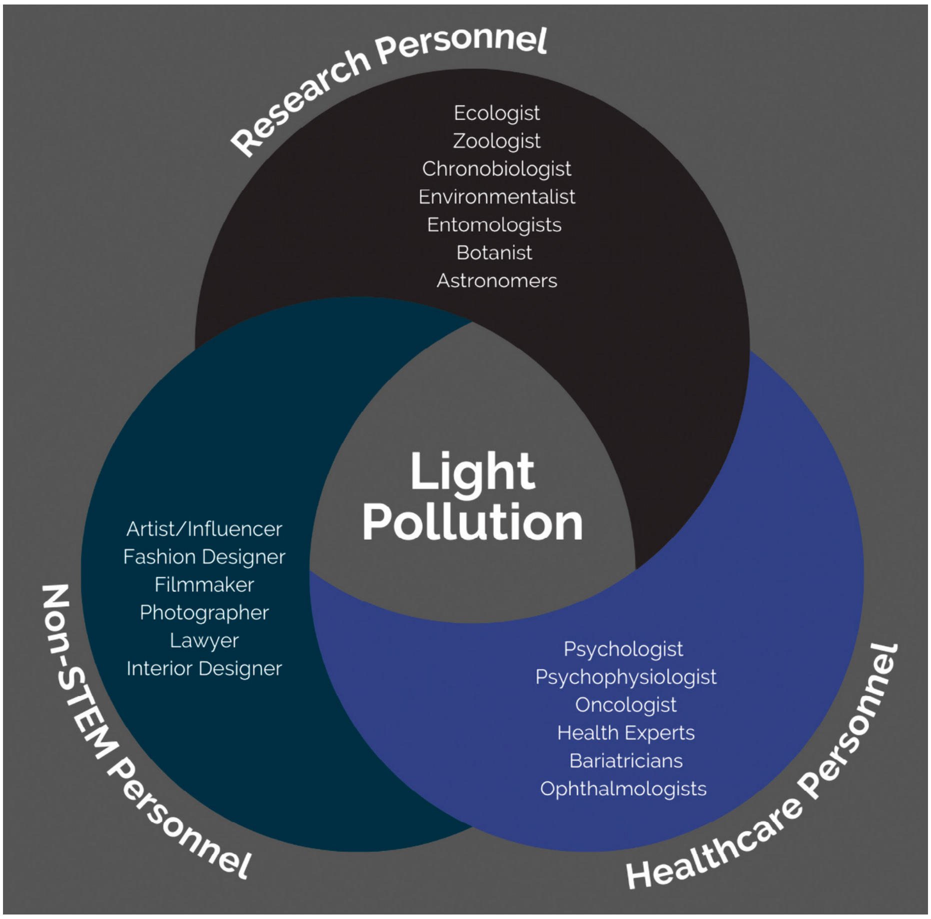

Figure 2: *A Venn diagram showing the intersectionality of light pollution, particularly between research, non-STEM and healthcare personnel.*

practical considerations. The authors advocate for interdisciplinary collaborations encompassing objective facts, existing practices, and core values to effectively address light pollution. Through this comprehensive approach, collaborative ideas are posited to generate substantive outcomes.

Interdisciplinary dialogues: A catalyst for informed science communication

Interdisciplinary collaboration is a pivotal mechanism for bridging the divide between scientific research and its practical application, as described in *Brownell et al. (2013)*. It facilitates communication between non-scientific stakeholders and science researchers and institutions. Concurrently, collaboration serves as a conduit for the reciprocal exchange of knowledge and resources, thereby optimising the efficacy of public engagement with science (e.g., *Stocklmayer & Rennie, 2017*).

Diverse strategies may be employed to cultivate and promote collaborative initiatives. These include establishing dialogue and knowledge exchange platforms, including fora, workshops, or conferences designed to accommodate various perspectives. Furthermore, the inception of joint projects or programs uniting scientists and nonscientists to pursue shared objectives offers a tangible means of fostering collaboration.

Nevertheless, the efficacy of collaborative endeavours is contingent upon the mutual commitment of both scientific and non-scientific stakeholders to engage in active listening and maintain respect for each other's areas of expertise (e.g., *Yeatman, 1996*). A culture of open communication and receptivity to constructive feedback is imperative to ensure the effectiveness of collaborative undertakings. There is a need for reconsideration and enhanced collaboration in non-STEM disciplines to address societal challenges effectively (e.g., *Uddin et al., 2021*).

Dark Sky Superhero: A collaborative journey toward dark sky advocacy

This study explores a pioneering initiative in dark sky preservation by introducing the "Light Pollution Fighter", a superhero character tailored to address the prevalent issue of light pollution. Motivated by the absence of superheroes dedicated to environmental causes, we present the origins and impact of the Light Pollution Fighter character and its associated costume. Harnessing the influential role of superheroes in shaping children's behaviour, our endeavour seeks to effectively raise awareness and instigate discussions on light pollution in an engaging and accessible manner. The conceptualisation of the Light Pollution Fighter is rooted in personal experiences: growing up as a child in Karachi, the author encountered hindrances to his astronomical pursuits due to light pollution.

Implemented with an environmentally sustainable ethos, the Light Pollution Fighter costume was meticulously fashioned from repurposed waste materials, including headphones, a smartphone, wires, headsets, car seat covers, toys, and scrap metal. Our primary objective was to convey the urgency of dark sky preservation through a creative and impactful medium, surpassing conventional modes of astronomy outreach such as public lectures or school visits. The success of this initiative relied on fruitful collaborations with visual artists and costume designers, emphasising the optimisation of individual strengths, realistic goal-setting, and adept utilisation of collaborative tools within the realms of art and social media.

This work demonstrates the imperative of diverse strategies in dark sky advocacy, encompassing educational initiatives, emotional resonance, and advocacy for legislative backing. Our innovative approach utilises art as a dynamic conduit for raising awareness, employing costumes to evoke public curiosity and initiate educational discussions (e.g., *Parks & White, 2021*). As a tangible outcome of our efforts, we unveiled the Light Pollution Fighter costume, symbolising our commitment to creatively addressing the challenges of light pollution. This contributes to the evolving discourse on inventive methodologies in environmental advocacy, highlighting the potency of artistic collaboration in fostering public engagement with critical issues.

Our distinctive costume (Figure 3) incorporates a smartphone device adept at converting the auditory signals produced by the Light Pollution Fighter into light signals. The costume is designed to activate the phone's light in response to the Light Pollution Fighter's speech, a feature strategically employed to highlight the contemporary reality that communication methods are increasingly mediated through light (e.g., *Rose, 2014*). Thus, the costume serves as a tool to amplify awareness regarding the pervasive effects of light pollution in our modern society.

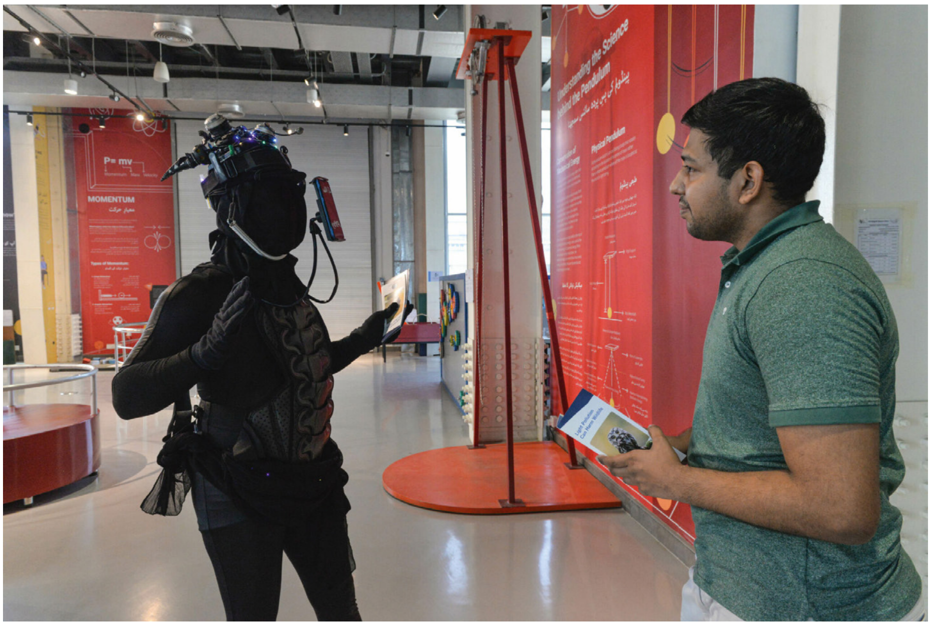

Figure 3: *The Light Pollution Fighter discusses light pollution with a member of the public at an event at the TDF Magnifiscience Centre-Karachi Pakistan. Image Credit: TDF Magnificience Centre – Karachi, Pakistan*

Our collaborative approach, specifically partnering with professionals beyond STEM fields – notably visual artists and costume designers – has proven to be a fruitful strategy for engaging a diverse audience. This innovative methodology enables us to present our research findings in a captivating, interactive, and easily comprehensible manner. Simultaneously, it represents the need to safeguard natural darkness. This interdisciplinary collaboration showcases the potential for non-traditional partnerships to enhance public engagement and understanding of complex scientific issues.

Unveiling the Dark Sky Defender: Bridging art and science to combat light pollution

The outcome of an interdisciplinary collaboration between artists and scientists, and based on the real-life Light Pollution Fighter, the Dark Sky Defender, shown in Figure 4, is a 3D animation marking a significant fusion of art and science to communicate the harmful effects of light pollution. The creation of this digital character stemmed from the recognition of the urgent need to raise awareness about light pollution and its detrimental effects on the environment and human health. The character symbolises the ongoing battle against light pollution, embodying the mission to protect natural darkness and promote sustainable lighting practices. This initiative was driven by a desire to engage a wider audience, especially children and young adults, in understanding the significance of preserving dark skies and reducing artificial light at night.

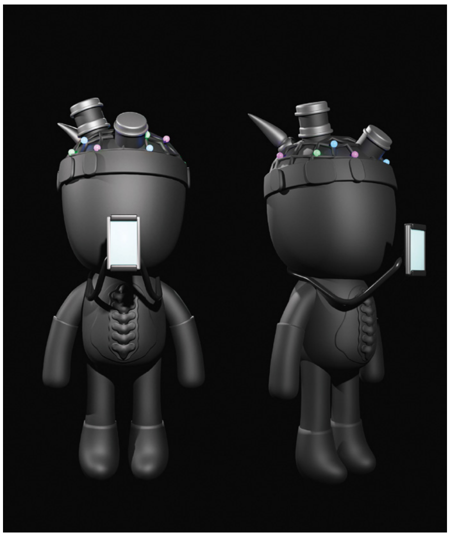

Figure 4: *3D Animated Character of Dark Sky Defender. Image Credit: Juliah S. Champion*

This collaborative effort aims to leverage the aesthetic appeal of digital art alongside scientific knowledge, utilising digital storytelling to enhance public understanding and inspire action. The Dark Sky Defender character is an effective conduit, offering relatability and engagement to connect with audiences, exemplifying the impactful integration of diverse fields for innovative solutions to complex issues and promoting a more sustainable future.

The collaboration of artists and scientists who created the Dark Sky Defender 3D animation highlights promising avenues for future outreach and engagement strategies, including digital storytelling techniques to engage the public further (e.g., *Niemi & Multisilta, 2016*). Moving forward, we plan to expand the reach and impact of the digital character initiative through various channels. This includes developing digital content such as short videos, animations, and online campaigns featuring the character to reach a broader audience via social media platforms and educational websites. We aim to build collaborations with schools, environmental organisations, and local authorities to integrate light pollution awareness into curricula, community programs, and policy discussions.

When created, this new content will incorporate the Dark Sky Defender character in diverse ways, such as illustrating the detrimental effects of light pollution on wildlife or emphasising the economic benefits of reducing light pollution. Leveraging the character as a relatable and engaging persona, we aim to capture viewers' attention and have a lasting impact on their comprehension of the issue.

Collaborative storytelling with Luke Korns

The author's collaboration with Luke Korns is an innovative approach to raising awareness about environmental issues like light pollution while leveraging the influence of digital media and popular culture.

In 2021, the author collaborated with YouTube influencer Luke Korns (*Korns, 2021*) to shed light on the issue of light pollution and advocate for dark sky preservation in Pakistan. The project aimed to showcase Pakistan's unique landscapes and cultures through a travelogue, offering a fresh perspective on the nation. The collaborative effort included a journey from Karachi, Pakistan's largest city, located on the Arabian Sea coast in the South, to Hunza, a mountainous region in the North bordering China.

Figure 5 shows a light pollution map of Pakistan, with areas with high light pollution in white and areas with low light pollution in black.

The data for this light pollution map of Pakistan was obtained from the Visible Infrared Imaging Radiometer Suite (VIIRS-2021)-Day Night Band (DNB) with a spatial resolution of 15 arcseconds. The map incorporates data from twelve tiles (*Stare, 2022*) that were mosaicked and clipped to the country's border. The journey from Karachi to the Northern areas of Pakistan, as documented through the collaborative effort with Luke Korns, is symbolically represented as a travel marker on the light pollution map of Pakistan, showcasing the expedition's geographic scope and thematic alignment with dark sky preservation.

The collaboration heightened awareness about the pressing need for dark sky protection, delineating the detrimental impacts of light pollution on the region's natural wonders. For example, Luke Korns's YouTube channel boasts 2.36 million subscribers at the time of writing, which likely played a substantial role in the video's extensive reach (16.9. million impressions by 2022). In addition, Korns's viewers are typically young people from the United States of America who may be predisposed to engaging in this kind of content.

The collaborative endeavour with Luke Korns represents a positive and insightful experience. It provides a platform to disseminate knowledge on light pollution and its consequences in a compelling and imaginative manner. The outcomes reveal the potential of collaboration and storytelling as potent tools for raising awareness and fostering understanding of significant issues.

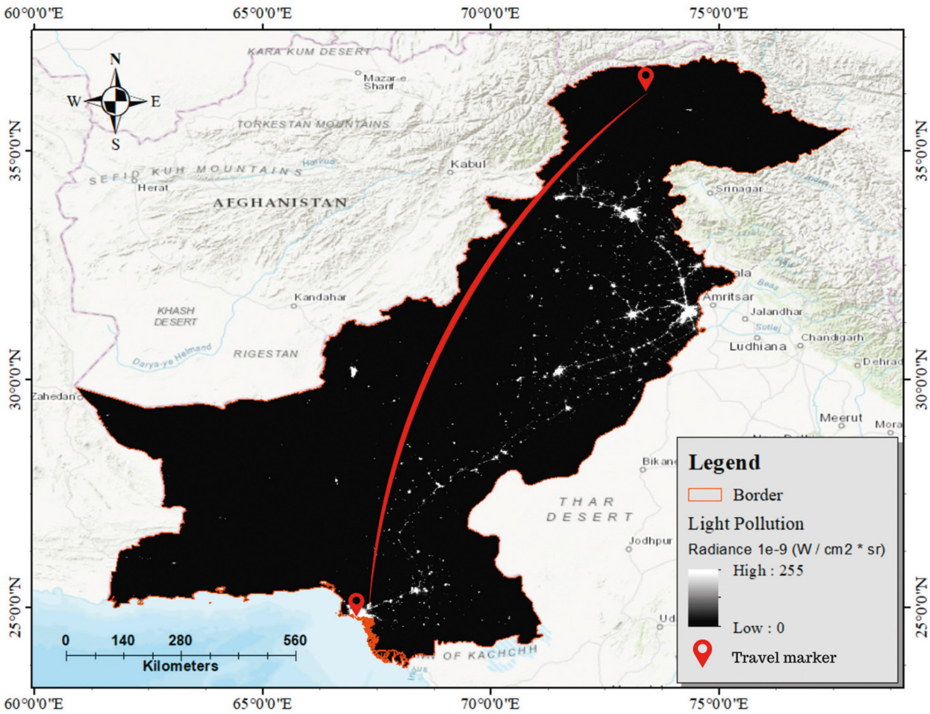

Figure 5: *Light pollution map of Pakistan. The red line demonstrates the journey from Karachi to Northern Pakistan. Image Credit: Muhammad Aly Gajani*

Collaborative horizons: Expanding public engagement on light pollution

Figure 6 visually represents various collaborative initiatives integrating art and science to address light pollution. The figure showcases three specific collaborations: an artist-astronomer collaboration, a musician-environmental scientist collaboration, and a photographer-community engagement collaboration. Each collaboration is designed to engage different audiences and convey the impacts of light pollution through creative and innovative means.

Artist and Astronomer Collaboration

An artist and astronomer can collaborate to create public art installations, such as an interactive light sculpture, raising awareness of light pollution's impact on observational astronomy (e.g., *Impey & Jasensky, 2018*).

Musician and Environmental Scientist Collaboration

A musician and an environmental scientist can collaborate to produce a music video highlighting the effects of light pollution on nocturnal animals and their habitats, juxtaposing natural habitats with images of urban lighting (e.g., *MacDonald & Miell, 2000*).

Photographer and Community Engagement Collaboration

A photographer and a community group can collaborate to organise a public photography exhibition showcasing the beauty of the night sky and the significance of dark sky preservation. The exhibition could also include talks and workshops on astrophotography and the effects of light pollution (e.g., *Moore & Hatcher, 2019*).

Interdisciplinary collaborations that address complex environmental issues like light pollution benefit from several best practices that foster effective teamwork and meaningful outcomes. Mutual respect and understanding between artists and scientists are foundational for success in such collaborations (e.g., *Nowotny et al.,2003*). This involves appreciating each other's expertise, perspectives, and contributions, which can be achieved through open and transparent communication throughout the collaboration process (e.g., *Casado-Aranda et al., 2023*).

Furthermore, establishing clearly defined goals for the outreach project is crucial. These goals should align with the intended impact – in the case of this study, on public awareness and understanding of light

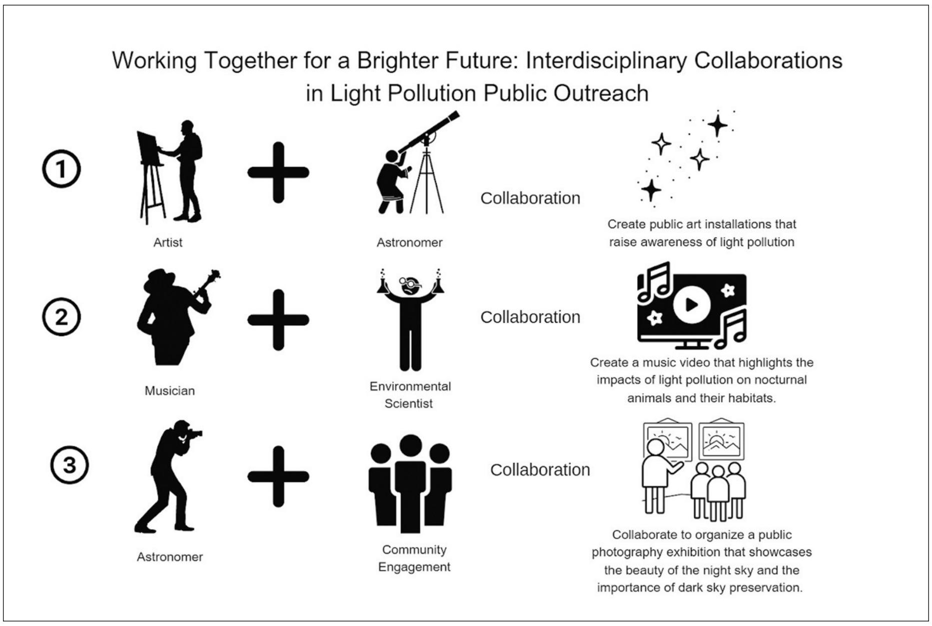

Figure 6: *Interdisciplinary collaborations can be used to address light pollution, public outreach, and community engagement through artist-astronomer, musician-environmental scientist, and astronomer-community engagement collaborations.*

pollution – ensuring that the artistic expression and scientific message are harmoniously integrated. A shared vision among collaborators regarding the project's objectives and desired outcomes is also essential (e.g., *de Ruiter et al., 2024, p. 202*). This shared vision serves as a driving force that motivates and guides collaborative efforts, leading to a cohesive and impactful final product. Additionally, leveraging each collaborator's strengths is paramount. Scientists can provide accurate and relevant factual information about light pollution, while artists can utilise their creativity and artistic skills to translate this information into engaging and accessible formats for diverse audiences (e.g., *Hicks et al., 2010*). By capitalising on these strengths and working collaboratively, interdisciplinary teams can create innovative and effective public engagement and advocacy strategies in environmental conservation.

The collaboration between artists and scientists in crafting the physical Light Pollution Fighter and the animated Dark Sky Defender is a significant advancement in integrating art and science to raise awareness about complex environmental issues like light pollution. Through sustained collaboration and ongoing innovation, the potential for utilising digital mediums to engage and inspire the public towards a more sustainable future remains substantial.

In the face of complex challenges requiring scientific solutions, ensuring a robust public understanding of science is more critical than ever. Interdisciplinary public engagement with science is vital to breaking down barriers between disciplines and enhancing communication. Collaborative efforts provide the public with essential information for making informed decisions about pressing issues like light pollution. Through our collaborative storytelling efforts on Luke Korn's channel, we have reached millions with the message of dark sky preservation and the impacts of light pollution. Ultimately, the night sky is not just for scientists but for us all.

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The author also thanks Juliah S. Champion for her significant contributions to our ongoing collaborative endeavours. Her Dark Sky Defender character has opened new avenues for us to delve into digital storytelling, amplifying the impact of light pollution awareness. Her 3D animation digital artwork has extended the reach of our project and brought a new dimension to our collective efforts. The author appreciates her unwavering dedication and commitment to advancing the cause of light pollution awareness.

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Biography

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

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Accessibility, Exhibition, Networking, Outreach, Radio Astronomy, Virtual Reality

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.

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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.

In 2022, the NOC Madagascar and Senegal Teams worked together on a NOCs Funding Scheme Project, ORION Astro Lab, which aimed to provide training, resources, materials and support to young people interested in starting their own astronomy clubs.

Zara Radriamanakoto

Pioneering research on the contribution of astronomy to the needs of older adult learners

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In recent years, mainly in developed countries, there has been a significant increase in healthy lifespans as a result of advances in healthcare. For older adults, learning is important in improving their quality of life. However, previous research on lifelong learning for older adults has not covered science subjects, including astronomy, as learning subjects. Thus, this study investigates the contribution of astronomy to the needs of today's older adult learners. Based on the findings, and contrary to classical studies about learning for older adults based on research in the 1970s, present older adult learners who focus on astronomy are: 1) not looking for practical benefits from their learning; 2) not attempting to make new friends or reflecting on their past lives; and 3) simply enjoying learning itself and aiming to broaden their perspectives through learning. These findings imply that the community of astronomy communication should contribute to older adult learners by adapting various strategies to their needs and characteristics.

Introduction

In recent years, especially in developed countries, the population has been rapidly ageing, and opportunities for lifelong learning among older adults have been increasing (*Hori, 2001; Withnall, 2009; Cabinet Office of Japan, 2021*). In this regard, there has been growing research on education and learning for older adults. However, studies on lifelong learning among older adults in natural sciences, such as astronomy, have not made significant progress. Researchers have only recently recognised the differences between older adult learning and learning for the younger generation. In particular, there has been limited research on why and what older adults choose to learn (*Kim & Merriam, 2004*).

As for lifelong learning, especially for older adults, typical needs include: 'satisfying curiosity', 'confirming and maintaining relationships with others' and 'preparing for coming decline and death' (*McClusky, 1971*). These findings contrast the learning needs of school students, who typically aim to 'prepare for life' and 'adapt to future social life'. In addition, this differs from adult learning, which typically focuses on real-world applications, such as job skill acquisition and obtaining licenses and certifications. In addition, older adults have the advantage of using their past experiences in learning. Conversely, due to their physical and mental decline, it is not necessarily a good idea to use the same teaching materials and methods as those for younger generations.

Thus, the present study investigates the contribution of astronomy to the needs of older adult learners. As a first step, we clarify what older adult learners might need from astronomy. We then suggest informal learning programmes that not only highlight this subject's importance but also meet the needs of this demographic.

Current status of research on lifelong learning for older adults

Current status of lifelong learning in developed countries

Healthy lifespans have been increasing annually, especially in developed countries. For example, according to a 2019 survey by the World Health Organization, life expectancy is 80.8 years (on average) in Organization for Economic Cooperation and Development (OECD) countries, while healthy life expectancy is 70.3 years (on average) in developed countries (see Figure 1). Additionally, Figure 2 shows the annual increase in Japan's average life expectancy and healthy life expectancy.

With the increase in healthy lifespans and the growing importance of careers for older adults, they must acquire social skills and new perspectives that can enable them to effectively integrate into social activities after retirement. Older adults who have lost income and relationships due to retirement need to find new employment and/or new activities in their new communities. *Withnall, (2009)* argued that under these circumstances, through continuous learning, even older adults can achieve a higher level of *active ageing* (i.e. a state in which personal enjoyment, human connections and social contributions are all at a high level).

Retirement also causes older adults to lose the center of their daily activities. This results in significant changes in their physical, mental, and social lives. To cushion this shock, some kind of alternative activity to work is essential. The primary significance of learning for older adults is to reduce the problems of old age caused by such changes in the environment by continuing to engage in some kind of activity and keep developing themselves (*Withnall, 2009*). In recent years, research has suggested that the motivation for learning among older adults is not only in the context of personal development, but also within a societal/emancipation framework (*Sibai & Hachem, 2021*). In an environment without a retirement age and with limited financial support for older adults, it is considered necessary to continue career development and learning in old age to maintain a stable life. In addition, in environments where discrimination and stereotyping against older adults (especially women) exist, learning can enhance social justice and participation. However, we will not discuss this aspect in depth in this article.

In recent years, the number of older adult learners has been increasing. More than half of older adults in developed countries have engaged in some type of learning activity, with the majority planning to continue learning in the future (*Withnall, 2009; Cabinet Office of Japan, 2019*). In this situation, the conventional idea that human life is divided into three stages (i.e. school age, adulthood and old age) has become an anachronism. Instead, it has been suggested that there is a new third stage between adulthood and (declining) old age: a "time when people are retired, but still have the energy to enjoy their lives" (*Withnall, 2009*, pp. 9-11).

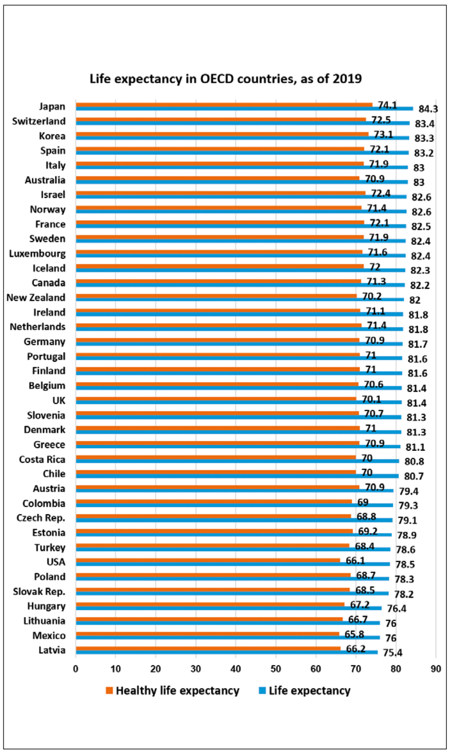

Figure 1: *Life expectancy and healthy life expectancy in OECD countries, as of 2019. Note: The data used for this figure were taken from World Health Organization (n.d.)*

Theories of lifelong learning

Research on lifelong learning for older adults has been conducted from both a social welfare perspective and an overall learning perspective. Moody and McCluskey were pioneers in theorising lifelong learning in the 1970s. Separately, they investigated how older adults' lives and experiences influence their perspectives on learning. Before their work, researchers recognised that adult education was different from educating children: in the 19th century, the term "andragogy" – the theory of learning for adults, just as pedagogy is for children – was already in use (*Jarvis, 2010)*. However, in the 1970s, there was a push to understand learning in older, retired adults. In this context, Moody and McCluskey both challenged the conventional belief that older adults do not need education. In particular, Moody considered that education is necessary for the self-realisation of older adults and that lifelong learning is based on their need to "transcend" – to overcome past roles and self-definitions. He also argued that their plentiful life experiences can be effectively applied to learning in the sense that they can learn by referencing their own lives (*Moody, 1990*).

On the other hand, McCluskey argued that learning is the driving force in the development and growth of all human beings, including older adults, and advocated that the needs of older adult learners are rooted in *stabilising margins* (*McCluskey, 1971*). In this case, margin refers to the excess of power (ability) overload (burden). In old age, power decreases as income and physical/mental health decline. Meanwhile, the overall margin decreases as the load increases due factors such as to rising prices and increased family responsibilities. McCluskey argued that education is important for readjusting the margin of power to such loading. Especially among older adults, the transcendent need becomes more significant to overcome physical/mental decline constraints. According to *Moody (1990)*, learning about human history allows older adults to find themselves in history, and learning about psychology and literature will enable them to objectively look at the struggles common to all of life and see that human life is one story. Hence, history, classical literature, religion and other themes related to eternity are popular subjects in lifelong learning.

From the perspective of gerontological sociology, it has been proposed that the theme of 'connectedness' exists in the needs of older adult learners. Such needs are based on the tendency that as people age, the weight of their desires and social needs shifts from *achievement needs* (the need to achieve goals) to *affiliation needs* (the need to enrich human relationships). With the increasing weight of older adults' need to cope with loss in old age, rebuilding relationships is an important issue. Thus, the need for connection should be the foundation of lifelong learning (*McClusky, 1990; Hori, 2001; Murahashi & Morita, 2015*).

Additionally, a relatively well-accepted theory of lifelong learning is the need for a life review (reflecting on one's own life), as studied by *Lowy and O'Connor (1986)*. A life review is a universal mental process that naturally occurs in the later stages of life. It has also been suggested that doing this can help reduce stress and improve the quality of life of older adults (*Merriam, 1990; Hori, 2001*).

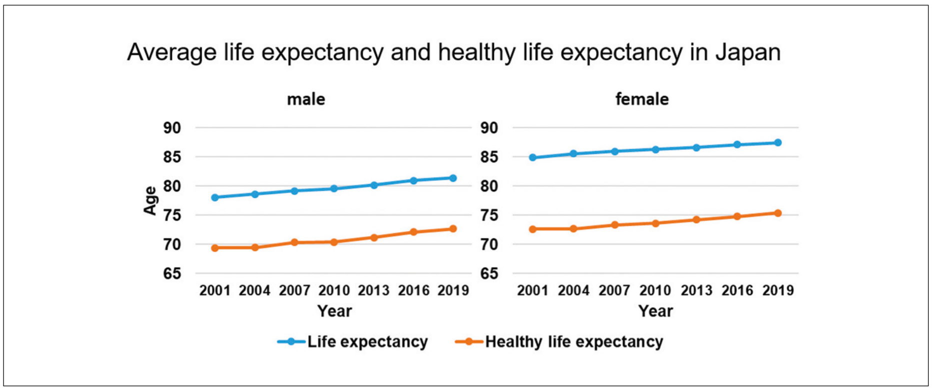

Figure 2: *Annual increase in average life expectancy and healthy life expectancy in Japan. Note: The data used for this figure were taken from Cabinet Office of Japan (2021).*

Londoner argued for the theories of *expressive* and *instrumental needs* as a different approach (*Londoner, 1990; Kim & Merriam, 2004*). The former refers to the need to enjoy learning, while the latter represents the need to obtain something as a result of learning. As people age, their lives can become unstable for physical and/or financial reasons. In such situations, learning activities are based on *instrumental needs*. Since participation in learning based on *expressive needs* only becomes possible after their lives have become stable, it has been argued that learning should be based on *instrumental needs*, especially in the later stages of life (*Londoner, 1990*). In traditional pedagogy and andragogy, the *expressive* need to acquire skills needed in social life was important (*Jarvis, 2010)*. Also, early gerontology focused on the *expressive* needs of coping with decline. One of the major research questions in this study is whether this is also true for older adults today.

Learning for older adults in today's world

The aforementioned theories of lifelong learning include several problems. Foremost among them is that the majority of these theories must be updated. Fifty years have passed since the first articles on lifelong learning were published, and healthy lifespans have dramatically increased, especially in developed countries. Thus, it is no longer appropriate to consider retirement as a withdrawal from society. Instead, we must consider that there is still a free and healthy period after retirement (*Hori & Cusack, 2006*). In today's world, healthy older adults value learning based on expressive needs more than the desire to cope with decline.

Second, although there have been several surveys on the needs of older adult learners, most of them did not assume that older adults might study astronomy or other science-related subjects. Since the starting point of lifelong learning theory is to deal with physical and/or mental decline, it is not surprising that astronomy might be inappropriate as a learning objective. However, as noted earlier, older adults have greater learning opportunities for enjoyment (*Kim & Merriam, 2004*). In such a context, astronomy could become a significant component of learning for older adults (*Impey & Buxner 2020; Pompea & Russo, 2020*).

In this regard, it has been pointed out that although older adults benefit from education, most education programmes for older adults are only designed from the perspective of the education provider. Moreover, the learning activities are not necessarily academic in nature; they include topics that range from hobbies and healthcare to economic savings. Thus, without research into the needs of older adult learners, it is impossible to construct educational designs that genuinely benefit older adults (*Withnall, 2009*).

Astronomy education has contributed to motivating and broadening the horizons of countless learners in school and adult education (*Pompea & Russo, 2020*). Applying such education to older adult learners may be considered a natural extension of astronomy education. Conversely, identifying the differences between the learning of older adults and that of younger generations, especially regarding their learning needs, is unavoidable. As a first step, this study focuses on the learning needs of older adults and examines the position and future of astronomy in this demographic.

Survey of the learning needs of older adults

In the previous section, we reviewed the learning needs of older adults based on current literature. Some of them are also appropriate for younger learners. However, transcendent needs and the need for connectedness are particularly evident in older adults. Thus, providing education in areas that address these needs could lead to greater satisfaction for older adult learners. Astronomy, which deals with the eternity of time and space, may meet their transcendent needs, although its relevance remains unclear.

This is not the first survey on the learning needs of older adults. For example, a survey conducted in Osaka (1998–1999) investigated the preferred learning subjects of older adults. *Hori and Cusack (2006)* compared this survey with a related one conducted in Vancouver in 2003. The results showed that various subjects, such as 'History and Culture of the Community', 'Current Topics (Economics, Politics)', 'Literature, Classics', 'Practical Information about Healthy Ageing' and 'Gardening, Potteries' were popular in Japan, while 'Volunteer Activities' and 'Activities Involving Communication with Other Seniors' were popular in Canada.

However, it should be noted that while the preferred learning subjects were examined in a multiple-answer format in these surveys, 'Natural Science' was not included as an option. In other words, these surveys assumed that older adults do not want to learn natural science, including astronomy. Unsurprisingly, the learning trends derived from such surveys do not match those of natural science. However, as discussed later, many older adult learners prefer to learn about astronomy and other science-related subjects. This indicates that there are unknown learning needs related to astronomy and natural science that have been overlooked in previous research.

Based on the assumption that older adults also have the need to learn astronomy and natural science, this study examines the demographics of older adults who prefer to learn astronomy and discusses the contributions that the astronomical education community can provide in the context of lifelong learning.

Questionnaire survey

To investigate the learning needs of older adults and their connection to astronomy, we surveyed a sample of participants in five educational courses for older adults held in Japan between October 2020 and July 2021. One of the courses was a specialised lecture on astronomy, to which 22 participants responded (mean age 73.7 years; standard deviation (SD) 5.5 years). In addition, three were omnibus courses in various fields, each of which included at least one lecture on astronomy. Overall, 59 participants responded in these three courses (mean age 76.0 years; SD 6.5 years). The remaining course was unrelated to natural science (psychology), yielding 24 responses (mean age 72.5 years; SD 6.3 years).

Surveys with incomplete or missing data were excluded from the analysis. The age and gender of the respondents in the present study are shown in Table 1. In this type of survey, a sample size of 200 to 400 can be considered reliable, depending on the statistical method used. The sample size here is 105 (73 valid responses), which is a little below this level but still somewhat reliable.

	~59	60-64	65-69	70-74	75-79	80-84	85~	Unknown
Male			6	18	4	9	1	
Female	1	2	4	17	2	3	1	2
Unknown								3

Table 1: *Age and gender distribution of the participants*

Survey items

The survey questionnaire in this study focused on the (1) motivation for learning and the (2) preferred learning subjects, in addition to items describing the attributes (e.g. gender and age) of the participants and the reasons for taking the course. In the following, we discuss the relationship between the learning needs of older adults and astronomy based on the aspects mentioned above.

Motivation for learning

A total of 15 items were selected regarding the motivation for learning (see Table 2). The participants were asked to rate each item on a four-point scale: 1: 'Not at all applicable'; 2: 'Not very applicable', 3: 'Somewhat applicable'; and 4: 'Very applicable'. Nine items were created as the *Enjoyment of Learning Scale*, which is in line with previous research (*Asano, 2006*). These items consisted of three sub-scales: 'Practical Enjoyment' (three items), 'Enjoyment of Broad Variety of Thinking' (three items), and 'Enjoyment of Knowing' (three items), respectively. In addition, we used six items from the *Motivation to Learn Scale*, which qualitatively categorised the learning needs and characteristics of older adults (*Murahashi & Morita, 2015*).

Preferred learning subjects

The 17 items used in the surveys in Japan and Canada were used as a basis (*Hori & Cusack, 2006*). However, since these surveys had no science-related items, we prepared three additional items, including 'Astronomy', 'Natural Science' and 'Philosophy, Ideology, Religion'. These 20 items are shown in Table 3. The respondents were asked to rate the degree of their interest in these areas on a four-point scale: 1: 'Not at all interested'; 2: 'Somewhat interested'; 3: 'Rather want to learn'; and 4: 'Would definitely like to learn'.

Results

Mean values for each scale and scores for each item

Table 2 presents the aggregated results for the (1) motivation for learning. When considering the *Enjoyment of Learning Scale* among the question items, the mean values for 'Enjoyment of Broad Variety of Thinking' and 'Enjoyment of Knowing' were relatively high. In contrast, the mean value for 'Practical Enjoyment' was relatively low. Statistical tests were also conducted using a one-factor analysis of variance to determine whether there are significant differences between the sub-scales of the *Enjoyment of Learning Scale*. The main effect was significant ($F(2,112) = 128.50$, $p < .001$), indicating that there was a significant difference among the groups being compared. In this notation, '*F*' refers to the ratio of variance between groups to variance within groups. At the same time, the numbers in parentheses represent degrees of freedom for the numerator (2)

	Items	Mean	SD
Enjoyment of Learning Scale (*Asano, 2006*)	**Practical Enjoyment α=.85***	**2.43**	**(.76)**
	I enjoy learning because it relates to my work, activities and life	2.32	(.86)
	I enjoy it because what I learn is useful in my work and life	2.40	(.81)
	I enjoy learning because I can use what I have learned in real life	2.59	(.93)
	Enjoyment of Broad Thinking α=.86	**3.32**	**(.60)**
	I am happy that my learning enables me to think in a variety of ways	3.26	(.75)
	I am happy that learning enables me to have a broader perspective	3.33	(.65)
	I enjoy learning about different ways of thinking	3.38	(.64)
	Enjoyment of Knowing α=.88	**3.50**	**(.55)**
	I enjoy increasing my knowledge	3.53	(.63)
	I enjoy knowing even one thing	3.45	(.65)
	I am happy when I gain new knowledge	3.51	(.58)
Learning Motivation Scale (*Murahashi & Morita, 2015*) α=.85	I want to learn proactively	3.33	(.71)
	I want to enjoy study itself	3.34	(.65)
	I want to expand my perspectives	3.40	(.62)
	I want to utilise learning in daily life	2.84	(.87)
	I want to connect with others	2.62	(.79)
	I want to think about the meaning of life	2.89	(.86)

* The reliability coefficient α is an index used to assess the consistency of items within a scale. Generally, higher α values indicate that items within the scale are related, suggesting higher reliability of the measurement method. When α exceeds 0.70, the consistency is considered sufficiently high, and it is deemed acceptable to create a composite variable.

Table 2: *Means and standard deviations for each of the two scales regarding the reasons for learning (N = 73)*

and denominator (112), respectively. Then, multiple comparisons using the Bonferroni method showed differences between all sub-scales. The Bonferroni method is a statistical technique used to adjust significance levels when performing various comparisons, ensuring that the overall risk of falsely identifying differences is controlled. Specifically, 'Enjoyment of Knowing' had the highest score, followed by 'Enjoyment of Broad Variety of Thinking'.

In contrast, 'Practical Enjoyment' had the lowest score. On the *Motivation to Learn Scale*, relatively high scores were found for items such as 'I want to proactively enjoy what I choose to do', 'I want to enjoy studying itself' and 'I want to broaden my perspective through learning'. Conversely, scores were relatively low for items such as 'I want to connect with others through learning' and 'I want to utilise learning in daily life'.

For the older adults surveyed in this study, which included many participants in astronomical courses, the results suggest that the enjoyment of learning was more important for choosing the learning content compared to applying the learning content to their daily lives. However, the enjoyment of learning score was also comparatively high among the psychology course participants.

We then looked at the mean values for each item concerning the (2) preferred learning subjects. Table 3 presents the average of the responses based on their interest in learning about the 20 subjects. Compared with the average, 'Natural Science' and 'Astronomy' had the highest values, followed by 'Current Topics' and 'History and Culture'. The same applies when comparing the number of respondents who answered 'definitely want to learn' or 'rather want to learn' as an option.

This result seems unsurprising since the population mainly consists of participants attending courses in 'Astronomy'. Yet, when the population was restricted to psychology courses and general education courses for comparison, the highest-rated items were 'Philosophy, Religion' (3.26; SD.64), 'Current Topics' (3.22; SD.74), 'Natural Science' (3.22; SD.83)' and 'History, Culture' (3.11; SD.74)'. Even when the participants in the astronomy and science courses were excluded, there was evidence of high learning needs in 'Natural Science'. 'Astronomy' (2.85; SD.80) also received more interest than the average for all items (2.81). This indicates that learning about natural science is a certain need among older adults in general, especially those with diverse interests (*Karino & Agata, 2009; Karino & Otabe, 2022*). It should be noted that these results were obtained in Japan, and there is no guarantee that they will be the same in other developed countries. A comparison between Japan and Canada in a previous study reported some differences (probably based on the difference in their learning circumstances) between the two countries (*Hori & Cusack, 2006*).

Learning Subject	Mean	(SD)
11_Natural Science	3.40	(.74)
12_Astronomy	3.26	(.76)
6_Current Topics (Economy, Politics)	3.16	(.74)
8_History and Culture of the Community	3.16	(.68)
7_Computers	3.11	(.82)
9_Hobbies	3.11	(.77)
20_Philosophy, Ideology, Religion	2.92	(.89)
10_Literature, Classics, Book Discussion	2.92	(.75)
13_Gardening, Pottery	2.88	(.96)
14_Arts, Painting	2.86	(.87)
3_Physical Fitness	2.84	(.72)
5_Practical Information about Ageing	2.77	(.82)
1_Volunteer Activities	2.67	(.68)
2_Activities Involving Communication with Other Seniors	2.56	(.72)
4_Day Trip	2.56	(.81)
15_Traditional Crafts	2.48	(.99)
18_Activities with Old Movies and TV programmes	2.42	(.77)
16_Activities Involving Communication with Students	2.40	(.87)
19_Life Review	2.36	(.87)
17_Activities Involving Communication with Children	2.31	(.83)

Table 3: *Preferred learning subjects (N=73)*

Analysis of the learning needs of older adults with a preference for astronomy

The results above were used to explore what motivates older adults to prefer learning astronomy and natural science. To compare with other typical subjects of lifelong learning, the preferred subjects in question (2) (i.e. motivation for learning) were first merged into six groups, based on the responses. A cluster analysis using the Ward method was then conducted for grouping, which are shown in Figure 3 and Table 4.

The items 'Astronomy' and 'Natural Science' were formed as an independent group

(Cluster F). The characteristics of each group from the correspondence analysis are also presented in Table 4. According to the two-dimensional plot of the learning subjects, Cluster F is located in a different area from the other groups, which is highly academic and distant from everyday life (*Karino & Otabe, 2022*). To investigate what motivated older adult participants who indicated a preference for Cluster F, which includes 'Natural Science' and 'Astronomy', we took the average scores of the answers in question (2) for each cluster. We performed a correlation analysis with the answers in question (1) (i.e. Preferred learning subjects).

Among the learning motivations, we examined the correlation between the *Enjoyment of Learning Scale* and each group. The results are shown in Table 5 and Figure 4. Focusing on the correlation between the *Enjoyment of Learning Scale* and Cluster F, including 'Astronomy', the correlation with 'Practical' was low. In contrast, the correlation with 'Thinking' and 'Knowing' was slightly higher. However, there were no significant differences compared to the other clusters. In terms of traditional subjects of lifelong learning (i.e. Cluster B, including 'Hobbies', 'Gardening, Pottery', 'Arts, Painting', 'Traditional Crafts', etc.), those who preferred Cluster B showed an overall high correlation with all of the enjoyment scales, especially in the enjoyment of having a broader perspective. The group that preferred Cluster C (i.e. activities related to socialising with other older adults and activities related to their lives) also had higher overall scores across all enjoyment scales. Moreover, the group that chose Cluster A (e.g. interactions with the younger generation and volunteering) had a high correlation with 'Practical Enjoyment'. In contrast, the other items were low, showing an opposite trend to Cluster F (which includes 'Astronomy').

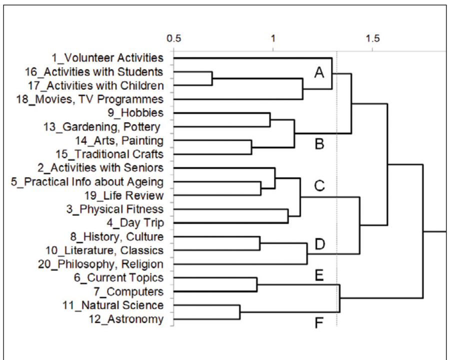

Figure 3: *Results of the cluster analysis as a tree diagram.*

Cluster	Learning subjects included		Learning oriented	Daily-life oriented
A	1_Volunteer Activities	16_Activities with Students	Low	Low
	17_ Activities with Children	18_Movies and TV programmes		
B	9_Hobbies	13_Gardening, Pottery	Low	Middle
	14_Arts, Painting	15_Traditional Crafts		
C	2_Activities with Other Seniors	3_Physical Fitness	Middle	High
	4_Day Trip	5_Practical Info about Ageing		
	19_Life Review			
D	8_History and Culture	10_Literature, Classics	Middle	Middle
	20_Philosophy, Religion			
E	6_Current Topics	7_Computeres	High	Middle
F	11_Natural Science	12_Astronomy	High	Low

Table 4: *Results of the cluster analysis*

		Groups of Learning Subjects					
Enjoyment of Learning		A	B	C	D	E	F
Practical	It relates to my work, activities and life	0.404	0.378	0.291	0.345	0.192	0.246
	What I learn is useful in my work and life	0.429	0.349	0.272	0.257	0.160	0.149
	I can use what I have learned in real life situations	0.397	0.455	0.429	0.338	0.271	0.184
Thinking	Learning enables me to think in a variety of ways	0.301	0.420	0.420	0.370	0.304	0.361
	Learning enables me to have a broader perspective	0.328	0.548	0.424	0.346	0.268	0.365
	I enjoy learning about different ways of thinking	0.221	0.257	0.355	0.222	0.239	0.360
Knowing	I enjoy increasing my knowledge	0.325	0.358	0.452	0.358	0.387	0.363
	I enjoy knowing even one thing	0.314	0.391	0.498	0.311	0.445	0.414
	I am happy when I gain new knowledge	0.218	0.224	0.360	0.385	0.255	0.362

Table 5. *The correlation coefficients between the subject groups and the Enjoyment of Learning Scale*

The horizontal axis represents the "distance" between subjects. The closer the subjects are to each other, the more they are connected on the left side. In this study, the

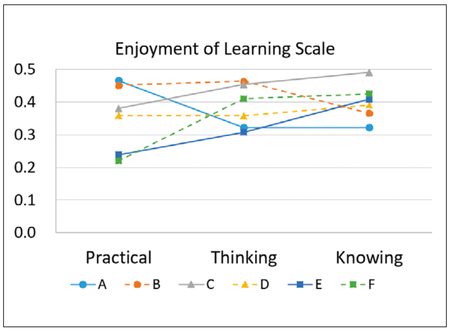

Figure 4: *The correlation between the subject groups and the Enjoyment of Learning Scale. The graph shows which motivations are more closely associated with the preference of learners among the six study subject groups.*

subjects are divided into six groups according to their similarities.

Conversely, the results showing the correlation between the *Motivation to Learn Scale* and each subject group are shown in Figure 5 and Table 6. Cluster F (which includes 'Astronomy') appears to behave peculiarly in these results. Specifically, Cluster F had the highest correlation with 'I want to enjoy study itself' and 'I want to expand my perspectives through learning'. In contrast, it had the lowest values for 'I want to utilise learning in daily life', 'I want to connect with others' and 'I want to think about the meaning of life'. When the other subject groups were considered, the correlation with 'I want to learn proactively' was low across all clusters. This suggests that for older adults, whether proactive or reactive, learning activities are not related to their chosen learning subject.

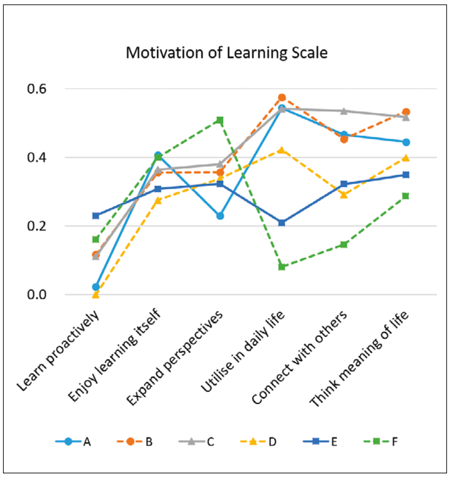

Figure 5: *The correlation between the subject groups and the Motivation to Learn Scale. The representation is the same as in Figure 4. Group F, which includes astronomy, is more motivated to expand their perspectives than the other groups.*

Even in the case of a relatively new survey conducted in Europe in the 2000s, most participants cited the 'desire to learn', 'maintaining an active spirit' and 'broadening perspectives' as their motivations for participating in learning activities. However, social reasons appeared to be less common. Furthermore, nearly half of the respondents answered that participation in learning was 'enjoyable', with many citing various motivations such as meeting new people and making friends (*Withnall, 2009*). The aforementioned survey suggests the existence of a 'third stage' of life consisting of retired but still active individuals with various learning needs (*Hori & Cusack, 2006*). The results of the present survey confirm these findings.

	Groups of Learning Subjects					
Motivation of learning	**A**	**B**	**C**	**D**	**E**	**F**
Learn proactively	0.024	0.117	0.112	0.000	0.231	0.161
Enjoy learning itself	0.407	0.356	0.364	0.275	0.308	0.400
Expand perspectives	0.230	0.356	0.381	0.338	0.323	0.509
Utilise in daily life	0.543	0.576	0.542	0.422	0.210	0.081
Connect with others	0.466	0.453	0.535	0.291	0.322	0.146
Think meaning of life	0.445	0.534	0.517	0.399	0.349	0.287

Table 6. *The correlation coefficients between the subject groups and the Motivation to Learn Scale*

Discussion

Learning needs of older adults

The results of the previous section show that older adult learners who prefer astronomy as a learning subject have the following tendencies:

1. They are not looking for practical benefits due to their learning.
2. The purpose of learning is not to make new friends or to reflect on their past lives.
3. They enjoy learning and want to broaden their perspectives through learning.

These findings indicate that the reason why older adult learners want to learn astronomy is not to recover from physical and/or mental decline, as pointed out in older adult learning theories (*McClusky, 1971*). Nor do they seem to be learning based on the need for connection or a life review, both of which were pointed out in previous studies (*Merriam, 1990; Moody, 1990*). Instead, when older adults study astronomy and natural science, they purely enjoy learning and the pleasure it gives them in gaining a broader perspective. The fact that they are not looking for practicality also indicates that older adults who prefer astronomy choose their study subjects based on their *expressive needs* (*Londoner, 1990; Kim & Merriam, 2004*). According to *Londoner (1990)*, *expressive needs* are found among older adults whose environment does not require *instrumental needs*, which aim to fulfil the needs of everyday life. Additionally, this suggests that a segment of the population that does not require *instrumental needs* to readjust their margins (i.e. healthy and fulfilled older adults) tends to choose astronomy as the favoured option.

On the other hand, as seen in Figure 5, the characteristics regarding the preference for astronomy and natural science among older adult learners are distinct from traditional lifelong learning topics such as history and gardening. However, previous studies of learning theories for older adults have not considered the potential for this demographic to learn about natural science. This may be why these studies have failed to capture the need to derive enjoyment from learning and broaden their perspectives. In related research on educational programmes for older adults at universities, the top motivations for participation were 'gaining knowledge', 'enjoyment of learning' and 'broadening perspectives' (*Kim & Merriam, 2004*), which are similar to those of the participants who preferred astronomy in the present study. The fact that the latter group does not fit into the traditional learning needs of older adults (e.g. margin-filling, connection-seeking, life review, *instrumental needs*, etc.) suggests that older adults who prefer natural science (including astronomy) may differ from the unique psychological situation of older adults that was perceived more than half a century earlier. Since that time, the healthy lifespan of older adults has considerably increased, while the thinking of older adults in retirement has significantly changed. Hence, it is not surprising that the needs of older adults back then would significantly differ from those of older adults today.

It is also possible that today's older adults may have increased their learning needs (including the need to recover margins and the need for connection and transcendence) as they age. To clarify this point, a broader survey is required to further examine the generational differences among this demographic.

As mentioned earlier, the learning needs of older adults are increasing as their healthy lifespans increase. In developing countries, where the older adult population is currently small, the importance of education for older adults will increase with future development. Providing educational opportunities for older adults is effective from a social welfare standpoint, e.g. protecting their health and preventing their isolation, and an educational standpoint, e.g. responding to their motivation to learn and improve their quality of life. An increased healthy lifespan will also mean more opportunities to support learning from the latter standpoint. Meanwhile, the astronomy education community should be able to make specific contributions as older adults have the motivation to learn about natural science.

Educational strategies for older adults

The University of the 3rd Age (U3A), founded in the 1960s, is said to be the pioneer of learning opportunities for older adults in Europe. This was due to the growing recognition of the importance of providing learning opportunities for older adults in the third stage of life, which is the period of self-realisation and self-fulfilment (*Hori, 2001; Withnall, 2009; Jarvis, 2010*). When the U3A started in France as a summer school for retirees, it mainly utilised existing facilities, teaching staff and other resources of various universities. However, when the U3A movement spread to the United Kingdom, it began to employ local resources and have the participants run the activities themselves. In some cases, the learners became the teachers (*Withnall, 2009*).

The advantage of the French-type U3A is that the quality of education was kept above a certain level. On the other hand, the UK-type U3A had the advantage of encouraging the development of social skills among older adults. Additionally, the participants formed self-help groups where the members could learn social skills and health literacy from one another in the face of the common and inevitable challenge of *ageing*. The strong point of the latter type was that the participants could construct such communities of practice (*Lave & Wenger, 1991; Withnall, 2009*).

Now, let us consider the position of astronomy education in lifelong learning. Astronomy is a complex discipline that requires basic knowledge of mathematics and physics. It is also a field in which knowledge is rapidly updated due to ongoing developments in observations and simulations. In this regard, the UK-type approach includes some limitations compared to the French-type education of lifelong learning with the help of experts in the field. To provide satisfactory educational programmes based on the latter approach, it is helpful to have a common understanding on the side of the organisers/professionals as to what motivates older adult learners and what their needs are for astronomy courses.

In addition, astronomy is a field that is generally popular and is used as an important theme of STEAM (science, technology, engineering, the arts and math) learning due to its aspect as a multidisciplinary study that includes the ability to examine celestial objects, space and the physical universe (*Karino & Agata, 2009; Pompea & Russo, 2020*). It is also a field with a broad base in research methods, with multi-messenger observations of various electromagnetic waves, cosmic rays and gravitational waves, as well as simulations and theoretical studies. In the present study, we have shown a demand for astronomy among older adult learners and that their learning needs are rooted in different areas than the traditionally considered needs of lifelong learning. In this context, it is necessary to consider what topics older adults are interested in, their needs, and what learning benefits can be achieved. Especially in developed countries, the older adult population will further increase, and the number of older adults who are potentially interested in learning astronomy will also increase. Reaching out to them will be an important topic for astronomy outreach.

Conversely, teaching methods must be considered in astronomy education for older adults, since there is no evidence that the educational methods used in classrooms and/or lifelong education are also effective in lifelong learning. School education, which aims to foster competencies for future life, and adult education, which intends to improve competencies for members of society, differ from lifelong learning regarding their goals and teaching materials (*Hori, 2001; Jarvis, 2010*).

In astronomy education, especially for students, the aim is to understand the natural environment in daily life (e.g. diurnal motion and seasonal changes), strengthen spatial awareness and understand nature (e.g. the origin of matter and the structure of the universe). For these purposes, planetarium projections, star parties, the use of remote telescopes and STEAM education are all helpful for understanding and deepening students' interests (*Impey & Buxner 2020*).

On the other hand, the primary goals of learning astronomy for older adult learners include satisfying their intellectual curiosity and enjoying learning. Some older adults may have commonsense knowledge of diurnal motion, seasonal changes, and so on. In addition, there is no content requirement in school education for the learning of older adults. Thus, significant changes in education strategies are necessary to satisfy their learning needs. It should also be noted that older adult learners may experience limitations such as reduced eyesight, decreased physical fitness and short-term memory (*Kim & Merriam, 2004*). Under such conditions, it is important to consider whether planetarium projections and nighttime stargazing events are as effective as those for younger generations. In this regard, it is necessary to take into account different safety considerations and hold discussions about these points to make astronomy more inclusive for older adult learners (*Ortiz-Gil et al., 2011; Impey & Buxner, 2020; Voelker et al., 2022*).

Finally, older adults have the advantage that their experience and knowledge can be used as educational materials (*Hori, 2001*). For example, many older adults have viewed starry skies, meteor showers and bright comets in their youth. Such real-life experiences are a strong point and should be considered when exploring different teaching methods and strategies. Moreover, although the short-term intellectual capacity of older adults is typically in decline, compared to younger students, their ability to evaluate and make sense of certain aspects is thought to be more effective (*Jarvis, 2010*). Therefore, developing astronomy education materials for older adult learners that incorporate these strong points would be interesting.

Conclusion

In recent years, there has been a significant increase in healthy lifespans, mainly in developed countries. In this situation, learning plays an important role in improving the quality of life of older adults. Meanwhile, from the perspective of social welfare, providing learning opportunities for older adults can be effective in maintaining their health and preventing their isolation during retirement. In this regard, this study examined the learning needs of older adults to provide effective informal educational opportunities for this demographic.

Although there have been several studies on the learning needs of older adults, such research may not match older adults today. Specifically, such learning needs were based on the idea that older adults prefer to learn traditional subjects such as history, literature, healthcare, and gardening. Consequently, previous research on older adult learning did not consider science-related subjects like astronomy. However, astronomy, in particular, has drawn a certain level of interest among older adult learners. Hence, we also investigated the fundamental needs of older adult learners when choosing to study astronomy.

In the present study, a questionnaire survey was conducted to investigate the learning preferences of older adults. The results showed that the motivation to learn astronomy was not based on the traditional needs of lifelong learning. Instead, they chose astronomy to find enjoyment in learning. Meanwhile, they wanted to broaden their perspectives through learning. These findings indicate that such tendencies of older adult learners clearly align with *expressive needs* instead of *instrumental ones*.

In the future, providers of lifelong learning should specifically consider the needs of older adult learners and provide appropriate learning subjects. At the same time, in support of astronomy and other science-related subjects, it is necessary to consider educational methods that are safe, effective and satisfying based on their life experiences as well as their possible physical and mental decline. This study also intends to propose the participation of the astronomy education community in the field of lifelong learning, which is in line with the current situation. Doing so will not only be effective for the current population but also an investment in our future selves (*Withnall, 2009*).

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Biography

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Expanding access: The effectiveness of online science events in attracting a wider audience

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Keywords
COVID-19, Lecture, Public Outreach, Survey, Online Activities, Online Engagement

Amid the COVID-19 pandemic, researchers and science communicators experienced a rapid and unprecedented transformation from in-person to online science communication activities. One of the advantages of online activities is now considered to be the ability to include a broader range of people in scientific activities, including women and ethnic minorities. In this report, we quantify the impact of the in-person or online communication mode on the registrants' and attendees' demographics and discuss the potential of engaging a broader range of people at online science events. Hosting online public lectures and analysing survey results for the registrations and attendees, we find the age distribution of the attendees showcases a much higher fraction of teens and younger participants compared with an in-person case. The result also demonstrates that the fraction of female participants was higher in the online lectures. Our survey results suggest that an online public lecture allows us to reach more young people in their teens and twenties, as well as those underrepresented in STEM, such as women. We also found that providing the online recorded video was essential to sharing scientific stories with a broader audience.

Introduction

In 2020, the COVID-19 pandemic and the subsequent infection prevention and control actions forced the suspension of in-person public programmes in Japan. The pandemic caused a dramatic shift to introduce online events to keep engaging with the public. During the pandemic, the number of people using online meeting applications suddenly increased (e.g., *Ministry of Internal Affairs of Japan, 2021*). Additionally, environmental concerns associated with in-person conferences, which are travel-intensive, became more pronounced. Researchers flying to attend conferences contribute significantly to greenhouse gas emissions (see, e.g., *Moss et al., 2021,* and references therein). Online events have demonstrated the potential to reduce access barriers and shrink carbon footprints (see e.g., *The Editorial Board, 2022*, and references therein). Inevitably, studies were conducted on attempts at online scientific communication and education (e.g., *Christoph et al., 2021; Dew et al., 2021; Penteado et al., 2021; Roche et al., 2021; Radin & Light, 2022*). Previous studies reported some areas where virtual interaction is considered inferior to face-to-face interaction. These areas include suppressing creative idea generation (e.g., *Brucks & Levav, 2021*) and reduced networking opportunities (e.g., *Moss et al., 2021; Skiles et al., 2021*). On the other hand, many successful cases of online scientific activities have also been reported (e.g., *Massey, 2021*). It is often mentioned that online scientific activities allow the inclusion of those who did not join in in-person activities (e.g., *Sarabipour et al., 2021; van der Wal, 2022; Köhler et al., 2022; Wu et al., 2022*). However, previous studies did not provide sufficient quantitative analysis.

In this study, we report survey results for registrations and attendees of online public lectures, hereafter "webinars". By comparing these webinars to an in-person lecture, we found that online public lectures may improve inclusion for women and young people in their teens and twenties. We also found that online outreach activities provide convenient opportunities for people in regions of Japan where science events are less frequent and accessible.

Unless otherwise stated, the level of statistical significance is defined as a p-value of less than 0.05 in this report.

Outline of the webinars

Table 1 summarises the content covered in and attendance of webinars hosted in 2021 and 2022. All speakers were professional astrophysicists working at universities or research institutes in Japan. Each webinar was held in Zoom and consisted of two talks: a 20-minute presentation and a 15-minute Q&A session conducted in Japanese. The webinars were advertised only online via X (formerly Twitter), websites and mailing lists.

In 2021, we prepared two registration methods: a web form and a Zoom form. The link to the web form was posted on the websites about one month before the webinar, and the applicants were provided with a link to connect about one week before each webinar. The other was an application directly through Zoom that was available about one week before the first webinar on the websites. In this case, the applicant received the connection link immediately after registration.

At the beginning of each webinar, a facilitator encouraged the attendees to submit their comments and questions during speakers' presentations and the Q&A sessions in Zoom's chat function. As a result, we received more than 70 questions during each webinar. More than 90% of them were sent as text messages using the Q&A function of the Zoom webinar. Asking questions and sharing comments by text

Date and start time	Theme	Number of accesses	View count on YouTube
Sunday, 7th Nov. 2021 14:00	Black holes	169	870 K
Sunday, 14th Nov. 2021 14:00	Supernovae	217	160 K
Sunday, 21st Nov. 2021 14:00	Galaxy Clusters	167	34 K
Saturday, 26th Nov. 2022 19:00	Black holes (Introduction and theoretical perspective)	128	3.7 K
Saturday, 3rd Dec. 2022 19:00	Black holes (Supermassive black holes)	112	7.1 K
Saturday, 17th Dec. 2022 19:00	Black holes (End of massive stars)	140	–

Table 1: *Outline of the webinars. Column 1 indicates the date and start time of the webinars. Column 2 presents the webinar topic. Column 3 shows the net number of accesses, excluding duplicates. Note that this number represents connections rather than individual attendees, as a single connection can encompass multiple attendees. Column 4 showcases the number of views for recordings uploaded to YouTube as of 20 May 2024. Notably, the webinar recording held on 17 November 2022, has yet to be posted due to technical issues.*

enabled participants to communicate with the speakers and each other. Other presenters or organisers responded to questions posted in the chat during the presentations, ensuring that as many inquiries were addressed as possible.

We conducted surveys before and after each webinar (hereafter referred to as the pre-survey and post-survey, respectively). The questions aimed to improve subsequent webinars and future outreach events. Respondents were informed before the pre-survey and post-survey about the aims of the surveys and that the data might eventually be published. The authors ensured the data were collected anonymously and individuals could not be identified.

All individuals who wished to attend the webinars were required to complete the pre-surveys. We collected email addresses, which were used to send the connection links for the webinars, making the provision of an email address mandatory. The persons wishing to register for the webinars could select “would rather not answer” for other questions if they did not wish to respond. The pre-surveys included demographic questions such as age, gender, and residential location. For gender, we offered four options: “female”, “male”, “other”, and “would rather not say”. A Zoom webinar administrator can access attendee reports that provide data on whether registrants attended or not. Since the pre-survey response data is linked to the attendee report data via the registrants’ emails, we used compiled data files that included both the attendee reports and the pre-survey data.

Because online events enable multiple people to participate under a single login, the net number of accesses listed in Table 1 represents a minimum number of attendees. For this reason, we asked those who filled out the survey to provide the primary audience demographic information.

Participation in the post-surveys was entirely voluntary. The post-surveys were conducted using the Zoom function, where a post-survey form automatically appeared in the participant’s web browser either at the end of the webinar or when the participant left. The facilitator asked the attendees to share their opinions through the post-survey. Additionally, the webinar organiser sent attendees a link to the post-survey form after each webinar. Although the post-survey form remained open for at least one week, over 92% of respondents completed and submitted it within one hour of each webinar.

Results of the 2021 webinars

Figure 1 shows the age distribution of the registrants and attendees. Some registrants and attendees indicated they were younger than nine years old; in these cases, we assume their parents or guardians answered the pre-survey questions. About 4% of the registrants did not provide answers about their age or gender, so these data are excluded from analyses that include age and gender variables.

Figure 2 displays the attendance rate of each age group separated by gender, while Figure 3 compares the attendance rate separated by the registration method. From Figure 2, the attendance rates of the older generation are higher than those of the younger. Figure 3 shows a much higher attendance rate of the applicants through the Zoom form.

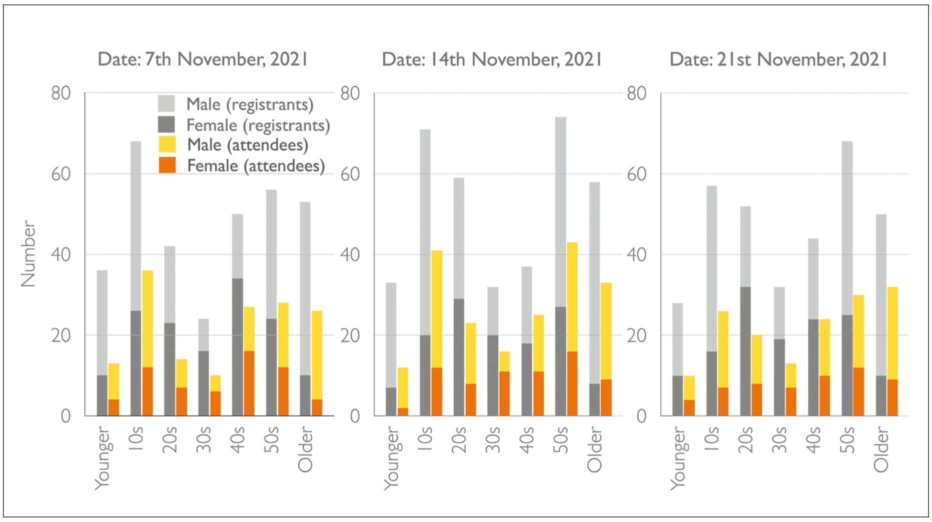

Figure 1: *Age and gender distributions of registrants (deep grey and light grey bars) and attendees (orange and yellow bars) at the webinars in 2021.*

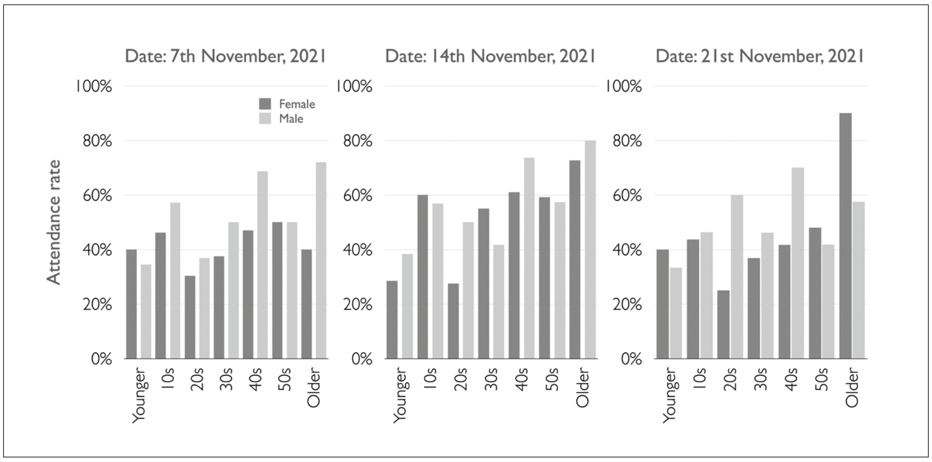

Figure 2: *Attendance rates of each age and gender group at the webinars in 2021.*

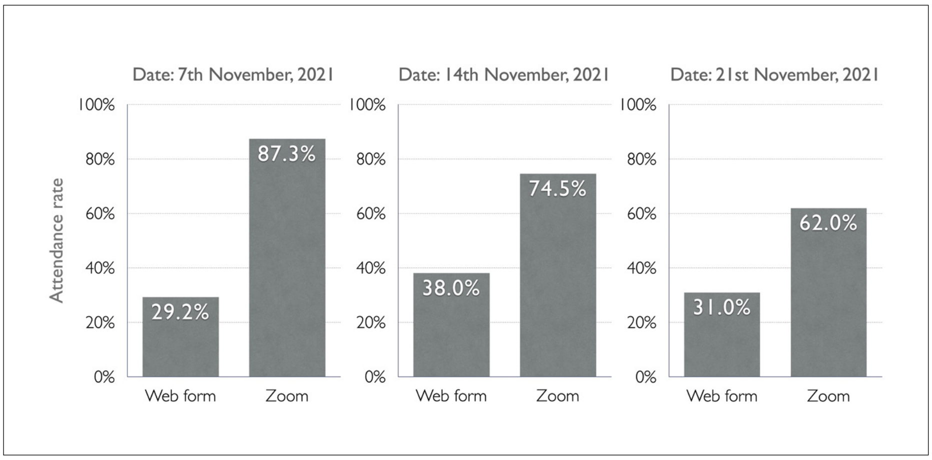

Figure 3: *Comparison of the attendance rates for different registration methods.*

We conducted a logistic regression analysis to understand how age group, gender, location, and registration method affect the attendance rate. In this analysis, the attendance rate was the target variable, and the predictor variables were age group, gender, location of residence, and registration method. The results indicated that the most important predictor variable was the registration method, with an odds ratio of 0.14 for registrations through the web form compared to the Zoom form. Notably, after the first webinar, we checked the attendance rate and subsequently sent reminders to all registrants for the succeeding webinars.

Figure 4 and Figure 5 show the post-survey results, respectively, the preference for the length of each presentation and the Q&A session. The post-survey response rate was about 60%. There was no significant difference in the response rates among the webinars. Although the 20-minute presentation during our webinars was shorter than the standard in-person presentation for the general public (at the National Astronomical Observatory of Japan or Japan Aerospace Exploration Agency, this is usually 30 to 50 minutes), more than 80% of participants answered that they liked the length. Conversely, the 15-minute Q&A session was relatively longer than those typically conducted during in-person public lectures aimed at the general public (excluding lectures specifically targeted at children) organised by our institutes. As shown in Figure 5, over 85% of the respondents indicated that the 15-minute Q&A session was appropriate length.

In the post-survey, we asked the attendees to rate each presentation on a 10-point scale according to clarity (1=least clear; 10=most clear). The distributions of the ratings were skewed towards higher values, and the level of the presentations was appropriate, as shown in Figure 6. Fewer respondents rated the webinars a 9 compared to those who rated them an 8 or 10. A similar pattern is observed in the post-surveys from 2022, as shown in Figure 11. This trend will be discussed in more detail in a subsequent sub-section. The medians for all three webinars were 8. However, the mean scores were approximately 7 for the first webinar and approximately 8 for the second and third webinars. The standard deviations of these scores were 2.44, 2.06, and 1.85, respectively. This variation in mean scores suggests that the first webinar was rated lower than the others. To determine if this variation was statistically significant, we conducted a one-way ANOVA (analysis of variance). We assumed the score distributions of the three webinars to be independent due to the variation in

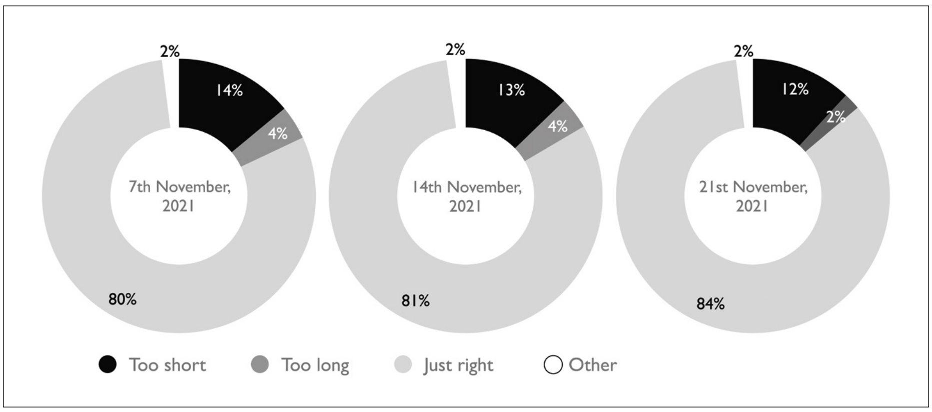

Figure 4: *Presentation length preferences for the webinars in 2021. The data are from questionnaires distributed after each webinar, where black is "Too short," dark grey is "Too long," light grey is "Just right," and white is "Other."*

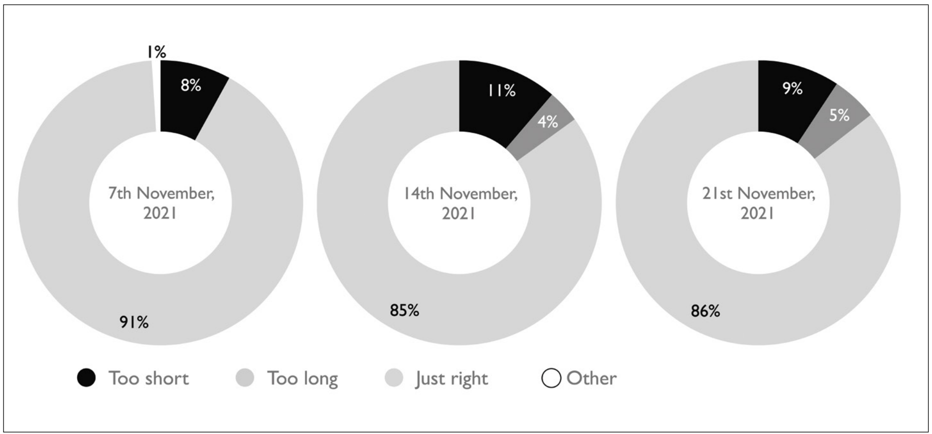

Figure 5: *Q&A session length preferences for the webinars in 2021. The data are from questionnaires distributed after each webinar, where black is "Too short," dark grey is "Too long," light grey is "Just right," and white is "Other."*

presenters across these events. The analysis revealed that the mean score for the first webinar was significantly lower than the mean scores for the other two webinars. Reading the comments from the post-survey of the first webinar, we found some feedback indicating that the presentation was too difficult or specialised. Such negative feedback was not observed for the other webinars. We speculate that the presentations were more specialised than some attendees had expected, resulting in a lower mean score for the first webinar. Interestingly, the first webinar recording garnered the highest number of views on YouTube, as shown in Table 1. This could suggest that YouTube audiences may prefer more specialised content, given the abundance of videos available online for beginners.

Results of the 2022 webinars

Table 1 also summarises the content covered in and attendance of the 2022 webinars. In 2021, we found that the attendance rate of registrations through the web form was much lower than that through the Zoom form. Therefore, we used only the Zoom form for the 2022 webinars. The structure of each webinar was the same as those in 2021, i.e., each webinar consisted of two talks: a 20-minute presentation and a 15-minute Q&A session conducted in Japanese. Because some attendees in 2021 commented that they preferred the weekend evening, and to avoid confusion between dates and starting times of events, we held all webinars on Saturday evenings in 2022 to check if the number of attendees and the attendance rate increased.

Figure 6: *Attendees were asked to rate each webinar based on how easy they were to understand. This plot shows the score distribution for each webinar. A higher score means the webinar was easier to understand.*

Figures 7 and 8 are the same as Figures 1 and 2, respectively, but for the 2022 webinars. About 20% and 3% of registrants and attendees, respectively, did not provide their age and/or gender. We excluded data without age and gender from the following analysis.

The total number of registrants for each webinar and the average attendance rate in 2022 was lower than in 2021 despite the webinars being scheduled on Saturday evenings in response to attendees' feedback. This time slot may not be optimal for attracting a larger audience.

Similar to our analysis of the 2021 data to study attendance rate, we performed a logistic regression using the same variables (excluding the registration method, which was consistent for the 2022 webinars) for the 2022 post-survey data. In contrast to the 2021 findings, we did not identify any predictor variable significantly impacting the attendance rate.

As with 2021, we asked the attendees to answer several questions about each webinar in a post-survey. The response rates were 51%, 67%, and 71% for the first, second, and third webinars, respectively, indicating an increase in post-survey participation from the first to the third webinar. Given that the theme of the 2022 webinars was consistent across all three sessions and considering that some attendees participated in multiple webinars (42 attendees attended all three webinars and 49 attended two of the three webinars), it is possible that those who attended multiple webinars responded to the post-survey only once after the last webinar they attended (either the second or the third webinar). We speculate that this contributed to the observed increase in post-survey response rates.

Figures 9 and 10 display the preference for each presentation and Q&A session lengths, respectively. They show that most attendees were satisfied with a 20-minute talk and 15-minute Q&A, which is consistent with the results from 2021. However, we noticed that the proportion of respondents who answered "Too short" in 2022 doubled compared to 2021. Several factors could explain these results. For instance, attendees of the 2022 webinars may have enjoyed the sessions more than those in 2021 and thus desired longer

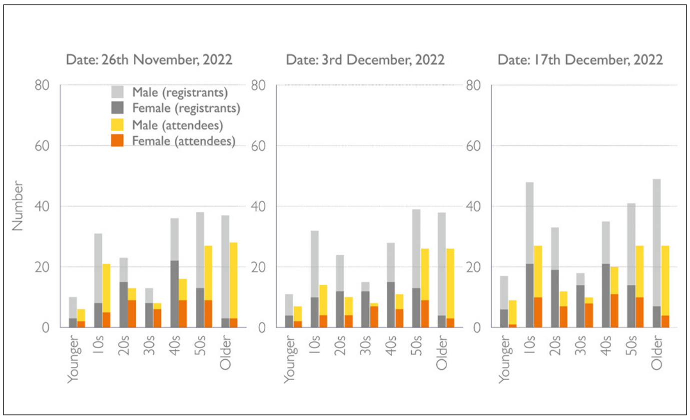

Figure 7: *Same figure as Figure 1, but for the lectures in 2022.*

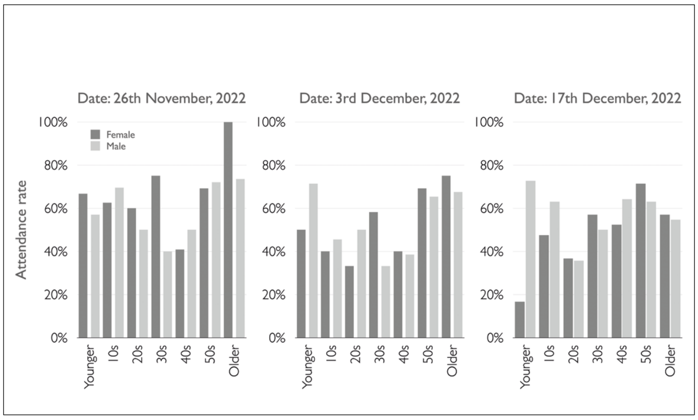

Figure 8: *Same figure as Figure 2, but for the lectures in 2022.*

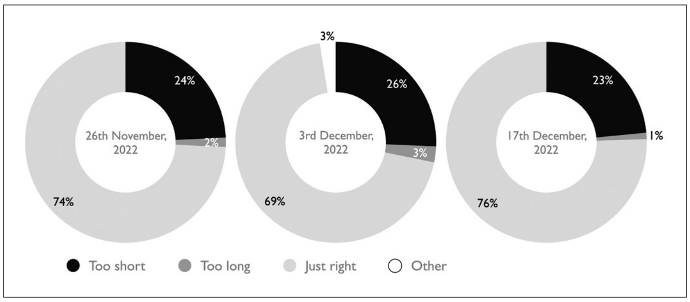

Figure 9: *Same figure as Figure 4, but for the lectures in 2022.*

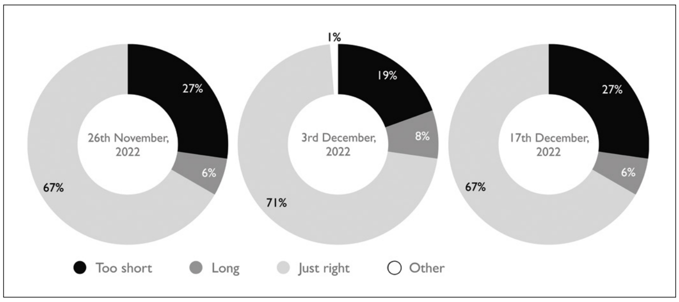

Figure 10: *Same figure as Figure 5, but for the lectures in 2022.*

presentations and Q&A sessions to ask more questions. Another possibility is that attendees might have become more accustomed to online meetings amid the pandemic, leading to a delayed onset of digital fatigue.

Figure 11 is the same as Figure 6, but for 2022. It shows that most attendees evaluated the presentations as easy to understand. The median scores were about 8 for the first and third webinars and about 9 for the second webinars. The standard deviations for the first, second, and third webinars were 1.4, 1.56, and 1.92, respectively. An ANOVA of each webinar's score suggests no significant difference between the three.

Figures 6 and 11 show score distributions with peaks at 8 and 10 and a noticeable dip at 9. Comparable datasets for public science lecture ratings or similar examples like school classes are scarce, as such data are often private. Thus, we can only speculate on the factors causing the distributions in Figures 6 and 11. Previous studies (e.g., *Krosnick & Fabrigar 1997*) suggest several psychological and behavioural factors. The respondents might avoid middle values like 9, seeing them as ambiguous, and prefer the explicit endorsement of a 10 or the cautious rating of an 8. Attendees might see 10 as perfect, 8 as very good, and find 9 lacking a distinct category or sentiment.

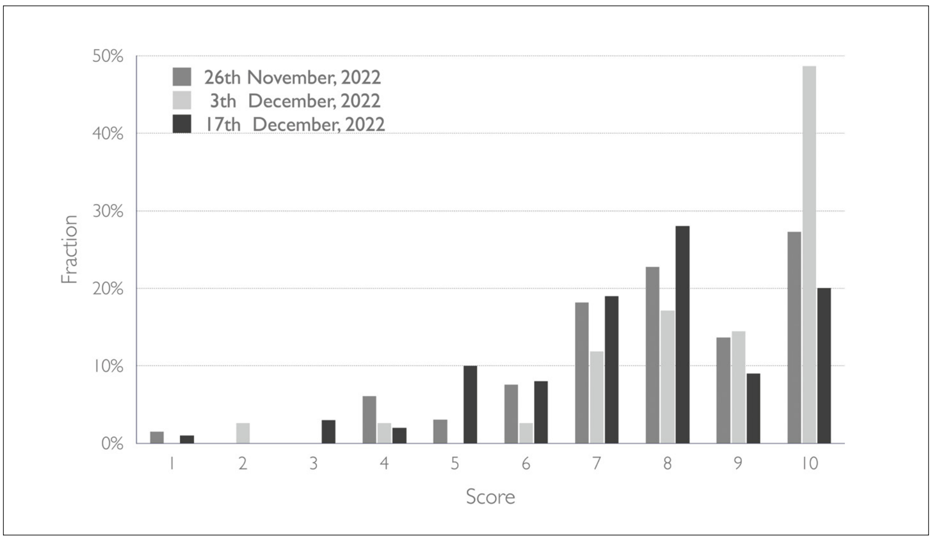

Figure 11: *Same figure as Figure 6, but for the lectures in 2022.*

Comparison with an in-person public lecture

Figure 12 compares the age and gender distributions of in-person and online public lectures. The presenter provided the demographic data for the in-person lecture. The number of respondents to the in-person lecture survey was 237. This survey was conducted independently from our webinars, and as such, there was some – but not total – overlap between this survey and the post-survey used for the online study presented here. The common questions included age and gender. The survey also asked respondents about the appropriateness of the lecture length using a five-point scale, unlike our post-survey, which used a three-point scale.

As shown in Figure 12, the prominent difference between the webinars and the in-person lecture is the fraction of males older than 50, who occupied more than 50% of the attendees of the in-person lecture. Our results demonstrate that having events online provides one solution to reach young people and women.

We would like to highlight the attendees' preference regarding the length of the in-person lecture. The structure of this lecture included three 50-minute presentations followed by a 30-minute Q&A session, resulting in a total event duration of nearly three-and-a-half-hours. The survey conducted among the in-person lecture attendees asked them to rate their perception of the lecture length on a five-point scale (very short, somewhat short, just right, somewhat long, very long). Over 76% of respondents indicated that the length was "just right." The length is

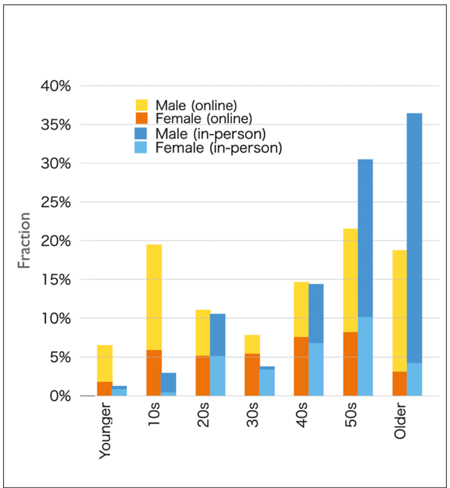

Figure 12: *Comparison of the age and gender distributions between the in-person (light blue and blue bars) public lecture and the average data over all webinars in 2021 and 2022 (yellow and orange bars). The in-person public lecture was held on 2 February 2020, with 237 respondents. The lecturer provided the data from the in-person lecture.*

significantly longer than the preferences indicated by the webinar attendees, suggesting that online attendees may have different preferences in presentation length compared to in-person attendees.

Discussion and future directions

In this article, we have demonstrated that hosting public lectures online is promising for reaching teens and women. Additionally, online outreach activities are more convenient for people in remote regions, allowing them to familiarise themselves with astronomy. In our 2021 and 2022 webinars, we observed nationwide participation. Although over 60% of attendees were from the Greater Tokyo Metropolitan area, the most populated area in Japan, there were also attendees from other parts of the country. This result highlights one of the primary advantages of online events: the ability for people to join from anywhere. Some attendees even sent messages after the webinars, expressing their gratitude for the opportunity to participate despite living in remote areas or far from where such events are typically held. Thus, online delivery of science talks enables broader inclusion.

As noted, attendees asked numerous questions during the webinars, and post-surveys indicated that the majority were satisfied with the length of the Q&A sessions, suggesting they found them enjoyable and informative. Studies on online learning (e.g., *Muzammil et al., 2020*) reported that interaction among attendees (including teachers) and interaction with content positively impact engagement. Therefore, active interaction using text tools and verbal communication may be vital in enhancing engagement and satisfaction among webinar attendees. Further studies are necessary to understand how interaction affects attendees' engagement and satisfaction. Additionally, it is important to explore whether engagement and satisfaction vary based on communication methods, such as text-based tools versus verbal communication.

All six webinars were recorded, and five were posted on YouTube after editing to protect participants' personal information and enhance the presentations with additional images. We found that the archived and posted videos reached at least 25 times more people. Publishing recordings online improves accessibility by allowing people to watch at their convenience, regardless of time or location. This on-demand distribution of science talks can improve inclusion by providing access to those who might be less able or willing to attend in-person events due to costs, caregiving responsibilities, or environmental concerns.

While our results show statistical significance, it is important to note the limitation of our small sample size. Future studies will be necessary to confirm if webinars can appeal to a broader audience. Based on our analysis of the feedback from online webinar attendees, a shorter presentation (e.g., 20 minutes) appears preferable for online lectures. However, this conclusion is drawn from data collected solely from online lectures and does not include a direct comparison with in-person public lectures. Future research should investigate this preference by comparing attendee responses from online and in-person formats.

Additionally, it is worth noting that all respondents in our survey were Japanese. Further research must examine whether these findings hold true in other countries and cultures.

Below are some takeaways for future online public lectures:

- Encourage attendees to ask questions and send comments. Dialogue between scientists and audiences helps to deepen understanding of the topic.
- Publishing recorded videos online can extend the reach of scientific content to an even broader audience.

In this report, we focused solely on lecture-type outreach activities. However, there are various other types of outreach activities, such as stargazing and hands-on workshops. Studies on different outreach activities, both online and in-person, will be essential to determine the optimal mode for each type of activity. Given that people have experienced a shift to online activities amid the COVID-19 pandemic, future research should focus on comparing online and in-person outreach activities to enhance and improve future outreach efforts.

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Biography

Chisato Ikuta is an Institute of Space and Astronautical Science (ISAS) associate professor at Japan Aerospace Exploration Agency (JAXA) and the Graduate University for Advanced Studies. She has more than ten years of experience in public outreach at National research institutes in Japan.

In their project, ASTRO4ALL, the NOC Togo Team travels to villages in underresourced areas to organise sky observations and run experiments. In this image, the Team is in Agbodrafo, a village in South East Togo, inviting everyone to observe the Sun and sunspots while participating in a cultural activity organised by a local association.

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