CAP journal

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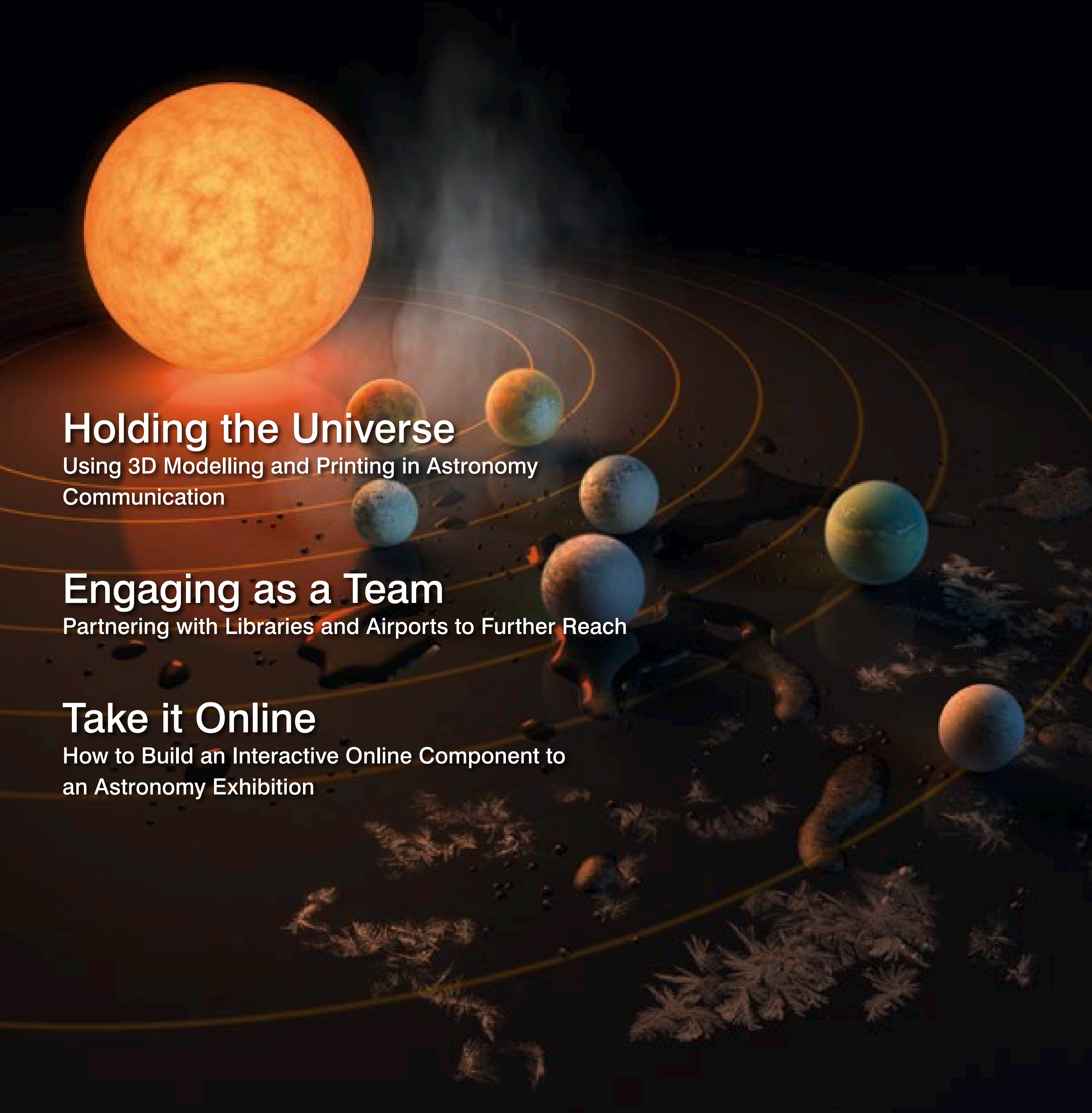
Communicating Astronomy with the Public



Holding the Universe

Using 3D Modelling and Printing in Astronomy Communication

Engaging as a Team

Partnering with Libraries and Airports to Further Reach

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How to Build an Interactive Online Component to an Astronomy Exhibition

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IAU

This artist's impression shows an imagined view from the surface of the planets orbiting the ultracool dwarf star TRAPPIST-1 (or 2MASS J23062928-0502285) which lies 40 light-years from Earth. This image was produced in Spring of 2017 when the first of the planets around the star were discovered by a telescope at ESO's La Silla Observatory. Since, the system has risen to fame with the discovery of seven Earth-size planets, three of which are firmly located in the star's habitable zone. These worlds are the best targets found so far for the search for life outside the Solar System. Credit: ESO/M. Kornmesser

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Cover: Artist's impression of TRAPPIST-1 and its planets. The potential for water on each of the worlds is represented by the frost, water pools, and steam surrounding the scene. The image appears on the 22 February 2017 *Nature* cover. Credit: NASA/R. Hurt/T. Pyle

Editorial

Welcome to the 22nd issue of *CAPjournal*, an issue that marks a decade since the first issue in October 2007. With ten years behind us 2017 is a year of change for the journal as we prepare to hand the publishing reigns from the European Southern Observatory (ESO) to a new home at the International Astronomical Union (IAU). This is a very natural and exciting move for *CAPjournal* as it has always been a key part of the IAU Communicating Astronomy with the Public Commission and now will have the chance to thrive and grow set firmly in the IAU's hands. We are very excited to see the journal develop and grow in its new home. At this time of change for the journal also comes my time for change and I have decided, after a privileged four years of learning so much from you all, to step down as editor-in-chief. Thank you to all of the authors and readers who I have worked with over the years; to the line of editors who came before me to which it is an honour to be part; and, of course, to Executive Editor Lars Lindberg Christensen and the team of designers, distributors, web editors and proof readers at ESO who have diligently worked to produce the journal since it first began — I hope you will join me in thanking and congratulating them all.

In this issue of *CAPjournal* you will find articles exploring the value and challenges of working in venues we do not usually associate with science — our libraries, airplanes and airport lounges. We look at the partnerships that grow behind the scenes when we use new spaces and what these can mean for the reach and diversity of our activities. In other articles, authors take astronomy to the hands of the public with 3D printing and "hands-on" computer visualisations; using modern technological advancements to their absolute fullest. We are proud to have here another issue with projects and authors coming from around the world — whether it be looking at astronomy events in Canada, science communication through television in Iran, or science festivals in the UK. We hope you will find something in every article that can be moulded to your own setting and that you, in turn, will share your learning with us so that we can continue to expand this global community.

Many thanks once again for your interest in *CAPjournal*, and happy reading,

Georgia Bladon
Editor-in-Chief of CAPjournal

Submit articles for one of the following journal sections:

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- Explained in 60 Seconds
- Announcement
- Best Practice
- Research & Applications
- Column
- Review

Explained in 60 seconds: What has the *Cassini* Mission Taught us?

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In 1997, a rocket was launched carrying an orbiter that would change our view of Saturn forever: *Cassini*. This would be the fourth time that we had sent a spacecraft to Saturn, but this time the probe was there to stay.

Cassini has been in orbit around the gas giant Saturn since July 2004, discovering new phenomena and taking awe-inspiring pictures. On its long journey through the Solar System *Cassini* was accompanied by the lander *Huygens*. In January 2005, after travelling 3.5 billion kilometres together, *Huygens* finally forged its own path and parachuted into the thin methane atmosphere of Saturn's moon Titan, drifting towards an unknown fate. As it went, *Huygens* revealed a stunningly familiar world beneath Titan's hazy atmosphere, taking sublime images of rugged landscapes with vast sand dunes, floodplains, river channels and sea beds.

Orbiting Saturn alone *Cassini* also made a swathe of spectacular observations. It unveiled new secrets about Saturn's potentially life-supporting moons, including the discovery of active, icy plumes and a salty subsurface ocean on the moon Enceladus. The spacecraft saw Saturn's ring system change in front of it, revealing a dynamic and active system akin to a small Solar System. It also studied gigantic storms, flashing lightning, colossal winds and unusual hexagonal hurricanes at each of Saturn's poles.

In the concluding phases of its pioneering adventure, *Cassini* made twenty-two final orbits around Saturn, including a series of life-threatening dives through Saturn's upper atmosphere as well as its innermost ring, gleaning information about how giant planets form. As it orbited, *Cassini* collected rich and valuable data about Saturn's gravity, magnetic fields and internal structure, and also about the rings themselves, which may reveal details of their mysterious origin. After completing these tasks, the spacecraft made a final sacrifice as it plunged through Saturn's atmosphere on 15 September 2017. In its last minute of communication, the craft sent back one final batch of images — a final addition to a collection of data that paved the way for the exploration of the Solar System and our quest for the origins of life itself — and then we lost contact with *Cassini* forever.

Figure 1. *In this rare image taken on 19 July 2013,* Cassini's *wide-angle camera captures the Earth and its moon in the same frame. Credit: NASA/JPL-Caltech/Space Science Institute*

Public Libraries as Partners in Astronomy Outreach

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Keywords
Libraries, partnership, public lectures, science communication

Public libraries have proven to be effective partners in bringing astronomy to audiences across the large and diverse city of Toronto, Canada, and enabling astronomers — both young and old — to interact with members of our community. This article reflects on the author's experience working with public libraries, especially the Toronto Public Library (TPL), the busiest public library system in the world, to deliver over forty public presentations.

Introduction

As astronomers at the University of Toronto we come from the Department of Astronomy and Astrophysics, the Dunlap Institute for Astronomy and Astrophysics, the Canadian Institute for Theoretical Astrophysics, and the Centre for Planetary Sciences. Collectively, we organise a large variety of outreach events[1]. These include: monthly public presentations and tours reaching audiences of 150–200; an annual keynote lecture by an eminent visiting astronomer; regular public shows in our small but powerful planetarium; and "Astronomy on Tap" — an informal, interactive programme in local pubs, reaching audiences of 400 or more.

Our graduate students play a major role in planning and delivering our outreach events but even with this support organising public lectures requires time, effort, and money. Rooms and audio-visual equipment need to be arranged and publicity needs to be done. Our lectures usually take place on our campus in the middle of the city, amid academic, hospital, and government buildings. This part of the city is perfectly safe, but can be distant and intimidating for some residents and as a result many of our events attract as their dominant audience middle-aged, middle-class, educated, and predominantly white males. Often, it's the same people who come to every event. We would like to reach out to new audiences, in every corner of the city, especially as engagement with the dynamic, diverse city is one of the three top priorities of our university's current President Meric Gertler, an urban geographer. We are delighted that our astronomers' long-standing commitment to community outreach and interaction is congruent with our university's priorities, which were arrived at after long consultation and discussion.

Partnerships

A successful partnership is a cooperative relationship between two or more individuals or groups which enables the partners to achieve their respective missions or goals more efficiently and effectively. Such partnerships are respectful, productive, mutually beneficial and an excellent tool for astronomy outreach.

Working in partnership was at the core of Toronto's celebration of the International Year of Astronomy 2009 (IYA2009: Hesser et al., 2010) and has played a key role throughout the author's and his team's work in astronomy outreach over the past half century (Percy, 2012). These partnerships enable us to connect with new audiences (Percy, 2009) and enable astronomers to engage the public in new activities without reinventing the wheel. To do something novel, we need only find like-minded partners who have the relevant skills, experience, and contacts to help make it happen. We supply the enthusiastic astronomer; our partners supply the infrastructure.

There is still a place in astronomy outreach for the live public lectures that these partnerships can help us achieve, even in this increasingly online world. People can meet scientists face-to-face, and see science as people, not just textbooks or the media. They can experience the enthusiasm that a real human brings to science, ask questions, and build connections. The astronomers too gain from this; for example the David Dunlap Observatory near Toronto — which at its time of opening in 1935 housed the second-largest telescope in the world — came about as a direct result of a public lecture by astronomy Professor Clarence Chant. Though, of course, that is not why we do public talks.

Toronto and its public library system

Toronto is one of the most ethnically-diverse cities in the world, with over half of its 2.79 million residents born outside Canada. The residents of Toronto speak 140 different languages and dialects. It is a city of dozens of vibrant neighbourhoods, whose boundaries are based on history, geography, and ethnicity. The Toronto Public Library (TPL) has a hundred branches spread across every neighbourhood and community in the city, with a collective 18.5 million visits per year[2].

TPL, like other modern libraries, is more than a repository and lender of books. As well as electronic resources, its branches offer a wide variety of programmes catering to their local neighbourhoods. The programmes include: sessions for readers and writers; workshops on practical topics such as computers, personal finance, small business, health, and career and job-search help; after-school programmes; projects designed for teenagers; reading sessions for children; and sessions tailored to newcomers to the city. Programmes and resources cover general-interest topics in science, culture, history, and hobbies, are provided in 40 languages, are no-cost, and provide free facilities such as computers

Figure 1. *The interior of a Toronto library. Credit: Jackman Chiu via Flickr*

and the Internet which are especially valuable to recent immigrants (of whom Toronto has many) and other disadvantaged groups. Bernardi (2016) discussed the merit of communicating astronomy in "unconventional" locations, such as book and toy shops and although to astronomers libraries may seem to be an unconventional location, they already offer programmes on a wide range of topics besides astronomy. Indeed, if astronomers want to reach new and diverse audiences, they should offer programmes in as many locations — unconventional and otherwise — as possible.

Many of our library presentations attract an audience of retired people and seniors, not necessarily with a science background. These later-life learners provide a growing, receptive, and important audience for astronomy outreach (Percy and Krstovic, 2001). Although we give many courses and lectures for this audience outside the library system, libraries provide an accessible local neighbourhood hub for such people. The presentations provide intellectual and social stimulation, which, along with good diet and exercise, has been shown to delay dementia perhaps better than any medication — so the impact of such sessions is far from superficial (Baumgart et al., 2015, Shurkin, 2015).

Toronto Public Library partnership in the International Year of Astronomy

A primary goal of the International Year of Astronomy 2009 (IYA2009) in Canada (Hesser et al. 2010) was to reach new and diverse audiences, at minimal cost. It therefore made sense to partner with TPL. The libraries provide the venue, the staff, the audio-visual facilities, and the publicity through their website and quarterly *What's On* magazine[3] (Figure 2). Other astronomy groups have reported success in partnering with public libraries, especially if they are well-enough funded to produce engaging displays and resources (Sharma et al., 2013, Summers et al., 2009). In our case, funds and costs were minimal and our presenters, though enthusiastic, were volunteers.

The key initial step for us was to identify the person who coordinates programming across the TPL system, and to develop an effective partnership with them. For most of the time since the IYA2009, that has been Miriam Scribner and it is to her we owe a great debt of gratitude. Initially we provided her with lists of available speakers and topics every few months which she circulated to her colleagues. Later, we set up an online speakers list[4] — as we suggest every astronomy group does — and this was circulated to the programme coordinators at each of the one hundred branches. The list provides pictures, brief biographies, and presentation topics for each speaker. The partnership coordinator, in our case Public Outreach Coordinator for

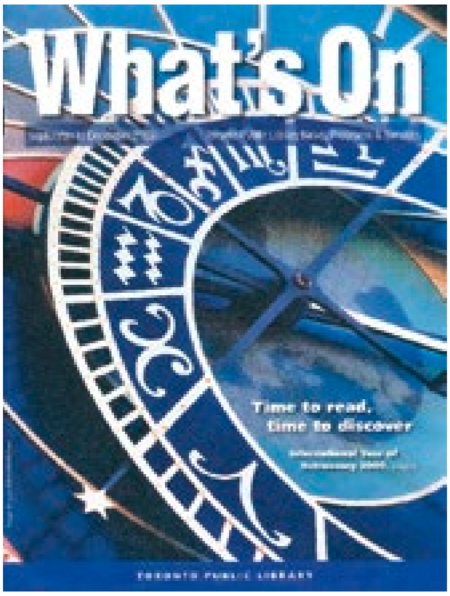

Figure 2. During the International Year of Astronomy 2009, the September 2009 edition of the Toronto Public Library's What's On *magazine featured astronomy (the Prague astronomical clock) on the cover, and highlighted a variety of astronomy programmes for people of all ages. Credit: Toronto Public Library*

the Dunlap Institute Michael Reid, keeps the speakers list full, and up-to-date, and manages requests from the librarians.

Once a speaker is chosen, either approached directly by librarians they know or requested through the website, they communicate with the local librarian, and provide a brief biography and the title and summary of their presentation, as well as learning about the library's individual needs and expectations. The presentations are advertised in *What's On*, on the TPL website, in posters in the local branch, and on various astronomy websites. The publicity itself is valuable as thousands of people see it and find out who astronomers are and what they do, even if they cannot attend the presentation. On the day of the presentation, the speaker arrives at the library branch well ahead of time, and meets with the librarian. The venue may be a corner of a one-room library, or a 250-seat auditorium in one of the larger branches. Often audience members arrive early, and some speakers invite them to ask informal questions while they wait or engage in discussion about any aspect of astronomy — not just the one that is going to be talked about.

In the summer, TPL organises programmes for children across the city. Astronomy, along with dinosaurs, is said to be children's favourite science topic, but some presenters, the author of this article included, are more comfortable giving presentations to adults. So, in IYA2009, funded by a grant from the PromoScience programme of the Natural Sciences and Engineering Research Council of Canada, we enlisted the help of Robby Costa, a recent science graduate who had also completed an undergraduate course in Science Education, and who aspired to be an elementary school teacher. Together, we developed and delivered a dozen programmes for children which were a mixture of engaging content, hands-on activities, take-home materials, and opportunities to "ask an astronomer".

***Figure 3.** A front-page photograph of solar observing after an astronomy presentation by the author, at the Midland Public Library. Credit: Midland Mirror*

Usually, no formal evaluation of these presentations is done, other than the presenters' own reflections. It is difficult to administer a survey when the astronomer is talking after the presentation with keen audience members and the librarian is managing a busy library. However, at my most recent presentation on 18 January 2017 "Misconceptions in Astronomy: From Everyday Life to the Big Bang" a simple evaluation form was distributed. Of the 110 attendees, only 27 completed the evaluation but all 27 agreed that "they would like to see more programmes on this topic". The average rating of the presentation was 9.2/10. Aside from this there is also word-of-mouth exchange between the librarians, and the fact that we continue to be invited back every year is a positive sign. Miriam Scribner tells me that she has never received a negative review of an astronomy talk and has noted that our young female astronomers are particularly very well-received. We try to ensure that our speakers list reflects the diversity of our astronomy group, and of our city.

Based on requests, and on my experience, the most popular topics appear to be: stellar evolution and death; black holes; exoplanets; extra-terrestrial life; and cosmology, though my "Toronto's Astronomical Heritage" presentation (Percy, 2014) is also very popular.

When promoting talks it is important for the title and summary of the presentation to reflect the excitement of the content.

***Figure 4.** Toronto Public Library atrium. Credit: Roberto Baca via Flickr*

Some of our most experienced presenters become well known to the librarians, and to the audiences, and consistently draw a good-sized crowd — typically fifty to a hundred or more. Many of the presenters are postdoctoral students or senior graduate students with a special interest and ability in communicating astronomy and giving a talk provides them with excellent experience in giving a non-technical presentation and interacting with the community. These young astronomers make use of various forms of preparation, including training and experience as teaching assistants, and workshops from experts such as astronomer and award-winning science reporter Ivan Semeniuk. Public Outreach Coordinator for the Dunlap Institute Michael Reid is also an award-winning instructor and serves effectively as a coach, mentor, and role model for our younger colleagues.

The partnership continues

Drawing on the success of IYA2009 in Canada (Hesser et al., 2010), the organisers decided to continue and expand their outreach activities and partnerships beyond 2009 with a special emphasis on reaching underserved and non-traditional audiences, especially youth[5]. These audiences include inner-city, rural, black and minority ethnic groups and people of low socioeconomic status. The grant from the PromoScience programme facilitated this. Library presentations in Toronto continued from 2009 but, with the help of the Ontario Library Association, we were also able to secure invitations from libraries in smaller towns and cities, without local astronomical organisations or facilities.

Mattawa, for instance, is a town of 2000 people, a four-hour drive north of Toronto. We have given presentations on “The Amazing Universe” to a total of 150 people in the local public library, and two local high schools. In the town of Sutton, north of Toronto, we reached 180 people, including a small group of schoolchildren with autism spectrum disorder, making the presentation very visual and hands-on to suit their limited communication and social skills. Other presentations were given in Brantford, Midland (Figure 3), Oshawa, Penetang, Port Hope, and Uxbridge, with audiences of up to one hundred.

There is still much to do, in Toronto and beyond. We encourage every professional and amateur astronomy group in Canada (and elsewhere) to contact and partner with their local library. The costs are minimal, and the rewards are high. In particular, there is untapped potential for programmes for children and teens. In multicultural cities like Toronto, it would also be worthwhile to offer programs in languages other than English. This should be possible in the future for our astronomy group at the University of Toronto, which is culturally and linguistically very diverse.

Conclusion

Astronomers have an obligation to bring astronomy to the public, especially if their salary and research are publicly funded, and it is easy; astronomy is appealing to people of all ages, from children to seniors. Members of our group are professional astronomers, but library programmes can be given by anyone experienced in astronomy outreach and communication, including knowledgeable amateur astronomers. Most public libraries offer programmes for the people of their community. They provide a venue, facilities, publicity, and audience; all that is needed is an enthusiastic astronomer. So make the connection! It’s a win-win-win situation.

Acknowledgements

I thank the PromoScience program of the Natural Sciences and Engineering Research Council of Canada for grant support, Professor M. E. Percy for providing references on the current status of Alzheimer’s Disease research, Miriam Scribner for her partnership, my many colleagues who have participated in the TPL partnership, and the local librarians who have hosted them.

Notes

1. The University of Toronto outreach page: http://www.universe.utoronto.ca
2. Toronto Public Library website: http://www.torontopubliclibrary.ca
3. Toronto Public Library *What’s On*: http://www.torontopubliclibrary.ca/print-pubs/
4. The University of Toronto astronomy speakers list: http://www.universe.utoronto.ca/connect-with-an-astronomer/speakers
5. Information on beyond the International Year of Astronomy: http://www.casca.ca/ecass/issues/2010-ae/features/hesser/biya_eng.htm

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Biography

John Percy is Professor Emeritus, Astronomy and Astrophysics, and Science Education, at the University of Toronto. His many awards include the inaugural (2012) Qilak Award of the Canadian Astronomical Society, for excellence in communicating astronomy in Canada.

Galaxy Makers Exhibition: Re-engagement, Evaluation and Content Legacy through an Online Component

Best Practice

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Keywords
Cosmology, website, app, metrics, analytics, re-engagement, online engagement

For the Royal Society Summer Science Exhibition 2016, Durham University's Institute of Computational Cosmology created the Galaxy Makers exhibit to communicate our computational cosmology and astronomy research. In addition to the physical exhibit we created an online component to foster re-engagement, create a permanent home for our content and allow us to collect important information about participation and impact. Here we summarise the details of the exhibit and the degree of success attached to the online component. We also share suggestions for further uses and improvements that could be implemented for the online components of other science exhibitions.

Introduction

Every summer, a carnival of science descends on London's Royal Society. Exhibitors from universities and science organisations around the UK are selected to display their world-leading research to the public at the Summer Science Exhibition. In 2016 the week-long festival featured twenty-two curated exhibits as well as an extensive programme of talks and activities for all ages.

Our exhibit, Galaxy Makers, created by fifty members of staff and students from Durham University, showcased the wonderful imagery and science of a recent revolutionary set of computer-simulated universes — the EAGLE simulations (Schaye et al., 2015) (Figure 1)[1]. By using the dazzling images and movies produced from the simulation we were able to draw in the younger generation and capitalise on their love of all things digital. We could demonstrate that the same tools used to make their favourite video games also have a use in world-leading research and hopefully inspire them to pursue a computing-focused career in scientific research, or some other field. In an effort to inspire both young and old audiences we built Galaxy Makers as an interactive educational experience that combines science, technology, and art.

Why communicate computational cosmology and astronomy?

Computational cosmology and astronomy allow us to address fundamental questions about the Universe, from how it formed to its eventual fate. The question of origins is relevant, and thus of interest, to the wider public. In other disciplines, scientists can run experiments to gain new information; however, we do not have this luxury — there is only one Universe! Therefore computers have become the laboratory bench

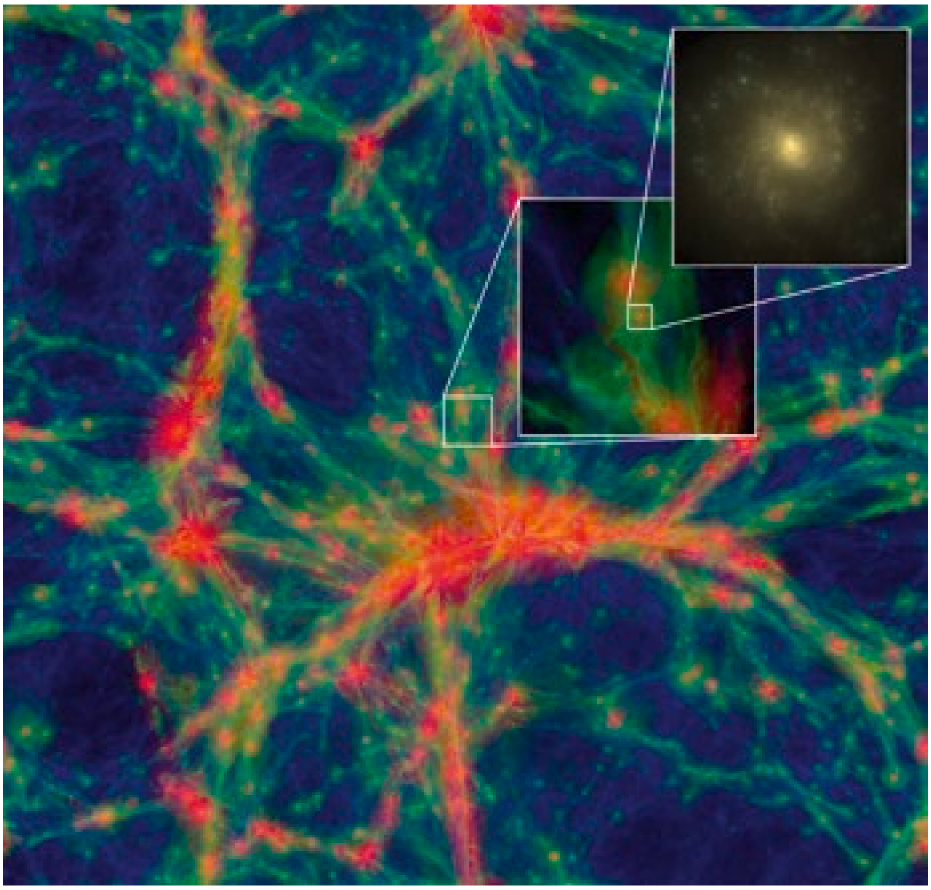

Figure 1. *EAGLE (Evolution and Assembly of GaLaxies and their Environments) is a simulation aimed at understanding how galaxies form and evolve. The simulation took three months to run on a supercomputer and hence is highly detailed; the above picture shows a zoom-in from the cosmic web to an individual galaxy. Credit: EAGLE Project Consortium/Schaye et al.*

Figure 2. *Three machines were presented at the Royal Society Summer Festival: the Universe Creator (left); Tour the Cosmos (top right); and Galaxy Maker (bottom right). Credit: Josh Borrow*

of cosmologists and astronomers, in which simulated universes can be created and "observed" again and again. This technique of simulation allows cosmologists to develop and refine their ideas about the physics that shapes galaxies, is a great application of computational methods, and is a popular way to introduce such methods to the public. Furthermore, astronomical imagery is inspiring and captivating and is therefore incredibly useful for cultivating interest. Computer simulations can produce fantastic animations of the large-scale Universe that are impossible to recreate from observational data; we can watch how galaxies form, speeding up billions of years of cosmic evolution into a few seconds of video.

The UK's school curriculum is now being updated to introduce programming, but this is not the case everywhere and it is important that we keep "pushing from the top" to ensure that the public is informed that computational methods are a key aspect of research in many fields. It is not the case that all scientists wear a lab coat, wield a flask, and use a pencil, but this is often the public's perception. Computational cosmology and astronomy lets us show the younger generation the wide range of possibilities that learning the initial concepts of programming can lead to.

The exhibition

Our week-long exhibition centred on the display and use of three machines — the Universe Creator; Tour the Cosmos; and Galaxy Maker (shown in Figure 2) — which used computer technology to allow users to explore and "create" galaxies. The machines were available over 64 hours in total. The 14371 visitors to the exhibition included the media, school groups, families, invited guests like Fellows of the Royal Society, and other members of the public.

The machines were worked to nearly full capacity for the whole week, with four to six demonstrators at a time constantly engaging with participants. By recording how many times each machine was used, we established that around 2000 people used the machines, with still more approaching the stand and engaging in conversation with the demonstrators about the project. Overall more than 3000 individuals engaged directly with the Galaxy Makers exhibition.

The Galaxy Maker — what is a galaxy?

Our Galaxy Maker activity (Figure 2) allows participants to make their own "holographic" galaxy by following various galaxy model instructions (or "recipes") to weigh out the components (or "ingredients") of different galaxies. After measuring out these components and pouring them into the various chutes of the Galaxy Maker, a projected movie appears in a pyramid, giving the illusion of a hologram. Some of the messages we aim to portray with this activity are that galaxies are vast collections of stars, gas and dark matter and that galaxies come in different shapes and sizes.

Tour the Cosmos — what happens during the life of a galaxy?

Our virtual reality Tour of the Cosmos (Figure 2) allows participants to submerge themselves inside our computer simulation using the virtual reality hardware Oculus Rift. This unique experience flies the "passengers" through space and time while the audio commentary talks them through some of the key events in a galaxy's creation.

Create a Universe — how do we simulate galaxies?

Our Universe Creator activity (Figure 2) enables participants to experience what it is like to run their own computer simulations. The participants use various knobs and levers to make their own assumptions about various aspects of astrophysics. For example, it is possible to change the amount of energy released by supermassive black holes and the amount of dark matter in the Universe. Once these decisions have been made the computer simulation is projected inside a large pyramid, giving the illusion of a hologram. If these assumptions are unrealistic the participant may end up with a universe that is too hot or perhaps one containing no galaxies at all! Through this, participants learn how scientists use similar experiments to understand how the Universe works.

The online component

During the in-person exhibition, attendees who created a galaxy or universe on our computers were given small pyramids (Figure 3) which could be used to view the "hologram" movies at home on a smartphone or tablet through the Galaxy Makers website (Figure 4)[2]. Users were given a unique code that represented their universe/galaxy to type into the website. On entering the code, the user is provided with a movie which, when played through their smartphone or tablet with the pyramid attached to it as shown in Figure 3, plays the "holographic" universe they created as a short movie. Additionally, further information is provided about their universe or galaxy so they can learn more about what they have created. The website also allows anyone who wanted to continue learning or could not attend the exhibit in person to learn more about the science and make new universes and galaxies.

Figure 3. *One of the hologram pyramids in use with a smartphone. Note the floating simulation. Credit: Josh Borrow*

The pyramids were an incredibly cost-effective way of ensuring that attendees re-engaged with our content. Google Analytics was set up on the website to analyse its usage; this showed that of the people who were given a pyramid, 40% (around 700 people) entered the website with 75% of those making repeat visits. In total, 898 unique users visited the website during or soon after the exhibition (as of 19 July 2016) from 22 different countries, with the majority of non-UK users being directed there through social media. Existing University websites related to the project also saw an increase in traffic during the exhibition period with the EAGLE project web pages having a 20% increase in page-views.

Creating the parallel online component of the exhibition required relatively little effort, needing only two team members. However, the benefits were many:

1. We re-engaged with hundreds of people;
2. We ensured that our content had a meaningful, lasting presence;
3. We created educational resources for future use;
4. We could obtain vital statistics on participation and impact;
5. We created online advertising for the institution;
6. We could engage people who could not visit Summer Science in person.

Re-engagement

As well as reinforcing important concepts, re-engagement allows interested participants to gain deeper insights into the subject matter. We aimed to achieve this re-engagement through our website, by providing more information for interested readers through text and extra videos. This was particularly important for the Royal Society exhibition because participants only had a very limited time in which they could engage with the exhibition, given the extremely busy nature of the festival.

As many users visited the website more than once and engaged with the content at least three times, we are much more confident that we have made a lasting impression on hundreds of people than we would be had we only utilised our in-person opportunity for engagement.

A record of materials

As with all exhibitions, a large amount of effort was put into developing materials; in our case, these were the videos for the exhibition computers. It would have been a huge shame, both for the exhibitors and the public, if those materials had only been available in one place at one time.

There are plans to show the Galaxy Makers exhibit at various events in the future — even so, the range would have been extremely limited compared to a web-based exhibition. As our analytics have shown — with our visitors originating from 22 countries — there is also a worldwide audience for public engagement materials that should not be neglected and who cannot always be reached in person.

Further education

As previously discussed, our online experience allows us to engage with a considerably larger audience and expose them to more material than the in-person exhibit alone. In the future, we plan to produce educational resources for use by teachers with the Galaxy Makers website so that classroom users can engage with the content as well. Because the Galaxy Makers website was developed in parallel with the in-person exhibition, developing the educational resources is considerably more straightforward than it would have been had we needed to "convert" the exhibit into a classroom-friendly format.

Measuring and recording impact

It is becoming more and more important to collect statistics and metrics to quantify the impact of outreach activities. With an in-person exhibition, particularly when it is incredibly busy, it can be difficult to collect useful metrics and feedback. This means that public engagement evaluation reports can only consist of very simple, broad information such as numbers of people reached.

Online, it is a different story, thanks to analytics programmes like Google Analytics[3]. Google Analytics allows us to study user behaviour and flow, as well as more basic metrics such as the number of users on our site. Furthermore, this includes details of the region and country the user is visiting the site from, their age bracket and the number of times an individual visited the website. These insights cannot be directly translated onto the exhibition but they do give us key insights into the most popular aspects of the exhibition, show us what users were most engaged by, and help track the long-term health of the exhibit.

As well as more information about the content of the exhibit, the Galaxy Makers website will allow us to catalogue the progress of the in-person exhibit with photos, updates and supplementary information about the exhibit that will be incredibly useful when approaching potential exhibition hosts or other organisations, or simply discussing our experience. The website allows us to give our metrics immediate context through the associated images and online exhibits that are available there.

The power of Social Media

Social media is often over-appreciated in public engagement communities. It is quite clear that tweeting about research is no replacement for getting out there and directly engaging with the public. This does not, however, prevent social media from being a highly useful tool.

Two months after the in-person exhibition had ended, an independent game developer found the Galaxy Makers website and tweeted it to his 5000 followers with the message "A wonderful lesson for all the #gamedev-s out there on how to gamify science." This tweet gave the website its single largest traffic spike (there were over 1100 engagements with the tweet) — a spike bigger than any during the exhibition.

Even now, users of the website are still sharing their experiences on Twitter and other social media platforms. Whilst some may be tired of the incessant cries of "use social media" from public engagement professionals, interactions like these show us just how powerful social and new media are, and just how important it is to cultivate relationships on these platforms. This sharing has allowed our content to be continually reused and allows it to remain visible. See Table 1 for metrics.

Advertising

The website proved useful during the in-person exhibits for advertising the exhibit to members of the public through social media. The ability to play around with an online experience before making the trip to the exhibition is certainly an interesting concept from an advertising point of view; this is a clear improvement over the traditional photos of people milling around the exhibition centre.

Further potential of online material

In some ways, we did not fully utilise our opportunity to collect information about the exhibition through the online component. For example, we could have produced a questionnaire on the website for qualitative and quantitative feedback. Consequently, we had a lack of participant evaluation, although some responses were collected through social media and email.

Another interesting possibility would have been to include participant information in the code that was given out to attendees. This could have been used to track which groups were most interested in the website and could have been made more interesting still by giving out different codes to different demographic groups (for example splitting by gender or age group) and tracking their use on the website. Including this information would have significantly bolstered our demographic data and is certainly a compelling opportunity for future exhibitions.

Social media could also have been used to greater effect during the Galaxy Makers exhibition. For example making the Twitter handle visible on all of our materials would have increased activity. Additionally, had the website received some attention from

Metric	Exhibition (1–17 July)	Lifetime (to 1 December)
Sessions	1580	3603
Users	892	2270
Page-views	5639	12486
Average Session Duration	3:18	2:47
Sessions by Return Users	43.5%	37.0%

Table 1. *Metrics have continued to grow over time, showing that the content produced for Galaxy Makers is continuing to be used. A large number of these interactions post-exhibition are due to users sharing their experiences on social media.*

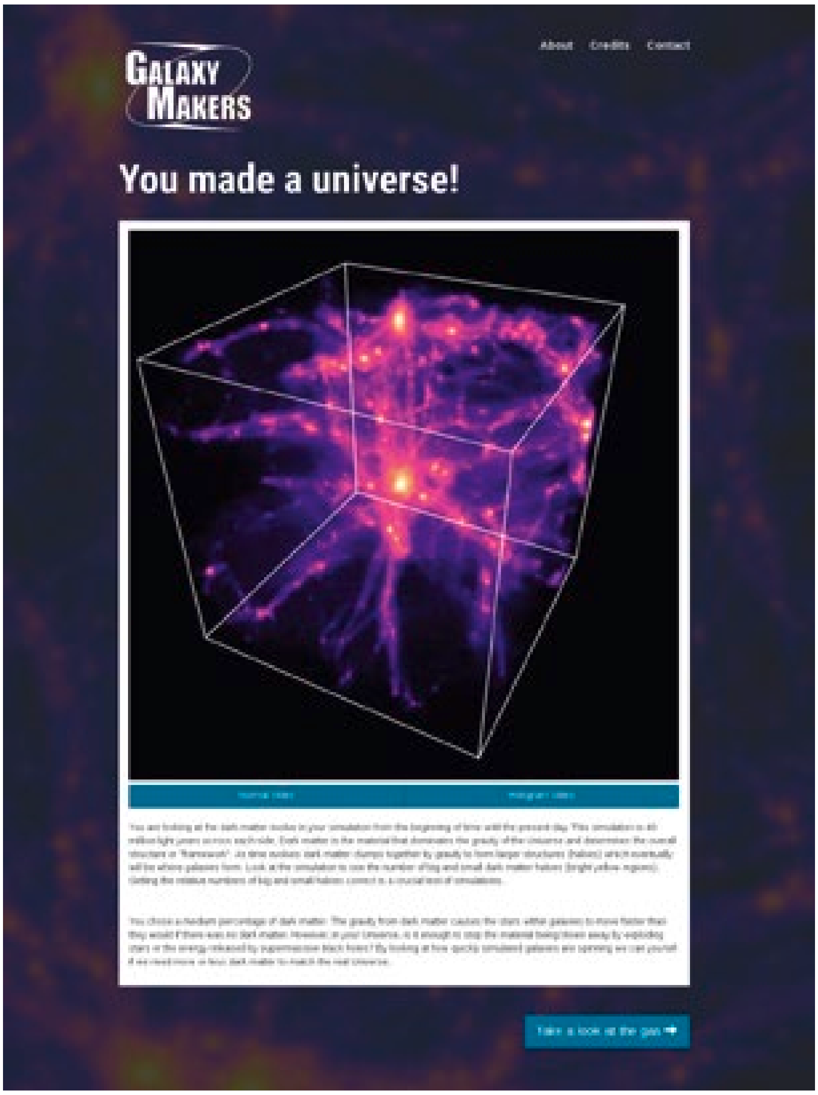

Figure 4. *The Galaxy Makers website. This is the view that users are presented with after creating a universe.*

more high-profile social media users, the engagement with the website would have certainly been higher. In future we will work harder to cultivate these relationships.

Conclusion

Much like some of the most interesting scientific breakthroughs, the success of the online exhibition came as a real surprise. The fact that nearly 40% of those who received a hologram pyramid went away and re-engaged with our content was astounding. Our expectation was that around 10% of users would go away and visit the website. It is clear that the younger generation loves all things digital and that this is a productive route to go down to foster re-engagement.

The material created for Galaxy Makers is already having a much farther-reaching impact than an in-person exhibition could have. We have been contacted by other universities who are using Galaxy Makers for their undergraduate labs, schoolteachers who are interested in using the project, and of course users stumbling across it on the internet. The content created for the Galaxy Makers exhibit is now also being commissioned for permanent display at Leiden Observatory.

When creating an exhibition, a parallel online experience is certainly something to consider. With only 4% of our total team (one person out of 25) working on the website, we have managed to re-engage hundreds of attendees and gain a large amount of valuable data for evaluation. We have also created a lasting, permanent home for our content that is now no longer relegated to a one-week experience; it is free to be shared around the world forever.

Acknowledgements

Many thanks to the builders of the EAGLE simulations (the Virgo Consortium) and the Galaxy Makers exhibit. In particular, we would like to extend our thanks to Professor Carlton Baugh for leading the Galaxy Makers project, and for his comments on this article. We would also like to thank the institutions that provided resources and funding either directly or indirectly: The Ogden Trust; The European Commission; Science and Technology Facilities Council (grant reference: ST/L00075X/1); Marie Curie Actions; The Royal Astronomical Society; the Royal Society; and DiRAC.

Notes

[1] More information about the EAGLE simulations and its creators are available here: http://icc.dur.ac.uk/Eagle/

[2] Galaxy Makers website: www.galaxymakers.org

[3] Google Analytics: www.analytics.google.com

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Biographies

Chris Harrison, following a PhD and post-doctoral position in Durham, UK, is now a Research Fellow at the European Southern Observatory. He uses multi-wavelength observations to establish how galaxies formed and evolved with an interest in the role of supermassive black holes. Chris also works in the new ESO Supernova Planetarium & Visitor Centre in Munich.

Josh Borrow is a first-year PhD Student at the Institute for Computational Cosmology, Durham University, and is a keen communicator of science. He runs the local Café Scientifique and built the website for Galaxy Makers.

Bringing Cosmic Objects Down to Earth: An Overview of 3D Modelling and Printing in Astronomy and Astronomy Communication

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3D modelling, engagement, science communication, space science

Three-dimensional (3D) modelling is more than just good fun, it offers a new vehicle to represent and understand scientific data and gives experts and non-experts alike the ability to manipulate models and gain new perspectives on data. This article explores the use of 3D modelling and printing in astronomy and astronomy communication and looks at some of the practical challenges, and solutions, to using 3D modelling, visualisation and printing in this way.

Introduction

Over the past decade, three-dimensional (3D) modelling in science has become more accessible. From models of chemical compounds and molecules to anatomical representations and geographic models of Earth, 3D data representations can offer scientists and the public cognitive tools for scientific inquiry (Saleh, 2011).

While interacting with 3D data on a computer screen can be powerful, the ability to create a physical manifestation of the model — through 3D printing — can take things a step further. One of the most popular methods of 3D printing involves what is known as additive manufacturing on demand, whereby a material of some sort — from sugar to plastic to titanium — is continually added in layers to create the object. This makes the production of scientific tools possible wherever a viable 3D printer can be found (Clements, Sato & Portela Fonseca, 2016). The process of additive manufacturing on demand is known as fused deposition modelling (FDM) and has become increasingly more accessible and affordable to consumers over the past five years.

Although 3D printing is still relatively young, its possibilities are varied and intriguing. From planning a possible sustainable lunar base from Moon dust (Klettner, 2013), to medical printing of skin or embryonic stem cells (Everett-Green, 2013), there are endless possibilities for 3D printing applications in science.

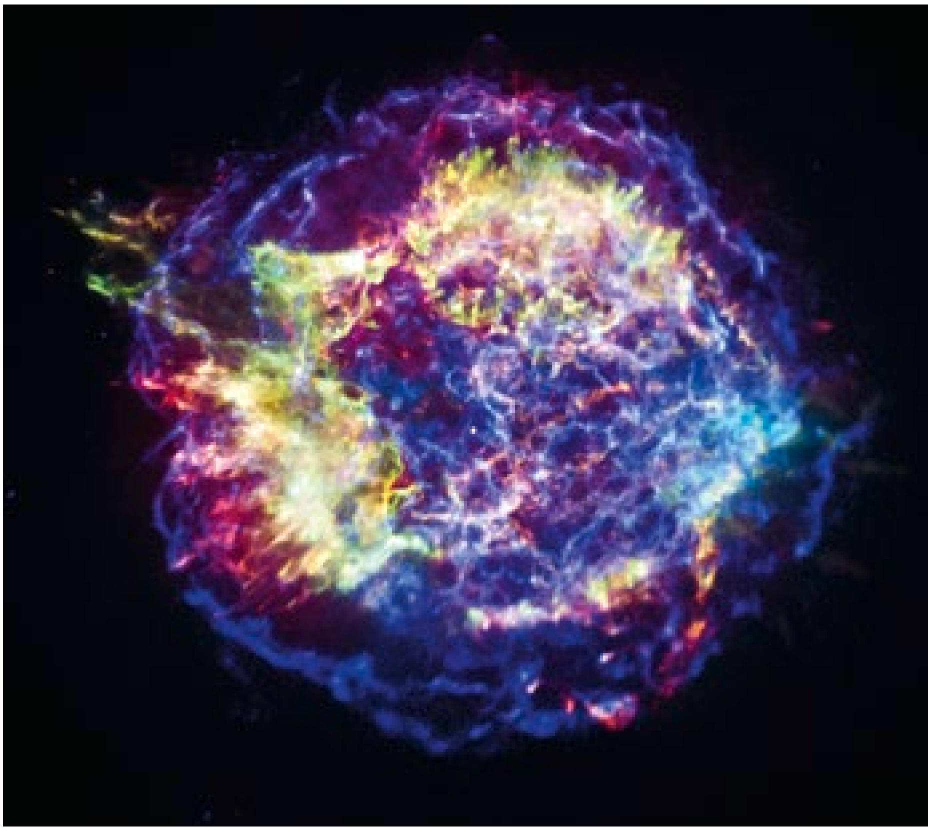
In astronomy, data and the images that astronomical data produce are often only two-dimensional (2D). From our vantage point on Earth and from nearby orbiting telescopes, the Universe appears as a flat projection on the sky. While some surveys will contain information about the distances to objects, it is rare to have three-dimensional information about the sources themselves. Therefore, those astronomical objects that have been explored to date in 3D represent only a small fraction of what astronomers observe overall.

The ability to study astronomical sources from every side gives scientists a better understanding of how cosmic objects are structured and their underlying physics. Astrophysicists, computer scientists, engineers, technicians, and developers are creating new techniques to push astronomy visualisation beyond 2D images and expand into this important third dimension of space. This enables scientists and the general public to view objects from any angle and in some cases to virtually travel through them. A push is also being made towards 3D data representation that includes other information, such as time and velocity.

The field of astronomy, despite the challenges associated with obtaining 3D data, has developed innovative ways to obtain such information about distant sources. Astronomy has already benefited from advances in 3D modelling and printing, and it will continue to do so in this era of big-data astronomy. In this paper, we include examples of successful astronomical projects and discuss best practice that we have developed or experimented with to date.

Astronomical medicine and 3D models of molecular clouds

Arguably one of the most innovative milestones in the recent development of 3D imaging in astronomy has been the Astronomical Medicine project (archived as of 2011). This effort combined the talents of a group of scientists at the Harvard-Smithsonian Center for Astrophysics and the Initiative in Innovative Computing with a program led by Alyssa Goodman[1]. Astronomical Medicine adapted existing 3D software and brain-imaging techniques from Boston-area medical personnel for use in astronomical data visualisation. The Astronomical Medicine project enabled



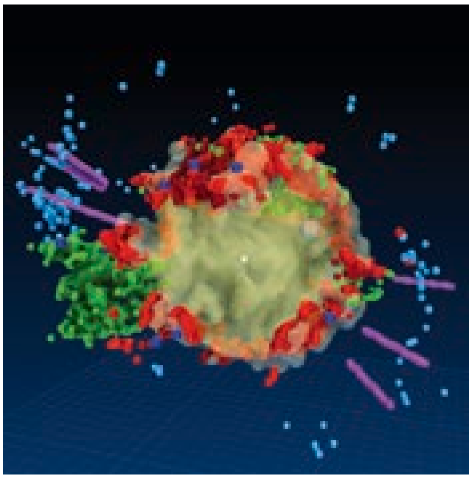


Figure 1. *Left: 2D* Chandra *X-ray image of Cassiopeia A. Credit: NASA/CXC/SAO.*
3D model of Cassiopeia A from multiwavelength data that can be manipulated by the user in their browser[4]*.*
Credit: NASA/CXC/SAO & Smithsonian Institution

researchers to generate 3D images of molecular clouds, which could then be interactively included in digital editions of journals such as *Nature*, allowing readers to manipulate the 3D model directly in the enhanced PDF (Goodman et al., 2009)[2].

Cassiopeia A: 3D visualisation to 3D print

Shortly after Goodman et al. began disseminating their results from the Astronomical Medicine project, technologists at the Chandra X-ray Center (CXC) began to apply it to another object type, supernova remnants. Cassiopeia A (Cas A) is the result of the catastrophic explosion of a star about 15–20 times the mass of our Sun (Orlando et al., 2016). The stellar debris of Cas A is known to be expanding radially outwards from the explosion centre.

Using simple geometry and Doppler effect data from *Chandra*, the *Spitzer Space Telescope*, and ground-based optical telescopes, Tracey Delaney, then at the Massachusetts Institute of Technology, collaborated with developers from the Astronomical Medicine project and CXC to create a 3D model of the supernova remnant with software such as 3D Slicer (Delaney et al. 2010). In partnership with the Smithsonian, a version of the 3D supernova remnant was produced (Figure 1) that could be manipulated in a browser by changing the viewing angle and selecting which data to show. This allowed the user to, for example, select data with different X-ray or infrared energies, allowing emission from different elements to be isolated, such as certain types of neon from *Spitzer*, or iron from *Chandra*. The CXC also created a fly-through, more transparent version adapted from the data into the commercial 3D software Autodesk Maya so that textures and colours more reminiscent of astronomical imaging and a star field could be applied. This Cas A 3D project was the first time astronomers could see above, below, around and through an exploded star based on observational data[3].

The insight into the structure of Cas A gained from this 3D visualisation is important for astronomers who build models of supernova explosions. The 3D visualisations tell them that the outer layers of the star come off spherically, but the inner layers come out in a more disc-like manner with high-velocity jets in multiple directions. Since the Delaney et al. (2010) study, two other groups have constructed 3D models of Cas A (Milisavljevic and Fesen, 2015; Orlando et al., 2016), demonstrating the high scientific value of such visualisations for astronomers.

While data-based 3D visualisations can be beneficial to expert populations, it is also recognised that there is much potential for non-experts to work with 3D models. The Cas A project is an excellent example of this and shows what can happen when "next steps" are taken. In the case of Cas A, it stands out as the first supernova remnant to be prepared and generated in a 3D printing.

Figure 2. *3D print of Cassiopeia A. Credit: NASA/CXC/SAO*

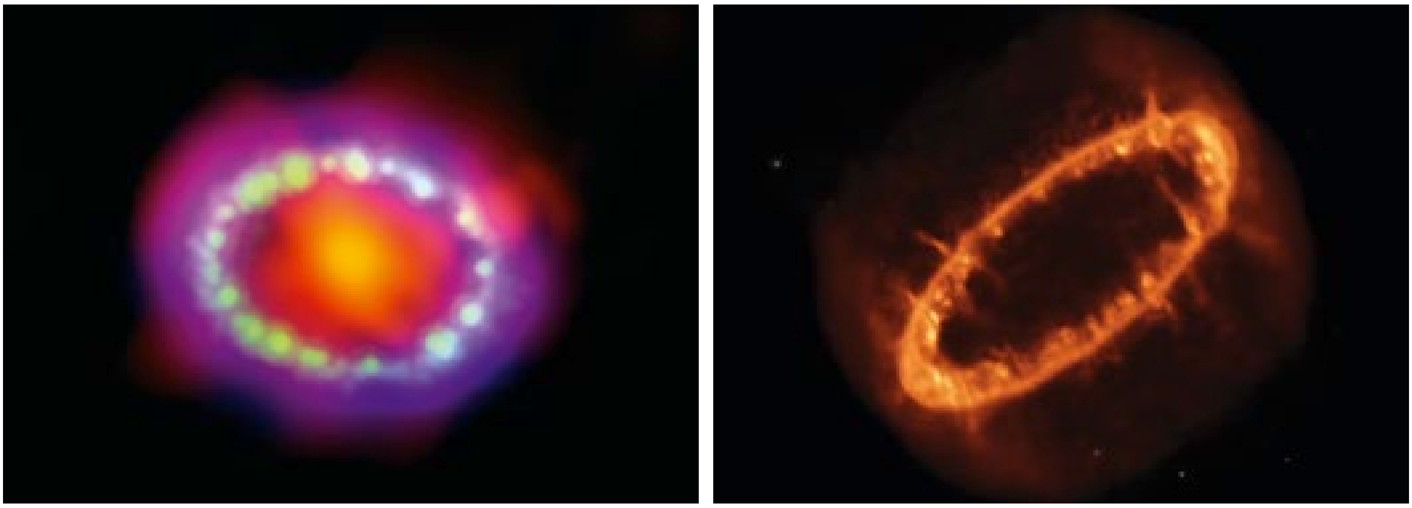


Figure 3. *Left: Multiwavelength 2D view of supernova SN1987A. Credit: NASA/CXC/SAO/PSU/K. Frank et al. (X-Ray); NASA/STScI (Optical); ESO/NAOJ/NRAO/ALMA (Millimetre). Right: This visualisation is based on a 3D simulation published by Salvatore Orlando and collaborators that incorporates the physics of SN 1987A, based on* Chandra *X-ray data. The simulations show how the shape of the X-ray structure and the amount of X-rays observed at different wavelengths evolve with time[7]. Simulation Credit: Salvatore Orlando (INAF – Osservatorio Astronomico di Palermo). Visualisation Credit: NASA, ESA, & F. Summers, G. Bacon (STScI)*

Collaborating with Smithsonian specialists in 3D scanning and printing[4], CXC generated the first ever 3D print of a supernova remnant (Figure 2) in 2013. Today, Cas A in 3D is freely available as a 3D print-ready model with supports (600 k triangle OBJ file at 27 MB)[5] and in volumetric data form (ASCII VTK files created from telescope data at 3.94 MB) for use with any 3D printer and proprietary software.

Research groups have shown that non-expert populations can benefit from such 3D-printed models, including students (Rennie, 2014) and populations with visual impairments (Grice et al., 2015 & Christian et al., 2015). To date, the Cas A 3D model has been printed and shared directly by CXC with numerous schools in the USA, libraries, Maker Spaces, STEM programmes such as Girls Who Code and Girls Get Math, groups of blind and visually impaired persons, members of the Smithsonian Astrophysical Observatory Advisory Board, the secretary of the Smithsonian, and politicians such as U.S. Senators Harry Reid and Jack Reed, among many others.

30 years of Supernova 1987A

In 2017, the CXC released another 3D model to help commemorate the 30th anniversary of the discovery of supernova SN 1987A. This model is primarily made from simulation data, but is constrained by X-ray observations and was also successfully 3D printed (Figure 4). The visualisation — the static image of the final epoch shown in Figure 3 — depicts SN 1987A and the evolution of the resulting supernova remnant up to the present day, beginning by showing the progenitor star surrounded by a ring of gas produced late in the life of the star. A flash of light depicts the supernova explosion, and is followed by expansion of the subsequent blast wave. The blast wave then collides with the ring of gas, causing high-density knots of material to become hotter and brighter, and lower-density gas to be blown outward. One frame is shown per year and the visualisation steps between them at four years per second. Upon reaching the present day (February 2017), the time development is halted, and the camera circles around the ring to show its structure[6]. With the skewed perspective we have of this system from our vantage point on Earth, understanding SN 1987A's inner structure is much more difficult without such a 3D representation.

To print the 3D representation, CXC created three STL files for this object: the Ring Debris 2017 (the final epoch from the visualisation); the Ring 2017; and a file that combines both objects. For the silver 3D

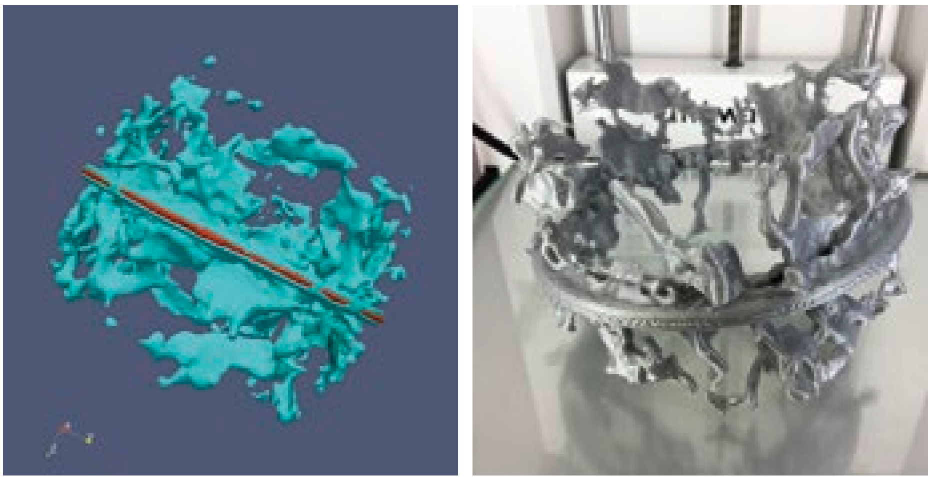


Figure 4. *This 3D file (shown in two colours on the left) was translated into a 3D print (shown in one colour on the right), depicting the SN 1987A supernova remnant at its current observed age of 30 years based on 3D simulations by Orlando et al., and constrained by X-ray observations. Simulation Credit: Salvatore Orlando (INAF – Osservatorio Astronomico di Palermo). 3D print Credit: NASA/CXC/A. Jubett et al.*

print version (Figure 4, right), dissolvable support structures were used, and the photo shows the model after the support structures were dissolved. Using the Ultimaker 3 printer with dissolvable supports at 0.1 mm resolution this model took about forty hours to print. Figure 4 (left) shows the 3D model of SN 1987A. Small blobs of gas, visible on the left, that were disconnected from other blobs or from the ring (floating free in space) were removed before production using 3D animation software for ease of printing, and noted accordingly on the website. Figure 4 shows two different colours for the ring versus the debris which can also be printed in a two-colour format on 3D printers such as the Ultimaker 3 that have dual extruders — the nozzles in the printer through which the material is deposited to create the print.

Eta Carinae & Pillars of Creation: shaping our view

We have found so far that one size does not fit all when it comes to creating 3D models and 3D prints of astronomical phenomena. We therefore briefly touch upon 3D prints of other object types using different techniques and data sets to help present a more balanced perspective of 3D printing in astronomy.

Researchers working with *Hubble Space Telescope* data have developed models of areas of stellar birth (the Eagle Nebula, or "Pillars of Creation") (Figure 5) and stellar aging (Eta Carinae and the Homunculus Nebula) (Figure 6). In both cases, scientists combined high-resolution spectroscopic data from the European Southern Observatory's (ESO) Very Large Telescope (VLT) with *Hubble's* views to reach a deeper understanding of the 3D environment of these objects.

Astronomers have found that the famous Pillars of Creation (Figure 5) are separated from each other in space — the tip of the largest pillar is pointing toward us, while the other pillars are pointing away from us (McLeod et al., 2015). Owing to this orientation, and the intense bombardment from nearby young stars, the tip of the tallest pillar appears brighter. The 3D plot (Figure 5, lower) shows the separation and orientation of the pillars, further adding to and expanding upon the information quotient of the 2D image.

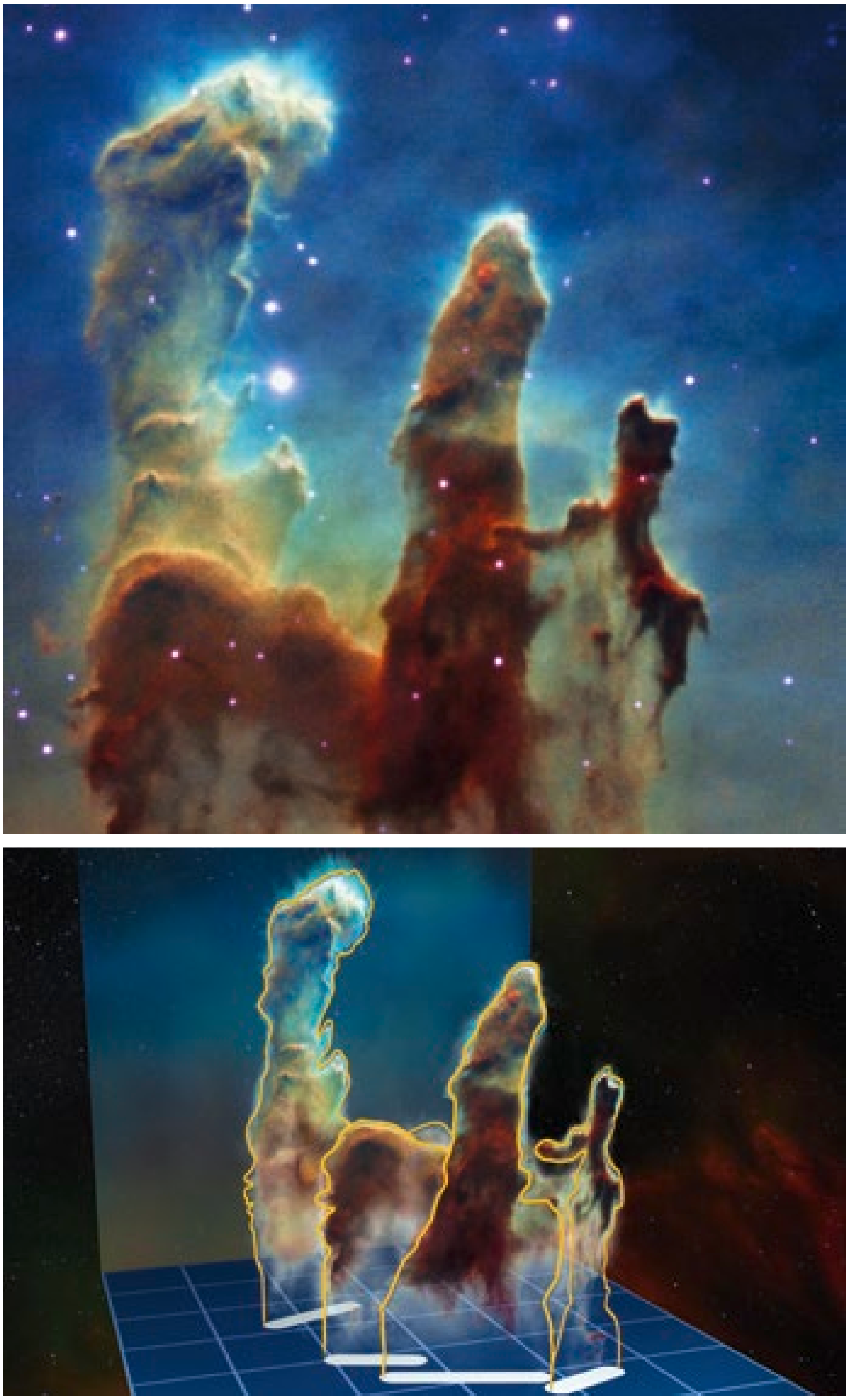


Figure 5. *Upper: 2D Optical image of Eagle Nebula/Pillars of Creation from the Very Large Telescope. Lower: The Pillars plotted in 3D. Credit: ESO*

In the case of Eta Carinae, scientists mapped the shape of the bipolar bubble, known as the Homunculus nebula, surrounding the star (Figure 6). Using 3D modelling software designed for astronomy called SHAPE[8], researchers built a printable 3D model of the Homunculus nebula (Steffen et al., 2014). Additionally, further 3D modelling of the Eta Carinae system has been done on much smaller

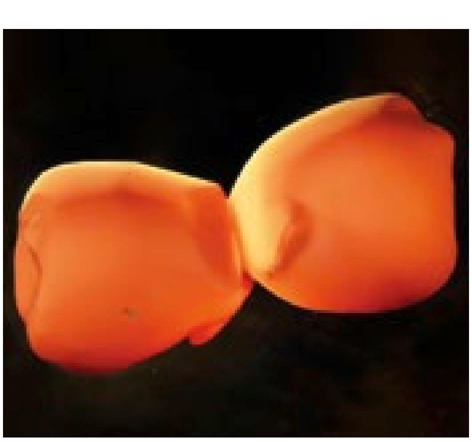


Figure 6. *Left: 2D Optical image of Eta Carinae from* Hubble*. Credit: ESA/NASA Right: Eta Carinae in 3D. Credit: NASA/STScI and NASA's Goddard Space Flight Center/CI Lab*

scales, close to the binary in the central region[9]. Such modelling helps to better show the multiple dimensions of this system, something that 2D images cannot individually do, particularly when the object's perspective in relation to observatories on or around Earth is so skewed.

Cosmic microwave background: touching temperature

A recent paper (Clements, Sato & Portela Fonseca, 2016) describing a 3D model of the Cosmic Microwave Background (CMB) demonstrates astronomical 3D printing on perhaps the grandest scale, as people can now hold the observable Universe (in a much scaled-down size, of course) in their hands. While the CMB is typically shown in a 2D projection map, astronomers have struggled to visualise it effectively in three dimensions. Projecting this map onto a sphere and mapping the temperature fluctuations to bumps and dips within the sphere proved to be effective in creating a model of the CMB that can be printed and explored through touch (Figure 7).

Next steps for 3D printing astronomical data

Though the amount of astronomical data extended to the third dimension remains limited, the collection is growing. NASA's 3D resource website[10] maintains a database of more local 3D objects such as the Moon and Mars (as well as many spacecraft models).

Certain types of celestial objects may lend themselves more naturally to obtaining, visualising and printing 3D data than others. For example, astronomers may be able to gather velocity data on supernova remnants other than Cas A using *Chandra* and other high-resolution telescopes, as well as data on other types of novae. Supernova remnants that are well studied often have the benefit of being relatively close by (in the Milky Way or a nearby satellite galaxy), and/or have been highly studied by many telescopes, so there is a larger source of multiwavelength data to work from. The CXC team and other researchers are currently investigating some of these sources, including Tycho's Supernova Remnant and supernova remnant E0102–72.3, among others.

The CXC group is also exploring the possibility of making 3D models of the region around the supermassive black hole in the centre of the Milky Way. Surveys such as the Sloan Digital Sky Survey[11], the 2MASS Redshift Survey[12] and the Hubble Ultra Deep Field[13] contain information on the distance to objects, so astronomers can generate maps of galaxies and larger-scale structures in three dimensions. We are not aware of any 3D printing of objects from these surveys yet.

Practical tips and challenges of 3D printing cosmic objects

File formats

When delving into the world of 3D printing, one will encounter a handful of file formats, which might seem inconsistent. Most 3D printers can print directly from OBJ and STL files, and each printer has its own unique set of acceptable formats. Some OBJ files can be stubborn, depending on the number of polygons in the model and other factors. OBJ is a bit more versatile, however, being commonly accepted to import into/export from multiple 3D software packages such as the Autodesk 3D design programmes Maya[14], 3D Studio Max[15] and AutoCAD[16], as well as OpenSource programs like MeshLab[17] and Paraview[18]. There are several software packages that can convert other file formats into STL or OBJ. MeshLab can handle several differ-

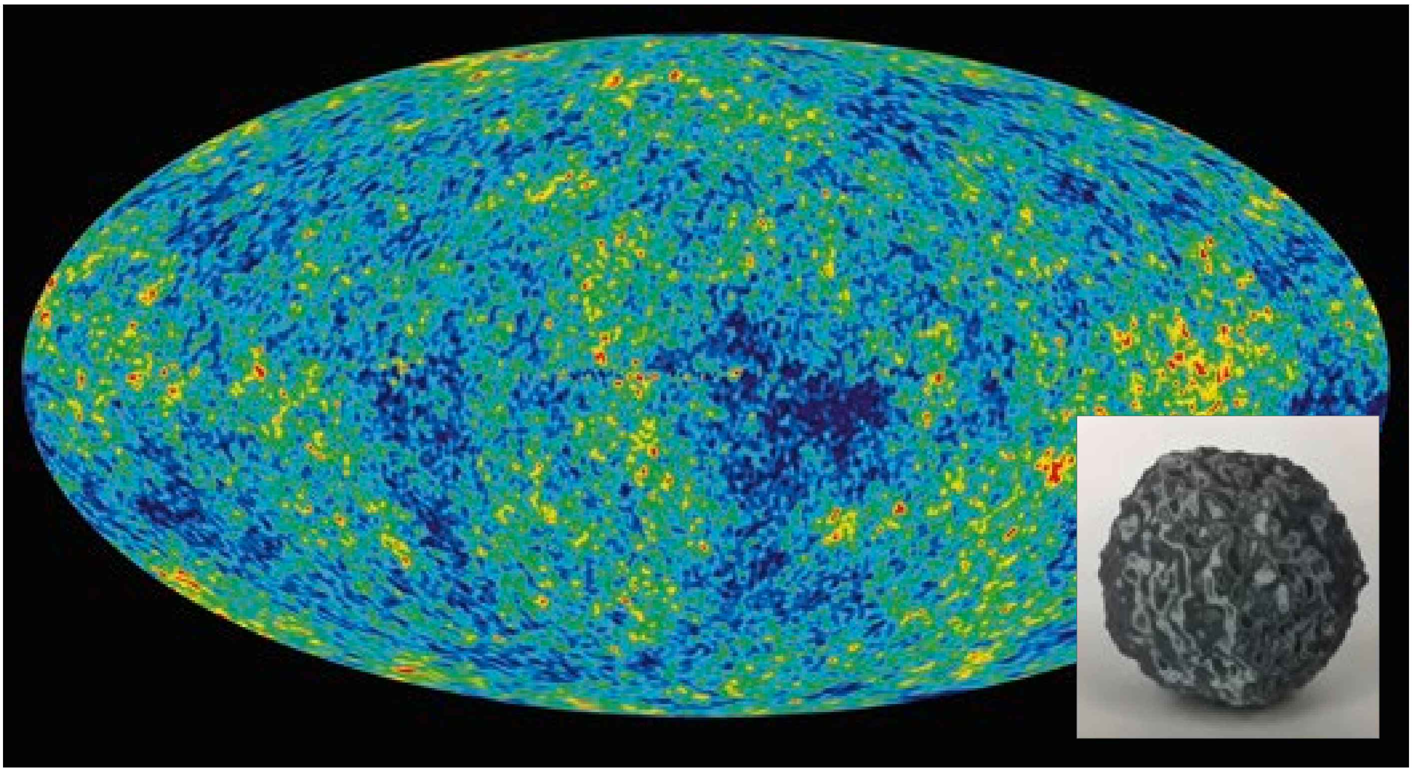


Figure 7. *A typical Mollewide projection of the CMB. Inset: A 3D print of the data mapped to a sphere. Credit: NASA/WMAP Science Team*

ent formats, including COLLADA (or DAE) files and PLY files derived from 3D scanners. Using Paraview, one can readily import VTK data files, which are commonly used by astronomers visualising data sets. With a bit of a learning curve and a few filters, one can visualise these data sets in Paraview as mesh objects and save the data as STL.

There are also some proprietary file extensions, including X3G and THING files, which are used by Makerbot software and printers. FBX is owned by Autodesk and can be converted by several Autodesk programs. Other Autodesk proprietary extensions are 3DS (3D Studio Max) and MB or MA (Maya Binary or ASCII files). Various CAD (computer aided design) programmes use DWG or DXF, which can typically be converted to other formats accepted by most 3D printers. PLY and DAE files often need to be converted in a 3D design programme as well. Conversions between format extensions can take a bit of research depending on the available software and the make and model of printer being used. Fortunately, there is a wealth of information available, and as 3D printer technology evolves, more of the once-obscure file formats are becoming more mainstream.

Some printers and 3D printing services can also accept colour data as WRL or VRML files. These provide colour information for the models which can be handled by some printers or when outsourcing to 3D printing services. A current goal for the Cas A 3D model, for example, is to 3D print a version with the separate elements (silicon, iron, etc.) marked by colour, as seen in the original 3D visualisation in Figure 1.

Structures

As with any new technology, there are unique challenges and limitations associated with creating successful 3D prints. This is especially apparent with the often complicated structures of astronomical objects. When using the FDM method of 3D printing, great care must be taken in creating the 3D model to ensure that all parts of the model are connected in ways that will be self-supporting in printed form. For example, a nebula with many interconnected and free floating knots of gas may fall apart when printed. Where applicable, the model might need to be simplified to allow for printing.

Additionally, one must be aware of large overhangs where additional support structures will be required for the print to be successful (Figure 8). These structures, though useful and often necessary, cause longer print times and use up more filament than simpler models. The supports must be carefully removed with needle-nose pliers and other similar finishing tools in post-processing of the print.

Alternatively, next-generation, dual-extrusion 3D printers are now capable of printing complicated objects with a dissolvable, water-soluble support structure which eliminates the need for time-consuming and potentially damaging removal of supports. Using newer, possibly more expensive, printers could result in limited dissemination of 3D-printed objects, however, and more difficulty for the end user. Many schools and libraries, for example, are likely printing on basic FDM models from Makerbot or similar companies, which offer affordable access to 3D printing technology but might have difficulty printing more complicated models. Care should be taken to know your audience and the type of equipment that they might have access to when creating and disseminating the 3D files.

Figure 8. *3D print of Cassiopeia A before support removal. Credit: NASA/CXC/SAO*

Conclusion

Astronomy communicators are in a strong position to take advantage of the recent and ongoing advancements in 3D modelling and printing, as well as immersive 3D environments such as Virtual Reality Modelling Language labs. As the costs of such efforts go down, the possibilities increase. In addition to enabling expert populations to have new views and therefore a new understanding of their data sets, non-expert populations can also benefit from 3D models and prints, including students and visually impaired participants. By taking astronomical images from two into three dimensions and placing 3D models and prints directly in the hands of both experts and non-experts, we can expand information access to a whole new medium, and sense.

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Biographies

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Astronomy at the Airport: Supernova Science in the Southampton Airport Departure Lounge

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Keywords
Airport, communication, hands-on engagement, public engagement, research-link

Over four consecutive days in February 2016 a group of astronomy researchers from the University of Southampton, UK, engaged a total of 1500 passengers waiting in the departure lounge at Southampton Airport with their astronomy research. This article reflects on the challenges and successes of the project which aimed to reach out to young families who would not normally attend science events, and show astronomers as positive role models.

Introduction

The idea to do astronomy outreach with airport passengers came about as a result of an outreach event on a plane above London during the March 2015 partial solar eclipse. During the eclipse a group of astronomers on the aeroplane gave out free eclipse glasses to fellow passengers so that they could view the event. We found that giving out a free gift to the passengers in such an unusual setting broke down a barrier and as a result the group became very open to learning about astronomy.

Based on this event we applied for and were awarded just over seven thousand pounds (GBP) of funding from the Science and Technology Facilities Council (STFC) Public Engagement fund to run an event in our local international airport, Southampton Airport. The main objectives of the event (called #AstroAirport on social media) were to raise awareness of the University's supernova research via a two-way conversation between astronomers and the public and to provide positive role models in science. We also wanted to attract new audiences who may not normally attend a science event.

Reaching audiences

For four consecutive days during the UK school holidays in February 2016 a group of four astronomy researchers from the University of Southampton engaged 1500 passengers waiting in the departure lounge with their world leading astronomy research. To start up a conversation with waiting passengers the researchers handed out free gifts such as towels with a simplified image of a supernova printed on them. For us to count the interaction as an "engagement" we had to have a conversation with the passenger where we not only told them information, but they responded with questions and insights of their own. This is in line with the definition from the National Co-ordinating Centre for Public Engagement (NCCPE): where "Engagement is, by definition, a two-way process, involving interaction and listening, with the goal of generating mutual benefit"[1]. Therefore, we did not count the engagement if we only gave the passenger a free goody bag and there was no discussion.

We expected the majority of passengers to be young families, as it was the school holidays; however, we estimate at least half of the engagements we had were with older people and airport staff.

Astronomers as role models

Another aim of the project was to provide positive scientist role models (both female and male) to challenge negative — or limiting — stereotypes. On each day there were four astronomy researchers explaining the research to passengers in the departure lounge. At least one researcher remained at the stand, which consisted of: a table filled with free gifts; hands-on demonstrations to explain core collapse supernovae; and a pop-up banner which had a greater level of detail about the research for the more interested public. The other astronomers would take goody bags (branded cloth bags filled with towels, leaflets and pens) and give them out to those passengers who were sitting at the gates ready to board. We made sure that on each day there was at least one female astronomer.

"I never knew you could be a scientist for a job! I want to be a scientist now!" — eight-year-old girl engaged via the project.

Do gifts result in engagement?

We found that giving out a novel gift or goody bag was a great way to start up a conversation with members of the public. The gift itself is useful to allay fears the public may have that you are selling something. We found we had to explain that we were not there to recruit students or promote courses, and that we were simply there to promote the research itself and raise awareness of the world-leading research happening at the University. The conversations we had often started from a much more basic level than we were used to from science festivals where people are expecting to talk to scientists. However, even those people who began by saying they are not normally interested in science mentioned their excitement about the discovery of gravitational waves, which had happened in the previous week.

One member of the public commented that: *"the gifts were a good prompt to re-tell what I had been told."*

Several months after the event we received two emails which revealed the unexpected impact of the free towels and the accompanying leaflets. The first email was from a passenger who said about the image on the towel: *"To me it portrays in a modern/cubist point of view a portrayal of not just the supernova but also how humans can be*

Figure 1. *The #AstroAirport design that was printed on the towel and other free gifts. Credit: Chris Frohmaier*

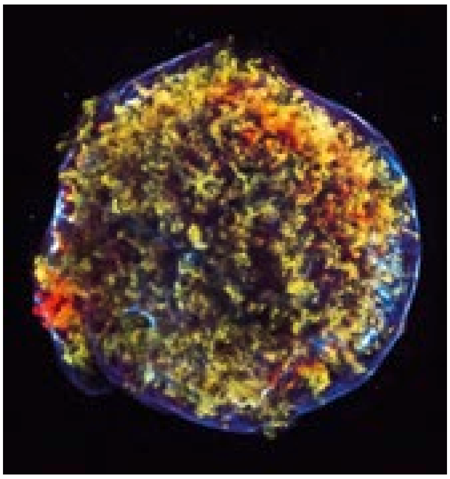

Figure 2. *Tycho Supernova remnant. Credit: NASA/CXC/SAO*

viewed — us in a collective but also separate; together and alone. An image that can be viewed at length, puzzling where we are and how we do (or don't) fit."

The second email was from a lady whose husband had suffered a stroke and his speech therapist had used the leaflet with him as part of his therapy: *"Years ago he completed a degree in astrophysics and he is still familiar with all that he learned and it has always been a subject of great interest to him. We are using your leaflet as a reading and comprehension exercise, as sadly both have been affected by the stroke. We are both enjoying researching associated material and new information inspired by your leaflet. We thought you might like to know where one of your leaflets ended up and how it has been put to use!"*

We ensured that the towel had a strong link to the research. The supernova that was printed on the towel was a colourful, simplified version of a real supernova Type Ia (the Tycho Supernova) and each of the 2200 towels was handed out alongside a leaflet which explained the image.

Figure 3. *PhD student Chris Frohmaier explains to a young child how core collapse supernovae work using a Hoberman sphere. Credit: Robert Firth*

The leaflet also had information on how supernovae are used as standard candles. We felt it was important that the gift itself was a reminder of the interaction, so that when people took it home and used it they would recall some science fact they had learned. At the airport, we used the colourful Hoberman spheres — toys made of spokes with intricate joints which can be expanded to a sphere and contracted to a core as seen in Figure 3 — to demonstrate the different stages of a core collapse supernova explosion.

As well as the towel, which was the main gift, we also had branded pens which were very popular with people of all ages, and we gave out branded colouring pencils and colouring sheets which also had an additional hashtag on them: #StressLessSupernova. The colouring sets were very popular with young children and with older members of the public who were visiting their grandchildren. We did try to promote the sets to lone adults as a mindfulness exercise, but with less success.

When long boarding queues formed at the gates in the lounge, two of us would walk up and down the queue talking to people

Figure 4. *PhD student Juan Hernandez explains what we are doing in the departure lounge to some interested adult passengers. Credit: Robert Firth*

Figure 5. *Undergraduate Jo Barzycki showing how a Hoberman sphere can be used to explain supernova physics. Credit: Robert Firth*

and offering them gifts in the #AstroAirport cloth bags. This was a good way to give potential reading material (in the form of the research leaflet) to people waiting to board, but most of the interactions in the boarding queues were not a two-way conversation so we did not count these in our number of engagements for the event.

The longest conversations that we had were with older people who approached our stand or with middle-aged people who were sitting waiting. In some cases we sat down next to them and had extended conversations after initially offering them the gift. Interestingly, some people who originally refused the free towel would then change their minds after hearing us talk enthusiastically about the science to the person sitting next to them.

Evaluation

Before carrying out any event evaluation one must always refer back to the original aims and objectives for the project. We made sure that for this project we had SMART (Specific, Measurable, Attainable, Relevant and Timely) objectives so that the success of the project could be easily quantified afterwards. We had three main foci for the event: to disseminate the supernova research; to promote the astronomy researchers as role models; and to improve the passenger experience. Within the research dissemination aim we also had three main messages/learning objectives for the public:

1. Understand what a supernova is.
2. Understand that supernovae can be used to measure distance scales.
3. Learn how supernovae are used in research at the University of Southampton.

To measure whether the learning objectives had been met we asked the public to complete both a paper form on the day and an online form one month after the event. The public were incentivised to fill out the paper forms by being entered into a prize draw to win prizes like Lego® Research Academic sets and glow-in-the-dark planets. At the bottom of the paper form people were asked for an email address so that we could contact them one month later with a Google form to assess what they had done in the weeks that followed the event. We also noted down quotes from passengers we engaged with on each day.

Owing to the amount that the researchers had to do they were only able to get fifty-nine out of the 1500 people engaged to fill out the paper evaluation form, which is only 4%. The small numbers and the fact that a large number of those who filled in the survey were people the researchers had had long conversations with, mean the evaluation data is likely to be heavily biased toward more positive opinions of the event. An external evaluator focused on getting audience responses via the survey would have been a useful addition to the project.

In the survey conducted on the day people were asked to list all the facts they had remembered from the interaction. What a supernova is, the life cycle of a star, elements released in the expansion and how hot a supernova is were mentioned twenty-seven times in the form whilst facts relating to using supernovae for research including for measuring distances and as standard candles were mentioned seven times. 100% of respondents correctly circled that a supernova is “an expanded star” and 92% said they had learned something about supernova research. Overall, we feel confident that the research was disseminated successfully and that the three main messages were successfully conveyed to the audience.

Originally, we had planned to have an electronic evaluation only, using three iPad minis at the airport and emailing a Google form out after the event. However, in general both the researchers and the public found it easier and quicker to use paper forms. The three iPad minis were instead used to show the interested public several free stargazing apps that they could download for themselves. We used these to explain to people what the sky would look like on that evening, and on two occasions people went away from the stand and then came back with a friend and showed them the app themselves and described all they had learned. The iPads would have had more use if they had been attached to a separate stand so that people could do the quiz or use the apps in their own time, rather than being hosted by the researchers.

To assess what people remembered a month after the event they were sent a link to an online Google Form. Out of the fifty-nine who filled out the paper form thirty-six gave their email addresses and said they were happy to be contacted, but only nine responded to the online form. Eight of the respondents said that the interaction they had with the astronomers had improved their passenger experience. We received several emails from people after the event thanking us and requesting more free gifts. The two emails below also show that the event had a wider reach than just those passengers who saw us at the airport. The second email is particularly interesting as one of the original objectives was to promote science to female children through their parents and grandparents (see research from WISE[2] and SAGE[3]):

"*Alf, my 7 year old, really enjoyed your event at Southampton Airport. It meant he had something interesting to do whilst waiting for our flight, thank you! Please if you have more towels could you send me some for Alf's friends?*" — mother flying to Scotland.

"*It was a delight to be able to talk about the supernova and space with my six-year-old granddaughter. I also heard her explaining to her two-year-old sister what the picture was on her flannel! An astronomer in the making!*' — female grandparent who gave the free gifts to her family.

As part of the evaluation we also tracked hits to our dedicated supernova research website and tracked social media engagements.

Even though the free gifts (towels, pens, cloth bags, colouring-in sets) were printed with both the supernova research website[4] and the event hashtag (#AstroAirport), only ten members of the public used the hashtag over the four days. The reason our hashtag was not used very much by the public was because the people coming through the airport during the half term tended to be either older people or young families so unlikely to be social media users. However, our research website did see a rise in visitors with 60% of website views being from new viewers, which translates to 81 new engagements. 100% of respondents to our online survey said they told someone about the interaction at the airport so we therefore feel confident that the event did reach our target of at least 2000 people. To incentivise the use of the hashtag online and filling out evaluation forms we held several competitions with prize draws. Members of the public who posted photos with the hashtag #AstroAirport to Twitter and Instagram were entered in a daily competition to win glow-in-the-dark planets. For completing the paper form they were entered into a prize draw to win a Lottie stargazer doll and Lego® Research Academics set. Finally, by completing the online form people could win tickets to Paulton's Park/Peppa Pig World, which is a local theme park for young children. All the prizes were chosen because of their appeal to our target audience — young families. This meant that older people, or people without young children in the family were not so inspired to fill out the evaluation form. At future events we will have a wider range of prizes to cater for all age groups; for example, many teenagers liked our supernova staff t-shirts, or wanted to buy the Hoberman spheres from us, so we will offer these as prizes at future events.

Figure 6. *The AstroAirport team. Credit: AstroAirport*

Impact on the researchers

The event itself definitely improved the overall science communication skills of the researcher team:

"*I felt I was there as a science promoter, not just a supernova expert. I had to step back from my usual approach at science events. A lot of the public were just interested in me personally or in more general subjects like how telescopes worked. They even asked probing questions like 'what is the point of your research?' I found these questions more interesting as they forced me think about the wider implications and economic impact of my research.*" — second-year PhD Student.

"*My confidence in my physics knowledge has dramatically increased; when people asked me questions it made me realise how much I know about my research and physics in general. I also feel confident now that I can approach all types of people and talk to them with ease.*" — second-year astronomy undergraduate who has now gone on to be employed in a public-facing PR role.

Challenges

Despite our event's being held only in an airport departure lounge, where security is a massive priority, we had very few challenges that stemmed from the location itself. The airport staff were all extremely supportive of our event, and we made an effort to include the airport ambassadors who were tasked with watching our activities each day. We were also lucky that Southampton Airport itself is so small and compact; this meant that we had access to all of the boarding gates from our location. Despite its being the school holidays during the Monday to Thursday period over which we ran the project, the Tuesday and Wednesday were particularly quiet. If we ran a similar event we would ask to work over the weekend, from Thursday to Sunday, when more people are likely to be travelling. We had originally planned to work over a weekend but unfortunately the airport did not have enough staff ambassadors to be able to supervise us on those days.

Despite sending out a press release via the University and via the airport media team, the only media coverage we got came in the form of a short entry in the News in Brief section of the local newspaper. The regional BBC News team contacted us on day two after they heard about the event through Twitter. The BBC News team had said they would send a cameraman and reporter to film the event on day three, but after receiving security clearance for departures they unfortunately got assigned to another story.

At the last minute we had the idea to link to the Hitchhiker's Guide to the Galaxy books and film series and had a quote from the books printed on the leaflet that went with the towel: "A towel is the most massively useful thing an interstellar traveller can have". We thought this quote tied in nicely with both our location — which was filled with travellers — and the towels we were giving out. However, we soon realised that very few of the audience at the airport during the school holidays knew of the series. We feel this link could have worked if we had planned our digital campaign further in advance and had been able to contact celebrities from the film beforehand.

Conclusion and recommendations

When organising any public engagement event we recommend coming up with at least three SMART goals. From these goals you should work out the precise aims and overall impact of the project, then decide on the learning objectives for both the members of the public and the researchers delivering the activity.

Based on our main challenges we would recommend using an external evaluator to assess the project. If you are bidding for funds for an event expect to spend at least 10% on the evaluation of the project.

Plan a digital marketing campaign well in advance and use sponsored posts. For our activity in particular we should have spent more time and funds on the design of the complementing leaflet. We did not budget design costs into the grant and therefore did the design ourselves in a short period of time. Given another chance to design it we would put less text on the front page and we would have all the social media links on the front. On the back of the leaflet we would have a research-themed puzzle, to give the public something to do on the plane. This puzzle could also be incentivised by means of a prize for those people who email us the correct solution. Another nice idea, which works well for travellers, is to give them two printed postcards — one for them to send to their family from their holidays and the other one for them to send back to us to tell us what they have learned/remembered about the research.

Finally, by only having the one stand in the departure lounge we neglected a whole other audience who were on the other side of security, dropping off or picking up friends and family. If we did a similar event we would make sure to have a presence both before security and after. We suggest either an iPad stand next to a pop up banner or even something hands-on like a mechanical Hoberman sphere. Ideally the additional stand would also be staffed by at least one researcher. However, a flat screen showing some information would suffice. Having a stand before the security gates would have not only increased our overall reach but would also have been likely to increase our media presence as it is much more accessible.

Notes

1. NCCPE public engagement: https://www.publicengagement.ac.uk/explore-it/what-public-engagement
2. WISE website: https://www.wisecampaign.org.uk/uploads/wise/files/not_for_people_like_me.pdf
3. SAGE website: http://journals.sagepub.com/doi/abs/10.1177/0361684313482109
4. Research website: http://supernova.soton.ac.uk

Biography

Sadie Jones is the Outreach Leader in Astronomy at the University of Southampton. She manages the Soton Astrodome mobile planetarium school visits with her team of PhD and Undergraduate students and presents talks and comedy sets on her own astrophysics research. She also organises large astronomy events such as the SETI Cipher Challenge, Stargazing Live evenings, and the Southampton Science and Engineering-Festival.

The Night Sky, The Forgotten Nature: Uncovering the Impact of One Television Programme on Astronomy Communication in Iran

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Keywords
Television; science programming; Iranian astronomy

In 2001, two brothers known as the Saffarianpour brothers started a television programme on Iranian state television called *Aseman-e-shab (The Night Sky)*. The programme, which explores astronomy and space science, became one of the longest-running television shows in the history of Iranian television and played a major role in the public communication of science and astronomy. It inspired many of the next generation of Iranian scientists and astronomers and played a key role in the advancement of science journalism and science communication in Iranian media. This article outlines a brief history of the show and its producer and describes the role they played in Iranian society.

Introduction

On 5 May 2017, channel four of Iranian state television broadcast a special programme. On a huge video wall in the background were images of the night sky and behind a V-shaped desk a group of science and astronomy communicators gathered and waited for the show to air.

As the lights went up, the presenter announced: "Ladies and gentlemen welcome to the 16th birthday of *The Night Sky*." This is the story of the sixteen years that preceded that moment and of how a live television show changed the path of astronomy and television science journalism in Iran.

The weekly show airs on channel four of the Islamic Republic of Iran Broadcasting network (IRIB-4) and aims to popularise science, inspire a new generation of astronomers and science journalists, rediscover the heritage of Iranian science and redefine the production of science programmes in Iran. With an ever-growing audience the show has spent sixteen years working towards these aims. It is the only programme specialising in astronomy in Iran and remains the longest-running scientific programme in the history of Iranian television, as well as one of the most popular shows on television.

Figure 1. *Siavash (right) and Foad (left) Saffarianpour, founders of the show, at the 16th birthday live broadcast in May 2017. Credit: Sepideh Faalkhah/Aseman-e-Shab*

Beginning a long journey

The story of *Aseman-e-shab* began when teenager Siavash Saffarianpour and his twin brother Foad Saffarianpour, went to the IRIB offices to pitch an idea for a television show that would explore the world of astronomy. Successfully hiding their real age the brothers were given permission to produce a selection of segments for children's programmes to gain the producers' trust.

Next, with trust earned, Siavash began producing special television reports about science and astronomy events. One of the most memorable of those reports was the live coverage of the 1999 solar eclipse

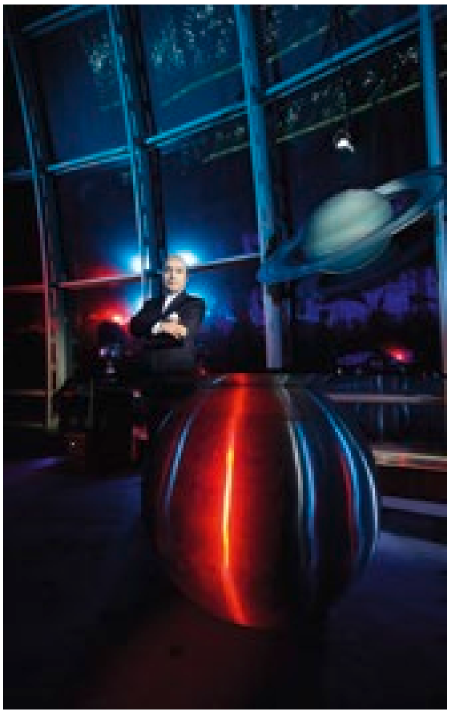

Figure 2. *Behind the scenes.*
Credit: Aseman-e-Shab/S. Saffarianpour

Figure 3. *The* Aseman-e-Shab *set. Credit: Aseman-e-Shab/S. Saffarianpour*

for which Siavash was co-producer and adviser. The success of this coverage led to another special program about the Mars missions late in 1999 and, as more content was signed off, Siavash moved through the roles of presenter, director and producer, gaining influence so that more astronomy content could be made.

Astronomy Day 2001: the beginning of *Aseman-e-shab*

In 2001 a group of young Iranian amateur astronomers decided to celebrate Astronomy Day in Iran. The idea came from Babak Amin Tafreshi, senior editor of *Nojum Magazine*, a monthly magazine that has been covering astronomy in the Persian language since 1991.

Siavash pitched the idea to IRIB-4 of producing a live TV show to celebrate Astronomy Day. It was to be a one-off one-night live show where people could call in and ask questions about astronomy and space.

"*We called the first programme The Night Sky, The Forgotten Nature, because we wanted people to start thinking about the night sky as a part of their natural environment, but a part they may have forgotten to look at,*" explained Siavash Saffarianpour.

The number of phone calls the show received during and after its airing was overwhelming and suddenly astronomy was being talked about around the country. The IRIB management asked Siavash to continue the programme and, inspired by the BBC's *The Sky At Night* with Sir Patrick Moore, he pitched a weekly live show. IRIB-4, however, decided they wanted the programme to air every night of the week.

Episodes brought groups of presenters and panelists together to discuss astronomy in front of screens of impressive graphics, had reporters visiting astronomical events like Messier marathons and astronomy day celebrations, and brought professional astronomers and science managers on air to introduce their work to the public and ask questions about opportunities and challenges in the field in Iran. A daily show, although only fifteen minutes per episode, was overwhelming for the production team. Each episode had to be packed with graphics, interviews and reports, and all on an almost non-existent budget.

After the first series, the show became weekly and, with more time and resource, started to invite astronomers and space activists from outside of Iran to tell their stories directly to Iranian audiences.

Advancement of science journalism in Iran

Aseman-e-Shab's use of primary sources to tell a story, like *Nojum Magazine* before it, marked a new age of science journalism in Iran which had previously relied on translation and secondary sources.

Guests during the last sixteen years of the show have included Anousheh Ansari (the first female space tourist), Firouz Naderi (former NASA Mars programme manager), Carolyn Porco (NASA's *Cassini* Mission), Cumrun Vafa (winner of the Breakthrough Prize in Fundamental Physics) and almost all of the Iranian astronomers, cosmologists and science historians. The show also moved beyond pure astronomy, crossing boundaries to look at the history of astronomy, art, philosophy, and even science fiction, and how they interact with science and astronomy.

The show also provided a platform to showcase special astronomical or space events. It broadcast both Venus transits live, aired a live report with an expedition team at the South Pole to observe the solar eclipse, and covered the *Huygens* landing on Titan.

Figure 4. *Siavash Saffarianpour (right) talking with Kazem Kookaram, amateur astronomer and specialist on observing sky events. Credit: Aseman-e-Shab/S. Saffarianpour*

Figure 5. *Sivash Saffarianpour, founder, producer and presenter of* Aseman-e-Shab*. Credit: Sepideh Faalkhah/Aseman-e-Shab*

Figure 6. *The* Aseman-e-Shab *set. Credit: Sepideh Faalkhah/Aseman-e-Shab*

On the scientific policy side, presidents of Iran, members of the parliament, ministers of science, managers of the Iranian Space Agency and others at the heart of Iranian policy making have been guests on the show and faced tough questions from its audience. Investigative reporting on Iranian science, such as the story of the Iranian National Observatory project and Iranian space programme, has also engaged with the politics behind science.

However, if this programme will be remembered for only one thing it will be the role it has played in changing the conception of science and astronomy amongst the general public. It has shown the people that science is not something boring and out of reach, and that astronomers and scientists are not untouchable people living in ivory towers. *Aseman-e-Shab* has inspired a new generation of Iranian Scientists.

"*The Night Sky played an important role in popularising science in Iran,*" said Dr. Reza Mansouri, the former Research Deputy of the Ministry of Science, Technology, and Research. Dr Mansouri is a cosmologist at Sharif University, former manager of the Iranian National Observatory project and one of the Iranian scientists who has worked for years in the field of scientific development in Iran. "*But more importantly, I think this programme played a major role in introducing and popularising the idea of scientific thinking and scientific method in society. This is much more valuable than just talking about information.*"

Inspiring a new generation of science enthusiasts

In 2017 *Forbes* magazine published its *30 under 30*, a list of 600 of the brightest young entrepreneurs, innovators and game-changers in the world. Payam Banazadeh, the co-founder of Capella Space and former JPL engineer is one of the people mentioned on that list. Long before he became a rising star in the space industry, Payam was a young teenager in Tehran and a huge fan of *Aseman-e-Shab*:

"*I remember coming home from school and being so excited to sit in front of the TV and watch the show. I would gather my entire family and almost force them to watch the show with me. The show gave me motivation, excited me about science, and put perspective behind all the concepts that I was learning in school. Most people struggle to find the purpose behind physics, math, and learning equations in school, and the show did a fantastic job of indirectly teaching the meanings to all those concepts and why they are important. It is because of such shows that I have stayed inspired and motivated to remain in this field.*"

The show not only helped people become interested in science and astronomy but also increased general knowledge about science and created a more supportive environment for those enthusiastic about science to follow it as a career path.

Azadeh Keivani, a Postdoctoral Scholar in particle astrophysics at Penn State University, was interested in astronomy before *Aseman-e-Shab* began but for her it was refreshing and encouraging to see state television broadcast a programme in her own field of interest:

"*Aseman-e-shab started not long after I got involved in astronomy. It was a great show, talking about the beauties of the night sky, the planets, the stars, space, and the Universe. On top of all the great things in this programme was the amazing eloquence of its host and the panel. Since the start of the show, the first reaction I get from people when I talk about my interest in astronomy is reference to the show. "Ah, yeah, Aseman-e-shab! We watch it every week!" Thanks to the show a love for astronomy was gradually becoming normal.*"

The effect of the show was not limited to the big cities in Iran either. In many remote and less developed villages of Iran, some teachers recorded the show and played it in their classrooms for students who did not have access to television. It became a source of education for many students.

Challenges are still ahead

Now, after sixteen years, 22 seasons and more than 900 episodes, Siavash is still working to produce an inspiring and informative show. The show is still broadcast once a week, on Friday night for one hour, and contains interviews, sky events, educational information and in-depth discussion about the world of astronomy.

Running a television show for such a long time, under different management systems and in the framework of Iranian state television, is challenging. Even sixteen years running successfully does not bring any guarantee for the future of the show and there is a constant fight to keep the show running and to keep its standards high.

The other challenge is competing with online media. The Internet enables new content to be produced and published with fewer boundaries and limitations. But because of this show the story of stars and the night sky is less forgotten in Iran and Siavash will continue to persevere: "*My philosophy has not changed. I want to talk about science and astronomy, inspire people to consider science and remind them that we all are living on this pale blue dot together.*"

Biography

Pouria Nazemi is an Iranian-Canadian science journalist and an amateur astronomer. He graduated from the Ferdowsi University of Mashhad in pure mathematics. For more than ten years he was senior editor and head of the science desk at *Jam-e-Jam* daily newspaper in Iran and a member of the *Nojum (Persian Astronomy) Magazine* editorial board. He was a member of the Iranian Astronomy Society on the Amateur Committee and participated in organising outreach and public events in astronomy and science. He has translated books on science and journalism into Farsi and also produces a weekly Persian-language science videocast — *IT Nights*.

A Website for Astronomy Education and Outreach

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Astronomy education, website, textbook, outreach, multimedia content

Teach Astronomy is a free, open access website designed for formal and informal learners of astronomy. The site features: an online textbook complete with quiz questions and a glossary; over ten thousand images; a curated collection of the astronomy articles in *Wikipedia*; a complete video lecture course; a video Frequently Asked Questions tool; and other materials provided by content partners. Clustering algorithms and an interactive visual interface allow users to browse related content. This article reviews the features of the website and how it can be used.

Introduction

Increasingly, people turn to the Internet for information. Over 90% of Internet users employ search engines to find information (Purcell et al., 2012) and 65% use the Internet as their primary source of scientific information (National Science Board, 2016). Traditional sources of scientific information such as textbooks written and curated by content experts are languishing as online information sourcing gains popularity, due in large part to the soaring price of printed textbooks (Senack & Donoghue, 2016). The new media landscape forces scientists and educators to find more effective ways to give the public accurate scientific information, on which complex societal issues increasingly depend (Brossard & Scheufele, 2013).

A Google search of the word astronomy returns well over a hundred million results. The most popular websites on astronomy are: those hosting new stories, like *Universe Today*[1] and *Space.com*[2]; those run by organisations that conduct astronomical research, like NASA[3]; or those that cater to amateur astronomers, like the websites *Sky and Telescope*[4] and *Astronomy Magazine*[5] (Jenkins, 2015).

Teach Astronomy[6] was started in 2011 to complement existing online sources of astronomy information and provide astronomy educators, students, adult lifelong learners, and amateur astronomers with high quality multimedia content. Some of the material present on the website is original whilst some is aggregated with the permission of outside parties.

An earlier article described the creation and early evolution of *Teach Astronomy* (Impey et al., 2016). The site has recently undergone complete reconstruction, with a new front end, a new back end, and significant new capabilities.

Site users

Google Analytics data show that the site has now had over a million sessions with more than 750 000 unique users and an average over the past two years of 45 000 unique users and 125 000 page views per week. The history of site visits is shown in Figure 1. Most users are in the USA (62%), followed by Canada (5.8%), the United Kingdom (5.7%), India (3.4%), Australia (3.2%), and the Philippines (3.2%). The site aims to appeal to a mixture of formal and informal learners and in 2017 we implemented a user survey which showed that the largest user groups are students (63%), amateur astronomers (15%), and college instructors (14%). In terms of age, 51% are in the range 18–24, 19% are in the range 25–34, and 19% are in the range 35–54.

Technology

The software behind *Teach Astronomy* was completely reconstructed in 2016. The previous code used Microsoft's web stack; the new code is built entirely on efficient, open source technologies. On the back end, we're using version 7 of a powerful, low-level scripting language called PHP: Hypertext Preprocessor[7], which provides production-level stability while enabling flexibility for the rapid deployment of new features. The backend system is designed to be segmented so that internal developers can build plugins to extend

Figure 1. *Daily visitor sessions to* Teach Astronomy *from early 2011 to late 2016. The data show seasonal dips each summer caused by the large fraction of students using the online textbook in place of a traditional textbook during the academic year.*

functionality and enable new features to be added quickly. With a growing number of visitors reaching the site from mobile devices (usually smartphones, not tablets), the front end is built on Zurb's Foundation[8] using a grid that flexes to automatically fit any screen size larger than 320 pixels through a web standard called media queries.

The newly developed code brought CPU and RAM usage down by almost 90%. This will enable us to add features without worrying about the hardware infrastructure. Such new features include a Content Management System (CMS) for maintainers of the site. We also plan to set up accounts for instructors, so that they can customise the content and the look and feel of the site for their specific purposes.

The most sophisticated technology behind *Teach Astronomy* is a mechanism for the indexing, clustering, and graphical delivery of astronomy content. A set of text-based items is sent to an indexing system called Lucene, by the Apache Foundation[9]. Lucene provides powerful algorithms to search through large collections of semantically related text. It calculates a "distance" between any two items in the index based on keyword overlap, so it is easy to list the "nearest neighbours" to any item. The output of a search and this clustering analysis is a graphical display called a Wikimap. The central node of the Wikimap is the closest match to a search and the nearest neighbours are shown as radial spokes (the default number is ten, for viewing convenience). Clicking on an outlying node centres that item, and a new set of nearest neighbours is displayed. The Wikimap provides an appealing method for browsing or "surfing" related content.

This approach is powerful and flexible. A Lucene index and the subsequent clustering can be created for any text-based content. The obvious application is for articles about astronomy, but images with keyword-rich captions work equally well, and for videos with transcripts the text of the transcripts is clustered. The nodes of the Wikimap are active, so clicking on them can pop up an article, an image, a video, or a URL. The Wikimap runs on HTML5, CSS3, and JavaScript. A full physics engine runs alongside the core renderer, dynamically keeping the nodes evenly spaced.

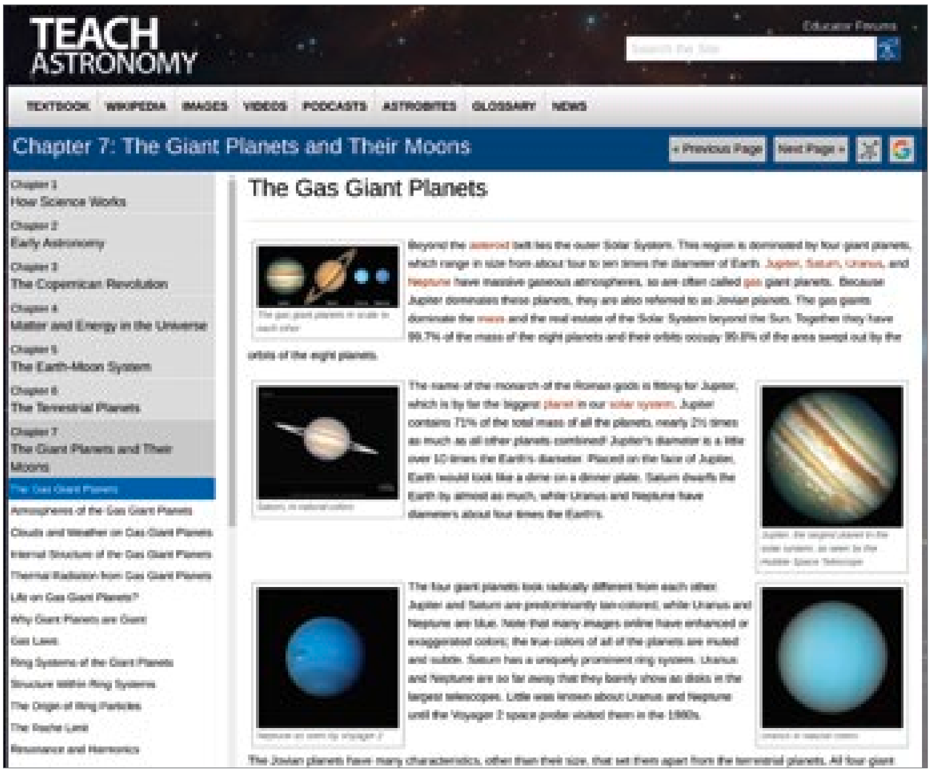

Figure 2. *A textbook article on* Teach Astronomy, *presented in standard chapter order. The open source figures are set in line in a format that adjusts to the web browser, even accommodating handheld devices. Credit: Teach Astronomy*

The most ambitious application of this technology is the curation of content from *Wikipedia*[10]. Astronomy is the testbed but we are extending the application to other subjects. *Wikipedia* is a largely unstructured collection of 5 million articles in English covering almost every topic imaginable, kept current by an army of editors (Mesgari et al., 2014). After capturing the entire set of articles, we use an algorithm called a naïve Bayes classifier. The classifier is given a set of hand-picked articles selected by an astronomy content expert, and a set of randomly chosen articles as a control. It then operates on the entire *Wikipedia* content to divide the articles into two categories: astronomy and non-astronomy. The process produces high completeness for relevant content at the expense of some contamination with unrelated content, but the Lucene indexing and clustering ensures that a user rarely encounters an irrelevant article.

Content

Each type of content on *Teach Astronomy* can be searched by keyword or phrase, and most can also be explored using Lucene clustering and visual display via a Wikimap.

Textbook

The core of *Teach Astronomy* is a set of over 500 articles and 400 000 words covering all topics in astronomy, written at the level of an introductory textbook. The articles are derived from a textbook (Impey and Hartmann, 1999), where figures in the book have been replaced by copyright-free images. The content is updated roughly once a year. The articles can be read in a traditional book order (Figure 2) or "surfed" using the Wikimap. Over 700 glossary terms are linked in the articles with pop-up definitions; the glossary can also be searched alphabetically. There is a quiz tool that draws from 1700 multiple choice questions, based on a search of a topic or a keyword. Articles can be translated into many languages using a Google Translate tool built into the web page.

Wikipedia

A unique component of the website is a walled garden of the astronomy content in the online encyclopaedia *Wikipedia*. The use of this resource for learning has been controversial in academia, but studies show that the science content is generally accurate (Konieczny, 2016; Casebourne et al., 2012). The benefit of *Wikipedia* is the long tail of articles on niche topics, plus the fact that editors keep articles current on topics where there is rapid progress. The naïve Bayes classifier returns over 70 000 astronomy articles, which can be accessed by keyword search and explored using the Wikimap (Figure 3). Every month, the entirety of *Wikipedia* is downloaded and the Lucene astronomy index is updated.

Images

There are 1200 images built into the online textbook, but *Teach Astronomy* also hosts two other large archives of astronomy images. One is *Astronomy Picture of the Day*[11], which now numbers over 7500 high resolution images. The other is NASA's *AstroPix*[12] which has more than 7100 images from ground- and space-based telescopes. Both image archives have captions with enough keywords to allow effective clustering and exploration with the Wikimap.

Videos

Teach Astronomy has over 1200 short video clips on astronomy subtopics created by the site authors. The videos are of one of the authors filmed on a green screen with astronomical backgrounds inserted. They are organised into 29 playlists on major topics, and taken together they form a complete video course. When accessed, the video clips play on an embedded *YouTube* viewer (Figure 4). They are also available on Apple's iTunes. The videos have transcripts, so can be searched by keyword. They create a thirty-hour video course, or they can be explored using the clustering tool.

A new feature of the site utilises live question and answer sessions that we have been conducting for two years for two massive open online classes: Udemy's *Astronomy: State of the Art* and Coursera's *Astronomy: Exploring Space and Time*. Questions on any topic are submitted by *YouTube Live* participants or by email and the video stream is posted every few weeks to *YouTube*. To increase the utility of live sessions, where the questions have no particular topic order, we transcribed the 1200 questions into a database, along

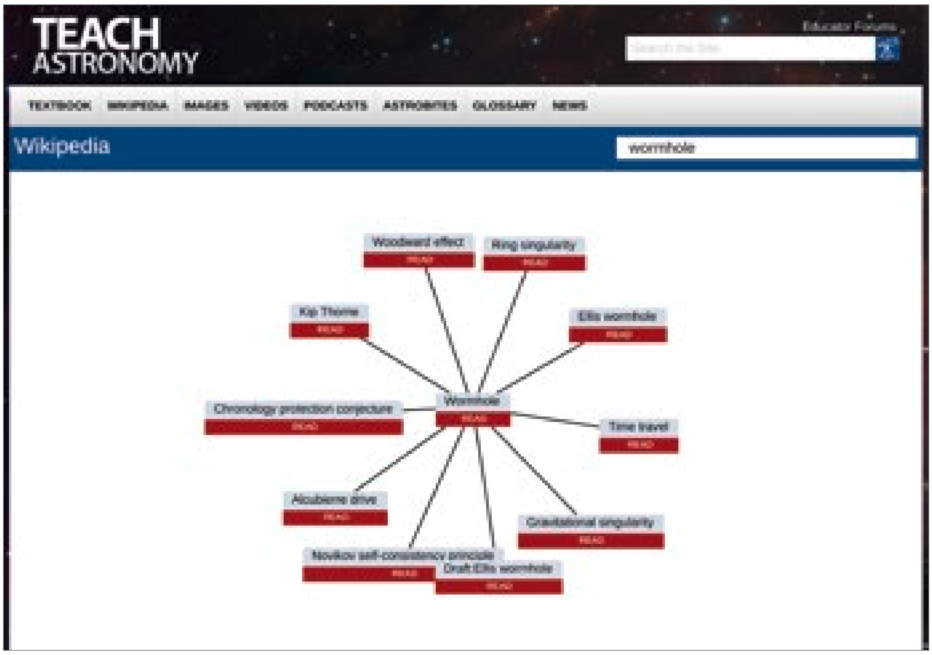

Figure 3. *A Wikimap of the* Wikipedia *content on* Teach Astronomy, *after a search on "black hole". The best-matched article is the central node, and the outliers are the ten most closely related articles based on keyword overlap. Credit: Teach Astronomy*

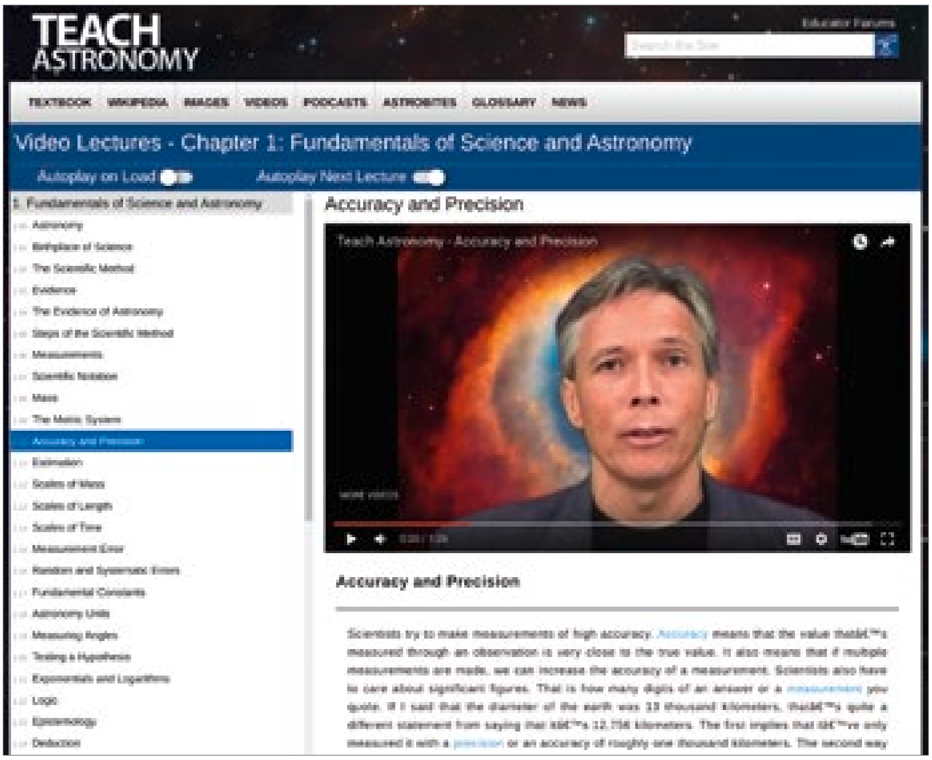

Figure 4. *Screen shot of one of the video lecture clips on* Teach Astronomy, *which can be played on an embedded* YouTube *player. Navigation on the left allows the user to stream an entire video lecture course. Credit: Teach Astronomy*

with time tags of their location in the video. Users type questions into a text box and get the closest answers based on keyword match in the database, with the video cued up to play at the appropriate time.

Partner content

By agreement with the curators of *365 Days of Astronomy*[13], *Teach Astronomy* hosts an archive of their 2000 podcasts. Most do not have transcripts, so they cannot be subject to the clustering process. We also host over 1000 summaries of important research papers, written by astronomy graduate students, called AstroBites.[14]. The summaries are suitable for science undergraduates or adults with some technical background. They can be searched by keyword. The final feature is an RSS feed from *Science Daily*[15], which posts three or four items on astronomy every day.

Testimonies

"*I have been using Teach Astronomy in my online introductory astronomy course for non-science majors at two separate institutions (South Florida State College and Florida Keys Community College) for the past four years. Shifting to this open educational resource textbook has been very well received by all my students (approximately 200 per year). I was initially concerned about providing access to the course textbook that is available only online but with rare exception, very few students complained while many of them thanked me for helping to reduce the cost of their education.*" — Erik Christensen, Dean of Applied Sciences and Technologies at South Florida State College. Erik holds engineering degrees from the U.S. Naval Academy and MIT. The main attraction of the site for him and his students is the textbook.

"*There is a need to supplement existing information with more images and videos, web links for additional information, and include wherever possible more references to amateurs, what they have done and what more they could do in the future, especially in terms of providing more information about the use of amateur telescopes and professional-amateur collaborations, past present and future…. I think the site is fabulous. I could spend many enjoyable weeks and months learning from the information you have provided there.*" — Irene Kitzman, a psychiatrist and amateur astronomer who spends much of her spare time at her telescope enjoying the dark skies of Portal, Arizona.

"*An outstanding, comprehensive website! And amazingly, it is free. It will be a great help for the MOOC learners (and the mentors) as they can just be given the link and then find what they are looking for and much, much more. The layout makes it extremely easy to use. It took me back to a time when the World Wide Web was new and searching for one thing led me to site after site exploring further and deeper. For lifelong learners and space enthusiasts it is a veritable treasure trove.*" — Christy Read, who grew up under the dark skies of Indonesia and four years ago discovered MOOCs. She has since taken around forty courses. She has taken about 40 astronomy courses on various platforms.

Notes

1. *Universe Today*: https://www.universetoday.com/
2. *Space.com*: https://www.space.com/
3. NASA: https://www.nasa.gov/
4. *Sky and Telescope*: http://www.skyandtelescope.com/
5. *Astronomy Magazine*: http://www.astronomy.com/
6. *Teach Astronomy*: http://www.teachastronomy.com
7. PHP: http://php.net/manual/en/intro-whatis.php
8. Zurb Foundations: http://foundation.zurb.com/
9. Apache: https://lucene.apache.org/
10. https://en.wikipedia.org/wiki/Main_Page
11. *Astronomy Picture of the Day*: http://apod.nasa.gov
12. *AstroPix*: http://astropix.ipac.caltech.edu
13. *365 Days of Astronomy*: http://365daysofastronomy.org
14. *AstroBites*: http://astrobites.org
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Biographies

Chris Impey is Professor of Astronomy and Associate Dean of Science at the University of Arizona. Winner of eleven national and university teaching awards, he has taught over 100 000 students in two massive open online classes, or MOOCs. He has written over 200 research articles on cosmology, fifty popular articles, and seven books on astronomy topics.

Alexander Danehy is a graduate of the University of Arizona. He has multiple degrees and extensive experience in software development, design, and engineering. He is a web developer and programmer in the Department of Astronomy at the University of Arizona.

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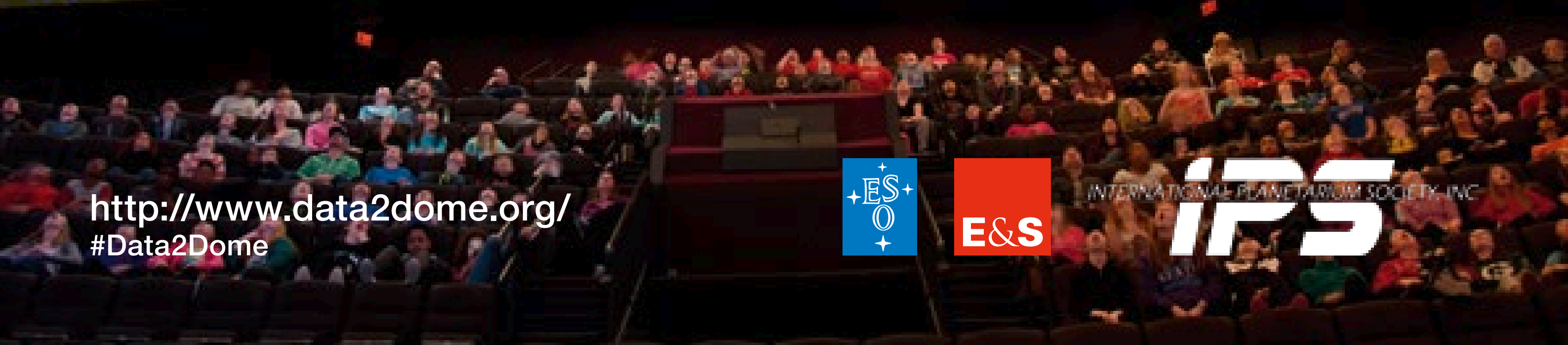

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