CAP journal
Issue 24 | October 2018
Communicating Astronomy with the Public

Virtual Reality
Walking into an exploded star

Astronomy and Cartoons
Stimulating interest using comics and animation

Under One Sky
Exploring the IAU 100th anniversary activities

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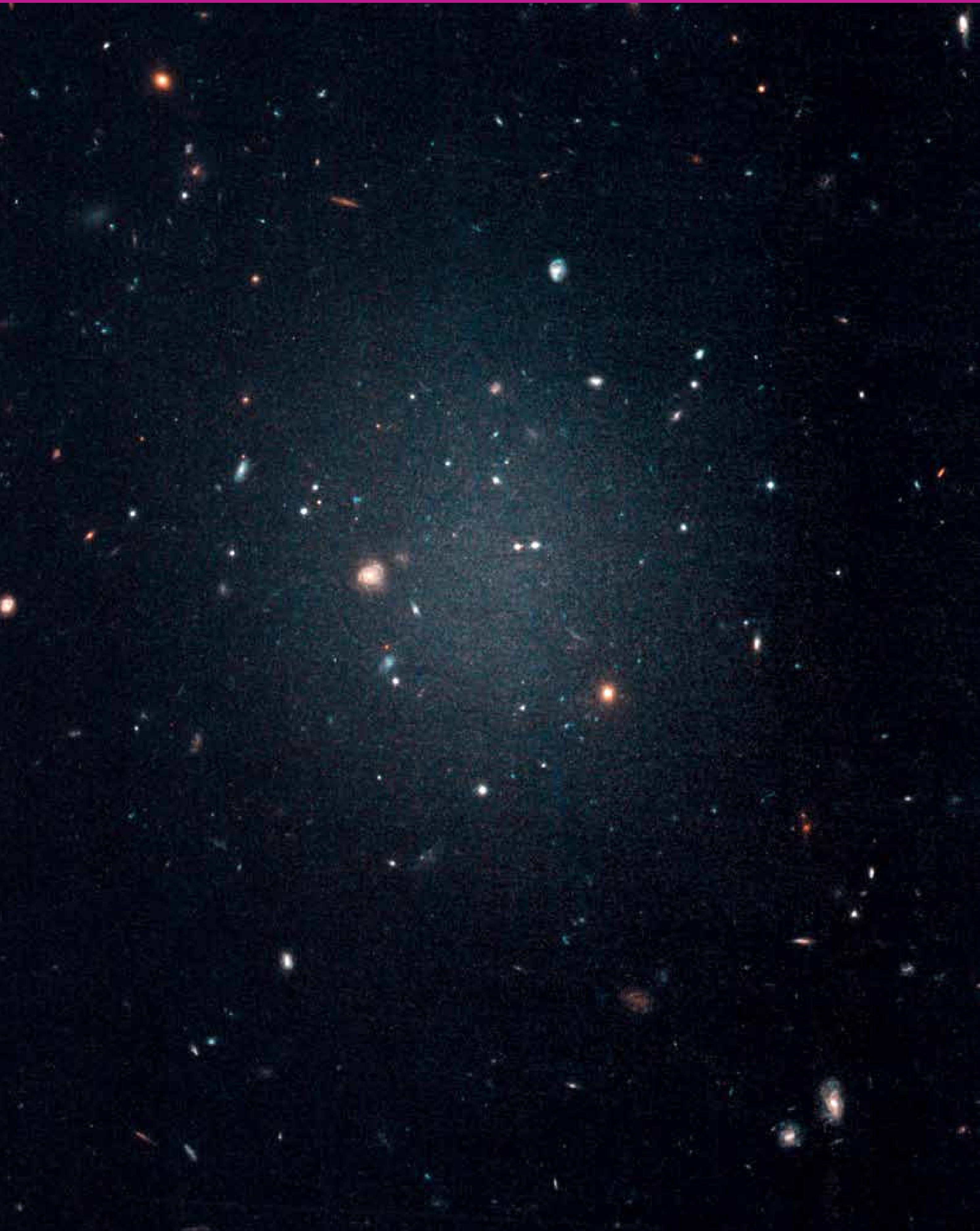
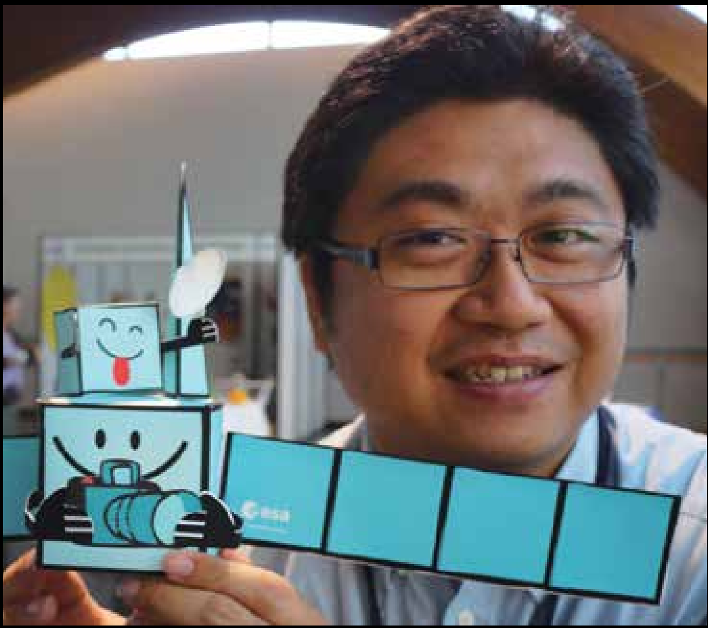
IAU
100 Years: Under One Sky

For the first time, astronomers have discovered a galaxy without dark matter. The galaxy pictured here, known as NGC 1052 DF2 contains very little, or possibly no, dark matter. This directly challenges the dominant theory which states that all galaxies require dark matter in order to form. Credit: NASA, ESA, and P. van Dokkum (Yale University)





Editorial

Since publication of the last issue of CAPjournal, there have been two significant conferences of relevance to our community. The first was the Communicating Astronomy with the Public conference (CAP2018) which was held in Fukuoka, Japan, in March with more than 400 participants in attendance. More recently, the IAU 30th General Assembly (GA) was held in Vienna, Austria, in August.

As part of the IAU GA the new IAU Strategic Plan for the 2020–2030 period was launched. The plan lists actions on how the IAU will engage the public in astronomy including the establishment of a new IAU office — the Office of Astronomy for Education (OAE). The full plan is available on the IAU website, if you have any ideas on implementing these actions, please feel free to contact us.

As we know, astronomy research can drive technological advancement and, at the same time, technologies create new ways for us to communicate research. In this issue, you will find articles exploring these uses of technology, including the use of virtual observatories, virtual reality technologies, video and animations.

With the IAU 100th anniversary celebrations in full swing now is an excellent time to conduct outreach activities, don't miss it and don't forget to tell us what you are doing to contribute. I would also like to ask once more for your help in providing feedback on CAPjournal by filling in a survey (see page 24). Your opinions and inputs are much appreciated. In the meantime, happy reading.

Clear skies,

Sze-leung Cheung
Editor-in-Chief of CAPjournal

Contents

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Cover: A virtual reality experience using 3D data of Cassiopeia A allows the user to walk inside the debris from a massive stellar explosion. More on page 17. Credit: NASA/CXC/SAO/ E. Jiang.

Explained in 60 Seconds: Virtual Observatory

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Virtual observatory (VO) is the name given to the idea of a cyber infrastructure for global astronomical research and education activities. Such an infrastructure takes advantage of information technology and big data in astronomy to facilitate international coordination and collaboration and enable global access to data gathered by astronomical observatories. More than twenty countries and regional members have formed the International Virtual Observatory Alliance (IVOA), a worldwide scientific organisation whose mission is to promote the research and development of a VO internationally[1]. The role of VO projects is to develop tools for end-users, while IVOA defines the protocols and specifications for data compatibility that make this possible. Important protocols include having a common data format, data models, query languages, data access interfaces and applications.

Notes

1 More information on IVOA: http://ivoa.net/

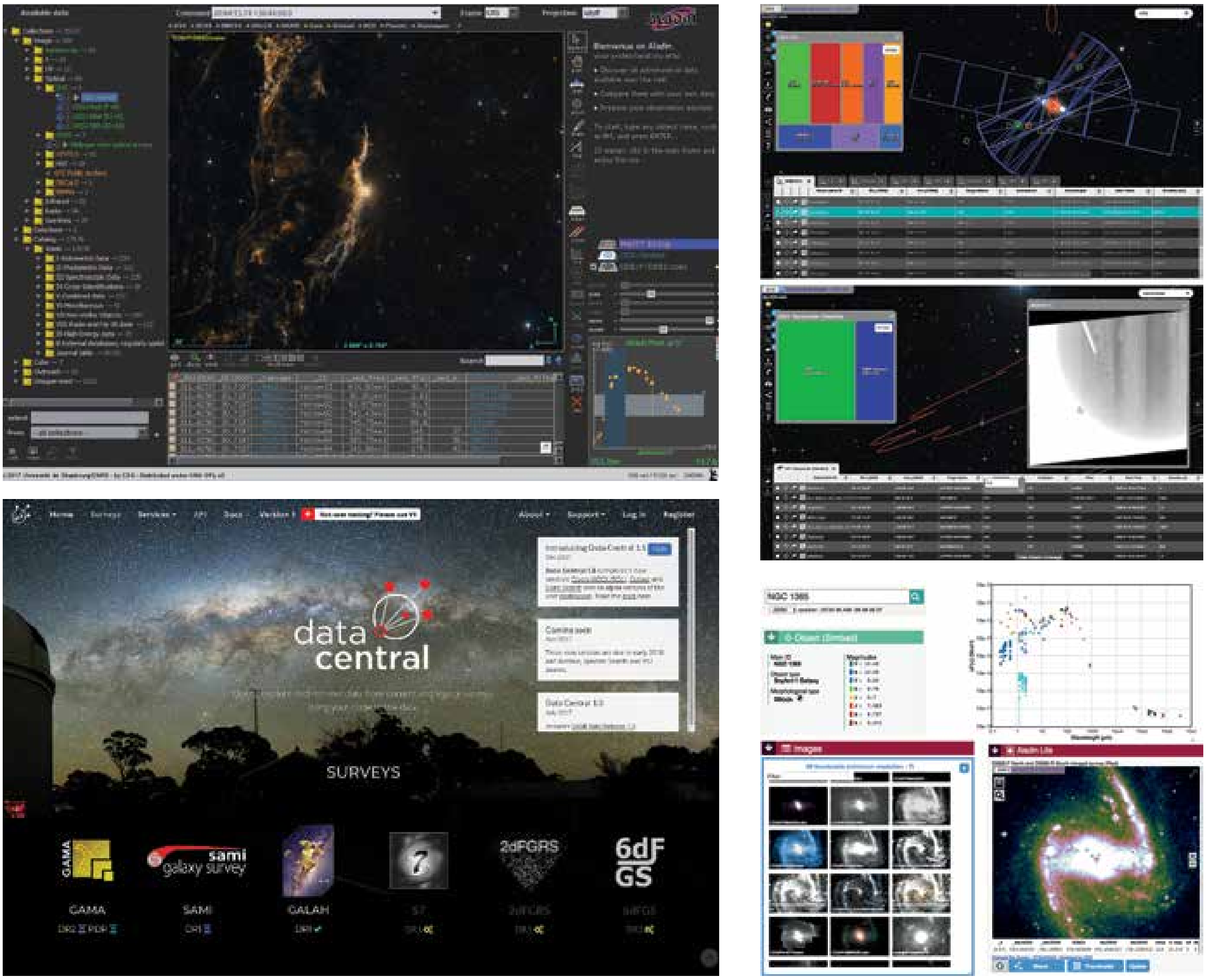

Figure 1. *Samples of virtual observatories interfaces: Aladin Desktop (top left); ESASky (top right); AAO Data Central (bottom left); and CDS Portal (bottom right). Credit: International Virtual Observatory Alliance.*

IAU100 Celebrations Launched at the IAU General Assembly in Vienna

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The International Astronomical Union (IAU) is eager to celebrate its 100th anniversary in 2019. Celebrations and events will take place year-round to stimulate worldwide interest in astronomy and science.

As part of the central theme Under One Sky, the IAU will reflect upon important milestones and discoveries in the past century, while looking ahead at what is to come. Events and activities will be open to all ages and will take place at a regional, national and international level. The IAU invites the global astronomical community, policy makers, students and the general public to take part in the IAU100 celebrations.

IAU100 Global Projects Overview

The IAU is organising a comprehensive programme of flagship initiatives to reach target audiences worldwide through the IAU National Outreach Coordinators and national astronomical societies. Below is an overview of just some of the exciting events planned for IAU100.

Above and Beyond Exhibition

The Above and Beyond open source exhibition was launched at the 2018 IAU General Assembly in Vienna, Austria. The exhibition was commissioned as part of the IAU 100th anniversary celebrations and showcases some of the most significant and surprising astronomical breakthroughs that have shaped science, technology and culture over the last century. Designed in the spirit of open science, it is designed as a travelling exhibition, touring major European cities in 2018 and 2019, and is accompanied by an open source toolkit to develop a variety of exhibition experiences worldwide. The exhibition is a collaboration between the International Astronomical Union and Science Now, a science communication and strategic design studio.[1]

100 Hours of Astronomy

This project invites anyone to arrange stargazing and other astronomy-related events around the world from 10 to 13 January 2019 to kick-off the anniversary celebrations. Organisers get a chance to win exciting prizes.[2]

IAU Einstein Schools

This initiative will develop a global network of Einstein schools with classes and clubs for learning about gravitation and general relativity and their relevance to the 1919 solar eclipse, which will have its 100th anniversary in 2019.[3]

Dark Skies for All

This effort will raise awareness about the preservation of quiet and dark skies. The project will encourage individuals to organise activities worldwide around the UNESCO International Day of Light, which is on 16 May. A call for Dark Skies ambassadors will be launched in autumn 2018.[4]

50th Anniversary of Moon Landing — Let's Observe the Moon!

IAU will encourage people worldwide to celebrate the 50th anniversary of the landing on the Moon on 20 July 2019 by organising activities related to space and Moon observations.[5]

Name ExoWorlds II

This initiative provides an opportunity for all the countries of the world to name an exoplanetary system.[6]

Inspiring Stars

This international exhibition highlights global initiatives that address the concept of inclusion in astronomy outreach and careers. The exhibition premiered in Vienna in August 2018 during the IAU General Assembly and will be organised in different countries throughout 2019.[7]

Open Astronomy Schools

This project will build teachers' knowledge on scientific topics and teaching techniques by organising teacher training worldwide to enable the development of scientific literacy and the acquisition of 21st century skills.[8]

IAU Women and Girls in Astronomy Day

This project will celebrate the United Nations International Day of Women and Girls in Science on 11 February through the organisation of activities involving astronomy.[9]

Get involved!

We have launched a new website dedicated to the IAU100 celebrations which talks about the multitude of astronomy events taking place worldwide and offers further information about the programmes and partnership opportunities.

Whether you are a professional working in astronomy, an amateur astronomer or just someone interested in astronomy, we would love for you to get involved in the celebrations. Please check IAU100 for the latest updates and get in touch with the IAU100 Secretariat for sponsorship opportunities or to endorse your astronomy event and have it included in the IAU100 Event Programme.

Full IAU100 website: www.iau-100.org

Notes

1. Exhibition website: http://100exhibit.iau.org/
2. 100 Hours of Astronomy website: www.100hoursofastronomy.org
3. Einstein schools website www.einsteinschools.org/
4. Dark skies for all website: www.iau-100.org/dark-skies-for-all
5. Moon landing anniversary website: www.iau-100.org/moon-landing-anniversary
6. Name ExoWorlds II website: www.iau-100.org/name-exoworlds
7. Inspiring stars website: www.iau-100.org/inspiring-stars
8. Open Astronomy Schools website: www.iau-100.org/open-astronomy-schools
9. Women and girls day website: www.iau-100.org/women-girls-astronomy-day

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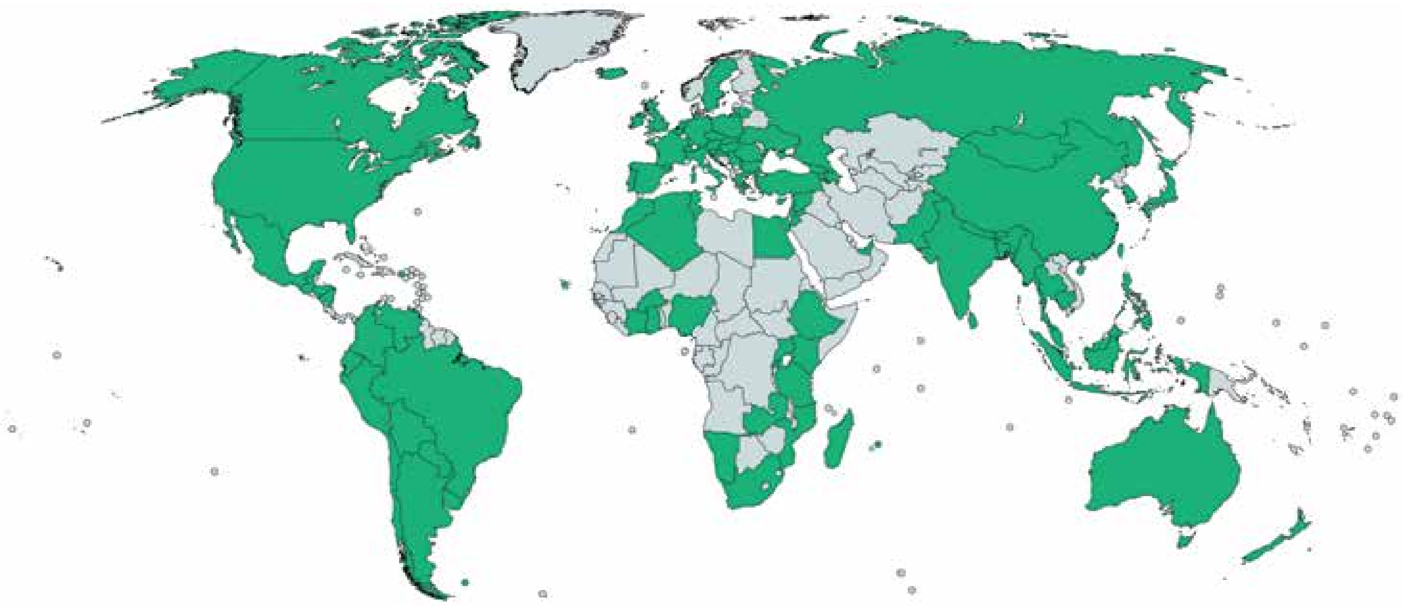
Call for IAU National Outreach Coordinators (NOCs)



Dear colleagues,

The IAU is seeking candidates to become the National Outreach Coordinators (NOCs), the NOCs will play a significant role in coordinating the IAU 100th anniversary activities. If your country/region does not have a NOC, and if you are interested, please contact outreach@iau.org or forward this message to any potential candidates.

The current list of NOCs is on https://www.iau.org/public/noc/
Further details on NOCs is available on https://www.iau.org/public/noc/role/

IAU Office for Astronomy Outreach

Costellazione Manga: Explaining Astronomy Using Japanese Comics and Animation

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Keywords
Public outreach, science communication, informal education, planetarium show, learning development

Comics and animation are intensely engaging and can be successfully used to communicate science to the public. They appear to stimulate many aspects of the learning process and can help with the development of links between ideas. Given these pedagogical premises, we conducted a project called Costellazione Manga, in which we considered astronomical concepts present in several manga and anime (Japanese comics and animations) and highlighted the physics behind them. These references to astronomy allowed us to introduce interesting topics of modern astrophysics and communicate astronomy-related concepts to a large spectrum of people. In this paper, we describe the methodology and techniques that we developed and discuss the results of our project. Depending on the comic or anime considered, we can introduce general topics such as the difference between stars, planets and galaxies or ideas such as the possibility of finding life on other planets, the latest discoveries of Earth-like planets orbiting other stars or the detection of complex organic molecules in the interstellar space. When presenting the night sky and the shapes of constellations, we can also describe how the same stars are perceived and grouped by different cultures. The project outcomes indicate that Costellazione Manga is a powerful tool to popularise astronomy and stimulate important aspects of learning development, such as curiosity and critical thinking. We show through our experience that Costellazione Manga has attracted a broader and more diverse public than traditional planetarium activities and astronomy lectures.

Introduction: The Role of Comics and Animation in Education

Walt Disney argued that animation is a flexible and stimulating tool that is well suited for the purposes of explaining and teaching, provided that an educator knows how to use it (Disney, 1948). Although it may seem unusual to make use of fantasy characters to popularise astronomy or other general science subjects, such use is in fact a long-standing practice that started in America in the early 1940s. During World War II, Disney started to produce many animated films aimed at popularising the practical and technical aspects of war, for example the workings of US aviation. These movies were followed by many others that promoted everyday topics such as the importance of of good nutrition or good hygiene for disease prevention. Other films, based on the scientific knowledge of the time, described human anatomy and behaviour, including *Reason and Emotion* (1943), a precursor of sorts to the recent Pixar movie *Inside Out*.

We also find examples of the use of cartoons in education and learning in Japan. One of the most famous authors currently is Leiji Matsumoto, creator of several comics and animated series such as *Galaxy Express 999*, *Captain Harlock*, *Queen Millennia* and *Space Battleship Yamato* (also known as *Star Blazers*). Some of the characters and plot lines of these sagas were reused and adapted into shows to be projected inside a planetarium. Leiji Matsumoto himself is active in popularising astronomy and in collaborating with universities and magazines to create special lectures and outreach conferences (Murakami, 1997).

Unfortunately, in some countries (including our own country, Italy), comics and animation have traditionally been seen as a lower type of art, mostly aimed at young individuals, and they are not considered worthy of the interest of adults or professionals. However, the market for comics and animation is changing and has expanded to include many authorial works and translations of world-known classics. Italy, France and Germany are the three largest markets for manga in Europe (Bouissou et al., 2010). An encouraging sign of change is that at the beginning of 2017, the magazine *Le Scienze* (the Italian edition of *Scientific American*) started to print a series of comics made for outreach purposes that include several works originally published in Europe, Japan and the USA. The topics of these comics range from astronomy, physics and biology to computer science and mathematics.

Effectiveness of Comics and Animation in Education

Several fantasy and science fiction comics and anime contain references to physics and astronomy. Most of these references are not fully explained but instead used as plot devices; other times, they are just embellishments. Following the path already proposed by Walt Disney and the example given by Leiji Matsumoto, we set out to create a planetarium show and other activities that would delve further into the science alluded to in our favourite mangas and address the questions that arose from them. These questions not only act as a starting point to generate curiosity about astronomy but also ignite a passion for asking questions and looking for

***Figure 1.** Front of the flyer for the first edition of Costellazione Manga, held in 2011 in Ravenna, Italy. The subtitle may be translated as "Stars in Japanese comics and animation". Credit: D. Dall'Olio*

answers, thereby connecting the pleasure of reading science fiction to the process of discovery. In the following sections, we describe some of the pedagogical premises on which our project is based.

Many formal and complex concepts can be easily transmitted to the public with the help of cartoons and comic books that support the learning process (Tatalovic et al., 2009; Hosler & Boomer, 2011). Using references from comics and animation is a way to reduce formality and break the wall between scientists and the public. Such an approach includes most of the "dimensions of change" that identify modern and effective science communication[1]: storytelling, humour, artistic expression, science as part of everyday life and emotion (since adults from the general public probably have childhood memories of several of the series). Moreover, it has been shown that learning is deeply connected to previously acquired knowledge: students connect the new things they learn to what they already know, and the same happens for the general public when they learn new things (Hemminki et al., 2013).

There are two possible approaches to using comics and animation for teaching purposes. One follows in the footsteps of Disney's seminal work and includes works produced with the main purpose of explaining a subject. Historical examples are Bruno Bozzetto's prize-winning animations for the Italian science outreach TV programme *Quark*. Sweden also has a tradition of animated documentaries. A number of comics dealing with many varied fields are nowadays on the market and under production to satisfy the curiosity of the public. The second approach takes an opposite stance, where no new material is produced but what people have already seen and is already part of their backgrounds is instead built upon. The main examples of this approach are L. Krauss's book *The Physics of Star Trek*, J. Kakalios's book *The Physics of Superheroes* (more pertaining to comics and animation) and T. Handa's book on understanding astronomy *Space Battleship Yamato 2199*. These books take something most people know, at least superficially (in *Star Trek*, spaceships travel faster than light; Superman flies; etc.), to introduce a topic and discuss the underlying science (Why is the speed of light a limit? What is gravity?). Since this approach builds on pre-existing knowledge, by choosing the right cultural reference, it can directly hook people's emotions and memories. Our project Costellazione Manga[2] follows this latter approach and, in the next sections, we will give an account of how and why it works.

The Birth of Costellazione Manga

Japanese animation started to be imported to Europe at the end of the 1970s. In Italy, the breakthrough happened in 1978, when the national TV broadcaster RAI imported the anime *UFO Robot Grendizer* (localised as *UFO Robot Goldrake* and also known in several other countries as *Goldorak*, from the French adaptation). *Grendizer* — a show so different from the Italian production, Disney and Hanna–Barbera styles and even from the European/Japanese co-productions of the time[3] — was met with huge success. New songs for the opening and closing titles, written by some of the best Italian composers of the time, probably contributed to the success: their disc sold more than one million copies. *Grendizer* even had an impact on the older generations, not least because of the controversies that arose when it was first aired (Nicora, 2017; Montosi, 2007).

A combination of the liberalisation of TV broadcasting and availability of cheap imports made Japanese animation the dominant form of children's entertainment throughout the 1980s and 1990s, with non-Japanese animation soon becoming the minority. This created a shared system of imagery and cultural references for at least one generation, whose members are now in their thirties and forties, although the most popular shows are known by younger and older generations, too (Pellitteri, 2018). It is on these shared cultural references that we based the development of our planetarium shows, seminars and nightly observations.

The Costellazione Manga (Manga Constellation in English) adventure started in October 2011 (Figure 1), during the 9th Edition of "Japanese October", a cultural event organised by the Association for Cultural Exchanges between Italy and Japan (ASCIG) in Ravenna, Italy. In the initial stages of the project, the authors collaborated with and benefited from the expertise of Marco del Bene, the President of the ASCIG and associate professor at the Department of Oriental Studies, La Sapienza University in Rome, and Alessandro Montosi, a freelance writer and expert on Japanese animation and its impact in Italy. Since the first conference, hosted by the Planetarium of Ravenna (Figure 2), we have been collecting ideas and materials from several manga and anime (Dall'Olio, 2015), considering both works that are famous worldwide and the more avant-garde ones. The proposed stories are often pure fantasy or science fiction. From these, we built an outreach show that aims to take the public through an unusual universe: not just an imaginary and fictional travel across the bizarre and funny adventures narrated in manga and anime but also an astrophysical journey exploring the starry sky.

Costellazione Manga: How to Build a Space Journey through Manga and Anime

In this section, we will describe the methodology that we used to create one of the Costellazione Manga shows. We will provide some examples of the manga and anime used, tips on how to use astronomy-related references and descriptions of how we develop them during the show.

Methodology

All the planetarium shows, seminars and activities related to Costellazione Manga have been offered as educational activities. The Planetarium of Ravenna has a Zeiss ZKP 2 analogue projector that is able to project more than 3000 stars in the two hemispheres and seat 60 people inside the dome (Figure 2). In general, the show is organised as a space journey across the starry sky, starting with a brief introduction to basic astronomical concepts and then simulating the sunset and the lighting up of the first evening stars. This introduction is needed to give first-time visitors the opportunity to understand how the planetarium works. Moreover, having time to let the eyes adjust to the darkness is useful for everyone. After the introduction, we recall the plot of the first manga or anime in our schedule and then start to highlight the astronomy-related references and peculiarities. We organise a guided tour between constellations and objects in order to cover several parts of the starry sky visible at that time of the year and connected to specific anime or manga. The maximum duration of a show is 60 minutes, so we typically touch on three anime/manga. Since these comics are so popular, the audience immediately recognises them and we need only a few minutes to describe the parts of the plot with astronomy-related references. Finally, we summarise what we have talked about and then leave time for questions.

Figure 2. *The Planetarium of Ravenna, Italy, in 2017. Left panel: The Zeiss analogue planetarium inside its dome. Right panel: Entrance to the planetarium building, showing the dome and the sundial panel. Credit: M. Garoni*

A sample script can be found in Table 1.

When conducting activities outside the planetarium dome, such as seminars and lectures, we prepare slides with sky charts to show the constellations and the position of various objects in the sky instead of using the dome-projected sky. The number of anime/manga used can be varied at the request of the seminar or lecture organiser, and we can also offer games, riddles and quizzes to generate a buzz. These devices also help the audience remember concepts, develop critical thinking and build links between topics.

Example script of a planetarium show	Duration (minutes)
Introduction.	5
Manga/anime 1 (e.g., *UFO Robot Grendizer*): description.	5
Astronomical references in *Grendizer*: Vega, M57 (Ring nebula), difference between planetary nebula and planetary system.	10
Manga/anime 2 (e.g., *Galaxy Express 999*): description.	5
Astronomical references in *Galaxy Express 999*: feasibility of space travel, comparison between artist impressions and real images.	10
Manga/anime 3 (e.g., *Saint Seiya*): description.	5
Astronomical references in *Saint Seiya*: constellations, objects inside the constellations.	10
Conclusions and questions. Feedback.	10

Table 1. *Sample script.*

When we organise night excursions, we use nothing but telescopes and a laser pointer to show the location of the object in the sky. In this case, the comics selection depends on the season, as some constellations or objects may only be visible at certain times of the year.

For both seminars and night excursions, the format can remain similar to that of the planetarium show or it can be modified on the basis of specific requests. For example, if the night excursion is organised in a nature reserve, we usually alternate the observations of the sky with other sensorial activities such as listening to the calls of night birds or smelling the scent of night flowers or other plants. At the end of the activities, we always leave time for questions and feedback (oral or written anonymous feedback).

Examples of Manga and Anime Used in Costellazione Manga

Galaxy Express 999: A Variety of Extra-Solar Planets

Leiji Matsumoto's *Galaxy Express 999* (Figure 3) tells of a future in which Earth has changed. Wealthy people live in mechanical bodies capable of surviving

Figure 3. *The cover of the Japanese edition of* Galaxy Express 999*, by Leiji Matsumoto. We see the two protagonists and Andromeda galaxy, the final destination of the fictional train. Credit: Leiji Matsumoto*

for hundreds of years, immune to diseases and ailments. Poor people face the most abject conditions. It is rumoured that in a distant planet in the Andromeda Galaxy, a mechanical body can be obtained for free. However, finding the money for a ticket to get there is a problem. The ticket is for the *Galaxy Express 999* intergalactic train. This is how the adventure begins for the two protagonists, the young Tetsuro and his mysterious guide Maetel, who travel to unknown and bizarre planets and stars. On this journey, we do not have precise astronomy-related references as Matsumoto invents almost all the saga's astronomical places, apart from the Andromeda galaxy and the Solar System. This comic gives us the chance to talk about observations of other planetary systems and the possibility of finding rocky planets, water and other molecules. We can also discuss the recent discoveries of Earth-like planets that orbit low-mass stars and how they can shed new light on the origin and evolution of planetary systems with more than two or three bodies (Gillon et al., 2017).

In *Galaxy Express 999* we find several images of the planet Mars. The images taken from the comic can be compared with real images observed by the satellites in orbit around Mars or by the robots on its surface. Thanks to this comparison, we can highlight the differences and the similarities between the artistic impressions and real scientific images, which stimulates the learning process. Quizzes can also help: for example, we show several pictures of Mars and of the Atacama Desert on Earth, and we ask the audience to Figure out which pictures are from Mars and which are from Earth and why they think so. Thanks to the recent discovery of water on Mars (Orosei et al., 2018), another possible topic is the history of water in our Solar System, from the chemical processes involved in the protostellar cloud to the presence of water on the planets. Moreover, since *Galaxy Express 999* features intergalactic travel on board a train, we usually discuss the feasibility of space travel, showing the difficulties of building a spaceship and the challenges that engineers face.

2001 Nights: A Realistic View of Space Travel

Written and drawn by Yukinobu Hoshino, *2001 Nights* (Figure 4) is an anthology, with the first three issues published between 1984 and 1986 and the last one in 2006. Unlike most other comics mentioned in this paper, its main characters are neither heroes nor villains but just representatives of humanity. In a number of short stories, 400 years of space exploration and evolution by human beings are narrated. Stories cover a range of advancements, from the first steps in space to a possible future colonisation of the Universe. Topics include fear, dreams and awareness of the solitude and fragility of human presence in space. Space exploration is analysed from both a physical and psychological point of view. The comic has a lot in common with science fiction films and books, with some atmospheres and settings closely resembling those of Arthur C. Clarke and Stanley Kubrick's *2001: A Space Odyssey*; other references include *Matrix* and *Avatar.* The title of the comic itself is not only a reference to Kubrick's masterpiece but also to the *One Thousand and One Nights* collection of tales, with which the comic shares the narrative structure. In *2001 Nights*, the Universe is perceived as slow: no fast chases, no spaceships rushing in battle, but a slow and difficult quest. It may even happen that after 400 years in the cosmos, humans realise they are not cut out for life in space after all. Despite having founded colonies and having many more worlds to explore, humans feel homesick and decide to go back to Earth. This manga can give us the chance to discuss the topic of space travel in a more realistic way than the previous example of *Galaxy Express 999* does. We can discuss the history of space exploration and talk about the recent successes of aeronautics, such as the Space X program. Moreover, we can illustrate the discoveries made thanks to probes and satellites launched to reach planets and other objects in our Solar System, such as *Juno, Rosetta, New Horizons* and *Cassini.*

We are still in the early phase of space exploration, which is mostly conducted using robotic probes. In the show, we use the example of the *Voyager 1* probe to show how difficult it is to programme a space mission and how long a satellite has to travel to reach other planets or the edge of our Solar System. Indeed, at several times during the last decade, we have had updates on the status of the *Voyager 1* probe, which is thought to have reached the heliopause (the point where the solar wind meets the interstellar medium). Forty years since its launch, it has travelled 120 au[4], making it the human-made object that has gone the farthest from Earth; it has gone beyond the heliosphere and is now travelling towards the Oort Cloud. However, for it to exit the Solar System, it has to travel another 100 000 au, which will take more than 30 000 years[5]. This probe is also

Figure 4. *Cover of the Italian edition of* 2001 Nights *by Yukinobu Hoshino, published by Flashbook. A hard science fiction work describing the human venture of exploring space. Credit: Y. Hoshino*

mentioned at the beginning of the manga in a very realistic sequence that illustrates the famous plaque that carries images of two humans and the Solar System. In one of Hoshino's stories set in the far future, technical developments allow faster-than-light travel, and humans reach *Voyager 1* to recover it.

This manga can also be used to introduce the topic of international collaborations under the common objectives of sustainable development and wellness for everyone. It is important to make the public aware that people of different cultures and nationalities can fruitfully work together in science, especially for the younger generations. Both in reality and in Hoshino's work, humanity is aware of its limits but wants to overcome them in a continuous quest for knowledge and growth. With this spirit, astronomy can help to create a better society by promoting peace and collaborations and making people aware that we are living under the same sky and that our planet is a small blue dot in a very big Universe.

Hokuto No Ken: Asterisms, Constellations, and the Traditional Chinese–Japanese Sky

Fist of the North Star (Hokuto no Ken) is a saga by Buronson and Tetsuo Hara (Figure 5). The plot starts with a nuclear war that has destroyed the planet and left humanity confined in small groups fighting each other for the small supply of remaining food and water. The main character, Ken, is the master of a deadly martial art called Hokuto Shinken. Opposing him are many members of the Hokuto and Nanto schools of martial arts. Both schools take their names from asterisms of the Chinese/Japanese sky: while Hokuto corresponds to the Big Dipper, known in Japan as Hokuto shichi sei (meaning "seven stars of the North"), Nanto is a group of six stars in Sagittarius whose shape is a mirrored image of the Big Dipper and that is part of a larger asterism known as the Teapot (Hokuto and Nanto literally mean "north star" and "south star", respectively, although the character used for "star" in both words may also mean "asterism"). On Ken's chest is a scar resembling the stars of Hokuto and, for this reason, he has the nickname of "seven-star man".

The purpose of the Hokuto school of martial arts is to guarantee peace, and Ken

Figure 5. *The cover of the Japanese manga* Hokuto no Ken*, by Buronson and T. Hara. The scars shaped as the seven stars of Hokuto are visible on Ken's chest. Credit: Buronson-Hara*

is forced into a long struggle to be able to finally bring peace into this dystopian world. During his trip, Ken has to fight against other martial arts masters, risking his life several times. While the manga has many references to Bruce Lee's films and the *Mad Max* saga, the plot dates back to an old Japanese legend that tells the story of seven brothers involved in a war against each other in order to conquer the entire country. Only the youngest of them succeeds in stopping the war and bringing peace to his brothers in heaven, where they become the seven stars of the Big Dipper.

The above references allow us to explain that the word constellation has a much more precise meaning than the word "asterism", because a constellation identifies not only the stars but also an area of sky whose boundaries are fixed by the International Astronomical Union (IAU) (Figure 6). We discuss what a constellation is, how they came about in history and the role of the IAU in standardising them. An important idea that we try to explain is that while the official constellations of the Northern sky come from Western tradition with roots in ancient Greece and Babylonia, all cultures have their own ways of looking at the sky. Within a constellation, we can find one or more asterisms. Asterisms are sometimes easier to observe and are well known traditionally. The most striking example in the northern hemisphere is the Big Dipper within the constellation of Ursa Major. In the same patch of the sky, the stars can be arranged in the constellation of Sagittarius, in the asterism of Nanto or in the asterism of the Teapot (Figure 6, right panel). There are also interesting astronomical objects in Ursa Major, such as the binary system consisting of the stars Alcor and Mizar.

On the basis of the comparison between Hokuto and Nanto, another possibility is

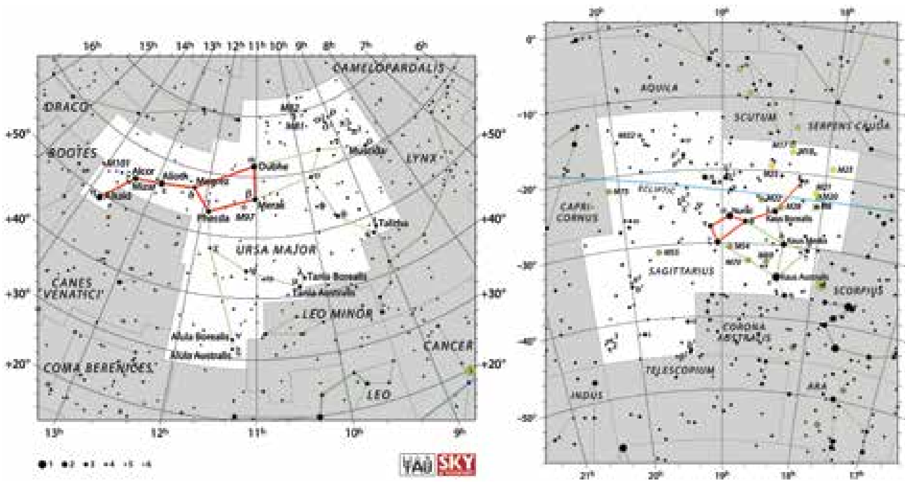

Figure 6. *Charts of the Ursa Major and Sagittarius constellations. The asterisms of Hokuto (in Ursa Major, left panel) and Nanto (in Sagittarius, right panel) from the traditional Japanese sky have been highlighted in red. While Hokuto corresponds to the Big Dipper, Nanto is a part of an asterism known as the Teapot (shown in green) and looks like a rotated version of Hokuto. Credit: IAU and Sky & Telescope*

to describe the Sagittarius constellation where besides Nanto, we find the galactic centre. Looking in that direction, we observe the central areas of the Milky Way, rich in stars and clouds of dust and gas where many new stars are formed.

Inside Ursa Major, there is the well-known asterism of the Big Dipper. In the planetarium, we can point to the stars composing the constellation. We can describe how in different cultures, these stars are grouped under different shapes. For example, in the USA and Iran, the seven stars are seen as a sort of big ladle; in Italy, Germany, Sweden and Spain they form a chariot; in France they are a big pot; and in the UK, they are a plough. Talking about asterisms provides the opportunity to connect the history of some populations with their mythology and traditions. Macro asterisms, which include stars belonging to several constellations, can be shown to illustrate nearby stars, for example, the Summer Triangle that groups Vega (α Lyrae), Deneb (α Cygni) and Altair (α Aquilae).

The presence of Alcor and Mizar in Ursa Major also allows us to explain how the stars are seen as projected onto the celestial sphere and how some stars appear close to each other only because of the effect of perspective, while other stars are physically near. In the case of Alcor and Mizar, they were born together from the same protostellar cloud and, like twins, they are similar but not exactly identical.

Talking about the galactic centre is a good way in to describe how a star is born and how a planetary system is eventually created. For example, we start by describing the star formation processes and discuss how star-forming regions are initially surrounded by a thick cloud, like a fog that prevents us from seeing anything. Over time, the cloud starts to fragment and the gas begins to collapse under the action of gravitational attraction. Dust and gas arrange themselves in a disc surrounding the protostar; their fate is to be either accreted or ejected away by violent jets. The young star begins to form, and the light of a new overwhelming dawn emanates from the dark cloud. Planetesimals are continuously formed in the disc through the collision of small dust grains (Andrews et al., 2016). This is probably the most important stage in the origin of life. With modern instruments such as The Atacama Large Millimeter/submillimeter Array (ALMA), it is possible to identify complex organic molecules in star-forming regions (Fayolle et al., 2017; Jørgensen et al., 2012). Molecules such as glycolaldehyde, organohalogens and acetic acid are considered as the building blocks of life, and their detection can help answer several questions about the origin of life and evolution in space.

UFO Robot Grendizer: Difference between Stars, Planets and Planetary Nebulae

One of the first animes introduced in Europe and America during the 1970s was *UFO Robot Grendizer*, created by Go Nagai and Toei Animation (Figure 7). *UFO Robot Grendizer* tells the story of Duke Fleed and his friends, who with the aid of the giant robot Grendizer, try and stop the invasion of Earth by evil aliens. Coming from the Vega system and ruled by King Vega, the aliens want to exploit Earth and all its precious resources, slaughtering the human race in the process. Duke Fleed and Grendizer are also aliens from the planet Fleed, which was previously attacked and destroyed by the evil Vega troops. Miraculously escaping, Duke Fleed manages to land on Earth and organise a resistance.

In the Italian and French versions, the series was dubbed and the main characters were named differently from those in the original Japanese (Montosi, 2007). While the original names were common Japanese names, the new ones were deeply connected to astronomical objects such as the stars Alcor, Mizar and Rigel and the planet Venus.

There are countless astronomy-related curiosities about this saga. For instance, Vega is of great importance in astronomy since it has long been used to calibrate observational instruments and as a reference for measuring the magnitude of stars. It is used as the zero point of the Johnson-Morgan photometric system. In the *Grendizer* saga, Duke Fleed's native planet belongs to the Vega system; we start from this to describe the elements that have been observed in this system to suggest the presence of a planetary system around Vega. One of these elements is a disc of dust, extending around 100 au, very similar to what is expected from an equivalent of a Kuiper belt (Su et al., 2005). Further investigations have shown the presence of condensations of material in the disc. This fact has led some researchers to assume the presence of giant planets, probably similar to Jupiter or Neptune, although they have not yet been directly observed and their presence is currently regarded as unlikely, at least in the inner few au of the system (Wilner et al., 2002; Piétu et al., 2011; Mennesson et al., 2011).

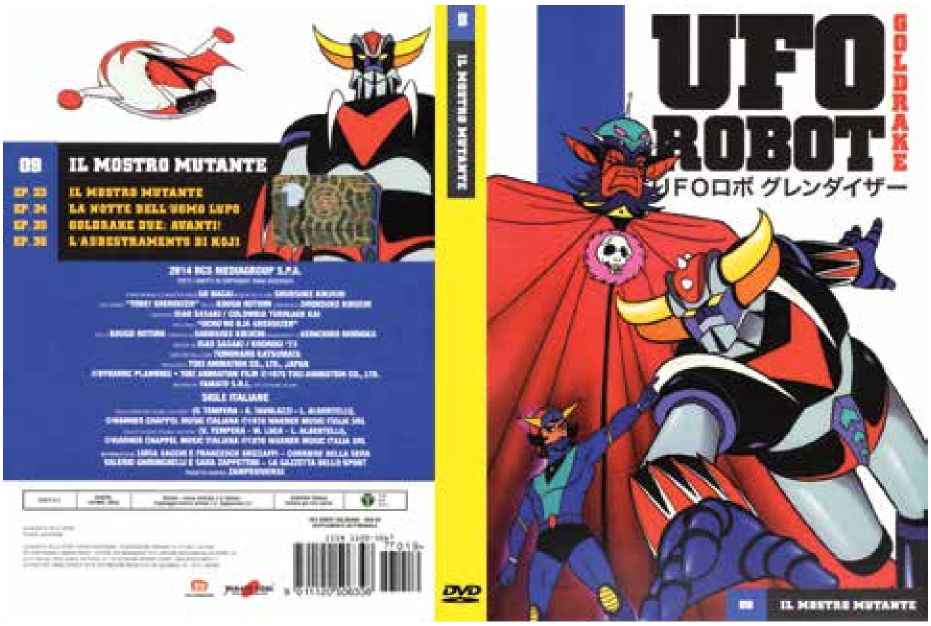

Figure 7. *Cover of the Italian edition of the anime UFO Robot Grendizer published by Yamato Video. The powerful robot Grendizer, Koji Kabuto and the evil King Vega are depicted in the cover. Credit: Go Nagai, Toei Animation*

In the constellation of Lyra we find the famous Ring Nebula (M57), a spectacular planetary nebula. M57 is a very good example to explain the difference between planetary nebulae and planetary systems. A planetary nebula is the final product of the life of a Sun-like star (from 0.8 to four times the mass of the Sun) that, at the end of its evolution, expels its outer layers in a series of explosions. The ejected gas forms a cloud of material around the parent star, which expands at great speed and generates a planetary nebula. The star continues its evolution as a white dwarf in the centre of the cloud, which diffuses incoming radiation. At this point, it is easy to understand that if there was a planetary system, it must have been destroyed much earlier than the planetary nebula phase.

Saint Seiya: Prominent Constellations of the Northern Hemisphere, the Zodiac and the Objects they Contain

Sagittarius and the other constellations of the zodiac are featured in *Saint Seiya* by Masami Kurumada (Figure 8). Five of the main characters in *Saint Seiya* are a group of knights (called "Saints"), valiant warriors who are faithful to the goddess Athena, protector of humanity. They fight against the dark forces that threaten Earth. Each character is linked to a constellation of the boreal or austral sky through the armour that they wear. The knights who wear armour representing zodiacal signs are the most powerful, although some of them are corrupt. The main heroes wear the less-powerful armour of the constellations Cygnus, Andromeda, Draco, Phoenix and Pegasus, and the plot follows their quest in fighting villain knights and becoming more powerful. Their fighting techniques are in some cases connected to the mythological and astronomical objects in these constellations. One example is that of the Andromeda knight. His armour has a chain that during the fight, may be disposed around the hero in a spiral shape resembling that of the Andromeda galaxy. *Saint Seiya* also has ties to Chinese traditions and Taoism. For example, heroes fight evil by widening their perceptions through the use of "the cosmos", a seventh sense that enables them to gain knowledge of their own possibilities and to increase their strength. Using this comic, we can illustrate some peculiarities about these constellations.

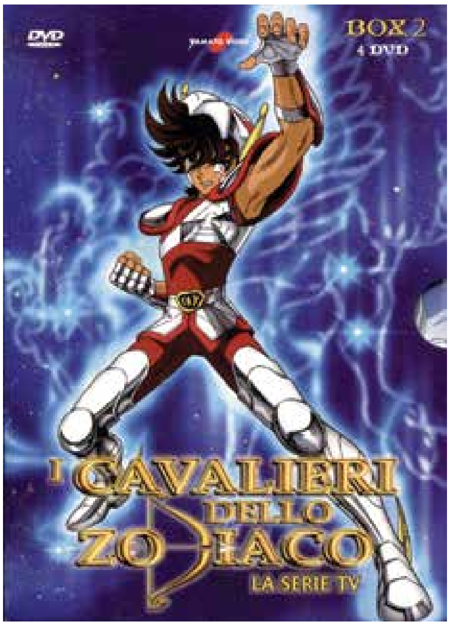

Figure 8. *Cover of the Italian edition of the anime* Saint Seiya*, published by Yamato Video. Seiya is wearing his armour connected with the constellation of Pegasus, which is visible in the background. Credit: Masami Kurumada, Toei Animation*

We usually start by pointing to all of the relevant constellations in the dome and connecting them with the heroes of the manga. We then proceed by showing the constellation shapes and brightest stars and by giving further astronomical details. For example, the Cygnus constellation is also known as the North Cross, as opposed to the more famous Southern Cross. The reference to the North often recurs in the comic, since the knight of Cygnus has his power connected to ice and snow. The brightest star in Cygnus, Deneb, marks the swan's tail; its name comes from Dhanab, which in Arabic means tail. Albireo is the star that marks the head; it is a double system like the aforementioned Alcor and Mizar. Close to Albireo, we find a famous and quite different source: Cygnus X-1, one of the first X-ray sources to ever be discovered (Bowyer et al., 1965). Cygnus X-1 is a binary system where the X-ray emission is due to the phenomenon of stellar cannibalism. During its evolution, one of the two components has become a black hole and is slowly eating its sister. The pulled material is attracted by the black hole and it arranges itself in an accretion disc surrounded by a hot corona. The material in the disc is compressed and heated, and it emits radiation whose energy is subsequently increased by the corona. It is this high-energy radiation that we observe in the form of X-rays (Webster et al., 1972; Young et al., 2001).

Another example is the constellation of Andromeda, which houses one of the most famous and beautiful objects of the northern hemisphere: the Andromeda galaxy. In *Saint Seiya*, this object appears often associated to the special fight moves of the knight of Andromeda, who has a chain that resembles the shape of the spiral galaxy. This reference gives us the chance to point to the Andromeda galaxy in the sky (it is barely visible with the naked eye but can be observed with small binoculars) and to explain that it is a spiral galaxy very similar in shape and size to our Milky Way. Andromeda is traveling in our direction and its eventual destiny is to merge with the Milky Way.

Close to Andromeda in the sky, we find Pegasus, which is easily recognisable in the sky because of its square shape. The first extrasolar planet orbiting a Sun-like star was discovered around the star named 51 Pegasi (Mayor & Queloz, 1995). It was also the first discovery of a hot-Jupiter planet: a very big, very hot, gaseous body orbiting extremely close to its star.

Discussion

Effectiveness of Costellazione Manga Compared to Traditional Outreach Methods

Compared to the traditional shows and lectures held at the Planetarium of Ravenna that mostly cater to people already curious about astronomy, Costellazione Manga seems to attract a broader and more diverse audience. While the usual audience often includes a good fraction of regular patrons, we have observed that for Costellazione Manga, most of the audience are first-time visitors to a planetarium. We have seen that the number of participants is larger by a factor of five or ten compared to the regular visitors at the Planetarium of Ravenna. In several cases, additional shows were needed because all the interested participants would not have fit in the room for a single show.

Costellazione Manga has also been presented as night excursions in natural parks in the area of Ravenna. The public had a chance to discover the beauty of nature and learn more about astronomy. In particular, they appreciated the idea of learning astronomy using manga and anime references, both because of the novelty of the approach and the proximity of the references to their cultural experience; conversely, the traditional way of explaining constellations using Latin and Greek mythology was perceived as a somewhat school-like experience, probably because Latin and Greek culture has a significant share in the Italian school curricula.

Localising Costellazione Manga outside Italy: The Swedish Experience

Japanese cartoons may not be as popular everywhere as they are in Italy or perhaps a different set of shows may have been imported elsewhere. To try and export the Costellazione Manga format, one needs to tune the show to the public's knowledge and expectations. Compared to Italy, France and Spain, Scandinavian countries do not have as developed a market for manga and anime. In creating a Swedish version of our show for the 2018 Gothenburg Science Festival (Figure 9), we were helped by cartoonist Yvette Gustafsson and by the personnel of the SF Bokhandeln bookstore in Gothenburg to identify suitable works. Fewer anime have been broadcasted by Swedish television, so in several cases, the popularity of anime in this country is mostly because of VHS and DVD editions. The popularity of manga also seems to be hindered, to a certain extent, by a lack of Swedish translations, with most manga being available only in English and by their distribution being limited to specialised bookstores. Under these constraints, we identified three suitable works: *Starzinger*, the first anime to be broadcasted in Sweden; *Sailor Moon*, a popular success for which a Swedish opening song was written; and *Dragon Ball*, whose manga was translated and whose anime and films were released in VHS and DVD format. The bulk of the Costellazione Manga show therefore relied on these three works, with *Starzinger* (a science fiction anime involving a quest through the Milky Way) being used to introduce the theme of space travel and extra-solar planets, *Sailor Moon* (a fantasy work where warrior girls have their powers linked to the planets in the Solar system) introducing a review of the planets and minor bodies in the Solar System, and *Dragon Ball* (a martial arts franchise featuring aliens) presenting the topic of life in the Universe. In the final part of the event, we also showed a few pages from the less popular *2001 Nights* and *Planetes*, with which we intended to encourage interested individuals to broaden their knowledge about the more mature and literary side of manga.

The Costellazione Manga event was held in the Sirius Café run by SF Bokhandeln in their premises and was a definite success, with the venue filled to capacity. We had provided feedback forms asking for the audience's feedback on the show; the main result was that the audience appreciated the format and valued the interaction with the speakers.

The Audience of Costellazione Manga and their Reactions

Costellazione Manga has been proposed in several forms: as planetarium shows, night observations of the sky or seminars. For each format, we had enthusiastic reactions from the audience, which included both adults and children.

The format has been successful both in Italy — a country where anime and manga are mainstream forms of literature — and in Sweden — a country where they are not as popular. We have seen that tuning the format to the expectations of the public has been key for success.

Adults were familiar with the cultural references and enjoyed being able to connect their childhood memories to science. They also appreciated that the learning experience was markedly different from traditional lectures.

Children were less familiar with some of the material (Japanese animation is still being broadcast on television and is available on modern distribution channels; but most productions aired are contemporary with only some classics from the 1980s are also aired) but they showed immediate interest in our stories and were curious about the astronomy-related aspects of the

Figure 9. *Daria Dall'Olio and Yvette Gustafsson presenting Costellazione Manga at the Sirius Café run by the SF Bokhandeln bookstore during the Science Festival in Gothenburg (Sweden) in 2018 (left panel). One playful moment during the conference, when we explain the Moon's tidal locking (right panel). Credit: P. Ranalli*

series, once we introduced these to them. Children and their parents (and grandparents too!) were linked together by a common fascination for astronomy. A great and somewhat unexpected outcome was that they started sharing appreciation for their own favourite stories and heroes, therefore establishing a fruitful dialogue among the generations. Thus, Costellazione Manga has proven to be a truly efficient pedagogical tool to popularise and communicate astronomy. The use of comics and anime deeply engages the public. It also stimulates important aspects of learning development, critical thinking and curiosity; moreover, it motivates people to read more about the astronomy references and helps them in remember concepts and build connections between different topics and subjects, which is a fundamental part of the deep learning processes.

Future Development and Conclusions

In the future, we aim to increase and improve our offer of outreach events and material by making them available in more countries. Our plan is to expand our team, involving astronomers and artists from different countries. This will allow us to tune content and topics according to the expectations of the public and to the country where the events will be offered. A good opportunity to expand our team will be the “AHA! Festival — Art x Science 2018” to be held in November at Chalmers University of Technology in Gothenburg, Sweden, where we will present Costellazione Manga. Another idea is to form associations with other disciplines like chemistry, biology or physics, which are deeply connected with astronomy, and start collaborations with experts and teachers in those fields. The plan is to encourage people to be curious about science and show them that different scientific disciplines overlap and have profound connections.

To conclude, Costellazione Manga has been presented as a planetarium show, night observation of the sky and seminar. We have seen that our audience can easily include both adults and children. Compared to a traditional planetarium show or astronomy-related outreach activity, Costellazione Manga caters to a broader variety of people and can thus reach a new audience passionate about comics and animation who may be curious about astronomy with the right framing. In our experience, adults are likely to understand the references and connect to childhood memories through them, while children soon get engaged after an initial introduction. A happy consequence is that children and their parents get to share their fascination for astronomy and appreciate the same stories. Costellazione Manga can be successfully used as pedagogical tool to explain astronomy in several countries, since the choice of anime and manga can be tuned to the needs and expectations of the public. We have reported our experience in two countries in Europe where the manga and anime markets are quite different: Italy, where the market is well developed and Sweden, where it is still nascent.

Costellazione Manga is based on stories that are part of our common background often associated to dear memories or funny moments. Therefore, it is perceived by the public more as a recreational activity than as a conventional lecture. Thus, the atmosphere is more relaxed, where the public is more inclined toward learning. The comparison between fiction and science stimulates curiosity and critical thinking. The novelty of the method seems to help people remember concepts and build links between topics and encourages people to discover and learn more about astronomy. Costellazione Manga can thus be considered an efficient pedagogical tool to popularise and communicate astronomy.

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Notes

1 The Evolving Culture of Science Engagement: www.cultureofscienceengagement.net/

2 The Costellazione Manga website: www.costellazionemanga.eu

3 European/Japanese co-productions of the time included Heidi — girl of the Alps and Vickie the Viking.

4 au is the measure astronomical units, roughly equal to the average distance between the Sun and Earth and defined to be 149 597 870 700 m exactly.

5 *Voyager 1* press release: www.jpl.nasa.gov/news/news.php?release=2013–278

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Biographies

Daria Dall'Olio is a PhD student in astronomy at Chalmers University of Technology — Onsala Space Observatory (Sweden), where she works on magnetic fields in star-forming regions. Daria is active in popularising astronomy and has authored several outreach articles and conducted seminars and planetarium shows.

Piero Ranalli has been an astronomy researcher since 2001 and is the author of more than 50 papers published in international refereed journals. He has expertise in X-ray astronomy and planet detection and is passionate about outreach. He spent two years in Japan conducting research at the RIKEN institute in Wakoshi, Saitama, where he also learnt the Japanese language. Currently he works as a data scientist at Combient AB in Göteborg (Sweden) and is an associate at Lund University (Sweden).

Walking Through an Exploded Star: Rendering Supernova Remnant Cassiopeia A into Virtual Reality

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Keywords
Data, virtual reality, science communication, visualisation, augmented reality, narrative

Data on the Cassiopeia A supernova remnant from NASA and other sources have been rendered into a three-dimensional virtual reality (VR) and augmented reality (AR) programme, which is the first of its kind. This data-driven experience of a supernova remnant allows viewers to take a virtual walk inside the leftovers of a massive star that has exploded, select parts of the remnant to engage with and access descriptive texts on what the different materials are. This programme is based on a unique three-dimensional (3D) model of the 340-year old remains of a stellar explosion, made by combining data from NASA's *Chandra X-ray Observatory*, the *Spitzer Space Telescope* and ground-based facilities. A collaboration between the Smithsonian Astrophysical Observatory and Brown University allowed the 3D astronomical data collected on Cassiopeia A to be featured in the VR/AR programme, which is an innovation in digital technologies with public, education and research-based impacts.

Introduction

Overview of Virtual Reality

Virtual reality (VR) is a computer technology that simulates a user's physical presence in a virtual environment. VR's close relative, augmented reality (AR), adds elements such as text, overlays and audio to enhance that experience with sensory input and is briefly discussed on page 19. VR has existed in some form since the 1980s (Faisal, 2017). Though it has faced many ups and downs (Stein, 2015), including the unrealised promise of a Virtual Reality Markup Language in the late 1990s, it has become more commonplace in the consumer market since about 2010 (Faisal, 2017)[1]. Given its potential for improving the gaming industry, media and even adult entertainment, there are major commercial driving forces behind the technology's development (Oracle, 2016; CNET, 2016).

The increased commercial prominence of these technologies, including the availability of less expensive yet good quality and more user-friendly technologies, presents new opportunities for their use in science (Ferrand et al., 2016). There is a potential for VR to revolutionise how experts — from molecular modelling to environmental conservation — visualise and analyse their data and how that data is then communicated to non-experts (Isenberg, 2013).

In medicine alone, VR is a unique tool for data visualisation and comprehension as well as for continuing education and user experiences. Uses of VR programmes that are in development and implementation range from improving health workers' understanding of brain damage (Hung et al., 2014) to implementing virtual surgery training for medical students (Murphy, 2018) and applying VR and AR techniques in an accessible way in the treatment of Alzheimer's disease (Garcia-Betances et al., 2015). VR has been shown to improve upon the traditional tangible model of using dummies to enhance medical students' preparation for assisting patients in high-risk real-life scenarios. It can allow physicians and other health professionals to work with specific cases to practice the applicable caregiving skills (Murphy, 2018).

Beyond the universe of the body and out into the Universe at large, astronomical data sets often provide high-resolution, multi-wavelength and multi-dimensional (lately, even multi-messenger) information. The process of converting photons, or packets of energy, into 2D images has been documented and studied (Rector et al., 2017; Arcand et al., 2013; DePasquale et al., 2015; Rector et al., 2007) but the translation of that information into 3D forms that use human perspective, cognition and stereoscopic vision, less so (Ferrand et al., 2016). Since the Universe is multi-dimensional itself, as Fluke and Barnes (2016) ask: "Are we making the best use of the astronomer's (and a non-expert's) personal visual processing system to discover knowledge?"

Astronomical VR experiences include exploring exoplanets (planets outside our Solar System) through science-informed 3D artists' impressions converted into

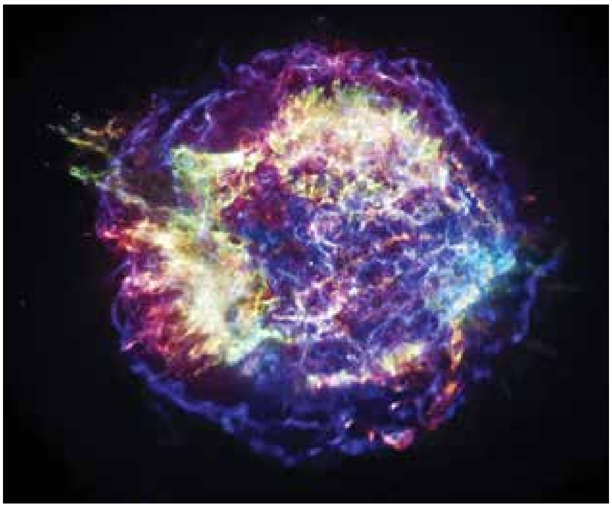

Figure 1. *Cassiopeia A (Cas A) is a supernova remnant located about 10 000 light years from Earth. This 2D visual representation of Cas A has been processed to show with clarity the appearance of Cas A in different bands of X-rays. This will aid astronomers in their efforts to reconstruct details of the supernova process such as the size of the star, its chemical make-up and the explosion mechanism. The colour scheme used in this image is the following: low-energy X-rays are red, medium-energy ones are green and the highest-energy X-rays detected by* Chandra *are coloured blue. The image is 8.91 arcmin across (or about 29 light years). Credit: NASA/CXC/SAO*

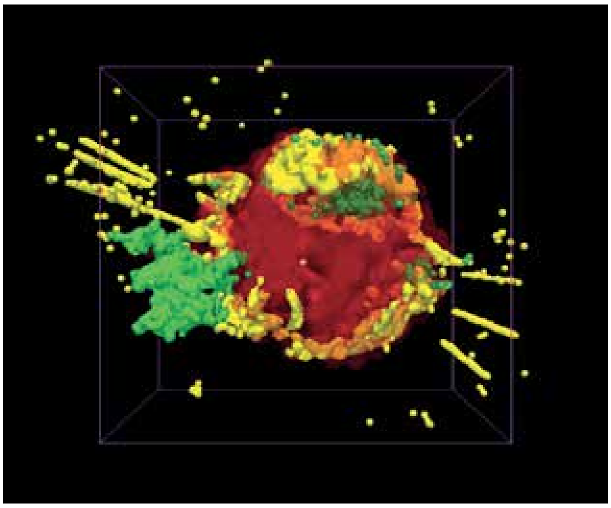

Figure 2. *By combining data from* Chandra, the Spitzer Space Telescope *and ground-based optical observations, astronomers were able to construct the first 3D fly-through of a supernova remnant. This 3D visualisation (shown here as a still image) was made possible by importing the data into a medical imaging programme that has been adapted for astronomical use. Commercial software was then used to create the 3D version of the data. The green region shown in the image is mostly iron observed in X-rays; the yellow region is mostly argon and silicon seen in X-rays, optical and infrared, and the red region is cooler debris seen in the infrared. The positions of these points in three-dimensional space were found by using the Doppler effect and simple assumptions about the supernova explosion. Credit: NASA/CXC/MIT/T.Delaney et al.*

VR[2]; experiencing a NASA mission spacecraft in VR such as the *James Webb Space Telescope*[3]; walking across the surface of Mars[4]; exploring dozens of massive stars from the perspective of the supermassive black hole at the centre of our Galaxy[5] (Russell, 2018); and viewing radio data cubes of a spiral galaxy (Ferrand et al., 2016).

Data Path for Cassiopeia A: From 2D to VR

Supernova explosions are among the most violent events in the Universe. When the nuclear power source at the centre of a massive star is exhausted, the core collapses and in less than a second, a neutron star typically forms. This process releases an enormous amount of energy, which reverses the implosion, blows material outwards and produces a brilliant visual outburst. The resulting debris field is referred to as a supernova remnant.

Cassiopeia A (Cas A) is a supernova remnant from an explosion that occurred approximately 340 years ago in the Earth's timeframe (Figure 1). A multi-wavelength three-dimensional (3D) reconstruction of this remnant was created using X-ray data from *Chandra*, infrared data from *Spitzer* and optical data from ground-based telescopes. In Figure 1, the green regions are mostly iron, the yellow regions include a combination of argon and silicon, the red regions are cooler explosion debris and the blue regions show the outer blast wave.

When elements created inside a supernova are heated, they emit light at specific wavelengths. Because of the Doppler effect, elements moving towards the observer will have shorter wavelengths and elements moving away will produce longer wavelengths. Since the extent of the wavelength shift is related to the speed of motion, the velocity of the debris can be determined by analysing the light. By combining this Doppler information with the expectation that the stellar debris expands radially outwards from the explosion centre, Delaney et al. (2010) used simple geometry to construct a 3D model of Cas A (Figure 2). A programme called 3D Slicer — modified for astronomical use by the Astronomical Medicine Project at Harvard — was used to display and manipulate the 3D model[6].

The visualisation shows that there are two main components to Cas A: a spherical component in the outer parts of the remnant containing light elements like helium and carbon from the outer layer of the exploded star and a flattened (disc-like) component in the inner region containing heavier elements like argon and iron from the inner layers of the star[7]. The blue filaments indicating the blast wave show a different type of radiation that does not emit light at discrete wavelengths, and, therefore, have not been included in the 3D model.

High-velocity jets of heavy material shoot out from the explosion in the plane of the disc-like component mentioned above. Jets of silicon appear in the upper left and lower right regions, while plumes of iron are seen in the lower left and northern regions. These had been studied before the 3D model was made, but their orientation and position with respect to the rest of the debris field had not been mapped before.

The insight into the structure of Cas A gained from this 3D visualisation is important for astronomers who build models of supernova explosions. They have learned that the outer layers of the star come off spherically, but the inner layers come out more disc-like with high-velocity jets in

Figure 3. A 3D virtual reality (VR) with augmented reality (AR) version of the 3D data of Cas A allows the user to walk inside the debris from a massive stellar explosion, select the parts of the supernova remnant to engage with and access short captions on what the materials are. This photo was taken of the first author inside the Brown University YURT, or VR CAVE, during testing of the Oculus Rift hardware and application. Credit: NASA/CXC/SAO/E.Jiang.

multiple directions (Delaney et al., 2010). Since the Delaney et al. (2010) study, two other groups have constructed 3D models of Cas A (Milisavljevic & Fesen, 2015; Orlando et al., 2016), demonstrating the rich scientific value of such visualisations for astronomers.

This 3D visualisation was initially created as an interactive for desktop viewing[8]. To move beyond the small screen, it was later translated into a 3D printable format (Arcand et al., 2017), which is particularly conducive for exploration by blind and visually impaired populations[9] (Grice et al., 2015; Christian et al., 2015).

The authors considered VR (Figure 3) as the next step in the translation process, an additional experience beyond the 2D visual and 3D tactile (Eriksson, 2014).

Augmented Reality in Astronomy

As mentioned above, AR adds text, image, sound-based elements or other effects to deliver an enhanced user experience with additional sensory input, typically by merging the real or "live" with virtual information.

AR has become popular because of the number of smartphones, wearable computing devices and other smart gadgets being pushed in the consumer market (Vogt & Shingles, 2013; Amer & Peralez, 2014). From computational interfaces popularised by Pokémon Go (Sicart, 2017) to AR leopards that visitors can interact with to help promote conservation[10], AR is only expected to grow in popularity[11].

The use of AR to explain topics in astronomy is neither a completely new nor a completely unexpected idea. Vogt and Shingles (2013), for example, make note of AR-based designs in astronomy developed for education purposes, including 3D displays of our Solar System, 3D demonstrations of the Sun–Earth interaction and a NASA application that allows users to get up close and personal with a NASA spacecraft[12, 13]. Vogt and Shingles also discuss the use of AR for astronomy research, citing their own interactive AR model of the supernova remnant N132d.

VR Translation and Technical Specifications

Currently, VR software has not been standardised to the point where we can use data as direct input into a VR programme. While software exists to allow visualisations to be displayed across different platforms (Brown Center for Computation and Visualization (CAVE)[14], Viscon Virtual Reality VR PowerWall[15], 3D televisions[16], head-mounted displays[17]) using a variety of input devices (6-degree-of-freedom trackers[18], multi-touch input devices (Marzo et al., 2014), haptic devices[19]), we have yet to design a system that can support raw data without any external software. Therefore, with each new type of data set, effort must be made to build the bridge between raw data and VR software in order to produce the visualisation.

This format of Cas A uses volumetric data (where volume, or the data inside an object, is rendered — as in an MRI or CT scan in medicine) and polygonal data (where only the surface, or the outside data, is rendered) of the supernova remnant Cassiopeia A collected by *Chandra*, *Spitzer* and ground-based optical observatories. It therefore employs volume and surface rendering techniques of the Visualisation Toolkit (VTK)[20] to create a MinVR-enabled programme[21].

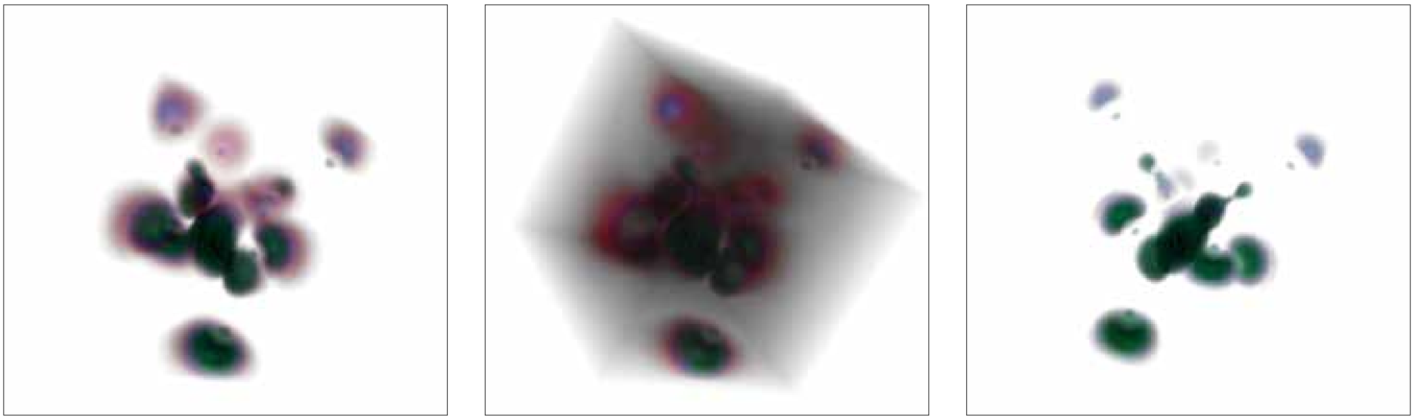

Figure 4. a) b) c) *(Left to right) Volume rendering. Credit: CXC & Brown University.*

Methods

Volume and Surface Rendering

To render the supernova both volumetrically and polygonally, we used VTK, an open-source, freely available software system for 3D computer graphics, image processing and visualisation. VTK supports a wide variety of visualisation algorithms including scalar, vector, tensor, texture and volumetric methods as well as advanced modelling techniques such as implicit modelling, polygon reduction, mesh smoothing and contouring[20] (Kitware, 2010). VTK has a suite of 3D interaction widgets.

With VTK, we were able to read the supernova data sets and use its built-in filters and mappers to render the remnant's volume and surface. The remnant is composed of seven different parts, and each part is represented by a different colour in the surface model.

Integrating with MinVR

MinVR is an open-source project, developed and maintained collectively by the University of Minnesota, Brown University and Malcalester College. It aims to support data visualisation and VR research projects by providing a cross-platform VR toolkit that can be used in many different VR displays, including Brown University's YURT (Yurt Ultimate Reality Theatre, or CAVE[14]).

A technical challenge with this project was integrating the VTK programme with MinVR. Since both programmes had their own render function, we had to use VTK's external module to allow the VTK programme to accept an external render window and render loop. As has been the case when working with our 3D/VR projects thus far, multiple bridges needed to be built between technologies in order to create something new. We worked with VTK to improve the external camera capacity. In the end, we were able to complete the integration and display the supernova models in YURT.

Progress & Results: Volume and Surface Rendering

Figure 4(a) shows a sample volume rendering demo that uses iron density data to simulate what a supernova would look like given its volumetric data.

Figure 4(b) shows that when the opacity level is low enough, one can observe an outer cube that encompasses the iron density data, illustrating the importance of adjusting opacity levels in volume rendering.

On the other hand, when the opacity level is too high, we cannot see enough of the data to observe the differing measurements of density. Figure 4(c) shows that

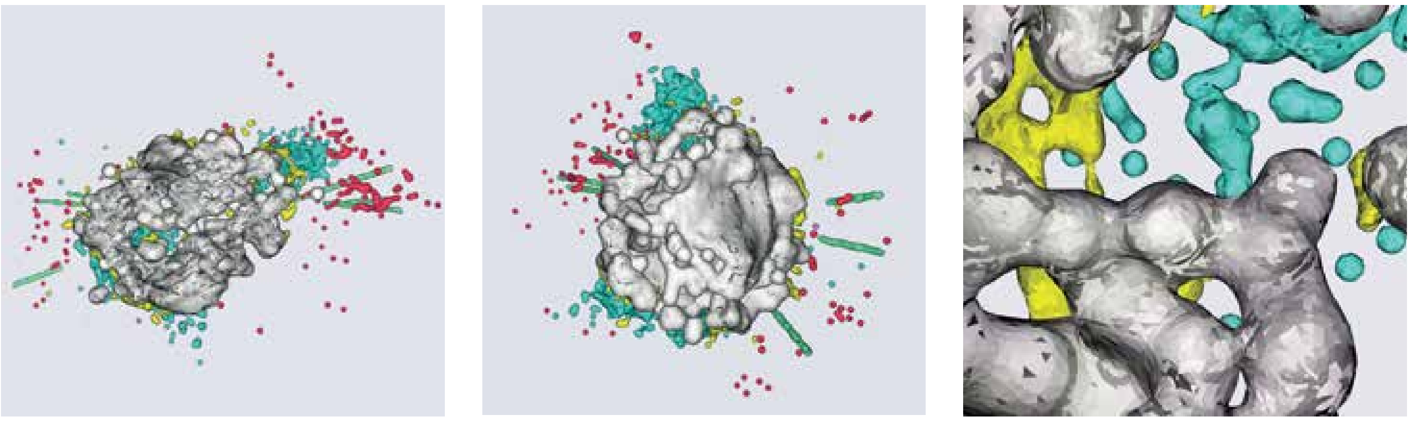

Figure 5.a) b) c) *(Left to right) Surface rendering. Credit: NASA/CXC & Brown University.*

we must work to find an optimal opacity level and an intuitive colour scale.

The model in Figure 5(a) is a surface rendering of Cas A, made up of seven different parts, shown in different colours. Each part is a separate ASCII data file consisting of polygon data and triangular strips.

The seven parts shown in Figure 5(b) include a spherical component (purple), a tilted thick disc (grey), and multiple ejecta jets/pistons (green) and optical fast-moving knots (red, yellow, blue, pink) all populating the thick disc plane.

Figure 5(c) shows the view from inside the spherical structure of the supernova. Here, it is possible to see that the rendering is a mesh of triangles that shape the surface.

Augmented Reality: Narrative Additions

For the Cas A VR experience, adding interactive text over the VR object was an important narrative component of the overall experience because of the complexity of the science model. Providing contextual information has been shown to improve the user's understanding and enjoyment of 2D and 3D astronomy images both among experts and non-experts and across technological platforms (Smith et al., 2017a, 2017b, 2014, 2010). Therefore, the addition of contextual information to VR data sets seemed ideal for users of all kinds.

Our enhanced VR Cas A model includes annotations for each part of the supernova remnant (for example, the neutron star, the iron and silicon debris, etc.) that describe both its components and its overall structure. Users can select a specific part of the supernova remnant by using their input device or wand (such as the Oculus Touch, a device that brings the user's hands or gestures into the virtual environment) to access the annotations and bring them up in their VR environment. They can cycle through each notation to discover more information about Cas A. These additional interactive narrative features may help educators to more effectively tell the life story of a star and provide resources to researchers observing changes in the size, density and shape of stars.

Figure 6(a) shows the addition of narrative text, where the user can select a part of Cas A to focus on and access captions. In this case, the user has chosen to focus on the Neutron Star at the centre of the remnant.

Figure 6(b) captures the screen of a user highlighting the reverse shock sphere that demonstrates wave expansion. Note how the caption superimposed over the image uses analogy to help increase understanding (Smith et al., 2017 (b)).

Discussion

The VR Cas A experience was created for 3D immersive environments such as CAVES and the Oculus Rift (Clark, 2014). Cell phone adaptations that can be viewed with pop-up personal VR viewers such as Google Cardboard and even those that can be used in a browser without any VR viewers have been created to allow additional entry points for viewers who do not have access to more expensive equipment[22].

The Cas A 3D VR model has the potential to be a useful tool that engages experts and non-experts in the data of astronomy and applications of computer science. For non-experts, specifically, astronomy data in general are popular as a science topic, as evidenced by the ubiquitous placement of astronomical images throughout popular culture everywhere from bed linens to computer wallpaper[23].

By linking the data and images of Cas A with unique computer tools in a project such as this, new connections can be made. Astronomy models in virtual reality can provide an unexpected visual and perceptual palette for the modern viewer. Such applications may be able to assist participants in establishing a sense of presence with data that is otherwise difficult to relate to because of the nature of the distance from Earth, sheer scale and other factors. This data can be shown at a monumental scale with VR. There are difficulties with VR technologies to consider, however, such as motion sickness caused by the visual disconnect, the need to incorporate an illusion of boundless movement, accessibility (both for underserved socioeconomic areas and also for physical accessibility by people who are visually impaired[24]), as well as struggles in establishing touch-responsive features (Steinicke, 2016; Amer & Peralez, 2014).

Just as in video games and educational software, VR-enabled science requires narrative integration whether for expert or non-expert users (Gottschalk, 2016). The key to making such a project more than just a toy is to provide meaningful information and content that is clearly embedded in the virtual experience. Projects such as

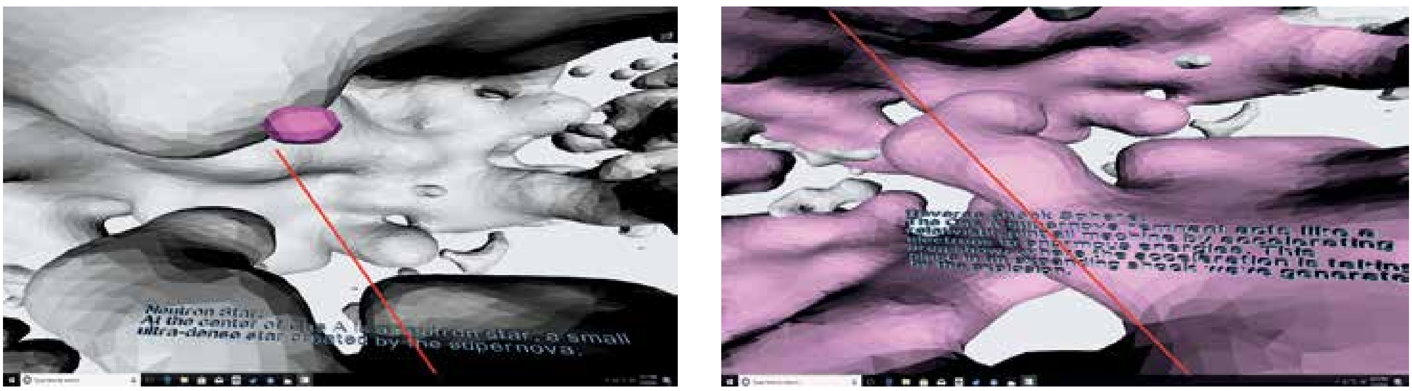

Figure 6.a) b) *(Left to right) Augmented Reality labeling. Credit: NASA/CXC & Brown University.*

this Cas A 3D VR/AR model could be used as a launch point for opportunities in a host of topics in astrophysics, chemistry, computer science and more.

With the current market trends in equipment and adaptations of content and technologies for VR experiences (including multimodal access points for those with physical disabilities), it is a critical time to create quality astronomy-based materials for experienced VR users as well as those new to VR. In education specifically, helping students maximise the potential of VR could be done partially through output adaptations to platforms such as YouTube, which can host 360-degree versions of many VR videos where they can act as a canvas for individualised VR experiences tailored to the needs of different learners (Cotabish, 2017). This aspect of the viewer-driven experience in VR (Chen et al., 2014) could potentially have a positive impact on users with different learning styles, viewers with autism (Lahiri et al., 2015), participants with different physical abilities or other special needs (Tyler-Wood et al., 2015).

Next Steps

Expansion of Astrophysics VR Library

While our current results have provided an immersive and interactive rendering of the supernova remnant Cassiopeia A, we plan to expand our astrophysics VR data sets to build additional 3D visualisations that help illustrate more fully the life cycle of stars, from birth to death, with further interactivity included for the user. We are investigating the application of additional 3D data-driven models that can be imported into the VR pipeline described in previous sections. Future models include volumetric data files of supernovae and younger star systems that might also lead to more comprehensive models.

We are also working to make the existing VR application ADA/Section 508 compliant for accessibility[25].

Beyond Supernovae and Supernovae Remnants

Through rendering 3D models of Cas A, this project has in addition implemented a generic programme with examples of how to create similar programmes to read in and display such data. In the future, the authors hope to demonstrate new models of another famous supernova, SN 1987A, an explosion on the surface of a white dwarf, V745 Sco, and other astrophysical density data. The goal is to generate these models with less effort than that for Cas A. Our intent is that this generic programme could act as a skeleton and tutorial for future data sets in biomedical, physical or other fields[26].

Conclusion

We are excited about both the current abilities and the future potential of opportunities for using VR/AR in astronomy. There is a potential for unique educational experiences that marry the popularity of a visual science like astronomy with the technological advances that continue to evolve in VR/AR. Making "real world" examples like Cas A part of the cadre of VR/AR could spur creative ideas of how to infuse science into a realm that might typically include more content from science fiction. We look forward to making deeper connections with the subject matter we are most familiar with, to see how we can expand its content into the virtual third dimension and beyond.

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Notes

1 Virtual Reality Markup Language: www.cnn.com/TECH/9710/14/3.d.reality.lat/index.html

2 Science-informed 3D artists' impressions converted into VR: www.space.com/38749-visit-six-real-exoplanets-with-virtual-reality.html

3 Experiencing NASA mission spacecraft in VR: connect.unity.com/p/vr-experience-james-webb-space-telescope

4 Walking on Mars: www.jpl.nasa.gov/news/news.php?feature=6978

5 Exploring dozens of massive stars from the perspective of the supermassive black hole at the centre of our Galaxy: chandra.si.edu/photo/2018/gcenter360/

6 3D Slicer (since archived, Initiative in Innovative Computing): am.iic.harvard.edu

7 Cas A 3D Model video: chandra.si.edu/photo/2009/casa2/

8 Smithsonian 3D model: 3d.si.edu/explorer?mid=45

9 Printable Cas A 3D Model: chandra.si.edu/3dprint

10 See for example www.smithsonianmag.com/travel/how-augmented-reality-helping-raise-awareness-about-one-armenias-most-endangered-species-1-180967670/

11 See for example www.thenational.ae/business/peter-nowak-why-augmented-reality-will-be-a-big-trend-in-2017-1.32774; venturebeat.com/2018/02/08/the-nyt-is-boarding-the-ar-train-heres-what-that-means-for-storytelling/

12 The Vogt and Shingles (2013) paper can be downloaded as an augmented article, illustrating the utility of the technology promoted in the paper. The authors argue for collaboration between science researchers and publishing platforms to create more stable, as well as backwards compatible, content for AR.

13 AR-based design in astronomy for education purposes examples from NASA: www.nasa.gov/mission_pages/msl/news/app20120711.html

14 Brown Center for Computation and Visualization (CAVE) software: web1.ccv.brown.edu/viz-cave

15 Viscon Virtual Reality VR PowerWall Software: viscon.de/en/vr-2/vr-powerwall/

16 LG provides a striking example of a 3DTV: www.lg.com/us/tvs/lg-OLED55E6P-oled-4k-tv; Reasonably priced glasses for the 3DTV are available at Kmart: www.kmart.com/edimensional-ed-4-pack-cinema-3d-glasses-for/p-SPM8624650802

17 A very affordable version of the head mounted display is available at: www.amazon.com/dp/B01LZA1EKZ/; See for a more costly option: www.amazon.com/dp/B00VF0IXEY

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[19] Explanation of haptic devices: www.youtube.com/watch?v=ABeAAHF6k1k

[20] Visualisation Toolkit: www.vtk.org/

[21] MinVR/MinVR". GitHub: github.com/MinVR/MinVR

[22] Online demonstration see: chandra.si.edu/vr/casa

[23] Space and Astronomy section of Geek Wrapped for an assortment of products decorated with astronomical images: www.geekwrapped.com/astronomy

[24] The ADA National Network explains What is the Americans with Disabilities Act?, adata.org/learn-about-ada

[25] United States Access Board (2000) sets out the Section 508 Standards for Electronic and Information Technology.

[26] The CXC does not endorse any specific commercial product, including the virtual reality technologies referenced throughout this paper.

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Engaging the Public with Supernova and Supernova Remnant Research Using Virtual Reality

Best Practice

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Keywords
Public engagement, virtual reality, immersive visualisation, 3D visualisation, astrophysics, supernova and supernova remnants

On 21 April 2018, the citizens of Wako, Japan, interacted in a novel way with research being carried out at the Astrophysical Big Bang Laboratory (ABBL) at RIKEN[1,2]. They were able to explore a model of a supernova and its remnant in an immersive three-dimentional format by using virtual reality (VR) technology. In this article, we explain how this experience was developed and delivered to the public, providing practical tips for and reflecting on the successful organisation of an event of this kind.

Introduction

Visualisation is an essential part of research, both to explore one's data and to communicate one's findings with others. Many data products in astronomy come in the form of three-dimensional (3D) cubes, and since our brains are tuned for recognition in the 3D world, we ought to display these in 3D space to get a better idea of what is being observed. This kind of experience is possible with virtual reality (VR) devices[3].

VR technology has huge potential for education and public outreach. Objects vastly larger (galaxies) or smaller (nuclei) than the human visual range can be presented at an understandable scale in an immersive 3D space. VR can allow non-experts to more directly connect with the science that is presented, and being at the cutting edge of technology, VR naturally appeals to young audiences, which are arguably the most important audiences to consider for the future of our discipline. Another option to increase the appeal of scientific data among lay people is 3D printing (Arcand et al., 2017).

Alongside our research, we have been developing VR visualisations of our simulation data. These were first used with our colleagues, that is, other astrophysicists[4]. Then, during the internal centennial celebrations at RIKEN in December 2017, the visualisations were used to showcase the work done at the ABBL to other employees, most of whom were not research personnel (Figure 1). On receiving positive reactions from the attendees, our laboratory decided to set up a VR booth for the annual Open Day of RIKEN held on 21 April 2018 at the main campus, in Wako[5], Japan. In the following article, we describe our experience, describe how we visualised our data in immersive interactive 3D format and illustrate in detail the organisation and outcomes of the event.

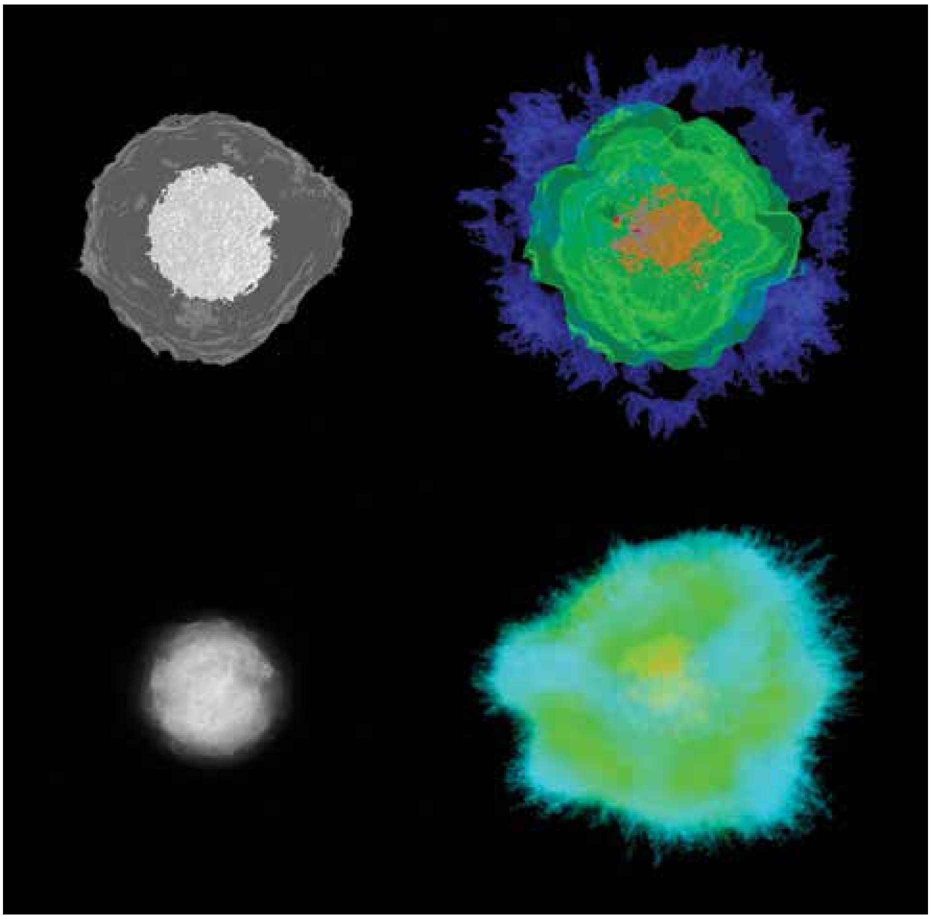
Experience

Our aim is to enhance scientific visualisation; to this end, we produced a visual rendering of actual science data. In our case, the data are simulated data, although the technique outlined in the next section applies equally well to observational data. Even though the visualisation is created on a computer and great attention has been paid to the way it looks, we are not showing an artist's rendition or computer-generated imagery (CGI). In an effort to engage the public with our research, we want to show them the actual output of our work.

Research at the Astrophysical Big Bang Laboratory (ABBL) focuses on explosive astrophysical phenomena and energetic particles. One of our current projects is to link studies on supernovae (SNe) and studies of supernova remnants (SNRs)[6]. Accordingly, our demo (dubbed SN2SNR) has two parts.

The first part shows data from simulations of a supernova, provided by our collaborator Fritz Röpke in Germany (published in Seitenzahl et al. 2013). It shows the structure of the supernova and the distribution

Figure 1. *Employees of the accounting department exploring a 3D model of a supernova at the ABBL during the RIKEN Centennial Meeting (faces masked for privacy). Credit: RIKEN/ABBL*



imprinted on the SNR phase from the SN phase (compare the two rows of Figure 3). Studying this imprinting is the scientific goal of the research project.

Development: The Hardware and Software

The project presented here builds on expertise gained during a pilot project conducted at the University of Manitoba in 2016[7]. The technical aspects related to VR were developed by the authors at RIKEN over about a year from the spring of 2017 to that of 2018. Here, we discuss the tools we chose and the parts we had to develop ourselves. The general architecture of the system is shown in Figure 4.

Figure 2. *Different visualisations of a supernova explosion. Models on the left show the mass density, while models on the right show the abundances of three chemical elements after the computation of explosive nucleosynthesis (red: nickel-56 that will decay into iron; green: oxygen; blue: carbon). Models at the top show isosurfaces (at 0.1% and 10% of the maximum for the density, at 90% for the abundances), while models at the bottom show volume rendering of the entire data cube. Credit: RIKEN/ABBL*

of chemical elements. The way it looks on a computer screen is shown in Figure 2. Of course, these snapshots cannot really convey the 3D feel of it. This part of the demo also presents two different kinds of 3D visualisation: *isosurfaces*, where the set of points at a given data value are displayed rendered as a mesh (top of Figure 2), and *volume rendering*, where the entire data cube is displayed rendered as a glowing gas (bottom of Figure 2).

The second part of the demo shows data from simulations of the subsequent supernova remnant phase developed by Gilles Ferrand, wherein the output of the supernova simulation is the input for the SNR simulation. The research paper for this is in preparation but the general method is as in Ferrand et al. (2010). This part of the demo uses a custom volume rendering of the shell of shocked material that makes apparent the unstable boundary of the material ejected from the supernova. The way it looks on a computer screen is shown in Figure 3. The user can switch between two different initial conditions for the SNR phase in order to highlight what is

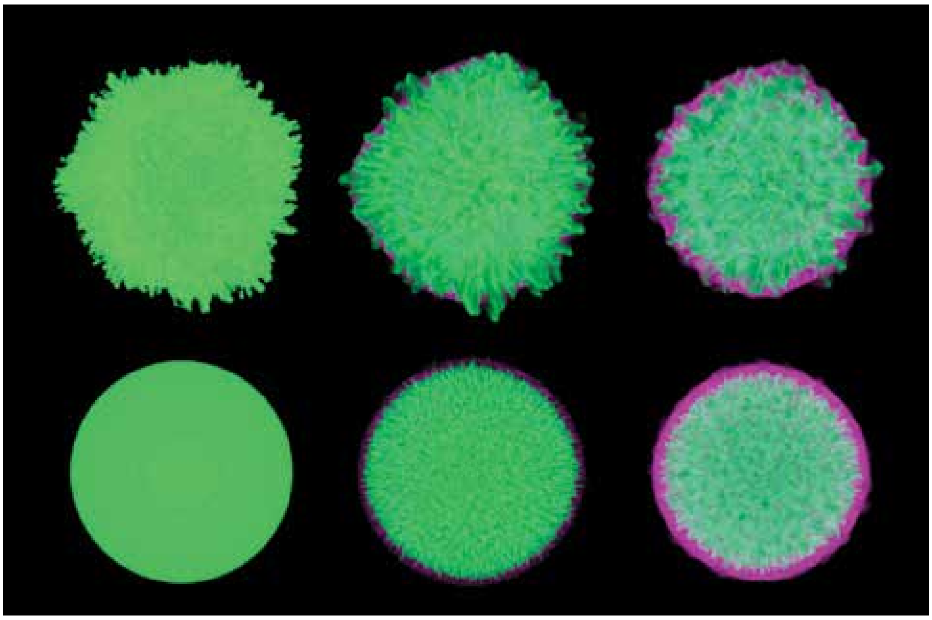


Figure 3. *Visualisation of the simulation of a supernova remnant. The quantity shows the mass density and the colour codes show the material: the stellar ejecta are green, while the interstellar medium (ISM) swept-up by the blast wave is purple. Only the shell of the shocked material is shown. The interface between the ejecta and the ISM is deformed because of Rayleigh–Taylor instability. The columns show the time evolution. Left: one year, centre: 100 years, right: 500 years. Images shown are on the same scale, and over this period of time, the SNR actually expands by a factor of about 150 (which is fine when rendered in VR). The two rows compare different initial conditions: turbulent at the top (as obtained from the SN simulation of Figure 2) and spherically symmetric at the bottom (after averaging out over angles). Credit: RIKEN/ABBL*

Different VR solutions are available, in widely different forms and with varying price ranges, from Google Cardboard[8] to the Visbox CAVE[9]. We chose the recently released HTC VIVE[10] headset, because we found that it offers great immersion with a relatively simple setup and is reasonably priced. The VIVE consists of a head-mounted stereoscopic display for creating images in 3D, two handheld controllers for in-world user interaction and two lighthouses which enable precise room-scale tracking of the headset and controllers. It is the combination of these that creates the full VR experience. It is important to stress that a convincing 3D model is not just about stereo vision. A 3D movie brings depth but is scripted and remains a passive experience seen from a pre-selected viewpoint. In VR, the user is able to actively explore the 3D content presented. Further, we do not merely seek a 360 degree experience, as is the case on smartphone-based systems, where one can only look around. The 6-degrees-of-freedom (d.o.f.) of the VIVE allow the user to freely move in the room around the virtual object and manipulate it as if it is really there.

On the software side, we rely on the Unity game engine[11]. We are not aware of a solution that provides what we want out-of-the-box, and rather than trying to extend an existing astronomy visualisation programme to advanced displays, we have taken the alternative route of customising one of the most popular 3D engines for game development[12]. While this may seem surprising at first, building on a high-level standard solution offers several advantages, in particular, fast prototyping and testing. Unity has already been used for a number of serious applications in the medical and architectural fields as well as in the natural sciences[13, 14]. Importantly, to us, it offers support for all existing VR displays, eliminating the burden of technical aspects like stereoscopy or tracking, so that we can concentrate on data rendering and the user interface (see below). For the VIVE, support is provided through the official SteamVR plugin[15]. The main disadvantage of this approach is that its versatility may result in suboptimal performance.

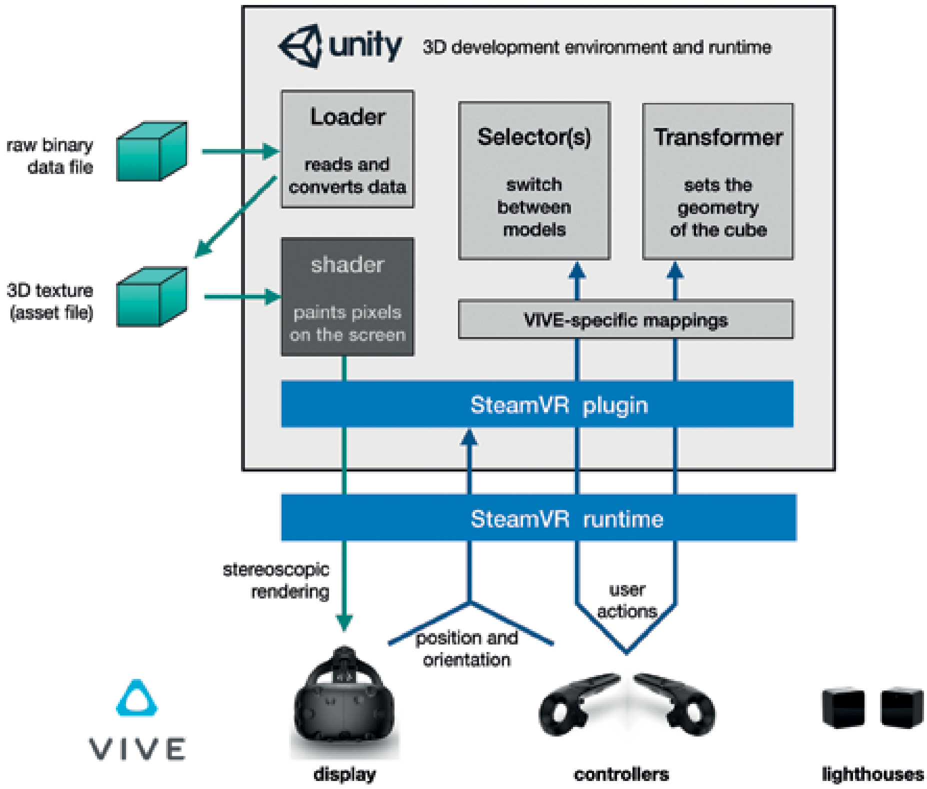


Figure 4. *Sketch of the different software and hardware components. The grey boxes represent our scripts (written in C#, except the shader, which is written in Cg). The green arrows show the data flow when the full data cube is loaded for volume rendering. The blue boxes and arrows represent the SteamVR layer that interfaces Unity with VIVE; it takes care of stereoscopy and tracking and listens to user inputs. Credit: RIKEN/ABBL*

Making it Work for Science

There were some technical aspects that had to be resolved in order to use Unity for astronomy (see also the earlier progress report Ferrand et al., 2016[16]).

The first step is to load the data. As volume rendering is done inside Unity, the raw data file had to be converted into a 3D texture format that could be loaded on to the graphics card. Isosurfaces, on the other hand, had to be extracted from the data cube beforehand (using visualisation software like VisIt[17] or Python/scikit-image[18]). Once saved as a standard mesh file (like in the .obj format), the data can be readily loaded inside Unity and placed in a 3D scene.

The next step is to create the desired visualisation. For volume rendering, we perform ray casting, where a colour and opacity are assigned to each volume element (voxel), and the RGBA colour is integrated along each line of sight (where R, G and B are the colour channels and A is the opacity). This is implemented using custom shaders (small programmes that run on the graphics processing unit), which gives us full control over the transfer function that maps data values into voxel colours. While ray-tracing is precise, it is computationally expensive, and this limits the data size we can handle to keep the user experience seamless[19]. For meshes representing isosurfaces, we need an external lighting source, so that they actually look three dimensional (the presence of shadows makes a considerable difference).

The final step is to code the interaction of the user with the demo. This involves mapping user inputs into the desired functionality. We offer manipulation of the cube with the controllers, either via the built-in trackpad (which users who have used a desktop setup will be familiar with) or with more native interactions: moving or rotating one's hands in space to impart geometrical transformations to the data cube. Offering a natural user experience is important, both so that researchers can be productive and so that public visitors engage well with it. We also localised the user interface

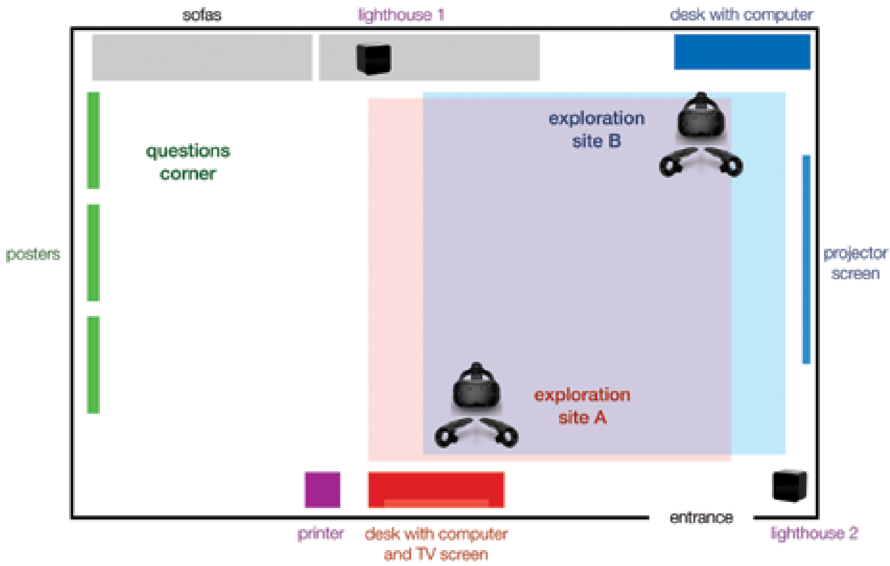


Figure 5. *Sketch of the room layout. Two VR systems were installed (in red and blue) with overlapping exploration areas. Also in the room were a set of posters explaining the research conducted in the laboratory and a questions corner where visitors were free to ask about anything related to astronomy (both were accessible independently of the VR demo, so as not to rely solely on the VR hardware). Credit: RIKEN/ABBL*

(currently available in English, Japanese and French).

Points to Consider and Lessons Learnt

Setting up a public VR experience was a first for our laboratory and presented some new challenges.

Using Space: Room Layout

The layout of the room assigned to our laboratory is shown in Figure 5 and in photographs in Figure 6. Two VIVE devices were set up at opposite corners of an area of approximately ten square metres, which allowed us to have two independent exploration sites in a limited space, while still allowing people to come and go in between. A nice feature of the VIVE's lighthouse system is that a single pair of devices can be used for tracking multiple headset/controller sets in the same room. The hardware setup worked well, considering how busy the room was at times, with very few technical glitches.

The live VR view was projected in two-dimensional (2D) form on a screen, so that others in the room could see what the person with the headset was doing; this was particularly useful so that groups of people could share the experience. This 2D preview did not, however, take away from the VR experience which was such a step up in terms of the level of immersion. It was still able to impress despite a 2D preview having been seen.

Managing Time: Ticketing System

An important aspect to consider when showing such a VR demo to the public is that headsets offer a one-person-at-a-time experience. Based on the interest shown during the RIKEN Centennial Meeting, we knew that we needed a ticketing system in place for the RIKEN Open Day (and that we needed to announce this in the event programme). The day was split into six one-hour blocks, with six ten-minute slots per hour and with both VIVEs operating in parallel. This could in principle accommodate 72 guests. To avoid being sold out too early and to distribute tickets throughout the day, we gave out the twelve tickets for any hour block no more than one hour before the start of this block, that is, twelve new tickets became available for the following hour every hour.

We knew our VR booth would be popular, but it went well beyond our expectations. A long line formed in the corridor when the event opened. As a downside,

Figure 6. *Panoramic photographs of the room during the event. Credit: RIKEN/ABBL*

ticketing proved to be the hardest task. Because so many people were lining up, we decided to accept small groups of people per ticket, as a trade-off between the number of people accommodated and the time spent by each person. The demo was given to approximately 160 people (more than double the expected headcount). To our surprise, many visitors were willing to wait in line for an hour until the next time tickets became available so they could be sure to secure one. This indicated that the potential of using VR technology to get the public interested in our research was massive and that in future, we need to be prepared for bigger crowds, with professional crowd management or a different way of distributing tickets. One solution would be to request online registration prior to the event. Another would be to use a lottery system or contest.

Team Work: Role Assignment

Delivering an experience of this kind requires a coordinated team effort. We had identified the following roles prior to the event:

- A doorperson to welcome people, explain the workflow and distribute the tickets. The workload of this individual was underestimated. Because the VR booth was unusual, quite a lot of explanation was necessary. This role requires two people at the very least at any time.

- Navigators to give the demo (one per headset) and explain the science, how it was simulated and visualised and how users can interact with it. There was a sizable pool of seven Japanese-speaking navigators present all day (all but one was trained on the demo beforehand). This made it possible to rotate them in each hour block, which is good because continuously giving the demo can be exhausting.

- Photographers to take, print and hand out photos of the participants. Although many members were available for this, it is probably sufficient to have two per block.

Briefing the Users

When ticket holders returned for their turn, they were handed two information sheets to read while waiting. One sheet lists basic precautions for using VR, which is a formal requirement, even though the risks are limited for our demo, and indeed, no one had any serious issues. The level of realism is such that some people were apparently genuinely scared when the controllers were first handed to them within the virtual world (others were just mesmerised). The other sheet shows the layout of the controllers, so that the people can familiarise themselves with the different buttons before putting on the headset. This was useful as it somewhat reduced the load on the navigators and saved time during the demos. Once the user is in VR, only verbal communication is possible.

Figure 7. Photo collage of visitors experiencing the VR demo. Credit: RIKEN/ABBL

Recording User Reactions

We had two methods of recording participants' reaction to the demo: the verbal account from the navigators and the comments written in the guest book, which the team tried to collect from each person. Visitors enjoyed the demo, despite the long wait; many were completely new to VR technology and so were very impressed by being able to hold the model in their hands or step in and peer inside, which has been described as feeling "like magic" the first time[20]. Rewardingly for us, people found the experience all the more remarkable since they were looking at actual astronomy data made by scientists: many expressed their gratitude that they could get to experience supernovae in such an intimate and personal way[21].

Given the short amount of time available for each participant, it was not possible to present all the aspects of the demo to everyone, and so the navigators focused on what generated the most enthusiasm. During such a large public event, visitors will always have different backgrounds and interests. So, in the future, we may build progressive disclosure in the software, with different user modes from beginner to advanced so that the demo can be better adjusted according to the user reactions.

Collecting Statistics

We were glad to have a varied crowd visiting our booth, see a sample in Figure 7. The age groups ranged from toddlers to the elderly (quite unexpectedly, both populations were able to use the headset, although the controllers proved more challenging), with most people coming in families, plus a number of groups of middle- and high-school students. A difference among genders was not apparent. We are not able to provide more quantitative demographic data for all the visitors. Given the nature of the event, we lacked both the time and the incentive to investigate this in detail, as visitors moved quickly and freely between the many booths at the Open Day event. Ideally, we would also like to know if they had experienced VR before (and in what context) and the extent to which the presence of a VR booth motivated them to visit us. How to obtain this information in the least disruptive way remains an open question.

Figure 8. *Example of a souvenir photo that was printed and given during the event. Credit: RIKEN/ABBL*

We know that some people were genuinely interested in the science (for example, a woman who follows the institute's news on its YouTube channel), while others were coming to try the technology (like a student who clearly stated having an ambition to make a career in VR). The youngest participants simply enjoyed the aesthetics and interactivity and got a welcoming introduction to the research institute, which their parents also appreciated. It is now our task to capitalise on the novelty of the technology for the promotion of science. In the longer run, we will try to assess the impact of the use of VR on the interest visitors show in our research and their perception of our laboratory.

Creating a Connection: Souvenir Photos

The VR demo is an intense, but short experience. In the hope of creating a lasting link between the visitors and our laboratory, the team leader had the idea to make and give out postcards of each participant trying the demo[22]. The laboratory invested in a small photo printer (similar to the ones found in photo booths), and the photographers used their smartphones to take snapshots and upload them on a shared online folder, so they could quickly be printed on site. We were able to give everyone (provided they approved it) a souvenir of their unique experience, branded with the RIKEN logo and our laboratory's name (a re-created example is shown in Figure 8). This proved very successful, and we highly recommend this practice. We are also re-printing a large collage of the photos to display on the wall at the institute to promote our activities.

Perspectives

We believe that our experiment was successful and shows the potential impact of 3D immersive visualisation in driving public interest in astrophysics research. The ABBL will continue to use VR to promote the work conducted at the laboratory. The VR booth will return for the next RIKEN Open Day, and we are contemplating the possibility of setting up a (semi-)permanent exhibition. Since several VR arcades have recently opened in Tokyo, why not use them to offer a science-based experience?

Most astronomers have not made the transition to the kinds of tools we have described here, chiefly because of the high costs and the difficulty (real or perceived) of use. To our knowledge, the only other application of modern VR for astronomy data is visualisation of the 3D structure of the SNR Cassiopeia A, as reconstructed from observations, produced by NASA's Chandra team[23]. However, recent developments on both the hardware and software sides have considerably lowered the cost of entry for VR, and we argue that now is a good time to get started — for research as well as outreach. It is also the time to build a community for VR astronomy and generally, for advanced visualisation in science. By sharing our method and insights[24], we hope to help others create innovative and engaging experiences for the public. Our generation may not be able to actually travel to the stars, but we can certainly do so virtually.

Acknowledgments

First, we warmly thank the team that made it possible to deliver this experience at the RIKEN Open Day: Shigehiro Nagataki and Tamaki Shibasaki (ABBL chief scientist and secretary); navigators Masaomi Ono, Hirotaka Ito and Susumu Inoue (post-doctoral researchers at RIKEN); students from Rikkyo University Masanori Arakawa, Hiroyoshi Iwasaki, Atsuhiro Ebata and Yutaro Yoshino; and photographers Haoning He, Oliver Just, Donald Warren and Gilles Ferrand (post-doctoral researchers at RIKEN). Extra thanks are due to Masaomi Ono for the Japanese translation.

We also acknowledge our colleague Fritz Röpke (Heidelberg Institute for Theoretical Studies and Universität Heidelberg) for providing us data from the supernova simulations as part of Ferrand's research project.

Ferrand extends special thanks to Jayanne English (University of Manitoba) for prompting his initial foray into VR and for remotely testing the early SN demo before the ABBL acquired its own headset.

Notes

1 More information on Astrophysical Big Bang Laboratory: nagataki-lab.riken.jp/research_en.html

2 More information on RIKEN (理研), the largest public research institute of Japan: www.riken.jp/en/about/

3 In augmented reality (AR), it is possible to place computer-generated elements in the real world. Our project however does not use this technique.

4 During the international workshop "Theories of International Big Bangs" held on our campus (2017-11-06 to 2017-11-17), the author included a live demonstration as part of his talk, which served both as an introduction to the scientific use of VR and as an illustration of his research work.

5 Open day information: http://openday.riken.jp (the supernova experience in VR is announced on page 10 of the PDF pamphlet).

6 A supernova (SN) marks the end point of the evolution of some stars (either a massive star or a white dwarf). As the ejected stellar material rushes away from the explosion centre, it triggers a strong blast wave that ionises and energises the ambient matter. It is this interaction between the ejecta and the interstellar medium (ISM) that produces the supernova remnant (SNR). While the SN phase may be measured in seconds, the SNR phase may last for thousands or tens of thousands of years, until the remnant dissolves into the ISM.

7 The pilot project, conducted by G. F. at the University of Manitoba, was a collaboration between the departments of Physics and Astronomy (principle investigator Jayanne English, radio astronomer) and Computer Science (principle investigator Pourang Irani, head of the Human Computer Interaction lab): hci.cs.umanitoba.ca/projects-and-research/details/3d-visualization-of-astronomical-data-using-immersive-displays

8 Google Cardboard: vr.google.com/cardboard/

9 Visbox CAVE: www.visbox.com/products/cave/

10 VIVE: www.vive.com

11 Unity can be downloaded from unity3d.com. It is commercial software, although it is free to use for developers with our needs and usage. It is available on all platforms, although at this time, the VIVE hardware is officially supported only on Windows.

12 Another generic software for 3D modelling that has proved popular for scientific applications is Blender, although it has been used more often for off-line rendering rather than for interactive visualisation. The most relevant programme for what we are doing is the FRELLED software by Rhys Taylor (www.rhysy.net/frelled-1.html).

13 An example in the field of oceanography and meteorology is TerraViz, the visualisation component of NOAA's Earth Information System, which is entirely built using Unity, described as "an ideal choice for providing a wealth of data to a user in real-time". www.esrl.noaa.gov/neis/library/terraviz-video.html

14 Another software for meteorologists, MEVA, combines "the power and variety of data abstraction methods of a visualisation tool (ParaView) with the interaction and presentation capabilities offered by computer-games engines (Unity)". www.ufz.de/index.php?en=37915

15 Steam VR: store.steampowered.com/steamvr

16 Our software is still very much a prototype. It is not yet a complete visualisation package for astronomy; rather, it is a workbench for exploration. For a full-fledged solution for scientific visualisation in VR, in a CAVE environment, see the VFIVE application originally developed by Akira Kageyama.

17 Visualisation software VisIt: wci.llnl.gov/codes/visit/

18 Visualisation software Python/scikit-image: scikit-image.org

19 In VR, real-time rendering is critical because the user determines the current viewpoint at any time. A noticeable delay between when they move and when the environment responds breaks the 3D illusion and can cause significant discomfort.

20 This was expressed by a number of すごい (*sugoi*) interjections, which loosely means "terrific" in Japanese and is the idiomatic equivalent of "awesome".

21 One eleven year old even reported feeling the "wind" from the explosion during the demo… even though we have not deployed such multi-sensory haptics yet!

22 The next step will be to show the person interacting with the virtual model by compositing the real-world photograph with the computer-rendered display.

23 Project "Walking among the stars", led by Kimberly Arcand (chandra.harvard.edu/vr/)

24 We are considering options to share the Unity project with colleagues and to share the final product with the public. If you are interested in trying our demo and have the hardware, please contact us directly.

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Biographies

Gilles Ferrand is an astrophysicist at the Astrophysical Big Bang Laboratory (ABBL) of RIKEN. He is working mainly on particle acceleration and supernova remnants. He also has a keen interest in scientific visualisation.

Don Warren is an astrophysicist for the Interdisciplinary Theoretical and Mathematical Sciences (iTHEMS) Program at RIKEN. He also helps organise and run the monthly outreach event Nerd Nite Tokyo.

Videos for Astronomy Education and Outreach

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Keywords
Science communication, YouTube, video, education, outreach, social media, astronomy, space, STEM, undergraduate students

This paper presents an unusual project in which astronomy videos were created for education and outreach with students playing a central role, from initial conceptualisation to final distribution of the videos on the Internet. Seventy videos were produced over the past three and a half years, on subjects ranging from tours of local observatories to complex concepts like adaptive optics. Students learned skills such as time management, interdisciplinary teamwork and optimising communication of technical information to the general public. Most of the videos have a strong student voice, and students' experience with social media helped in reaching other young audiences. This paper describes the organisation, management and workflow of the project. The time and money required to create educational astronomy videos are also discussed.

The Rise of Video

The meteoric rise of video content on the internet over the past decade has transformed the way people learn. Videos are routinely used for personal improvement, providing how to instructions for a myriad of tasks, informal learning through massive open online classes (MOOCs), and formal instruction in online classes offered by colleges and universities worldwide. MOOCs in particular have harnessed the power of video content for education (Margaryan et al., 2015; Reich, 2015), including the teaching of astronomy (Impey et al., 2016). At the epicentre of this rapid growth in video content is YouTube, a website started in 2005 and operated since 2006 by Google. YouTube is the second most popular website in the world, with 400 hours of content uploaded every hour, and a billion hours of content viewed every day (Zhou et al., 2016).

Broadband Internet and smart phones are now available to the majority of the population in the United States and a rapidly growing fraction of the world's population (Lee et al., 2015). Thus, video has become an obvious tool for science education and outreach. The video medium allows storytelling, conveying a vivid sense of place, and in the example of astronomy, displaying the visual beauty of the Universe. The use of short-format videos delivered over the Internet and created without any professional production capabilities has grown rapidly and can potentially reach very large audiences. TED talks on science are a well-known example (Sugimoto & Thelwall, 2013). Audiences are not restricted to college or high school students but include adult free-choice learners (Rosenthal, 2017). Early research indicates that although professionally produced YouTube science content dominates in terms of number of videos, user-generated content is significantly more popular (Wellbourne & Grant, 2016). There have been limited experiments with student-generated science videos (Wang & Shao, 2016; Hoppe et al., 2016), but factors that drive engagement with science videos are still being measured at this level (Wade & Courtney, 2013; Yoo & Catrambone, 2016). The most popular science channels on YouTube as of 23 July 2018 are (searched with the categories "education" and "science and technology") Smarter Every Day, Sci Show, Veritasium, Minute Physics, NASA, Minute and Cody's Lab (Reemer, 2018).

Astronomy has long been well served by long-format (television episodes) videos from national media producers such as PBS/NOVA and National Geographic. A sense of the landscape for astronomy videos comes from searching YouTube with a Chrome browser set in the anonymous mode (to avoid bias due to user preferences or viewing history). A search for "astronomy" returns 2.9 million results, with about 5000 new videos added every day. The most popular videos at present are from the *Astronomy Crash Course* series, hosted by Phil Plait and created by PBS Digital Studios. There are 47 videos in this series, ranging from ten to 15 minutes long, with a total of 9.5 million views. The umbrella channel Crash Course, started by John and Hank Green in 2006, has over seven million subscribers and is approaching a billion total views. Other astronomy-specific channels include Sci Show Space, with a million subscribers, and Vintage Space, which is more about space flight than astronomy. Amusingly, three of the most commonly viewed videos are songs with astronomy in the title by rock groups Metallica, Pink Floyd and Blue Oyster Cult. Other astronomy videos with over a million views are single lectures, typically an hour long, from various public events and television shows for a national audience.

The Project: Active Galactic Videos

From the outset, undergraduate students played a central role in the current project. The lead author (Impey) had been working with students on education and outreach for a decade and had occasionally created educational astronomy videos for teaching non-science majors at the University of Arizona. A lot was learned from the production of videos for two MOOCs. The first, *Astronomy: State of the Art*, has been available on Udemy since March 2013 and has had over 62 000 enrolments. The second, *Astronomy: Exploring Space and Time*, has been running on Coursera since February 2015, with over 75 000 enrolments. The project management team also includes the second author (Wenger) acting as education manager, and the fifth author (Danehy) web programmer and developer. From its inception, this project has had multiple goals: (1) disseminating astronomy through the appealing medium of short-format videos, (2) conveying cutting-edge astronomy research being carried out at one of the world's major observatories and (3) providing undergraduates with opportunities to learn new skills, practice teamwork and apply their creativity to astronomy.

Students involved in the project enthusiastically embraced the idea of systematically creating a series of videos to communicate astronomy concepts to wide audiences and to highlight the research going on at Steward Observatory, which is one of the world's prominent astronomy centres. The title selected by the students for the project, the associated website and the YouTube channel was Active Galactic Videos. The YouTube channel was launched on 21 July 2015. As of late July 2018, it hosts 68 videos and has around 6100 subscribers and 110 000 total views (Figure 1). While viewership is modest, it is rising and the audience will grow as new content is added and the site is promoted through social media networks.

The Active Galactic Videos project got a big boost at the beginning of 2018 when one of our videos was featured in a guest spot on the YouTube channel operated by the British science populariser Tom Scott. He has 1.1 million subscribers and his videos have had 210 million views since 2006. Our tour of the Steward Observatory Mirror Lab got nearly a quarter of a million views on this site within two weeks of being posted, several times the total number of views of the Active Galactic Videos YouTube channel (at the time the video was launched). This boost to the project highlights the role of prominent social media influencers in drawing attention to a new video channel.

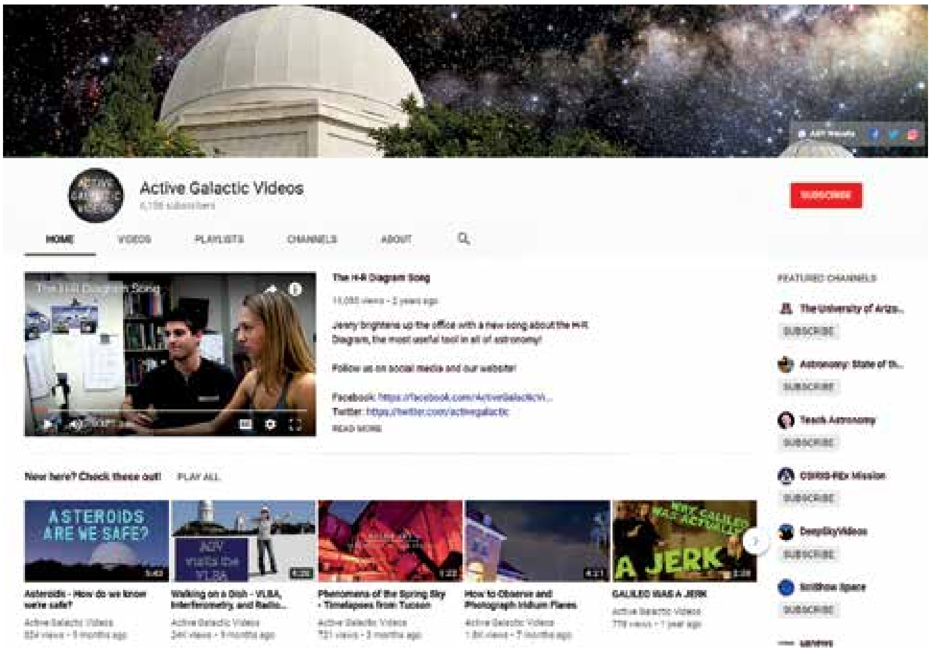

Figure 1. The YouTube page of the Active Galactic Videos project (viewed July 2018). The homepage is set to highlight new releases and provide a sampler of the content. Below that are the most popular videos and the various playlists with videos grouped according to themes. Credit: Active Galactic Videos

Project Management

The Active Galactic Videos activity is part of a larger education and outreach effort centred in the Department of Astronomy at the University of Arizona, which includes the development of astronomy content for the Teach Astronomy website and support for two MOOCs, as described earlier. Over twenty undergraduate students have been employed to make videos over the past two and a half years. Most of the students are juniors and seniors with a full class load, able to work 10 to 15 hours per week. The project is supervised by the first author, a distinguished professor of astronomy and an associate dean of the College of Science. Day-to-day management is handled by the second author (Wenger), a full-time member of the Steward Observatory scientific staff with the title of Education Manager.

At the beginning of the project, astronomy majors and minors were mostly hired. We quickly discovered that our students excelled at developing ideas for videos and creating the associated content. We also found that many of the best astronomy students had hobbies such as singing and photography in addition to their science training. These students with varied backgrounds in music, English, film and television and acting produced the best videos. Beginning in the second year of the project, we began to specifically hire students who were non-science majors. We matched students with majors in filmmaking, cinematography, sound design and creative writing with students majoring in astronomy to create the best and most well-received videos. When we first hired students with sound and video expertise, we had them recommend video and sound equipment that would improve the production value of our project. There was

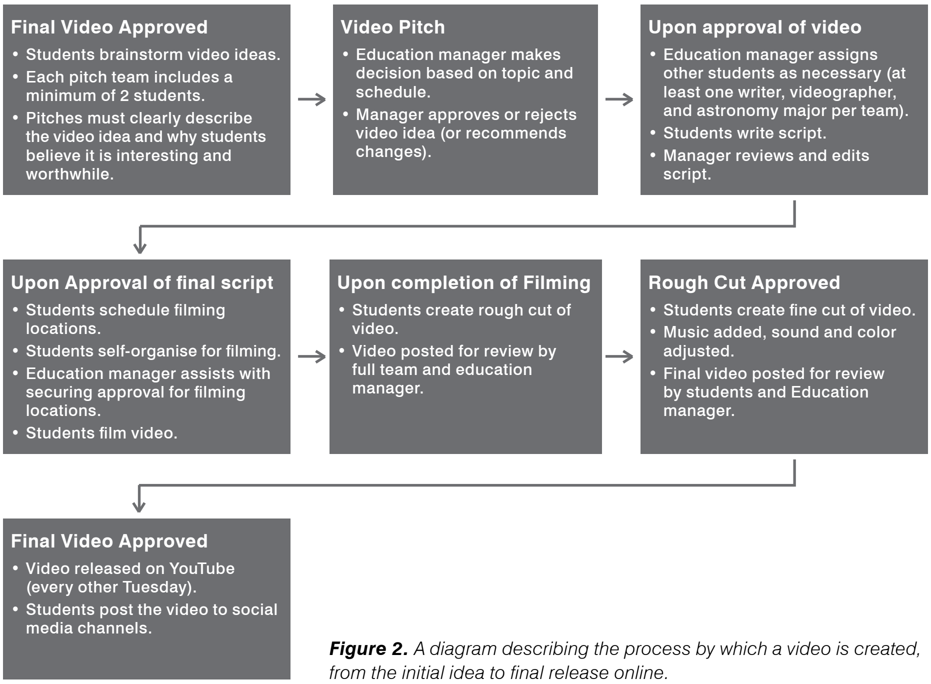

Figure 2. *A diagram describing the process by which a video is created, from the initial idea to final release online.*

an immediate and noticeable improvement in the quality of the videos, based on changes in equipment alone. This aspect continued to improve as the students became more familiar with the equipment and their skill level increased.

On the basis of several years of experience, we came up with a system to pitch video ideas. The first requirement was that at least two students had to work on every pitch. We found that this helped weed out ideas that sounded entertaining but were too gimmicky or had a flawed premise. This process also helped eliminate projects that initially seem like a good idea but ended up being too simple to underlie a whole video or were too complex to pull off. Next, the students had to present the idea, including an overview of the purpose and goals of the video and a plan for how to film it. We found that by thinking through these components of the video ahead of time, we spent less time backtracking on videos that were not feasible.

The overall goal of the project is to create appealing videos with a high production value and a strong and authentic student voice. Creation of the videos is a rich learning experience for the students involved (Smith, 2014). Our videos ranged in length from two to six minutes. Some were standalone ideas such as *Why are Barns Red?*, *Galileo was a Jerk and Asteroids — How Do We Know We're Safe?* Others had a timed release linked to a particular astronomical event, like *Lunar Eclipse 2018* and *Highlights of the Cassini Mission*. A third category had a general theme explored with multiple examples: these videos were predominantly observatory tours, such as *AGV visits the VLBA* and *Astronomy Research at the MMT*. A fourth category was a series of videos with a consistent format or a single theme, like *Five Facts* and *Einstein Out West* (Figure 2). Although there is some evidence that videos using a single, consistent science communicator are more successful (Wellbourne & Grant 2016), we chose to explore a range of styles with various student hosts. The fact that all of the videos were not equally effective or successful is a characteristic of this type of enterprise.

Hardware and Software

Tools like iMovie and inexpensive, ubiquitous cell phone cameras have democratised video production to a large extent. However, to be a highly regarded channel that attracts loyal viewers on YouTube, it is necessary to meet a certain minimum level of requirements for video and audio quality. At the very least, videos should be recorded and edited at a resolution of 720p, although it is common for most modern videos to be recorded at a 1080p. resolution. This takes up a significant amount of storage space, and it takes a while to export a final video, but the high-quality final product is worth the space and effort. To keep pace with improving technology, video producers should consider purchasing a 4K camera. For our project, we bought a Canon 80D DSLR camera, which has video capabilities. This camera has a large sensor and uses high-quality photographic lenses.

In addition to the camera, a basic audio setup is recommended. A shotgun microphone can be used for voice-over work if the budget does not allow for multiple microphones. USB microphones are also available, but a traditional XLR microphone and digital recorder setup is more versatile and modular than on-camera audio or

	Minimum Required	Preferred	Our Solution
Video	720p video camera.	4K digital video camera or DSLR.	Canon 80D DSLR camera.
Audio	On-camera audio.	Digital audio recorder with 4–6 channels. Shotgun microphone. Lavalier microphones.	Tascam DR-70D 4-channel audio recorder. Rode NTG-2 shotgun. Shure Lavalier microphone.
Lighting	None.	Three fully adjustable (colour, temperature and brightness) LED studio lights.	Cowboy Studio kit including three softbox lights with 5500K fluorescent bulbs.
Other Equipment	None.	C-stands. Green screen. Backdrops for interviews.	Tripod with collapsible reversible green/blue and black/white screen.

Table 1. *A description of the minimum and preferred video, audio, lighting, and supplementary equipment as well as a list of the items we purchased for this project.*

Figure 3. *An example of one of the videos from Active Galactic Videos. This video was created using the process described in Box 1. Credit: Active Galactic Videos*

Box 1. Process for Active Galactic Video episode featured in Figure 3.

Carmen from Active Galactic Videos visits a radiotelescope on Kitt Peak that is part of a network of radiotelescopes called the Very Long Baseline Array (VLBA).

The VLBA consists of ten dishes that are each 25 m in diameter and stretches from St. Croix in the Caribbean to Mauna Kea in Hawaii.

Carmen takes us on a tour of the facility, talks to experts and climbs to the top of the telescope where she gets to walk on the dish and explain how it works to focus and amplify radio signals so that astronomers can study the Universe.

a USB microphone. Lavalier wireless mics are also recommended for high-quality sound and location filming. Video and sound equipment is evolving and the merits of different types of hardware are hotly debated; in Table 1, we present our suggestions for the minimum level of equipment, the preferred level and our solution. Other equipment that we purchased and used extensively are a portable green screen and a small lighting kit. Although we ordered an inexpensive Cowboy Studio brand lighting kit with fluorescent lights, the recommendation is to buy an LED lighting kit with adjustable brightness and colour balance.

We did not have access to a dedicated studio space for filming, so we often filmed in our team office or on location. If you have a place to set up a permanent sound- and lighting-controlled studio environment, it is highly recommended. This is beneficial for a variety of reasons. In particular, if you want to use a green screen, colour keying is easier when you have bright, even lightning. Additionally, if you want to produce videos quickly, a dedicated studio space means that you do not have to repeatedly set up and take down your equipment.

Finally, for editing video, we purchased an Apple Mac Pro and a professional level video editing package. We started with Final Cut Pro X and found it to be easy to learn and use, particularly for new students. It has some advanced features, like key-frame animation capabilities and colour keying for green/blue screen removal. More recently, however, we moved to Adobe Premiere and After-Effects. Although not considered as high end as Avid Pro Tools, Premiere is still a professional level editing program and is used widely by YouTube video creators and industry professionals. It has more options and controls than Final Cut Pro X does but is not as easy to learn for new editors. The University of Arizona also has an Adobe site license, so Premiere, After Effects and the rest of the Adobe Creative Suite are all available to us and to all the students; thus, we do not have to restrict their use to a single computer. It may not be necessary to have the most advanced video editing hardware, but an old computer would be a significant bottleneck in the process of editing and exporting videos, so be sure to test out the computer you are planning to use for editing. We also recommend using a computer that can support one or two external monitors to improve workflow.

One innovation we have used in certain videos is the use of a drone for aerial views and to add drama to the visual presentation. The drone used is a DJI Mavic Pro. Because of the drone's mass, it must be registered with the FAA for recreational operation as a U.S. commercial flight and requires a strict, Part 107 license. The drone's camera can shoot at many different resolutions and framerates, including raw (D-LOG) footage up to 4K at 30 frames per second. It has a maximum range of up to seven miles, but the law requires that the pilot or spotter always be within visual contact of the drone, which limits the practical radius to less than one mile. In addition to adding drama, flying cameras provide previously unseen perspectives on remote locations such as observatories, thus improving film quality (Figure 3).

Professional Development

Students play a central role in the project, from pitching ideas in team meetings to forming groups with the appropriate skill sets to create a video and filming and editing the videos. To illustrate this, Box 2 shows quotes from some of the undergraduate participants on the benefits they experienced by working on AGV. Early in the project, we determined that everyone on the team would benefit from specific and purposeful professional development, with the goal of improving our videos in the following areas: sound quality, visual quality, storytelling and presentation and acting.

Each week, we had a one-hour meeting to specifically talk about video projects. In general, at least half of this meeting was dedicated to professional development. To address this aim, two exercises were undertaken: in the first exercise, two students signed up to present to the group and lead a discussion each week. The Education Program Manager always presented at the beginning of the semester to set expectations for the students. Prior to the meeting, the presenters chose a topic and found a variety of videos that illustrated the point they were trying to make. For example, if we wanted to talk about the

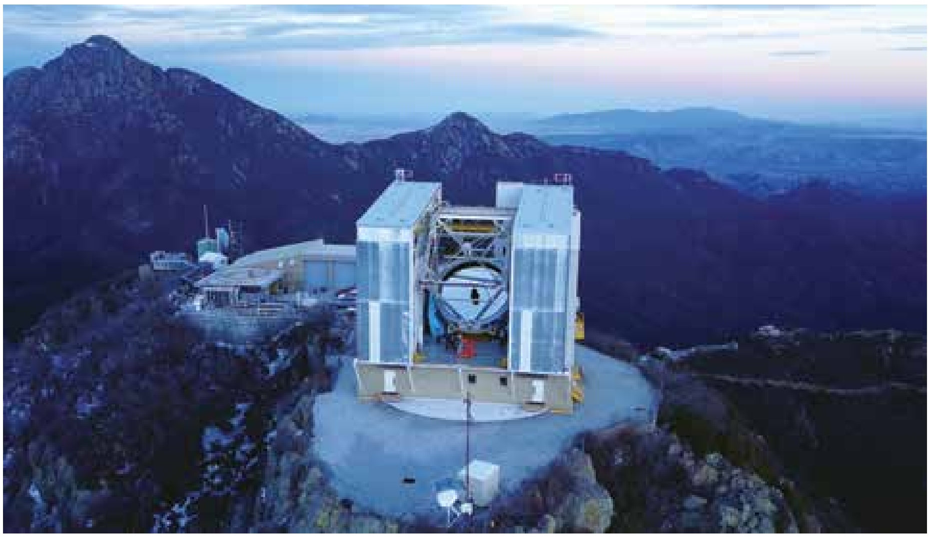

Figure 4. *A drone shot of the MMT Observatory at the Fred Lawrence Whipple Observatory on Mount Hopkins, in southern Arizona. This research facility was the subject of an Active Galactic Videos tour. Credit: Active Galactic Videos*

use of animations in videos to show scientific concepts, the presenters found two or three videos that illustrated best practices and a few that did it poorly. The presenters wrote several guiding questions for a discussion about the topic. These were meant to stimulate the conversation and were usually framed in the context of "Which of these worked best?" or "How did the creator use this well and what could have been improved?" Video links and questions were sent out ahead of time and everyone was expected to have watched the videos and prepared to participate in the discussion. Ultimately, the goal was to incorporate the lessons learnt into our own videos.

The second professional development exercise that proved effective was to go back and critique old videos from our own channel. We began by watching the video and then each participant was asked to make at least one comment (positive or negative) about the video. After we went around the room, we opened up the discussion to comments or additional critiques that people want to bring up. One of the most important ways to improve video quality is just to make a lot of videos and reflect on them, making slow, incremental improvements. This can be particularly challenging with a constantly rotating group of undergraduate students, but given the wide range of ages and experience levels, there is often enough continuity to pass on the lessons learned to the next group of incoming students. It also helped that there was a consistent staff manager who could carry these lessons forward and review important information with incoming students that the existing team might have taken for granted.

Filming Issues

At the beginning of the project, we filmed most of our videos with a presenter standing in front of a green screen. Because our equipment was limited, this allowed us to exert some control over the video and sound quality. Unfortunately, this gave our videos an amateur look and feel. As we progressed, we started filming on location, or at least outside of our small office-based studio. While this made filming more of a challenge (with regard to sound, in particular), we simultaneously brought

Box 2. Students' views on the project

Why Students Joined the Project

"Any student interested in science and education can benefit from being a part of the AGV project. If they have this interest, almost any major and skillset can find a place in the project. Our team has artists, journalists, filmmakers and scientists, and all of them can find a way to grow with AGV".
Aidan Gibbs, Astronomy and Physics major

"I joined the AGV team to further my science writing skills. I was interested because I had taken a few astronomy classes prior and was interested in learning more. It ended up being a great fit because I learned a lot and advanced my science writing skills".
Jessica Blackburn, Journalism major, Spanish minor

Professional Development

"AGV helped shape my interest in documentary work and opened my mind to other styles of production I wouldn't have been exposed to. This is true because of my experiences working alongside other people producing content as well as because of our continual evaluation of other YouTube channels and content creators".
Galen McCaw, Music major, Film and Television minor

"AGV has generally broadened my knowledge and interest in science. I came to the project with a keen interest in astronomy and physics, but the specifics were not exactly my thing. It has also provided useful experience when it comes to writing under time pressure, which is a much needed skill for a writer of any kind".
Grant Bowman, Computer Science and Creative Writing major

Interdisciplinary Experience

"AGV is special because of the interdisciplinary nature of the group; I'm constantly learning, whether it be about science or how to be a better filmmaker. The diversity in the AGV team— (astronomers, journalists, geologists, physicists, graphic artists, filmmakers) —allows us to be extremely creative".
Carolyn McKee, Philosophy major, Film and Television major

"AGV shows students like myself that we can make some amazing things when collaborating with people outside our disciplines. I'm a film student and have always been the art kid of my family, but I also really enjoy learning about science and astronomy, despite not having much knowledge on the subject. AGV gives us a space to come together and make content that is leagues better than what we could do on our own, giving us a way to give back to our community through education and enhance our personal skills in the areas that we hope to pursue after graduation. Also, I've become friends with everyone here at AGV, and it's been such a wonderful experience getting to know new people who are so passionate and talented".
Victoria Pereira, Film and Television major, Creative Writing minor

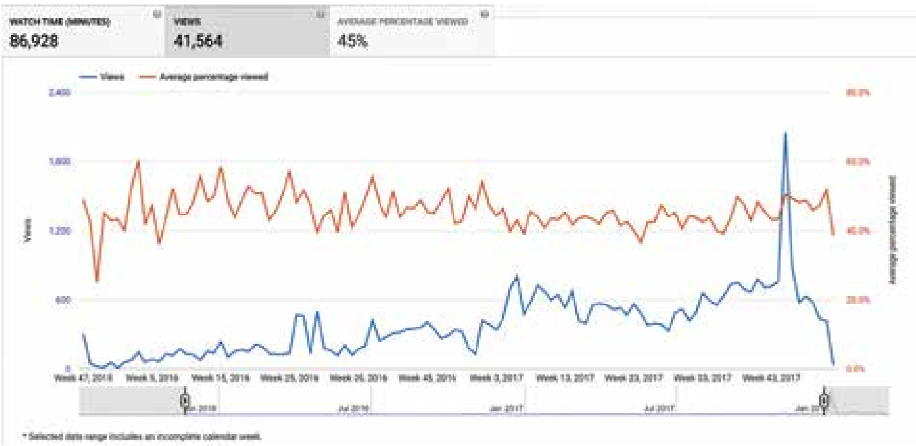

Figure 5. *The classic version of YouTube's analytics enables users to compare various metrics against each other. This graph shows the total channel views (blue) and the view percentage averaged across all videos on the channel (orange), per week. The latter statistic is also known as audience retention and depicts how much of a video the average viewer watches. Credit: Active Galactic Videos*

on students with expertise in sound and videography.

One issue we encountered was obtaining permission to film at certain locations. Although we always work with the staff at the locations where we want to film, large organisations such as observatories can have complex administrative structures. Permission from a collaborator was often insufficient to allow us to film, and permission was required from a high administrative level. We learned to get approval from director-level administrators if possible and to alert as many people as we could about our visit, giving everyone a chance to give their inputs. Major observatories deal with filming requests frequently, and they may have a formal structure in place, with permission forms on their websites. But other facilities have no such structure. It is best to work with an on-site contact and inform an administrator at the highest possible level. We also frequently offered to share our footage with the staff at the locations where we were filming. These organisations may not otherwise have a way to get this footage themselves. It is important to be aware of particular filming concerns and note any special requirements and "off-limit" subjects or areas. For example, filming at Kitt Peak and Mount Graham required sensitivity to the concerns of the Tohono O'odham and San Carlos Apache tribes, respectively. Additionally, many major observatories are on land that is controlled by the U.S. Forest Service, and they may have their own filming requirements, forms and fees. The simple recommendation is to ask lots of questions and be aware that many organisations have these kinds of concerns.

Dissemination and Metrics

YouTube was the primary channel for disseminating Active Galactic Videos and soliciting feedback from viewers. Creating a YouTube channel occurs as a by-product of having a Gmail account. The real challenge arises when attempting to cater to a growing audience. Each new release enables creators to fine-tune their content to best-serve their audience, since YouTube provides many metrics, and many dimensions therein, known collectively as analytics. YouTube's analytics includes data on external sources, YouTube search terms and audience retention (Figure 4). From these and other analytics data, the team could decide how long a video should be to hold viewers' attention, which words and phrases to use in a video's title and description and which topics or types of videos draw the most attention. By evaluating metrics like audience retention in contexts such as video type or video duration, it quickly became apparent what kind of content would draw the most attention (Figure 5). There are no fixed good or bad values for audience retention, but analysts tend to agree that a good retention rate is greater than or equal to 65%. If your audience continues to grow and your retention rate either maintains its value or improves, then your content is also likely to be improving.

Managing a YouTube channel is just a small portion of what is required as part of branding and overall outreach. In any context, outreach is about maximising exposure, so each release on YouTube should be accompanied by social media activity such as posting on Twitter, Instagram and Facebook. Potentially engaged users on YouTube often want to know more about the content and its creators, which requires the use of various social media platforms. Although this activity helps to garner new viewers and provides a framework for word-of-mouth propagation, it also adds quite a bit of complexity to the analytics. Posts on

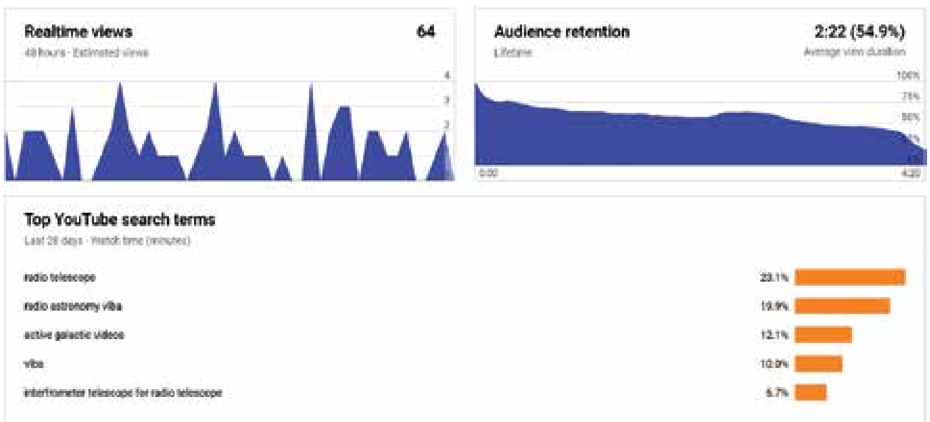

Figure 6. *Part of the YouTube analytics for a single, public video on the channel. The Realtime views graph shows the number of views per hour, including the current hour. The audience retention graph shows the percentage of viewers who made it to any given point in the video. The shape of this plot reflects the anecdotal decline of the average attention span of YouTube viewers. The lower chart shows which search terms people used to find the video. This is the most valuable data, as it can help guide tag and title selection for future videos. Credit: Active Galactic Videos*

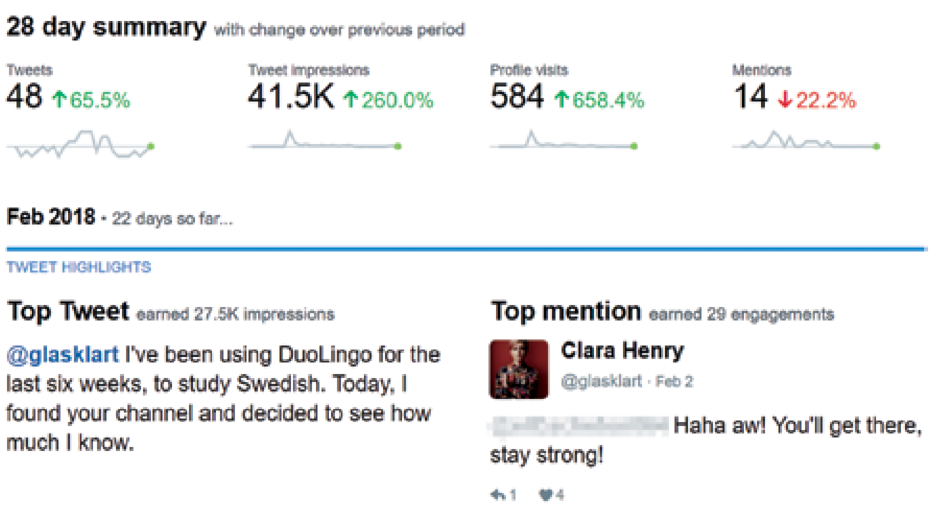

Figure 7. *Twitter analytics page for a single user. The default view is a 28-day breakdown of activity. The Tweet Impressions data along with the Top Tweet/mention fields highlight which words, phrases or topics are considered the most interesting. A Tweet Impression is the number of times a person saw this Tweet on any device for a measurable amount of time. Credit: Active Galactic Videos*

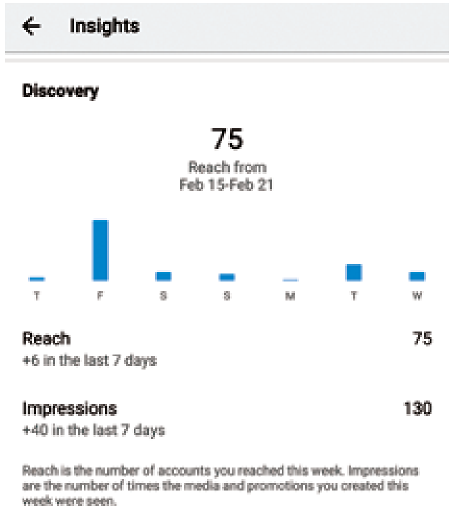

Figure 8. *This is the Instagram Business Analytics viewer. The tool provides sparse information, requiring a manual approach to look for any potential correlation between the posts and impressions data. Credit: Active Galactic Videos*

Twitter and Instagram must be accompanied by hashtags in order to be given an advantage by the algorithms of these platforms. However, words and phrases used to boost viewership on YouTube do not necessarily translate to Twitter and Instagram. As with YouTube, Twitter provides analytics to help determine which hashtags perform the best (Figure 6). Additionally, Twitter makes it clear which networking efforts are the most beneficial.

Instagram also has its own analytical data available only to Instagram Business accounts (Figure 7). Converting an account to Instagram Business is just as easy as creating the account itself. Among the platforms mentioned so far, Instagram has the sparsest analytical data which is the most subject to interpretation. This platform does nothing to inform the user of which hashtags or keywords helped viewership. Additionally, Instagram's analytical data is only viewable on a mobile device, which makes assimilating and using the data very inconvenient.

Facebook provides a thorough, high-level set of analytical data. While it is not evident why one post performs better than another, it is easy to compare among posts (Figure 8). Like with Instagram (a Facebook platform), the analytical data is subject to interpretation and theory. All three major platforms (Twitter, Instagram and Facebook) provide the ability to boost a post. This service costs money and is the equivalent of buying ads. Since this is one major part of Facebook's revenue, they focus their analytics page on boosting posts.

Project Costs

Active Galactic Videos is funded in part by the Department of Astronomy and the College of Science, who pay the salaries of the second and fifth authors, respectively, and by a grant from the Howard Hughes Medical Institute, held by the first author.

The grant supports an array of educational projects, but it is possible to itemize the expenditure that supports the videos. Depending on seniority, students are paid between $10 and $15 per hour. Most have full class loads so they work an average of ten hours per week for the 30 weeks of an academic year. There is flux as new students join the project and senior students graduate, but over the past two years, an average of eight students have been working on the videos. This works out to about $29 000 per year on student stipends. With employee-related expenses at 3.5% and

Figure 9. *Facebook's analytics page for a business or public group. Reach is defined in the same way as on Instagram: the number of accounts who saw any particular post. Engagement shows how many of those accounts interacted with the post by clicking and/or liking it. The task of determining why any post got more engagement than any other posts is up to the user. Credit: Active Galactic Videos*

indirect costs at 54%, the cost to the grant is $45 000 per year. If the portion of staff time supporting this project is included, this number doubles.

Most of the costs of producing videos for education and outreach lie involve salaries and stipends. We have bought, and occasionally upgraded, mid-range video equipment (i.e. not professional level) and have had to purchase consumables like batteries. There are costs for computer peripherals, storage media and video editing software (the latter is available at low costs through licenses to the University of Arizona). Additional costs arise from location filming, including car or van rental, and occasional hotel and meal expenses for longer trips. The sum of all these ancillary costs has averaged about $8000 per year. Therefore, the entire annual cost is around $100 000. If staff support is already provided by the institution or if the student team is small, the costs can be kept below $50 000. There are 67 universities with astronomy majors in the USA, totalling over 1600 juniors and seniors, and all these universities have Liberal Arts students who could be included in such projects (American Institute of Physics, 2017). Thus, we believe this model for the creation of videos for education and outreach could be replicated at many colleges and universities in the USA and elsewhere.

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Biographies

Chris Impey is Associate Dean of Science and University Distinguished Professor of Astronomy. His astronomy research areas are galaxies and cosmology, along with science literacy and pedagogy. He also writes popular science books.

Matthew Wenger is an education researcher and Program Manager at Steward Observatory. He develops online courses and researches learning in online environments. He leads students participating in the Active Galactic Videos project on YouTube.

Carmen Austin is an education specialist at Kitt Peak National Observatory. While completing her undergraduate degree at the University of Arizona, she was one of the founding members of Active Galactic Videos and was a part of the project for three years.

Jenny Calahan is currently an astronomy graduate student at the University of Michigan. While completing her undergraduate degree at the University of Arizona, she was one of the founding members of Active Galactic Videos and was a part of the project for three years.

Alexander Danehy is a software engineer. His computer science research areas are computer vision and machine learning. He works in the Department of Astronomy at the University of Arizona and for the NASA Astrobiology Institute.

Best Practice

Your Night out under the Stars: Reaching beyond Native Audiences

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Keywords
Public engagement, public events, astronomy workshops

To invite an international audience to engage with astronomy in Lisbon, we organised an outreach event with lectures, workshops and observations with telescopes. The event was held in the evening, was attended by 203 people and was aimed mainly at young adults visiting or living in Lisbon, as well as families. We aimed to give a large number of people of diverse nationalities the opportunity to interact with researchers and be inspired by astronomy, while enjoying a nice evening out. Lisbon is a trendy tourist destination, and we used this event to project a more international image of Instituto de Astrofísica e Ciências do Espaço (IA). This event was organised by IA in Lisbon, in collaboration with Leiden University (the Netherlands) and the Planetário Calouste Gulbenkian — Centro Ciência Viva (Lisbon). In this paper, we outline the methods chosen to achieve these goals, how they were implemented in practice and discuss the effect of the chosen methods. We also share suggestions for organisers of similar events in the future.

Introduction

In recent years, Lisbon has become a trendy destination for tourists, international students, independent workers and entrepreneurs. Its culture and urban landscape have been the main attractions for non-native speakers. However, Lisbon has many research centres and science outreach institutions, which can take advantage of this new audience to promote the nation's achievements in science, and at the same time offer engaging and exciting content and experiences to those who do not understand Portuguese.

In this paper, we describe the process of designing an event titled *Your Night out under the Stars*: an evening with workshops, lectures and observations with telescopes to inspire people to learn about astronomy. This was the first large-scale outreach event organised by the Instituto de Astrofísica e Ciências do Espaço (IA) to be presented exclusively in English[1]. Through this project, we wanted expatriates, foreign students and tourists to engage with science and research and spark their interest in astronomy.

The Science Communication Group (SCG) of IA believes that the knowledge that astronomy generates is universal, and its mission is to share this knowledge with the wider public by inviting them to get involved and participate. IA has a very active collection of science communication initiatives, and its SCG has many years of experience in organising and participating in regular large-scale local and national astronomy events in Portuguese. Each event engages from a few hundred to a few thousand attendees. These events usually consist of lectures, observations of the night sky with telescopes and hands-on activities. In this context, we identified the need to address the potential audience of non-Portuguese people visiting or living in Lisbon and organised an event in English to attract this audience.

We had five core aims for the project:

Aim 1: Broaden the target audience of IA engagement to non-Portuguese speakers, in order to create a more international image of IA and promote its awareness among foreign students and visitors.

Aim 2: Create enthusiasm for astronomy among the intended audience.

Aim 3: Give the audience a unique experience, an evening out with science.

Aim 4: Improve public understanding of the Universe and of astronomy research.

Aim 5: Experiment with interactive workshops to see how the public and the researchers react.

Research by Buckley and Jensen (2014) on the motivations for people to attend science festivals shows that close contact and informal discussions with researchers work well to improve knowledge and understanding. Moreover, live events are apt to create an interest among the public. An inspiring and exciting atmosphere is often more important to the attendees than the actual content. Various types of activities, social interaction and close contact with scientists provide a unique experience and act as motivations to attend. In surveys on the motivations to attend astronomy events at the Institute of Astronomy, University of Cambridge, the importance of learning new scientific content was highlighted, apart from the enthusiasm and accessibility to astronomers (Curtis, 2013). Another interesting initiative is Astronomy on Tap. These activities aim to enhance the interaction between scientists and the public through short presentations and discussions in an informal environment, like a bar (Rice & Levine, 2016). Combining these insights, inspirations and our main goals, we decided to develop our own event with hands-on activities, inspiring lectures and opportunities to interact with scientists. To gain further insight into designing such events, we contacted the organisers of similar events and conducted research on the target audience.

On Saturday 21 October 2017, the planned event was held at the Planetário Calouste Gulbenkian — Centro Ciência Viva, in Belém, Lisbon. This venue is a landmark in the city and hosts a monthly event (in Portuguese) organised by IA. Having our event at a location that is clearly linked to astronomy added to the inspiring and exciting atmosphere. More than 200 people attended the event, and their feedback about the evening was very positive.

Research

To plan the project, we conducted desk research and studied the target audience with the help of case studies, statistics, interviews and an online survey.

Case Studies

In Lisbon, we identified a science communication initiative in English, AR Respire connosco, organised by the Champalimaud Neuroscience Programme. The initiative covered a wide range of subjects, often connecting science with daily life. The organisers shared lessons learned from their experiences with us (Table 1).

To inform the design of an event best suited to attract and engage our non-Portuguese target audience, we conducted simple interviews with five organisers of evening events. These events were organised by museums and research institutes all over the world. These interviews focused on the motivation to organise such events and reasons for choosing the particular design, how well this design worked for their audience, ways of promotion and recommendations. Except for AR Respire connosco, these initiatives were held in the country's native language. A summary can be found in Table 1.

In total we spoke to five organisers from the United States, the Netherlands and Portugal. Most of the evening activities in the science museums we contacted were designed for adults and aimed to attract people who were not regular visitors. The concept was a fun night out with science, without a great focus on the scientific content. Activities included were freely roaming through a museum, science shows, hands-on activities, drinks and public talks. The organisers had arrived at these formats by learning from their experience and from trial and error when running this type of event.

The organisers offered important practical advice about the flow of people and how to distribute the audience over the activities and the space that is available at an event.

Promotion of their events was mainly done via social media (Facebook). Recommendations included giving each event a theme and modifying activities and drinks and food according to that theme. Another recommendation was to target the promotion at expats and international students, as they might spread the word so that for the following events, less promotion was needed. It was also recommended to include some students in the process of developing the event, so that they would feel connected.

Statistics

Lisbon is a multicultural city, with a large population of non-Portuguese individuals living and working there. It also attracts large numbers of tourists. In 2015, there were 12 569 non-Portuguese residents in Lisbon from within the EU and 37 211 from non-EU countries. In October 2016, guests and tourists in Lisbon from outside Portugal totalled 316 574, mostly from Brazil, France, Germany, Spain and the United States[2]. This shows that there are many non-Portuguese visitors in Lisbon, strengthening the aim to target this group.

Reponses from a 2015 survey conducted by the City Hall of Lisbon showed that almost half were between 46 and 54 years old, whilst 23.8% were between 35 and 45, 15.9% were between 25 and 34. Most of the visitors came as a group of friends (42.8%). This was followed by couples (28.2%) and families (24.4%). In the survey, 57.3% of the respondents said they gathered information about Lisbon beforehand through friends and family, and 44.2% visited websites for accommodation. Only 5.7% used the Lisbon tourist office website[3]. From these figures, we concluded that most of our target audience consists of adults and young adults.

Interviews with tourists in Belém, Lisbon

To get some inside information on the behaviour and interests of tourists, we approached groups of tourists on the streets in the area near the venue and conducted short interviews. Due to limited time and human resources, we were only able to interview sixteen groups of between two and eight people. The interviewees were of varied nationalities and ages, but primarily young people between 20–30 years old. As the setting was informal and people were approached in groups, most answers were given collectively.

We used the following questions as a guideline:

1. Where are you from?
2. With whom are you here?
3. Where and how do you find the activities you want to visit?
4. What do you think of science in Portugal, and particularly astronomy? Why?
5. Would you be interested in an astronomy night? (why?)
6. What kind of activities would you be most interested in?
    a. Lecture
    b. Hands-on workshop
    c. Observations with telescope
    d. Theatre show
    e. Concert
    f. Bar/drinks

The options given in question six were chosen based on the case studies and on IA's SCG portfolio, further limited by the human, material and financial resources available for a one-off event.

Title	Naturalis After Dark	Adler After Dark	Science on the Rocks	Night Skies in the Observatory	Ar | Respire Connosco
Location	Naturalis Biodiversity Center, Leiden, the Netherlands.	Adler planetarium, Chicago, USA.	Discovery Place, Charlotte, USA.	The Franklin Institute, Pennsylvania, USA.	Fundaçao Champalimaud, Lisbon, Portugal.
Activities	Late night show with a scientist as guest, open museum at night.	Open museum night, shows, hands-on activities, exhibits, drinks.	Free roaming in museum, extra activities.	Activities, telescopes, lecture.	Science-themed evening with speakers, hands-on activities, performance, round-table conversation, open bar.
Target Audience	20- to 45-year-olds.	20- to 40-year-olds.	21-year-olds and above.	21- to 45-year-olds.	All ages.
Frequency	Varied, approximately once a month.	Once a month.	Once a month.	Once a month.	Varied.
Promotion	Social media, newsletter, brainstorming with students.	Word of mouth, Facebook, newsletter.	Social media, flyers, radio advertisement, word of mouth.	Facebook, concierge association, public announcements on speakers, science-themed websites.	Closed Facebook groups, online cultural groups.
Design motivation	Competing against bars and Netflix — the event needs to be more attractive than that. Inspiration from a Dutch round-table television programme.	Need for events without children, trial and error: best of the museum combined with live entertainment and drinks.	Attract 21+, without children. Experience that millennials do not want a lecture, they want freedom of choice in activities.	Provide intelligent conversation and knowledge, as people do not interact with science on a daily basis.	Inspire people to talk about science, open bar induces people to stay and chat.
Recommendations	Use social media for promotion.	The venue and mood are more important than how much scientific content you can deliver. Include a variety of different types of activities, to interest the novice and the lay experts.	Target locals, international students and expats. They will generate publicity amongst friends. For tourists, you have to do all of the promotion every time as the audience is new with minimal word of mouth. Give the event a theme and build your activities around that. Have hands-on activities.	Make the activities inclusive. Creative activities work well. Talks should not be too long (maximum 20 minutes). Ask enthusiastic audience members to come and talk to the expert if they want to know more. Think about the flow of people, how are you going to guide them through the activities, how will they be distributed over your space.	Have a creative, interactive workshop. Talks should be 30 minutes maximum. Videos in a talk attract the audience.

Table 1. *Overview of similar initiatives.*

Most of the interviewed tourist groups were very interested in attending an astronomy event (81%). They said they found events by searching the internet and Facebook (63%), using the booking.com information app, accidentally stumbling up on the event or flyers at a bar (38%) or asking at their hotel (31%). No one had any knowledge about science in Portugal. They expected a lecture with explanations and recent insights in astronomy, watching the night sky, social events and a bar. They were most interested in a lecture about new discoveries, information about the history of astronomy and the building. The younger respondents were interested in the social aspect and the bar. Everyone was enthusiastic about observations through a telescope. The options of theatre or a concert were discarded by most as having nothing to do with the subject.

Online Survey

To extend the target audience research, we used an online survey, using the same questions as those used for the in-person interviews. The target group for the survey was foreign nationals living in Lisbon. The survey was featured in ten Facebook groups for Lisbon expats, roommates, accommodation and international or Erasmus students. The total membership of these groups was approximately 10 000; however, it is likely that there were significant overlaps between the groups so the actual number of individuals exposed to the posts was likely to be much lower. We do not have access to the actual reach of the posts, but given the number of likes and the fact that we were a new member of these groups, the reach is probably low.

In total, 20 people filled in the survey within a week. Most of them were from Europe with 60% between 20 and 30 years old and 35% between 30 and 40. Sixteen out of the 20 respondents left their email address to receive more information and invitations to future events. 20% lived on their own in Lisbon, and 70% with a partner or with friends/flatmates.

The respondents reported using Facebook as their primary way of finding out about events in Lisbon (80%); second to this was recommendations from friends and searching the internet. Again, they had very little knowledge about science and astronomy in Portugal. In an open question, they mentioned they would expect observations in a planetarium or with telescopes, discussions with scientists and a lecture on the history of astronomy. Afterwards, the options mentioned in question six were given. The most popular activity, under what they would like to see at an astronomy event (95%), was observations with telescopes, followed by a lecture on the latest discoveries in astronomy (65%) and hands-on workshops (60%). Half of the respondents reported that they would like to see a social aspect/bar. The information gathered through these surveys was used to create a list of possible activities.

Event Concept and Design

The information gathered from the case studies and target audience research, via interviews and online survey, supported the development of the programme shown in Table 2. In summary, the popular choices were lectures about the history of astronomy or about the latest discoveries, observations of the night sky with telescopes, a planetarium show, hands-on workshops, conversations with scientists and a bar to socialise. In the final design of the event, we included all of these, with the exception of dedicated conversations with scientists and the bar. We had to rule them out because of space and regulation constraints at the venue.

In terms of venue, the event was organised at a landmark site for astronomy in Lisbon, the Planetário Calouste Gulbenkian — Centro Ciência Viva, which is an outreach partner of IA. The rich history of the Planetário, its central location and room dimensions (with a total capacity for 320 people), made it the perfect venue for this event.

By having workshops and lectures, or a light and sound show simultaneously, people could choose to engage in hands-on activities or just sit back, listen and relax. We decided to have two hands-on workshops and an activity in the dome of the planetarium at the same time as the workshop. The reason for not having more workshops was that there was not enough space at the venue. We decided to have a bigger activity simultaneously in the dome, so that all the people could engage in at least one activity at any given time. In this way, we also considered the flow of people, as was mentioned in the case studies. That is, there was always a spot for everyone in at least one activity.

The workshops were chosen by the IA's SCG on the basis of inputs from researchers and students of IA. After the activities were chosen, we contacted the researchers who were best suited to conduct these workshops. Every hands-on workshop could accommodate 16 people and the rest of the audience could attend the other activity in the dome. As a large part of the audience would perform the activity in the dome during both workshop rounds, we decided to have two different activities there and repeat the hands-on workshops in the second round.

Time	Activity	Who
20.30	Doors open and registration for workshops.	
21.00	Workshop round 1. A (very) brief history of astronomy (lecture). Workshop: Build your own 3D Orion. Workshop: The warped side of the Universe.	Alberto Negrão, researcher at IA. João Luis, PhD student in Physics. Francisco Lobo, researcher at IA.
21.30	Multiverse! Keynote lecture.	Andrew Liddle, Visiting Professor at IA.
23.00	Workshop round 2. Light and sound show in the dome. Workshop: Build your own 3D Orion. Workshop: The warped side of the Universe.	João Luis, PhD student in Physics. Francisco Lobo, researcher at IA.
22.00–00.00	Observations with telescopes.	

Table 2. *Programme of Your Night out under the Stars.*

The hands-on workshops, light and sound show and observations were designed in such a way that high proficiency in English was not necessary, thus making the evening more accessible. Almost all respondents in the pre-event research showed a keen interest in observations with telescopes. Luckily the weather on the day meant that everyone had the opportunity to observe and discuss observations with the volunteers.

One of the hands-on workshops, titled *The Warped Side of the Universe*, was conducted by IA researcher Francisco Lobo[4]. In this workshop, the bending of spacetime by matter is visualised with marbles on a lycra cloth that is spread across a circular frame (Figure 1).

The second hands-on workshop was titled *Build your own 3D Orion*[5]. In this workshop, João Luis, a PhD student in cosmology, demonstrated to the audience why we see the constellations as if the stars are all in the same plane in the sky, when in reality they are all at different distances from Earth. Using boards, sticks and foam balls to represent stars, the participants built a 3D model of the Orion constellation (Figure 2).

During the first round of the workshop, Alberto Negrão gave a short-lecture about the history of astronomy in the dome. During the second round, there was a light and sound show in the dome, consisting of projections of stars and constellations on the dome ceiling, accompanied by music. Andrew Liddle, a renowned British cosmologist who is currently living in Lisbon, agreed to give the keynote lecture. His talk about multiverse and the possibilities that our Universe is not unique was thirty minutes in length, and afterwards the public asked questions for a further twenty minutes, and the session closed with not enough of time for all the questions.

Outside, at the back of the planetarium, three telescopes gave the public the opportunity to see several stars and the planet Uranus (Figure 3).

Francien Bossema hosted the evening, giving short introductions to the speakers, explaining the project and programme and managing the questions for the speakers.

Figure 1. *Workshop "The Warped Side of the Universe". Credit: B. Bento.*

Figure 2. *Workshop "Build your own 3D Orion", people working on their project. Credit: B. Bento.*

Figure 3. *Outside at the telescopes. Credit: B. Bento.*

Logistics and Resources

In addition to the speakers, workshop facilitators and astronomers handling the telescopes, the event required technical support for talks, audience management inside and outside the planetarium dome, guiding registered participants to the corresponding hands-on workshops, collecting audience responses to the questionnaire at the entrance (given to every participant) and for the survey at the end of the event (optional), among other tasks.

To have a smoothly organised evening, with over 200 attendees, we needed a number of people to support us. We thus asked for volunteers from among the students of a science communication training programme managed by IA, named Viver Astronomia[6]. Applying the acquired skills in outreach events is part of this programme, and 18 students volunteered to assist at the event. Each of the volunteers was assigned a task (Table 3).

Task	Number of People Needed
Scanning tickets at the door.	3
Asking questions from the questionnaire at the entrance.	5
Assisting at workshops.	2
Distributing workshop tickets.	2
Checking tickets at the door and guiding people to their seats.	2
Mounting and handling the telescopes.	3
Survey after the event.	3
Technical support.	3
Photographer.	1

Table 3. *Tasks and number of people needed. Note that some may have assisted with several tasks (for example the questionnaire before the event and the survey after were done by the same people).*

Members of the IA's SCG were also present to oversee the technical material and arrange the light and sound show. A video recording was taken of the keynote lecture in the dome[7].

The total material cost for the event was 40 euros, which was needed to buy materials for the workshops. The implicit costs of human resources were borne by IA members, planetarium staff and volunteers (18 people). The venue and associated costs were borne by Planetário Calouste Gulbenkian — Centro Ciência Viva. For these reasons, organising this event did not require specific funding beyond the normal running costs of the involved institutions.

Promotion and Registration

After a brainstorming session about the keywords and main attractions for the public, we decided to call the evening "Your Night out under the Stars". This related to the unique experience of an evening out (night out), with astronomy (stars) and directly appealed to the reader (you), giving them a personalised experience and the freedom to choose their activities on the evening. Thus, it gave the reader and the potential audience a fairly good idea of what they could expect and sparked their interest at the same time.

In the promotion texts we used for the publication of the event, we tried to address the same key notions: an exciting evening out with science and friends, freedom in activities, a personalised feeling and of course astronomy. The venue Planetário Calouste Gulbenkian — Centro Ciência Viva, with one of the largest planetarium domes in Europe, was an attraction in itself. An example of a short text for, among others, cultural websites and Facebook groups is:

Experience a night out with stars, planets and astronomers at one of the largest planetariums of Europe. The event will take place on Saturday 21 October starting 20.30 and is free! Registration in advance is required. Come with your friends and enjoy the workshops, lectures and observations with telescopes together. All activities will be in English.

A flyer was designed (Figure 4). We chose this arc of the phases of the Moon for three reasons. Firstly, the Moon is very recognisable, immediately making the viewer think of astronomy and space. Secondly, the shape of the Moon resembles the dome of the planetarium, in which the event took place. Lastly, the words "Under the stars" are in this image placed under the crescent of the Moon. The placement of the text again highlights the important aspects of the title. The flyer was designed against a mainly white background for printing purposes.

In order to reach a wide audience, the event was promoted on several websites, in Facebook groups and via newsletters of embassies and institutions. An overview of promotion methods and which audiences they mainly targeted can be found in Table 4.

The event was published on the website of IA and the website of the planetarium as well as thirteen Facebook groups of (international) students in Lisbon and two Facebook groups for expats (total number of members exceeding 15 000, although members may not be unique and may be in many groups simultaneously). It was published online on the website of the tourist office[8]. The Erasmus office of the Science Faculty of the University of Lisbon sent an invitation for the event to all the current Erasmus students, and an invitation was also sent to the people who left their email address in the online survey of the

Figure 4. *The digital flyer. Credit: Instituto de Astrofísica e Ciências do Espaço, John Colosimo (colosimophotography.com)/ESO.*

target audience research. Several embassies were contacted: the British, American and Dutch embassies agreed to promote the event through newsletters and on their Facebook pages to reach their expat communities (Figure 5). Foundation Champalimaud added the event to the newsletter for their employees. A Facebook event was created on the Facebook page of IA, and publicity was also generated via IA's Twitter profile. The event's Facebook page had a total reach of 22 300. Another way of promoting, learned from the background research, was to leave flyers at hotels and guesthouses in the vicinity of the venue, asking them to notify their guests. Because our event sold out quickly, we did not try this route of promotion. For the same reason, we did not send a press-release to the local media contacts.

The registration was done via Eventbrite, which is a platform that can be used for selling tickets for an event and is free to use if the event is free[9]. Registration opened on Thursday, a week before the event. Within a day 90 tickets had been sold, and five days later, the event was sold out (320 tickets). When there were 100 people on the waiting list, we closed the waiting list. Because of IA SCG's experience that approximately 40% of the people holding a ticket do not show up at a free event, we asked for a confirmation of attendance four days before the event with the message that in the absence of confirmation, the registration would be cancelled. This method is used by IA for their other events and has considerably reduced no-show. The confirmation request led to 52 registrations being cancelled. Some people emailed afterwards to re-register, other tickets

Promotion method	Target audience
Institutional websites.	General.
Universities (mailing lists).	International students.
Facebook. Institutional/events. International students/Erasmus groups. Expat groups. University groups. Accommodation and flat-sharing groups.	General. International students. Expats. Students in general. New international students/expats
Cultural groups.	General.
Tourist websites.	Tourists.
Flyers at hotels/bars.	Tourists, students.
Invitation via international offices of the university.	International students.
Embassies.	Expats.

Table 4. *Overview of promotion methods and target audience.*

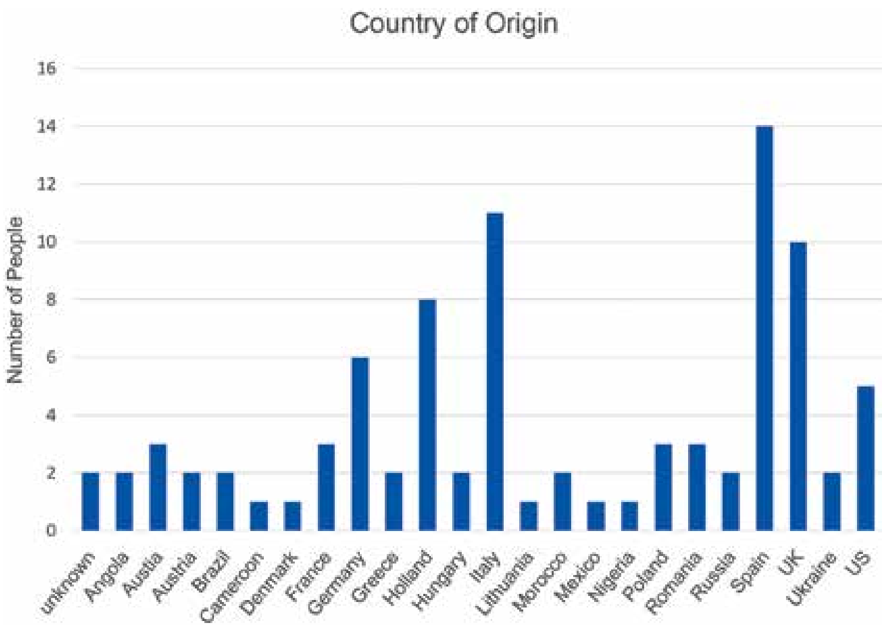

Figure 5. Summary of the nationalities of the attendees of Your Night out under the Stars.

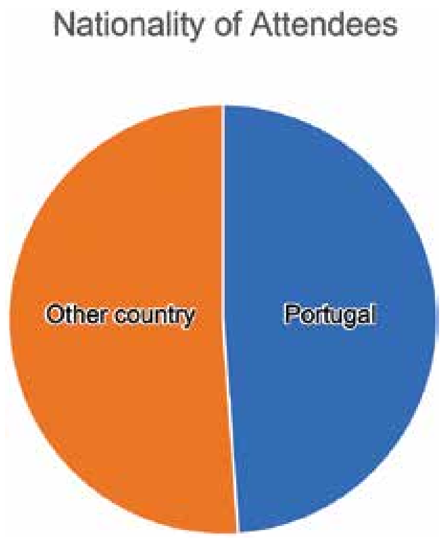

Figure 6. *Country of origin of the audience (absolute numbers). Only 51.2% non-Portuguese attendees came to the event.*

were offered to the people on the waiting list. Eventually all the registration spots were not filled, and a total of 287 tickets were taken. On the night itself, the tickets were scanned using the Eventbrite organiser app..179 tickets were checked in, ten more tickets were distributed at the door and 14 guests of organisers and speakers attended, taking the total attendance to 203 people.

Evaluation and Analysis

The evaluation of the event consisted of qualitative analysis — observation and speakers' feedback — and quantitative analysis, conducted using a pre-event questionnaire at the entrance and another optional questionnaire after the event. In the first questionnaire, each participant was interviewed by a volunteer, collecting basic demographic information and data on how people learnt about the event. The post-event questionnaire was optional and collected the audience's impression of the event itself and their opinion on several activities.

The timing of the activities overall suited the audience and there were a lot of questions following the keynote lecture. It would have been nice to have more room at the workshops, but the space did not allow for this. In total 15–30% of the audience went to one or both workshops. The workshops took place in the corridor — an unexpected result of this was that the workshops were very visible as part of the programme, and even those who did not participate were able to observe.

Pre-event Questionnaire

In a questionnaire at the start of the event, volunteers asked the audience about their nationality, how they learnt about the event, whether they would have attended the event if the evening was in Portuguese and their sex. They asked 174 people, which is 85.7% of the audience. Of these 100 were women, 74 were men. In total 51.2% of the respondents were of foreign nationality (Figure 5). For the distribution of countries of origin, see Figure 6.

Of the people who answered the questionnaire, 67.6% said that they would have attended the event if it were held in Portuguese, 28.9% said they would not. After leaving out the Portuguese public, these figures are respectively 65.1% and 31.5%. If we run a similar event in the future, we may explore this in more detail by finding out if the non-Portuguese visitors also spoke, or could understand, Portuguese, or if this is because one did not need to

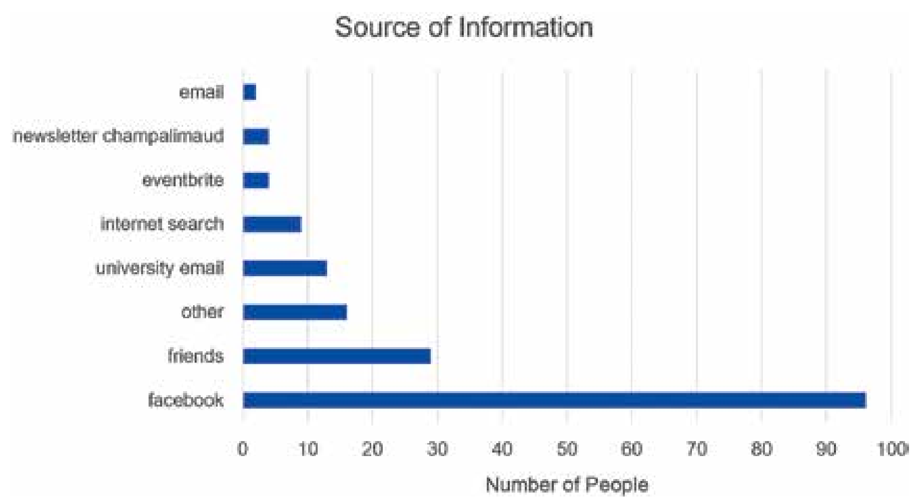

Figure 7. *Sources of information about the event (absolute numbers).*

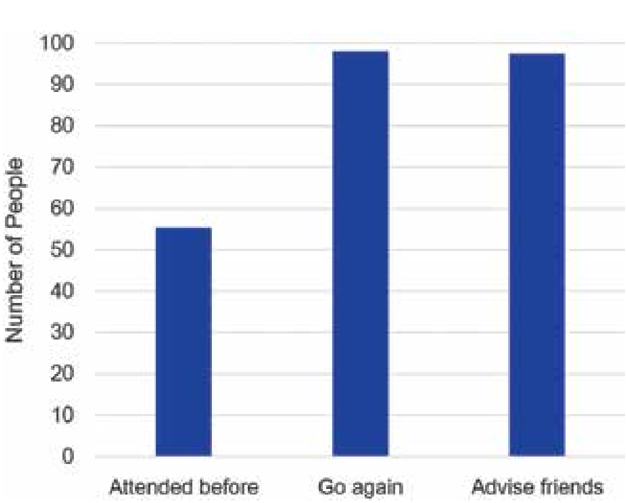

Figure 8. *Percentage of attendees who answered "Yes" to the following questions: whether they had attended an astronomy event before (55.2%), whether they would want to go again (98%) and whether they would advise their friends to attend (97.3%).*

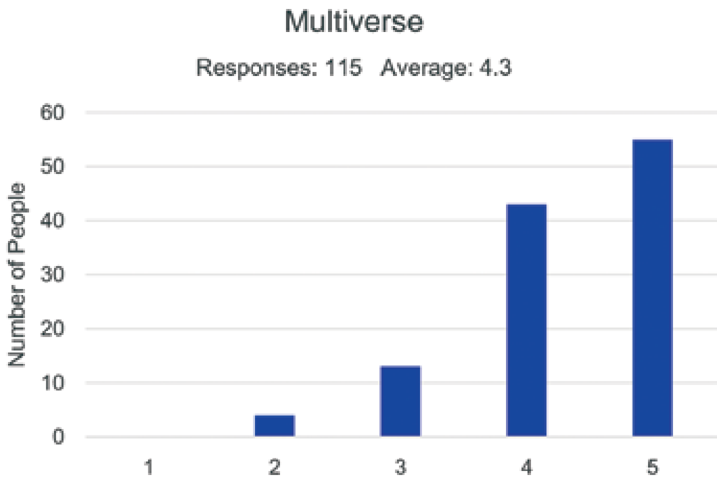

Figure 9. *Grades from the survey for the keynote lecture.*

fully understand the spoken elements to enjoy the activities.

According to the survey, Facebook was the main source of information about this event. Word of mouth or invitation by friends was the second source. We also concluded that the email to Erasmus students (university email list) was effective. The distribution of the reported source of information about the event can be found in Figure 7.

Post-event Questionnaire

An evaluation survey was conducted by asking the audience to fill in a post-event questionnaire about their experiences and opinions regarding the event. In total, 152 people filled in this questionnaire, which is 74.9% of the audience. This is a high response rate, and it may be influenced by the fact that we stressed the importance of filling out the questionnaire for research purposes, during the introduction of the event, and the volunteers actively asked the departing audience to fill in the questionnaire. We also made sure that the questionnaire was only one page, making it quick to fill out. The questionnaire consisted of three yes/no questions (previous attendance at an astronomy event, interest in future events and inclination to advise their friends to attend) and a rating scale of one to five for each of the activities, one being "did not like this activity at all" and five "I liked this activity very much".

People were asked to write their reasons for grading and any other remarks in an open comment section at the end of the survey. Because of the overlapping workshops, it was not possible to attend all activities, so people were asked to leave the answers blank if they did not attend the activity. However, 36 people rated all the activities, making it impossible to use their rating of the activities. Of those 36 surveys, only the yes/no questions have been used for analysis. The results of the yes/no questions are shown in Figure 8.

The best graded activity was "Build your own 3D Orion" workshop, and the lowest graded was the history lecture. See Table 5 for the average grades of each activity. The activities were mostly rated with 3's and 4's. See Figure 9 for the distribution of ratings for the keynote lecture.

Workshop 1: Warped	4.5
Workshop 2: 3D Orion	4.7
Universities (Mailing lists)	3.4
Talk: History	4.3
Keynote: Multiverse	4.5
Light and sound show	4.0
Observations	4.0

Table 5. *Average grades for each activity.*

Note that different activities had a different number of respondents. The respondents were very positive about the event, and some of the remarks were as follows:

Great event! Enjoyed the variety of talks, both on introduction level and also very deeply scientific. Good atmosphere and friendly people,

Hope this event can happen more often. Great job!

Thank you for reigniting my interest in Astronomy.

Conclusion

Given the fast sale of tickets and the positive reactions of the participants who filled in the surveys, we can infer that there is a high interest in English-language science-related outreach events in Lisbon. Holding an event in English opens up opportunities to involve a more international public. Moreover, we saw that a lot of Portuguese people attended the event as well, making it a great opportunity to mix national and international audiences. The event was successful, the design was well suited to our aims and IA intends to continue with similar activities in the near future. We summarise our recommendations for organisers of similar events and give a proposed timeline for the organisation of an event like *Your Night out Under the Stars* in Box 1 and Table 6.

Box 1. Recommendations to other organisers

- Think about the flow of people, how to use the space optimally.
- Make sure that everyone can do an activity at any time, meanwhile giving people some freedom in choosing their own activities.
- Hands-on activities are popular with the public and create close contact between researchers and the audience, which has a positive effect on the engagement of the public with science.
- Communicate the programme clearly (for example by printing the programme).
- Based on the case-studies research, a bar, drinks or food might enhance the conversation For inspiration see (Trotta, 2018).
- If your event is free, keep in mind that there might be a high rate of no-show. A way to lower no-shows is to ask people to confirm some days in advance.
- Promotion via Facebook, embassies and newsletters to international students were effective.
- Eventbrite is a useful platform. The people at the door scanning tickets need an account beforehand and a smartphone. Scanning tickets is easy and fast and the app gives real-time information about the number of people inside the venue. It is easier if people are only allowed to buy one ticket each, as this is the case for those on the waiting list.

At least two months before	• Set a date. • Find a venue. • Approach a keynote speaker.
A month before	• Finish the programme (times and activities). • Arrange researchers to give a workshop, discuss which workshops to give and the materials needed. • Contact possible sponsors/promotion partners (universities, municipality, embassies). • Design a flyer. • Think about and, if applicable, arrange for broadcasting or recording.
Three weeks before	• Create a webpage with all the information. • Make a list of social media sites to promote the event on. • Produce promotional material. • Send the website and other information to online cultural groups and the tourist office. • Ask for volunteers for checking tickets, assisting at workshops, mounting telescopes, performing surveys, etc. and a photographer.
Two weeks before	• Open registrations. • Publish event on several social media pages, send newsletters to contacts, create Facebook event. • Arrange the logistics, technical requirements (microphone, slides, telescopes etc.), workshop materials.
One week before	• Contact speakers and volunteers to explain the logistics and programme of the evening and divide tasks (explain if you are using Eventbrite, people at the door will need the app). • Deliver flyers at bars, tourist office, university etc. • Prepare questionnaires/surveys for evaluation. • Prepare tickets for the main event and the workshops. • Think about the flow of people and the arrangements for the evening.
The day itself	• Print registrations list. • Test the microphones, slides, technical equipment, etc. • Instruct volunteers. • Set up the workshop.
Following	• Evaluate, with the help of the surveys. • Thank the volunteers and speakers. • Put pictures and the recording of the event online.

Table 6. *Proposed timeline for similar events.*

More than half of the attendees were non-Portuguese, which means our first aim of broadening the target audience was met. On the evening itself, many people were enthusiastic, and the survey results confirm that enthusiasm for astronomy was generated among at least a section of the audience. Most of the participants were interested in attending follow-up events, implying they enjoyed their night out with astronomy. The many questions and interaction between the public and the researchers suggested that a step towards better understanding of the Universe and astronomy research had been taken by this audience. The hands-on workshops were successful in their aim to get people to interact with scientists and learn in an interactive way, and they were, for the most part, positively rated by the public. For future events, it would be interesting to investigate the degree of increased understanding at this kind of events.

The research conducted in advance was very useful for shaping our ideas and designing an event tailored to our aims. Of the data sources, the case-studies and speaking to other organisers of similar events gave us the most useful information. This was partly practical information, for example how to think about the flow of people and how to promote the event, and partly inspiration for inclusive activities. Given our previous research and the fact that both the case studies and target audience analysis highlighted the importance of drinks to enhance social interactions between scientists and audience as well as among the attendees themselves, it would be interesting to try out and study the effect of a bar at the event. We have summarised the main recommendations from the case studies and our own experience in Box 1.

We would advise people who plan on organising an outreach event to contact other organisers to learn from their experience. The evaluation research attached to this project could be extended. We chose to collect information on demographics and source of information at the start. We received a high response rate because of the direct way in which this information was sought. The response rate of the surveys after the event was higher than we expected. It would have been good to merge these two questionnaires, so that we could have linked the nationality data to how the event was experienced and rated. Even though questionnaires after an event do not always achieve high response rates, we would advise future organisers to merge the two questionnaires into one for this reason.

In conclusion, the event was successful, and both researchers and the public enjoyed the interaction and the activities. It showed us that there is an audience for this type of event, which opens a door to a series of events to be held in the future.

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Notes

1. Website, in English: divulgacao.iastro.pt/en/evento/your-night-out-under-the-stars-en/
2. Numbers obtained via email from the Lisbon City Hall
3. Survey of tourists' activities and information, 2016: www.visitlisboa.com/sites/default/files/2016-10/INQU%C3%89RITO%20%C3%80S%20ACTIVIDADES%20DOS%20TURISTAS%20E%20INFORMA%C3%87%C3%83O%202015_0.pdf
4. The workshop The Warped Side of the Universe, was based on the following Youtube video: www.youtube.com/watch?v=ZkURrrACG0g
5. The workshop Build Your Own 3D Orion was inspired by an article of the Astronomical Society of the Pacific that can be found here: astrosociety.org/edu/activities/F7_3D_Constellations.pdf
6. As part of the Viver Astronomia ("Living Astronomy") programme, students receive monthly training in mounting telescopes, in current scientific topics and in theoretical and practical aspects of science communication. They put into practice the acquired skills at outreach activities. More information online at divulgacao.iastro.pt/en/projeto/viver-astronomia-en/
7. Video of the keynote lecture: youtu.be/gnKhUFyPre8
8. Visit Lisbon website: www.visitlisboa.com/pt-pt/node/7619
9. Eventbrite: www.eventbrite.co.uk/e/your-night-out-under-the-stars-tickets-38588645678#

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The World at a Glance - Highlights from IAU National Outreach Coordinators

Editor's note: The IAU National Outreach Coordinators (NOCs) network[1] was created by the IAU Office for Astronomy Outreach (OAO), by volunteers with extensive experience in public outreach, to facilitate communication and actions between the IAU and its national communities.

Argentina

Beatriz García: The fever for the 2019 total solar eclipse has begun, and hotels in San Juan are already fully booked.

Canada

Michael A. Reid: Commemorative coins for the 150th anniversary of the Royal Astronomical Society of Canada were produced with meteorite fragments.

Colombia

Carlos Augusto Molina Velásquez: XVIII Meeting of the Colombian Astronomical Network to be held from the 12 to 15 October 2018.

Guatemala

José Rodrigo Sacahui Reyes: Several astronomers attended the talk De Guate al Cosmos.

Algeria

Jamal Mimouni: The Masters in Astrophysics ran for the first time with seven graduates, all being female.

Madagascar

Zara Randriamanakoto: Astrophysics graduate students to publish the first-ever Astronomy Magazine in the country.

Ethiopia

Alemiye Mamo Yacob: Four hundred Ethiopian gold medalist graduates from universities across Ethiopia visited the Entoto Observatory and Research Center.

Mozambique

Claudio Moises Paulo: Two radio astronomy projects set out to train students ready for work on the Square Kilometre Array (SKA) radio telescope's outreach.

South Africa

Sivuyile Manxoyi: The MAPPP9 programme was launched — a national collaboration focused on science communication and project management training.

Zambia

Prospery C. Simpemba: An astronomy road show was held during World Space Week, covering six towns.

Ireland

Clair McSweeney: Ireland is now a member state of the European Southern Observatory and celebrating astronomy with 200 events nationwide for Space Week[2].

Armenia

Sona Farmanyan: 51 students participated in the 5th Byurakan Science Camp.

Syria

Mohamad AlAssiry: A public sky-watching event for over 30 consecutive days was held during the national festival of AlSham.

• ***The IAU NOCs Network***

Slovakia

Rudolf Galis: The 50th Meeting of young astronomers was held in July. at cottage under hill Hrb.

Spain

Amelia Ortiz Gil: Fifteen different activities were held throughout Spain on Asteroid Day 2018.

China Taipei

Mei-Yin Chou: In July 2018, an application was filed to make Mountain Ho-Huan in Taiwan the country's first International Dark-Sky Park.

Indonesia

Avivah Yamani: August 6 was celebrated as National Space Day and Dark Sky Night in Indonesia.

Japan

Hitoshi Yamaoka: A Mars viewing event at Makuhari on the 1 and 2 August attracted more than several thousand people.

Pakistan

Ghulam Murtaza: The Space and Upper Atmosphere Research Commission has installed a 0.5 metre telescope at the Sonmiani site.

South Korea

Seo-gu Lee: The Korea Astronomy and Space Science Institute Teacher Training Program was held over the summer, including astronomy education for visually impaired people.

Sri Lanka

Thilina Heenatigala: Skyline 180° is an immersive experience for the public screening astronomy videos in July.

Notes

[1] IAU National Outreach Coordinators (NOCs) network: www.iau.org/public/noc/

[2] Space Week in Ireland: www.spaceweek.ie/

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