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Communicating Astronomy with the Public

A Global Audience for the New Race to the Moon

Lessons Learned from the Google Lunar XPRIZE Outreach

A Picture Speaks a Thousand Words

Artist's Impressions in Astronomy and Planetary Science

Stargazing Live goes Dutch

Reflections on Bringing Astronomy to a Mass Audience

Creating a Giant

Ten Challenges of Producing an Astronomical Gigapixel Image

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On 24 April 1990 the NASA/ESA Hubble Space Telescope was sent into orbit aboard the Space Shuttle *Discovery* as the first space telescope of its kind. It offered a new view of the Universe and has, for 25 years, beamed back data and images that have changed scientists' understanding of the Universe and the public's perception of it.

This image shows infrared Hubble observations of M16: the Eagle Nebula's Pillars of Creation. This image was made public in January as part of the Hubble 25th anniversary celebrations.

Credit: NASA, ESA/Hubble and the Hubble Heritage Team

Contents

Cover: On the cover of this issue is an image released to celebrate 25 years in orbit for the NASA/ESA Hubble Space Telescope. The image's central region, containing the star cluster Westerlund 2, blends visible-light data taken by the Advanced Camera for Surveys and near-infrared exposures taken by the Wide Field Camera 3. The surrounding region is composed of visible-light observations taken by the Advanced Camera for Surveys.
Credit: NASA, ESA, the Hubble Heritage Team (STScI/AURA), A. Nota (ESA/STScI), and the Westerlund 2 Science Team

Editorial

Our first issue of *CAPjournal* for 2015 arrives with you a little late in the year, but we hope that you will find it worth the wait.

Astronomy communication comes in many forms, and with many names. We communicate, we engage, we co-create and we reach out. Sometimes we want to spread a message to millions, sometimes we aim to inspire just a few and at other times our aim is to learn what the public have to offer us, our mission or our project. We communicate through words, images and videos onscreen or in print, through exhibitions and hands-on activities *in situ* and by bringing astronomy directly into communities with events, competitions and star parties — to name just a few.

CAPjournal acts as a platform for papers and articles that share best practice and discuss and debate challenges across the whole palette of astronomy communication methods. I consider this issue a particular success in this regard as it covers a huge range of approaches.

The issue presents best practice in communication methods, to audiences of any size, from reaching a vast audience through TV broadcasts, to the high-impact engagement of smaller groups through citizen astronomy campaigns. It shares projects that range from the large-scale outreach programmes that surround campaigns such as the Google Lunar XPRIZE, to the focused projects that build highly specific resources, like the tactile planetarium for the visually impaired. There are papers here that recount individual journeys in surveying the landscape of science centres, employing the arts in astronomy communication, and creating gargantuan astronomical images to inspire and attract the public.

As always, our papers have come from across the world and represent a global industry of bringing astronomy to everyone.

If you have any comments, feedback, or wish to send a submission or proposal of your own for our upcoming issues, do not hesitate to get in touch: editor@capjournal.org.

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

Georgia Bladon
Editor-in-Chief of CAPjournal

Submit articles for one of the following journal sections:

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

Explained in 60 Seconds: Windy with a chance of flares

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Keywords
Space weather, solar wind

If you thought that weather forecasts here on Earth were changeable, spare a thought for those dealing with the even more unpredictable conditions of space.

It may sound odd to be considering what the weather is like in the airless and uninhabited emptiness of space, but it is an all-too-pressing issue for astronomers. Unlike the conditions we see here on the Earth's surface, in space, weather is an entirely different — and altogether more dangerous — animal.

As on Earth, in space, weather is driven predominantly by the Sun. Our star's surface is turbulent and powerful, and dense streams of charged particles speed away from it, forming the solar wind. This wind floods the inner Solar System, filling it with energetic particles driven outwards along densely packed magnetic field lines.

When this wind is particularly strong, we can see its effect directly as particles from the solar wind enter and interact with the Earth's atmosphere. They cause eerily beautiful phenomena such as the aurorae, commonly known as the northern and southern lights.

Occasionally, the Sun's magnetic field accelerates clumps of material to incredible speeds, resulting in a violent expulsion of high-energy particles known as a coronal mass ejection.

These high-energy particles can pass effortlessly through spacecraft walls, threatening the safety and health of any people on board and causing electronics to malfunction. They can also affect satellites, GPS systems, and power grids here on Earth. The International Space Station plans for scenarios like this, with areas shielded by extra-thick padding for astronauts to huddle inside.

Predicting space weather accurately is still a challenge, but many observatories constantly monitor the Sun in near real-time. They track the active patches of the solar surface — areas where the Sun's magnetic field is much stronger — in the hope of spotting warning signs for when these often unpredictable eruptions might take place.

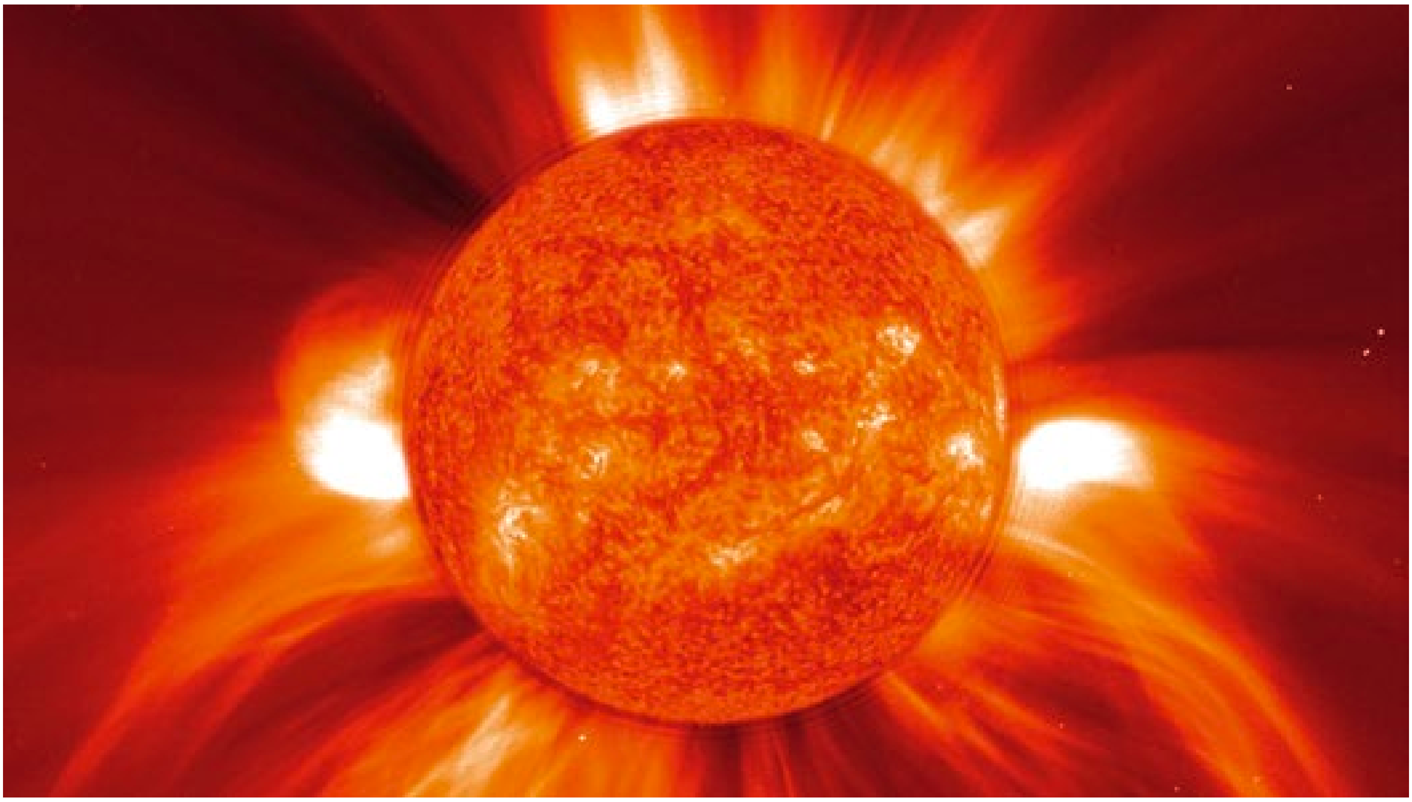

Figure 1. *In this image a widely spreading coronal mass ejection blasts more than a billion tonnes of matter out into space at millions of kilometres per hour. Credit: Courtesy of SOHO/LASCO consortium. SOHO is a project of international cooperation between ESA and NASA*

Communicating Astronomy with a Mass Audience — BBC's *Stargazing Live* goes Dutch

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Keywords
Television, astronomy television series, broadcasting

Summary

Following on from the hugely successful airing of Heel Nederland Kijkt Sterren — a Dutch stargazing event modelled on the BBC's programme *Stargazing Live* — this article explores some of the issues involved in communicating astronomy directly to a mass audience. This includes the production process, co-sponsorship, content, the reach and lessons learned.

Introduction

On a cold and cloudy night in early December 2014, the Dutch public broadcaster Omroep Max aired a 1.5-hour live stargazing event on its Channel 1, modelled on the popular BBC series *Stargazing Live*. It was the first time the BBC format had travelled abroad. Despite the disappointing overcast weather, the prime-time show, dubbed *Heel Nederland Kijkt Sterren* (*HNKS;* The Netherlands are Gazing at the Stars) was a huge success. Three million people — 18.8% of the market share — watched the show, #HNKS was trending on Twitter within half an hour, and over five hundred people posed questions on a dedicated website.

The astronomy community in the Netherlands was closely involved in this production as co-sponsor of the TV show.

Public broadcasting

The public broadcasting system in the Netherlands is quite different from that of

Figure 1. *Still from* HNKS. *Joeri van Leeuwen (middle) comments to the co-hosts of* HNKS *Jeroen Latijnhouwers (right) and Govert Schilling (left). Credit: Tuvalu Media*

the United Kingdom and other European countries. There are many commercial stations and three national public television channels, each with their own profile. Over twenty public broadcast organisations, some with a statutory role, others with a sufficient number of members, receive broadcast time on these three channels. Every channel has an independent channel manager, who is responsible for the programming and protects the profile of the channel. The profile of Channel 1 (NPO1) dictates that the programmes should attract a broad audience, so typically consists of shows, games, series, drama and comedy. It is not the first channel you would think of to air astronomy or stargazing.

So how did *Heel Nederland Kijkt Sterren* get a prime-time slot on this popular channel?

External production companies are usually the producers of big live shows like *HNKS*. In this case the production company Tuvalu Media[1] obtained the BBC *Stargazing Live* format and got the broadcaster Omroep MAX interested in airing a ninety-minute local version of *Stargazing Live*. Tuvalu Media's executive producer Dannis Kramers said of the programme: "We have brought BBC formats to Dutch television before and they were all successful, but the BBC's *Stargazing Live* exceeded all of our expectations. The unexpectedly high ratings were a pleasant surprise for us."

Omroep MAX

Omroep MAX[2] is a broadcasting company skewed to an older demographic and not immediately self-evident as a broadcaster for a popular science programme on national television. Whereas the BBC has a rich history with respect to science programmes in general, and astronomy and stargazing programmes in particular, this tradition exists to a much lesser extent in the Netherlands. However, the director of Omroep MAX, Jan Slagter, was convinced of the potential of the *Stargazing Live* format and facilitated the allocation of a prime-time slot. "We were almost certain the format would be successful", explained Slagter. "The cosmos captures the imagination, not just for our 50+ age group target audience, but basically everyone. Who does not gaze at the night sky during their vacation, wondering what is happening out there?"

Figure 2. *Still from* HNKS. *ESA astronaut André Kuipers with amateur astronomers in front of a public observatory. Credit: Tuvalu Media*

The Dutch Broadcast Magazine voted Slagter Broadcaster of the Year 2014 on the grounds that the MAX programmes "seamlessly connect to the wishes and needs of their target group". Slagter does not want to admit that he has a knack for predicting what's hot and what's not, but at its peak 1 478 000 people were watching *HNKS*. The overall market share was 18.8% (for ages six and up) and in the target 50+ age group the market share was 25.4%. Kramers aptly described these figures as "very convincing".

Co-sponsorship

In the current world of television, at least in Europe, the financing of shows like *HNKS* is no longer feasible on the basis of public money and commercial adverts alone. Big live programmes need external co-funders to make them possible. Co-sponsorship faces some stringent rules, and direct visibility of the co-sponsor in the programme is forbidden. Right from the start of the project in early 2013 Tuvalu Media involved the academic astronomical institutes in the Netherlands, as well as the amateurs, and gauged the mood of the community for a programme like *HNKS* and for co-financing. Kramers succeeded in bringing on board the Netherlands Organisation for Scientific Research (NWO)[3], the Netherlands Research School for Astronomy (NOVA)[4] and the NWO organisations, the Netherlands Institute for Radio Astronomy (ASTRON)[5] and the Netherlands Institute for Space Research (SRON)[6].

Although this collaboration worked out very well, there were difficulties on both sides and the co-financers occasionally found it challenging to accept that the broadcasters had final say on the programme content. Two completely different worlds (science and TV) had to get used to each other," explained Kramers. "Transforming fundamental science into a programme that attracts a broad audience is really difficult, but we received great input from our co-financers. We were very happy with this collaboration."

Despite the challenges, the astronomy community also considers the collaboration to have been a success. The chair of the NOVA Committee for Outreach, Alex de Koter (University of Amsterdam), puts it this way: "For scientists it is sometimes difficult to let the TV producers do what they are good at. They have different rules and customs, and a different perspective. But, with our input and with balance added by experts in outreach and popularisation, you get the best of both worlds."

The co-sponsors were important for Tuvalu Media both for the funding and as a resource for the content of *HNKS*. They also provided fact and data checking during the production process.

Heel Nederland Kijkt Sterren

In late spring 2014 Tuvalu Media came up with the first outline for the live show. After that a team was appointed to develop this further into a final script. The script contained a central live presentation, cross talks with live stargazers at two locations, and items and reports that were produced in advance, to air throughout the programme.

The original BBC show was first broadcast in the United Kingdom on BBC 2 in 2011 and has now run to five seasons, the last of which was aired in April 2015. It is presented by the popular physicist Brian Cox and stand-up comedian and television presenter Dara O'Briain. The local Dutch version can be regarded as a modest copy of the original: only one show — instead of three consecutive evenings — and no foreign reports from observatories around the world. All of the elements were produced within the Netherlands. The popular Dutch astronomy writer Govert Schilling and former news host and TV presenter Jeroen Latijnhouwers acted as the co-hosts. Astronomer Joeri van Leeuwen and planetary scientist Sebastiaan de Vet were introduced as experts on some topics, as well as the European Space Agency astronaut André Kuipers.

The event was broadcast live from the control room of the Westerbork Synthesis Radio Telescope[7] in the north east of the Netherlands, operated by ASTRON. André Kuipers reported live from one of the many public observatories in the country. Sebastiaan de Vet was standing outside the control room at the base of one of the Westerbork telescope dishes.

For Govert Schilling it was the first time he had been a presenter on such a large live event. He said of the experience: "Although I've often talked about astronomy on TV programmes before, I was pretty nervous! But everything went smoothly, and doing the presentation together with the Dutch TV personality Jeroen Latijnhouwers (who doesn't know too much about astronomy) worked very well: the audience could easily identify with him and his questions, and I didn't have to talk to an anonymous TV camera."

In this first *HNKS* edition almost all aspects of astronomy were covered, from simple stargazing and Solar System studies to extrasolar planets, black holes and the Big Bang. Schilling commented on the content of the show by saying: "I think the content covered, and how this was approached was very successful. It's like your very first visit to Paris: you want to see all the major highlights! As a result, TV viewers didn't really get a chance to become bored or lose their initial interest. I believe the fast pace of the show was one of its strengths. I was less enthusiastic about some of the demonstrations that we did during the show."

Kramers added: "The programme was an excellent introduction to astronomy and stargazing for a wide audience. We had many topics and the pace was fast. For a second edition I would like to see fewer items but more depth."

Conclusion

On 3 December 2014 — the night of the live show — the skies were overcast, but this did not make much difference to the success of the event. Schilling explained that: "It is completely unthinkable that over a million people would have stepped outside onto their balcony or into their garden when they were sitting comfortably on their couch watching TV, even if the sky had been completely clear. So in the end, despite the title, the programme was much more about getting across basic knowledge and enthusiasm about astronomy, than about turning people into active amateur astronomers."[8]

During the live broadcast, the BBC was present at Westerbork. For them it was a first as well. The Netherlands is the first country outside the UK to have brought the *Stargazing Live* format to national TV. "They are very pleased with the success of *HNKS*," says Kramers, who is already working on funding a second edition of *Heel Nederland Kijkt Sterren*. Will there be a sequel? Kramers is confident that there will be, but emphasises that a decision has not yet been taken. MAX director Jan Slagter is positive as well: "Yes, we are developing the programme right now. I can't give any details yet, but there will definitely be a second edition of *HNKS*."

Notes

1. More about Tuvalu Media: http://www.tuvalu.nl/en/
2. More about Omroep Max (in Dutch): http://www.omroepmax.nl/home/
3. More about Netherlands Organisation for Scientific Research: http://www.nwo.nl/en
4. More about the Netherlands Research School for Astronomy: http://www.nova-astronomy.nl/
5. More about Netherlands Institute for Radio Astronomy: https://www.astron.nl/
6. More about the Netherlands Institute for Space Research: https://home.sron.nl/
7. More about the Westerbork Synthesis Radio Telescope: http://www.astron.nl/radio-observatory/public/public-0
8. Netherlands Research School for Astronomy Dutch astronomy website for the general public: http://www.astronomie.nl

Biography

Marieke Baan is head of communication at the Netherlands Research School for Astronomy (NOVA) and was involved in that capacity in the realisation of *HNKS*. The four university astronomy institutes in the Netherlands work together in the top research school NOVA.

Column

Artist's Impressions in Astronomy and Planetary Science

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Keywords
Astronomy, engagement, Hubble Space Telescope, outreach, science communication

Summary

The visual impact of images taken with telescopes like the Hubble Space Telescope is comparable with any of the most beautiful conventional works of art. These images are not only art in their own right, they also inspire space artists to create new pieces of art. This article explores the role of space art in astronomy outreach.

Introduction

Astronomy and space science receive a great deal of attention in the media, fuelling public interest. Space agencies and astronomical associations realise the strategic importance of communication and produce press releases. However, the general public often perceive science as difficult and disconnected from everyday life and it remains difficult to stand out in the explosion of online media.

As science communicators we can use the artistic appeal of images to give scientific results more newsworthiness, a broader appeal and, in some cases, to help to better explain the discoveries.

Images from some telescopes, of some objects, can grab headlines by themselves, but when these images are not available, an artist's impression can catch the attention of the media, who more often than not will need a good visual to support a story, no matter how interesting the science.

The history of art and science

Both science and art involve structural representation, imagination and curiosity. These similarities are represented in the work of the great scientists and inventors of the Renaissance. The Italian polymath Leonardo da Vinci (1452–1519) is famous for his beautiful yet scientifically accurate drawings of the human body, animal anatomy and of the machines of his own invention. As is the Dutch anatomist and physician Andreas Vesalius (1514–1564)[1].

The illustrations of da Vinci and Vesalius were an effective way of recording, publishing and spreading scientific findings to other scholars. Astronomy too has a very long tradition of translating observational data into visual representations in order to leave a record for future generations. Chinese astronomers depicted stars and appearances of comets on oracle bones and ox scapula for millennia[2].

The history of illustration in astronomy

The introduction of the telescope in 1608 vastly improved astronomical observations. Four centuries later we can compare the scientific data embedded in early illustrations made before the invention of the telescope with those that came afterwards.

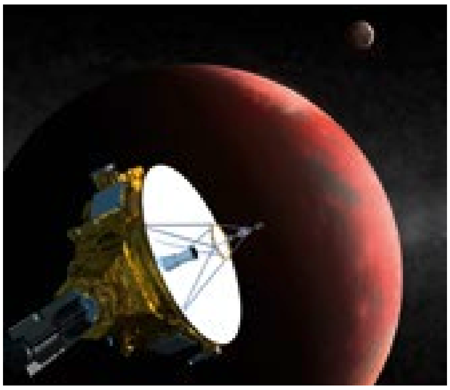

Figure 1. *NASA's artist's illustration depicted* New Horizons' *flyby of the Pluto–Charon system. The icy dwarf planet is covered by a red carbon-rich residue caused by the breakup of solid methane due to ultraviolet radiation from the distant Sun. Credit: NASA*

While the informational content in the Moon drawings of Galileo Galilei (1564–1642) was limited to revealing the mountainous topography, the splendid illustrations made by Thomas Harriot (1560–1621) plotted the locations of lunar features precisely, culminating in a cartographic map of the near side of the Moon. As telescopes grew bigger, astronomers such as William Parsons (1800–1867) were able to produce detailed representations of spiral galaxies and planetary nebulae[3, 4].

With the advent of astrophotography in the mid-nineteenth century and radio astronomy in the mid-twentieth century it seemed that there might come an end to astronomical sketching. However, new discoveries and beautiful imagery from the telescopes themselves have boosted the creativity of a new generation of space artists.

The modern space artist

In the 1960s, new astronomical discoveries and the emergence of spaceflight inspired illustrators such as the Czech Ludek Pesek (1919–1999), the American Chesley Bonestell (1888–1986) and the Russian Andrei Sokolov (b. 1931). Their paintings, which depict rocket ships, meteors, lunar and Martian landscapes, binary stars and galaxies, strived to show the wonders of the Universe in a different light[5].

Figure 2. *Artist's impression by the Dutch space artist Ed Hengeveld showing the dwarf planet Pluto and its largest moon Charon lit by the faint illumination from a distant Sun. Hengeveld explicitly depicted Pluto as a classic icy small Solar System body. Credit: Philip Corneille/Ed Hengeveld*

Space artists have worked closely with scientists to help them visualise scientific concepts and communicate astronomical discoveries to the general public. In 1982, the International Association of Astronomical Artists was founded to bring space artists together[6]. Their creations, from traditional paintings to digital creations, have graced numerous magazine covers, provided movie effects and illustrated scientific articles in a unique manner.

Astronomy illustrations and the media

Since the new millennium, illustrative space art has become an inescapable element of scientific publications and contemporary media. Contemporary artist's impressions make articles aesthetically more appealing and more inviting to read. Artist's impressions are often created to represent concepts and objects that cannot be seen with the naked eye, that are very big, very small, in the past, in the future, fictional, or otherwise abstract. Herein lies the strength of an illustration, which can give an audience an impression of the nature of hostile objects like pulsars and black holes.

My experience with astronomy illustration

In the winter of 2007, after a decade of illustrating my articles with the well-known drawings created or commissioned by space agencies and observatory press offices, I commissioned the Dutch space artist Ed Hengeveld (b. 1956) to create a few paintings to embellish my articles on the unmanned exploration of the outer Solar System. Hengeveld is famous for his depictions of astronauts on the Moon during the *Apollo* projects of the 1970s, but he also creates artworks on the subject of astronomical discoveries. So, he seemed to me the obvious choice to illustrate the exciting and distant Pluto–Charon encounter in the Kuiper Belt by NASA's *New Horizons* spacecraft[7, 8].

As there is no direct observational image of these Trans-Neptunian objects, NASA released an artist's concept, shown in Figure 1, of the spacecraft approaching Pluto and its largest moon Charon[8]. This was based on observations by the Hubble Space Telescope, which showed the red carbon-rich residue left behind as the ultraviolet radiation from the distant Sun broke up methane on Pluto's surface.

I explicitly asked Hengeveld to depict a more classic small astronomical body showing white–brown surface frost, seen in Figure 2. By using both NASA's and Hengeveld's depictions in a single article, readers were encouraged to think about how Pluto might look. Most Kuiper Belt objects may have a reddish colour,

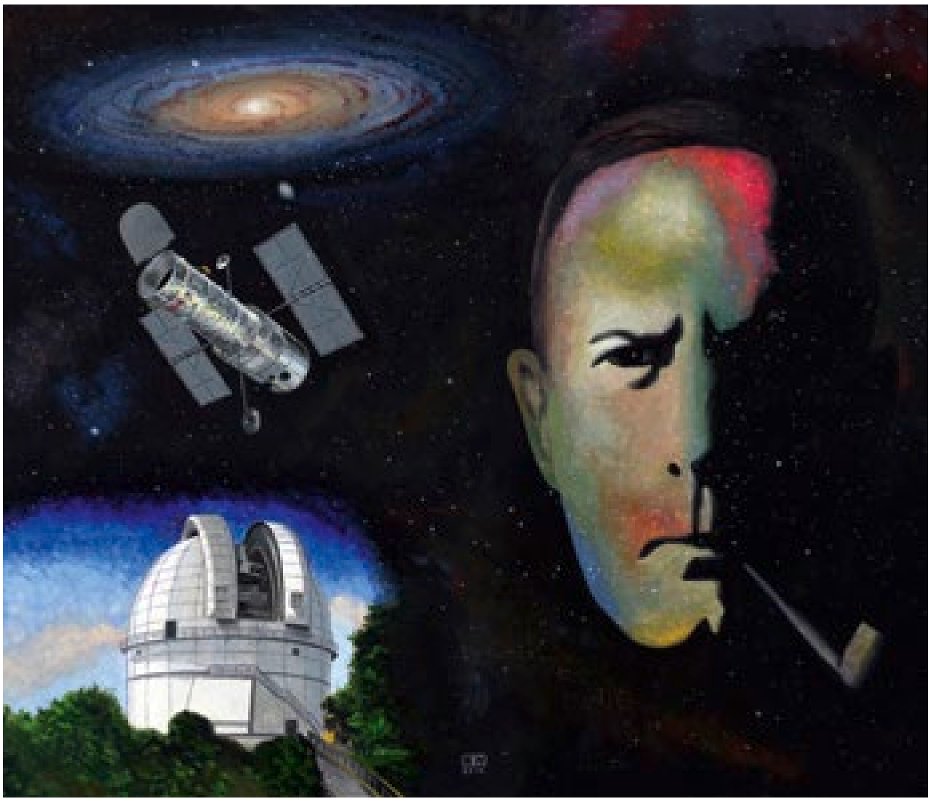

Figure 3. *Dutch space artist Ed Hengeveld created an informative artwork full of symbolism to celebrate the 125th anniversary of astronomer Edwin Powell Hubble and the 25th anniversary of the Hubble Space Telescope. Both the astronomer and the eponymous space telescope played an important role in discovering the accelerating expansion of the Universe. Credit: Philip Corneille/Ed Hengeveld*

whereas scattered-disc objects, which have more eccentric orbits as a result of gravitational interactions, might look whiter. We will soon know as *New Horizons*, zipping through the outer Solar System at nearly 1.5 million kilometres per day, is due to arrive at Pluto this year.

Illustrations for Edwin Hubble's 125th anniversary and the Hubble Space Telescope's 25th anniversary

In November 2014, the astronomical community celebrated the 125th anniversary of the American astronomer Edwin Powell Hubble (1889–1953) who discovered the expansion of the Universe using the 2.50-metre telescope at Mount Wilson Observatory in California, USA[9]. In April 2015, the Space Telescope Science Institute in Baltimore, USA, together with the European Southern Observatory (ESO) and the American (NASA) and European (ESA) space agencies celebrated 25 years of Hubble's namesake telescope, the Hubble Space Telescope (HST).

I commissioned Ed Hengeveld again to create a painting combining both anniversaries in a single informative artist's impression, shown in Figure 3. The result was an amazing artwork showing the astronomer together with the 2.50-metre telescope and the Hubble Space Telescope observing the spiral Andromeda Galaxy, also known as Messier 31.

Beauty is in the eye of the beholder, but Hengeveld's painting is full of symbolism, and effectively combined history and science in a unique way. The meaning and subject are immediately apparent, crossing language barriers so that the painting can be used to popularise science worldwide.

To commemorate a quarter century of the HST's success in engineering, science and outreach, the general public participated in the celebrations by creating their own Hubble-inspired video artworks. The winning videos from the competition can be found on the ESA/Hubble website[10].

Conclusion

Sharing the wonders of the Universe is one of the most enjoyable and rewarding aspects of astronomy. Moreover, by pairing our natural love of art with exciting science, we can create an engaged public and capture their imaginations. It is one of the most exciting ways of bringing astronomical science closer to the people.

Notes

1 For more information on Leonardo da Vinci and Andreas Vesalius:
https://en.wikipedia.org/wiki/Leonardo_da_Vinci
https://en.wikipedia.org/wiki/Andreas_Vesalius

2 For more information on astronomy in ancient China: http://en.wikipedia.org/wiki/Chinese_astronomy

3 For more information on selenography and lunar mapping: http://en.wikipedia.org/wiki/Selenography

4 For more information on deep sky observations using large reflectors in the 19th century: http://www.klima-luft.de/steinicke/ngcic/persons/rosse3.htm

5 For more information on space art and a list of space artists: http://en.wikipedia.org/wiki/Space_art

6 For more information on the International Association of Astro-Artists: http://iaaa.org/

7 For more background on Dutch space artist Ed Hengeveld: https://www.hq.nasa.gov/alsj/hengeveld.html

8 For the latest on NASA's *New Horizons* mission to Pluto-Charon: http://www.nasa.gov/mission_pages/newhorizons/main/

9 For more information on the history of the Mount Wilson Observatory:
http://www.mtwilson.edu/

10 For more information on 25 years of the Hubble Space Telescope:
https://www.spacetelescope.org/projects/Hubble25/

Biography

Philip Corneille is an amateur astronomer who works as a distance e-learning & ICT consultant with a keen interest in remote robotic technologies. As a Fellow of the Royal Astronomical Society, he documents the history, telescopes and instruments of professional astronomical observatories. Philip is member of Astronomers Without Borders and so far, he has visited 160 observatories in 33 countries.

A Global Audience for New Race to the Moon: Outreach for the Google Lunar XPRIZE

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Keywords
Moon, robotics, competitions, planetarium show, education kits, outreach, informal learning

Summary

The Google Lunar XPRIZE aims to open up a new era of space exploration and entrepreneurship through a competition to land a commercially funded robot on the Moon. To raise awareness of the competition, and to help inspire a new generation of scientists and engineers, XPRIZE has developed a suite of public engagement and informal learning activities. These include the MoonBots Challenge robotics competition, the digital planetarium show, *Back To The Moon For Good*, and the MoonBots-in-a-Box interactive kit for science centres. This article presents a review and preliminary evaluation of the Google Lunar XPRIZE's outreach activities to date.

Introduction

The Google Lunar XPRIZE is a competition to land the first commercially funded robot on the Moon and to transmit high-definition imagery and video back to Earth from two points on the lunar surface. Currently, sixteen teams from fourteen countries are building spacecraft to attempt a lunar landing before the prize expiry date of December 2016.

The competition is administered by XPRIZE, a not-for-profit organisation based in Los Angeles, USA, that designs and operates incentivised competitions to encourage innovation and technology breakthroughs. Google Incorporated sponsors the competition and has put up the prize purse totalling 30 million American dollars.

As well as opening up low-cost access to the Moon, a core objective of the prize is to inspire and engage people around the world with science, technology and innovation[1]. More than a third of the competing teams are headed by young entrepreneurs under 40 years old, who are potential role models in science, technology, engineering and maths (STEM).

XPRIZE has developed a suite of outreach programmes to build global awareness of the Google Lunar XPRIZE, the challenges of lunar exploration and the human stories of the competitors. Since 2010, these activities have been implemented through the informal learning environments of robotics competitions, planetariums and science centres.

The MoonBots Challenge — Introduction

Programmes that engage students in project-based learning founded on real scientific problems can have a significant effect in promoting an interest in STEM and a positive attitude to science (Welsh, 2010). As its first outreach programme, Google Lunar XPRIZE conceived a junior version of the competition, called MoonBots[2], in which teams of young people would construct a robot using LEGO MINDSTORMS[3] and complete a series of challenges on a simulated lunar surface.

Like the Google Lunar XPRIZE teams, MoonBots competitors were also given a remit to communicate their activities in their local and online communities. The MoonBots Challenge was launched in 2010 and has subsequently run in 2011, 2012 and 2014. Over the four rounds, MoonBots has attracted more than 2500 participants aged 9–17 and around 700 adult team members from 36 countries. There have been at least 120 000 views on YouTube of videos associated with the competition and around 25 000 people have attended community outreach demonstrations by the finalists.

The MoonBots Challenge — Promotion

MoonBots was set up through a partnership of organisations that included the XPRIZE Foundation, Google, LEGO Group,

	2014			2012			2011			2010			Overall		
	Phase		Winner*	Phase		Winner*	Phase		Winner*	Phase		Winner*	Phase		Winner*
	1	2		1	2		1	2		1	2		1	2	
# Participants	1131	107	21	527	110	18	302	86	14	887	84	13	2847	387	66
% Female	36	57	33	30	33	33	26	16	29	27	29	33	31	35	32
% Male	64	43	67	70	67	67	74	84	71	73	71	67	69	65	68
Number of all-female teams	53	7	0	11	2	0	4	1	0	12	1	0	80	11	0
Number of all-male teams	121	3	1	61	10	1	32	11	1	89	8	1	303	32	4
Number of mixed teams	124	15	4	65	18	3	40	8	2	110	11	2	339	52	11
Average age	12.56	13.15	13.95	12.93	12.85	13.89	12.94	13.17	13.36	13.12	13.73	13.83	12.87	13.19	13.78
Team size	3.8	4.28	4.2	3.84	3.7	4.5	3.97	4.3	4.67	4.2	4.25	4.33	3.94	4.09	4.4

Table 1. *Basic quantitative data for each phase of the competition over the four-year period. The 2010 dataset has been filtered to exclude adult members. *Includes winning and runner-up teams.*

WIRED and National Instruments. Because of the ambitious scope of trying to launch a competition to a global audience, the partners decided to focus on working with existing networks, such as the FIRST LEGO League (FLL), that had already developed communities and dissemination channels.

MoonBots was promoted through LEGO Education[4], editorials in WIRED[5] and GeekDad[6], XPRIZE social media channels and through dedicated online and social media platforms for MoonBots. In later years, to attract a wider participation from outside the US, the competition was promoted via international educational, science communication, and science centre networks and mailing lists, such as Ecsite[7], Psci-Com[8] and the Galileo Teacher Training Programme[9]. The Google Lunar XPRIZE teams have also promoted the competition through their own outreach networks and, in some cases, have acted as mentors for MoonBots teams.

The MoonBots Challenge — Teams

Initially, the 2010 MoonBots competition was open to teams of 4–6 adults and children aged 13 and over, with at least three members aged 13–18. However, due to requests from potential participants, the minimum age was lowered to nine years old. In subsequent years, the rules have been amended so that teams include one adult (the team captain) and the other 2–5 team members are aged 9–17 years old.

The MoonBots Challenge — Format

The basic format for MoonBots is a two-phase competition.

Phase 1: Teams submit a profile and a video in response to a question like: "Who is your favourite Google Lunar X PRIZE Team and why?" Or, "How can robots influence future space missions?" From these responses, 20–30 teams are selected.

Phase 2: Chosen teams receive a LEGO® MINDSTORMS® robotics toolkit, LEGO bricks and other materials to create their own robot and lunar landscape. The finalists must complete their simulated lunar mission in front of a live audience and through a live-stream for the judges and online followers.

The competition is free to participants. All submissions are online and the MINDSTORMS® NXT kit and any other equipment needed are sent to finalists free of charge.

On registration, teams supply contact details of the team captain plus names and ages of the team participants. We have used this information to carry out a basic quantitative evaluation of the participation in the competition.

The MoonBots Challenge — Overall participation

A total of 722 teams have competed in MoonBots from 2010–2014. The number of teams registering has varied quite widely year-on-year (Table 1), possibly due in part to variations in the timing of the competition's start and finish months. In the most successful years (2010 and 2014), the competition was launched in early spring, with Phase 2 running from mid-June until the end of August. This fits in with the "off-season" for participants involved in FLL challenges[10].

In 2011 the launch of the competition was delayed until May and in 2012, the competition ran from June–December. While changes in marketing strategy may also be a factor, the significant dip in numbers does suggest that the timing of the launch of Phase 1 of the competition has a strong effect, especially on the number of participants from the USA and those participating in FLL.

The MoonBots Challenge — Geographical spread

MoonBots has been dominated largely by teams from the USA, which account for

73% of the participants overall (Figure 1). However, this has varied substantially year on year: while in 2010 and 2011, more than 80% of the teams were USA-based, in 2012 USA teams only accounted for 48% of registrations. This drop may partly reflect the timing issues mentioned above; but the numbers also represent a trend towards international teams entering the competition.

In 2012, there were significant spikes in participation from teams from Egypt and Chile. These two countries are second and third respectively in the ranking for the number of teams participating in MoonBots overall, followed by India and Brazil. The peak in interest from Chile in 2012 could be attributable to outreach efforts by the Chilean Google Lunar XPRIZE competitor, Team AngelicvM. There is no Egyptian team competing for the Google Lunar XPRIZE, however, all the Egyptian MoonBots competitors have affiliations to robotics clubs, so it may be that advertising through Egyptian robotics networks proved particularly successful.

The top five countries aside from the USA participating in MoonBots are not English speaking and the rules have gradually been changed to make the competition accessible to a more international and diverse audience. In 2012, a deaf and hard-of-hearing team reached Phase 2 of the competition, delivering their video essay and commentating on their live events in sign language.

Since 2014, teams have been allowed to create videos in their own language, so long as they add English subtitles. They can also speak in their native language for the live-streamed outreach and judging event, so long as there is an English translator on site.

The increased internationality has been reflected in Phase 2 and the winners of the competition. A Hungarian team won the 2012 competition and one of three runners-up came from South Africa. The 2014 MoonBots Challenge was won by a USA team but two of the four runners-up came from Europe — Spain and the Netherlands.

The MoonBots Challenge — Gender balance

Female participants account for 31% of MoonBots competitors overall, 32% of winners and runners-up, and 33% of team captains. The gender balance for 2014 shows slight signs of improvement, with a 6% rise in the number of female participants compared to the 2012 competition.

In addition, there was a noticeable increase in the number of all-girl teams, rising from 11 to 53, which translated into an increase in all-girl team finalists. In 2014, for the first time, girls outnumbered boys in Phase 2 of the competition — although only a third of the 2014 winners and runners-up were female. While mixed-gender teams form the majority of both the finalists and runners up in each year, the 2010, 2011 and 2012 rounds of MoonBots were won by all-boy teams.

The increase in all-girl teams is largely USA-based, and may possibly be linked to strategic alliances developed by FIRST[11] to promote female participation in FLL.

The overall figures are naturally skewed to reflect the gender breakdown of the USA teams and the small samples make it difficult to draw any conclusions about gender breakdown for teams in most of the non-US countries participating in

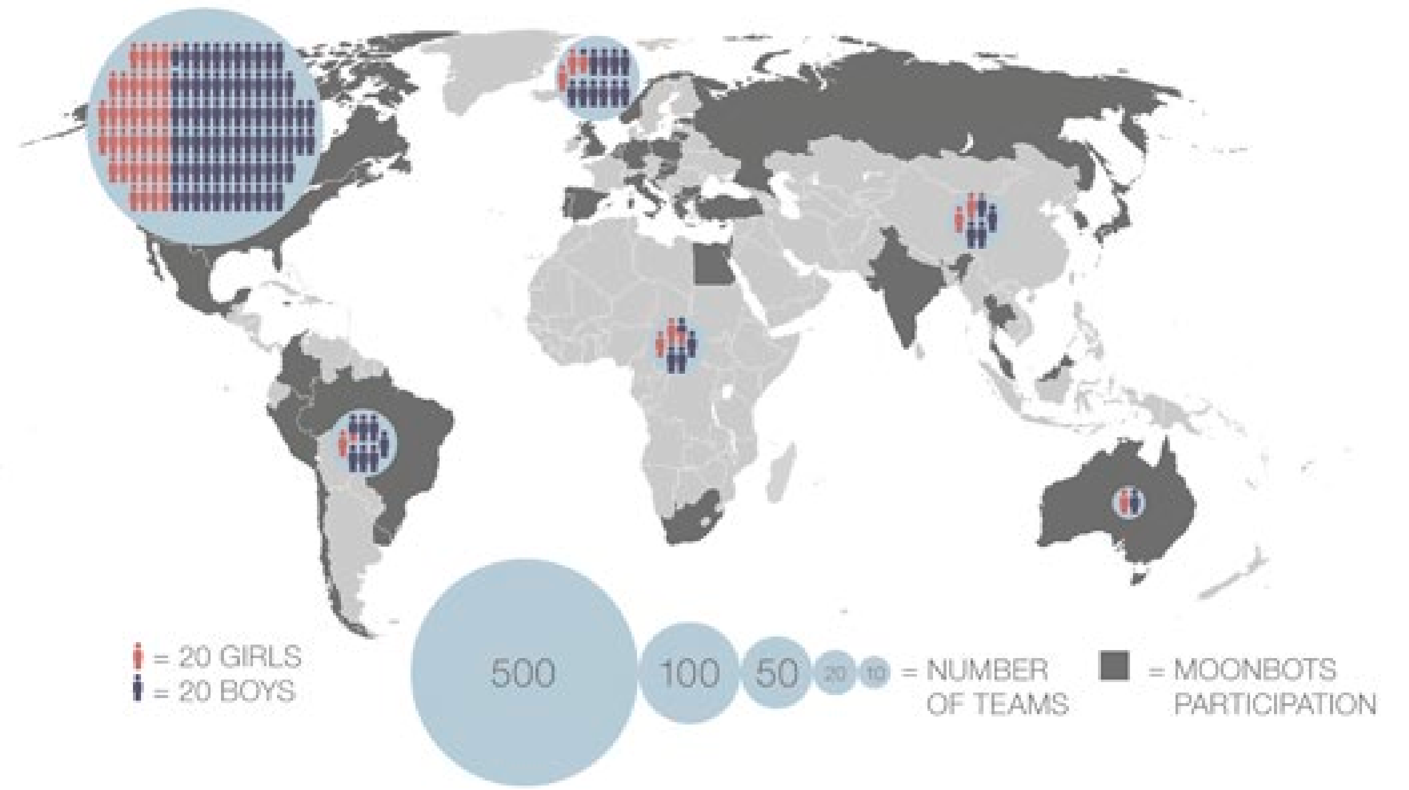

Figure 1. *Geographical distribution of teams participating in MoonBots 2010–2014 and gender balance by region. The regions are North America, South America, Europe, Africa, Asia and Australasia. Credit: Google Lunar XPRIZE/MoonBots*

MoonBots. However, the other top-five ranked countries do hint at the spectrum of gender balance between different nationalities. Forty-two percent of Egyptian teams are girls and India also has an above average female participation of 36% over the four years. Of the Brazilian contestants 27% are female but only 7% of the Chilean team members are female.

The MoonBots Challenge — Age and team size

In each year there is a general upward trend in the average age of teams as they progress through the down-selection stages. The winner/runner-up average age is 13.78 compared to 12.87 for all participants. Larger teams also tend to do better in the final phases of the competition.

The MoonBots Challenge — Repeat participation

Repeat participation in the competition is high and teams that have members or captains who have participated year-on-year show increased chances of success. Of the 722 teams, 211 share a team captain, either with teams competing in the same year or with a team from a previous year. Eighty-four team captains have coached more than one team, with 41 coaching multiple teams in the same year and 52 coaching teams in different years.

Thirty percent of team captains who coached multiple teams reached the final at least once and 13% reached the final in two or more years. Five of the 12 winner/runners-up teams in 2011, 2012 or 2014 had either participated in previous rounds of the MoonBots challenge or had a team captain who had participated.

The Nebulans, a team from Egypt and finalist in MoonBots 2014, state in their profile: "This is our third year in the competition because that is the AWESOMEST way to spend the summer!" The next round of the MoonBots Challenge launched on 23 April 2015. Registration closes on 23 June 2015.

Back to the Moon for Good fulldome show

There are an estimated 3900 planetariums worldwide, attracting an audience of more than 90 million people each year in over 100 countries[12]. These planetariums range from 280-seater fixed-dome facilities that are visited by several hundred thousand people per year, to 3-metre inflatables that seat 20–30 school children. They are operated by a wide range of organisations, including museums, science centres,

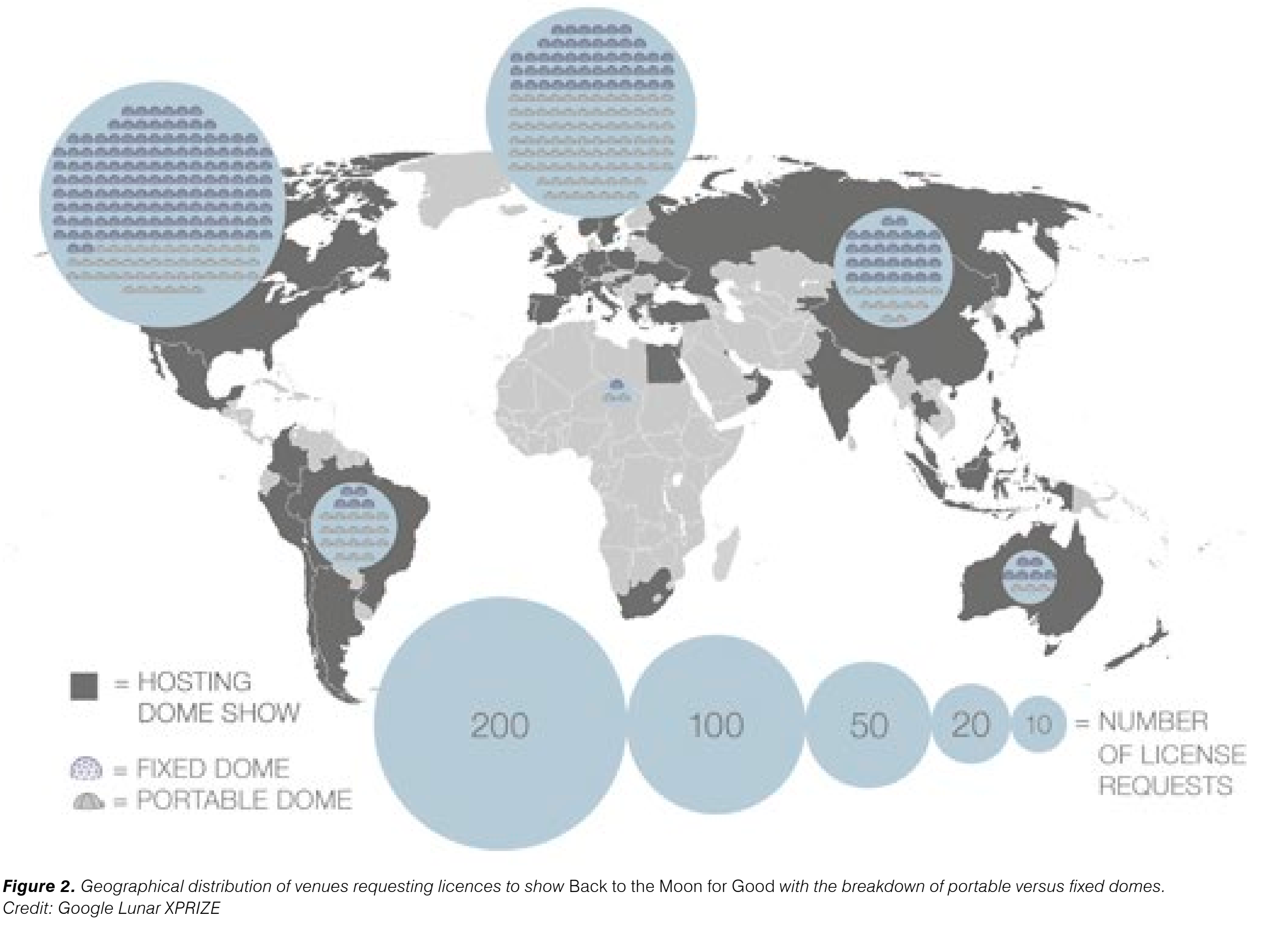

Figure 2. *Geographical distribution of venues requesting licences to show* Back to the Moon for Good *with the breakdown of portable versus fixed domes.*
Credit: Google Lunar XPRIZE

Figure 3. *Advertisement for* Back to the Moon for Good *fulldome digital planetarium show. Credit: XPRIZE/NSC Creative*

astronomy clubs, universities and schools (Petersen, 2014).

In January 2013, XPRIZE contracted NSC Creative[13] to produce a 24-minute digital fulldome show that chronicles the history of lunar exploration, introduces the Google Lunar XPRIZE and tells the story of some of the people attempting to win the competition.

Ryan Wyatt, Director of the Morrison Planetarium at the California Academy of Sciences, wrote the script and the show was narrated by the actor Tim Allen. *Back to the Moon for Good (BTTMFG)* was premiered at the National Space Centre in Leicester, UK, in November 2013.

A sign-up sheet and marketing material for planetariums interested in hosting the show are available from the Google Lunar XPRIZE website. The lease for the show is free of charge and the only costs incurred by planetariums are for the hard drive and its shipment.

Back to the Moon for Good — Promotion and reach

The show was promoted through two planetarium lists[14] and through adverts in the *Planetarian Journal*[15]. In addition, XPRIZE contacted directly all the digital planetariums listed in the Fulldome Compendium, a list of thousands of digital planetariums in 70 countries[16].

XPRIZE set a goal of having the show screened in at least 10% of the world's planetariums. In the first year, 2014, 408 planetariums in 49 countries signed licences for *BTTMFG*, already meeting that target. At the time of writing, new enquiries average ten per week. To date, the show is available in 18 languages and XPRIZE has provided the audio for the show in non-narrated format to allow for regionalisation. The script has been translated thanks to the generosity of volunteers working in planetariums around the world. In 2014, the show won awards at the FullDome Festival Jena and Macao Fulldome Film Festival.

It is difficult to give a robust estimate of how many people have actually seen the show. Although most domes signing the license agreement give annual visitor numbers, *BTTMFG* will only form part of their programme.

XPRIZE has sent out questionnaires on a quarterly basis asking for viewing figures and comments on audience responses. According to 116 responses from the 160 planetariums that initially received the show, approximately 800 000 people viewed *BTTMFG* during the period November 2013 to April 2014. Further numbers for the period April to November 2014 have been requested but the response rate has been low. Extrapolating from the 800 000, we can estimate that more than two million people have seen the show in its first year. More than 90% of planetariums surveyed rated the audience response as "Great" or "Good".

MoonBots-in-A-Box kit

Feedback from informal consultations at the Ecsite and ASTeC conferences in 2012 suggested that science centres would welcome a way to engage with a MoonBots-style activity outside the competition format and timescale.

In 2013, XPRIZE started to develop a MoonBots-in-a-Box kit that could be used for workshops or on-gallery activity in science centres or other informal education environments. The final kit included a 3D lunar landscape, a LEGO Mindstorms robot, a pre-programmed Raspberry Pi[17] and game pad controller, LEGO bricks and build instructions for models designed for the robot to complete a lunar mission, an instructional video and a demonstration script. Thirty one of these kits have been distributed to science centres and planetariums around the world with priority given to those that were launching the *BTTMFG* shows. A further seven were shipped to Google Lunar XPRIZE teams; the remaining two were retained by XPRIZE for outreach events.

In March 2014, XPRIZE sent out an evaluation questionnaire and received 12 completed surveys from 11 science centres. All except one had used the kit for at least one event or workshop and most had established it as part of a regular programme. In the period October 2013 to March 2014, the MoonBots-in-a-Box kits were used by 6000 to 10 000 visitors to facilities. The kits have been used in a variety of ways, including to develop curriculum-linked schools, workshops and as an interactive exhibit for the general public.

The Chabot Science Centre reported that due to the kit's popularity we plan to expand it to allow more visitors to use the kit at a time and try to reduce the long lines of people waiting to use it. We are also testing it for use in after-school and outreach programmes.

Conclusions

The aim of Google Lunar XPRIZE's outreach programme is to raise awareness of the competition worldwide. Although the *Back to the Moon for Good* dome show was a significant outlay, with a budget of around 600 000 American dollars, the sizeable visitor numbers for planetariums means that it can be considered to be a very cost-effective way of reaching global audiences.

Assuming two million visitors to planetariums have already seen the show, then the

Figure 4. *The MoonBots-in-a-Box kit in action. Credit: XPRIZE*

cost per head is only 30 American cents per person.

The audience numbers reached by the MoonBots competition are more modest, but the feedback and the repeat participation suggests that the programme has a high level of engagement from participants and that they retain an interest in both MoonBots and the Google Lunar XPRIZE.

The MoonBots-in-a-Box kits have not only been demonstrated as a useful resource, but have been a helpful way of building working relationships with planetariums and science centres. This will be an invaluable channel for engaging with the public as the Google Lunar XPRIZE teams prepare to launch their missions to the Moon.

Notes

[1] More information on the Lunar XPRIZE: http://lunar.xprize.org/

[2] More information on MoonBots: www.moonbots.org

[3] More information on LEGO MINDSTORMS: http://www.lego.com/en-us/mindstorms/?domainredir=mindstorms.lego.com

[4] More information on LEGO education: http://education.lego.com/en-gb?noredir=true

[5] More information on WIRED: www.wired.com

[6] More information on Geekdad: www.geekdad.com

[7] More information on Ecsite: www.ecsite.eu

[8] PSCI-COM mailing list: https://www.jiscmail.ac.uk/cgi-bin/webadmin?A0=psci-com

[9] More information on the Galileo teacher training programme: www.galileoteachers.org/

[10] More information on First LEGO league: www.firstlegoleague.org/challenge/participationrules

[11] More information on FIRST: http://www.usfirst.org/aboutus/nlsept14/first-alliances-corner

[12] Tallying the World's Planetarium Attendance: http://www.lochnessproductions.com/reference/attendance/attendance.html

[13] More information on NSC Creative: www.nsccreative.com

[14] The two planetarium mailing lists used were Dome-L and Fulldome.org

[15] Planetarian Journal: http://www.ips-planetarium.org/?page=plntrn

[16] Fulldome Compendium: http://www.lochnessproductions.com/lfco/lfco.html

[17] Raspberry Pi is a system designed to teach basic computer science: www.raspberrypi.org

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Biographies

Anita Heward is European Outreach Manager for the Google Lunar XPRIZE and has spent a career communicating topics in astronomy and space.

Chanda Gonzales is Senior Director of the Google Lunar XPRIZE and led the development of the MoonBots Challenge.

Cynthia Ashley is Project Manager for the *Back to the Moon for Good* show and has a background in both formal and informal education.

Pearl Hwang is a consultant for the MoonBots-in-a-Box kit for science centres. She is a professional engineer and a FIRST robotics coach.

Steven Canvin is a consultant for the MoonBots Challenge and has a background in design, marketing, LEGO and robotics.


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Astrotour 2010: A retrospective

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Keywords
Science museums, science centres, public engagement, science communication, outreach, North America

Summary

This article looks back at my four-month trip visiting science centres and museums across North America, illustrating the examples of best practice I found whilst there. This is not a commentary of how they are now, but a glimpse into the timeless factors that made them special and brought science alive for the inquiring public.

Introduction

My keen interest in science centres and planetariums began at centres around the United Kingdom: The Black Country Living Museum[1], Dudley; the Birmingham Science Museum (now Thinktank) and Jodrell Bank Discovery Centre, Manchester[2]. The inspiration I gained as a teenager during these visits would underpin my later decision to study for an MSc in astronomy at Jodrell Bank Observatory and further motivate my vocational work in the planetarium at Birmingham's Thinktank[3]. Between 2010 and 2014 I was director of The Big Bang in the West and East Midlands — the Big Bang being the largest children's science festival in the UK — and invited the Black Country Living Museum and others to bring the same joy in science, technology, engineering and mathematics (STEM) to new audiences of budding scientists.

In 2009 I decided — whilst performing Shakespeare in India — that I would undertake a grand tour of North America's institutions and see how science communication was championed on that side of the pond. In January 2010 I was the proud — and nervous — bearer of a flight ticket to Toronto, flying out on 7 May and returning from San Francisco on 8 September. What would happen in between was anyone's guess but I was sure that there would be a great deal to discover on the way. I was not disappointed!

As I worked my way around the continent I blogged about my experiences, detailing examples of best practice as I went[5]. I visited large, multi-million dollar museums such as the American Museum of Natural History, New York, USA[6] and Chicago's Museum of Science and Industry[7], USA, as well as smaller local institutions such as the Halifax Discovery Centre, Nova Scotia, Canada[8] and the Woodstock Museum, Canada[9]. I found that the size of the building made little difference to the overall experience; rather three main factors stood out, which for the sake of this

Figure 1. *The Exhibit Workshop in the main Exploratorium building in San Francisco. Credit: David Ault*

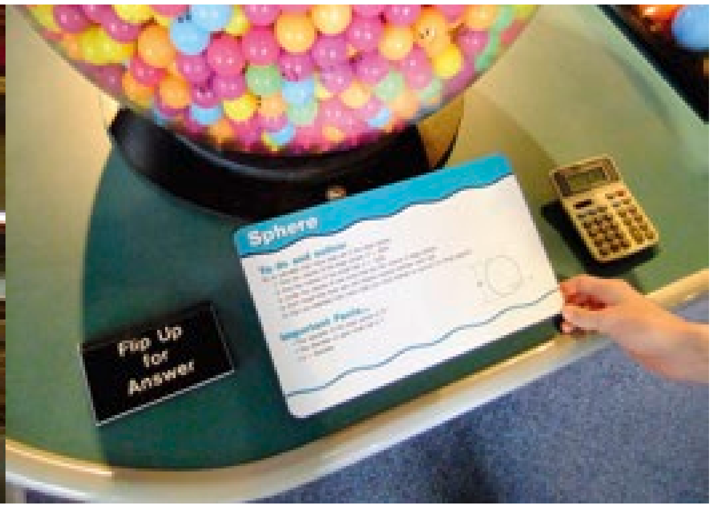

Figure 2. *The mathematics of bubble-gum balls at the Great Lakes Science Center — calculator provided! Credit: David Ault*

Figure 5. *Map showing locations visited during the trip. Credit: David Ault*

article I shall discuss under the headings: Locality, Actuality, and Personality.

Locality — Making the most of where you are

It is difficult to pass through Washington DC without a trip to the Smithsonian[10], and particularly the Udvar-Hazy Center[11] slightly further out in Virginia. Here you can see the Space Shuttle *Discovery*, marvel at Concorde, and take in a host of other thrilling exhibits. One thing that really inspired me was that the Smithsonian used the advantage of its location to communicate science in action. The proximity of the centre to Dulles Airport gave it an excellent view of the comings and goings of the aircraft. To grant visitors an insider's experience of the daily functioning of air traffic control they make it possible to hear the normally unheard dialogue that directs the intricate proceedings from the control tower. This was such a simple idea, but was extremely effective.

The Three Rivers Foundation[12] at Comanche Springs in the panhandle of Texas was almost thirty kilometres from the nearest village. Gone was the light pollution of the urban sky and in its place the vast expanse of the night sky was revealed in all its glory. It was no wonder then that each month the Foundation hosted star parties where the public were invited to come together and gaze upwards for a time, leaving life's concerns for a taste of awe. It was not, however, only these that drew the crowds. Schools and colleges were also encouraged to bring their students to study astronomy and learn about the rich observable ecology of the local area.

You might be asking, how though did visitors see the night sky in the middle of the day? The Foundation's solution was found in collaboration; teaming up with a similar site in Australia. Both places could now enjoy unspoiled views of the stars via the internet whatever the time of day, and in addition each gained an appreciation of a different part of the sky.

Engaging the community in another way, though not related to astronomy, was the California Science Center in Los Angeles[13] — which presented the public with rubbish from a 1994 landfill site nearby to demonstrate just how little it had decomposed — and the Great Lakes Science Centre[14] which had taken time-lapse pictures of the bay outside to enable visitors to scroll through the shifting weather systems and seasons of the area.

Throughout my journey I found that those museums that engaged with their local communities and environment had higher return rates than those that didn't, addressing the perennial problem of how to coax back those visitors who had "seen it all before". When the partner museums Science North and Dynamic Earth[15] in Canada were being built, the local community was invited in at the various stages of construction, giving them a sense of ownership over their science centres. They also used the nickel mines that had built the town in the first place, giving a sense of ongoing narrative.

Figure 3. *Maryland Science Center's Wonder Workshop. Credit: David Ault*

Similarly San Francisco's Exploratorium[16] asked the community to bring in bits of wood, metal and so forth to create the interactive displays. They expanded upon this principle by building the interactive museum displays as a series of prototypes. These were observed through the working day and repaired each evening before repeating the next day. This encouraged visitors to be curious, to play and to touch with a view to sparking their imaginations.

Actuality — Making the most of what you have

When it comes to how to make and showcase what you have there is a distinction to be made between science centres and museums. The latter have collections that need to be shown, whilst the former can be built simply from an idea. Chicago's Museum of Science and Industry used its massive space to begin to breach this distinction, by placing the interactive exhibits at the heart of the building and allowing those interested to follow the paths further into the building to see the collections.

Allowing the visitor to engage on different levels was an important factor in signage, and was taken up by many centres. The Great Lakes Science Center was one such place. Its display boards gave the headline of what was in front of you, a brief description below that, and further down a more in-depth analysis for the interested reader. Moreover, it was one of the few centres that was unafraid to use mathematical symbols and terminology without apology. I feel that sometimes we shy away from using such terminology for fear of putting people off, but it may also lose those who could be interested. A long-standing debate, I know, but I would err on more information over less.

There is also a perception sometimes that if it's not on a screen, then it won't be engaging to the under 25s, but in reality using an excessive number of screens can become very costly and science centres are rarely awash with funds. The Woodstock Museum's curators had researched all similar institutions in a two-hour radius to create the most effective displays they could. The museum was thus mostly sign-based but with smatterings of screen-based interaction which worked very well indeed. One simple use of a screen was simply to stream the current science news — in Toronto this became an hourly show which explained the headlines.

In the nearby Cleveland Museum of Natural History[17], my guide told me that whilst the exhibits had changed little since she was a child, the signage had been refreshed, giving the impression of renewal. This is one area to consider if budgets are tight, whilst another was to get local sponsorship for exhibits. The Halifax Discovery Centre started as a touring theatre in a van and kept a rough and ready feel. It was their ingenuity in reusing old exhibits, keeping things as simple as possible and getting sponsorship that I appreciated. They overcame their problems of space by creating a maze with translucent sheeting, and suddenly there was an exciting area with no overcrowding problems!

Do you have some table-tennis balls of different sizes? Use them with implements to start a discussion about beaks and natural selection, demonstrating how the right beak — implement — will be able to pick up the food — table-tennis ball — and survive, whilst those that can't, won't.

A sandpit? That can be a Dino Dig, as in the Dallas Museum of Nature and Science, or an exploration of the scientific method as in the California Science Center, where visitors could unearth Egyptian pottery and skeletons to then ask themselves how they got there. This was an important distinction for me, because instead of telling people the theory, it invited them to examine the evidence and draw conclusions — essentially, to do the science yourself.

The space itself can also be used in different ways, and this idea was picked up upon my return to the UK. The University of Texas's planetarium in Arlington[18] could be hired out by couples seeking a romantic dinner under the stars. For a modest fee, the in-house kitchens would serve a three-course meal whilst the stars wheeled above the happy pair. A simple reframing of the space, two hours usage of projectors and an unparalleled view!

Another amazing site was the Maryland Science Center[19], with its Wonder Warehouse, where everything was created by the staff out of whatever was around, including the packaging from the previous touring exhibition which was reincarnated as dividers. The staff were allowed to play, and that enthusiasm was transmitted very quickly to the visitors.

Personality — Making the most of who you have

This is above all the main point that I have to make. Above everything — the exhibits, the tools, the funds, the space, the community — come the staff. When your staff are happy and enthusiastic, your visitors are too. From the moment you approach a museum or science centre, you are being influenced; if the people on the door are bored or stressed, this will start a visit on the wrong foot. I met some amazing individuals on my travels, inspirational people who are unafraid to cross boundaries between the arts and sciences, and let their vision fly.

At Ontario Science Centre[20], there are no scientists donning lab coats to provide the explanations of exhibits; they use actors. The rationale is that it's easier to give an actor scientific knowledge than to give

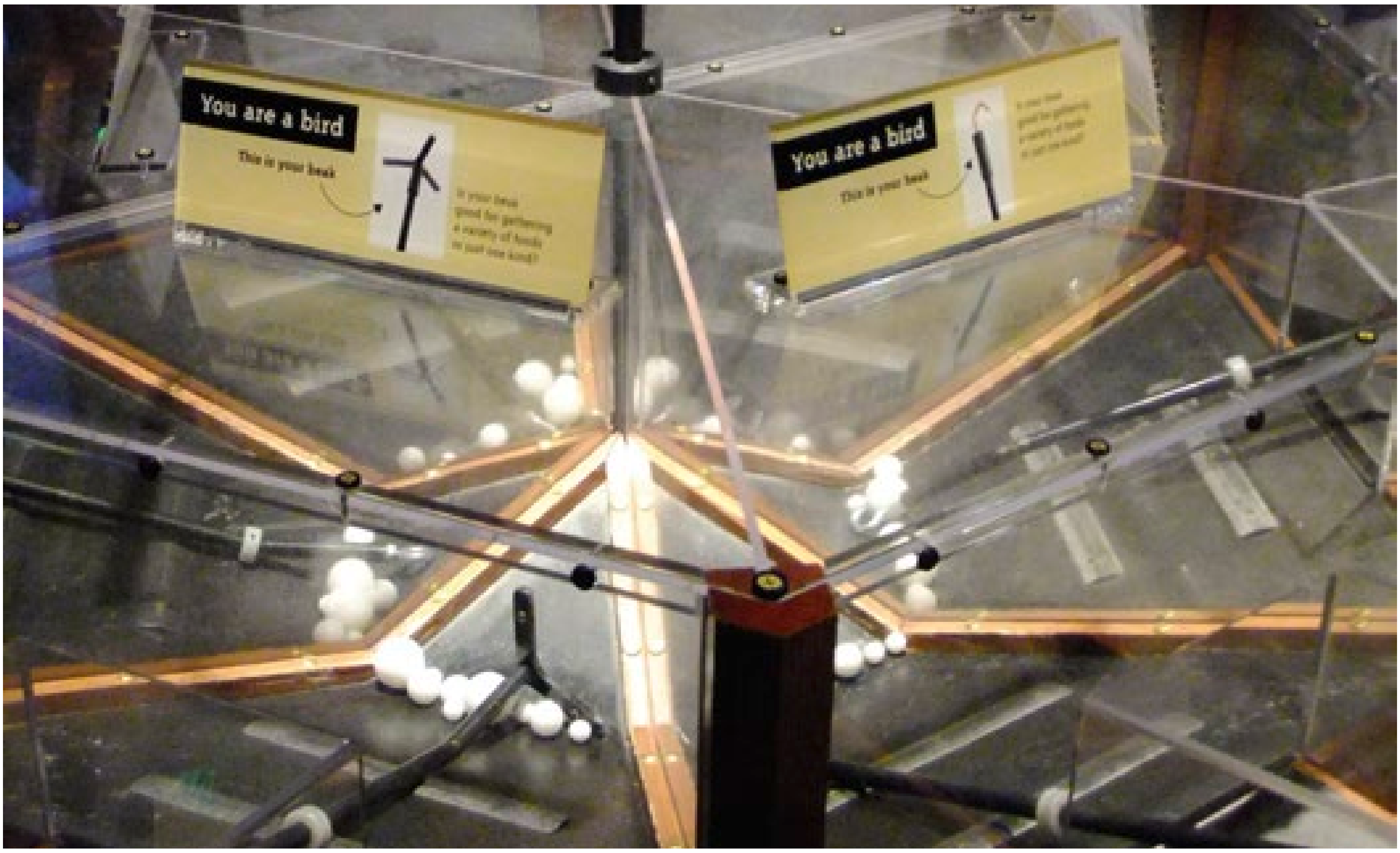

Figure 4. *The evolution of beaks as demonstrated by table-tennis balls and implements. Credit: David Ault*

scientists presentation skills, and I was swept up in the infectious enthusiasm they had for discovering more about the world around them. As they discovered more, so did the visitors.

The Exploratorium in San Francisco worked with high school students during the summer holidays. If the students didn't know how something worked, they would be encouraged to work it out together with the visitor, or to ask someone who did know. Either way, it was an opportunity to discover, to question and to be curious.

I have mentioned already the Maryland Science Center's Wonder Warehouse, where the staff had free rein over the gallery; in Toronto everyone from across the centre was brought together to decide what interactive display was needed and to come up with prototypes. At Science North and the Exploratorium prototypes were made and improved by the staff on the shop floor, and certainly for the latter these were arts graduates and inventors.

Buildings that were attached to or near a university were able to tap into such local resources. The Halifax Discovery Centre trained up graduates to be part of the roving teams. Arlington Planetarium gave its graduates vital experience and the Ontario Science Centre gave academics research space and time in return for talks and demonstrations.

Even in museums where collections were fixed, staff could be encouraged to be more than just custodians or warders. At the Canada Science and Technology Museum in Ottawa[21], an old artefact was illuminated on a button push rather than constantly, to limit damage caused by light exposure. Staff then used this as a point of engagement, asking visitors to consider how light affects certain objects. They were also encouraged to have a favourite exhibit and find out more about it, so that even if they did not have ownership over what went into the museum, they could still be enthused by it.

Staff are by far an institution's biggest asset, because it is that interpersonal spark of fascination that will encourage visitors to find out more. The technology at Dalhousie University's Halifax Planetarium in Canada[22] was half a century old, but my guide there was as joyful about it as he could be. In the nearby Bedford Institute of Oceanography[23], real scientists showed me around their work in the bay, just as I was able to see the coveted Sudbury Neutrino Observatory[24] and meet everyone who worked two kilometres down that mine day in, day out.

My point being that if staff are given autonomy and ownership, they will, in my experience, reap dividends in terms of their own wellbeing and the experience for the visitors. This was true from the biggest to the smallest, the richest to the poorest centres — it was the staff that made a place enjoyable or not.

Conclusion

Engaged and friendly staff and volunteers, imaginative and relevant displays, and the availability of information at all levels — this is what makes a science centre.

It was Einstein who said, "The most beautiful thing we can experience is the mysterious. It is the source of all true art and science".

There are no boundaries between the two, and it is this sense of mystery and wonder that we are trying to communicate to those who visit our science centres. I was very privileged to travel across North America five years ago and see many different ways of doing just that, and if you would like to find out more about the various places I visited then all the reviews are at: http://astrotour2010.blogspot.com.

Notes

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8. Halifax Discovery Centre Halifax Discovery Centre, Nova Scotia, Canada: http://thediscoverycentre.ca/
9. Woodstock Museum, Canada: http://www.woodstockmuseum.ca/
10. Smithsonian, Washington DC, USA: http://www.si.edu/
11. Udvar-Hazy Center, Virginia, USA: http://airandspace.si.edu/visit/udvar-hazy-center/
12. Three Rivers Foundation, Texas, USA: http://www.3rf.org/
13. California Science Center, Los Angeles, USA: http://californiasciencecenter.org/
14. The Great Lakes Science Centre, Ohio, USA: http://www.greatscience.com/
15. Science North and Dynamic Earth, Canada: http://sciencenorth.ca/promos/iceage/
16. Exploratorium, California, USA: http://www.exploratorium.edu/
17. Cleveland Museum of Natural History, Ohio, USA: https://www.cmnh.org/
18. University of Texas's planetarium in Arlington: http://www.uta.edu/planetarium/
19. Maryland Science Centre, Maryland, USA: http://www.mdsci.org/
20. Ontario Science Centre, Canada: https://www.ontariosciencecentre.ca/
21. Canada Science and Technology Museum, Canada: http://cstmuseum.techno-science.ca/en/
22. Dalhousie University's Halifax Planetarium, Canada: http://www.astronomynovascotia.ca/index.php/planetarium
23. Bedford Institute of Oceanography, Canada: http://www.bio.gc.ca/
24. Sudbury Neutrino Observatory, Canada: http://www.sno.phy.queensu.ca/

Biography

David Ault's love for science centres began early in life, leading him to present in the planetarium at Thinktank, Birmingham's Science Museum. His love of travel sprang from touring Shakespeare around Rajasthan, India, fulfilling a love of theatre that took him to drama school. Upon return from his four-month trip across North America he directed and ran The Big Bang Fair Regional programme in the West and East Midlands. He is currently producing astronomy podcasts, sci-fi/fantasy audio-drama and narrating audiobooks, eager to find the next challenge.

The Aristarchus Campaigns: Collaboratively measuring the Solar System

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Keywords
Citizen astronomy, lunar orbit, lunar distance, Moon calculations, speed of light, astronomical methods, astrometry, citizen science

Summary

Citizen astronomy has proven to be one of the most effective ways to actively involve amateur astronomers in real scientific endeavours. We present here the Aristarchus Campaigns, a citizen astronomy project intended to collaboratively reproduce historical astronomical observations. During the campaign amateur astronomers were invited to use simple optical instruments to gather data about some common astronomical phenomena. This data was used to calculate the value of well-known physical and astronomical quantities such as the speed of light and the distance to, and size of the Moon. We describe the project and the results of the first two Aristarchus Campaigns. We argue that this type of simple campaign may help to engage the public with astronomy in developing counties and prepare their astronomical communities to participate in high-impact observational campaigns.

Introduction

Ancient astronomers devised inventive methods to measure the Solar System. Using these methods, which are in principle very simple, we can measure the sizes of the Sun, the Moon and the planets, and their distances from us. One of the best known of these ancient methods was originally proposed by Aristarchus of Samos (*ca.* 310–230 BCE) who devised procedures that used lunar phases and eclipses to estimate the relative sizes and distances of the Moon and the Sun (Van Helden, 2010; Heath, 2013).

More recently, physical constants have attracted the attention of astronomers. Using the huge spatial and temporal scales natural to astronomy, astronomers have devised ingenious ways to measure the values of these physical constants. Take for example the method devised by Ole Rømer (1644–1710) who measured the speed of light in vacuum by observing the periodic occultation of the moon Io by its host planet, Jupiter (Cohen, 1940).

Now, many centuries after the invention of these historical methods, astronomers and physicists have measured these quantities with exquisite precision using vastly more elaborate tools and methods. The distance to the Moon can be determined using powerful lasers and retro-reflecting arrays of mirrors placed on the lunar surface by the Apollo astronauts, so that the distance is now known to within just a few centimetres (Tapley, 2004; Dickey, 1994). The diameter of and distance to the Sun have been determined to one part in a billion and one part in a 100 billion respectively (Schou, 1997; Muhleman, 1969) and the speed of light, which until a few decades ago had only been constrained using astronomical methods, is now regularly measured in the laboratory so precisely that it is known to roughly one part in a billion (Sullivan, 2001).

In contrast to the classical methods devised by such pioneers as Aristarchus or Rømer, most of these modern techniques are far from the reach and technological capacity of most amateur astronomers. Therefore, measuring distances in the Solar System, and constraining the physical constants that govern it, today seems to be a matter of sophisticated instrumentation and advanced scientific capabilities. But, these classical methods have a great deal left to offer and still find a privileged place in astronomy and physics textbooks. They are used today as educational tools, not only for teaching science history, but also for teaching the methods of astronomy and physics and inspiring new ways of thinking about the results (Salvador, 2009).

Today, the advent of advanced and accessible technological devices such as smartphones is opening new doors for do-it-yourself astronomy. Many personal electronic devices such as smartphones come with a GPS receiver, fast internet connections and precise clocks. This gives us, the science communicators, an incredible opportunity to involve astronomy enthusiasts, and the wider public, in astronomy projects. They allow for *in situ* measurements that would otherwise be prohibitively expensive and available only to professional scientific teams.

This scientific and sociological phenomenon is called citizen astronomy, or more generally, citizen science (Raddick, 2010).

Our citizen astronomy campaigns aimed to reproduce historical astronomical observations and measurements that helped to determine the size of the local Universe. Here, we will give a background to the project and the role that citizen astronomy plays in science outreach; we describe the project and the specific campaigns that we have run with the participation of individuals and communities in Colombia and abroad; summarise some the most important scientific results of the campaigns; and discuss the challenges involved when organising and running this kind of initiative.

Tiempos de Contacto

A continuación ingrese su posición geográfica exacta (tal y como es provista por un GPS).

Longitud: -75.0
Formato: +GG.gggg, +GG:MM:SS.sss, +GG MM SS.sss. Ejemplos: -75 35 23.99, -75:35:23.99, -75.43555

Latitud: +6.0
Formato: +GG.gggg, +GG:MM:SS.sss, +GG MM SS.sss. Ejemplos: -75 35 23.99, -75:35:23.99, -75.43555

Uso horario: -5
Formato: +UTC. Ejemplo: -5, -4.5

Altura: 1600.0 metros
Formato: +AAAA.aaa. No use "," ni separadores de miles.

Calcule

Observador

Longitud:-75
Latitud:6
Altura:1600.0 metros
Huso horario:UTC-5

Contacto	Tiempo Estimado (Velocidad de la luz Infinita)	Tiempo Estimado (Velocidad de la luz finita)
Contacto 1 (Marte toca la Luna)	2014 JUL 05 21:11:25.08	2014 JUL 05 21:11:01.91
Contacto 1 punto medio (La mitad de Marte esta ocultada)	2014 JUL 05 21:11:44.68	2014 JUL 05 21:11:21.54
Contacto 2 (Marte esta ocultado completamente)	2014 JUL 05 21:12:04.33	2014 JUL 05 21:11:41.26
Contacto 3 (Marte empieza a emerger)	2014 JUL 05 22:12:54.64	2014 JUL 05 22:12:29.75
Contacto 3 punto medio (La mitad de Marte ha emergido)	2014 JUL 05 22:13:11.92	2014 JUL 05 22:12:47.09
Contacto 4 (Fin de la ocultación)	2014 JUL 05 22:13:29.13	2014 JUL 05 22:13:04.33

Figure 1. *Screenshot of the iContact web-based application developed for the 5 July 2014 Aristarchus Campaign[1].*

The rise of citizen astronomy

A recent, inadvertent example of the power of citizen astronomy took place on 15 February 2013. On a cold morning in Siberia, hundreds of thousands of citizens of several large cities around the Chelyabinsk region in Russia witnessed only the second large asteroid impact ever recorded. Hundreds of pictures and videos were taken that day by random observers and shared almost instantaneously via social networks. The data collected by these *de facto* citizen scientists allowed professional astronomers around the world to study the phenomenon in unprecedented detail (Brown, 2013; Zuluaga, 2013).

Another well-known citizen astronomy project is the Globe at Night project, a successful initiative intended to measure light pollution around the world (Barringer, 2011).

Collaborative astronomical observations that involve many amateur and professional astronomers are not new (Meech, 2005). These campaigns have been run in the past to study the evolution of comets, measure the position of near-Earth asteroids or observe the occultation of stars by Solar System objects (Ortiz, 2011). Projects like these have led to new discoveries and breakthroughs but, in most cases, the people enrolled in these campaigns are experienced observers, whether professional or amateur. More simple astronomical campaigns, such as those described here, aim instead to measure or to observe common astronomical phenomena such as lunar and solar eclipses and occultations, which use simpler and more readily available instrumentation and methods. These may serve as initial experiences for those who might then go on to participate in more advanced projects. Mass participation in these simple campaigns from communities in developing countries may prepare them for more interesting and challenging collaborative projects.

In 2014, with all of this in mind, we designed and launched a new set of citizen astronomy projects in Colombia called the Aristarchus Campaigns. The projects involved amateur astronomers distributed over a geographic area covering not only Colombia but several neighbouring countries.

The Aristarchus Campaigns

On 15 April 2014 a total lunar eclipse was visible from most of the Americas and the Caribbean. Lunar eclipses are very common phenomena that are spotted, photographed, and even measured by hundreds of millions of observers. They provide well-known opportunities to measure the size of, and distance to, the Moon and the Sun, as recognised over two thousand years ago by Aristarchus of Samos (Heath, 2013).

In 2014, a group of professional astronomers and astronomy undergraduate students at the University of Antioquia in Medellín, Colombia teamed up with the Sociedad Antioqueña de Astronomía — a regional astronomical association — and launched the Aristarchus Campaign. The campaign was intended to make the experience of observing the total lunar eclipse not only an enjoyable recreational activity, but also an opportunity to perform simple measurements using readily available astronomical equipment — such as binoculars, small telescopes and cameras — and personal electronic devices — like mobile phones and tablets.

The initiative was promoted by local astronomy clubs and through social networks. An observing guide was written to observe and measure the lunar eclipse and the public in Medellin were encouraged to submit their measurements and pictures for potential scientific use.

The weather in Colombia on the date of the eclipse made it very difficult for many committed enthusiasts to perform most of the measurements. However, despite this slow start we were motivated by the enthusiastic response on social networks and proposed, in the same year, several similar campaigns.

We now call these observational initiatives, collectively, the Aristarchus Campaigns. At the time of writing, there have been three Aristarchus Campaigns:

Campaign 1:
The 15 April 2014 campaign centred on the total lunar eclipse.

Campaign 2:
The 23 May 2014 campaign associated with the meteor storm of the 209P/Linear comet.

Campaign 3:
The 5 July 2014 campaign corresponding to an occultation of Mars by the Moon visible in most parts of South America.

Campaign design and preparation

Preparing observations of a simple astronomical phenomenon, such as a lunar eclipse, an occultation or a meteor shower, is a relatively simple task. Finding the most interesting things to observe and measure and devising ways to achieve these measurements with simple and readily available instrumentation, is much more challenging.

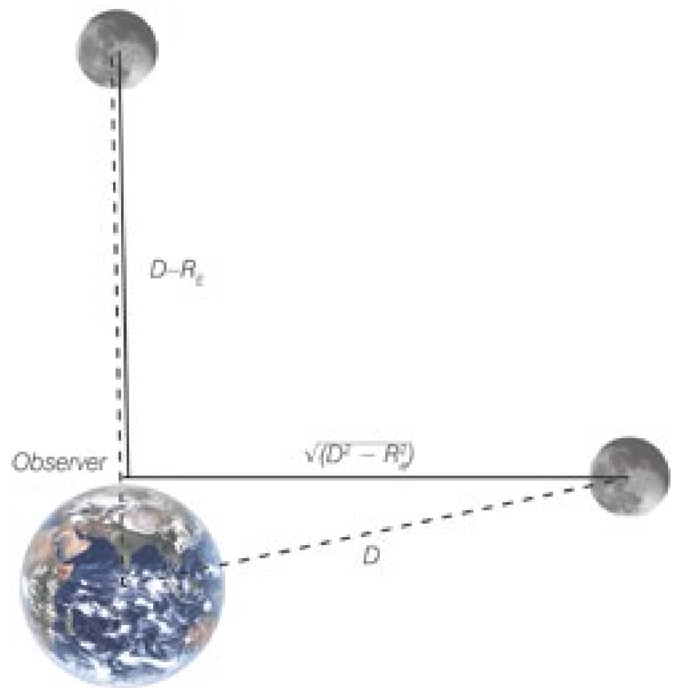

Figure 2. As the Moon rises its distance to an observer on the Earth's surface of is reduced. Objects are not shown to scale.

The campaign preparations began by selecting a phenomenon that could be observed from a wide geographic area. Lunar and solar eclipses, lunar occultations and meteor showers make ideal targets.

Once the phenomenon was identified, details of where in the sky the phenomenon would be visible for the specific geographic area covered by the campaign had to be prepared. In the case of an eclipse this meant calculating the contact times of the Moon with the shadow of the Earth and the magnitude of the eclipse, and for meteor showers the position of the radiant — the point in the sky where the meteors appear to originate for a ground-based observer — and an estimate of the meteor-sighting rate had to be calculated.

Occultations are far more challenging as contact times depend much more strongly on geographic position. In this case it is important to provide access to astronomical tools giving the occultation information for specific locations. These tools should be user-friendly and be accessible without any advanced astronomical or computational skills.

For our occultation campaign we developed a simple web-based application that was to provide contact times for a given location inside the occultation area[1]. A snapshot of the website we designed and created for this campaign is shown and described in Figure 1.

The selection of specific quantities to be measured or objects to be photographed is the next step in the preparation process. Since the campaigns are intended to reproduce historic astronomical measurements, it is good to start from the methods and quantities that were selected by astronomers in the past.

We prepared and distributed a short observing guide featuring information on the campaign and the observations. A guide of this type should be engaging, short and very easy to read and follow. It should also include a clear description of the goals and scope of the campaign and more importantly, a statement about the precise usage of the data provided by participants. For the purpose of the call for participants it is very important that the guide is easily downloadable.

Depending on the complexity of the observations, we additionally prepared and distributed detailed guides containing further technical instructions, intended for more advanced observers.

The guides from all the campaigns can be downloaded from the official website of the project[2].

Call for participation

It is important that the local institutions and groups that normally act as sources of astronomy information for the public be fully involved in the marketing of the campaign. For the first Aristarchus Campaign we were supported by Medellin's planetarium and the local science museum, as well as by the astronomy clubs.

Social networks, Facebook, Twitter, email lists, blogs and other astronomy-related websites allowed us to reach communities in other regions of Colombia and other countries.

Gathering the campaign measurements

For gathering the data and images obtained by the participants in the campaigns we use three basic methods:

Social networks
Social networks such as Facebook and Twitter are the simplest method for gathering the data. Social media is especially suitable for providing information that can be summarised in a few words, for example, contact times of occultations or equipment specifications.

Email
When the information to be provided is more complex, we ask participants to send emails to the campaign organiser with their images or data files attached.

Upload repository
If the amount of data to be provided is very large and cannot be sent using the two previous methods, participants may upload pictures and files to a public repository especially prepared for this purpose.

We have not yet designed a specific web interface to gather the campaign data, as has been done in other citizen science projects, as there are significant differences between the data requirements for each campaign, making it harder to design a universally applicable platform. For one campaign we may primarily need pictures or videos, whilst for another we may just need positions and times.

One of the biggest challenges when dealing with information provided by a large community of observers, is the diversity of data formats that has to be dealt with. Differences in equipment, time zones, observational experience and even operating systems, can make the analysis of this information potpourri a very challenging task.

Our second and larger campaign taught us that it is very important to instruct observers in advance on how to deal with the data they are gathering. For instance, it is important to warn participants that pictures should not be modified after being digitally extracted from the cameras as it is important to preserve the EXIF data stored by the devices as this contains key information needed for analysis. These data manipulation tips are the kinds of best practices that astronomy or science citizen campaigns can use to improve the skills of the community before they participate in advanced or global projects.

Analysis of the observations and publication of the results

The last part of the campaign was the compilation and analysis of the observations. In most citizen astronomy projects this process is performed by researchers, but in the Aristarchus Campaigns we have always tried to actively involve some of the participants. Additionally, all the analytical tools, such as numerical methods, formulae and computer codes, have been made publicly available to allow other experts, and amateur astronomers, to reproduce the results.

For each campaign we prepare a technical report describing the campaign itself, its scientific goals, the data provided by the citizen astronomers and the full results of the data analysis. Two technical reports have been written so far, the first on the 15 April 2014 lunar eclipse (Zuluaga, 2014) and the second on the 5 July 2014 occultation of Mars by the Moon[3].

Results of the campaigns

In the following paragraphs we summarise the two successful Aristarchus Campaigns we have already concluded.

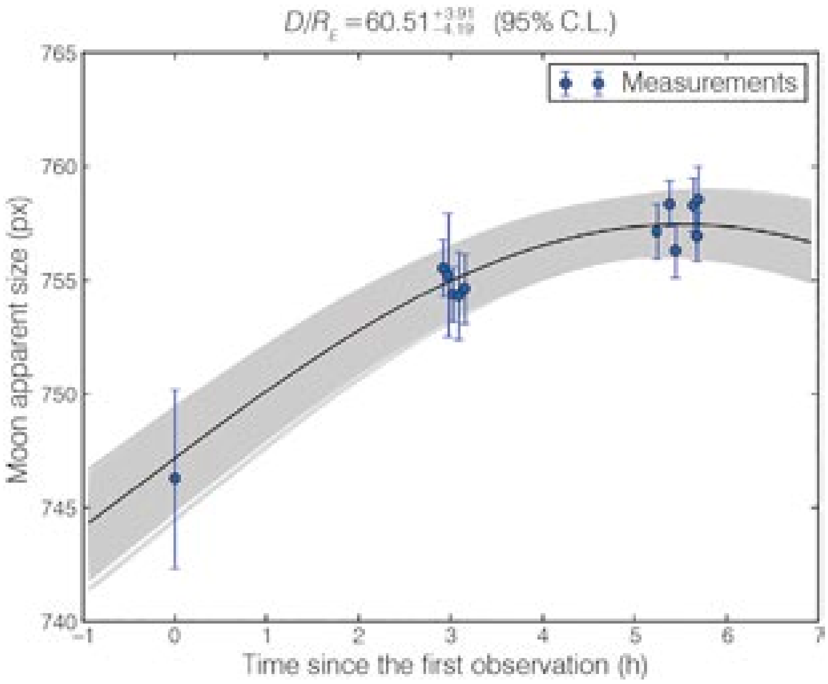

Figure 3. Best fit of the measured apparent sizes (data points) of the Moon compared to the theoretical model (continuous line). The shaded region corresponds to solutions statistically compatible with the observed apparent sizes at a 95% confidence level.

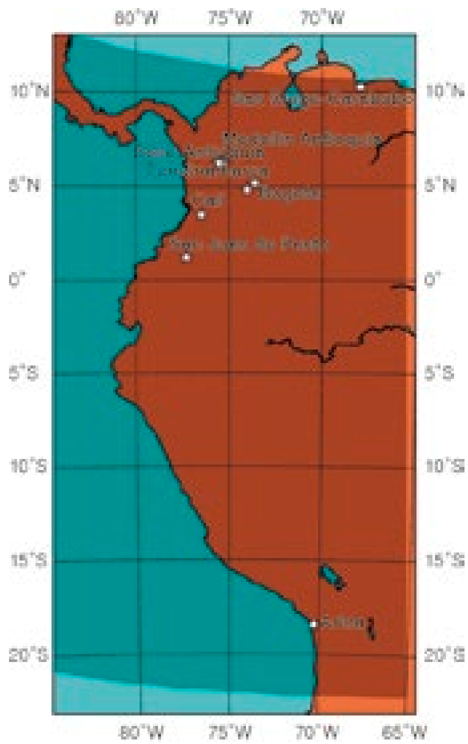

Figure 4. Locations of the observers who contributed to the 5 July 2014 Aristarchus Campaign for the occultation of Mars by the Moon. The shaded areas correspond to the region where the occultation was visible.

A simple method to measure the distance to the Moon

Although our perception seems to indicate that the Moon is larger, and thus closer, when it is just above the horizon, the reality is actually the opposite. The distance from the Moon to any observer on the surface of the Earth decreases as the Moon rises in the sky, although the distance from the Moon to the centre of the Earth remains approximately constant. In Figure 2 we show the cause of this nightly observer-Moon distance variation. Measuring the angular size of the Moon as a function of elevation provides an estimate of the lunar distance to the centre of the Earth.

Five specific observations and measurements were proposed for this campaign, to be executed during the lunar eclipse. The first — actually unrelated to the eclipse itself — invited people to take pictures of the full Moon from rising to culmination, when the Moon reaches its highest altitude in the sky. The aim of these measurements was to detect the subtle variation in the lunar disc size due to changes in the lunar distance that result from observations taken from different locations on the Earth's surface as the Moon rises, rather than at the centre of the Earth.

The second task involved taking pictures of the Moon before it entered the Earth's shadow and after it was completely eclipsed. The aim of this measurement was to evaluate the properties of the light refracted through the Earth's atmosphere.

The third task was to measure, as precisely as possible, the times of the eclipse contacts and the fourth was to photograph the partial eclipse with the shape and size of the Earth's shadow clearly visible.

The fifth and last task was to take a picture of the Moon and include in the same field of view as the star Spica and the planet Mars.

From the pictures that were taken and the measurements that were made we were able to determine the distance to the Moon with a fractional precision of 3% (ie to three parts in a hundred; see Figure 3), finding a value of 386 000 kilometres, fairly accurate when compared to the accepted value of 384 400 kilometres. (Zuluaga, 2014)

We discovered that the only information required to achieve this precision is the angular size of the lunar disc and the precise time when the disc size is measured. This constitutes the most simple and affordable way to measure the lunar distance and radius devised so far. The only instrument required to achieve this is a good camera.

Measuring the speed of light with an occultation of Mars by the Moon

On 5 July 2014 we had an occultation of Mars by the Moon that was visible from the northern part of South America (see Figure 4). This phenomenon provided a perfect opportunity for setting up an Aristarchus Campaign.

It is well known that when we observe an object in the sky, we see the object as it was in the past as light takes a finite amount of time to reach us. For bodies with a substantial apparent motion, like Solar System objects, whose position on the sky changes from day to day, the effect of this light travel time is a detectable difference between the position predicted without taking the light travel time into account and the observed position of the object in the sky.

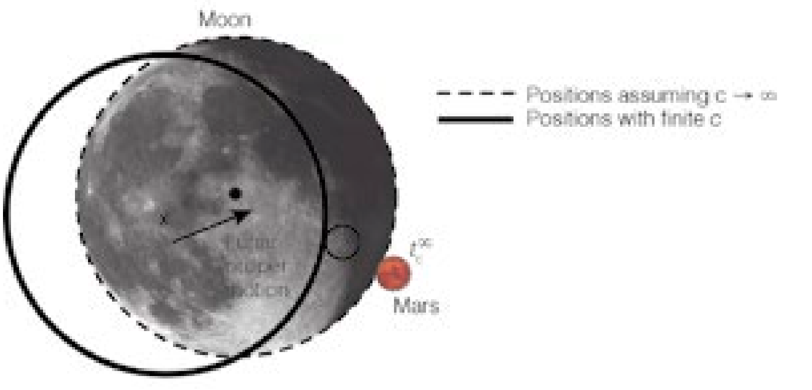

Figure 5. *Illustration comparing the positions of Mars and the Moon in the sky assuming an infinite speed of light (c) (dashed lines and photographic representations) and a finite speed of light (solid lines). The contact times for an infinite or finite speed of light are different. The solid lines show what we would observe. Sizes and apparent motion were exaggerated for illustration purposes.*

During the occultation on 5 July 2014, light took approximately 8.5 minutes to reach us from Mars. On the same date the apparent motion of Mars was one arcsecond per minute and the apparent motion of the Moon was approximately 21 arcseconds per minute. To put the arcsecond unit into context, the Moon has an angular size of about 1800 arcseconds, or, in other words, it extends up 1800 arcseconds across the sky. Due to the time taken for the light from Mars to arrive at the Earth, its apparent position on the sky was almost 8.5 arcseconds off from the position calculated assuming that the light had arrived instantaneously (as shown in Figure 5) and the occultation took place 24 seconds later than expected. Using simple mathematics this meant that, by working out the difference between when we could expect the occultation to take place if the light travel time were zero, and when it was actually observed to take place, the speed of light could be calculated. For the Aristarchus Campaign we exploited this effect to measure the speed of light in a vacuum. Although this is a novel method it was inspired by the original method devised by Ole Rømer to measure the speed of light by looking at variations in the predicted times for the transits of Jupiter's moon Io.

For the campaign we asked participants to measure visually or photographically the contact times of the occultations in different locations across a wide geographic area. We gathered results from at least nine groups and individuals from Colombia, Venezuela and the north of Chile (see Figure 4). The joint analysis of the data provided by these groups, allowed us to determine the speed of light in vacuum as 320 180 kilometres per second, a value that, although inaccurate, is just 7% different from the value measured with more sophisticated methods. We show in Figure 6 the contact time delays measured by the participants and the theoretical delay expected for different values of the speed of light.

Acknowledgements

We want to thank all the friends and colleagues who supported the Aristarchus Campaigns by sharing information about the project via social networks and by encouraging people to participate in the observational campaign. We also thank our co-authors in the technical reports for sharing some of the results and figures presented in this paper. The Campaign is a project of the Sociedad Antioqueña de Astronomía (SAA) and the University of Antioquia. We thank both organisations for promoting and supporting these public initiatives. Jorge I. Zuluaga is funded by El Programa de Sostenibilidad de la Vicerrectoría de Docencia de la Universidad de Antioquia 2014-2015 and El Comité para el Desarrollo de la Investigación de la Universidad de Antioquia.

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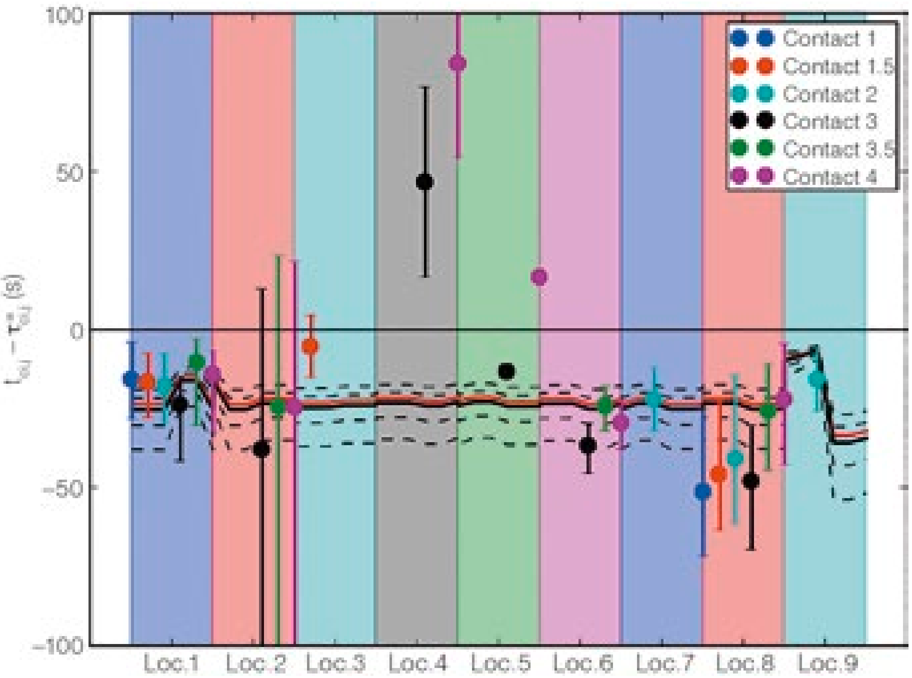

Figure 6. *The difference between the contact times measured at each location and the value expected if the speed of light was infinite. Dashed lines correspond to the expected contact time difference if the speed of light was (from bottom to top) 200 000; 250 000; 350 000 and 400 000 kilometres per second. The solid black line corresponds to the actual speed of light; 300 000 kilometres per second. The solid red line is the best-fit value obtained after excluding the most problematic measurements.*

Notes

1. The simple web-based application developed to provide contact times for a given location inside the Mars occultation area is now publicly available at: http://github.com/facom/iContact
2. The official website of the project: http://saastronomia.org/campana-aristarco
3. Further details about the campaigns and the analysis or their results can be found in the technical reports available in the arXiv e-print repository: http://arxiv.org/abs/1405.4580 and: http://arxiv.org/abs/1506.00346

Biography

Jorge I. Zuluaga is an associate professor at the Institute of Physics at the University of Antioquia, Colombia and a collaborator of the Harvard–Smithsonian Centre for Astrophysics. He is the founder of the undergraduate programme in astronomy at the University of Antioquia, the first of its kind in Colombia and the Andean region. Jorge has more than fifteen years of experience as a university lecturer in physics and astronomy and as a science communicator. His public talks have appeared on local television networks and his contributions to the development of astronomy in Colombia was recently recognised by the International Astronomical Union by naming asteroid 347940 with his name.

Juan C. Figueroa is a computer scientist with a bachelor's degree in Engineering from the Universidad EAFIT (jointly, the Escuela de Administración y Finanzas [School of Administration and Finance], or EAF and the Instituto Tecnológico [Institute of Technology] or IT) and is currently an undergraduate student of astronomy at the University of Antioquia. He recently completed the Diploma Course in Astronomy, a three-semester programme offered by the same University. Juan has fifteen years of experience as a software developer and ten years as a teacher of programming languages. His passion for astrophotography led him to participate actively as a contributor to the Aristarchus Campaigns and design of some of its experiments.

Ten Challenges of Producing an Astronomical Gigapixel Image

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Keywords
Image processing, astronomical images, VISTA, VVV survey

Summary

Public outreach involves developing new methods, testing new technologies and integrating new ideas. Sometimes, the craft of outreach even leads into completely unknown territory. This is the story of a project that led into astronomical and technological *terra incognita*. It is about the production of a mosaic of the central parts of the Milky Way made with ESO's VISTA telescope as part of the VVV survey. The outreach system at ESO was tested to its limits, and beyond, by the production of what is still likely to be the largest astronomical image in the world. Several significant challenges had to be overcome, extensive hardware and software upgrades were undertaken and compromises had to be made to produce this stunning image for the public.

VISTA and the VVV survey

VISTA — the Visible and Infrared Survey Telescope for Astronomy — is part of ESO's Paranal Observatory and is the largest survey telescope in existence. It is also the most powerful near-infrared survey telescope ever built. The telescope has a 4.1-metre primary mirror and is dedicated to conducting wide-angle surveys of the skies with its 67-megapixel digital camera.

VISTA's observing time is entirely devoted to mapping the sky systematically and six huge public surveys will take up the majority of the telescope's first years of operation. One of these surveys is the VVV — or VISTA Variables in the *Vía Láctea* — survey, which started in 2010 and was granted a total of 1929 hours of observing time over a five-year period. The survey is scanning the southern plane and bulge of our galaxy — 520 square degrees in total — in five near-infrared filters.

When the survey is completed in 2016, the outcome will be a catalogue with around one billion point sources, including about a million variable objects. This will be used to create a three-dimensional map of the bulge of our galaxy, the Milky Way, to calculate the ages of stellar populations and study the evolution of globular clusters.

In addition to its scientific purpose, VISTA's superb image quality and the wide field of view make the telescope an excellent source of stunning images to be used for public outreach. As of March 2015 ESO has published 17 press releases based on results delivered by VISTA, seven of which were directly related to the VVV survey.

The final image

The image which tested the limits of ESO's system, and its team members, covers about 315 square degrees (20.4 × 15.4 degrees) and shows the centre of the Milky Way. The observations were carried out using three different near-infrared (*JHK*) filters and the resulting image is monumental. It is 9 gigapixels in size, measuring 108 199 by 81 503 pixels[1]. The image is so large that, if printed with the resolution of a typical book, it would be nine metres across and seven metres tall. This makes it likely the largest astronomical image in the world.

The gigantic dataset contains about 173 million objects, out of which about 84 million have been confirmed as stars, which is ten times as many stars as in any previous study. It is a major step forward in our understanding of our home galaxy.

Ten problems to solve

Work on the image began in 2012 with the preparation of a science release[2] based on a paper by Saito et al. (2012). The ESO public outreach team quickly realised that the huge mosaic of the central Milky Way could be the main focus of a release. When the work on the image began the team was confronted with ten major problems which had to be solved.

Problem 1: Getting the astronomical data

Simply moving the raw data from place to place turned out to be a great challenge. Early on it was decided — on an exceptional basis and only because of the sheer amount of data — that the data had to be down-sampled by a factor of almost two. Ordinarily ESO always releases images pixel by pixel as they are observed, to make sure that the images the end-user receives are optimal. With the support of ESO's helpdesk the available storage on the ESO FTP server was extended and the vast quantities of data — 166 gigabytes of FITS[3] files — could be moved back and forth between science team member Ignacio Toledo (Atacama Large Millimeter/submillimeter Array [ALMA]) and ESO over several iterations.

Problem 2: Distortions over the large field

The next problem occurred during the astronomical data processing. Due to the large field of view, the image happened to have significant projection and distortion effects. Most of these problems were

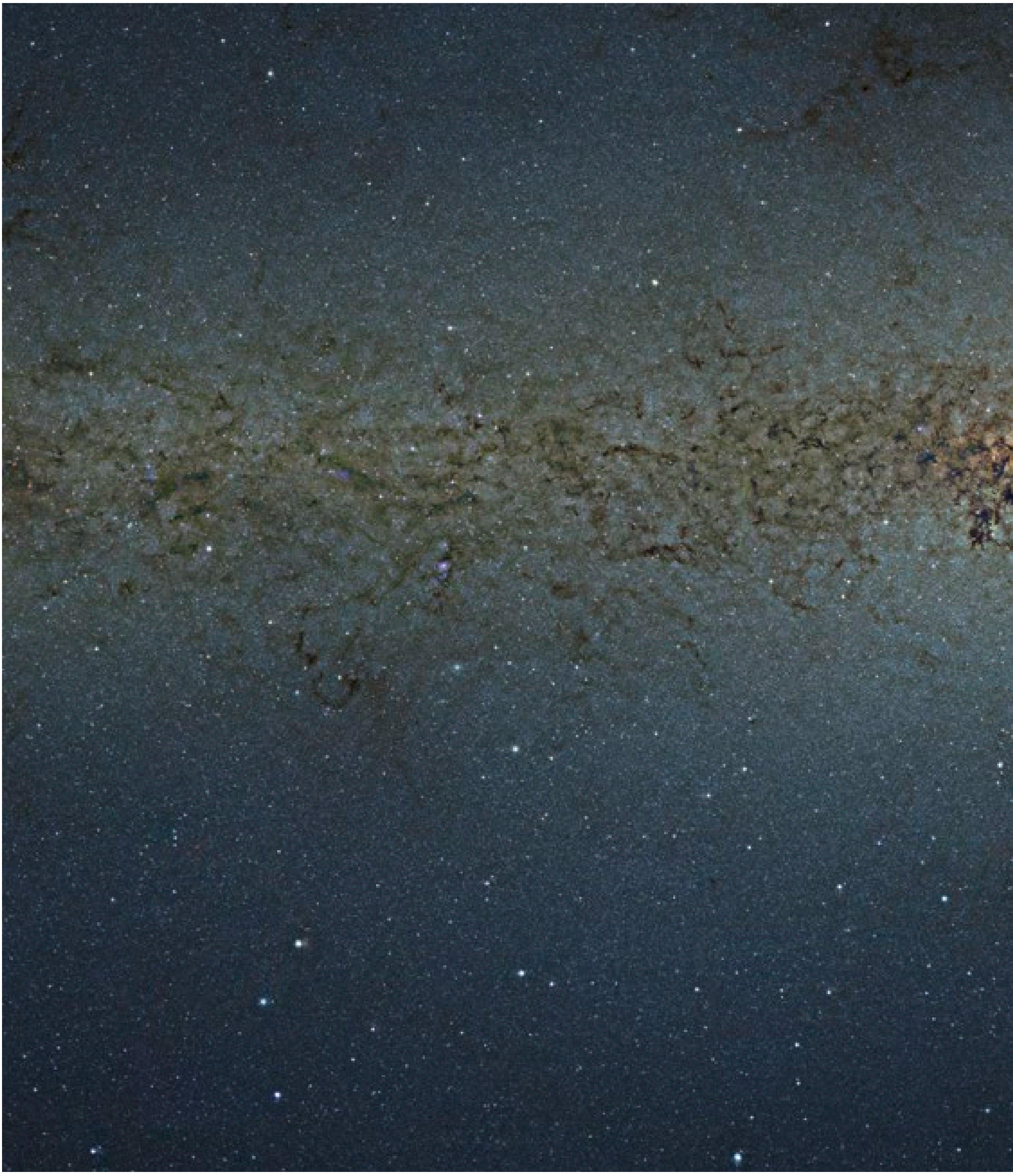
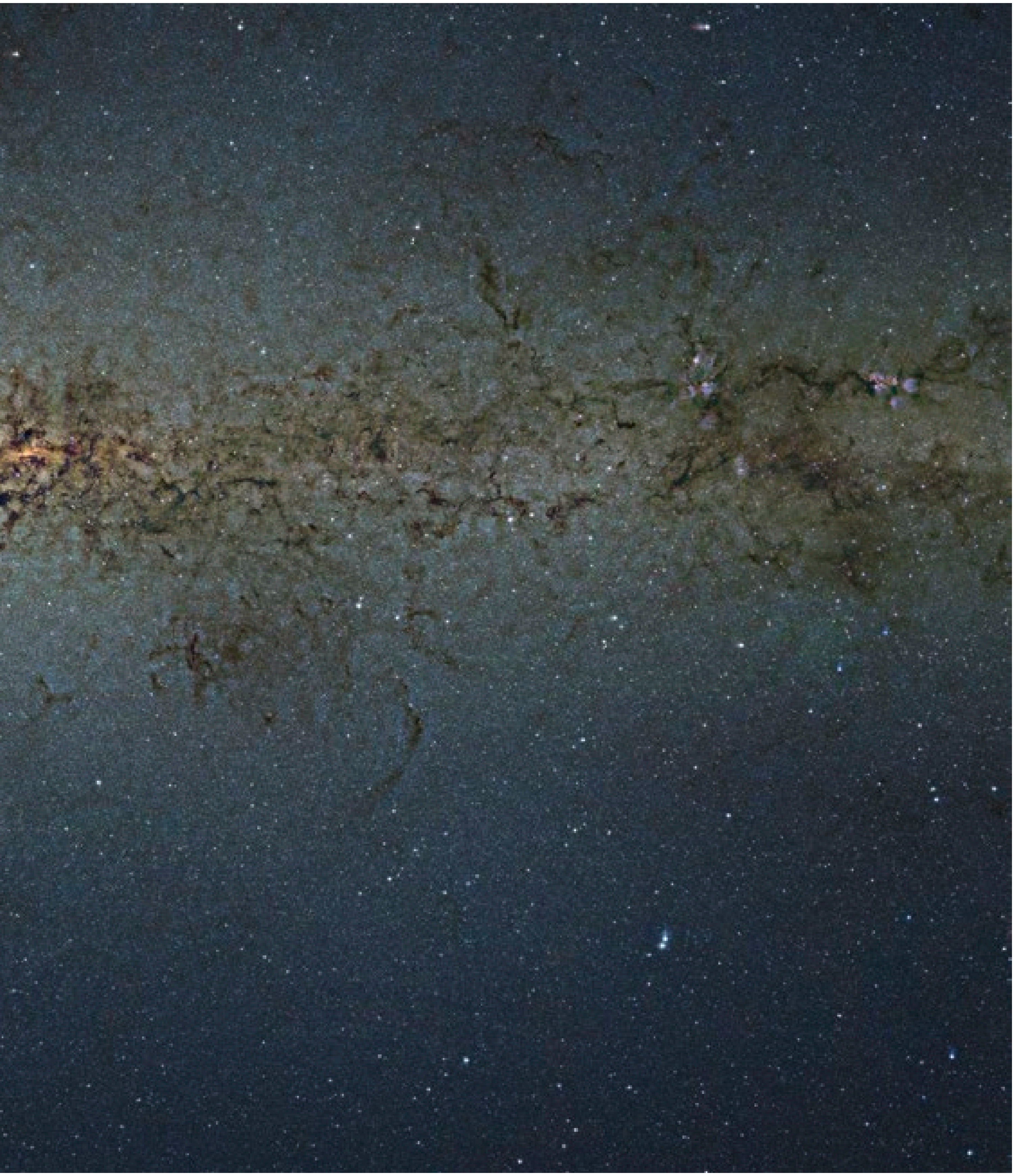


Figure 1. *This striking view of the central part of the Milky Way was obtained with the VISTA survey telescope at ESO's Paranal Observatory in Chile. This huge picture is 108 200 by 81 500 pixels and contains nearly nine billion pixels. It was created by combining thousands of individual images from VISTA. Credit: ESO/VVV Survey/D. Minniti*



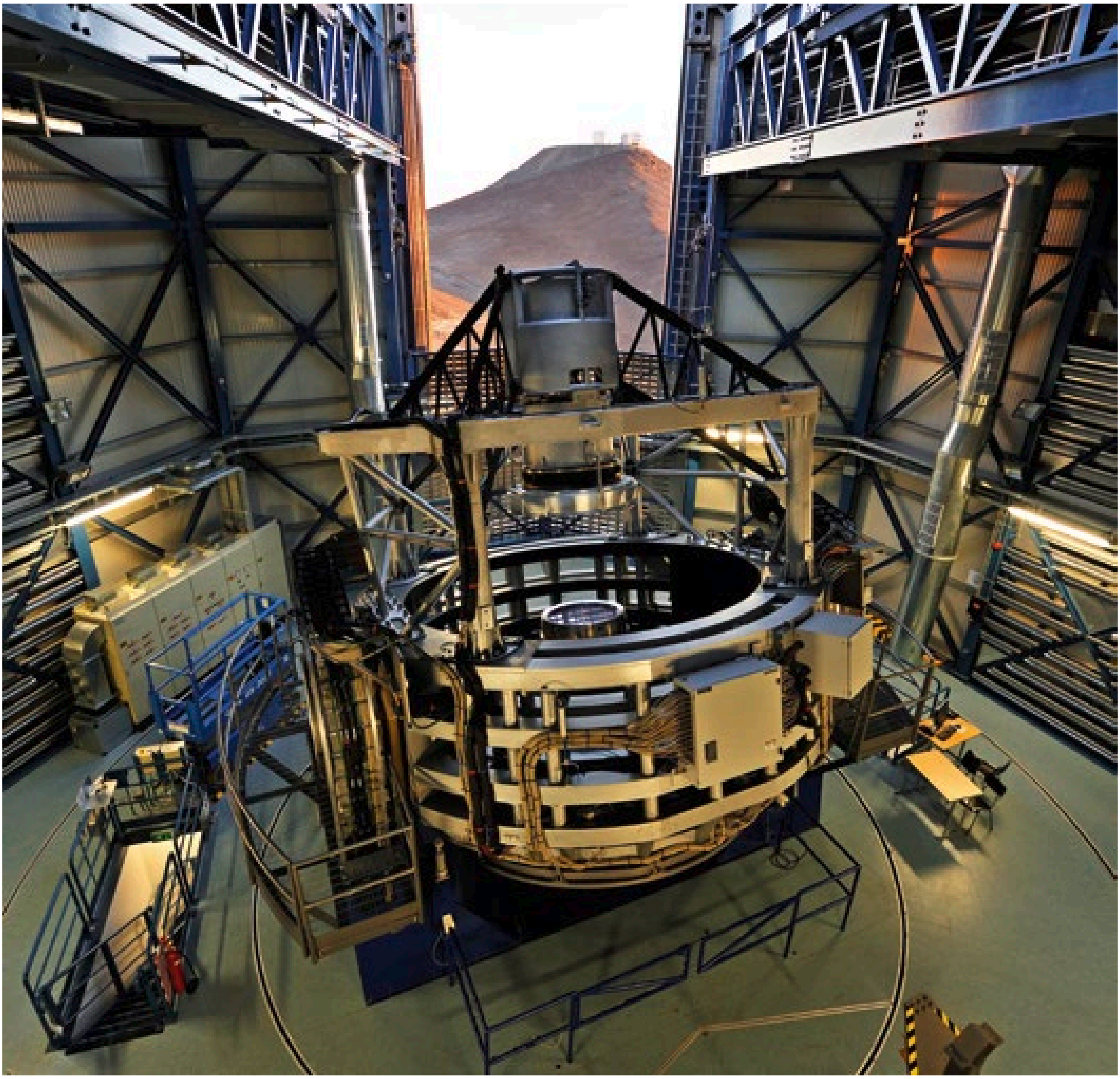


Figure 2. *VISTA is the largest telescope in the world dedicated to surveying the sky. Its primary mirror is 4.1 metres in diameter and it has a huge camera that is sensitive to near-infrared wavelengths. Credit: ESO*

corrected by Ignacio Toledo. However, a much smaller residual misalignment of only a few pixels between the three different exposures (*JHK* filters) had to be corrected manually in Photoshop later on.

Problem 3: Dynamic range compression

The normal dynamic range compression, which converts files from FITS format to tiff format, failed as the ESO/ESA/NASA FITS Liberator programme[4] was unable, at the time, to create tiff files above 2 gigabytes. Since the dynamic range in the dataset was not extremely large, the team reverted to using a less interactive method, using the software STIFF[5] which can create BigTIFF[6] files of almost unlimited size. Meanwhile, the FITS Liberator programme has now been updated to write BigTIFF files as well.

Problem 4: Reading BigTIFF

Not only did the available version of the FITS Liberator prove to be inadequate, but Photoshop 5, which was used by ESO at the time, also fell short as it could not read BigTIFF files properly. Thankfully, and as a matter of pure luck, Photoshop 6 was released only a few weeks before the start of the project and this version was able to read BigTIFF files. With the new

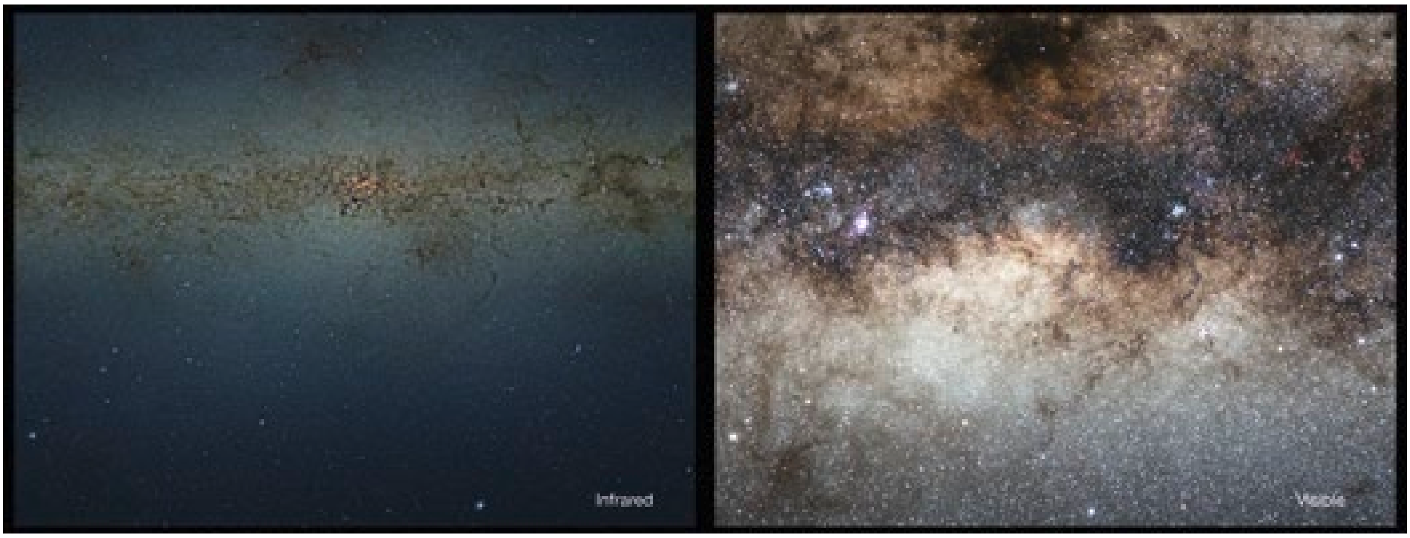


Figure 3. *This view compares the huge mosaic in infrared light from the VISTA survey telescope and a visible-light mosaic view of the same region taken with a small telescope. Credit: ESO/VVV Survey/D. Minniti/Serge Brunier. Acknowledgement: Ignacio Toledo, Martin Kornmesser*

software installed, the images could finally be opened in Photoshop; and due to their size had to be reduced to eight-bit colour depth immediately — normally astronomical images have 16-bit colour depth and hence have twice the size. This is something which is otherwise only done at the last stage in the production of an astronomical colour composite.

Problem 5: Swapping 600 gigabytes

As soon as the team started to work on the image in Photoshop the next challenge emerged. Working on three 9-gigapixel *JHK* layers with corresponding adjustment layers in Photoshop used unforeseen amounts of memory — up to 600 gigabytes of memory/swap space. To perform the swapping a state-of-the-art solid-state disk (SSD) was quickly procured to give a workable solution by providing a pseudo-memory delivering up to 1000 megabits per second in real throughput.

Problem 6: Graphics card

Even with the SSD onscreen interaction with the image for the clean-up in Photoshop, the image was impossible to handle. Besides the new SSD, a modern graphics card was added to the system to provide the necessary speed and onboard memory for the onscreen navigation in Photoshop.

Problem 7: Cosmetic cleaning

The next step was a cosmetic cleaning stage to remove instrumental artefacts and other blemishes of a non-cosmic origin. ESO normally uses an outsourcing company, but in this case the transport of the individual layers was impractical and the clean itself would have been too costly as it is paid for per megapixel. Therefore it was decided to perform a more modest, but sufficient, in-house cleaning. This led to some interesting feedback from the public later on, which will be discussed in the lessons learned.

Problem 8: Distribution file format

It was clear that the final image should be accessible to as many people as possible, so the team had to look for the most appropriate and viewable final file format. Unfortunately Photoshop 6 does not write BigTIFF, so an alternative format was needed. In the end only Photoshop's proprietary PSB format proved itself suitable for formats above 65 000 pixels. Since this is a much less used format than formats like TIFF, this was naturally a compromise. The final PSB file was 24.6 gigabytes in size; but smaller intermediate size formats of 40[7], 25[8] and 10[9] thousand pixels were also created and made available in TIFF format for download.

Problem 9: Zoomable version

Assuming that very few users would be able to actually handle the full 9-gigapixel image, ESO wanted to offer a zoomable image[10] as the main vehicle for delivering the experience to the public. However Zoomify[11], the usual tool for creating zoomable products at ESO, did not work with PSB files. The tools Krpano[12] and Panotour Pro from Kolor[13] were finally used and proved themselves to be very good alternatives.

Problem 10: Web serving

The final challenge that the team had to face was to actually serve the large individual files and the panorama to the public. The news of the image spread like wildfire. The image is the most successful ESO release to date with many more than one million visitors to the press release on the ESO page alone. At the time of publication this success nearly melted the servers at ESO Headquarters during the peak load — they were sluggish for days and at times the available slots for download were all filled, which undoubtedly left some visitors disappointed. Therefore the large 24.6 GB PSB file first had to be moved to another server and finally to peer-to-peer distribution in Bittorrent as it took up too many slots for too long. After a couple of weeks the normal distribution system was reinstated, but the image is still downloaded many times per day. Since the release the ESO server system has been upgraded to a more resilient system.

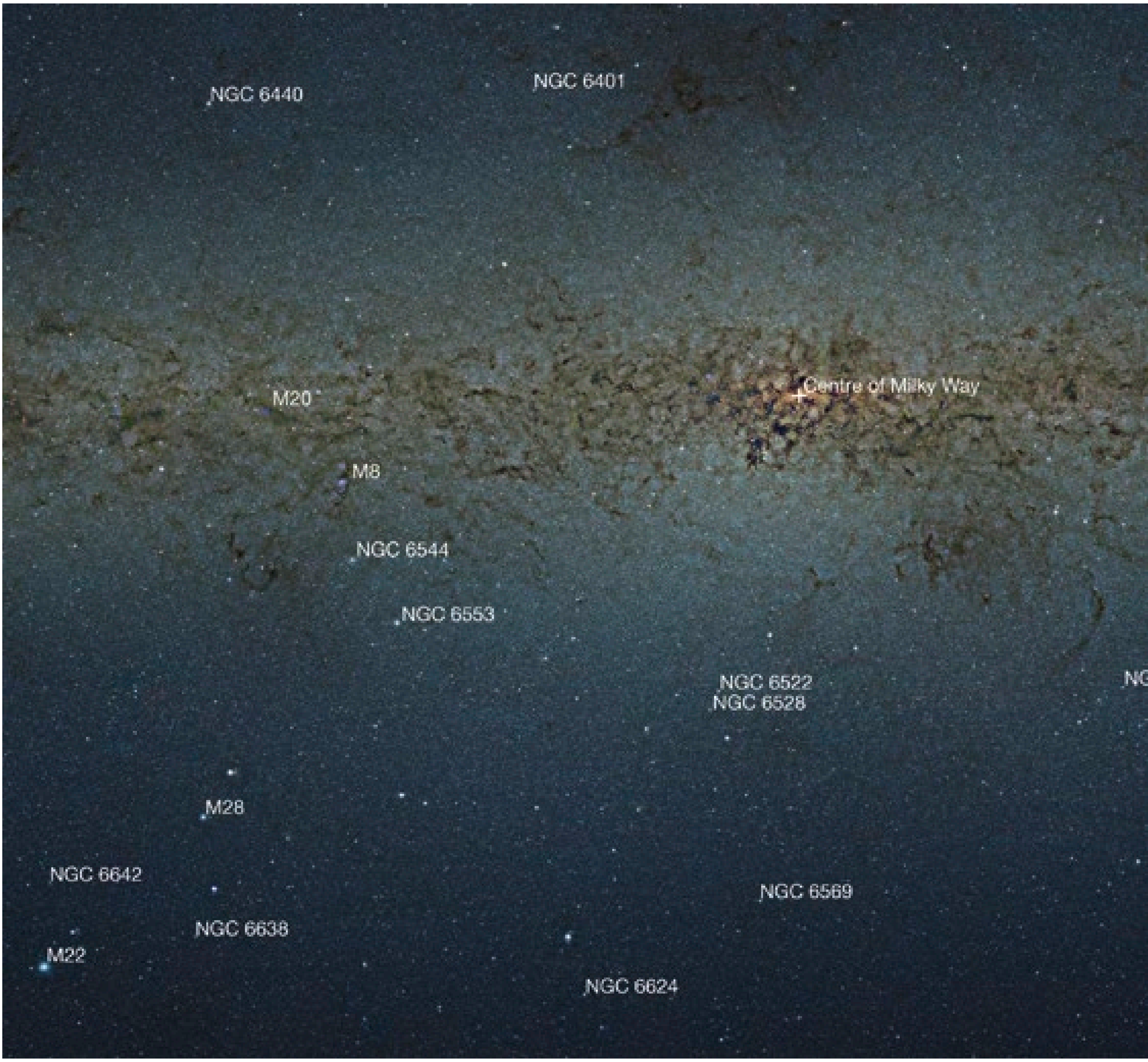


Figure 4. *Central part of the big VVV image with some prominent objects labelled. Credit: ESO/VVV Survey/D. Minniti. Acknowledgement: Ignacio Toledo, Martin Kornmesser*

Lessons learned

The completion of the project — despite the setbacks — and its great success made everyone involved proud of the result. The aftermath of the release was also a good time to summarise the lessons learned during the project; and there are almost as many as there were challenges.

The first and most obvious lesson learned was the fact that the data volumes of the new survey telescopes are a new paradigm for the creation of astronomical images. A significant investment in the design of new outreach pipelines and in modern hard- and software is needed to handle, edit and publish the images produced by these telescopes.

It is also of the upmost importance not to underestimate the needs of the target groups. In far more cases than one might expect the public prefers the largest files in the highest resolution. This also indicates that the users have the capabilities to handle and use these files.

The overloaded ESO servers showed that alternative ways of content delivery have to

be found and used. Peer-to-peer networks like Bittorrent turned out to be an excellent way to carry out distributed content delivery. Content distribution networks may also be an interesting solution to take the load off the central server.

As already mentioned above, the team learned that it is necessary to remove every single artefact from the image at the cosmetic cleaning stage. The in-house cleaning left some artefacts, such as black spots in the centres of saturated stars, in the image. As a consequence, ESO is still receiving feedback from hopeful people, who report spotting possible new transiting planets around a few of the bright stars.

The last and final lesson learned was probably the most important one: teamwork. Without an amazing team of experts in the areas of astronomy, technology and graphics it would have been impossible to overcome the individual challenges. In particular this project was made possible due to a collaboration between Olivier Hainaut (project lead, PhD astronomer), Martin Kornmesser (graphic designer), Richard Hook (astronomer, press officer), Mathias Andre (developer), Davide de Martin (engineer and amateur astronomer), Kaspar Nielsen (PhD physicist and developer), Luis Calçada (graphic designer), Georgia Bladon (science communicator) and Lars Lindberg Christensen (astronomer, head).

Producing colour composites from astronomical data is an important way of illustrating astronomical progress to the public. Sometimes, work such as this brings us to the forefront of existing technology and stretches the imaginations of the science communicators. The VVV image is such a case, but in turn it has also managed to make a significant impact on the public.

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Saito et al. 2012, Astronomy and Astrophysics, 544.

Notes

1. Download the full VVV image: http://www.eso.org/public/archives/images/original/eso1242a.psb
2. ESO science press release: http://www.eso.org/public/news/eso1242/
3. FITS is a specialised format used in the astronomical community.
4. ESO/ESA/NASA FITS Liberator: http://www.spacetelescope.org/projects/fits_liberator/
5. The software STIFF: http://www.astromatic.net/software/stiff
6. More about bigTIFF files: http://bigtiff.org/
7. Download the 40 000 pixel VVV image: http://www.eso.org/public/archives/images/publicationtiff40k/eso1242a.tif
8. Download the 25 000 pixel VVV image: http://www.eso.org/public/archives/images/publicationtiff25k/eso1242a.tif
9. Download the 10 000 pixel VVV image: http://www.eso.org/public/archives/images/publicationtiff10k/eso1242a.tif
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12. Zoom tool Krpano: http://krpano.com/
13. Zoom tool Panotour Pro from Kolor: http://www.kolor.com/

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The Universe at the Fingertips of the Visually Impaired: Building a tactile planetarium

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Planetarium, visually impaired, accessibility, astronomy outreach

Summary

In this work we describe a tactile planetarium made with the goal of teaching astronomy to visually impaired people, but which is accessible to all. The planetarium consists of two hemispheres representing both the northern and southern hemispheres, with around 72 constellations and more than 500 stars with different apparent magnitudes.

Introduction

Astronomy has been a major focus of attention for people since the most remote times, as can be seen from the many and varied records made by ancient civilisations (Verder, 1992; Marriott, 2004; Matsuura, 1996).

In Egypt the night sky was the vault of heaven. It was a place of the gods, which linked the sky with the body of the goddess Nut, the air god Chu (foot) and the earth god Geb (Figure 1; Marriott, 2004; Matsuura, 1996).

Historically observations of stellar objects had a practical use as the positions and movements of these objects were used to guide sustainable agriculture and production, but they were also associated with mysticism through astrology in the Sumerian–Babylonian (3000 BC), Mayan (300 BC) and other cultures (Kaufmann, 1998; Marriott, 2004; Matsuura, 1996).

Through observation and research many new questions about the Universe have arisen and many others have been answered. Today one can study the different branches of astronomy using a wide range of technologies (Matsuura, 1996; Arantes, 1995).

Figure 1. *Symbolic representation of the presence of gods and goddesses on Earth, in the sky and in the air made by the Egyptians. Credit: Photographed by the British Museum*

New technologies have advanced astronomy research, but although these technologies can be used for outreach, they can also present a barrier to those lay astronomers and members of the public who wish to learn about the Universe but do not have access to the appropriate technology.

Planetariums provide an interesting and versatile way for many people to view the arrangements of celestial bodies such as stars, clusters, constellations, galaxies and planets in the sky, and to observe planetary motion (Kaufmann, 1998; Marriott, 2004; Arantes, 1995; Puig, 1985).

In recent decades the design of planetarium technology has evolved significantly to become today's modern digital optical devices, with the capacity for almost unlimited presentation. However, this phenomenal equipment does not allow a visually impaired individual with no or only a small amount of sight to access astronomy.

The problem is clear when we look at astronomy's history, in which different views of the night sky and a large amount of imagination have played important roles in progressing our view of the Universe. For example the early people of Mesopotamia, now Iraq, imagined that the sky was composed of precious stones; the Mayans believed that the sky was formed in layers; and Aristotle and Empedocles thought that the Universe was a sphere (Friedlander, 1985; Filho et al., 2004; Verder, 1992;

Figure 2. Photograph of a spherical surface made of Styrofoam stacking layers. Credit: Aquino, H. A.

Figure 3. Spherical surface coated with plaster to remove imperfections. Credit: Aquino, H. A.

Figure 4. Gradual formation of a hemisphere by building up polymer plates 40 centimetres in diameter. Credit: Aquino, H. A.

Kaufmann, 1998; Marriott, 2004; Blum, 1990; Matsuura, 1996).

The aim of this project is to adapt the planetarium to include people with visual impairments in the study of astronomy. A planetarium that would enable disabled people to better understand some basic concepts of positional astronomy, whilst also providing a tool for fully sighted individuals to experience the Universe in a new way, was designed and built.

Methodology

In general, individuals with visual impairments have a more sensitive and accurate tactile sense as their ability to feel is very important, as when reading Braille for example. This sensitivity was used in the project by building hemispheres representing the southern and northern hemispheres of the sky that could be explored with the hands.

The hemispheres are constructed using polymer resin deposited on a plaster sphere one metre in diameter[1]. On the inside of each hemisphere constellations are defined by boundary lines and some of their respective stars. The stars were made from small plastic spheres whose size is associated with their apparent magnitudes, and varies from two to nine millimetres in diameter. A wire of 0.8 millimetres in diameter outlines the area covered by the constellations.

Figure 5. Celestial northern hemisphere with some of its main constellations represented by lines of metallic wire and plastic spheres. Credit: Carvalho, C. L.

The distribution of the stars in the hemispheres follows the system of equatorial coordinates used by astronomers and the Stellarium® software[2]. In addition, the constellations and the stars can be identified by their names written in Braille and in conventional print, making the installation accessible to both fully sighted and visually impaired individuals[3].

Construction

The use of styrofoam in building a spherical mould made the work much easier due to its malleability and lightness. Thin layers of Styrofoam with one centimetre thickness were cut with different diameters up to half a metre. The layers were stacked and bonded to form the object seen in Figure 2, which shows a sphere composed of several layers of Styrofoam with small irregularities on its surface.

The spherical surface of Figure 2 was covered in several layers of plaster to give it a very smooth surface, which was used as a template for the construction of the inner surface of the celestial hemisphere. Imperfections or irregularities presented in the object in Figure 2 were eliminated completely as can be seen in Figure 3.

Once the mould was complete, polymer resin platelets were deposited on its surface to form the celestial hemisphere. Figure 4 shows the gradual formation of a hemisphere by building up polymer plates 40 centimetres in diameter.

The handling of the polymer resin allows easy moulding of such small plates and each joint was made with the polymer itself. Removal of excess polymer and refining of the inner surface of each hemisphere can be done with acrylic paste and sandpaper. The inner surface of the hemisphere should be very smooth as the tactile sensitivity of visually impaired people means that any irregularity can be misinterpreted.

The constellations and their brightest stars — those with apparent magnitude between 6 and −1 — were distributed on the inner surface of each hemisphere using equatorial coordinates and with the help of the Stellarium® software. In Figure 5, the lines

Figure 6. Photographs of the hemispheres and the constellation of Scorpius. Credit: Carvalho, C. L.

made with metallic copper wire and plastic beads represent the lines marking the constellations and stars, respectively.

Figure 6 shows how the northern and southern hemispheres of the sky look when ready, including a detailed picture of the constellation of Scorpius, indicating the names of the stars written in Braille and in conventional print.

Initially the planetarium was tested by individuals with a visual impairment, but not selecting for specific problems or types of disability. Figure 7 shows two visually impaired people interacting with the celestial hemispheres. On the left, the young person interacting with the inner part of hemisphere was able to read the names of the stars and constellations as well as to make out the shape of each constellation very easily. On the right, the individual interacts with the outside of the sphere, having explored the inner part of hemisphere.

In both cases some initial guidance was given, and there had been discussion on several questions that the subjects had related to astronomy, but both were free to explore in their interactions with the hemispheres.

According to users, this type of model can greatly help to clarify the ideas they have about the night sky and frequent interaction with it makes it easier to locate the stars in relation to the constellations. The users also emphasised that being able to control the height of the hemispheres makes it more comfortable and makes it easier to read the Braille writing and explore the objects in high relief, as shown in Figure 8.

Figure 7. *Visually impaired individuals interact with the celestial hemispheres. Credit: Carvalho, C. L.*

Conclusion

We built two hemispheres representing the northern and southern hemispheres of the sky containing 72 constellations and over 500 stars. Both hemispheres were embossed and contained names in Braille and conventional alphabetic script, making the hemispheres accessible to both fully sighted and visually impaired people. Through experiments, we observed an easy interaction with and between visually impaired individuals using this teaching tool. New experiments are underway. So far, this type of instrument is completely new in Brazil.

Figure 8. *Indicating the ideal position of the hemisphere for users.*

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Notes

[1] Polymer resin http://www.moldflexmodelagem.com.br/r_poliuretano.html#produto01

[2] Stellarium software http://www.stellarium.org/

[3] Braille booklet http://www.lapeade.com.br/publicacoes/documentos/Apostila%20Braille.pdf

Biographies

Professor Hermes graduated in physics from the State University of Campinas (1979) and has a Masters in Physics from the University of São Paulo (1983) and a PhD in Materials Science and Engineering from the Federal University of São Carlos (1998). Currently, he is an assistant professor at the Universidade Estadual Paulista Júlio de Mesquita Filho. His experience in the area of physics, specialising in dielectric materials and dielectric properties, is used in the following subjects: activation energy, polymer materials, instrumentation for science education, teaching and learning of science and amateur astronomy.

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