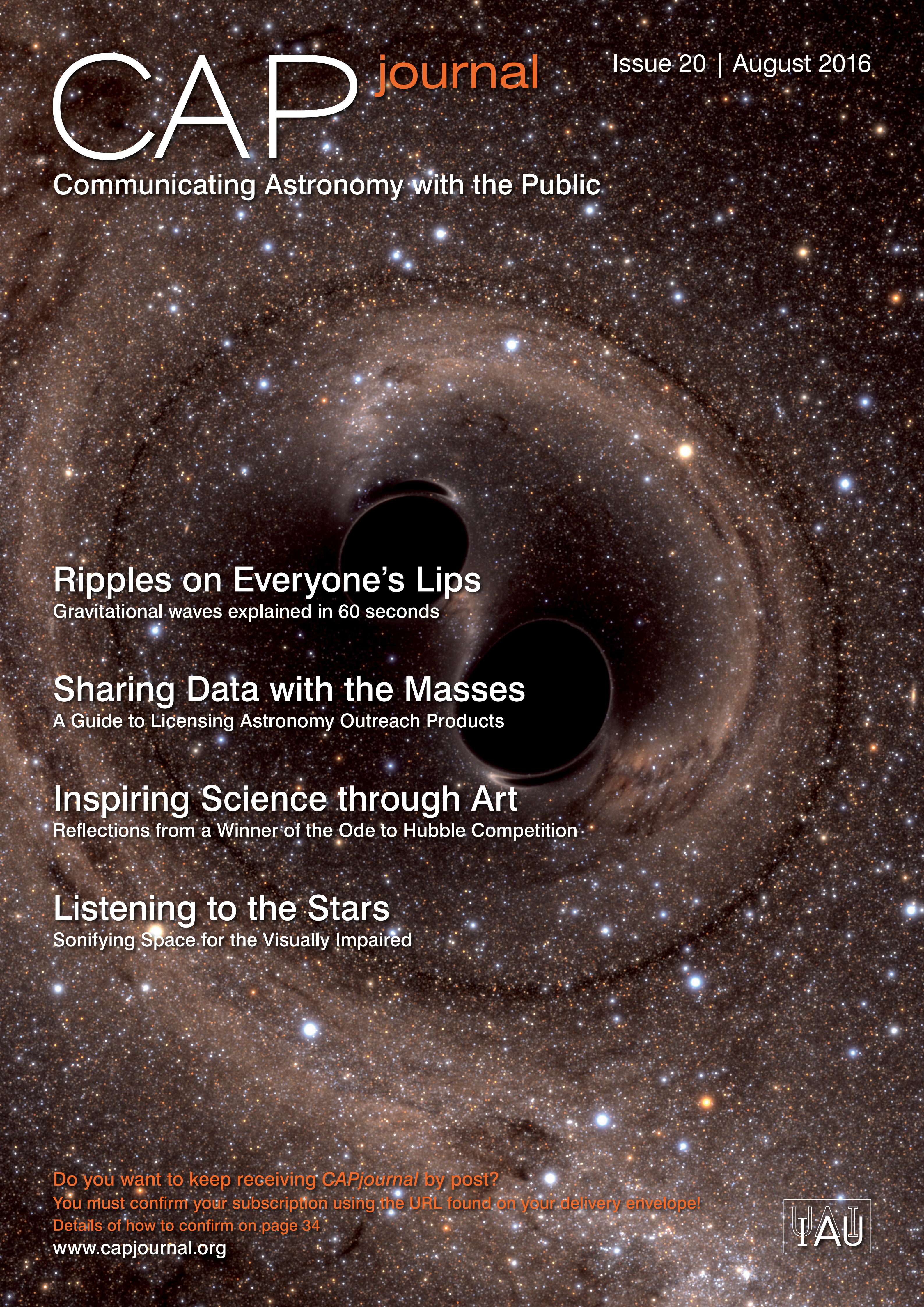


CAP journal

Issue 20 | August 2016

Communicating Astronomy with the Public

Ripples on Everyone’s Lips
Gravitational waves explained in 60 seconds

Sharing Data with the Masses
A Guide to Licensing Astronomy Outreach Products

Inspiring Science through Art
Reflections from a Winner of the Ode to Hubble Competition

Listening to the Stars
Sonifying Space for the Visually Impaired

Do you want to keep receiving *CAPjournal* by post?

You must confirm your subscription using the URL found on your delivery envelope!

Details of how to confirm on page 34

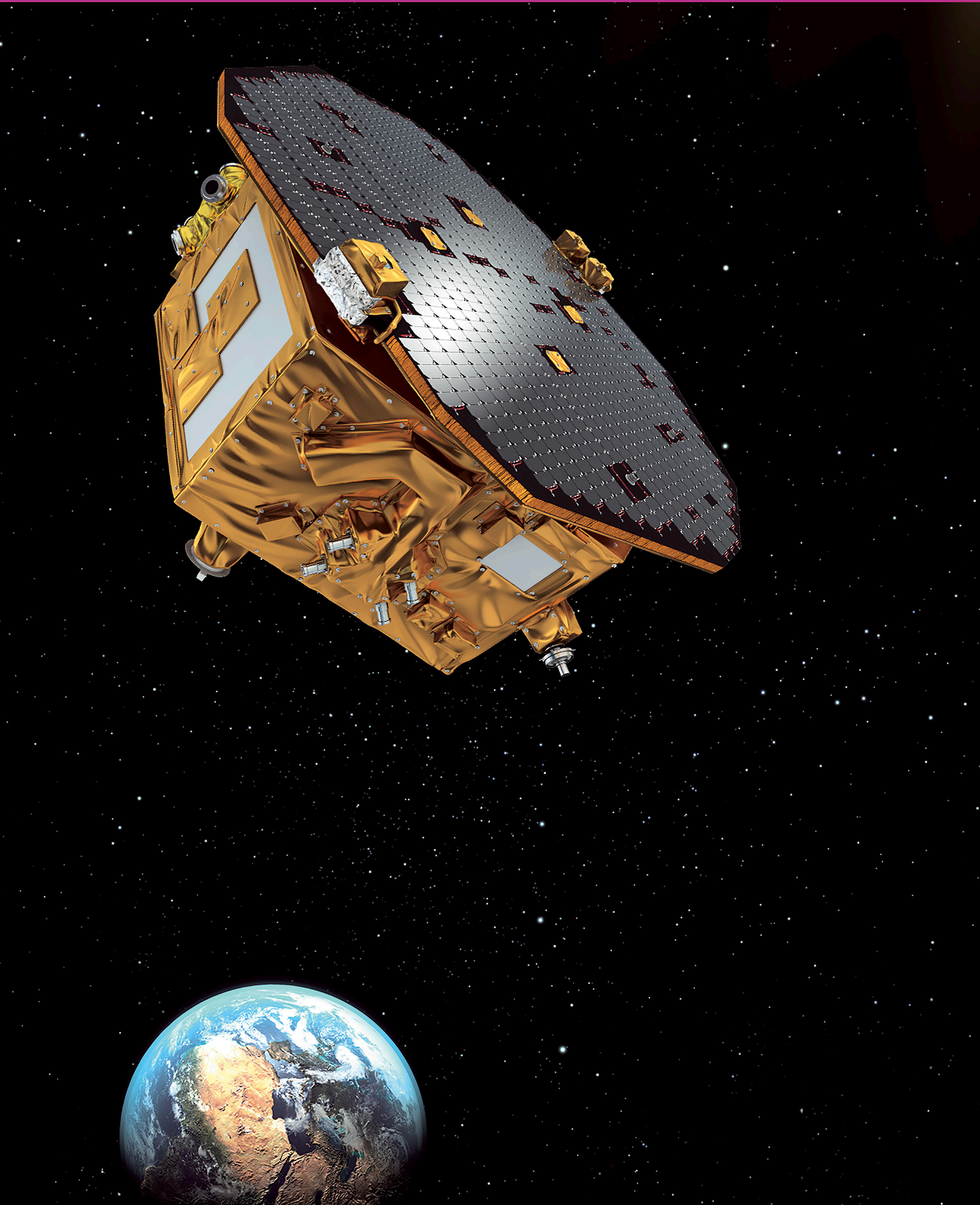
www.capjournal.org

IAU

This image shows an artist's impression of *LISA Pathfinder*, the European Space Agency's mission to test technology for future gravitational wave observatories in space.

After only a few months of science operation *LISA* has already exceeded expectations and the *LISA Pathfinder* team have demonstrated that the key technologies needed to build a space-based gravitational wave observatory work.

Credit: ESA (C.Carreau)



Editorial

Nine years after the first issue of *CAPjournal* was released in 2007 comes this, our twentieth issue of the journal. Those nine years have seen vast developments in astronomy and the way it is communicated the world over. New online infrastructure has made information about astronomy more accessible and observatories, research centres, and universities are able to bring their discoveries to the wider world more easily than ever before.

Changes in the tools available to us have led to remarkable innovation in our field as more people dedicate their careers to communicating astronomy better, more widely, and with those who may previously have been excluded from it.

In this issue practitioners share with us new sonification software designed to bring the Universe to the visually impaired, they reflect on the impact social-media-driven competitions can have, and they discuss projects that engage with the people behind the science in an attempt to counter traditional, and ever more outdated, views of science and the scientist.

But with all changes come challenges, and we also find here articles addressing some of the issues that have arisen with the age of internet sharing. On page five practitioners explain and explore licensing and the changes scientists, and science communicators, may have to make in the face of a more engaged public and a more accessible world.

Many thanks once again for your interest in *CAPjournal*, and I remind you that if you have an article to share with the community, would like to comment on articles in this or previous issues, or have a letter to the editor that you would like us to publish you are welcome to get in touch.

I look forward to hearing from you and happy reading,

Georgia Bladon
Editor-in-Chief of CAPjournal

Contents

Cover: This still from a computer simulation shows how the collision of two black holes might look. Last year, for the first time, astronomers detected ripples in spacetime caused by the collision and merging of two such black holes. These ripples, or gravitational waves, were detected by the Laser Interferometer Gravitational-Wave Observatory, LIGO. Credit: SXS, the Simulating eXtreme Spacetimes (SXS) project

Submit articles for one of the following journal sections:

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

Explained in 60 Seconds: The Ripples on Everyone's Lips

Georgia Bladon
Science communication consultant and writer
gr.bladon@gmail.com

Keywords
Gravitational waves, Einstein, LIGO, general relativity, gravity, black holes, spacetime

Gravity is the force that binds us. It pulls mass together to create the celestial bodies that give form to the Universe and warps the very fabric of spacetime.

But it is also at the heart of some of the Universe's most cataclysmic events.

When two black holes collide, compelled together by gravity, the moment of merging produces a gravitational jolt which disrupts spacetime and creates characteristic ripples radiating from that spot. These ripples, predicted by Einstein over 100 years ago, are gravitational waves and until now had never been detected. Black hole mergers, some of the biggest events in the Universe, had never been seen and their existence couldn't be proven.

Then came the Laser Interferometer Gravitational-Wave Observatory (LIGO) which has twice now successfully detected these waves — from two separate black hole mergers. It does so by measuring the subtle stretching and compressing of spacetime caused by the gravitational waves.

LIGO splits a laser beam, sending two beams down two identically sized, perpendicular, tubes. All being normal, the beams will bounce off mirrors at the end of the tubes and reconvene at the splitting point, having travelled an identical distance. But the presence of gravitational waves will distort space, if only by a minute amount, and slightly change the difference in length between the two tubes. The result is an almost inconceivably small difference in the alignment of the two light waves that return to the laser's splitting point. For the particular arrangement of the optics in LIGO this means that rather than the waves cancelling each other out a small amount of light is detected seeping through to a detector placed beyond the splitting point. This light disappears as the length between the tubes returns to normal, and reappears when the tubes are once again warped by the gravitational wave.

From Einstein first prediction that gravitational waves existed, to successfully executing this experiment, has taken a hundred years and has required the development of exquisitely precise technology, but it marks the beginning of an exciting new field of astronomy. This is not the last that we will hear from these ripples through time and space.

Figure 1. *The LIGO Laboratory detector site near Livingston, Louisiana, USA. There is another site near Hanford in eastern Washington, USA. Credit: Caltech/MIT/LIGO Lab*

A Guide to Licensing Astronomy Outreach Products

Rebecca Davies
Freelance science writer, former intern at ESO ePOD
davies.rebeccalouise@gmail.com

Lars Lindberg Christensen
Head of the ESO education and Public Outreach Department
lars@eso.org

Keywords
Creative Commons, licensing, copyright

The aim of this article is to provide a guide to the most useful of the Creative Commons licences under which public outreach products can be licensed. It is directed towards those who wish to spread awareness about astronomy, maximise exposure of their outreach assets and avoid inappropriate uses of those assets.

Introduction

Public outreach is a vital part of every science organisation. It not only serves to provide a stronger understanding of current research and its wider relevance to society, but helps to build support, which, at a practical level, may lead to a better justification for research and funding.

One of the simplest ways to increase awareness of an organisation is through outreach materials, or assets, whose exploitation can be efficiently increased by allowing people to use them as widely as possible. In practice, this means putting the assets into the public domain or applying liberal Creative Commons licences.

Trovatello and McCaughrean (2014) describe ESA's rationale for adopting Creative Commons and quote Creative Commons itself:

Our vision is nothing less than realising the full potential of the Internet — universal access to research and education, full participation in culture — to drive a new era of development, growth, and productivity.

One of the many reasons that the liberal sharing of outreach materials is more important than ever is the growing influence of the millennials (individuals born between 1980 and 2000). This particular target group, described in detail by Sandu (2014), is argued by some to have unique needs — to be creative, to be engaged, to collaborate and to be treated on equal terms — which can be fulfilled by free, unimpeded access to images and videos. Enforcing questions, registration, and online forms before allowing assets to be downloaded can put off users, thus

Figure 1. *An image from the Japanese Selenological and Engineering Explorer mission (SELENE). This image is not released under Creative Commons and cannot be used without sending a formal application to JAXA. This image had the potential to be as widely known as the Apollo pictures if more open access had been granted. Fair use is here invoked. Credit: JAXA/NHK*

Figure 2*. Interacting galaxies NGC 474 taken with the Canada–France–Hawaii Telescope. This image is not licensed under Creative Commons and can only be used by media, textbook authors etc. after submitting an application. Fair use is here invoked. Credit: Canada–France–Hawaii Telescope/Coelum*

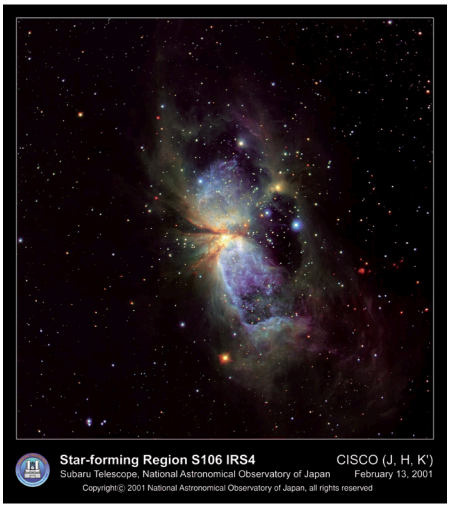


Figure 3. *The star-forming region S106 taken by the Subaru Telescope. This stunning image — possibly one of the very best of a star-forming region ever captured — has not received due attention due to complex licensing conditions (not Creative Commons). Fair use is here invoked. Credit: National Astronomical Observatory of Japan*

restricting how widely the assets are distributed. Without such hoops to jump through, users can redirect their efforts away from copyrights and permissions and towards creativity with the assets.

These measures, however, often require considerable control over the materials to be relinquished, allowing for adaptations, and possibly commercial exploitation, of the materials. Some science organisations have difficulty accepting these compromises. In this article, we argue that this compromise ultimately leads to a net positive gain for the organisation.

Note that this is a simplified hands-on guide and it cannot replace the full legal texts found on the Creative Commons website, which we highly recommend that you consult before making any legal decisions[1].

Box 1. Terminology quick guide

Adaptation	A new, original asset created by altering and/or building upon pre-existing assets. It is typically considered when material has been modified enough — manifesting a sufficient level of new creativity — that it qualifies to be copyrighted as its own original piece of work.
Asset	In this context, a creative piece of outreach work, typically an image, video, text or audio regarded as having value, owned by a content creator.
Attribution	A credit below the asset showing the content creator, the location/source of the material and the material's licence.
Commercial use	Use of an asset in a way that is primarily intended for commercial or monetary gain.
Content creator	The person who created the asset.
Copyright	A legal right that grants the content creator exclusive rights for its use and distribution. The copyright holder can grant the rights for its use and distribution to others through a license. All creative works are copyrighted, by international agreement, unless they fall into the public domain or their copyright is explicitly renounced.
Creative Commons	A specific type of copyright licence designed to maximise the availability of creative works by allowing others to legally build upon and share the materials. These licenses allow content creators to communicate those rights they reserve and those they waive for the benefit of others who wish to copy, adapt and distribute the material.
Licence	A legal authorisation in which the licensor allows a licensee to use the licensed material.
Licensee	In this context, a person who can use content from another because the content creator has allowed the licensee to do so.
Licensor	A person who grants a license to another.
Public domain	A content creator can waive the right to the copyright by explicitly placing the content in the public domain, where the material is not restricted by copyright and does not require a licence nor fee to use.
Remix	See adaptation.

Licensing

The field of copyright is governed by rigorously defined, and often complex, legal terms. Although copyright licences often appear straightforward on the surface, it is not always clear in their terms of use which materials can be used, where, and for what purpose.

It is, therefore, necessary to establish some of this terminology — and that used in this article — in the box on this page (Box 1). This is an introduction to terminology and it would be worthwhile to supplement this with the short primer on copyright by Lewis (2009) and the sources quoted therein.

Creative Commons

Creative Commons (CC) is a non-profit organisation founded in 2001 to expand the range of licenses under which creative works can be made freely available for others to legally copy, share and build upon.

The organisation has created a fully legal mark and language that stands up in court and provides the ability to share some of the rights of ownership. Such sharing language takes copyright into the computer age. Creative Commons licenses were created with the help of computer scientists, cyberlaw experts, artists, and entrepreneurs and stands up under not only American jurisprudence, but international copyright courts. Lewis (2009)

The licences provide a standardised way for content creators to grant others permission to use their assets without cost, encouraging the sharing and distribution of materials — whether original or adapted — as widely as possible.

The licenses are not an alternative to copyright. They work alongside copyright and enable content creators to modify their copyright terms to best suit their needs, and to change the default of "all rights reserved" to "some rights reserved".

A group of astronomy communicators recently visiting Japan were so impressed with the quality of the assets from Institute of Space and Astronautical Science (ISAS)/ Japan Aerospace Exploration Agency (JAXA), National Space Development Agency of Japan (NASDA) and the National Astronomical Observatory of Japan (NAOJ), (see Figures 1 and 3), that they wrote an open letter called The Mitaka Declaration (Box 2), drawing attention to the restrictive conditions under which the assets are distributed. This letter should not be seen as a criticism of the Japanese context as it could equally be addressed to many other organisations around the world who do not use CC (see for instance Figure 2), but it serves as an example of the pros and cons of CC licensing.

The licences

For work in astronomy outreach, there are six main CC licenses typically in use. Each ensures that content creators retain credit for, and copyright over, their work, but allows and restricts different uses of the original material.

Under all six licenses, material must be appropriately attributed. However, with the proliferation of electronic media including apps, games, and YouTube videos, it is not always clear how to do so correctly. As a rule of thumb, the attribution must be visible to the end user, it should neither be hidden nor detached from the material and must include a link to the licence and indicate if changes were made. Figure 4 serves to illustrate the most common decision tree for choosing a CC licence for outreach assets.

The six licenses are explained below in order, from the most to least liberal use of the original material.

1. Attribution (CC BY 4.0)

Under the Attribution licence, material can be displayed, distributed, published, and adapted freely, both commercially and non-commercially, as long as the content creator is explicitly credited for the original work. This is the most accommodating and liberal licence available, and is recommended for maximum exposure of the asset[2].

Used by

This licence has been adopted by astronomy organisations, including the European Southern Observatory (ESO)[3], the International Year of Astronomy 2009, and Universe Awareness who, as taxpayer-funded organisations, have decided to relinquish the authority to decide how taxpayers utilise their materials.

Comments

Assets under this licence can be used for commercial purposes, including advertisements, but cannot be used to imply endorsement by an organisation or employee for commercial products or services.

2. Attribution–ShareAlike licence (CC BY-SA 4.0)

The ShareAlike licence enables others to build on and adapt the original material,

Box 2. The Mitaka Declaration

The space science and astronomy outreach community represented by undersigned at the International Symposium on the NAOJ Museum, discussed how to improve the recognition of the outstanding Japanese space science and astronomy.

This gathering at NAOJ is concerned with how best to increase public awareness and appreciation of important science results in Japan and internationally. This is an important topic especially given the nature of national expenditure for science, which is essentially a matter of public ownership and providence, and cultural heritage.

Following the UNESCO's Open Educational Resources Paris Declaration which encourages the open licensing of educational materials produced with public funds: "Governments/competent authorities can create substantial benefits for their citizens by ensuring that educational materials developed with public funds be made available under open licenses (with any restrictions they deem necessary) in order to maximize the impact of the investment."

Recognising the success of providing universal open access to education and public outreach resources by organisations and projects like NASA, ESO, the International Year of Astronomy 2009, Universe Awareness and others.

Recognising the excellence and importance of Japan in producing world class scientific results in space and astronomy from organisations such as ISAS/JAXA, NASDA and NAOJ.

Recognising the need of the scientists to preserve a proprietary period of the data for e.g. 12 months to conduct their research.

Recognising that Japan have produced some of the most important scientific images and videos of humankind resulting from these data.

Recognising that currently these Japanese public resources cannot be used as widely as they deserve, for instance on Wikipedia and also not by journalists, textbook authors and others without a lengthy and time-consuming process.

Recognising the great potential for international public recognition of the frontline Japanese space science and astronomy projects and results.

Recognising that broadening the access to educational and public outreach products, such as images and videos, from the science being conducted and facilitated by organisations like ISAS/JAXA and NAOJ, will have a positive feedback on the recognition of the organisation and of Japan.

Urging that universal access to the results of science in the form of images and videos from ISAS/JAXA, NASDA and NAOJ should be given, after the scientific proprietary period, for the purpose of open public sharing under a simple Creative Commons licensing.

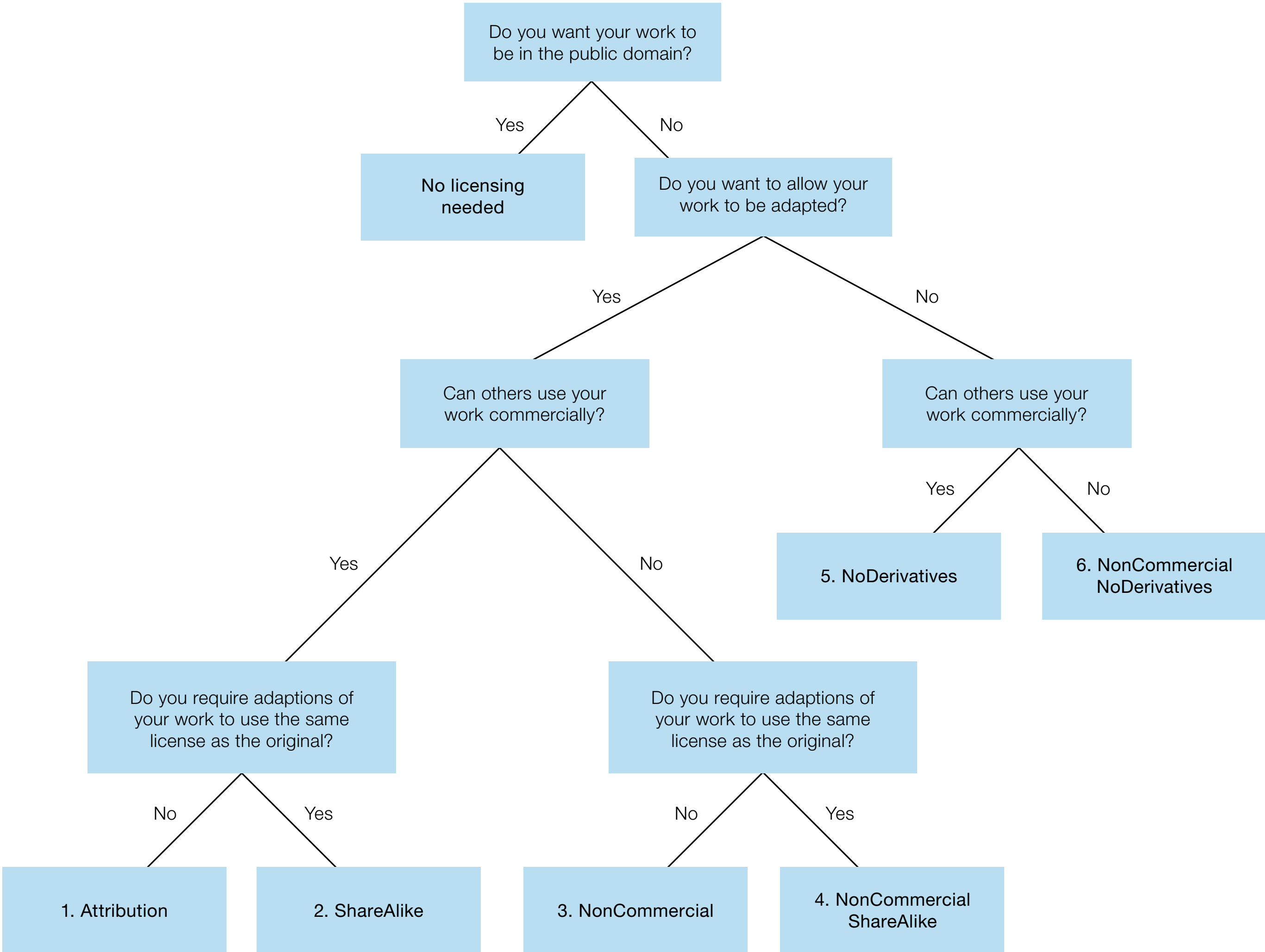


Figure 4*. Decision tree for choosing a Creative Commons license for outreach assets.*

even for commercial purposes, but requires adaptations of the original material to also be released under the ShareAlike licence[4].

Used by
Wikipedia's textual content and most of the accompanying visual media (such as photos and illustrations) is licensed under ShareAlike or a more liberal licence. This licence, or a more liberal one, is therefore required for any materials that are to be uploaded to a website.

This licence also forms the basis of the slightly modified CC licence used by the European Space Agency (ESA). As an intergovernmental organisation, ESA uses an Attribution–ShareAlike 3.0 Intergovernmental Organisation licence[5] that allows for special mediation and arbitration processes if the licence is violated (Trovatello & McCaughrean, 2014).

Comments
Some commercial entities, such as TV broadcasters, cannot release their materials under a ShareAlike licence and cannot, therefore, include footage licensed with the ShareAlike licence. This limitation should be taken into consideration if you would like your material to be freely available to such commercial entities.

3. Attribution–NonCommercial (CC BY-NC 4.0)

Under the NonCommercial licence, others can distribute the original material and adaptations of the material, but for non-commercial purposes only[6].

Used by
The NonCommercial licence is used by those who would like to retain the commercial rights to their work, but allow for all other uses and adaptations. This maximises the distribution of the materials and the content creator's exposure, which, in turn, can increase monetary opportunities for the original artist — something that cannot occur as easily for material locked up under a more restrictive copyright.

Comments
What constitutes commercial use is broadly defined, but in practise the term can be applied to any income-generating activities, both direct and indirect. In our interpretation, this includes charging for tickets in a planetarium, regardless of whether this is mainly intended for educational, non-profit use, and will never create a net profit.

4. Attribution–NonCommercial–ShareAlike (BY-NC-SA 4.0)

NonCommercial–ShareAlike enables others to change and build upon the licensed work non-commercially, as long as the content creator is credited and the new work is licensed under the same terms as the original[7].

Used by
This licence is used by those who are happy for others to adapt and utilise their original material, as long as any adaptations are licensed identically to the original material and the content creator retains the right to be the only person to profit from the original material.

5. Attribution–NoDerivatives (CC BY-ND 4.0)

The NoDerivatives licence only allows the distribution of unadapted copies of the original material. This means that the material must be passed along unchanged and in whole with credit to the content creator[8].

Used by
This licence is adopted by those organisations who are interested in distributing a complete work, for instance a documentary or a planetarium fulldome production, but who want to prevent others from editing and using snippets of the material. This could be for artistic reasons or because parts of the material come from third parties and are only licensed for use in the original product.

Comments
The product cannot be sub-licensed, meaning that a distributor can distribute the show with credit to the content creator and a clear indication of the licence, but not sub-license it to others.

6. Attribution NonCommercial–NoDerivatives (BY-NC-ND 4.0)

The most restrictive of the CC licenses, NonCommercial–NoDerivatives only enables others to download and share the licensed work. It does not allow for others to adapt the work or to use it commercially[9].

Used by
NonCommercial–NoDerivatives should be used by those content creators who want to prevent others from changing their original material, creating adaptations of it, and using the original work for their commercial gain. This ensures that no matter how many times the original work is copied or shared, the content of the copies will be the same as the original and used only for non-commercial purposes.

Acknowledgements

The authors wish to thank the following individuals for valuable inputs: Jason Fletcher and Dani Leblanc (Charles Hayden Planetarium, Boston Museum of Science), Douglas Pierce-Price (ESO), Marta Entradas (UCL/LSE/ISCTE-IUL) and Oana Sandu (ESO).

Notes

1 More information on Creative Commons: http://creativecommons.org/

2 More information on the Attribution licence: http://creativecommons.org/licenses/by/4.0/

3 Further information regarding ESO's image use policy can be found on the ESO website: http://www.eso.org/public/copyright/

4 More information on the Attribution–ShareAlike licence: http://creativecommons.org/licenses/by-sa/4.0/

5 More information on the Attribution–ShareAlike 3.0 Intergovernmental Organisation licence: http://creativecommons.org/licenses/by-sa/3.0/igo/

6 More information on the Attribution–NonCommercial licence: http://creativecommons.org/licenses/by-nc/4.0/

7 More on the Attribution–NonCommercial–ShareAlike licence: http://creativecommons.org/licenses/by-nc-sa/4.0/

8 More on the Attribution–NoDerivatives licence: http://creativecommons.org/licenses/by-nd/4.0/

9 More on the Attribution–NonCommercial–NoDerivatives licence: http://creativecommons.org/licenses/by-nc-nd/4.0/

References

Lewis, R. 2009, *To Share or Not to Share, That is the Question*: http://business.tutsplus.com/articles/to-share-or-not-to-share-that-is-the-question--fsw-3556 (retrieved 28.12.2015)

Sandu, O. 2014, CAPjournal, 14, 12

Trovatello, M. & McCaughrean, M. 2014, *Rosetta NAVCAM images now available under a Creative Commons licence*: http://blogs.esa.int/rosetta/2014/11/04/rosetta-navcam-images-now-available-under-a-creative-commons-licence/ (retrieved 26.12.2015)

Biographies

Rebecca Davies is a freelance science writer from the UK. She has a first-class honours BA in Journalism, Media and Cultural Studies from Cardiff University and a passion for astronomy and spaceflight. Previously a community radio presenter and a media ambassador for the National Youth Agency (NYA), Rebecca has recently worked as a science communication intern at ESO's education and Public Outreach Department (ePOD).

Lars Lindberg Christensen is a science communication specialist, who is Head of the ESO education and Public Outreach Department (ePOD) in Munich, Germany. He leads public outreach and education for the La Silla Paranal Observatory, for ESO's part of ALMA and APEX, for the European Extremely Large Telescope, for ESA's part of the Hubble Space Telescope and for the IAU Press Office.

Communicating Astronomy to Children in Unconventional Locations

Gabriella Bernardi
Freelance journalist, science communicator and writer
gabriella.bernardi@gmail.com

Keywords
Education, astronomy, science communication, outreach

Communicating astronomy to children can take place in many locations outside of conventional learning spaces such as classrooms, planetariums or museums. For example, book or toy shops can provide great backdrops for communicating astronomy. It is in these kinds of places, full of distractions, that finding entertaining ways to communicate concepts becomes all the more important. Used in the right way what might initially seem like downsides to these spaces can quickly be turned into advantages. This article explores the role of these locations in communicating astronomy and how they can be used as effective, and fun, forums for engagement.

Is it possible to talk about astronomy effectively in a book or toy shop?

This is the question I asked myself when I was first asked to design short astronomy courses for children in some quite unusual places. These locations included book and toy shops that specialised in science education and entertainment and wished to extend what they could offer to customers.

The courses had to be organised as a series of four or five hour-long sessions which, according to the requirements of the promoters, had to be packed with reliable and instructive information, but characterised by a playful and entertaining atmosphere. In order to encourage an informal and friendly atmosphere, parents were allowed to attend as well, but just as a passive audience. Moreover, the groups were likely to be mixed in terms of age, which could range between five and nine years old.

As a science communicator, this was a challenge that immediately captured my interest, but the main problem in my mind was how to keep the children focused for that length of time in a setting with books, games and toys displayed around them.

Mathematics and equations were forbidden, but the host shops did provide some equipment like a small children's corner with a table, a large monitor or a small planetarium.

I took up the challenge and now, after two years of experience, I can draw some conclusions. What I have discovered is that more or less everything is possible with due preparation, some tricks, lots of patience, improvisation in the face of the unexpected, and a bit of practical psychology. Plus, not to be forgotten, some throat lozenges!

***Figure 1**. A small unconventional classroom inside a children's bookstore. Here I taught astronomy through fun using a computer, videos, books, drawings, a small planetarium and some small games.*

Astronomy on my mind

Although we can believe that there is just one science of astronomy, the truth is that in each child's mind there is a unique and very personal view of astronomy. For this reason, the very first step is to understand your students and why they are interested in the subject. More specifically, it is fundamental to understand what they would like to be told or what they would like to do. Another important issue is to understand their attitude, and in this sense age plays an important role. With kindergarten children, you can expect very spontaneous reactions, while older children who are already going to school are usually warier.

Astronomy deals with some very intriguing and visually interesting objects and with a computer, a projector and the right software you can bring these to life with fantastic shows that are very effective in holding the children's attention and breaking the ice. One good idea is to start each lesson with a short clip, prepared with a specialised programme like Celestia[1]. For example, you can show a hypothetical journey in the Solar System, or show-

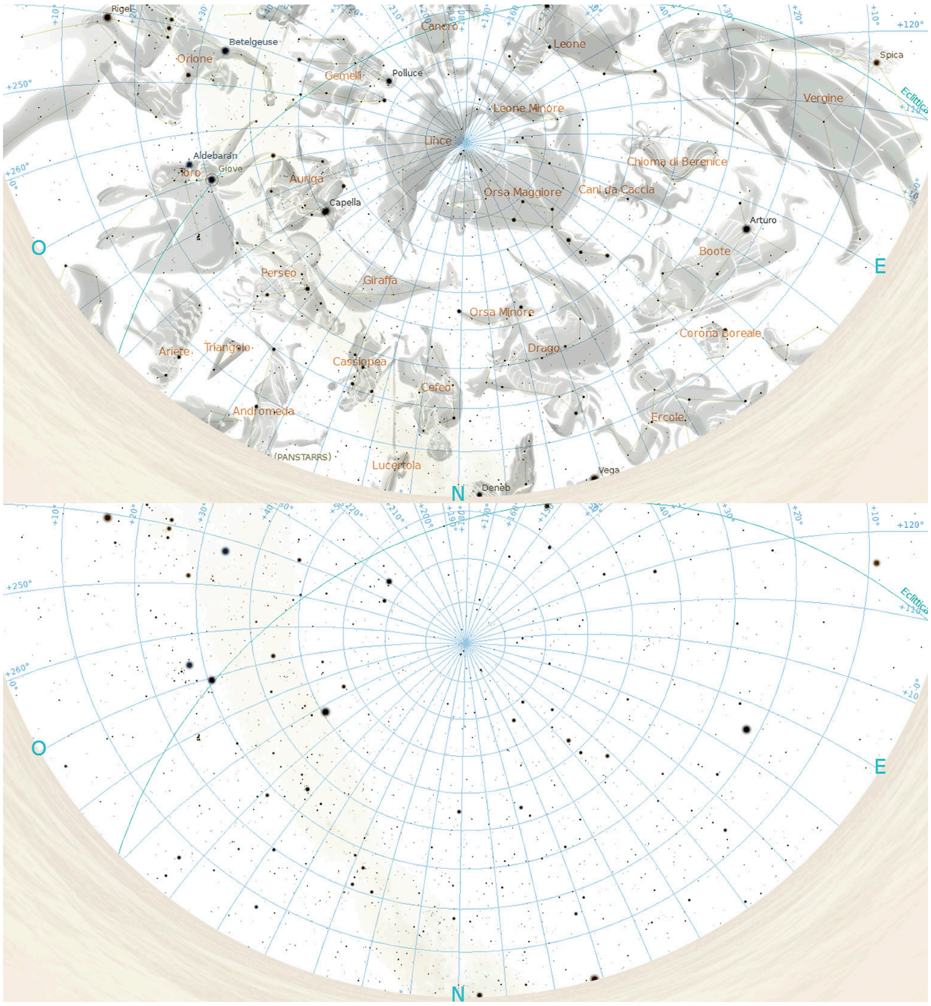


Figure 2. *Stellarium is a good piece of software for showing the night sky. You can choose the date and location so it can help with teaching about the movement of the constellations over the year. The bottom image shows how it can be used to let children draw their own constellations on the sky.*

case the constellations. This should typically last for less than fifteen minutes, and you can easily comment verbally over the images, adapting your remarks to the specific needs of the audience.

There are many advantages to this approach. One is that it helps you to identify the different personalities in your audience. There is the dreamer, eager to discover the worlds around us; the rationalist, who thinks about the lack of oxygen in space and on other planets; and the worrier, seriously concerned when they learn that the Sun will eventually die, and wanting to know how many billions of years we still have, to name but a few. Another advantage is that the participants are naturally involved in the course, without the need for questioning or forcing. They are encouraged to participate with comments and questions, and any former knowledge acquired from books, television or planetarium shows is reinforced. After this video, I generally have to leave a good chunk of time during which to answer the questions that inevitably arise.

Usually at this point, if the attendees are very young (under around six years old), drawings of the Solar System planets are distributed and coloured with my assistance, using the bookshop's products on this subject as a guide. It is important to let them be as independent as possible during this task. The very fact of having to choose the right colours naturally stimulates their observing skills, and their curiosity: why does Neptune have that blue colour while Mars is reddish? Since they are leading the game, the answers about chemical composition are followed with great curiosity and learned much faster and more easily than when the information is offered without being asked for.

Sizes and scale

Generally, during the Solar System movie, the problems of the size of the objects and the distances in space emerge organically. For the size of the planets it is very helpful to use drawings with data sheets for the various planets, but the best way is always to compare the sizes of different objects with the help of images specifically created to help the children understand the objects' relative proportions, for example, by comparing the Sun and the Earth.

To make it clear that the Sun is just one of many stars I often use another movie that shows the size of different stars by gradually introducing bigger and bigger stars until we meet the biggest one known up to now. This naturally leads the discussion to the stars' locations, so it is easy to introduce celestial maps, the constellations, the seasons and finally the children can even learn how to use sky charts.

When available, a small planetarium is a great plus. It can be used to show the daily and seasonal motions of the stars and the planets, making it possible to immediately appreciate the difference between these two types of celestial objects. It is also possible to identify the major constellations and to locate the North Star using the Big Dipper, and therefore to introduce the concept of orientation by means of the stars.

At the end of the session it is a very good exercise to show an image of the sky as it will be that night and a map with the main celestial objects so that they can try to observe it that evening. Crossing the border between a simulated observation inside and that of the real sky can be very important. If you are lucky and are conducting a course at the same time as a major celestial event like an approaching comet visible to the naked eye, then drawing the group's attention to this and how to observe it is a must.

See beyond

Artificial satellites are charming, and it is not unusual to read in the news about

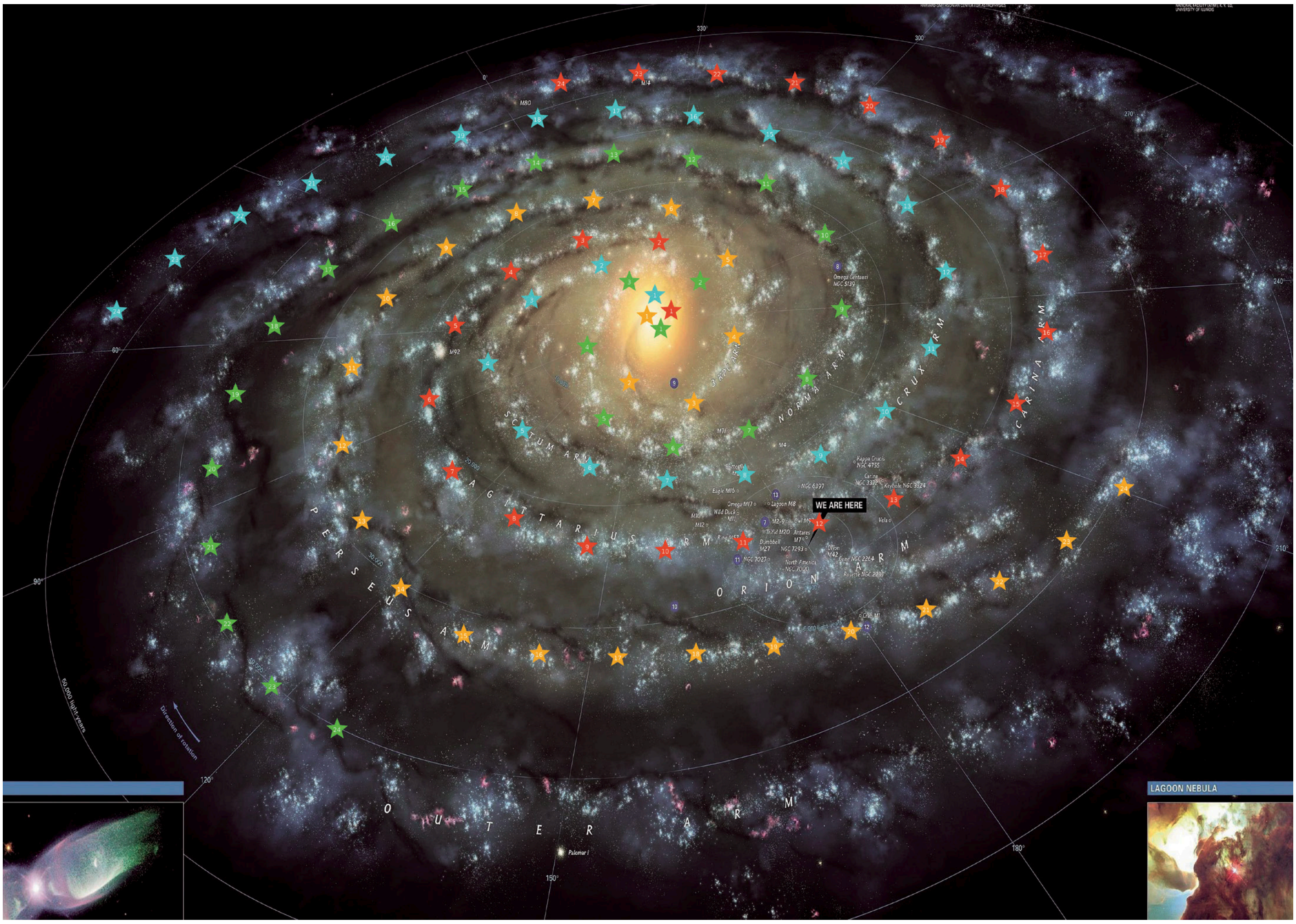


Figure 3. *At the end of a short course, generally after four meetings, I present a game which helps to sum up all the topics covered during the course. At each turn a child throws the dice and draws a card requiring them to say or to do something related to the lessons.*

space mission launches. These reports can give the opportunity to talk about several topics, from distant comets and downgraded planets to missions involving the mapping of the Milky Way. But they can also help to introduce concepts like gravity and the other forces acting in outer space or inside stars. Once again, the most important thing is to ease the explanations with little games and practical activities. You don't need great sophistication or complexity. Quite the contrary, simple is better. Obviously you cannot do accurate experiments, but it is interesting to notice how simple and common objects are useful for explanations of concepts that might seem difficult to demonstrate without complex laboratory tools.

Sometimes you might find yourself with a group of very knowledgeable children, with a rich background of information acquired from many sources, like books, visits to museums or even specific lessons at school. While in this case it might seem harder to meet their expectations, I was surprised to realise that in many cases it makes the task easier. Having been exposed to so much information often means that this information is stacked randomly in their memory, with no logic, causality or understanding of the basic principles. Moreover, the kinds of courses that led to this information being gathered at such a young age typically favour a passive approach, which implies that the children, with little possibility, or lacking the courage to ask for clarification, are left with a huge number of unanswered questions just waiting for a chance to be unleashed. The right approach in these cases, is just ask if there are any specific questions, be open and thorough, and the rest will flow naturally.

One problem I have faced is how to talk about topics that might be quite advanced without resorting to mathematics, providing understandable yet accurate explanations and at the same time keeping alive the attention of your group. It would be impossible to give a complete list of all the topics and the solutions that I have found in these two years, so I will try to give just one example which can show the general approach I always try to follow.

I was explaining the effect of gravitational lenses using some drawings and the spectacular images from the Hubble Space Telescope. At a certain point I was explaining that some of the background objects were quasars, so I was immediately asked what a quasar was. This provided the perfect opportunity to introduce other concepts that are far from the everyday experience.

In particular, the idea that quasars are "old" and that closer, and therefore younger, objects of the same kind such as nearby galaxies are very different from them, made it possible to understand that even in space things change with time and "grow old". From this starting point, always driven by questions, we went on to talk about the evolution of stars. In practice, we managed to modify the way in which the information flows from teacher to students. Instead of telling them about unrequested concepts that follow my line of reasoning, I explained the subjects that flowed naturally from their own unique curiosity and reasoning, an approach that cannot be used in books.

In this way the teaching experience that resulted was both easier and more effective, because the children were not forced to concentrate on subjects in which they were not interested, but rather my role was simply to facilitate their own paths of enquiry and ensure they had the information needed to answer their own burning questions.

Finally, the magic word is... fun

In an entertaining yet educational laboratory of astronomy fun is a must. When attention wanes or interest drops, perhaps because the children are coming from a long day at school, the magic question that teases the minds and raises smiles is: "Would you like to play?"

These words are always a hit. The topic of the game will obviously be an astronomical one, and if you can create games with a clear objective they will always be successful because everyone will want to try to reach the final goal. This is a fantastic way to revise the concepts seen in the previous lessons, but it is particularly important that such games can involve all participants with manual and visual activities. This is also a technique that suits atypical locations like toy shops where children may be more open to play and more confident that they are allowed to play than in a school or museum environment.

In one case, I wanted to try something daring: the discovery of the Hertzsprung–Russell (HR) diagram, an advanced subject typically addressed in university lectures, but presented as a game to a group of children where the oldest was just nine years old. In this way I managed to introduce the use of plots and scales, and even give a glimpse into logarithms. I selected a suitable stellar sample, with each star represented by a disc of paper. These discs, all with different dimensions, were then put inside a box from which the children had to pick them one by one. The properties of each particular star were written on the corresponding disc, and after reading them the child had to put the disc on a large sheet of paper marked with the axes of the HR diagram. In this way, star after star, the diagram emerged, and at the end, without giving further details, I encouraged them to try and analyse what they were seeing. At the end I gave them a smaller version of the diagram asking them to check whether all the stars were in the correct position.

This game, and others like it, demonstrate the advantage of taking astronomy out of the classroom and into a location associated not only with learning but with excitement and fun. The children are given the freedom to enjoy the process and the courage to ask questions, follow lines of enquiry that they may not even have known they had and to indulge their curiosity. It is a method that I will continue to use and which I hope others can also take something from.

Acknowledgements

I want to thank my family; their suggestions, their inventiveness, their time and technical resources have helped me to develop and to carry out these astronomical games.

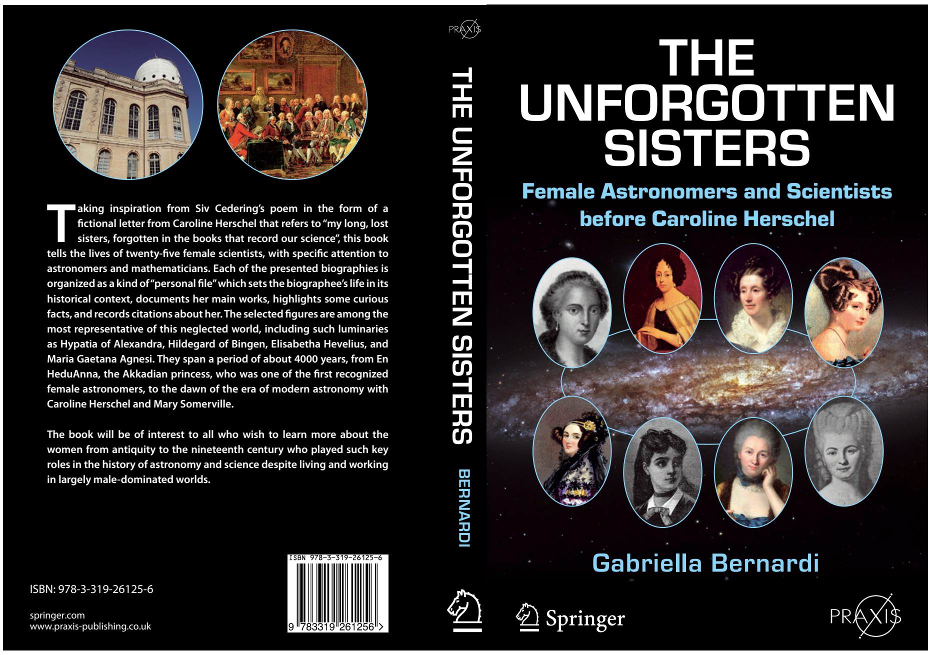
Notes

1 Free space simulation software Celestia: http://www.shatters.net/celestia/

Biography

Gabriella Bernardi was born two years after the landing of the first man on the Moon. She has a degree in Physics, a Masters in Scientific Communication, and she has been working for several years on the popularisation of astronomy and in scientific journalism. She is a member of the Union of Italian Scientific Journalists (UGIS) and the European Union of Science Journalists' Association (EUSJA). In 2007 she won the Voltolino prize for scientific popularisation. As an author she has written, in Italian, *Dov'è il cigno?* (2010; *Where is Cygnus?*); *Il cielo dimenticato in un baule* (2012; *The sky forgotten in a trunk*), a book for children about the female astronomers of the past; *La Galassia di Gaia* (2013; *Gaia's Galaxy*); and, most recently and available in English, *The Unforgotten Sisters-Female Astronomers and Scientists before Caroline Herschel* (Springer, 2016).

New book now available from the author



Column

Interdisciplinary Approaches to Astronomy: The Music of the Spheres (Part 2)

Andrew Fraknoi
Chair of Astronomy
Foothill College, Los Altos, USA
fraknoiandrew@fhda.edu

Keywords
Interdisciplinary, science in music

In issue 18 of *Communicating Astronomy with the Public journal*, we explored some of the influences of astronomy on fiction, drama, and poetry. In this second part of our interdisciplinary survey, we examine some musical examples of astronomical inspiration.

Introduction

Many aspects of our modern understanding of the Universe have influenced composers, in the realms of both classical and popular music. Indeed, it may well be in the musical arena that astronomy has had its largest direct cultural influence in our time. In a recent review, I was able to cite 133 different pieces of recorded music influenced by serious astronomical ideas (Fraknoi, 2012), not including casual references to the Moon in lyrics such as "it's June, there's the Moon, let's spoon". In that review, I restricted myself to pieces that can be found on CD, although the tremendous growth of YouTube, Spotify and other online video and audio repositories is making that distinction less and less important.

Music about astronomers

The life and work of astronomers has served as the inspiration for music from opera to heavy metal and everywhere in between. In part one of this piece we discussed operas about Kepler, Galileo and Einstein, but there are many other musical tributes to noted astronomers. The late-romantic Danish composer Hakon Borresen wrote a 1924 ballet about Tycho Brahe called *At Uranienborg: Tycho Brahe's Dream*. It takes place on the island of Hven, Sweden, where Brahe had his observatory, and it features dancers who portray stars, comets and the supernova of 1572.

The year 1973, the 500th anniversary of the birth of Copernicus, saw many celebrations, and several musical compositions. Perhaps the best known of these was Polish composer Henrik Gorecki (Goretsky)'s 2nd Symphony *The Copernican*.

Despite not being the most well known, the most interesting piece from this period to my mind is Leo Smit's *Copernicus: Narrative and Credo*. In 1953, the composer Smit became friends with the astronomer Fred Hoyle. They talked and hiked together, and even wrote an unproduced opera. Their 1973 Copernicus piece is an oratorio of sorts, the last part of which is a moving declaration of modern cosmic belief written by Hoyle. A recording of this has recently become available on CD[1].

On their hikes, one of the many late-night topics that Smit and Hoyle debated was who would be more useful if they were suddenly transported into the far future — a 20th century composer or a 20th century physicist. Hoyle then wrote a science fiction novel based, in part, on this debate called *October the First is Too Late* (which we mentioned in the science fiction discussion in part 1 of this paper). Hoyle and Smit later gave a concert and lecture at Caltech, USA, based on the ideas and music in *October the First Is Too Late*. The Copernicus piece, it seems, grew out of this earlier collaboration.

Moving forward to our time, and picking one example, Stephen Hawking and his work were the subject of great popular interest, even before the release of the award-winning film *The Theory of Everything* in 2014. In 1989 the rock singer and songwriter Todd Rundgren produced a song called *Hawking*, a first-person meditation on the British scientist's work and disability. The song's lyrics are quite poignant — about being trapped in a broken body, questioning why the disease that crippled him happened and asking whether Hawking can see further in space and time because of his illness[2].

Figure 1. *The author with two of the giants of Renaissance astronomy, Tycho Brahe and Johannes Kepler in Prague. Credit: Alex Fraknoi*

Astronomer Carl Pennypacker and science writer Judith Goldhaber also wrote a musical piece about Hawking, entitled *Falling through a Hole in the Air: The Incredible Journey of Stephen Hawking*. The Oakland Symphony Chorus serenaded Hawking with a selection from the piece when he visited Berkeley, USA, in 2007[3].

Music about constellations

The constellations, which were the only form of wide-screen entertainment available to our ancestors, have provided inspiration for many kinds of music over the years. For example, Philip Glass's *Orion*, commissioned for the 2004 Olympic Games in Athens, draws inspiration from the myths in different cultures that come

Figure 2. *Engraving of Nicolaus Copernicus, from the library of the Wellcome Trust. Credit: Wellcome Trust*

from this well-known constellation. The sections were performed using players and native instruments from around the world, including an Indian sitar, an Australian didgeridoo, and a Chinese pipa[4].

Hayg Boyadjian, a classical composer who is an active amateur astronomer and a member of the Amateur Telescope Makers of Boston, has a number of pieces inspired by constellations, including *Scorpius Rising* and *Cassiopeia*. In both cases, the shape of the constellation in the sky is reflected in the shape the notes make on the stave for the principal motifs in the piece[5].

Taking that idea further, we have the work of John Cage, who is notorious in modern classical music for undermining the rules of how music is made. In one of his projects, entitled *Atlas Eclipticalis*, he put see-through musical notation paper in front of a star atlas, and let the positions of the brighter stars in the atlas determine the positions of the notes on the paper. The notes that emerged were the ones that were played. Such music is, as you might imagine, much more fun to contemplate than it is to listen to.

Music about astronomical objects

Focusing now on more specific topics in astronomy, let us begin with music about the Earth's natural satellite. One of the best known Moon songs is *Walking on the Moon* by the Police, on their album *Reggatta de Blanc*. In this song the singer compares the feeling of being in love to walking on the Moon — where the lower gravity allows you to take much larger steps and where you hear no outside sounds. There are other songs that also use characteristics of the Moon, especially its phases. The *Whole of the Moon* by the Waterboys plays off the idea of a crescent moon being a small part of a full moon, and how the singer, wrapped up in himself, saw and felt little in a relationship, whilst his lover saw the larger emotional picture. The 2002 song *Earthshine* by the Canadian rock band Rush uses the notion of earthshine as a metaphor for a lover who feels his role in the relationship is merely to be a faint reflector of his beloved's glory. There are of course countless others who have found inspiration in the mystery of our closest neighbour.

Many classical music fans, when they think of astronomical music, think first of Gustav Holst's 20th century romantic suite, *The Planets*. Unfortunately, this suite was inspired by Holst's interest in astrology and not astronomy, and the music reflects astrological aspects of each planet. Holst was introduced to astrology by the brother of fellow British composer Arnold Bax, and actually began casting horoscopes for friends and colleagues. I no longer include the piece in my list of astronomical music, but I understand that the popularity of *The Planets* is undeniable, and NASA, documentary film makers, and several creative astronomers have used the music to illustrate talks, slide shows, or films about the planets.

A number of modern composers have written pieces to accompany Holst's suite and to portray other Solar System bodies, including Pluto and some key asteroids. An example can be found on the version of Holst's piece conducted by Simon Rattle, on the British multinational EMI's recording, which features pieces entitled *Pluto*, *Ceres* and *Asteroid 4179: Toutatis*. The New Zealand Symphony Orchestra recently commissioned a companion piece to *The Planets*, based on native Maori conceptions of the open star cluster Pleiades and its use in determining the new year. That piece, *The Glittering Hosts of Heaven,* by Eve de Castro-Robinson, was recorded on video and is available on Vimeo[6].

There are a good number of other pieces of music that are inspired by the modern

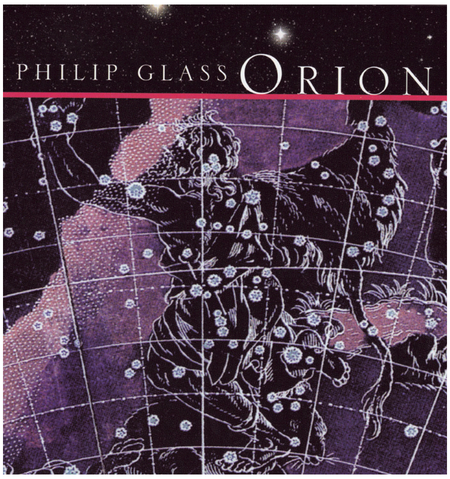


Figure 3. *The cover of the CD of Philip Glass's piece Orion. Credit: Image courtesy of Orange Mountain Music*

exploration of the planets and more are being composed. For example, there is the American composer Judith Lang Zaimont's suite of solo piano pieces from 2000 called *Jupiter's Moons*. These were inspired in part by seeing NASA images coming back from the exploration of Jupiter's system and are available on an Albany Records CD[7].

The 1970 album by the British rock group Van der Graaf Generator has a title that has endeared it to my students: *H to He, Who Am the Only One*. The three steps of the proton–proton chain of nuclear fusion are written out at the bottom of the cover. One can only imagine what the typical rock music fan who had not taken an astronomy course thought of the title. However, the songs on the album have little to do with astronomy.

When it comes to stellar evolution, there is no topic like a black hole to inspire dramatic songs. The Canadian rock group Rush, in their 1977 album, *Farewell to Kings*, had perhaps the most astronomically accurate set of lyrics for a black hole song in *Cygnus X-1* (see Table 1)[8].

Over the years, with the help of my students, I have found five other songs inspired by black holes. The group Aqualung has a song entitled *Black Hole* on their 2007 Album *Memory Man*. A song with the same title appears on Amanda Lear's 1979 album *Never Trust a Pretty Face*, in which the destructive power of a relationship is compared to the destructive power of black holes.

The other three black hole songs that we found are: *Places Named After Numbers* by Frank Black — lead singer of the Pixies, whose real name is Charles Thompson — on his 1993 album *Frank Black*; *Beyond the Black Hole* on the 1997 album *Somewhere Out in Space* by the German metal band Gamma-Ray; and *Black Holes in the Sky* on the 1975 album *Phoenix* by the group Labelle, whose lead singer is Patti LaBelle.

Quasars have not broken into the public sphere in quite the same way as black holes, but in the 1960s there was a brief flurry of public attention paid to quasar CTA 102 because its radio signals were claimed to include coded information from an advanced civilisation. There was nothing like a message there, it turned out, but the American singing group The Byrds was intrigued by the original story and wrote a song entitled *CTA 102* on their *Younger than Yesterday* album. Radio astronomer Eugene Epstein then thought it would be a lark to include the names of the Byrds' members in a reference in a paper on CTA 102 he was writing for the *Astrophysical Journal*. He got it past the editors in proof stage[9], referring to the song as a private communication and using the names of the band members as authors. He sent a note with the paper to Columbia Records and Roger McGuinn, the leader of the group, came to visit him and even attended a colloquium with him on the search for life elsewhere.

In the constellation of Cygnus
There lurks a mysterious, invisible force
The black hole
Of Cygnus X-1…

All who dare
To cross her course
Are swallowed by
A fearsome force…

Through the void
To be destroyed
Or is there something more?
Atomized at the core
Or through the astral door
To soar

I set a course just east of Lyra
And northwest of Pegasus
Flew into the light of Deneb
Sailed across the milky way…

Headed for the heart of Cygnus
Headlong into mystery

The X-ray is her siren song
My ship cannot resist her long
Nearer to my deadly goal
Until the black hole
Gains control

Table 1*. Lyrics from the Canadian rock group Rush's song* Cygnus X-1*.*

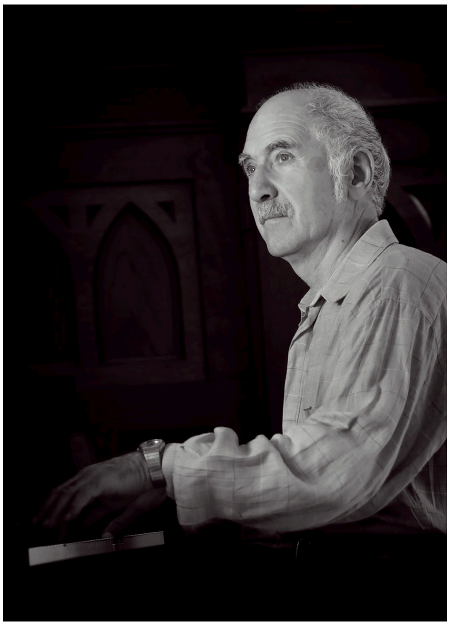


Figure 4. *The composer Hayg Boyadjian at the Follen Church in Lexington, Massachusetts. Credit: Andrea Joliat*

Figure 5. *Judith Lang Zaimont.*

Converting astronomical data to music

The idea of using actual data from cosmic objects to drive music in some way has captured the imagination of a number of composers and technicians. Data that people used to make music several decades ago include the instantaneous velocity of each planet in its orbit, as a way playing Kepler's *Music of the Spheres* (Rodgers & Ruff, 1979), and the index that measures how solar activity affects the Earth's magnetic field (the Kp index of geomagnetic activity)[10].

More recently, the alternative Reggae band Echo Movement used transit data for two Kepler planets in the introduction to their 2012 album, *Love and the Human Outreach*. The album also features songs inspired by the uncertainty principle and quantum entanglement, and by the *Voyager* mission and Carl Sagan.

The notes for the music *Supernova Sonata* are supplied by the distance and characteristics of 241 Type Ia supernovae, seen on the Canada–France–Hawaii telescope Legacy Survey. Created by Alex H. Parker from the Southwest Research Institute, Texas, and Melissa L. Graham from the University of California, Berkeley, USA, the piece can be seen and heard on the internet[11]. The volume in the piece is determined by distance, the pitch by the light curve, and the instrument playing the note by the mass of the host galaxy.

The European Space Agency also realised the potential of creating song from the sounds of space and released an audio track called *The Singing Comet*, a sonification of magnetic field data created by the *Rosetta* RPC–MAG instrument team. This piece has had almost six million listens on SoundCloud and has since been widely used by musicians (Baldwin et al., 2016).

Astronomers as musicians

A different perspective on the relationship between astronomy and music can be seen in the work of astronomers who write and perform music, starting in the 18th century with William Herschel, who was a professional musician and a self-taught astronomer[12]. We have mentioned Fred Hoyle providing text for a piece of music, but he is by no means alone in doing this. Physicist Lisa Randall recently provided text for an opera based on the idea in her cosmology book *Warped Passages* and astronomer Fred Watson provided text for composer Ross Edwards' *Fourth Symphony*.

A group from NASA's Goddard Space Flight Center called The Chromatics have put together a number of straightforward songs exploring ideas from modern astrophysics[13]. If music by scientists in general is your cup of tea, don't miss Walter Smith's expansive website on physics songs[14].

Figure 6. *Canadian rock band Rush. Credit: Photo courtesy of Rush.com*

Figure 7. *Eugene Epstein at the Aerospace Corporation. Credit: Image courtesy of E. Epstein*

Conclusion

There are many other pieces of classical and popular music with deep astronomical influences. If you want to see more, you can take a look at the catalogue of pieces in my resource guide (Fraknoi, 2012).

The sampling of connections between astronomy and the humanities considered in these two articles was meant merely to whet your appetite and makes no claim to be comprehensive. Please see the sources in the footnotes for many other examples and ideas about the cross-fertilisation of the fields. I continue to collect such examples, and would welcome additional suggestions from any readers. My hope is that you might be inspired by some of the above to explore such connections on your own and to share them with students and audiences as I have. I wish you many hours of enjoyable reading, watching and listening.

Notes

1. Leo Smit's *Copernicus: Narrative and Credo* is available on a CD from the American record label Composers Recordings, Inc. (CRI)'s American Masters series.
2. A performance of Todd Rundgren's *Hawking* is available on YouTube: http://www.youtube.com/watch?v=jk7uZO1iED8

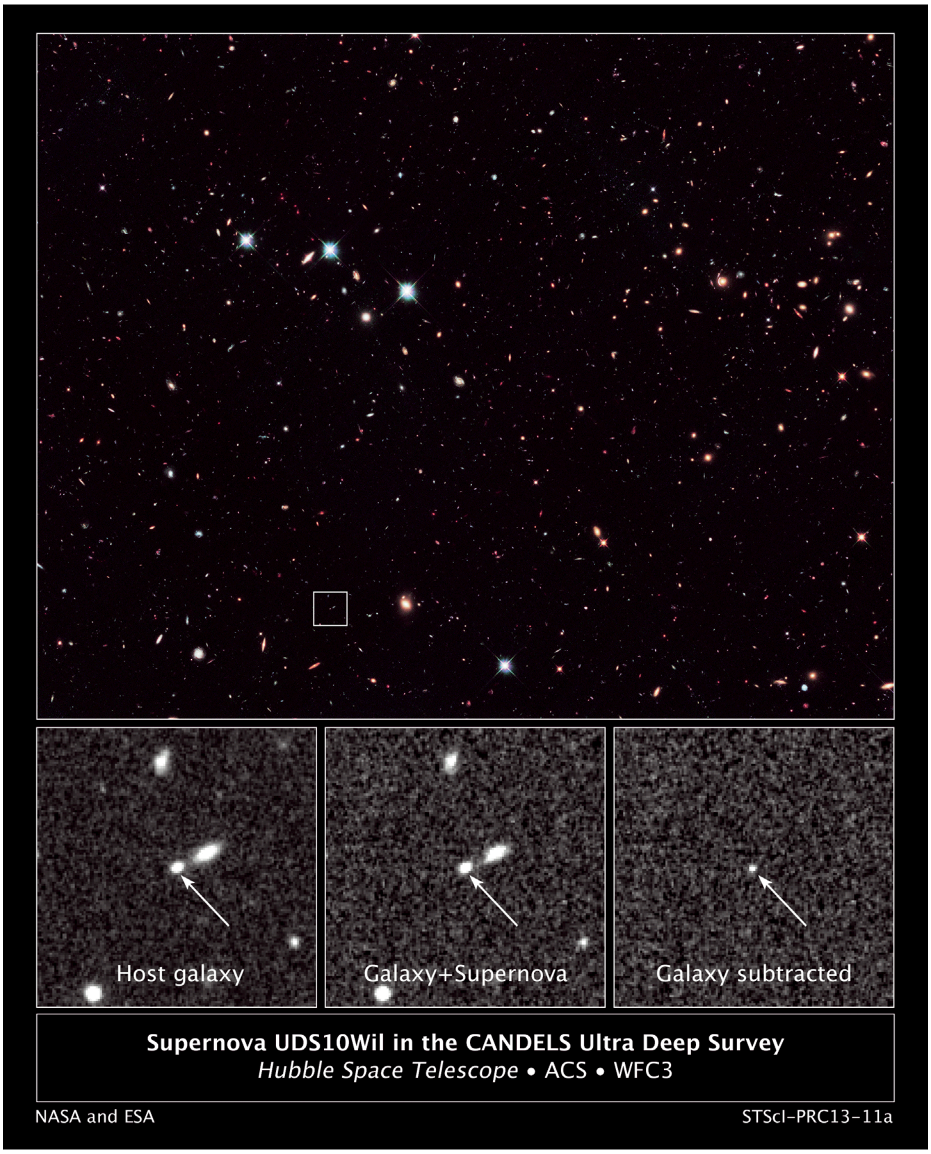


Figure 8. *This Type Ia supernova, seen with the Hubble Space Telescope, is designated SN UDS10Wil, and was one of the 241 Type Ia supernovae used in Alex H. Parker and Melissa L. Graham's piece* Supernova Sonata. *Credit: NASA, ESA, A. Riess (STScI and JHU), and D. Jones and S. Rodney (JHU)*

3 A clip from the performance at Berkeley of Carl Pennypacker and Judith Goldhaber's *Falling through a Hole in the Air: The Incredible Journey of Stephen Hawking* is available here: http://www.berkeley.edu/news/media/releases/2007/06/22_hawking.shtml

4 A pipa is a four-stringed instrument that is plucked and is something like a lute; a didgeridoo is a wooden drone pipe wind instrument; a sitar is an Indian string instrument. Philip Glass's *Orion* is available on a CD from Orange Mountain Music.

5 For more on Boyadjian's works, see: http://www.haygboyadjian.com/

6 *The Glittering Hosts of Heaven* by Eve de Castro-Robinson is available at: https://vimeo.com/68986729 (For an interview with the composer, see: https://www.nzso.co.nz/enotestheplanets/)

7 Judith Lang Zaimont's *Callisto* piece can be heard at: https://www.youtube.com/watch?v=V1M7Rp6tKgw. Her website is available at: http://www.jzaimont.com/

8 A British comic book version of the song *Cygnus X-1*, produced in 1979, can be found at: http://www.cygnus-x1.net/links/rush/comicbook-cygnus-x1-b1.php

9 The reference to the Byrds in Eugene Epstein's paper on CTA 102 can be found in *Astrophysical Journal* volume 151 in the second paragraph of page 31.

10 The index that measures how solar activity affects the Earth's magnetic field is known as the Kp index of geomagnetic activity. The music inspired by this is by composer Charles Dodge; it can be heard at: https://www.youtube.com/watch?v=j5M-Hsnc67yw and is explained at: http://music.columbia.edu/cmc/musicandcomputers/popups/chapter1/xbit_1_1.php

11 A recording and explanation of *Supernova Sonata* by Alex H. Parker and Melissa L. Graham can be found here: http://www.astro.uvic.ca/~alexhp/new/supernova_sonata.html

12 A CD with a selection of William Herschel's music is available on Newport Classics under the title *Sir William Herschel: Music by the Father of Modern Astronomy*.

13 More information about the Chromatics: http://www.thechromatics.com/

14 A listing of physics songs: http://www.haverford.edu/physics-astro/songs/

References

Baldwin, E. et al. 2016, CAPjournal, 19, 30

Duckles, V. 1962, Publications of the Astronomical Society of the Pacific, 74, 436, 55 (http://adsabs.harvard.edu/full/1962PASP...74...55D)

Fraknoi, A. 2006, Astronomy Education Review, 5, 1, 139 (http://dx.doi.org/10.3847/AER2006009)

Fraknoi, A. 2012, Astronomy Education Review, 11, 1 (http://dx.doi.org/10.3847/AER2012043)

Hoyle, F. 1966, *October the First is Too Late*, (London: William Heinemann)

Rodgers, J. & Ruff, W. 1979, American Scientist, May/June, 286

Biography

Andrew Fraknoi is Chair of the Astronomy Department at Foothill College near San Francisco, and serves on the Board of Trustees of the SETI Institute and on the Lick Observatory Council. His book of teaching activities on the Sun, Moon and eclipses (*Solar Science*) is published by the National Science Teachers Association. He does not play a musical instrument (although he loves to listen to music); a few years ago he got to write and perform astronomical narration to Holst's *The Planets* with the California Symphony Orchestra.

Ode to Hubble: Inspiring Science through Art

Halley Davies
Ode to Hubble video contest winner
Canada
halleydavies@hotmail.com

Martin Hellmich
Ode to Hubble Video contest winner
Canada
mhelmich@gmail.com

Keywords
ESA, NASA, Hubble Space Telescope, contest, prize, creativity, education, creative engagement

In early 2015 ESA and NASA invited participants of all ages to create an art piece that would celebrate Hubble's 25th anniversary in space. Contestants could use any form of art, with the final presentation being in video format. Throughout the competition animators, photographers, painters, songwriters, and many more shared their art and appreciation for Hubble. Martin and I had a special interest in stop-motion animation and we used this in our film, *Hubble's Universe*, to illustrate some of the discoveries that had enhanced people's interest in, and knowledge of, the Universe. Over a year later, reflecting on the contest and its effect on our lives, we will expand on our creative process, what inspired us, how we continue to inspire others, and how future competitions can continue to engage people from different fields and backgrounds with science.

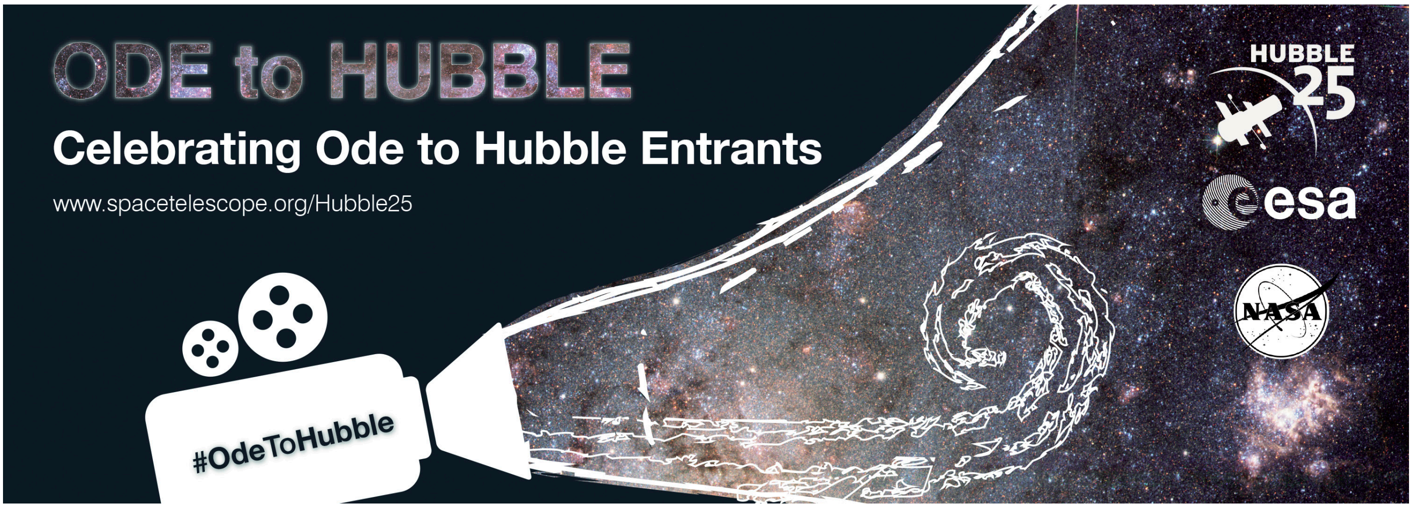
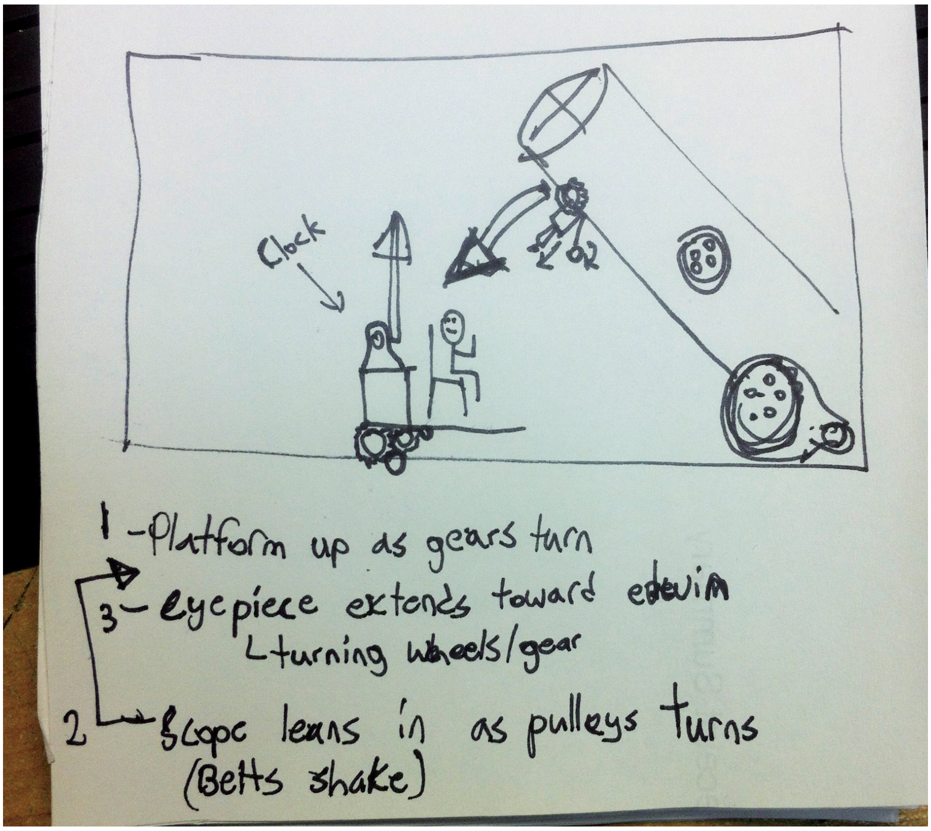


Figure 1. *Promotional image from the Ode to Hubble competition. Credit: ESA/Hubble*

Introduction

When I first heard about Hubble's 25th anniversary competition, Ode to Hubble, I was immediately excited about making a short film[1, 2]. It was an opportunity to use my skill set in photography and filmmaking to express my appreciation for a telescope that has given us a world-changing view of what lies above and beyond the sky. However, I didn't know what more to say beyond that. I had a filmmaking degree, I had spent plenty of time working and volunteering on films, I had made my own films; but what did I know about Hubble? Although I knew of Hubble, I had not taken the time in my day-to-day life to learn more. So I did not have the level of understanding or expertise to write a script that would direct my creative output. Luckily, my friend Martin had also been thinking about the contest. He was originally also a filmmaker, but is now in the process of making the transition to a science career. We realised that we were both thinking of creating an animation and that we needed to collaborate and combine each other's skills and interests to pull it off. Martin was drawn to the competition through his love of space and, after years of absorbing all the information he could, it was the right time to share that accumulation of ideas. I knew that I could collaborate with Martin to create a short film that would be historically and scientifically correct.

To our delight, our hard work and the amazing support from everyone during the voting process paid off and we won first place for the 25s and under category. With the prize in hand (a piece of Hubble's solar panel) I went to a local school to share my passion for film and educating through film. The children, who were aged nine to eleven years old, were drawn into my talk either through their interest in filmmaking, or their interest in science, or both. Because Martin and I had created a film that is interesting on two levels, both arts and science, I was able to capture their interest for well over an hour! Building on that success, I looked for more ways to inspire children to challenge what they see, to expand what they know, and to be courageous about what



they feel. The direction and excitement that the Hubble contest gave me, and I'm sure other participants like me, meant that I could share the passion of space not just on the internet, but back in our local community. Not everyone who participated in the Hubble contest had a science background. Many, like myself, were artists who saw the opportunity to ignite a passion for the world around us. The strength of the contest was that it allowed collaboration. Science has big topics that can be intimidating, but, with the help of friends and colleagues, we can overcome the overwhelming feeling of just how much there is to learn and learn to share the parts we do know.

The spark of interest

Although I did not study science past the age of eighteen, it was a subject that I always enjoyed as it teaches us about ourselves and our world. However, like many interests, it became dormant as I focused on my arts studies and my career. Two simple events two years ago challenged

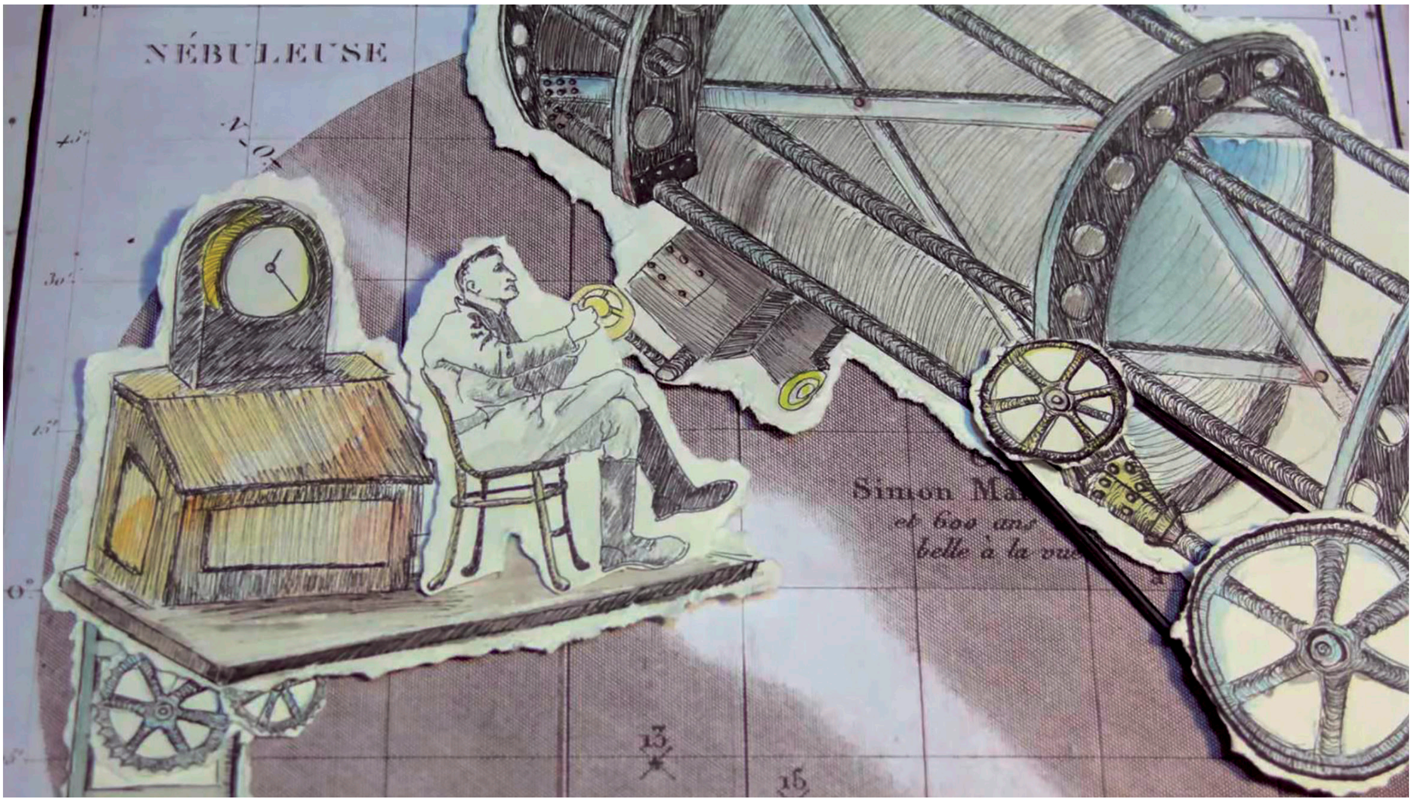


__Figure 2.__ The top image shows drawings by Martin that would be used to clarify ideas about how the shots would work. The bottom image is what Halley would create from these drawings. Rather than words on a page the creators used this storyboard as a working script in order to visualise as much as possible before shooting of the animation, where reshoots can mean losing a great deal of time.

this. The first was when my friend Martin introduced me to a television series from the 1980s called *Cosmos: A Personal Voyage*. This beautiful series talked about the history of astronomy, and its importance. Before watching this series, my appreciation for the sky was much simpler. I would take the time to look up at the night sky and admire the distant lights, and then continue on without further thought. With the influence of *Cosmos*, I now take the time to read science articles, seek a deeper understanding and join sky-gazing events so that I can learn more from other astronomers. Now, the Royal Astronomy Society of Canada (RASC), has even generously made me an honorary member because of our Hubble film.

The second event that brought my interest in science back to the fore perhaps inspired similar feelings in me to those that astronomers felt when they first observed the sky through a telescope. I had just begun to observe through telescopes and Martin and I chose a particularly dark and high point in Nova Scotia. He set his telescope towards the Hercules Cluster and as I looked through the eyepiece I gasped at what I saw: fireworks frozen in time! I had never seen such clear detail of something in space in such an intimate way. This is the kind of special moment that is key to stimulating that spark of inspiration which makes science become so important to us. At that time, Martin had been deeply invested in learning about space for about five years and it was the same television series and the experience of sky gazing that had also been part of what inspired him.

Figure 4. *Props from the animation.*
Credit: Halley Davies and Martin Hellmich

Figure 3: *This image shows the set of the animation. Inside the giant black box is our stage so we could shoot at any time of day and shine in controlled light. One person would move each object a tiny bit and then when they were satisfied would call out to the other person who would take a picture. The process requires a great deal of patience as a single shot can take hours! We listened to an audiobook to help with focus.*
Credit: Halley Davies and Martin Hellmich

Following these events Martin and I spent a great deal of time discussing what it would be like to see a planet or nebula in detail for the first time, and to not understand what it was. This would lead to the starting point for our film; thinking about how the sky was perceived before our knowledge had reached today's level, and in understanding that mindset we found a new appreciation for Hubble. We took imagery that denoted seeing and knowing very little about the Universe and compared it to Hubble's well-known photographs. We did so to show the progress that has been made, as we believed that audiences would enjoy reflecting on the steps taken to create this window onto other worlds; hopefully creating sparks of interest.

Developing the idea

The idea for our Ode to Hubble video would never have developed if we had not seen an email from our friend Dave Chapman from the RASC. Dave had known Martin for several years through the RASC and had seen him do astrophotography and make videos for the astronomy community. Dave knew me from a star party and was aware that I was making a career in filmmaking. However, the contest had already been running for some time. We had roughly two weeks to write, prep, shoot and edit a short film! Martin and I discussed many ideas as we worked on the script and developed the vision of the film. Both of us felt that a stop motion would create a theatrical and storytelling feel that would best express the awe that learning about space inspires. However, it was difficult deciding whose voice the film should follow. We thought it could be told through the eyes of a young child, or perhaps from the perspective of a famous scientist as he or she teaches the audience about Hubble. The solution was to take a more abstract approach and make the main character human thought itself. We would focus on how humanity's perspective has grown as scientific discoveries have been made. Each new discovery inspires new art and new questions, creating a kaleidoscope of historic imagery that leads us to the achievements of Hubble. In striving to convey these feelings as visually as possible our original plan to include a narration was not necessary anymore. The film is stronger when interpreted by the individual.

We wanted *Hubble's Universe* to be so easy to understand that a young child could enjoy watching it, whilst also including some of the rich history of Hubble and a contemplation of the Hubble Deep Field. Like the Hercules Cluster that first took my breath away, understanding what the Hubble Deep Field is and what it means for the scale of the Universe are beautiful thoughts. This iconic image shows like nothing else the awe-inspiring fact that in every speck of sky there are billions of planets and stars. This would be the grounding image that would represent the awe of the Universe. As we continued with the idea, we realised that many of our audience members would already have some knowledge of science and of Hubble's history, which is why many of the historic images and references we chose to use are ones that audiences without a science background may not recognise. This was not intended to alienate less science-literate audiences and the video was given a complementary playfulness to draw viewers in and encourage them to ask more questions.

We used drawings, diagrams and photographs of scientists to visually express how those scientists are or were connected to the Hubble Space Telescope. We also included Vincent Van Gogh's work *The Starry Night* because, before astrophotography was invented, interpretation of the sky was left to those who could draw or paint. Although *The Starry Night* was painted at the dawn of astrophotography[3], we wanted to open the film with this painting as it is perhaps the most familiar from our selection to the majority of audience members. The film would then continue on through stop-motion planets, scientists' drawings and direct planetary imaging to further show how, as understanding has progressed, so has the visualisation of planets and stars. We chose historical images based on discoveries that have drastically changed humanity's view of the Universe: Galileo's discovery that the Moon was solid and tangible (Drake, 1957); Kepler's speculation about the boundaries of the Universe (Murdin, 2011); and Edwin Hubble's discovery of galaxies outside our own, known at the time as Island Universes[4]. With our vision on paper we knew that we were going to

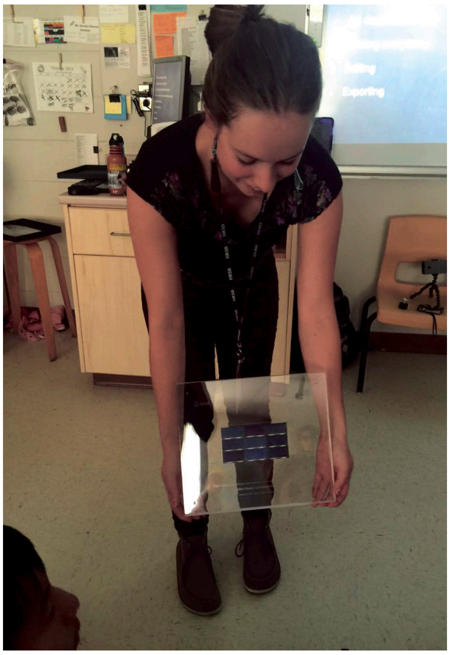


Figure 5. *Halley presenting the Ode to Hubble prize at a class presentation to young children. Credit: Halley Davies and Martin Hellmich*

need to use some difficult tricks to bring it to life, but we were ready to begin the focused work of animation.

The filmmaking

We researched the historical images and space photos for about two days. The plan was to print out certain images, paste them on a Styrofoam backing and insert a stick and a base. This created a sort of "puppet" effect for the planets, stars and galaxies to move across our set. We used this same technique for the opening shot with *The Starry Night*. Keeping our background black by creating a large black box, also made of Styrofoam, we cut a slit in the top of this same black box. Then we set up a light that would point down into the black void from the top of the box. Using this effect, we created stage-like lighting, where our "puppets" of planets and stars could be in the spotlight. The theatrical energy that the lighting and stop motion created was essential to our idea of creating that wonder and awe of space.

By attaching a dense black cloth to the front of the black box facing the "stage" area, we were able to make an accessible place for the camera. In this way, we had full control of our lighting within the

CBCnews | Nova Scotia

LIVE Halifax More Streams
CBC Radio One
Listen Live
radio one

Home | World | Canada | Politics | Business | Health | Arts & Entertainment | Technology & Science | Trending | Weather | Video

Canada > NS > Photo Galleries

Halifax space enthusiasts create winning Hubble tribute video

The contest, called Ode to Hubble, was put on by the Hubble and European Space Agency

CBC News Posted: Apr 24, 2015 11:12 PM AT | Last Updated: Apr 24, 2015 11:12 PM AT

The Hubble Space Telescope was launched into space aboard the Discovery space shuttle on April 24, 1990. (NASA)

102 shares

Haligonians Halley Davies and Martin Hellmich took first place in an international competition to celebrate the Hubble Space Telescope.

Stay Connected with CBC News

Mobile Facebook Podcasts Twitter Alerts Newsletter

ADVERTISEMENT

Summer

FIND OUT MORE >

Latest Nova Scotia News Headlines

Iconic Halifax retailer

Figure 6. *Local news coverage on the winners and the competition.*

Figure 7*. Halley and Martin preparing to speak to the Ode to Hubble team as part of a 25th anniversary Hubble Hangout event.*

black box, so we could shoot without daylight interfering with our lighting setup. It took around a week to create the drawings, cut-outs and the stage where we filmed, although this did overlap with some of our filming days. Martin shot several of the sequences while I was still putting the final touches on puppets or drawings for the next scene to be shot!

One of our most exciting stop motion sequences explained the Ultra Deep Field image[5]. We expressed the vastness of space by reversing an animated video of the Ultra Deep Field image, zooming out until the image shrank into a tiny dot surrounded by black. The video continues to sweep backwards to reveal that the black background to this dot is in fact a black sphere. This sequence expresses how, although Hubble's Ultra Deep Field image may show thousands of galaxies, it is only a tiny section on the sky. We wanted to demonstrate the vastness of the Universe and also show how astronomers estimate just how many galaxies there might be in the visible Universe. To achieve the latter, and ensure that we were doing so accurately, Martin met with Professor Rob Thacker at the Astronomy and Physics Department at Saint Mary's University to go over this sequence and make sure that our representation was correct.

The black ball used to represent the Universe in this scene is a papier-mâchéd balloon that was painted black. The dots of light that appear during the sequence and represent the many galaxies are created using a torch shining through holes that were poked into the papier-mâchéd ball.

After the filming process was complete, the final step was to edit it all together and submit it for the first phase of voting in the competition. During the editing process we were incredibly lucky to find the perfect music to fit with the timing and emotions for our scenes[6]. With the video as complete as possible, and with not a minute to spare, we entered it into the contest. We were quite happy at this stage just to have submitted a project into this worldwide competition, but as the voting started, we realised that we might have a chance not just to participate, but to make it onto the shortlist. The anticipation grew until we were checking our votes every couple of minutes! As we received so much support from our friends and astronomy communities around the world, we started thinking about what we would do if we won. The prize — a piece of Hubble's decommissioned solar array and a signed photograph of the Hubble 25th anniversary image — was an amazing item to have on display in your house, but we thought it would be most effective if people could see it and be inspired by it. It would be the perfect opportunity to share our interests, and hopefully encourage other people to share our love of space.

Sharing the prize

Before even receiving the prizes, Martin and I looked forward to sharing our excitement at having a little bit of space and history in our hands. Martin's plan to share the piece of Hubble was to have it on display at the Saint Mary's University Observatory. The observatory hosts public observation nights where members of the public of all ages come to learn about the stars and look through their telescope. The piece of Hubble, which powered Hubble's instruments for three years, would be an inspiring addition to such an event. We have also made plans so that the prize will to travel to RASC events and presentations in Toronto and around Nova Scotia. Closer to home, I am visiting schools to share the video and prize with children.

In the Nova Scotian curriculum students learn about space at around age 12. I have done artist's visits to schools before and I was excited to share my new inspirations from science, astronomy and Hubble. My presentation is about the excitement of learning about space through the process of filmmaking. During the presentation, I learned that a number of the children had not even heard of Hubble! It made me realise how important my artist's talk was in educating some of our younger generation.

I was very happy to see that my presentation kept the children's interest for over an hour and that it was followed by many questions. Some asked questions about space and what they saw in the video, whilst other students were more interested in the filmmaking aspect. The combination of these two components to the video — filmmaking and science — was the key to holding the students' interest for so long. Both are exciting and popular subjects and students could either connect because of their own filmmaking experience, or because of their passion for space. I had done presentations in the past, but the combination of these subjects notably drew great interest. In turn, I realised this is what drew me to creating a film about Hubble: I had a passion (filmmaking) and I was curious about something real but that I did not know much about (space). It was important for me to share this with the children and emphasise that learning can take many forms. I will be going back to the school to show the children various animation techniques that they can use in their own films to explore a subject that inspires them.

An appreciation of the different ways in which you can learn about a subject was one of the strengths of the Ode to Hubble competition. It reached out not just to those interested in, or already involved with science, but to artists. Artists are inspired by the application of the creation process and this can motivate collaboration with a scientist to encourage research for their art project. We are challenged by a modern world saturated by media, a world that demands a level of entertainment or visual "reward" in order to be captivated, but by allowing artists of all backgrounds to find different ways to create an eye-catching educational piece the competition found a way to captivate the minds of distracted viewers. Bit by bit, new audience members can learn about science through short and simple pieces presented in various media. Variety is important as all art forms contribute to educating and creating discussions among viewers and scientists in their own way, and there was no lack of variety in the competition entries, which included painting, song, poetry, animation, dance, and much more.

Conclusion

The Ode to Hubble competition made a difference to participants across the world. Every participant had taken time to think, either alone, or with friends, about what Hubble meant to them. It created conversations, which would promote contemplation about great accomplishments, but also great mysteries. I was drawn to join the competition by my love of art and curiosity about space. Martin was drawn to it for the excitement of sharing his passion for, and knowledge of, space. Together we strived to make a short video that would be educational, inspirational and accessible, much like Hubble has been.

The film, along with all the other entries, was shared across the world and has also reached the public through the RASC and my school events. The reach is wide, but the individual effect is also wonderfully personal. My confidence was boosted when I could approach science with a familiar background and this background for me was filmmaking, but there was amazing variety among the other participants.

Competitions like these present a great opportunity for scientists and artists to collaborate and together embark on creative adventures that tackle the challenges of communicating astronomy in a fun and effective way. Tapping into people's personal interests is another way to allow science to be an active part of our lives, and not a distant acknowledgement.

The challenge and deadline of the the competition format gave participants direction and a destination whilst the prize is certainly part of the motivation. I believe people have more tools to be creative than ever before and this provides the perfect opportunity to invite the public into astronomy and other sciences.

Notes

1. More information on the Ode to Hubble competition: http://www.spacetelescope.org/projects/Hubble25/odetohubble/
2. The Ode to Hubble animation that we produced can be viewed here; the video has now been viewed over 7500 times: https://www.youtube.com/watch?v=iuvG8LaJDy8
3. More information on the timeline of astrophotography in Pedro Ré's *History of Astrophotography*: http://www.astrosurf.com/re/history_astrophotography_timeline.pdf (accessed 28th December 2015).
4. More information in the S*hapley-Curtis Debate,* 1920, http://apod.nasa.gov/diamond_jubilee/debate_1920.html (Accessed 3 January 2016)
5. More information on the Hubble Deep Fields: http://www.spacetelescope.org/science/deep_fields/
6. The music used was *La Madeline Au Truffe* (composed by Jeris) by basematic: http://dig.ccmixter.org/files/basematic/33580 (accessed 6 January 2016)

References

Galileo Galilei, Starry Messenger, 1957, in ed. Drake, S. *Discoveries and Opinions of Galileo*, (New York: Anchor Books), 43

Murdin, P. 2011, *Mapping The Universe*, (London: Carlton Books), 34

Biography

Halley Davies is a filmmaker and camera assistant. She studied at the Nova Scotia College of Art and Design (NSCAD), Canada, and continues to share her love of learning through film presentations in her community.

Martin Hellmich is an astrophysics student at Saint Mary's University, Canada. He enjoys studying and sharing the beauty of science through film and photography.

Astro Homus: Revealing the Astronomers behind the Science

Best Practice

Pedro Figueira
Institute of Astrophysics and Space Sciences, University of Porto, Portugal
pedro.figueira@astro.up.pt

Susana Neves
Institute of Astrophysics and Space Sciences, University of Porto, Portugal
sueneves@gmail.com

Filipe Pires
Institute of Astrophysics and Space Sciences, University of Porto, Portugal
filipe.pires@astro.up.pt

Paulo Pereira
Institute of Astrophysics and Space Sciences, University of Porto, Portugal
paulo.pereira@astro.up.pt

João Retrê
Institute of Astrophysics and Space Sciences, University of Porto, Portugal
jretre@iastro.pt

Ricardo Cardoso Reis
Institute of Astrophysics and Space Sciences, University of Porto, Portugal
Ricardo.Reis@astro.up.pt

Pedro Mondim
Institute of Astrophysics and Space Sciences, University of Porto, Portugal
pedro.mondim@astro.up.pt

Keywords
Science and Art, photography, astronomers' testimonies

Astro Homus is a project that focuses on individuals behind astronomy research. It aims to present scientists not as lone wolves with almost superhuman skills, as is so common in the current media, but as people who the reader can relate to as human beings. Using the language of photography and the personal stories of scientists, Astro Homus reveals the human dimension of astronomy. Through the project's journey across three countries, addressing questions ranging from the biggest unknowns to the most personal matters, the public is presented with a glimpse of what it is like to be an astronomer. In doing so, we hope to bridge the gap between researchers and non-researchers, and to contribute to an inclusive view of the astronomer, and indeed of astronomy, in society.

Introduction

There is a great divide between those who spend time watching the skies, reading about astronomy, or discussing it with friends, and those who show no interest in it at all. Most outreach activities try to engage the public by providing new information or new experiences within the realm of the subject, but these often appeal essentially to people who are already interested in the topic. Those who organise regular outreach events are very familiar with the idea of meeting the same faces, time and time again. People who regard astronomy or science as unimportant tend to remain unconcerned about it.

It is remarkable — and dangerous — that while our society does value physics and astronomy, it often feels as if it is mostly uninterested in the subject matter itself (Miller, 2000). Physics and astronomy are not part of most people's everyday lives and they seldom relate emotionally to it (Michaels, 1996). In many countries in Europe science seems to be unappealing to students and the uptake of subjects like physics and maths is fairly low[1]. Misconceptions about what it means to be a physical scientist that are fueled by the popular media do not help with this and create a sense that it is a subject largely populated by geniuses and mavericks.

Using the readily available material from high-profile scientists such as Hawking or Einstein, the scientist is often portrayed by the media as a lonely individual who has achieved recognition through their individual work. This directs the attention of the audience to very individual and prominent stories of success, often supplemented by dramatic interpretations that present scientists with either heroic of villainous traits. While this is a good recipe for engaging stories and commercial success, the scientists who come to life in such depictions are not representative of the community as a whole. By showing scientists as the complex, multidimensional and flawed human beings that we all are, Astro Homus establishes an emotional bridge to people, and thus to science, that is lacking in the classic depictions.

Capturing stories: The book

Astro Homus combines biographical portraits gathered through testimonies across three countries and compiles them with photographs from the experienced lens of photographer Susana Neves[2]. The project took off with 2000 euros of funding from the Portuguese Directorate General of Arts. It was supported by the Centre for Astrophysics at the University of Porto, Portugal (CAUP), who provided most of the manpower behind it, and the Centre for Astronomy and Astrophysics at the University of Lisbon. Since the project's inception the institutes have merged to form the Institute of Astrophysics and Space Sciences.

The project team worked at an international level with the National Galileo Telescope on La Palma, Canary Islands, and the Astronomy Observatory at the University of Geneva, Switzerland. These institutes opened their doors to the project, making it possible. The ongoing collaborations in the three institutes allowed us to come into contact with 29 researchers who kindly agreed to contribute their time,

Figure 1. *Starting from CAUP, the exhibition travelled across Portugal. Credit: Nelson Miranda*

Figure 2. *Alexandre Cabral, Institute of Astrophysics researcher and member of the Laboratory of Optics, Lasers and Systems hard at work. Credit: Susana Neves*

Figure 3. *Carlos Alarez, telescope operator of the Gran Telecopio Canarias, preparing for an observing night in the control room. Credit: Susana Neves*

testimonies and pictures to the project. The selected institutes from our network are located in different countries, allowing for a wider cultural diversity, and the topics discussed were chosen deliberately so as to give a cross-section of the community as a whole.

Figure 4. *Monika Lendl, postdoctoral researcher at the University of Liège, in Belgium. Credit: Susana Neves*

The aim was to engage in a discussion with common topics that could be used to connect the interviews of the different scientists, and organise the interviews around major themes that would unfold as the book progressed. The conversational perspective and the existence of shared dialogue threads allowed us to remove the interviewer from the scene completely, and the scientists were understood as talking directly to and with the reader. The creation of such a structure required a significant amount of material to select from for editing; moreover, as the testimonies were collected, it became necessary for the interviewer to direct some discussions in order to ensure the continuity of the common threads connecting the whole material.

For several months, we discussed with astronomers how they saw astronomy and the society they are part of. We collected insights on topics as diverse as "What is working in an observatory like?" to "The role of women in astronomy". We told a chronological story that addressed astronomy as a whole field as well as specific areas like the emerging field of exoplanets. The latter, although a young field, has already attracted a significant number of researchers in Portugal and relates to people in a way that few other topics do. We explored the questions that will be raised by the discovery of a planet like our own, and used the momentum gained from this to explore the deeper questions of what we expect from astronomy, and ourselves. These testimonies were compiled into a bilingual book in Portuguese and English, covering our project across three countries[3].

Travelling faces: The exhibition

Alongside the book, Susana Neves produced a photographic exhibition which travelled across Portugal, showing the protagonists of our project. With a wealth of experience of stage photography and different kinds of portraits, Susana's perspective showed the rich human dimension behind research. The tour route for the exhibition aimed preferentially for small cities and interior venues[4] that typically have fewer cultural events and only afterwards headed back to the large cities of Lisbon and Porto. The exhibition was visited by approximately 4200 people, and now that the Portuguese tour has officially ended, the exhibition will visit locations close to the international partners.

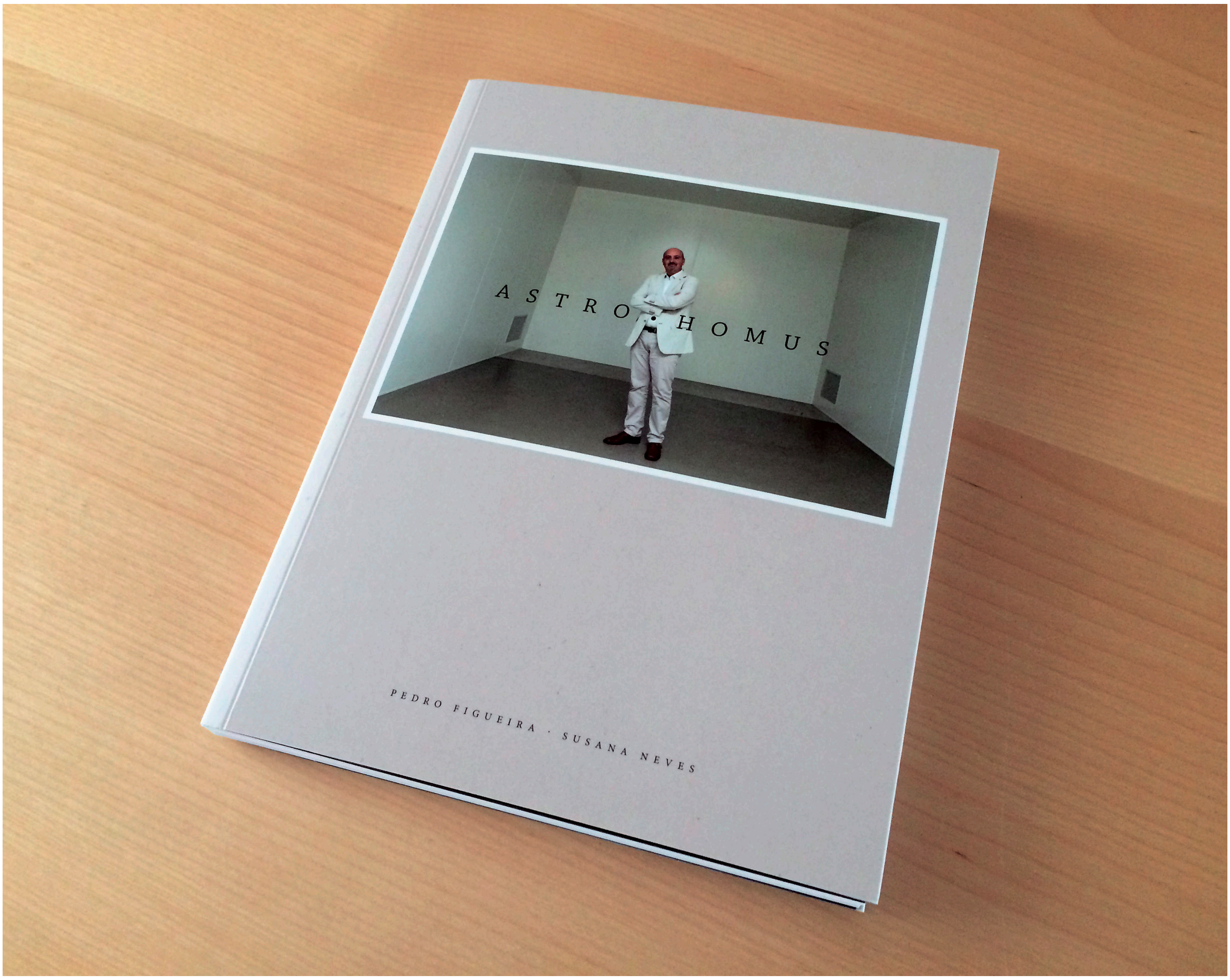


Figure 5*. Astro·Homus book cover. Credit: Susana Neves*

Lessons learned

We learned several important lessons from this project. First and foremost, that we had underestimated the work necessary to collect all the material and put it together. Making the travel arrangements and organising meetings in order to reach a wide number of participants of different ages, fields and nationalities, and then, later, organising and transporting a photographic exhibition are two particular aspects that took more time and resources than planned. But it did pay off. The ability to engage people in a different kind of discussion, about what astronomy is and who astronomers are, captivated many people beyond the usual groups of people who are already interested in astronomy. Being at the interface between science and the arts, the project appealed to many for its artistic dimension, and people interested in this aspect formed a large fraction of the visitors to the exhibition.

At several book release events many attendees were surprised by the inherent proximity between the astronomer and the audience. The audience was expecting a more standard one-sided presentation, with a typical fixed interview-plus-portrait structure for each astronomer. Instead they found themselves immersed in an ongoing dialogue, with several unwinding threads. Although there was no formal evaluation of the events, the feedback received was overwhelmingly positive, and most people were engaged and interested in the discussion, the testimonies, the pictures and the stories behind them.

Astro Homus, both book and exhibition, has shown us that alternative forms of communication can reach beyond the usual target audience of astronomy-minded people, by emphasising the human side of science. In this case, the use of an art form to attract and reach out to people worked remarkably welll.

Notes

1 In the UK the physical sciences ranked tenth (2014) in terms of the popularity of degree subjects. https://www.hesa.ac.uk/pr/3456-press-release-211

Sample testimonies from the Astro Homus book

"Going observing is, for me, one of the most amazing parts of being an astronomer. While I am at the observatory, I work all the time (I have, what, 15 minutes while having my breakfast in the morning?), but it's just a great experience. For two weeks, you dedicate yourself completely to what you do, and it is a wonderful experience. The funny thing (that occurred to me while I was observing two months ago in Chile) is that you have a very rigorous schedule. You wake up at four p.m., you are at the telescope by five p.m. (the latest), you do your calibrations, have dinner, do this and do that, day and night. But you are actually super-happy doing it, and you don't feel that you're missing out on a lot of things. Perhaps it is so because you know it's only going to last for two weeks, and then you'll have your free time again, your life and friends. But people at the observatory are friends anyway; you go there and meet the same people again and again, it feels a bit like a family. You arrive there and they go "Monika, how are you doing? Haven't seen you in a year...", it's a bit like coming home, too.

I think what makes it so easy is that it has a purpose. You have a job to do and you're there to do it. Calling it a meditative experience would be a bit of an overstatement but, somehow, we're like monks that live in a secluded monastery following a very strict time schedule, but who are happy doing it. After completing a good observing run, I have a great feeling of achievement. If I know a lot of people got good data, not only myself, I am really happy. I think that is a really important point: that when you are there, you are actually working for other people, too."

Monika Lendl, postdoctoral researcher at the University of Liège, in Belgium.

"In my astronomy lectures, I present to the students the following perspective: all the questions about the Universe are questions to which the Universe itself is trying to answer through us, because we are part of it. Therefore, we are trying to answer questions about what we are. The Universe built this little thing called a human being, which is now trying to understand its own nature. To me, this raises serious doubts that we will ever reach an answer. In our daily life, we would definitely say that it is impossible for you to make an evaluation of yourself because you are always biased and because there are always limitations in your perspective. When we are studying the Universe, there is also a fundamental problem: the Universe is trying to understand the very Universe itself. Maybe this will get us nowhere.

But that is alright: we keep studying, trying to understand and building models about what the Universe is like. I am fine with that; I do not know whether people who are faced with this issue are also fine with it, though. [This vision] may lead to philosophical problems: I will never know where I came from or where am I going to, it is impossible. I will build a model that pleases me, I will realise it is not completely correct and will try to change and improve upon it but, yet, it is still the same thing around itself, because we cannot look at it from the outside. Perhaps there is a fundamental inability to reach this goal of understanding the Universe. But I am at peace with that."

José Manuel Afonso, coordinator of the Institute of Astrophysics and Space Sciences.

[2] Website of Susan Neves: http://www.susananeves.com/

[3] The project book (ISBN 978-972-98162-1-5) can be ordered and sampled for free here: http://astrohomus.astro.up.pt/livro

[4] For a detailed record of the exhibition see: http://astrohomus.astro.up.pt/tagged/itinerancia

References

Miller, J. D. 2000, *The public understanding of science and technology in the United States: a report to the National Science Foundation; Science & Technology Indicators*, National Science Foundation

Michael, M. 1996, *Misunderstanding Science? The Public Reconstruction of Science and Technology–Chapter 5: Ignoring science: discourses of ignorance in the public understanding of science*, (Cambridge: Cambridge University Press), 107

Biographies

Pedro Figueira is a full-time researcher working on the subject of extrasolar planets. His work focuses on the development of instrumentation and software for the detection of low-mass planets. As an extension of his research work, Pedro spends part of his time on outreach activities that go from talks to participation in projects such as Astro Homus.

Susana Neves has been a freelance photographer since 2000 and has added portrait and documentation to the core focus of her work, which is stage photography, including theatre, music and various types of performance. She has participated in solo and group exhibitions in Portugal, Spain and Brazil.

Pedro Mondim is involved in many astronomy outreach activities for the general public and especially for students. He regularly presents planetarium sessions, develops new experimental activities and guides students in the hands-on laboratories. He previously worked as a trader in investment banking, while finishing his master's degree in astronomy, and he is also currently finishing a medical degree.

Paulo Pereira has been a communication designer since 1992, sharing his professional activity between design consultancies, university teaching and freelancing, with a special interest in the field of knowledge visualisation.

João Retrê currently develops astronomy educational content for teachers and students, and outreach activities for the general public; João is also the creator and developer of several innovative projects that aim to involve the academic community and general public in active astronomy communication.

Filipe Pires has a degree in astronomy from the University of Porto and has coordinated the Porto Planetarium's activities since 1997, being responsible for the production and presentation of planetarium shows, production and presentation of hands-on laboratories, and a wide diversity of public outreach sessions.

Ricardo Cardoso Reis is involved in strategy for the promotion of scientific culture, by producing and presenting planetarium shows, writing press releases about research, presenting telescope observation nights (and days), and guiding hands-on activities.

How to Simulate the Surface of a Cometary Nucleus for Public Science Demonstrations

Jean-Baptiste Renard
Laboratoire de Physique et Chimie de l'Environnement (LPC2E) — CNRS/University of Orléans, France
jbrenard@cnrs-orleans.fr

Anny-Chantal Levasseur-Regourd
Laboratoire Atmosphères, Milieux, Observations Spatiales (LATMOS)/ Sorbonne University, France
Anny-Chantal.Levasseur-Regourd@latmos.ipsl.fr

Sylvain Lefavrais
Palais de la Découverte Science Museum/ Universcience, France
slefavrais@gmail.com

Keywords
Comet activity, Rosetta *mission, public exhibitions, experiment, comet analogue, interactive exhibitions*

To celebrate and appropriately illustrate the rendezvous of the European *Rosetta* spacecraft with comet 67P/Churyumov–Gerasimenko and the landing of *Philae* on the surface of the comet's nucleus on 12 November 2014, the French science museum Palais de la Découverte developed and presented a new and original demonstration. The experiment simulates the behaviour of a cometary surface in a vacuum and shows the formation of jet-like features. We explain here how to prepare an analogue to cometary material from porous ices and carbon, how to approximately reproduce the cometary environment at low pressure, temperature and solar illumination, and how to present the experiment at a public science demonstration.

Introduction

On 12 November 2014, for the first time in the history of Solar System exploration, a module landed on the solid nucleus of a comet and sent back its observational data. The *Philae* lander was released from the *Rosetta* spacecraft, which had begun its rendezvous with comet 67P/ Churyumov–Gerasimenko (67P/C-G) in August 2014. The purpose of the *Rosetta* mission, a cornerstone of the European Space Agency (ESA) science programme, is to escort the comet until September 2016, and to study critical changes on the nucleus and in the cometary environment along its elongated orbit[1].

Local observations have already given evidence of unexpected properties of the interior of the nucleus, its surface and its surroundings. *Rosetta* continues the cometary exploration programme conducted by ESA, starting with flybys by the *Giotto* spacecraft of comets Halley and Grigg–Sjellerup (Reinhard, 1986; McBride et al., 1997), which produced the first images of a comet nucleus.

Figure 1. *The nucleus of comet 67P/C-G Churyumov–Gerasimenko, seen by the NavCam camera on board the Rosetta spacecraft on 19 August 2014. Credit: European Space Agency*

To celebrate the *Rosetta* rendezvous and prepare for the *Philae* landing, public initiatives were conducted by the media and science museums. The Palais de la Découverte in Paris worked with ESA and two French research laboratories — the Laboratoire de Physique et Chimie de l'Environnement et de l'Espace (LPC2E) in the National Centre for Science Research (CNRS), and the Laboratoire Atmosphères, Milieux, Observations Spatiales (LATMOS) at the Université Pierre et Marie Curie (UPMC) — to produce an original experiment for a public science demonstration that reproduces the composition and activity of a cometary nucleus. Although the experiment was designed before the *Philae* landing, the results obtained by *Rosetta* have confirmed that this experimental setup was appropriate.

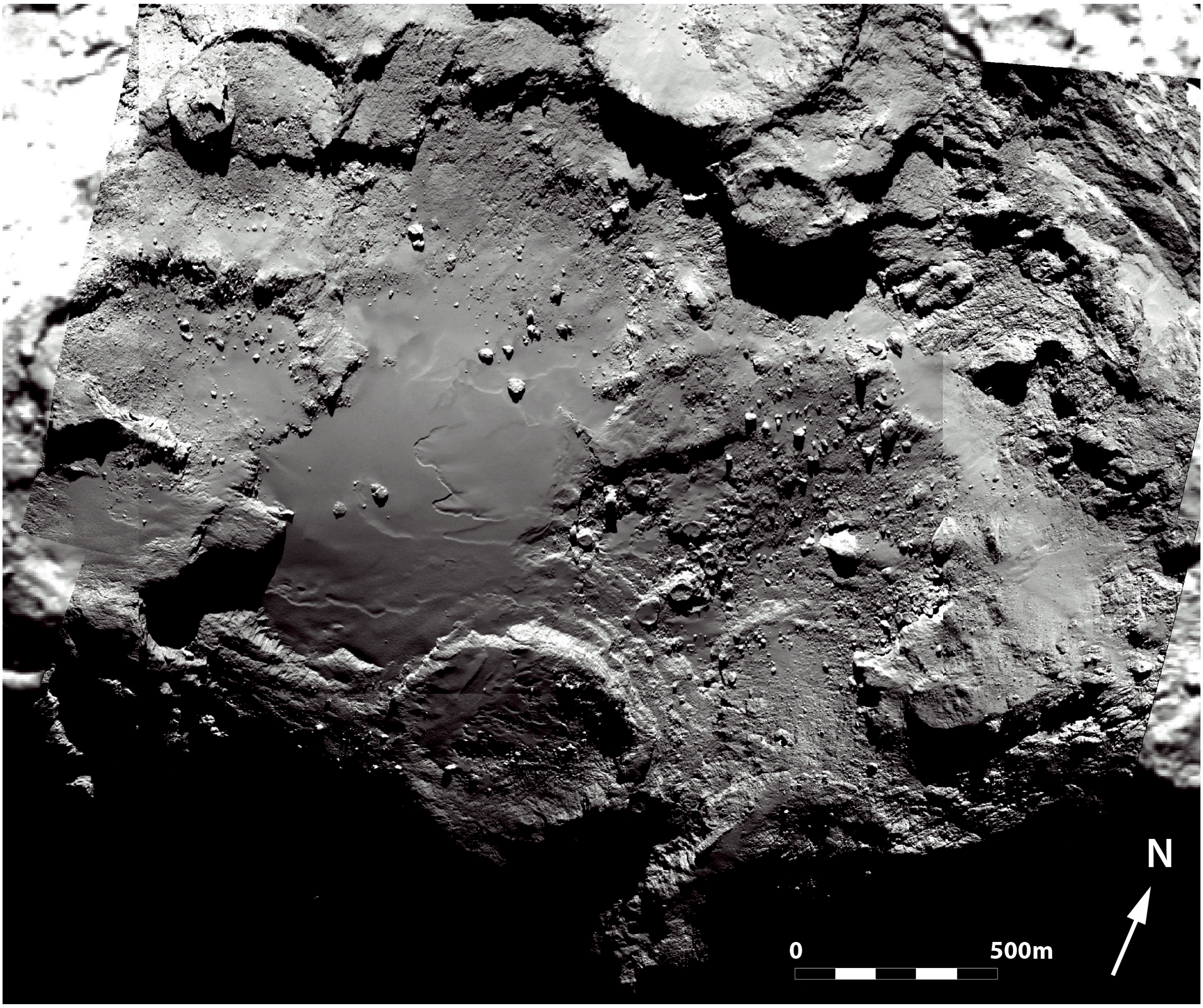


Figure 2. *Details of the surface of 67P/C-G (Imhotep region), obtained between 3 August and 5 September 2014 by the OSIRIS imaging system. Credit: ESA/Rosetta/MPS for OSIRIS Team MPS/UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA*

The experiment, first presented to the public in October 2014 at the Palais de la Découverte, is now part of the permanent exhibition. It was also presented at the science museum La Cité des Sciences in Paris on 12 November 2014 during a special public event organised for the *Philae* landing. Public events are also planned to take place between the 29 and 30 September 2016. The mission will then be coming to an end as the distance between the spacecraft and the Earth increases.

We will first summarise the motivation behind studying comets, together with key preliminary results from the *Rosetta* mission. Then we will describe how to prepare material that is a reasonable approximation to the composition of a cometary nucleus, and how to present this experiment to the public.

Why study comets and why present them to the public?

Comets are unique remnants from the era when the Solar System was forming, composed of ices from water, carbon dioxide, silicates and complex organic compounds (Cochran et al., 2015). These dark, solid bodies of a few kilometres in size are usually located in the outer reaches of the Solar System, far from the Sun, and have barely changed since their creation four billion years ago, making them valuable time capsules.

Occasionally a comet will plunge into the inner Solar System, and when a cometary nucleus is unlucky enough to approach the Sun, the solar radiation supplies it with heat. The solar radiation turns the ices that comprise the nucleus into gases, which are ejected from the sunny side of the nucleus, carrying dust particles with them. Most of this dust and gas forms a coma, a non-permanent atmosphere that envelops

Figure 3. *The cometary analogue sample in a glass container.*

the comet nucleus and can extend for tens of thousands of kilometres.

The impressive appearance of comets and the fact that they can often be seen with the naked eye makes them popular among the public, but they are also associated with interesting historical stories that can be used to attract a public audience.

Because cometary material is kept in stasis in the outer Solar System, studying it as it enters the inner Solar System should lead to a better understanding of the material from which planets in the early Solar System formed, and provide clues that will help to decipher our origins.

The bombardment of planets by comets (together with some asteroids) may also be responsible for delivering a significant portion of Earth's water and enriching the surface of the Earth with the complex organic compounds needed for life. This combination of aesthetic interest and a window onto our history make comets a perfect subject for a public demonstration.

What does 67P/C-G look like?

Rosetta started its observations of 67P/C-G while the comet was still far from the Sun and not very active. However, at its closest point of orbit, which fell between the orbits of Mars and Earth on 13 August 2015, a surge of activity led to the onset of numerous jet-like features on the surface of the nucleus and to progressive changes on its surface.

Measurements from *Rosetta* and *Philae* showed the surface to be irregular (Figure 2), with dark, dusty smooth regions, local fracturing, and large depressions and wide pits most likely resulting from ice and dust ejection (Thomas et al., 2015). Before the time of closest orbit most of the surface will have been covered by dust (Schulz et al., 2015). Evidence for carbon-bearing molecules, including compounds not previously reported in comets, were also found (Capaccioni et al., 2015; Goesmann et al., 2015), as well as molecular nitrogen and oxygen ices (Rubin et al., 2015; Bieler et al., 2015). The interior of the nucleus, composed of ices and dust, appears to be fairly homogeneous on a spatial scale of tens of metres (Kofman et al., 2015).

To simulate the behaviour on the surface of this cometary nucleus we decided to simulate a low-density mixture of ices (not only water) and dark minerals and to supply heat to the surface in a vacuum to simulate proximity to the Sun and allow the formation of jet-like structures.

How to produce cometary material for a public demonstration

The original element of this science museum experiment is to reproduce most of the conditions encountered at the surface of a comet, including the local vacuum, low temperature, solar radiation and low gravity. While the latter cannot be reproduced, since the public is not likely to be watching the experiment on board the International Space Station, all the other conditions can be easily achieved during a public demonstration. The public are also invited to watch the setting up of the apparatus and the preparation of the material to learn more about how these conditions are replicated, which takes about ten minutes.

The ingredients that are used to simulate the cometary material are less complex than the real ones, but are acceptable as a first approximation: water, frozen carbon dioxide pellets and amorphous carbon powder. Gloves must be used to protect the hands from the low temperature of the carbon dioxide pellets.

The following procedure will produce a volume of about 200 cubic centimetres of cometary analogue:

1. Pour fifty cubic centimetres of liquid water into a soft container (a little plastic bottle cut to two thirds of its height).
2. Add a few grams of carbon powder and mix with water.
3. Using gloves, add around fifty grams of frozen carbon dioxide pellets (at -78 degrees centigrade).
4. Stir the mixture vigorously for one minute while kneading the bottom of the bottle.
5. Pour in another fifty grams of carbon dioxide pellets.
6. Continue to stir and knead the mixture for a further minute. This procedure will produce porous iced granules of the order of one centimetre in size rather than just an ice block.
7. Put the granules into a small glass container and lightly pack down the sample. The bulk density of the sample inside the glass container is about 0.5 grams per cubic centimetre, comparable to the density of 67P/C-G7.
8. The last step is to cover the surface with about one millimetre of carbon powder.

Figure 3 shows the cometary analogue in its glass container.

Experimental setup

1. The small glass container containing the cometary analogue should be put inside a transparent vacuum chamber.
2. The chamber should contain a tank into which liquid nitrogen (at –196 degrees centigrade) will be poured (Figure 4). This tank has two roles: first, to maintain a low temperature in the vacuum chamber, and secondly to condense and trap the water vapour and the carbon dioxide that will be released by the sample.
3. Liquid nitrogen is poured into the tank, then the vacuum pump is switched on. Tests have shown that a curious phenomenon occurs for a pressure below ten hectopascals, whereby all of the carbon dust is violently ejected from the surface of the analogue to the wall of the chamber. This phenomenon is also observed if the vacuum is prepared first and the liquid nitrogen is added later. Two possible explanations are proposed: there could be a delay before the sublimation (where ice turns to gas) takes place when the change-of-state conditions are sufficiently exceeded; or there could be a change in the ice's morphology for critical values of temperature

and pressure, as is invoked to explain sudden outbursts that are sometimes observed on comets that are far from the Sun (Prialnik & Bar-Nun, 1992). Thus we recommend maintaining the pressure just above ten hectopascals to avoid this phenomenon.

4. A halogen lamp of at least 250 watts should be mounted typically between ten and twenty centimetres above the sample, to simulate solar illumination. The amount of energy per unit surface area is obviously greater for our sample than at the comet's surface. This is motivated by the need to accelerate the process of ice sublimation for the public demonstration.

When the lamp is turned off (assuming the environmental lightening is not too strong), nothing will happen, mimicking the conditions far away from the Sun. When the lamp is switched on, small jets of dust are soon ejected from the surface of the sample (Figure 5). The black carbon on the surface absorbs the light and the surface heats up, just as the black surface of the comet does. The gas coming from the sublimating ice accumulates in the porous parts of the sample, and is suddenly ejected, carrying the dust. Jets appear at different locations over the surface and may last from several seconds to more than one minute.

Figure 4. *Experimental setup. The glass container with the sample is in a vacuum chamber; the liquid nitrogen trap is the copper cylinder in the middle of the chamber which is open at its top; and the halogen lamp is above the sample.*

This behaviour is not observed if a single compact block of ice is used instead of granular ice. A careful examination of surface of the sample shows that some small solid particles move constantly on the surface, due to the sublimating ice and the flow of gas. After a few minutes, a crater of a few millimetres depth will form under the zone of illumination.

The jets seen in the experiment are quite similar to the large-scale jets observed by *Rosetta* (Figure 6). For our experiment, their velocity is about one metre per second. On comets, the velocity can be hundreds of times higher. This difference could be due to the near-absence of gravity on the comet, the larger pressure in the gas in the cometary material, and the acceleration of grains at larger distances by the expansion of water vapour into the interplanetary medium. The experiment can be continued until the nitrogen trap is empty, which takes about twenty minutes for the apparatus presented here.

Public demonstrations

This demonstration must be carried out by someone trained and familiar with the manipulation of liquid nitrogen and carbon ice. Some safety rules must be strictly applied: safety shoes, safety glasses and protective gloves must be worn when the carbon ice and the liquid nitrogen are being handled. Gloves and glasses can be removed after this point. Secondly, the audience must be at least one metre away from the vacuum chamber when the nitrogen trap is filled, to avoid any cold burns from any accidental spillage of liquid nitrogen.

Since the public will be standing fairly far from the vacuum chamber, a camera may be used to project the experiment in real time onto a screen; we recommend zooming in on the jets and the sample surface, to see the movement of the solid particles and the evolution of the surface better.

This demonstration has been given at the Palais de la Découverte without any age restriction, although it is not recommended for too young an audience. The audience, whatever its age, was impressed by the sudden appearance of jet-like structures when the light is switched on, and their disappearance when the light is switched off.

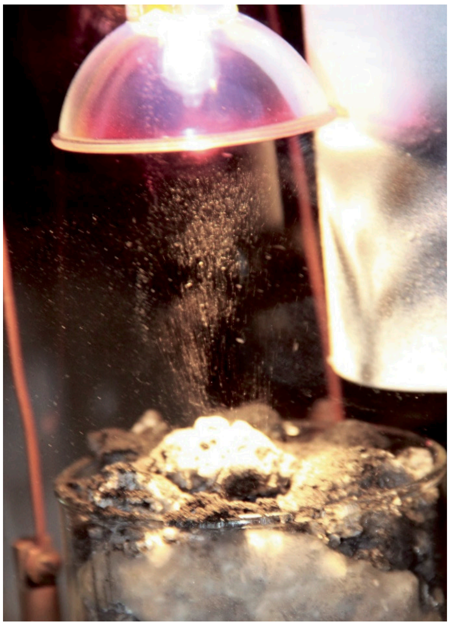


Figure 5. *Jets coming from the porous comet analogue sample once the halogen lamp is switched on. The nitrogen trap is visible on the upper left.*

When the nitrogen trap is empty, pressure can be slowly and steadily increased inside the chamber. Then, the glass container with the sample can be removed from the chamber and shown to the audience. It is even possible to touch the material, which is a dark mixture of water, ice and carbon, but do so quickly to avoid cold burns. Teenagers in particular seem to like to touch this cometary material and feel the chill from the surface.

Conclusion

This experiment is straightforward to prepare for a public demonstration and accurately illustrates the formation of jet-like structures near the surface of a comet when porous granules of ice and dust are locally illuminated in a vacuum. It also illustrates the change in the surface morphology of a comet under the local action of the jets. Obviously, the true composition of the cometary material is far more complex than the material used for this public demonstration. However, with regard to the sublimation, these laboratory conditions are not very different from the real ones. Thus, this easy-to-realise experiment can be a good complement, together with *Rosetta* and other spacecraft images or videos, to explanations of the nature and surface of comets and their evolution.

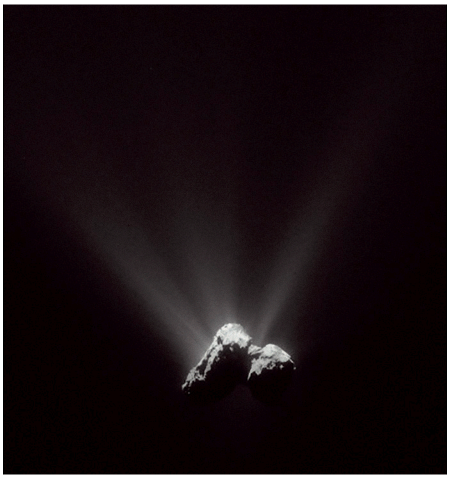


Figure 6. *Jet-like features rising from the nucleus of 67P/C-G on 16 August 2015, seen by the NavCam camera from a distance of 331 kilometres. Credit: ESA/Rosetta/NAVCAM*

Acknowledgements

We gratefully acknowledge Nicola Firth of the European Space Agency for her support in this project.

Notes

[1] More information on the *Rosetta* mission: http://www.esa.int/Our_Activities/Space_Science/Rosetta

References

Bieler, A. et al. 2015, Nature, 526, 678

Capaccioni, F. et al. 2015, Science, 6220, aaa0628, 1–4

Cochran, A. L. et al. 2015, Space Sci. Rev., 197, 9

Goesmann, F. et al. 2015, Science, 6247, aab0689, 1–31

Kofman, W. et al. 2015, Science, 6247, aab0639, 1–6

McBride, N. et al. 1997, MNRAS, 289, 535

Prialnik, D. & Bar-Nun, A. 1992, A&A, 258, L9

Reinhard, R. 1986, Nature, 321, 313

Rubin, M. et al. 2015, Science, 6231, 232

Schulz, R. et al. 2015, Nature, 518, 216

Sierks, H. et al. 2015, Science, 6220, aaa1044, 1–5

Thomas, N. et al. 2015, Science, 6220, aaa0440, 1–6

Biographies

Jean-Baptiste Renard is a senior scientist at le Laboratoire de Physique et Chimie de l'Environnement et de l'Espace (LPC2E-CNRS). He works on the detection of aerosols and dust in Earth's atmosphere and in comets. He has developed several experiments to determine the optical properties of the dust.

Sylvain Lefavrais was the creator of "*Un chercheur une manip*" at Palais de la Découverte in Paris and the director of their activity until 2015. For ten years, he has been inviting scientists to present their work for public exhibition, and helped them to design or adapt the necessary experiments.

Anny-Chantal Levasseur-Regourd is Professor Emeritus at Université Pierre et Marie Curie (UPMC), LATMOS. She works on the properties of dust particles in comets and on the structure of comets' nuclei. She is presently involved in the *Rosetta* mission and other space missions, and was the Principal Investigator for the Optical Probe experiment on board the *Giotto* spacecraft and for other space experiments. She is also active in public outreach activities related to astronomy, with emphasis on planetary sciences.

Confirmation of CAPjournal subscription

Dear Subscriber,

We are currently updating our subscribers' database for the print edition of *CAPjournal*. If you wish to continue receiving a hard copy of the journal, please read further.

On the label of the envelope in which you received this issue of the journal you will find a unique web link, written in the format http://eso.org/capj/MMMM. Please do the following:

- Find your unique web link on the envelope of this issue.
- Type the link into a browser.
- **Tick the box** next to "Subscribe to receive *CAPjournal*".
- **Press the "Submit" button.**

By following these steps you will continue to receive the **print** version of *CAPjournal*.
If you want to check your physical address, you can click on "**Update your profile**". Enter your correct address and press the "**Save**" button.

If we have your email address, we will also send you an email to remind you about the confirmation of your subscription.
This is your last chance to confirm your print subscription.

If you do not confirm your subscription by **15 September 2016**, we will assume that you no longer have an interest in receiving *CAPjournal* in print form and wish to continue reading it online instead.

Bell3D: An Audio-based Astronomy Education System for Visually-impaired Students

Jamie Ferguson
University of Aberdeen and University of Glasgow, Scotland
jfergusoncompsci@gmail.com

Keywords
Sonification, human-computer interaction, multimodal, visually impaired, software

This article presents a software system that allows astronomical data to be represented and analysed purely through sound. The goal is to use this for communicating astronomy to visually impaired students, as well as providing a new modality of astronomy experience for those who are sighted. The programme — known as Bell3D and developed at the University of Aberdeen — allows various stars to be selected from a database and then maps a variety of their astronomical parameters to audio parameters so that they can be analysed, compared and understood, solely through the medium of sound.

Introduction and background

The ability to experience the surrounding Universe is inherent and taken for granted by those who are sighted, but for those with a visual impairment, the night sky remains almost entirely impenetrable. Utilising sonification — the use of non-speech audio to convey information (Kramer et al., 2010) — allows those with a visual impairment to engage with data that would previously have only been accessible via visual modalities, and therefore available exclusively to sighted people. Sonification allows traditionally visually-oriented and data-driven fields such as astronomy to be explored and experienced by visually-impaired people, some of whom may never have had the opportunity to enjoy and experience these fields before. Furthermore, this technology allows a new, complementary modality to visual experience for sighted people, with potential applications across data science, science communication, art and education.

A simple example of sonification would be a kettle whistling when the water within it reaches around a hundred degrees centigrade. The data in this example being the temperature of the water and the information extracted from analysing the whistling being that the water has reached its boiling point. Another classic example is a Geiger–Müller radiation detector, which creates an audible click when particles associated with radioactivity strike the detector. However, sonification is not to be confused with audification. Audification is the direct playback of data samples (Kramer, 1993), as opposed to sonification which is the "transformation of data relations to perceived relations in an acoustic signal" (Kramer et al., 2010).

Sonification, in many situations, is better suited to analysing large datasets for patterns and anomalies than visual modalities (Kramer et al., 2010). For example, a significantly large dataset such as a genomic sequence, which would traditionally have taken a lot of time and resources to analyse for patterns and anomalies visually, may be sped up and compacted using sound, allowing it be analysed in the order of minutes.

Both sonification and audification have, until recently, only been applied sporadically throughout the history of astrophysical and astronomical research. The first use of these technologies in the literature was during the *Voyager 2* mission in the late 1970s (Scarf, 1982). These technologies have more recently been used to analyse radio plasma waves around Saturn (Gurnet, 2005), as well as examining large collections of solar wind data (Wicks et al., 2016). Furthermore, recent work into a sonification prototype for analysing satellite and radio telescope data (Candey et al., 2006; Diaz-Merced, 2013) has shown that researchers within the astronomy and astrophysics communities are hopeful of the potential of applications of sonification at the leading edge of these sciences.

The astronomy and astrophysics communication communities have experienced a surge in the use of sonification and audification in the last decade. Recent works including the European Space Agency's use of sonification as a method of public engagement with the *Rosetta* mission (European Space Agency, 2014); NASA's Earth+ system[1] and the Harvard–Smithsonian Centre for Astrophysics' Star Songs: From X-rays to Music project[2]. Furthermore, during the press coverage of the LIGO experiment's recent detection of gravitational waves (Abbot et al., 2016), the audification of the detection was used ubiquitously by the media and has become synonymous with the detection[3]. These technologies have only recently begun to be implemented as astronomy communication tools, but computing and audio technologies are now reaching a level of low cost and high performance that gives sonification the potential to be used throughout astronomy communication and education for the visually impaired.

How the system works

The Bell3D system[4] was developed after realising the potential of sonification and audio-based data displays within astronomy communication and education, not only as an essential resource for visually-impaired people, but also as a new, engaging medium of astronomy experience for those who are sighted. The programme is in its infancy and requires more work, but has so far proven to be an important step towards ubiquitous access to astronomy experience and education.

The software involves the user selecting a constellation and then specific stars within that constellation to be sonified — meaning data relating to the selected stars is transposed into audio signals. When stars are selected, their astronomical parameters such as magnitude, location, size and distance from Earth obtained from the SIMBAD database[5] (Wenger, 2000) are mapped onto audio parameters such as volume and pitch. The audio is spatialised, meaning that the user listening to the sounds perceives that these sounds are in three-dimensional space, with audio coming from particular areas around their head; the star's equatorial coordinates are used for this. This provides an engaging experience and gives the user an idea of where the star(s) reside in relation to Earth.

The sounds produced are simple and easy to analyse. For each star there are two sounds: a repeating "ping" sound and a continuous tone. Both can be turned on and off independently. The former encodes three data points within one sound — a star's distance from Earth, its location with reference to the Earth and its apparent magnitude — and the latter encodes one attribute — a star's colour index.

The ping represents distance, location and apparent magnitude data values in the following manner: The star's distance from Earth is represented sonically by how loud the ping is, with the volume of this sound being inversely proportional to the star's distance from Earth (the closer the star, the louder the sound); the star's location (based on its equatorial coordinates) is represented by the sound's perceived location in the three-dimensional sound space; and, finally, the star's apparent magnitude or brightness is represented by the pitch of the ping sound, the pitch being proportional to the star's apparent magnitude.

The second sound — the continuous tone which represents a star's colour index — is represented sonically by the pitch of the continuous tone. The higher the pitch of the tone, the further towards the red end of the spectrum a star is, the lower the pitch, the further toward blue end.

This rather simple mapping of parameters allows the user to make basic assumptions about stars based on what they hear. For example, one can assume that Betelgeuse is a red star, based on the fact that the pitch of its tone sound is high, or that Proxima Centauri is closer to Earth than Sirius, because its "ping" sound is louder.

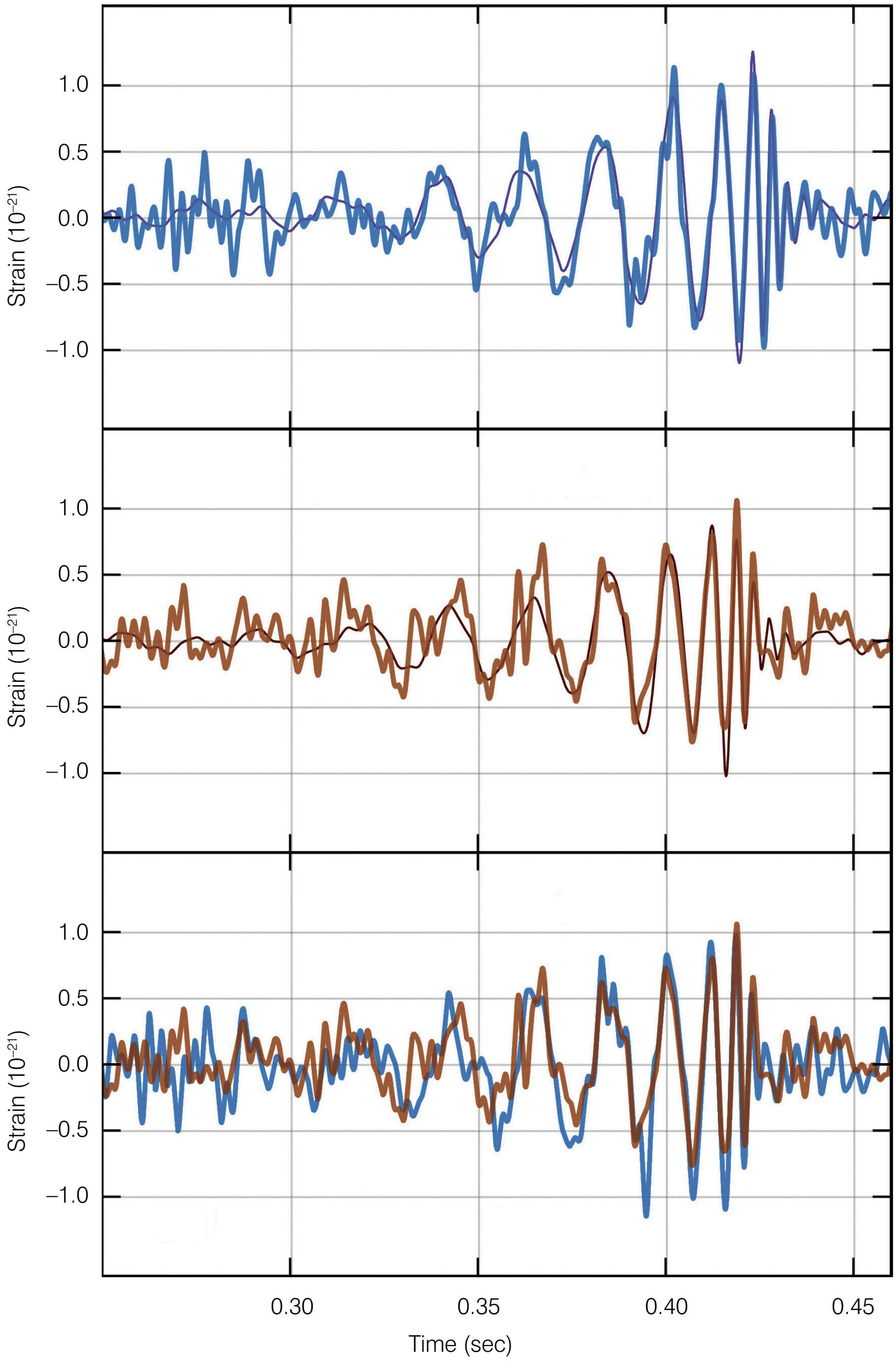


Figure 1. *The LIGO gravitational wave detection waveform, which was audified as a successful means of communicating the discovery in the media. Credit: LIGO Scientific Collaboration*

Additional applications of the system

The obvious, prevalent use for the system lies within astronomy education and communication, but uses within the arts have been discussed as potential further applications of the Bell3D software. Sonification and audification have been employed successfully within artistic endeavours attempting to explore ideas combining science and art on many occasions (Mast et al., 2015; Polli, 2005) and have been the basis of many sound artist's practice, such as Robert Alexander[6], Mélodie Fenez[7], Ryoji Ikeda[8] and Rory Viner[9]. Bell3D has the potential to be used in such a way in future either as a composition or performance tool for artists.

The system was used as an astronomy-teaching resource by Dr Wanda Diaz-Merced of the Harvard–Smithsonian Centre for Astrophysics during a recent series of lectures and workshops at South Africa's national science festival, SciFest Africa[10]. Dr Diaz-Merced used sounds from the system to explain the basic ideas of sonification and how astronomical data can be portrayed via sound.

Future work

Development of the Bell3D system and, potentially, further astronomy-related sonification tools will continue during a project that will commence in August 2016, run in collaboration with the International Astronomical Union's Office of Astronomy for Development (OAD) in Cape Town, South Africa. During this project the software will benefit from input by researchers, educators and outreach specialists at the South African Astronomical Observatory, as well as being used in OAD-led astronomy lessons with students at the Athlone School for the Blind. This will allow for preliminary evaluation of visually impaired users' responses to and perceptions of the system's sonifications.

Work on the Bell3D system will be the basis of a PhD within the Multimodal Interaction Group at the University of Glasgow, Scotland, beginning in late 2016. Plans for additions to the system include: head-tracking to provide a more engaging experience for the user; functionality for planets, galaxies and other astronomical bodies to be sonified; and a completely "visual-free" interface, so that those with a severe visual impairment can use the system without a screen via the use of haptic technologies and speech recognition. This further research will focus much more thoroughly on investigating user perception and response to sonification within astronomy in both visually-impaired and sighted groups. The prototype described here is a useful preliminary investigation into the software technology needed to facilitate such sonification interaction, however it lacks thorough empirical analysis on response and perception.

Furthermore, as the University of Glasgow played a significant role in both the recent LIGO discovery of gravitational waves (Abbot et al., 2016) and the communication of it in the media, a collaboration between the multimodal group and the astronomers and astrophysicists involved at Glasgow will be discussed in the coming years. The media presence surrounding the LIGO

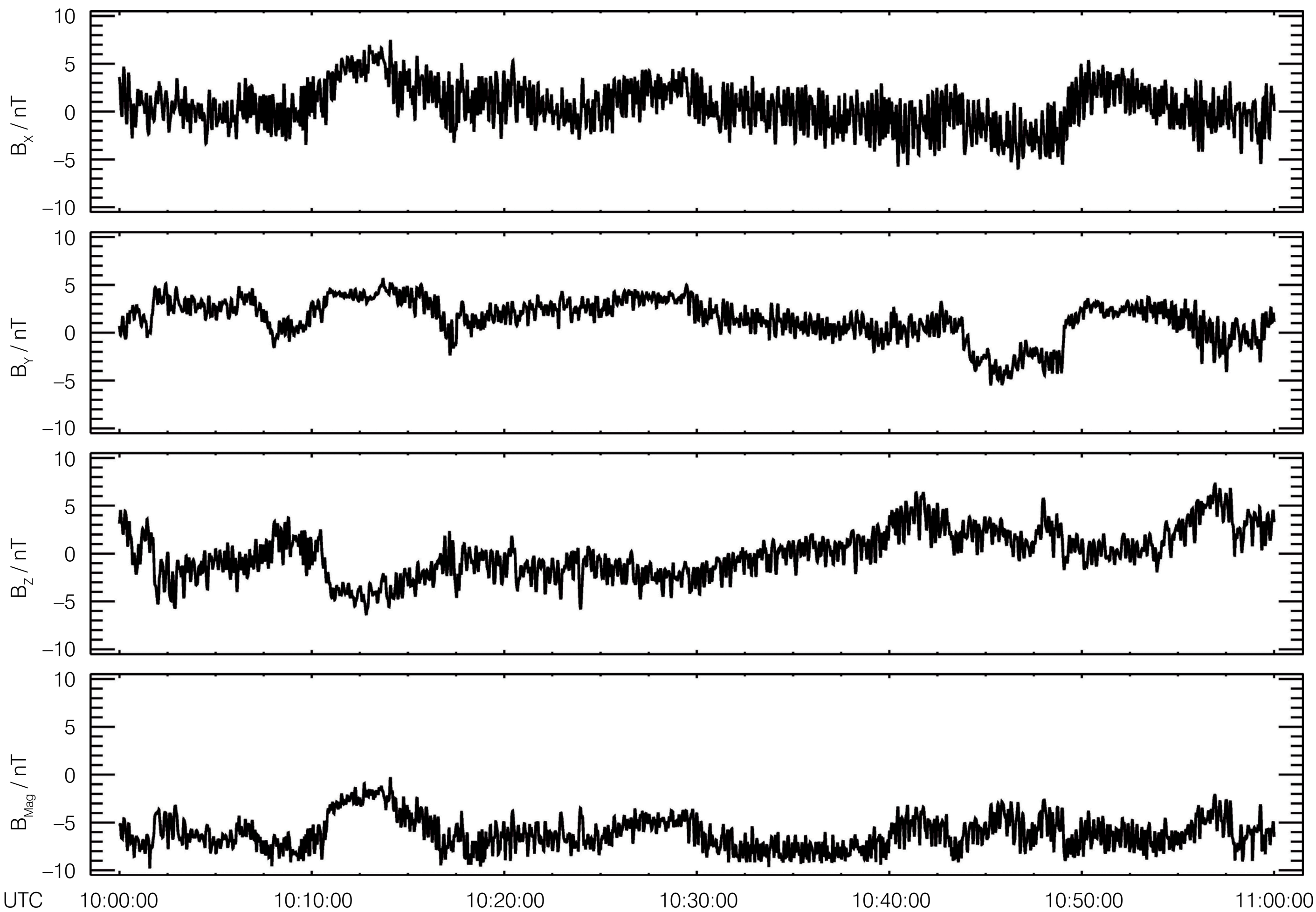


Figure 2. *The magnetic field parameters of comet 67P/Churyumov–Gerasimenko, measured by ESA's* Rosetta *spacecraft, which were sonified and the resulting audio used as the base for the highly successful blog post titled The Singing Comet[13]. Credit: Karl-Heinz Glaßmeier, Technische Universität Braunschweig, Germany*

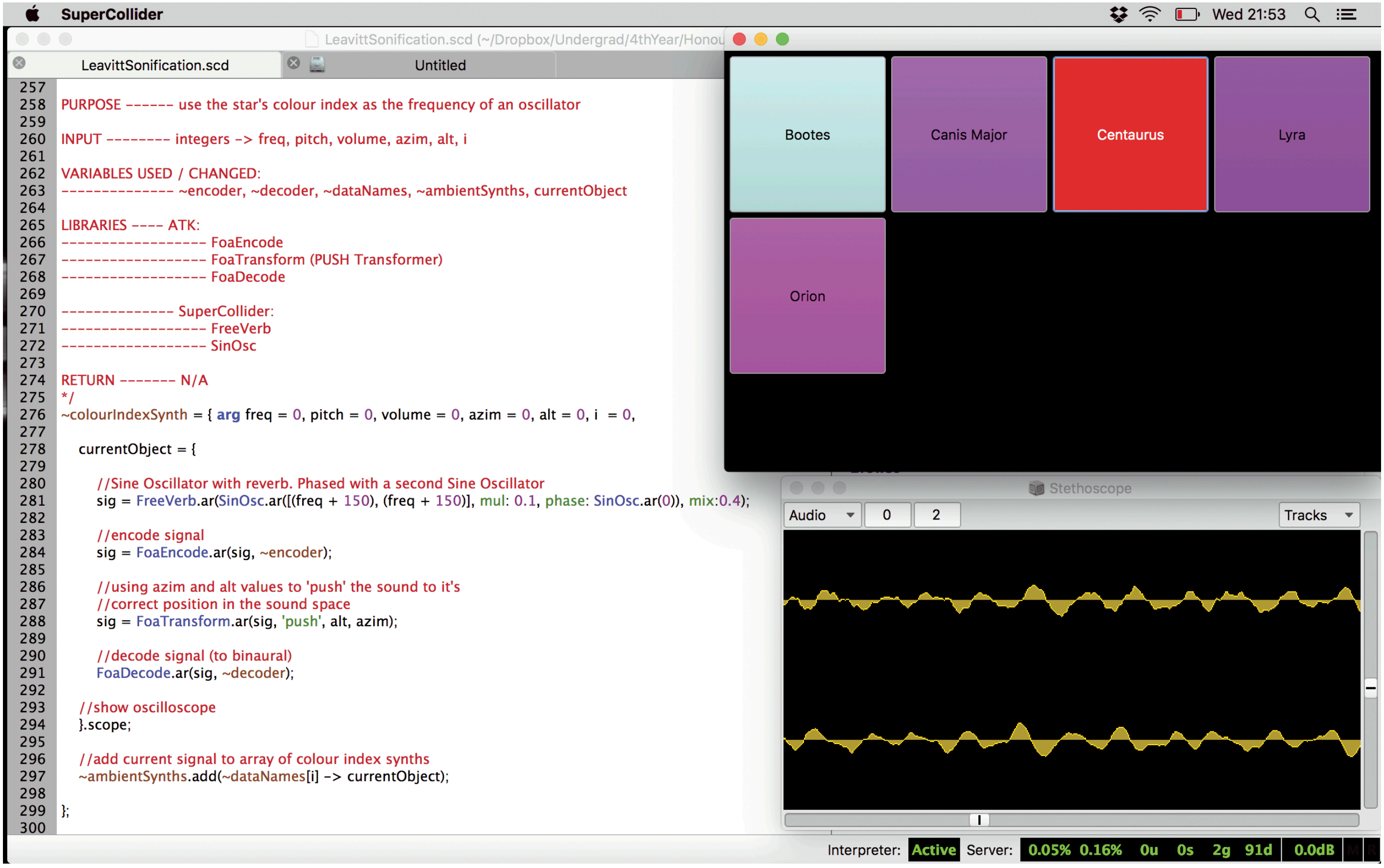


Figure 3. *Bell3D prototype running on OSX. Credit: Jamie Ferguson, University of Aberdeen*

discovery was a major win for sonification and audification as a science communication tool, therefore taking advantage of having both teams being based at the same university will allow us to capitalise on this success.

Discussions have also taken place with the Glasgow Science Centre Planetarium — one of the UK's foremost establishments for science communication — to potentially include sounds from the Bell3D system in exhibitions and presentations within the planetarium and science centre.

Conclusion

This system provides the opportunity for people of all ages with a visual impairment to access, experience and learn about basic astronomy and the night sky; an opportunity that should be accessible to everyone. With a wealth of new astronomical instruments becoming operational in the coming years, such as the James Webb Space Telescope[11] and the Square Kilometre Array[12], and the ever-increasing ubiquity and accessibility of computing devices there have never been more opportunities to communicate astronomy to as many people as possible, regardless of disability.

As our telescopes, probes and satellites continue to provide an ever-increasing volume of data to be analysed, research into utilising more senses than the eye for data analysis is becoming increasingly vital. A more multimodal approach to data analysis will not only allow vast amounts of astronomical data to be analysed more efficiently, it will also begin to open the discoveries made, and the opportunity to make them, to people who mere decades ago would have had little opportunity to be involved with astronomy.

Notes

1. NASA's Earth+ system: http://prime.jsc.nasa.gov/earthplus/
2. The Harvard–Smithsonian Centre for Astrophysics' Star Songs: From X-rays to Music project: https://www.cfa.harvard.edu/sed/projects/star_songs/
3. Audifications of LIGO gravitational wave detection: https://losc.ligo.org/events/GW150914/
4. Further details and sounds from Bell3D: http://jfergusoncompsci.co.uk/research
5. SIMBAD database: http://simbad.u-strasbg.fr/simbad/
6. Article by Michael Byrne, 2013 on Robert Alexander *Spaced Out: 'The Space Composer' is Making Music With the Sun*: http://motherboard.vice.com/read/spaced-out-making-music-with-the-sun
7. Sound artist Mélodie Fenez: http://www.a-melodie.com/
8. Sound artist Ryoji Ikeda: http://www.ryojiikeda.com/
9. Sound artist Rory Viner: http://rory-viner.tumblr.com/
10. Video of SciFest lecture: https://www.youtube.com/watch?v=QilOFTvCTzA
11. James Webb Space Telescope: http://www.jwst.nasa.gov/

[12] Square Kilometre Array: https://www.skatelescope.org/

[13] European Space Agency, *The Singing Comet*, 2014, available http://blogs.esa.int/rosetta/2014/11/11/the-singing-comet/, (accessed 9 January 2016).

References

Abbott, B. P. et al. 2016, Physical Review Letters, 116, 6, arXiv:1602.03837

Candey, R. M., Schertenleib, A. M. & Diaz-Merced, W. L. 2006, Proceedings of the 12th International Conference on Auditory Display (ICAD), London, UK

Diaz-Merced, W. L. 2013, *Sound for the exploration of space physics data*, PhD Thesis, University of Glasgow available http://theses.gla.ac.uk/5804/1/2014Diaz-MercedPHD.pdf, (accessed 15 June 2016)

Gurnett, D. A. et al. 2004, *The Cassini-Huygens Mission*, (Netherlands: Springer)

Kramer, G. 1993, *Auditory display: Sonification, audification, and auditory interfaces*, (London: Perseus Publishing)

Kramer, G. et al. 2010, Faculty Publications, Department of Psychology, University of Nebraska, Paper 444, http://digitalcommons.unl.edu/psychfacpub/444

Mast, S. et al. 2015, Leonardo, 49, 1, 19

Polli, A. 2005, Leonardo, 38, 1, 31

Scarf, F. L. et al. 1982, Science, 215, 4532, 587

Wenger, M. et al. 2000, Astronomy and Astrophysics Supplement Series, 143, 1, 9

Wicks, R. T. et al. 2016, The Astrophysical Journal, 819, 1, 6

Biography

Jamie Ferguson completed his undergraduate studies in computing science at the University of Aberdeen earlier in 2016. He is beginning a PhD at the University of Glasgow later this year on multimodal computer applications within astronomy and astrophysics.

Colophon

Editor-in-Chief
Georgia Bladon

Executive Editor
Lars Lindberg Christensen

Proofreader
Anne Rhodes

Layout and Production
Mafalda Martins
Joanna Law
Jutta Boxheimer

Contributors
Jean-Baptiste Renard
Sylvain Lefavrais
Anny-Chantal Levasseur-Regourd
Andrew Fraknoi
Pedro Figueira
Susana Neves
Pedro Mondim
Paulo Pereira
João Retrê
Filipe Pires
Ricardo Cardoso Reis
Jamie Ferguson
Halley Davies
Martin Hellmich
Rebecca Davies
Lars Lindberg Christensen
Gabriella Bernardi
Georgia Bladon

Web Design and Development
Raquel Shida
Mathias Andre

Distribution
Sebastian Wassill
Oana Sandu

IAU DIVISION C
Commission C2 Communicating Astronomy with the Public Journal Working Group
Farid Char
Lars Lindberg Christensen
Georgia Bladon
Pedro Russo
Detlef Koschny
Bruno Merín Martín

Sponsors
IAU and ESO

Address
CAPjournal,
ESO ePOD,
Karl-Schwarzschild-Strasse 2
85748 Garching bei München
Germany

E-mail
editor@capjournal.org

Website
www.capjournal.org

Phone: +49 89 320 06 761
Fax: +49 89 320 2362

ISSNs
1996-5621 (Print)
1996-563X (Web)

CAPjournal submission guidelines

We are keen to encourage readers to submit their own articles, reviews, etc. Some key points are addressed below.

Technical and esoteric language should be either avoided or used with a footnoted explanation if absolutely required. All contributions will be made to conform to British spelling and punctuation practice. Figures and tables should be referred to "Figure n" and "Table n" respectively. Acronyms should be spelt in full once and then parenthesised; henceforth they can then be used as lettered acronyms. Numerals should be used for numbers greater than two words and always for numbers greater than ten.

Manuscripts should be delivered in MS Word or text (.txt) format, with no formatting apart from bold, italics, super and subscripts. Hard carriage returns after each line should be avoided, as should double spacing between sentences. If the contribution contains figures, these may — just for the sake of overview — be pasted inline in the Word manuscript along with the caption (Word files below 4 MB are encouraged). However, images must also be delivered individually as Tiff, PDFs, vector-files (e.g.,.ai,.eps) in as high a resolution as possible (minimum 1000 pixels along the longest edge).

Copyright
Authors are solely responsible for ensuring copyright clearance to reproduce illustrations, text, etc., for which they themselves do not own the copyright. *CAPjournal* accepts only original submissions and will only reproduce previously published work by special arrangement.

Contact
Submissions should be sent to the Editor:
editor@capjournal.com

Submit articles for one of the following journal sections:

- **News**
- **Explain in 60 Seconds**
- **Announcement**
- **Best Practice**
- **Research & Applications**
- **Column**
- **Review**

www.capjournal.org
Online issues
Free subscriptions
Article submission

Sponsors