CAP journal

Issue 29 | March 2021

Communicating Astronomy with the Public

Citizen Science
Motivations and patterns of engagement of CosmoQuest participants

Community Building
First-hand experiences using astronomy outreach in East Java, Indonesia

Astronomy Talks with Tactile Resources
Making astronomy accessible to blind and visually impaired (BVI) communities across Chile

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IAU

Telescopes for All is a project that distributes telescopes signed by astronauts and scientists, including Nobel Prize winners, to underserved communities around the world. In 2020, 17 communities of underrepresented groups were selected to receive the telescopes. Telescopes for All is a partnership between the IAU Office for Astronomy Outreach, Sterren Schitteren Voor Iedereen (SSVI, Stars Shine for Everyone), Bresser Telescopes and Leiden University. Credit: Jean Pierre Grootaerd, SSVI

Telescopes For All
In Nepal wit Sristi KC at Blind Rocks! Kathmandu

Telescopes For All
Peru Huaycán Cultural with Eduardo Quispe Salcedo

Telescopes For All
with Manuel E. Grulion in Dominica Republic at Sociedad Astronómica Dominicana

Telescopes for All
In Spain with Juan Carlos Gomez at project"Socio-educative suport for migrant and refugee children" in Andalusia.

Telescopes For All
in Brunei with Bazilah Za at Astronomical Society of Brunei Darussalam (PABD)

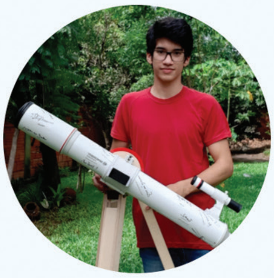
Telescopes For All
In Chile with Nadia Valenzuela. "Hermanos Carrera" School, Angol, Los Lagos Region

Telescopes For All
In Tunisia with with Ahlem Loudaief at Secundary School Endifah-1 Astronomy Club

Telescopes For All
In Argentina with Carlos Acebal at "Telescopio para todos en el Corazón de la Argentina"

Telescopes For All
Mehdi Essaidi In Morocco with: Astronomy is Open to Everyone, Asif n Ait Bounouh Association for Culture and Awareness

Telescopes For All
In Haïti with Geosciences Schneider Munder at Groupe Astro Jeunes Ado



Telescopes For All
In Paraguay with Jose Daniel Pinho Avalos at Mirando al Cielo

Telescopes For All
In Saigon with Duy Dang Tuan 'Saigon Astrokids' (SAK), a social enterprise founded by leaders of Ho Chi Minh City Amateur Astronomy Club (HAAC)

Telescopes For All
In Indonesia Miratun Nafiah, club ANDROMEDA, Universitas Ahmad Dahlan,

Telescopes For All
In Panama with Karen Avila at at Panama Rainforest Discovery Center

Telescopes For All
in Brazil with Ricardson B.Vieira. Seichu-Jurá Project, Sociedade de Astronomia do Maranhão

Telescopes For All
In Tuktoyaktuk, Canada (arctic circle) with Michèle Tomasino at Mangilaluk School

Editorial

Welcome to the 29th edition of the CAPjournal! With our previous two issues dedicated to astronomy outreach for development and the IAU's 100th-anniversary celebration, the CAPjournal returns once again with a regular edition.

We start by highlighting the winners of the 2020 Telescopes for All programme, which sent 17 telescopes to groups in 17 countries to be used in under-represented communities. Led by the IAU Office for Astronomy Outreach and Stars Shine for Everyone in collaboration with Leiden University and Bresser Telescopes, this programme is a direct legacy of the IAU100 celebrations.

Next in this issue is information on the upcoming edition of the Communicating Astronomy with the Public Conference, the CAP 2021 Virtual Conference. The conference organisers have provided information on what to expect from the first free and entirely virtual CAP Conference. Please see the announcement section to learn how you can engage and present your work at the largest conference in astronomy communication.

At the core of this CAPjournal you can then find information about a number of citizen science and astronomy outreach projects around the world. Leaders in the citizen science CosmoQuest present their research on the motivations and engagement patterns of their participants, while organisers for FOKALIS JATIM share their community-building experiences using astronomy in Indonesia. The Dedoscopio team in Chile explains how they have created astronomy activities for the blind and visually impaired communities, educators from the Lowell Observatory in the US share how they have created a live observing programme and, finally, the creators of VOS⁴O describe their free, simple web service to generate scale models of our Solar System.

In 2020, the world changed, deeply impacted by the COVID-19 pandemic. Our team is in awe of the numerous efforts and inspiring examples our community of astronomers, communicators and outreach professionals have undertaken to keep their community actively engaged with astronomy. To celebrate these accomplishments and share the best practices with the community at large, our next issue #30 of CAPjournal will be a special edition on Communicating Astronomy in a Time of Confinement.

Finally, we want to thank our editorial board, peer reviewers and contributing authors for their efforts in bringing you this edition of CAPjournal. If you are interested in sharing your work in a future issue of the CAPjournal, we continually accept abstracts and encourage you to submit for consideration in issue #31, which will be a regular issue.

Wishing you clear skies and good health,

Lina Canas
Editor-in-Chief

Cover: Tusi Bohm Planetarium Azerbaijan, one of the telescope winners for the 100 Hours of Astronomy in 2019. Credit: Heydər Aliyev Mərkəzi Bakı

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Column

Explained in 60 Seconds: Impact of Satellite Constellations in Astronomy

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Astronomers are living in a conundrum. The development of space and technology has now allowed for private and public organisations to create large satellite constellations. These 'constellations' of similar type and function operate in unison and are deployed for a variety of purposes, including geodesy, satellite telephony, Earth observation, and most recently global satellite internet[1]. While astronomers, in general, acknowledge the merits of worldwide internet services that satellite constellations can supply, especially to previously hard-to-reach areas, there are repercussions for anyone who looks at the night sky. The good news is that these repercussions can be partially mitigated and many organisations are working on it.

Within the field of astronomy, there are new observatories and instruments coming online in the next decade that will substantially increase humanities' understanding of the universe. However, these new capabilities require a dark night sky to uncover the secrets of the most fundamental questions about the nature of our universe as this next decade will also see the launch of over 100,000 satellites into low-Earth orbit.

In order to investigate the impact from these satellite constellations to the field of astronomy, as well as possible mitigation strategies, two workshops were conducted in 2020, SATCON1 (June) and Dark and Quiet Skies (October). Astronomers and individuals from the satellite and illumination engineering industries, among other stakeholders, conducted research and held discussions in the areas of observation, simulation, mitigation testing, and metrics to produce recommendations for stakeholders. The results were presented at the workshops and published in reports online[2].

The reports suggest several strategies for observatories and satellite companies to mitigate the impacts associated with satellite constellations. These strategies include lowering satellite orbits so that they are in the Earth's shadow much of the time, using materials on the satellites that are less reflective (e.g., darkening them with paint or sun shields, as SpaceX has done), adjusting attitudes so that most of the surfaces of the satellites are not facing the Earth, having fewer satellites launch (and only the number needed), orbit-raising or deorbiting satellites as soon as possible, supplying astronomers with the location and timing of these satellites over the observatories, and helping astronomers create avoidance and streak removal software.

At this point in time, no combination of mitigation strategies will completely remove the impacts of low-Earth orbit satellite trails on the science programmes for the upcoming generation of optical astronomy facilities. If the companies cannot meet astronomers even part way, then satellite constellations will endanger these new technology telescopes coming online in the next decade, just as existing telescopes have been affected. Additionally, this issue of dark skies affects more than just professional astronomers; satellite constellations are even impacting amateur astronomy and cultural traditions like wayfinding now.

The next workshops on the effects of satellite constellations on astronomy will be held in May and October 2021. Both meetings will use the reports from the first workshops to explore ways astronomers, satellite operators, and other stakeholders can collaborate on implementing the highest-priorities or most achievable recommendations and consider the resources required to do so. The Dark and Quiet Skies executive summary will be presented at the UN COPUOS[3] Science and Technical Subcommittee meeting in April 2021 to increase global awareness of this issue.

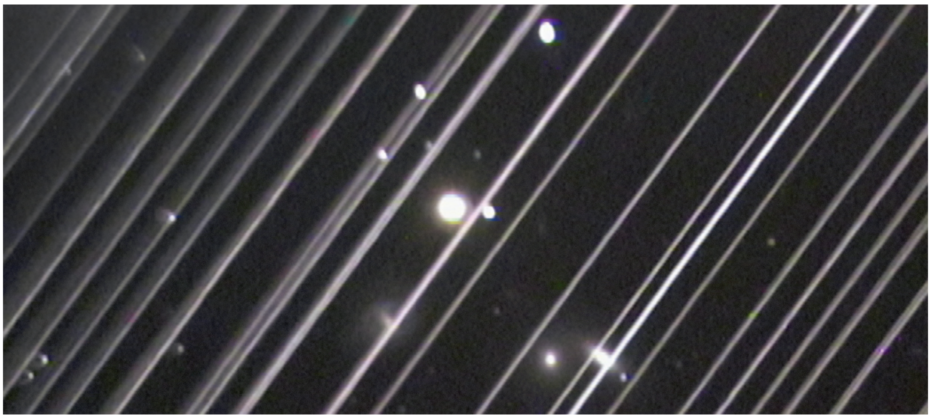

Figure 1. *This image, taken on 25 May 2019 with a telescope at Lowell Observatory in Arizona, US, illustrates the impact of satellite constellations on research programmes in astronomy. The diagonal lines running across the image are trails of reflected light left by more than 25 Starlink satellites as they passed through the telescope's field of view. Credit: Victoria Girgis/Lowell Observatory*

Notes

[1] International Astronomical Union theme "Satellite Constellations": https://iau.org/public/themes/satellite-constellations/

[2] Reports from the 2020 satellite constellation workshops on the NOIRLab website: https://noirlab.edu/public/products/techdocs/

[3] UN Committee on the Peaceful Uses of Outer Space (COPUOS) website: https://www.unoosa.org/oosa/en/ourwork/copuos/index.html

Communicating Astronomy with the Public (CAP) Conference Goes Virtual in 2021

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The next Communicating Astronomy with the Public (CAP) Conference will be held online 24-27 May 2021. The free virtual conference will provide space for science communication professionals of all fields as well as professional and amateur astronomers to discuss how to best engage the public in astronomy during a global crisis, among other topics. CAP is also an excellent opportunity to learn from peers and make new connections.

In 2021 International Astronomical Union (IAU) Commission C2, Communicating Astronomy with the Public (CAP), will host an entirely virtual edition of its long-running Communicating Astronomy with the Public Conference (CAP Conference) series. Registration for the free conference is open through mid-May.

The CAP 2021 Virtual Conference will be held 24–27 May 2021, under the central theme 'Communicating Astronomy with the Public in the Age of Global Crises'[1].

The topics to be discussed at the conference include:

- Nontraditional ways of communicating astronomy during a pandemic;
- Communicating climate change through astronomy;
- Communicating astronomy and its relevance in a post-factual society;
- Anti-science actions, disinformation and fake news;
- Promoting diversity and inclusion through astronomy communication;
- Current challenges in astronomy communication;
- The media's role in astronomy communication;
- Using multimedia, social media, immersive environments and other technologies for public engagement with astronomy;
- Communicating astronomy across different regions.

Figure 1. *Logo for the CAP 2021 Virtual Conference. Image Credit: Caterina Boccato/IAU Commission C2*

In addition, the SOC is planning two special sessions, for which abstracts are also invited:

- Legacy of the IAU100 Celebrations;
- Communicating Astronomy: The IAU Strategic Plan 2020–2030.

The conference will feature live online sessions for different time zones as well as recorded sessions where participants will be able to watch at their convenience and later engage in live discussions with the speakers and other participants. There will also be discussion forums and networking sessions for participants and speakers to reach out and engage with each other. Attendees will also have the opportunity to add their own topics for discussion during 'unconference' slots.

We invite professionals in science communication, informal education, and outreach, as well as professional and amateur astronomers, planetarium and science centre staff members, journalists, public information officers, and other creatives to attend the conference to meet peers, exchange ideas and discuss best practices.

The conference is free to all attendees thanks to The Kavli Foundation, which has provided a grant to strengthen public engagement programmes and scientific meetings of the IAU. Registration is however required in order to gain access to the streaming platform.

To stay up to date with the latest information on the Virtual CAP 2021 and future news and updates, please join the conference mailing list[2], follow us on social media[3] with the hashtag #VirtualCAP2021, or send an email to cap2021@oao.iau.org.

Notes

[1] Virtual CAP 2021 Official Website: https://www.communicatingastronomy.org/cap2021/ and IAU Announcement: https://iau.org/news/announcements/detail/ann21007

[2] Mailing List: https://www.eso.org/lists/listinfo/capconferences

[3] Twitter: https://twitter.com/CAPconference and Facebook: https://www.facebook.com/CAPconference/

Box 1. Important Dates

- Grant winners announcement & accepted works notified: 5 April 2021
- Submissions of presentations & posters: 5 May 2021
- Registration deadline: 15 May 2021
- Virtual CAP 2021: 24–27 May 2021

Motivations and Patterns of Engagement of CosmoQuest Participants

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motivations, engagement, online, citizen science

Citizen science in astronomy involves the exchange of volunteer effort for scientific data or data analysis needed by researchers. In order to maximize the effectiveness of citizen science projects, the motivations of these volunteers should be understood as they initially draw volunteers into the project and encourage continued engagement. Through detailed interviews with 30 participants in an online astronomy citizen science project, we categorise initial motivating factors into intrinsic and extrinsic factors and reasons for ending participation into external and internal factors. We find that volunteers with more frequent engagement in citizen science tasks are more intrinsically motivated than those who participate less frequently. Our findings that infrequent visitors, who as a whole make a significant contribution to citizen science projects, are often extrinsically motivated reveals a need for both intrinsic and extrinsic motivating factors to be built into a project and project communications in order to diversify the pool of volunteers and to maximise participation. In addition, we report on factors that led to citizen scientists stopping their engagement with a project over the short and long term.

Introduction

Citizen science, a form of public participation in scientific research, continues to provide opportunities for lay participants to work with professional scientists in data collection and analysis, engaging volunteers in various aspects of science *(Shirk et al., 2012)*. Participation in online citizen science is increasing with the proliferation of online platforms and tools, giving participants with access to the Internet a wide range of projects and tasks from which to choose, such as classifying and/or interpreting videos, pictures, and sounds, running simulations, and playing computer games *(Bonney et al., 2014; Curtis 2015a)*. Within the field of astronomy, there has been a steady increase in the number and types of citizen science projects available over the past decade, as well as an increase in the number of participants, and this trend is expected to continue to increase *(Marshall, Lintott, & Fletcher, 2015)*. Many of these are online projects, involving large datasets and providing an online forum to facilitate participant communication (e.g., Moon Mappers, GalaxyZoo, Ice Investigators, PlanetHunters).

Researchers can make the most of the citizen science process by centring and understanding the experience of the participants. One way to understand this is by exploring what motivates citizen scientists to start, continue and end their engagement with projects. This can also give citizen science project managers insight into what kinds of messaging and incentives to build into the project and include in recruiting new participants. Citizen science has a “long tail” of participants that engage casually, infrequently, and/or over a short period of time. Although this long tail does not, as a whole, contribute the majority of data collection or analysis to the project itself *(Eveleigh et al. 2014)*, wide participation fulfils another primary goal of citizen science, that of using it as a science communication tool. Specifically, citizen science projects give participants unique insight on the processes of science, a lesson that is often difficult to achieve otherwise in formal or informal education *(Bonney et al., 2015)*.

Several groups of researchers have studied the participants involved in online astronomy citizen science, looking at their motivations, types and patterns of engagement, and learning *(see Gugliucci, Gay, & Bracey, 2014; Prather et al., 2013; Raddick et al., 2010, 2013; Reed et al., 2013)*. Much of the motivation research has been conducted with the purpose of improving participant recruitment and retention, seeking to understand who participates and what can lead to a better experience for the public and the scientists. However, much citizen science research investigates motivations for projects related to ecology and conservation which offer participants a connection to their specific location and involvement in a problem of immediate ecological importance *(e.g. He et al. 2019)*. Also, many of these studies have not gone beyond classifying participants' motivations at a surface level and do not look more deeply at the underlying motivational constructs. *Curtis (2015b)* went beyond the initial motivation to explore motivation for sustained participation for one such astronomy project, Planet Hunters, and two non-astronomy projects. As online citizen science has expanded to include many popular projects outside of astronomy, so has the research into participant motivations.

We set out to do a deeper exploration of how and why participants in an online astronomy citizen science project begin, continue and end their engagement. Building on results from an initial large survey study, we investigated online astronomy citizen scientists' motivations for participating in these projects. We interviewed participants engaged in CosmoQuest (cosmoquest.org), a collection of online astronomy citizen science projects, to gain a greater understanding of participants' rationale behind participating in citizen science and to learn if participants' original reasons for participating changed over time. Understanding why participants originally engage in citizen science and what drives continued engagement, as well as correlations with frequency of engagement, can ultimately help to understand and improve online citizen science projects' connection to and communication with their participants. In this paper, we present the findings from our thematic analysis of the interviews. Our study expands on previous work by allowing free responses to questions of motivation and categorization of these responses into intrinsic and extrinsic categories. Furthermore, we look at the motivations alongside the interviewees' self-reported level of engagement with citizen science projects. Finally, we look at how motivations have changed and reasons why participants stop their engagement for the day or for good.

Motivation and Engagement in Online Citizen Science

Many citizen science projects exist entirely on the Internet. Participants access projects like Fold-it, GalaxyZoo, Old Weather and Moon Mappers through a website interface and complete their tasks online. Some projects are passive, meaning that the participant's computer is doing most or all of the work, while others require more active involvement from the participant such as identifying and marking images. Participants have the freedom and flexibility to login anytime and anywhere they have an Internet connection and spend as much or as little time as they'd like engaging in the projects *(Curtis, 2018)*. Online citizen science participants tend to be white, male, middle-aged, and scientifically/technologically literate *(Gugliucci, Gay, & Bracey, 2014; Curtis, 2018)*. Citizen science projects are looking increasingly for ways to attract a more diverse audience in order to facilitate more inclusive science communication. For example, recruiting a wide and diverse audience to citizen science has the effect of creating more "societal value" of the science as shown by *Brouwer & Hessels (2018)* who targeted specific households with invitation to participate in citizen science projects related to drinking water research. *Füchslin, Schäfer, and Metag (2019)* found that gender, education and scientific literacy were not significant predictors for potential citizen scientists in Switzerland, finding that a positive attitude towards science was a better predictor. Although this indicates that many citizen science projects are mainly reaching those already inclined towards science, it is encouraging that other measures of diversity in this sample did not appear to affect participation.

Participants usually offer several different reasons for taking part in citizen science projects, often focusing on an interest in the scientific content and in helping the scientific endeavour. For example, *Raddick et al. (2010)* explored the motivations of Galaxy Zoo users by analysing open forum responses and interviews of 22 volunteers. Using a grounded theory approach, the researchers identified 12 categories of motivation, including interest in astronomy, helping, and learning. Most participants indicated more than one motivational factor. These categories formed the basis of a larger survey by *Raddick et al. (2013)* of 11 000 users that found "contribution to science" to be the most prevalent primary motivation (39.8%) across genders, ages and educational levels. However, these motivations are only reported for a single point in time. Many participants' motivations shift over time *(Rotman et al. 2012; Iacovides et al. 2013)*, and they may leave and return to a project or leave permanently as their reasons for participation change.

Participant engagement in citizen science projects has been the subject of a growing number of studies, with some exploring how engagement intersects with motivation. *Everett & Geoghegan (2016)* examined levels of participants' engagement and enthusiasm for the scientific process, particularly those who are already engaged as traditional amateur naturalists. They note in their qualitative study of a biodiversity related project that there is no one correct approach to increasing engagement, but that a range of approaches is needed to reach a range of audiences. Astronomy has a parallel, in that many citizen science participants also self-identify as amateur astronomers *(Gugliucci, Gay, & Bracey, 2014)*.

Nov, Arazy, & Anderson (2011) used the framework of intrinsic vs. extrinsic motivators in looking at other large collaboration activities, such as Wikipedia. This study compared low granularity citizen science tasks (i.e., more passive, such as SETI@Home, where the work is done by the idle computer) vs. high granularity citizen science tasks (more active, such as Stardust@home, where the user interacts with the data). They found higher granularity correlated with higher motivational levels in general. Motivations were also correlated with intention and contribution level. These researchers stressed the importance of intrinsic motivators as driving project participation.

Citizen science project communications may offer extrinsic motivators to encourage participation, such as challenges and "gamified" aspects. *Tiago et al. (2017)* show that participants that are most engaged have high levels of intrinsic motivations such as "enjoyment" and "perceived competence." They conclude project design that encourages fostering those intrinsic motivation after using initial extrinsic instruments.

Iacovides et al. (2013) provide a different view. They found that in an online project with gaming aspects, many individuals begin to participate due to their intrinsic interest in the topic, not the gamified aspects. However, these extrinsic motivators, the game elements and community engagement through forums, encourage further engagement with the project.

Eveleigh et al. (2014) looked at the motivations of "dabblers and drop-outs," or users who do a project for a short period of time or sporadically, also known as "the long tail" referenced earlier. Studying patterns of engagement and types of motivations in Old Weather, they found that participants with intrinsic motivators are more likely to make more varied contributions. Reasons for dropping out included boredom and lack of information from project leaders about where the project was heading.

Methods

Overview of CosmoQuest

CosmoQuest (cosmoquest.org) is a suite of online astronomy-themed citizen science projects that ask participants to explore the surfaces of solar system objects using images from several NASA missions. Citizen scientists identify and mark craters and other surface features of Mars, Mercury, the Moon, and the asteroid Vesta to help scientists create detailed maps of these worlds. CosmoQuest offers an online forum for community interaction, a project blog and support materials for use in classrooms and planetariums.

Initial survey

Between May 16 and June 12, 2013, we conducted an online survey given to visitors of CosmoQuest who were recruited during a visit to the site. The online survey was designed to understand who was participating in CosmoQuest and how CosmoQuest could improve. This survey was used to determine general demographics and initial motivations of CosmoQuest users. As reported in *Gugliucci, Gay, and Bracey (2014)*,the survey was completed by 334 respondents. Respondents were given a series of statements based on *Raddick et al. (2013)* and asked which one was their primary motivator. Respondents reported mostly participating in CosmoQuest for the learning opportunity, personal interest and to give back to science. Half of the survey participants reported their primary motivator for participating in CosmoQuest as being "I am interested in astronomy/space science" and "I am excited to contribute to original scientific research" (Table 1). After collecting the survey results, additional information was desired on why individuals were excited to contribute to scientific research in more detail and without the restrictions of a multiple-choice response.

Participant selection and consent

Participants were recruited from a community of users engaged in online astronomy citizen science projects at CosmoQuest. Selection was purposefully done from server logs to recruit users with a range of citizen science experience on the site. The individual's duration as well as the number of CosmoQuest projects the individual participated in were both considered for inclusion in the study. Participants who had been involved in CosmoQuest for less than one month were categorised as short duration participants. Participants who had participated in CosmoQuest for three months or more were considered high duration. Users who had participated in single or multiple projects on the site were also selected. This was meant to strike a balance in the types of individuals to be interviewed and allowed researchers to evaluate their motivations and activities related to time spent engaging in astronomy citizen science projects to help understand the primary driving forces for individuals' engagement.

Primary Motivation	Count	Percent
No Answer	44	13
I am excited to contribute to original scientific research.	83	24
I was looking to find ways to learn about the solar system.	15	4
It's fun to make friends from all around the world.	5	1
I find it to be a useful resource for teaching.	14	4
I enjoy looking at the beautiful images.	6	1
I have a lot of fun marking surface features.	1	0
I am amazed by the rocky worlds in our solar system.	1	0
I am happy to help.	10	2
I wanted to see how CosmoQuest worked.	8	2
I am interested in astronomy/space science.	81	24
I find science really interesting.	25	7
I like to participate in crowdsourced projects.	3	0
I want to discover something previously unknown to researchers.	13	3
I might discover something scientifically interesting.	9	2
Other	16	4

Table 1. *Primary motivation for engaging as selected by users of CosmoQuest.org.*

Data collection

The team contacted 200 individuals via email, and 60 responded. We were able to schedule interviews with 33 participants which were all who agreed to be interviewed. All 33 individuals were interviewed between May and October of 2014. All participants were read a Statement of Consent before each interview and asked to give a verbal, recorded "yes" if they wanted to continue with the interview. The statement and procedure were approved by the Institutional Review Board at Southern Illinois University Edwardsville and designated exempt from further review on 18 April 2013 with modifications and extension approved on 13 March 2014. One interview was rejected once the participant reported that they were under 18 near the end of the interview, and that participant's data were deleted as the study was not authorized for participation by minors. Two more participants did not use any citizen science projects, only participating in other parts of the site, so they were not used in the following analysis. This left 30 interviews to analyse.

Interviews were conducted by four different individuals using a structured interview protocol that was developed by looking at the results of the initial survey and literature on motivation and citizen science. Interview questions about motivation were left open-ended so as to not restrict the participants to choose from a pre-set list. Additionally, interviewers asked the participants about their initial and continuing motivations. Interviews were conducted by phone or voice-only Skype since participants were interviewed from around the world, but video calling was not available to every participant. Interviews were conducted in English as all participants were fluent in English. Interviews took approximately 30 minutes, with the shortest being 20 minutes and the longest 46 minutes. The full list of questions can be found at Appendix A[1].

Participants were interviewed about their current and previous experience with astronomy-related citizen science. Although the focus was on astronomy citizen science projects, participants were not discouraged from discussing non-astronomy-related science activities. All interviewees had been participants in the active project of CosmoQuest, and we desired to capture their answers with respect to all astronomy projects in general. Topics of further questions included involvement in science in general, participation in different citizen science projects, frequency of engagement in citizen science projects, motivation to participate in projects, and how participation in projects has changed over time. In addition to the research questions, participants were asked to answer a series of demographic questions. These questions consisted of age, gender, country, ethnicity, highest education, and income. General demographic information was asked at the very end of the interview to avoid the possibility of stereotype bias *(Danaher & Crandall, 2008)*. Each interview was audio-recorded and transcribed verbatim. Anonymised data can be made available upon request.

Analysis

Coding was completed by five members of the research team. At least two of the five researchers independently coded each individual interview transcript using a basic thematic analysis approach *(Braun & Clarke, 2006)*. The researchers focused the analysis on three main questions that specifically addressed participant motivation and engagement:

- *What were your reasons for first participating in citizen science?*

- *Do you still participate in citizen science? And if so, are your reasons the same?*
  - *If Yes: What typically causes you to end your engagement for the moment/day?*
  - *If No: Why do you no longer participate?*

- *How often do you engage in citizen science activities?*

One coder reviewed the entire batch of interviews and developed themes for each question. These themes related to participants' initial motivations for participating and reasons for continuing or stopping engagement. Then the interviews were split among the five coders. Each coder read the entire interview to identify answers to these three questions that may have come up earlier or later in the conversation, as sometimes participants volunteered the information sought before it was asked or clarified later on.

Each coder categorised each answer to the questions as fitting into one or more of the generated themes, or "other" if they felt that it was not covered, in a similar fashion as the analysis of interviews in *Raddick et al. (2010)*. Then, interviews were redistributed so that each was worked on by a new coder and they categorised the answer without prior knowledge of what the original coder used.

After the interviews were coded twice, a process of comparative analysis was made by the entire coding team of five researchers to determine the level of agreement. The initial level of agreement was high, over 90%. In each case that there was disagreement, the team revisited the transcripts and came to a resolution of coding. After this process of resolution, a third coder checked again for consistency in the coded responses.

At this point, the researchers identified that motivations could be grouped into intrinsic and extrinsic motivations. We adopted the extrinsic/intrinsic definitions described by *Ryan and Deci (2000)* and utilised in an examination of participant motivations in the online citizen science project Old Weather *(Eveleigh et al., 2014)*. With this definition, motivators can be broadly divided into intrinsic (those which stem from the task itself) and extrinsic (the outcomes of an activity). Examples of intrinsic factors include having an innate interest in a particular subject matter or a particular project, finding an activity enjoyable or fun, and feeling confident about successfully completing the work. Extrinsic factors include wanting to accomplish something (e.g., achieve a certain number or level of tasks, make a contribution to science) or to engage in social interaction (Table 2).

Answers to questions of continuing engagement were separated into two categories: internal factors that can be controlled, changed, or manipulated by the managers of a citizen science project, such as negative feedback or frustration at the task or interface, and external factors, which were those things that could not be helped by the design of a citizen project, such as the participant having too much to do or suffering from eye strain.

Motivational Factor	Definition	Type	Count (D, P)
General interest	Favorable attraction to the project or activity	intrinsic	11 (4, 7)
Interest in the subject	Favorable attraction to the specific topic	intrinsic	14 (5, 9)
Help out, give back	Benefit the greater good of the project	extrinsic	21 (9, 12)
Accomplish something	Accomplish a task; do something useful	extrinsic	4 (3, 1)
To learn	To increase personal knowledge	extrinsic	5 (3, 2)
To use as an educator	To use as a tool to educate others	extrinsic	2 (2, 0)
Be a part of science	Be a part of the combined efforts to make something for science	extrinsic	8 (3, 5)
Had time/ skill	When a person perceives that they have enough time to participate or skills needed to do the task	intrinsic	3 (1, 1)
Meet people, be part of a community	When a person seeks to create a collaboration, connection, or relationship with others within CS	extrinsic	1 (0, 1)
Attractive visuals	Specific interest in the images or visuals themselves	intrinsic	3 (1, 2)
Other	Significant reasons not included in original themes		3 (1, 2)

Table 2. *Motivational factors coded by the researchers from an analysis of 30 interviews, including a breakdown into "dabblers" and "persisters"*

Results

Participant Demographics

The data analyzed in this paper consisted of interviews with 30 participants from all over the world. Respondents represented a range of ages from 23 to 70 years of age. Nine participants (30%) of the respondents were between the ages of 23 and 35. Four participants were 65 or over (13%). 80% of the respondents identified as male (n=24), and six identified as female (20%). Most were well educated with over 60% with either a bachelor's or master's degree. The largest subgroup had a bachelor's degree (39%) as their highest educational attainment. Participants' careers emphasized STEM (45%) and education (16%). An additional nine participants (29%) were in trade careers that are not related to STEM. Other participants mentioned that they were no longer working, and the career field was not mentioned, so these participants were counted as unknown (10%). 90% of participants reported having a job and over 40% of participants were career professionals between the ages of 18 and 35 years old.

Over three fourths of participants were derived from the United States (n=23) and seven participants were from: Germany, United Kingdom, Canada, South Africa, Sweden, and a country in South America. Within the United States, participants were found to be from the West (n=5, 17%), South (n=4, 13%), Mid-West (n=6, 20%), and North-East (n=8, 27%).

In the participants' free time, they fulfill personal interests in science by giving back and participating in various citizen science projects. Over half of the participants (n=17, 57%) responded that their engagement in citizen science lasted for less than an hour at a time and 20% (n=6) reported spending two hours or more during a typical engagement period for online citizen science. One fourth of respondents (n=8) reported taking part in citizen science every day, 13% of participants (n=4) reported engaging twice a week and 23% reported engaging once a week (n=7).

What are participants' initial and continuing motivations to engage in citizen science? Participants were asked about their initial motivations for engaging in citizen science with the question, "What were your reasons for first participating in citizen science?" Most participants (23 out of 30) indicated more than one motivational factor, as coded using the analysis above. The number of motivational factors coded per participant ranges from one to six with a mean of 2.5. See Figure 1.

For example, one respondent replied to the question, "What were your reasons for

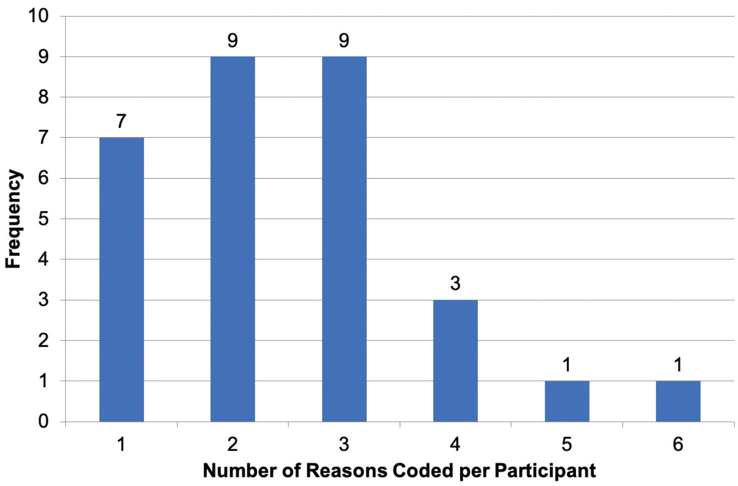

Figure 1. *Histogram of motivational reasons listed per participant. The vast majority of respondents gave more than one reason as a primary motivational factor for starting citizen science. Credit: Nicole Gugliucci*

participating in citizen science?" with the response:
"Well, I think the first participation — if you go back to SETI — was just an attitude to contribute. Then similarly with this I find it interesting and if there is truly — if what I am doing is valuable to what the researchers. Then I'm glad to contribute and the same thing for participating in this survey. I've been a grad student and I know that, you know, you try to gather data."

Since this participant specifically spoke of being interested in the CosmoQuest project in this interview, it was coded as "interest in the subject." It was also coded as "help out, give back." Table 2 lists the themes determined by the coders described in the "Analysis" section above, along with their definitions.

When respondents described why they first participated in citizen science, the three most reported reasons were to help out and give back (n=21, 70%), interest in the subject (n=14, 47%) and finding the project interesting and fun (n=11, 37%). For a smaller fraction of participants, being a part of science (n=8, 27%), learning something (n=5, 17%), and accomplishing something (n=4, 13%) were given as motivators. A few participants described other motivations such as perceiving that they had the time and skills to accomplish the tasks (n=3, 10%), using it as an educator (n=2, 7%), because the project was attractive visually (n=3, 10%), and to meet people and be part of a community (n=1, 3%).

Three "other" reasons were identified by the coders that appeared significant but did not fit into one of the previous themes. These are:

- "engage in scientific process, and advance science" which was a more specific description of "be a part of science," which was also coded for this individual;

- Be an "explorer" — although this is often a descriptor used for the scientific process, it is not solely limited to it and could not be further categorised;

- "Curiosity" — although this is often a descriptor used for the scientific process, it is not solely limited to it and could not be further categorised.

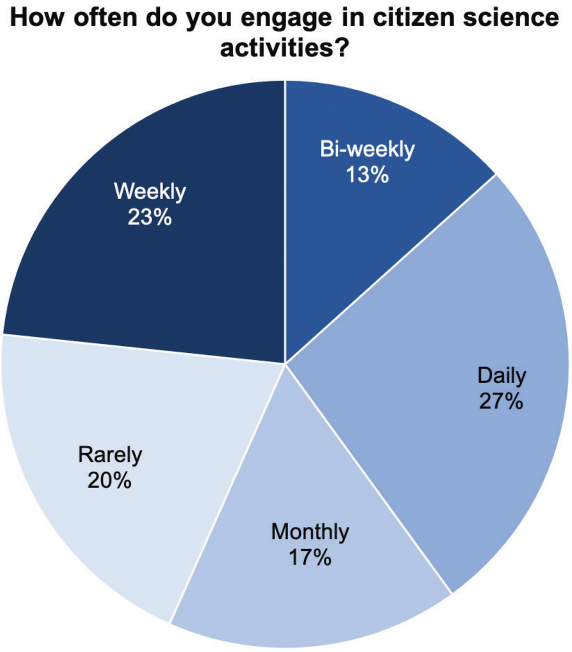

Figure 2. *Frequency of participation. Respondents were grouped by how often they participate in citizen science activities (self-reported). Credit: Nicole Gugliucci*

Excepting the three "other" responses, there were a total of 72 motivations coded among the 30 participants over the ten themes. These ten themes were divided into two main categories, intrinsic and extrinsic motivators, as described in the analysis section above. The intrinsic and extrinsic label for each of the ten categories are included in Table 2.

Half (15) of the participants indicated a mix of intrinsic and extrinsic motivational factors. Of these, 10 indicated only extrinsic factors and five indicated only intrinsic factors.

Twenty-three respondents (77%) answered that they still participate in citizen science

Theme	Definition	Type	Count
Have to do other things	Having prior obligations to attend to which stopped the participation for the time	external factor	20
Physical effects of computer time	The body feeling stiff, sore, or uncomfortable which ended the engagement in the project for the day	external factor	3
Schedule events that ends	The project was only to be for a limited duration and then ended	external factor	3
Attention span, tired	Individual's mental concentration was depleted causing the person to end their engagement	external factor	14
Computer or programme issues	Personal computer/programme was experiencing issues making connecting and engaging difficult	internal factor	1
Negative feedback from programme	Citizen science programme provide unsupportive feedback that was perceived as adverse	internal factor	1

Table 3. *Reasons for disengaging temporarily from citizen science, coded by the researchers from an analysis of 30 interviews.*

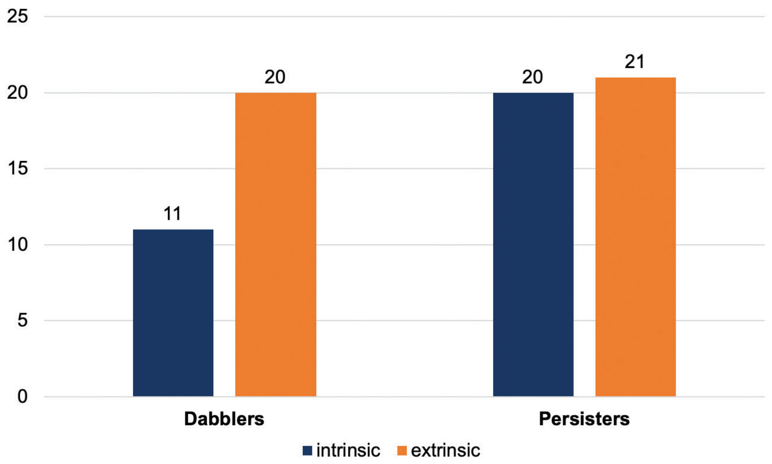

Figure 3. *Intrinsic and extrinsic motivators by frequency. Histogram of reasons coded per type for the "dabblers," those participating in citizen science on a sporadic basis, and "persisters," those participating in citizen science on a regular basis. Credit: Nicole Gugliucci*

projects. Twenty of these indicated that their reasons for participating are the same as when they began. Of the three that said their motivations changed, they now indicate making a difference or furthering the science, both extrinsic motivators, as reasons why they continue to participate.

How do participants' motivations relate to their self-reported patterns of engagement in an online citizen science project?

Participants were asked, "How often do you engage in citizen science activities?" Answers were grouped as shown in Figure 2.

Inspired by *Eveleigh et al. (2014)*, the participants were divided into two categories of self-reported behaviour. Twelve were categorised as "dabblers," or those who reported doing citizen science tasks rarely or monthly. Eighteen participants were categorised as "persisters," or those that reported doing citizen science biweekly, weekly, or daily. Users are more likely to list extrinsic motivators when they are dabblers (rarely or monthly) than if they are persisters (biweekly or more). Specifically, the dabblers, as a group, were coded with 11 intrinsic reasons and 20 extrinsic reasons. The persisters were coded with 20 intrinsic reasons and 21 extrinsic reasons. The number and type of reasons in each group is shown in Figure 3.

What factors contribute to participants ending their engagement?

Participants were asked, "What typically causes you to end your engagement for the moment or day?" Responses were grouped according to the categories in Table 3. As with motivations, some respondents recorded multiple reasons for stopping any given day's engagement. Twenty (67%) listed having to do other things as a reason for stopping for the day, and 14 (47%) noted that their attention span or tiredness were factors. Other external factors included the physical effects of time on the computer (n=3, 10%) and being part of a scheduled event until it came to an end (n=3, 10%).

Only two participants indicated factors internal to the project as reasons for ending their engagement. These reasons could be categorised as "technical issues with the computer or programme" and "negative feedback from the programme".

When asked if they still participate in citizen science, seven of the 30 participants (23%) indicated that they no longer contribute. Four of the individuals that no longer contribute cited external reasons, such as no longer having time to participate or having to give time to competing interests (work, family, school, etc.) (Table 4). Three of these cited reasons internal to the project themselves, categorised into three groups:

- Not having enough context or communication,
Example: "There is kind of a context issue. Looking at the individual small maps, since I don't know where on the Moon I am it loses part of what makes it special. When I have a close in image of a crater or feature on the Moon is that I know where to point on the Moon, 'this is where that was'"

- Perceived lack of ability due to negative feedback from the project, and
Example: "Trying real hard to make MoonMappers work and then being told that I was so far off it was pathetic. I wanted to get it right. The computer would say, 'Are you kidding me? You got so many wrong', and then I'd have to stop."

- Frustrating aspects of the project or programme.

Theme	Definition	Type	Count
No time	Lack of available time to work on the project	external factor	3
Competing distractions	Having something or someone that inhibits the ability to focus on project	external factor	3
Not enough context or communication	The project was unclear on what was wanted or how it fit into a larger picture	internal factor	2
Perceived lack of ability	User does not feel they have the ability to perform the task well	internal factor	1
Frustrating aspects of the programme	Personal computer/programme was experiencing issues or had a problematic design element, making connecting and engaging difficult	internal factor	2

Table 4. *Reasons for permanently disengaging in citizen science, coded by the researchers from an analysis of 30 interviews. Seven of the 30 interviewees indicated that they have permanently disengaged in citizen science.*

Example: "There were questions I had that I didn't know how to get answered because for me navigating a website is profoundly confusing and frustrating. If I had a question about a particular thing, for a long time I didn't even know about the chat on the side of the screen and so I would try to find a place on the forum to ask my question but then when I found the proper place in the forum I would've lost the image I had the question about."

Discussion

The results of this analysis of 30 interviews with citizen science participants reveal a complex set of motivations for starting with such a project. This may not be surprising given the open-ended nature of the questions. Most participants in this study were coded to have more than one motivational factor, and half of the participants indicated some mix of both intrinsic (relating to the task itself) and extrinsic (relating to outcomes) factors. The most prevalent factors in this analysis are indeed a mix of these as well, interest in the project or subject (25 participants), an intrinsic motivator, and helping out or giving back to science (21 participants), an extrinsic motivator (See Table 2). Although only a small number of interviewees (5 participants) indicated a motivation to learn from the citizen science project itself, an additional 7 participants indicated that "being a part of science" was a motivating factor. (One participant indicated both.) This is notable as citizen science projects are a unique way to teach about the process of science in action.

The most significant finding is a trend that emerged when study participants were sorted by reported frequency of use. We define dabblers as those who reported contributing monthly or rarely, and these tended to code with more extrinsic than intrinsic motivators. Persisters were defined as those who reported participating more frequently, and these were more evenly split between intrinsic motivators and extrinsic motivating factors. This supports the emphasis on intrinsic motivators found by *Nov, Arazy, & Anderson (2011)*.

However, while intrinsic motivation can be powerful, relying solely on this type of motivation may reduce the size of potential participant pools to those who already have an innate interest in the subject *(Prestopnik, Crowston, & Wang, 2017)*. Citizen science participant motives are often associated with participation intentions which are then related to participation efforts. External motivators can bring in new participants while also encouraging participants' commitment to the project. Projects should communicate the project's mission and results in order to foster interest in the project's collective goals *(Nov, Arazy, & Anderson 2011)*.

Although the interviews were done for a single point in time, continuing participants were asked if their motivations had changed from those they described as initial motivating factors. The overwhelming majority said that their motivations were the same or, if anything, that their motivation factors were the same, but the level of motivation increased. For the three continuing participants that said their motivations changed, they were more motivated by the opportunity to further the science or to make a difference and contribute. They added these external motivations that had not been present for them initially. To quote one participant, *"before it was I used to do it just to do it. Now, I do it because of the hopes of trying to further the science as well"*. Though a small sample, these responses further support the need for communication of the broader project goals and results to encourage sustained participation.

Although we were only able to interview 30 individuals of the thousands who have participated in this citizen science project, we were able to gain insight from these narratives that were unavailable through surveys alone as participants were free to answer without restriction from a list of choices. We were fortunate to interview several people who used to participate in these citizen science projects but no longer did. Most discussed reasons that are familiar but, ultimately, out of the control of those creating such projects, such as family obligations and work schedules. However, we were able to get useful feedback from those who indicated project-related reasons for stopping work altogether, namely, issues of communication, frustration with the programme itself, and a perceived lack of ability. The last one of these was caught early in the project and feedback prose was later rewritten to better encourage users struggling with their matching scores on randomly inserted test images. Collecting such feedback from users early in and regularly during a project can help avoid loss of engagement due to controllable factors in the long run, or "deterring the drop-outs" in the language of *Eveleigh et al. (2014)*. Issues of communicating the larger context of the project was also cited as a factor for dropping out in that study using Old Weather. Here again, we see continuing communication with citizen scientists to be a key factor in retention where, if done poorly, it can actually drive participants away.

One further observation was about the importance of passive citizen science projects. CosmoQuest projects are considered "active" as users have to engage with the image on their screen. However, participants were prompted to list all citizen science activities with which they engage, and passive projects such as SETI@home came up a number of times. In fact, this was occasionally listed as a starting point for citizen science activity, which is not surprising considering the long lifetime of that project in comparison to newer, active projects. In fact, one participant described that they received a sense of "satisfaction" from running SETI@home, especially when they did not have time to devote to more active projects.

Implications

As astronomy citizen science projects compete for attention in an ever-increasingly crowded media landscape, project designers will have to take into account the intrinsic and extrinsic motivators of their participants. These are also influenced by the project's own scientific and educational goals. Projects featuring active, but monotonous, tasks may design an interface and communication scheme that aims to pique the interest of a large audience over a short period of time or encourage referrals to bring in a steady stream of new participants. However, tiers of activity levels can be designed to further encourage persistent participation among the most highly motivated members. When pitching projects to wide and diverse audiences, project designers should consider building in extrinsic motivators that are meaningful to the communities they want to attract, e.g. integrating with fully developed lesson plans for teachers.

Future work should test the effects of these various motivators in recruiting specifically from groups that are underrepresented in astronomy citizen science efforts.

This research provides a context for recruiting and nurturing two different kinds of citizen science populations: short term dabbling and long-term persisting volunteers. Both of these groups have diverse extrinsic motivations. Put differently, we consistently find that people are motivated to participate by rewards of one form or another. By designing citizen science projects to reward users in one way or another, addressing these extrinsic needs, all populations can be satisfied. At the same time, the key population of persisters, that population which provides the greatest percentage of citizen science data, need to have the intrinsic motivations met as well.

According to *Deci & Ryan (2001)*, "When intrinsically motivated people engage in activities, it is because they find them interesting and satisfying and not because the activities lead to separable rewards or consequences". By knowing what these intrinsic motivations are, citizen science programmes can grow these key populations by design toward promoting their ability to satisfy people's personal hunger to, for instance, engage with astronomical images. If people don't know that a project will speak to their personal motivations, they will have no reason to join it. This is a design challenge for future projects. It is easy to promote extrinsic rewards through social media sharing, badging systems, and leaderboards, but promoting "you can give needed help" is harder to socially share.

This is where it can become a matter of promoting need rather than promoting reward. Citizen science is, at its core, the exchange of tasks that meet needs. Scientists need data analysed, and citizen scientists have personal needs that are met in their participation. Murray's Manifest Needs Theory *(Murray, 1938)* states that "Individuals are driven based on the object towards which the need is directed and the intensity of the particular need (e.g. educational achievement, social success)". If a project is contextualised as having a need for help, it may be more effective at attracting the necessary persisters who are driven to help.

Based on this research, we find that astronomy citizen science projects must design projects to provide the carrots that speak to extrinsic motivations. Those carrots can attract all types of participants. In order to attract persisters, projects must also promote their ability to satiate intrinsic motivations. Once these volunteers are recruited, keeping them requires providing a nurturing site that communicates the need for improvement in a gentle way and that proactively provides community members with invitations to community events and answers to common questions. Even with all the motivations fulfilled and barriers removed, it is important to note that no project can retain the typical user for a long duration because life, and its myriad of obligations, does tend to tear people away. The key is to make sure that volunteers stay as long as time and life allow and leave feeling satisfied.

Conclusions

Interviews with 30 citizen scientists recruited from CosmoQuest provide a detailed look at the motivations of these participants in conjunction with their behaviours.

The citizen scientists interviewed described a complex set of initial motivations that include both intrinsic and extrinsic motivating factors. Interest in the subject or project was the top intrinsic factor, and a desire to help out and give back with the top extrinsic motivator. The majority of respondents indicated that their motivations are the same as they were when they began.

"Persisters" who participate on a more regular basis are more likely to list intrinsic reasons for participation than "dabblers" who participate on a more sporadic basis. This highlights a potential area of improvement on the part of citizen science projects and their recruiting effort, especially in regard to attracting more diverse audiences. By expanding to and emphasising a wider range of extrinsic outcomes, such as teaching, learning, community building, or the specific impacts of the science itself, citizen science projects are more likely to sustain engagement over time.

Many factors drawing participants away from citizen science, either in the moment or for good, are outside the scope of a project's control, such as time available and family responsibilities. However, projects and communication about projects can be designed in ways that encourage "just one more" classification or a return to the project after a hiatus. Factors that can be controlled, such as communication methods, feedback, and technical issues, could be minimized through careful project testing and immediate feedback mechanisms built into the projects.

Notes

[1] You can access Appendix A here: https://drive.google.com/file/d/1cS_XZ6l5ju0sTI-mupTvq4mEjI2NSZoR/view?usp=sharing

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Astronomy as a Tool in Community Building, Promoting Social Unity, and Solidarity: First-hand Experience in East Java, Indonesia

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Community building and social unity have become important for almost every developing country, including Indonesia. These issues are reflected in the economic limitations, and, in turn, the limited access to education and outreach initiatives. The East Java Amateur Astronomer Communication Forum uses a ‘safari of the telescope’ to visit several cities in the province of East Java. In these expeditions, we invite people to observe celestial objects together in groups and gradually provide scientific information to bring them closer to science, especially astronomy, using other fun, interesting, and engaging activities. Through this process, astronomy communication has become a potential tool for community building, promoting social unity and solidarity in various regions and even remote islands in East Java. We describe the importance of this ‘other side of astronomy’ and of fostering public awareness of the importance of tolerance, moderation and unity.

Introduction

Demographics and Diversity of East Java

The province of East Java is located in eastern part of Java, latitude 7.5361° S, and longitude 112.2384° E. East Java is the most populous island in Indonesia. It also includes the island of Madura, which is connected to Java by the longest bridge in Indonesia, and the Kangean and Masalembu islands, which are located further east and north of Java, respectively. The capital of East Java is Surabaya, the second-largest city in Indonesia and a major industrial center. It covers an area of 47,800 km^2. According to the 2010 census, there were 37,476,757 people residing in East Java, making it Indonesia’s second most populous province; the latest official estimate (mid-2020) is 39,886,288. East Java has the largest base of amateur astronomy communities in Indonesia (Figure 1).

Barriers and Solutions to Increasing Inclusion

Various barriers related to human resource development, such as East Java’s vast geographical landscape and inequality of access to technology, have resulted in gaps in various fields, especially in education between people living in cities vs rural areas.[1]

Astronomy public engagement and educational activities are a capable means of bridging between cultures, as well as of being inclusive of various cultural backgrounds and an important cross-cultural communication tool. Appropriate efforts and strategies are needed so that the people of East Java can maintain their diverse culture and identity and pass them on to the younger generation.

Fewer people in East Java and even in Indonesia are pursuing studies in scientific fields *(Desi, 2019; Widianingtyas, 2019)*. The millennial generation has taken less interest in the field of science in secondary school and university, choosing instead to study other fields. This has become a trend among young people and sparked concern. There are indications that this trend is caused by the saturation of specific

Figure 1. *Distribution of astronomy clubs in Indonesia. The red part is the province of East Java, which has the most clubs. Credit: FOKALIS JATIM*

topics in formal education, making science less attractive for students to pursue *(NFER, 2017)*.

Lately, there is also a belief that science is becoming ‘obsolete’ and this has become a new trend among young people *(Desi, 2019; Widianingtyas, 2019)*. This trend is a normative call for amateur astronomers to become educational ambassadors as well as agents of change for the popularisation of science. In everyday life, the astronomical community is one of the frontlines for raising public awareness of astronomy.

Therefore, a new creative and innovative strategy is needed so that interest in science can grow. One solution is problem-based learning using practicum methods. Another is public education outside of school settings. Both of these solutions are applied by various astronomical communities in East Java through the ‘safari of the telescope’. (Figure 2).

Apart from a lack of interest in science, the loss of indiginous culture can lead to a waning of identity which can cause social problems such as misunderstanding, intolerance and even cynicism towards diverse groups of people. So that the local culture remains resilient, it is necessary to maintain indigenous culture and community building. We expect that by including Javanese indidgenous culture into science and astronomy outreach and educational activities we can uplift the awareness of Javanese indigenous culture alongside the currently predominant foreign contents (e.g. Greek, Egyptian, Chinese, or Northern American celestial object naming mythologies). As an example: when speaking about constellations, Javanese people imagine constellations as forms, such as Waluku (Orion), Wuluh (Pleiades), Kalapa Doyong (Scorpio), Sapi Gumarang (Taurus), etc. For inland communities in East Java, these celestial objects are still used in everyday life to determine farming times, means of worship, calendars and navigation *(Yamani, 2008)*.

Figure 2. *Several ‘safari of the telescope’ programmes carried out by astronomy clubs in East Java: (top) Surabaya Astronomy Club at a local elementary school, (left) Jombang Astronomy Club in the city Madiun, neighboring Jombang, (right) members of FOKALIS JATIM and LAPAN Pasuruan teach at the newly established Arya Wiraraja Astronomy Club. Credit: FOKALIS JATIM.*

In accordance with the circumstances, problems and tendencies faced, and with consideration of policy changes, the follow-up needed to improve community building and cultural resilience are as follows:

1. Equalising and expanding opportunities for experiential learning;
2. Developing quality and inclusive education practices.
3. Collaborating with productive and conducive community institutions as centres of learning, education, and culture.

The Importance of Astronomy for Science Popularisation and Social Change

Astronomy is considered unique among sciences *(Rosenberg, 2013)*, and can be a promising avenue for the popularisation of science, community building, and even social unity *(Howard, 2009)*. Through astronomy, we can reach the interest, not only of the amateur astronomer community or students, but to reach all levels of society in the importance of learning throughout life.

Observation is the first and foremost way to introduce science through astronomy because people can directly experience various astronomical phenomena, such as meteor showers, lunar eclipses, solar eclipses, comets among others *(Rollinde, 2019; Topper, 2013)*.

In Indonesia, astronomy is not yet present in primary to secondary education curriculums. Involving the community directly is a practical action that has been applied to teaching and learning activities for formal education, and has shown to increase interest and improve learning outcomes *(Faj, 2018; Yuliana, 2017)*. After gaining interest in astronomy through an informal learning activity, a person is enticed to further explore the knowledge acquired.

Astronomy communication, which gained momentum during the International Astronomical Union (IAU) centenary, IAU100, has become a potential tool for community building, social unity, and solidarity in various regions *(Downer, 2018; Matsumoto, 2018)*. To this end, we use the 'safari of the telescope' approach to share astronomy in East Java (Figure 2).

In principle, the 'safari of the telescope' is an astronomical education activity for the public that travels from one city to another. This activity itself covers all cities in East Java, as many as 38 cities. Apart from being public, this activity also includes school visits and was chosen because it represents astronomy as a whole. This activity was originally created by one of the astronomy clubs in East Java, the Surabaya Astronomy Club, in 2014. However, over time, the idea for this activity was adopted by various other amateur astronomy communities in East Java and became a tool to initiate conversations in their respective communities about global citizenship and uniting people from all cultures and backgrounds. Furthermore, this activity aims to inform East Java's people about climate change by using the perspective of astronomy to remind people that the Earth is our only habitable home. In the 'safari of the telescope' series, there are several main activities, such as star parties or astronomical observation sessions in the city center for communities to share knowledge with the public.

We were inspired to work within more communities because there are still imbalances among the amateur astronomy communities throughout East Java, including: an insufficient number of astronomical instruments, uneven distribution of astronomical knowledge, few members, few local meetings for socialisation through astronomy, among other obstacles. These barriers could be minimised through interactions and assistance from other astronomy clubs, which then builds social solidarity across the islands. This is the main point of the 'safari of the telescope'. Specifically, to get around an insufficient number of astronomical instruments, in addition to borrowing and lending between communities. When the 'safari of the telescope' was held, we also raised mutual funds to then buy an astronomical device which in turn will be given to potential communities to be able to use and develop it when the 'safari of the telescope' is held in their city.

Through the programme we invite people to observe celestial objects together, gradually provide education, and bring them closer to science, especially astronomy, with fun, interesting and innovative activities. We have repeatedly stated in various visits, that no matter how different we are, at least we are still standing under one sky.

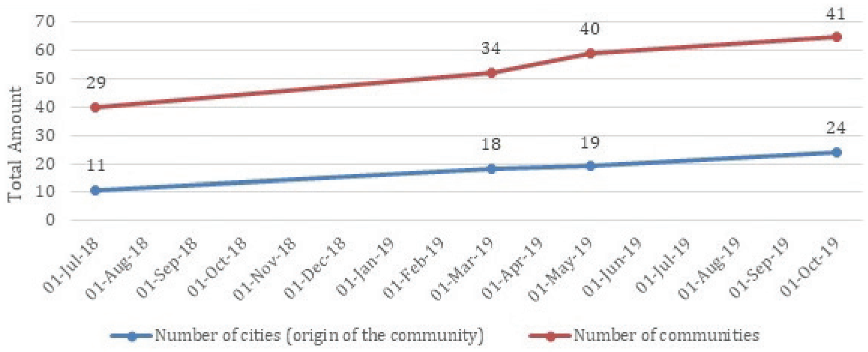

Figure 3. *The growth of FOKALIS JATIM membership. Credit: FOKALIS JATIM*

With this approach, slowly but surely, people will become aware of the importance of education, tolerance, moderation and unity. Additionally, we believe that the development of this activity will be directly proportional to an increase in people's creativity and confidence *(Hwang, 2014; Davies, 2018)*. This, in turn, will indirectly control social inequality *(Zulfiqar, 2020)* and simultaneously improve the socio-economic level of the East Javanese community *(Oldfield, 2009)*.

Developing the East Java Astronomical Communities

East Java Amateur Astronomer Communication Forum (FOKALIS JATIM)

The East Java Amateur Astronomer Communication Forum (FOKALIS JATIM) is a discussion forum and organisation for amateur astronomers in East Java, Indonesia. This forum was formed to support friendships and information sharing among local amateur astronomers and develop the potential of each amateur astronomy community in East Java, based in togetherness, unity and a harmonious vision in the effort to develop astronomy in East Java.

The idea of forming this regional astronomy organisation began at the JANAKA (Indonesian Astronomy Club Jamboree) event, the largest gathering of amateur astronomy communities in Indonesia, on 22-24 September 2017 at the Pasuruan Space and Atmospheric Observatory[2] in East Java. The event was attended by 38 communities from across Indonesia. Of the 38 participating communities, 13 came from East Java. East Java also drew the largest number of participants.

FOKALIS JATIM was subsequently founded in 2018, and welcomed 29 amateur astronomy communities. At the end of 2019, we had 41 amateur astronomy communities: 18 based in a city, 11 based at colleges, and 12 based at schools. The growth of FOKALIS JATIM is illustrated in Figure 3.

Actions and Activities

The 'safari of the telescope' activity has been integrated into FOKALIS JATIM. The forum also initiates various other educational activities, such as guest lectures, seminars, webinars and workshops. Sometimes we also coordinate a huge wave of astronomy events throughout the amateur astronomy communities. One example was a Yuri's Night celebration which gathered almost 300 participants in 28 communities all across East Java in 2019 (Figure 4).

In the virtual realm, we also built a virtual data bank called 'BATAVIA'[3], in which we have collected astronomical educational materials from many sources, and amateur astronomers in East Java are free to access them. By using those materials, the amateur astronomy communities could more easily learn and share knowledge with the public and popularise science (Figure 5).

We also have many discussions about astronomy and the practical use of telescope through our official Instagram[4]. Through these interactions on social media, we often mediate between amateur astronomers who are not in a community

Figure 4. *The Yuri's Night held on 13 April 2019 at Pasuruan Space and Atmospheric Observatory in East Java to commemorate a number of milestones in space exploration, including the 50th anniversary of the Apollo 11 mission and centenary of the International Astronomical Union. Credit: FOKALIS JATIM*

Figure 5. *Club members present on an astronomical topic using material on file with FOKALIS JATIM. Credit: FOKALIS JATIM*

with the astronomy community closest to them. In addition, our social media has at least three main functions: plan activities for the club members, document the activities of club members, and share general astronomical information.

In line with the concept of unity and solidarity promoted by our forum, we create social opportunities through FOKALIS JATIM. We hold biweekly discussions with representatives of every amateur astronomy community to share their experiences and problems, and we have raised funds to help the recovery of members who had an accident. By doing these things we can easily understand each other and increase solidarity among each member club *(Koudenburg, 2013).*

Astronomy inherently needs the collaboration of various parties[5]. Examples of global collaboration through astronomy have existed since the field's infancy, when early astronomers attempted to perform simultaneous measurements across distant parts of the Earth to measure its circumference. More recently, amateur astronomers in East Java have linked their communities across cities and districts to conduct collaborative astronomical events such as the Pale Blue Dot celebration, World Space Week and International Observe the Moon Night. With regional collaborations such as FOKALIS JATIM, amateur astronomers in East Java now transcend regional borders and all kinds of differences with the goal of exploring astronomy.

Conclusions

It has been shown that there is a great and very realistic potential of the amateur astronomy community in East Java. This is especially true now with the formation of FOKALIS JATIM as a forum that houses all amateur astronomy communities in East Java, and created one of the largest collectives for astronomy outreach in Indonesia.
Eventually, the amateur astronomy community can become an essential part of astronomy popularisation, community building, social unity and solidarity in East Java.

Notes

[1] Further information can be found at: Information Management and Documentation Office of the East Java Provincial Government, 'Permasalahan Pembangunan Daerah'[Regional Development Problems], 2014. http://jatimprov.go.id/ppid/uploads/berkasppid/BAB-2.3-Permasalahan.pdf and OECD, 'Equity and Quality in Education: Supporting Disadvantaged Students and Schools', OECD Publishing, 2012. http://dx.doi.org/10.1787/9789264130852-en

[2] Balai Pengamatan Antariksa dan Atmosfer LAPAN Pasuruan (Pasuruan Space and Atmospheric Observatory) Instagram: https://instagram.com/lapanpasuruan/

[3] You can access BATAVIA website here: http://bit.do/BATAVIAFOKALIS,

[4] FOKALIS JATIM Instagram: https://www.instagram.com/fokalis.jatim/

[5] International Astronomical Union Office of Astronomy for Development (IAU OAD), 'Science Diplomacy through Astronomy – Celebrating our Common Humanity', International Astronomical Union Office of Astronomy for Development. http://www.astro4dev.org/science-diplomacy-through-astronomy-celebrating-our-common-humanity/more-on-the-flagship-science-diplomacy-through-astronomy-celebrating-our-common-humanity/

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Biographies

Muchammad Toyib is an astronomical activist from Surabaya, East Java, Indonesia. He first became interested in astronomy when studying astrophotography, learning about the other side of the sky's landscape and views. He is very adventurous, currently fighting for the 'One City One Astronomical Community' programme and planetarium development in East Java through the East Java Amateur Astronomer Communication Forum (FOKALIS JATIM).

Aditya Abdilah Yusuf is a staff member of ITERA Astronomical Observatory Lampung (IAO) and has a passion for popularising astronomy through public education programmes. He received a bachelor's degree in astronomy at Bandung Institute of Technology (ITB). Besides professional work at IAO, he is active in several astronomy clubs: Lampung Astronomy Community, Jombang Astronomy Club, and East Java Amateur Astronomer Communication Forum (FOKALIS JATIM).

Engaging the Public with Live Video Observing

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As part of the ongoing efforts to enhance the visitor experience at Lowell Observatory in Arizona, US, the observatory's public outreach team has established a live video observing programme. Using extremely sensitive cameras on a modest–sized telescope, we present detailed colour views of many spectacular celestial objects. With those images on a large television screen, we introduce discussions of many of the most interesting ideas of modern astronomy, supplementing the sky views with stored material to expand this exploration. This model overcomes some of the limitations of traditional visual observing with crowds and has proven to be an excellent way to engage our visitors. Here we provide specifications on our equipment and suggestions for assembling a public video observing system.

Introduction

Lowell Observatory, in addition to being an active research institution, attracts approximately 100,000 public visitors each year through our public outreach programmes. These programmes give us a unique opportunity to connect visitors from all over the world to the science of astronomy. Covering basic concepts to cutting-edge research, we offer live presentations, exhibits, and, most enticingly, sky viewing using modern and historic telescopes.

We have added live video feeds to augment traditional observing using optical telescopes in our public programming at Lowell Observatory and at smaller observing venues. This has allowed us to more actively engage our visitors with enhanced views of deep sky objects, and has provided us with opportunities to discuss those objects in groups. We can facilitate conversations that address the big ideas and discoveries of modern astronomy, leaving guests with a sense of awe at the beauty of the night sky and a deeper understanding of the universe.

Our Public Outreach Programmes in Action

Astronomy is the most visually stimulating of the sciences. For decades, stunning imagery from instruments such as the Hubble Space Telescope have been easily accessible and have captured our imaginations and formed the way we envision our universe[1].

But you don't need access to the Hubble Space Telescope to bring colorful visual appeal and scientifically interesting imagery to your public observing events. As astronomy educators, we need to find ways to combine the inherent beauty of the universe and the power of scientific ideas to create a rich environment for engaging minds.

The science of astronomy's constant groundbreaking discoveries, striking images, and big ideas inspire awe in all of us regardless of background or education level. No matter where you live, you have access to the sky. It connects us all. Those in rural or dark-sky areas undoubtedly can see and appreciate more of the night sky, but even in the largest cities you can be treated to views of the Moon and planets. The combination of concepts, images, and universal accessibility makes astronomy an ideal vehicle for introducing 21st century science.

Observing through eyepieces certainly has its appeal, and is of course the classic way to bring astronomy to your community. Nothing can compare with the grandeur of the night sky seen through a visual telescope: seeing inconceivably distant, immeasurably huge and unbelievably beautiful objects while hearing the stories they tell is not an experience anyone is likely to forget.

But there are limitations to this visual model. Depending on wait times, visitors to the Observatory or star party event may only have a few moments at the eyepiece and human vision is not optimized for speedy night-time observing. When our world is illuminated by starlight, our night vision has very little colour sensitivity[2]. This is particularly detrimental during visual observing as much of what we know about the universe has been learned by observing colour. The striking pink of hydrogen-rich star forming regions appear a murky grey through an eyepiece, and our own eyes rob us of the full-color experience. Additionally, many of the objects that we observe are extremely faint, limiting what we can see even with the largest visual telescopes. Galaxies with lower surface brightness, such as Messier 33, appear in an eyepiece with little definable structure, even through our 32" Dobsonian. When viewed through our video system with a 30 second exposure, we are able to clearly make out its core and breathtaking pinwheel structure (Figure 1).

Expanding the Conversation: Some Examples

Rather than a brief glimpse through an eyepiece, new digital cameras can rapidly produce excellent colour views of many dozens of deep sky objects with exposures of less than 30 seconds (Figure 2). Visitors are treated to full-colour images piped directly from the telescope with an attached camera.

***Figure 1.** An image of Messier 33 (the Triangulum Galaxy) from our system using a 14" Planewave CDK and a Mallincam DS10cTEC. Exposure time was 30 seconds. Credit: Sarah Burcher, Lowell Observatory*

For example, the Sagittarius emission nebulae, M8, M20, M16, and M17, can each be seen in exquisite detail and in full colour with an exposure time of roughly 15 seconds (Figure 2), and each can provide a wonderful platform from which to start a conversation about star formation. That conversation can then be extended to the end states of stars by moving to planetary nebulae, such as M57 and M27. The stunning colouration of M27 provides a splendid introduction to the notion of element formation (Figure 2). M97 is another option that is visible from our latitude (35° N) throughout most of the year. In winter, we can point out the Orion Nebula with a laser pointer and then show stunning views of M42 in its full spectrum of red and blue, as well as neighbours like NGC 2024 (the Flame Nebula), to illustrate the notion of star formation. Finishing with the supernova remnant M1 (the Crab Nebula) completes the story of stellar evolution and element formation.

The Moon is another excellent object to present (Figure 2). Displaying a live lunar image allows us to examine the many interesting features of our nearest celestial neighbour. Detailed views of the craters and their central peaks, the rilles, the different colours of the mare, and the Apollo landing locations are all good starting points for a wide range of discussions. It is also fun and educational to demonstrate the speed of the Earth's rotation by shutting off the telescope tracking and watching the Moon drift rapidly across the screen. Live video views of the Moon also tend to show the rippling effect caused by Earth's atmosphere, leading to discussions about the value of space telescopes.

When used with a solar telescope, the same camera used for night-time observing can produce exquisite views of the Sun, capturing sunspots, prominences, flares, and minute details of the surface granularity.

We host weekly 'Meet an Astronomer' events where Lowell astronomers lead conversations with the public using our video observing system. This allows researchers to show live views of objects they actively study, as well as images from their recent papers (Figure 3). The guests enjoy the chance to interact with 'real scientists' and learn first-hand about the process of science and recent discoveries. In the time of the COVID-19 crisis, we are able to extend this to a virtual interaction hosted on YouTube entitled 'Interactive Stargazing'. Via a live chat, viewers can interact with our hosts and request objects to be viewed live with our system.

Virtually or in-person, guests also love to ask the 'big questions' about our galaxy and beyond (Box 1). A live view of the face-on spiral galaxy M51 (the Whirlpool Galaxy) with its smaller companion, NGC 5195, provides a wonderful platform for introducing galaxies and galaxy interactions (Figure 2). The red glow at the intersection between M51's spiral arm and NGC5195 nicely demonstrates what happens when galaxies collide. Additionally, the northern hemisphere summer combination of the M51 and NGC 4565 (the Needle Galaxy) provides a three-dimensional view of spiral galaxy structure and adds depth to conversations about stellar evolution.

Increased Accessibility of Observing

Our video programme allows us to increase the accessibility of in-person observing. Our model of engaging our guests in conversations, rather than simply lecturing them, allows us to bring even the most challenging aspects of science and astronomy to any level of education or interest. The set-up provides every guest a view through a telescope regardless of mobility limitations.

The camera is operated via a laptop computer, and images are displayed on a large screen for the public. We always ensure the screen is placed a sizable distance from the visual telescopes and angled away from guests to minimise interference with guests' night vision. We also cover our screens with a translucent dark film to further reduce screen glare.

The display shows not only the view from the telescope but the interface we use to optimize the image. Visitors can watch as we adjust the exposure time, focus, and image properties. This allows us to lead a discussion about image processing and the values of different kinds of instrumentation.

Since we have access to the internet and stored resources, we can bring up pictures from the Hubble Space Telescope and other scientific sources to compare them side-by-side with our live images. We can then explain the steps of scientific observation and how many of the astronomical pictures we see are not necessarily just in the visible spectrum, but include data from other wavelengths. This can lead to discussions about the limitations of Earth-based telescopes and the value of arrays, interferometers and radio telescopes. One of the benefits of this informal setting is the ease with which conversations develop. One question begets another and that may be the best index of the effectiveness of the presentation model. Having this flexible

Box 1. Big Ideas Addressed Using Video Astronomy

- Star formation and stellar evolution
- Supernovae, planetary nebulae, and element formation
- Planet formation
- Comets, asteroids, meteors
- Big bang, expanding universe, age of the universe
- Stellar endings: dwarfs, neutron stars and black holes
- Scales of the universe
- Number and structures of galaxies (and how the Milky Way compares)
- Dark matter, dark energy

set-up allows us to touch on aspects of modern research that would be hard to explain with only an eyepiece setting.

At an eyepiece, guests can feel pressured by the line of others behind them waiting to view, and can be reluctant to engage the operator with their questions. We have found that in these larger groups gathered around our screen, guests feel more engaged in our conversation than as an individual at an eyepiece. They are welcome to stay as long as they like, and listen to the questions of others around them. It becomes a community learning opportunity. Guests learn what we have to teach about astronomy, but also – and possibly more importantly – learn that everyone has questions about our universe.

In these large groups, we often find visitors with mixed levels of education and astronomy knowledge. In these instances, we strive to find ways to captivate the entire audience. We do appreciate when learned guests come to us with their complicated technical questions, and the best educators are adept at using these questions as a stepping stone to a larger conversation with the whole group. We try to avoid technical jargon and focus on bringing the ideas to a level everyone can understand. We strive to explain concepts simply but completely by using analogies, stories, and even hand motions to bring tough material to an understandable level. A notable example is when guests ask about dark matter. In this instance, we would bring up live images of a few select galaxies, especially face-on galaxies with clear disk structure. We would then lead the guests along a conversation about the rotation of galaxies, and how we would expect them to rotate like solar systems, with the objects closer to the center moving faster. We then explain that galaxies move instead like records on a record player – with every point making revolutions at the same rate. We've then laid the foundation for delving into the history of the discovery of dark matter and, for example, Vera Rubin's work on the predicted versus angular motion of galaxies (some of which was done at Lowell Observatory)[3].

The large screen gives visitors who normally have trouble viewing through eyepieces, like the elderly, children, and individuals in wheelchairs, access to a live telescope experience. When we use video to observe we do not need to coach each guest as he or she approaches the scope. Rather, our time is spent examining the objects before us in much greater detail than we could with purely visual tools. Eyes vary substantially; with our video feed, focus is not an issue. By accumulating light, the camera allows us to see faint objects in greater detail than purely visual observing would permit. That said, we always operate the video system alongside visual scopes, including the 24-inch Clark refractor that Vesto Slipher used to gather the first evidence of the expansion of the universe.

The large display also addresses the issue of queues. Time spent waiting in a queue to see celestial objects is time wasted. We should optimize use of people's time

Figure 2. *A sampling of images taken with our systems. All pictures have less than 30 seconds exposure time, and are presented here (like they would be live to the public) with only minimal editing of brightness and contrast. Objects shown clockwise from the upper left:* ***a)*** *Messier 97 (the Owl Nebula).* ***b)*** *Messier 51 (the Whirlpool Galaxy).* ***c)*** *NGC 891.* ***d)*** *Messier 8 (the Lagoon Nebula).* ***e)*** *The Moon after occulting Aldebaran. The images on the top row were taken with a Mallincam DS10cTEC and the images on the bottom row were taken with a Mallincam Xterminator. Credit: Sarah Burcher, Lowell Observatory*

Figure 3. *Our system incorporated an 11-inch Celestron telescope, a Mallincam Xterminator camera, and a large-screen television to display images directly to the public (left). We used live images from the telescope to entertain large crowds on busy evenings at Lowell Observatory and during our always popular 'Meet an Astronomer' evenings (right). Please note that the live television display of the Moon is overexposed in the right photograph, but clearly visible in the left. Credit: Sarah Burcher, Lowell Observatory (left); Jim Cole, Lowell Observatory (right)*

by actually seeing and considering those objects. Video observing serves this goal well by allowing us to engage a dozen or more people at once. The camera's view is also much less compromised by a bright Moon or light pollution than a person's visual view. That allows us to provide good images of many reasonably bright objects at any time during the lunar cycle or even in heavily populated areas.

Tools and Tips

Live video observing is only possible because extremely sensitive cameras have become available[4], allowing us to present viable images of deep sky objects in exposures of 5-30 seconds. Astronomical images like those seen in astronomy magazines generally require much longer exposures, often many hours in length. With our system there are hundreds of objects that we can use in our programmes with exposures under 30 seconds.

There is a substantial range of equipment available to implement a video observing programme. Lowell Observatory added a new observing plaza, the Giovale Open-Deck Observatory (GODO), for its public programmes. Our video observing system includes a Mallincam DS10cTEC video camera attached to a 14-inch Planewave CDK (f/7.2) optical tube. This model is not mobile, and we know that this may not be a financially-viable option for many public observing ventures.

We thus invite you to consider the system that we formerly used at Lowell Observatory. Our less expensive, mobile set-up included a Celestron CGEM GoTo German equatorial mount with a StarSense automatic alignment system, a Celestron 11-inch Schmidt-Cassegrain optical tube with a 0.33 focal reducer, and a Mallincam Xterminator CCD video camera. We used a laptop with a video frame grabber to control the camera and display the images on a 27-inch plasma television screen (Figure 3).

The first thing to do if you are contemplating setting up a live observing system is to study the state-of-the-art camera technology. There has been rapid growth in the availability of cameras for live observing, some with the high sensitivity needed for outreach projects like ours, and others requiring substantially longer exposures[5,6]. The latter are useful for applications like private observing where the time requirement is more relaxed. Often these cameras require an order-of-magnitude more time to image an object. Until recently, only CCD cameras were suitable for outreach, but developing a camera that can produce images in dozens of seconds requires some tradeoffs. Our CCD camera, for example, sacrifices resolution by using large sensor elements and small sensor arrays. However, recent advancements in CMOS technology have yielded camera chips that have very low noise levels allowing higher sensitivity and resolution than earlier cameras.

There are excellent resources to learn how to evaluate a camera. The Cloudy Nights EAA (Electronically Assisted Astronomy) forum[5] is a good place to explore the technology and ask questions. Their 'Astro Video Image Gallery' archive provides a good measure of what can be done now with a camera and a way to trace the evolution of the technology over the last 11 years. Two night skies websites[7] broadcast live observing sessions with a wide range of equipment and afford an opportunity to chat with the presenters during webcasts.

To set up a video observing system you can begin with any optical tube (we are familiar with set-ups from 2 to 27 inches) and any mount with reasonably accurate tracking. The scope should be reduced to f3 – f4 to accelerate image acquisition. Suitable cameras are available for 300 USD.

Broadcasting events in a time of crisis

Our programmes as described above were established as local events with in person visitors. When the COVID-19 pandemic forced the suspension of our public programmes we introduced broadcast observing events to allow us to continue our outreach. The broadcast programmes differ significantly from our local programs. There is, of course, some loss of intimacy, and the loss of feeling as one with the universe. There are also advantages. Our broadcast programmes have reached wide audiences. We have generally attracted audiences of 500 to several thousand for these "Interactive Stargazing" programmes including significant numbers from around the Earth. Clearly there is the potential to reach very large numbers of people. One extreme example was an extended programme that we did on the occasion of the recent Saturn / Jupiter conjunction. That event attracted over 2 million views on YouTube.

There is extraordinary potential here. We can do basic programs, or much more rigorous programmes or anything in between. These programmes are broadcast on YouTube and are archived and available for viewing later. They also have chat options so that viewers can ask to see specific objects or ask questions.

We are in the planning stages of online observing events for private groups that range from astronomy clubs to organisations that serve persons with special needs, and will tailor each program to fit the audience.

We will welcome the opportunity to get back to local guests, but the opportunity to address vast and diverse audiences via the internet programmes is clear.

Conclusions

We have found that augmenting traditional telescope observations with video observing systems at public astronomy events substantially adds to the quality of our presentations. Visitors can see distant galaxies, planetary and emission nebulae, and many other objects in full colour and higher detail than they would using only optical telescopes.

We do not endeavor to replace the observing experience that occurs at an eyepiece. Viewing the wonders of space with your own eyes, while breathing in the chill of the night, with the heavens glistening above you, remains an experience that cannot be outdone, regardless of technological advances in imaging. A major benefit of our video astronomy programme is that it can reach global audiences when streamed online. This allows us to provide a genuine astronomy experience when in-person programmes are not accessible.

Though either can stand alone, we believe that visual and video programmes work best in tandem. We draw on the awe that occurs at the eyepiece and use that experience to further engage our guests with our on-screen full-color imagery.

Our video observing format allows us to present information in many ways, generate detailed conversations with our guests, and address the needs of the old, the young, and most visitors with physical and visual limitations. We are able to reduce the waiting time to observe and provide excellent views of bright celestial objects despite factors such as a bright moon or light pollution. Based on our experience, it is hard to imagine a better platform to introduce visitors to the ideas of science.

Notes

[1] 'An article about the cultural impact of Hubble Imagery: https://mag.uchicago.edu/arts-humanities/astronomical-sublime#

[2] A good reference on the limitations of human eyesight in low-light situations: Hood DC, Finkelstein MA. Sensitivity to light. In: Boff KR, Kaufman L, Thomas JP, editors. The handbook of perception and human performance, vol. 1. Sensory processes and perception. New York: John Wiley; 1986.

[3] Here are two sites where people webcast live video observations including opportunities to discuss objects and tools with the presenters:NSNLive.com and https://www.nightskiesnetwork.com/

[4] An article from the Arizona Daily sun concerning Vera Rubin's work at Lowell Observatory: https://azdailysun.com/news/opinion/columnists/view-from-mars-hill-vera-rubin-broke-new-ground-in-astronomy/article_f2639329-39d9-5f8c-8805-31cab3fe1c13.html

[5] Observing with Astrovideo Cameras' by Rob Mollise is an article in the February 2013 issue of Sky and Telescope. It gives a good overview of video astronomy and includes set-up tips as well as background information on the differences in versatility between astronomical video cameras and traditional cameras for observing: https://www.mallincam.net/uploads/2/6/9/1/26913006/observingwithastrovideocameras_feb2013snt.pdf

[6] There is an excellent discussion group at Cloudy Nights EAA forum. It is a good place to familiarise yourself with the possibilities of electronically assisted astronomy (EAA): https://www.cloudynights.com/forum/73-eaa-observation-and-equipment/

[7] Another resource is the Electronically Assisted Astronomy EAA Discussion and Images Facebook group. Images using a wide range of cameras and telescopes, accompanied by guidance and assistance, can be found there: https://www.facebook.com/groups/289077791456944

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Biographies

Sarah Burcher has a Master's degree in biomechanics from Northern Arizona University, and fell in love with astronomy when she became an educator at Lowell Observatory. She now works full-time in the observatory's outreach department facilitating observing experiences for the public.

Bill McDonald started his engineering career at a geophysical observatory, developing seismic instruments to install on the Moon and the ocean floor, then ended it at another university lab. He retired to Arizona, US where he discovered the night sky and began to explore ways to optimise the way astronomy is presented to the public.

Dedoscopio Project: Making Astronomy Accessible to Blind and Visually Impaired (BVI) Communities Across Chile

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tactile material, inclusion, BVI

Chile currently hosts more than 50 percent of the world's astronomical infrastructure and is internationally recognised for its pristine skies. Motivated by this access to the field, the Chilean astronomical outreach community over the past 10 years has brought the complex language of astrophysics closer to the public. However, Chilean people affected by blindness and visual impairments (BVI) are still largely marginalised from the inherent visual beauty of the cosmos. Science outreach channels, in general, do not account for the needs of people with disabilities. Expanding the frontiers of astronomy outreach and, more importantly, bringing visibility of the BVI community into society at large, resulted in the creation of Dedoscopio. We, the Dedoscopio team, have developed outreach activities for people with visual disabilities, using tactile materials as a medium to represent astronomical concepts and phenomena. The materials are handmade by the team using accessible, everyday and low-cost materials. While developing our work, we found a void in equal access to both scientific and cultural activities. In this article, we explain the materials Dedoscopio has produced and the different activities we have implemented to increase the number of scientific-cultural activities for people who are BVI within Chile.

Introduction

Chile has a very important role in the development of astronomy due to the excellent observing conditions in its northern region. The country hosts 55,6 percent *(Unda-Sanzana, 2020)* of the observatories around the world. This makes astronomy a popular subject within the country, in addition to the intrinsic attraction that people have towards this science.

Outreach activities have increased in Chile in the past 10 years. Public and private entities have started to invest in science outreach to encourage interest in astronomy and to stimulate scientific literacy. However, there is a particular segment of the population who has great difficulty accessing these activities: blind and visually impaired (BVI) people.

According to the Chilean Society of Ophthalmology (SOCHOF) *(Lopéz, 2018)* about 850,000 people in Chile live with a visual impairment, 80,000 of whom have blindness.

Inclusion as a concept proclaims that all people, despite their disabilities, have the tools to develop themselves within society, but this does not ensure that inclusion takes place in all areas of society.

For such a large population, we found that there were very few resources available, particularly in astronomy, during our three years doing outreach activities through the Faculty of Mathematics and Physics at the University of Concepción. After completing our degrees we decided to focus on astronomy outreach to BVI communities to reduce this gap in access. Thus, at the beginning of 2018 we began to give astronomy talks around Chile focused on visually impaired audiences as Dedoscopio. We aim to create a more inclusive society through these multisensory astronomical talks and in this article we show how we have reduced this inequality gap to science for people with disabilities.

Dedoscopio Resources: Talks Complemented by Tactile Materials

Our materials go through testing and development before reaching their target audiences.

First we decide the subject we will talk about according to the latest news in astronomy at a global level, such as the landing of InSight in Mars or the first Black Hole picture, or commemorations such as the Asteroid Day or the annual theme of the Day of Astronomy in Chile.

Then, we define 4 to 6 associated multisensory experiences and models, which we develop, test and improve upon. When the talk is ready, we then schedule free visits to BVI groups in Chile in exchange for their feedback. The whole process takes between 2 to 3 months until we reach the target groups.

Over three years we have created five tactile astronomy talks with the following topics:

Electromagnetic Spectrum: Audiences learn what an electromagnetic wave is and its importance within astronomy. In this presentation we show the electromagnetic spectrum, where each part of the spectrum is represented with wool, thread, and noodles of different thicknesses and textures. As an example we represent the multiwavelength Milky Way picture, with every part of its spectrum textured in a specific way (Figure 1).

Asteroids: Audiences learn about asteroids, meteors and 'shooting stars'. Here we present a not-to-scale representation of the Solar System to highlight the asteroid belt and Kupier belt, which are depicted using small circular noodles. The planets are represented through balls of different sizes complemented with an orbit in wood and the Sun is represented by a ball covered with cotton.

Mars: Audiences learn about the exploration of Mars and the use of robots to obtain information. We share a Mars model made of a polystyrene sphere. We have carved the Martian mountains and canyons into the model and marked the polar ice caps with salt. Also we show Deimos and Phobos to-scale as non-uniform moons.

Black Holes: Audiences learn about the formation, growth and shape of a black hole (BH). We share a representation of an Active Galactic Nuclei (AGN) using a spiral cardboard base. We glued synthetic cotton (gas) to the base to form a torus and sand (dust) closer to the centre of the base to form the accretion disk. We placed a stick through the centre of the base to form 'jets' and so we could spin the model to recreate the movement of the AGN (Figure 1). To represent the effect of the BH on an object we used magnets that would feel as the attraction around the event horizon.

Solar Eclipse: Audiences learn the cause of solar eclipses, how often they occur and the precautions to take when observing one. In this demonstration, we make Earth-Moon scale models with small plastic spheres and a wool thread to show their mutual distance to-scale, the Sun is represented with arms outstretched held a meter apart, explaining that this would be the diameter of it.

The models in these presentations are handmade with accessible materials such as cotton, lentils, paperboard, silicone, sugar, and wooden sticks (Figure 1).

Different materials stimulate the sense of touch differently *(Salinas, 2013)*, so people associate different textures to different concepts and physical processes. We are careful of this phenomenon as we create our models. For example, to show the Milky Way in different wavelengths we print images of the galaxy in each part of the spectrum and paste a different material onto each image: EVA foam to represent radio waves, sugar for UV band to show the young, hot stars, small circular pasta to represent X-ray sources, etc. (Figure 1) We also account for people with partial blindness when we develop these models. We make sure the material and the textures have contrasting colours, i.e. we place dark soil onto white cotton or yellowish wood onto black paperboard. Additionally, we use labels in Braille and macro-type in contrasting colours so more people can easily read them.

Testing Dedoscopio Resources

All our tactile materials are tested before they are presented at a talk. The social sciences department of University of Concepción hosts ARTIUC[1], a programme for BVI students at the university. ARTIUC members test the materials and give us feedback to improve them.

During a testing session we usually meet with 4 to 5 students, give a short background talk on the astronomy topic, and then show our materials and explain their meaning. The students test the shape, steadiness and comfort of the material with their hands. Sometimes they understand the meaning of the materials, but other times they recommend changes to the material or suggest a different way to explain. In one particular instance, when we created the not-to-scale representation of the Solar System to highlight the asteroid belts, we only used cotton to define the Sun. Our test group suggested that, as the cotton may have a confusing shape, it is not a good representation of the Sun as a sphere. They recommended that it would better to cover a sphere with cotton instead.

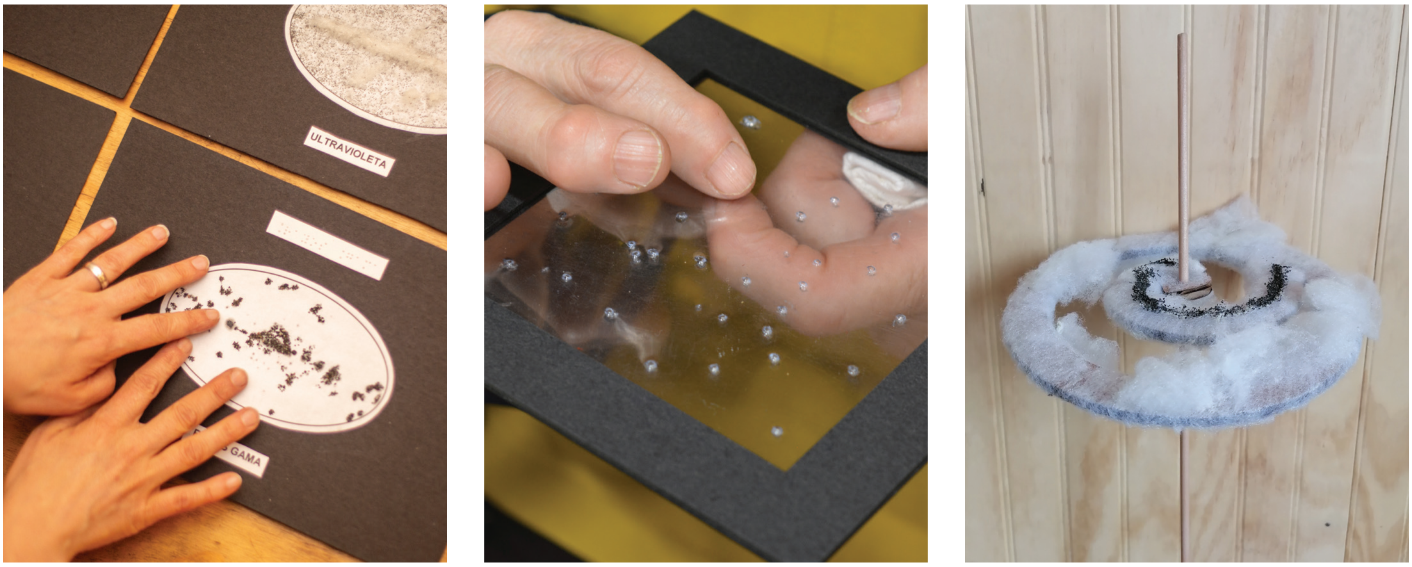

Figure 1. *Examples of handmade materials for Dedoscopio.* ***a)*** *(left) A multi-wavelength images of the Milky Way, where different parts of the electromagnetic spectrum are represented by different textures (sand for gamma-ray, sugar for UV, pasta for X-ray, and confetti for IR).* ***b)*** *(centre) A tactile sky field where the 3D dots represent asteroids in the field. The other side of the card is the same field an hour later, so a user can use both hands to search for dots and understand how the field has shifted.* ***c)*** *(right) A representation of an Active Galactic Nuclei using cotton for the torus, sand for the accretion disk and a wood stick for the jets. Credit: Dedoscopio Project*

We also receive additional feedback from specialist educators, differential educators, and social workers at ARTIUC. The group loan us their machines to create Braille and macro-type labels.

Outreach Actions in Schools around Chile: Implementation and Assessment

Typically, the Chilean BVI communities meet in small groups of 12 to 20 people in their towns. Their ages range from 20 to 63 years old. Children are immersed into the school system, so it is difficult to reach them through these communities.

On February 2010 a law was enacted which promotes development at social aspects (e.g. education, work, health, etc.) of people with disabilities in Chile. Although it is a law, there are no guarantees that it will be fulfilled successfully. In our activities we have found that, on average, 15 percent of the attendees know Braille. With children attending schools of their parents' choice there is no guarantee that they will have a teacher who knows Braille.

We started our tactile talks in 2018 in our home region of Biobío. Chile is a long and narrow country divided into 16 administrative regions. The first talk was in Cañete, Biobío Region, located at the end of the central zone, and then we visited 6 cities in the same region: Mulchén, Los Ángeles, Concepción, Penco, San Pedro de la Paz, and Lebu. We later expanded throughout Chile (Figure 2).

Over the past three years, we have visited 263 people, mainly adults, through 15 groups in seven regions in our country. In addition to the Biobío Region, we have been to the towns and cities of Freire, Lautaro, Loncoche, Padre Las Casas, Pucón, Teodoro Schmidt (Araucanía Region); Puerto Aysén (Aysén Region); La Serena (Coquimbo Region); Panguipulli (Los Ríos Region); Santiago (Metropolitana Region); and Rancagua (O'Higgins Region).

To understand the impact of our talks, we administered brief pre- and post-event tests. The questions were directly related to the main concepts of the delivered talk and highlighted by the tactile materials.

The test was performed on participants, who agreed to freely answer the pre- and post-tests, where we also included data on their level of visual impairment, age, gender, level of education and valorisation questions related to the talks.

Regarding the content of the pre-test, the central question was:

- *What do you know about astronomy?*

This question is open, i.e., the participants freely answered what they knew about astronomy or the first concepts that they can remember.

For the post-test, the central pre-test question was repeated, adding further questions about the concepts and tactile materials addressed during the talk, both as closed or open type questions.

According to the tactile representation:

- *How many parts does a black hole have?*
- *What is the light path?*

According to the content of the talk:

- *Do black holes work like a vacuum cleaner?*
- *What is a Supernova?*

The tests were carried out on the same day as the talk, either a few minutes before starting (pre) and at the end (post).

From the participants who took the test 41,1 percent of them were high school students, 30 percent university undergraduates, 11,8 percent university graduates and 17,1 percent had only finished primary school.

Through these tests, we found that more than half of the participants understood the astronomical and physical phenomena through the materials presented and that they had a strong interest in participating in similar activities in the future.

The answers about their previous knowledge focused on what they had learnt during their schooling period, such as concepts of the Solar System, the Moon, and the Milky Way, but they recognised that they never really understood them. The answers about their gained knowledge revealed that only 33 percent of them

Figure 2. *The red pins in this representation of Chile, indicate where the Dedoscopio team has visited across Chile since 2018. The team has visited 21 groups and cities across seven regions. The team has visited the following groups: (from top, or north, to bottom, or south): the school Colegio Luis Braille and groups Acaluces and Ulivis in La Serena, Coquimbo Region; the school Colegio Santa Lucía in Santiago, Metropolitana Region; the school Juan Tachoire Moena in Rancagua, O'Higgins Region; the groups Acivic, ARTIUC, Grupo Renacer, Luceritos, and Victor Jara, the school Escuela Juan Madrid Azolas, the rehabilitation center Amilivi, and municipalities of Cañete and Mulchén in the Biobío Region; the cities Lautaro, Loncoche, Padre Las Casas, and Pucón, and the towns Freire and Teodoro Schmidt in the Araucanía Region; the city of Panguipulli in the Los Ríos Region; and the group Visión Futuro in the Puerto Aysén, Aysén Region. Credit: Dedoscopio Project*

Figure 3. a) *(left) An example of the talk using tactile materials, kids from Colegio Luis Braille speak with a Dedoscopio team member while interacting with tactile material to understand black holes.* ***b)*** *(centre) A Chilean Sign Language interpreter signs during the talk Eclipse Curioso: Una Actividad Inclusiva (Intriguing Eclipse: An Inclusive Activity).* ***c)*** *(right) During an astronomical congress, sighted astronomers wearing blindfolds participate in a tactile talk. Credit: Dedoscopio Project*

understood the new concepts delivered during the talk.

This small increase may have three main causes:

1. Our talks are the first time they attended a science talk, so they were not used to receiving new, unusual information and adding it to their knowledge base;
2. The education level affected how they understood new concepts;
3. The structure of the talks was not well designed.

Since both the talks and materials were tested with ARTIUC, we therefore believe that the small change in knowledge acquisition is a combination of the first two causes and the wide age range of the groups.

The 15 groups agreed that their present access to scientific activities is non-existent. They claim that the only channels to science they have ever had were TV, radio, and newspaper outlets, but these presented science in a way that they could not understand the concepts in their entirety.

All participants on the test agreed that they are segregated from scientific culture. Thanks to our talks, they were able to have a deeper and more direct understanding of the phenomena that we presented to them, according to their needs and comprehension.

Dedoscopio Working for and with the Community

Through these years we realised the importance of associating with different entities such as non-profits, NGOs, astronomical observatories, and government corporations. These partnerships allow astronomy to reach the Chilean BVI community in a more effective way and the science becomes as accessible as it can be (Figure 3). We needed outreach beyond what our small team could do.

Outreach to Teachers

We have visited five schools to speak with primary and secondary school teachers. We show our material and discuss how they can modify them to represent other natural phenomena beyond astronomical ones. Through these discussions the teachers are now able to teach a physical process in a low-cost, tactile way to a student who is BVI while showing the sighted classmates how to be inclusive.

Outreach to Professional Astronomers

Another important activity we have developed is to show our material and work to astronomers at different scientific congresses. In a tactile talk or workshop, we demonstrated our work by covering their eyes and asking them to identify astronomy concepts with only their hands. We helped them realise that adding an inclusive activity to their outreach better conveys an astronomy idea to everybody, no matter their abilities.

Bridging with Other Groups in Accessible Astronomy in Chile

Dedoscopio is not the only project working on accessibility within astronomy in Chile. A lot of outreach practitioners have created tactile models with different materials and goals[2] in the last five years. Because of this, we have collaborated and shared material with other tactile projects. With their work, we have been able to include the stellar formation by Astro UDP[3] and the different types of galaxies from the AstroBVI Kit *(Argudo-Fernández et al., 2019)* in our talks.

Using Solar Eclipses to Promote Astronomy as an Inclusive Science

In 2019 and 2020, we took advantage of the two total solar eclipses in Chile to reach more BVI communities within the country. In 2019 we carried out Eclipse Curioso: Una Actividad Inclusiva (Intriguing Eclipse: An Inclusive Activity), a talk series which helped attendees see astronomy as an inclusive science in the city of Concepción. Through short talks the audience learned how solar eclipses have impacted different historical events, the eclipse-related rites of the indigenous Mapuche people, the mathematics behind an solar eclipse, and the precautions we must take when looking at a solar eclipse.

One highlight of this activity was the talk about the Mapuche's cosmovision. The Mapuche people are the largest indigenous community living in Chile and their culture is different from Chilean culture at large. With the inclusive aim of Dedoscopio, having this talk showed the importance of the Mapuche with relevant astronomical information, like the meaning of the Lai-Antü ('eclipse' in the Mapudungun language) and other celestial phenomena to the culture.

We invited the whole community to be a part of this talk series so we brought in a Chilean Sign Language interpreter, printed 3-D tactile materials for the audience, and secured space for attendees with wheelchairs. More than 150 people enjoyed this activity and were grateful for the inclusive considerations.

In 2020, due to the COVID-19 pandemic, with the support of social and governmental institutions, we sent Kit Eclipse Curioso (Intriguing Eclipse Kit), a box of tactile astronomy materials, to 142 families with one or more BVI members located in the pathway of the total solar eclipse in southern Chile. The box had five tactile experiences to explain the following ideas: sizes of the Earth and Moon and their relative distance, the comparative sizes of the Sun and Moon, different types of eclipses, and the phases of an eclipse. For families with children, we also included the Abre Tus Sentidos a los Eclipses: Sudamerica (Open Your Senses to the Eclipses: South America) book *(Runyon et al., 2019)* and the Lightsoud device *(Hyman et al., 2019)*. We contacted the families via Zoom or Youtube to explain how to use the materials with precaution and answer their questions before the eclipse.

Conclusions

According to the results of our tactile representation test, most of the BVI participants correctly identified the physical processes in astronomy due to our tactile materials that facilitated its understanding. Although we built these materials for the BVI public, we realized through the feedback of teachers and non-BVI participants that it also works for all public which makes it truly inclusive.

The final part of our questionnaire was about valorisation, where BVI communities present a lot of enthusiasm and we received very positive feedback, as they want to learn more about planets, stars, the big bang and wormholes. They also agreed that they feel distant from science in general. One of our new goals is to encourage other scientists in taking their subjects to new audiences, including people with disabilities.

Through activities for and with the community, Dedoscopio has been successful, not only as an inclusive astronomy outreach project, but also as a collaborative network, raising awareness to the BVI community within society. Thus, after three years of work, we will continue implementing our activities, committed to reaching more places across Chile.

Notes

[1] ARTIUC website: http://artiuc.udec.cl/

[2] Instagram of the Astronomía Inclusiva network in Chile: https://www.instagram.com/astro.inclusiva/

[3] Núcleo de Astronomía UDP website: https://astronomia.udp.cl/es/category/outreach/

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Biographies

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Pamela Paredes-Sabando received her Bachelor in Physics from the University of Concepción in Chile. She is the co-coordinator for Dedoscopio, a project that creates tactical astronomy materials and brings accessible astronomy talks and workshops around Chile.

VOS^{4}O: Virtual Observatory Solar System Scaling Service for Outreach

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Keywords
solar system, scale model, web service, astronomy outreach

We present VOS^{4}O, a simple and free web service aimed at helping the public create scale models of our Solar System. The user can set the scale, the diameter of the Sun or any planet, and the distance from the Sun to any planet. VOS^{4}O then returns both a table with the numerical values and figures displaying the locations and sizes of the planets. The service allows customisation: users can choose the units of lengths, the language (12 are already available), and the epoch of display (useful for explaining planetary motion to, for example, elementary school kids). VOS^{4}O proposes a web interface with a simple query form for most users. However, it is fundamentally a web service following the Virtual Observatory standards, and it can be easily integrated in a web page or software by querying its programming interface.

Introduction

What would the size of the Earth be if the Sun was a tennis ball? Or a soccer ball? How far away would Neptune be? These questions are more often than not asked by the public, kids, teachers and even local astronomers.

Knowing the true physical diameters of the Sun and the planets, and the semimajor axes of their orbits, the solutions to these questions are straightforward and only require a cross-multiplication. We present VOS^{4}O which aims at providing these answers to the wider public through a web service, free of charge.

Furthermore, VOS^{4}O allows users to more easily understand the real orbital dynamics of the Solar System. The question of scales in the Solar System is often raised to teach how immense space is compared to the sizes of the planets. Hence, planets are usually presented in alignment, creating a biased representation of our Solar System as the eight planets are never aligned in space. Building upon the ephemerides computation library of the Institute for Celestial Mechanics and Computation of Ephemerides (IMCCE)[1], VOS^{4}O thus presents users with the positions of the planets on their orbits (given as their ecliptic longitudes (Figure 1.a)), allowing users to easily understand the real orbital dynamics of the Solar System.

Typical Use Cases of VOS^{4}O

We present here three examples of how people may use VOS^{4}O: by setting a maximum size of a Solar System scale model, by using a common object as a reference for size, and to illustrate planetary motion. These three are common requests from primary school teachers.

Although scaling the Solar System is a simple cross-multiplication, users of VOS^{4}O highly appreciated the ease of use and the graphical outputs with figures generated on the spot, ready for use in a classroom.

How Can I Put the Solar System in My Lecture Room? On My Patio?

Many schools or associations wish to build scale models of the Solar System on their premises. The natural question is therefore the size and distance of each planet from the Sun, knowing the maximum length available. VOS^{4}O provides a direct answer by setting the distance of the furthest planet to the available length, for instance, 100 metres (Figure 1a).

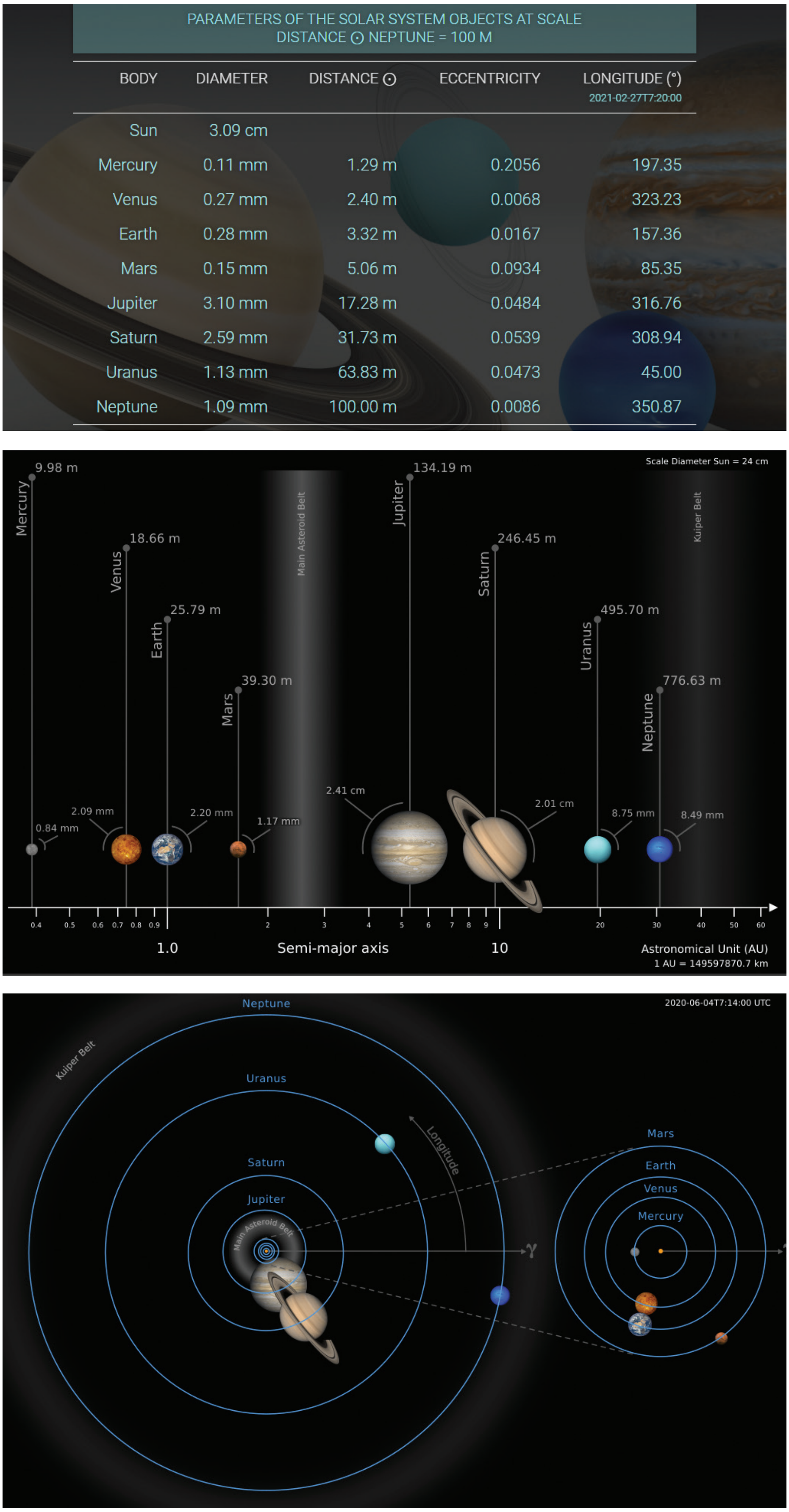
If the Sun Is a Basketball, Where Shall I Place the Earth?

A common approach to teaching scales is to present a round object to students, setting the size of the Sun, and then asking for the corresponding size and distance of the Earth (or any other planet). VOS^{4}O offers an easy way to get the answer by setting the diameter of the Sun or any planet (Figure 1b).

How Do Planets Move?

Understanding the motion of planets, and in particular the large difference of orbital periods, is non-trivial for children at the primary school level. VOS^{4}O allows users to input a set date and receive the positions of planets along their orbit with a view of the Solar System (Figure 1c). Displaying several results from VOS^{4}O at different epochs offers a convenient way to illustrate planetary motion to the public.

We note from experience, that one of the key points in the VOS^{4}O is its "numerical" output of the ecliptic latitude. We have seen educators preparing markings on the ground and placing children on the markers at "different epochs" so they reenact the planet's motion, rather than to experiencing it only visually. The children roleplaying Neptune won't barely move



PARAMETERS OF THE SOLAR SYSTEM OBJECTS AT SCALE
DISTANCE ⊙ NEPTUNE = 100 M

BODY	DIAMETER	DISTANCE ⊙	ECCENTRICITY	LONGITUDE (°) 2021-02-27T7:20:00
Sun	3.09 cm			
Mercury	0.11 mm	1.29 m	0.2056	197.35
Venus	0.27 mm	2.40 m	0.0068	323.23
Earth	0.28 mm	3.32 m	0.0167	157.36
Mars	0.15 mm	5.06 m	0.0934	85.35
Jupiter	3.10 mm	17.28 m	0.0484	316.76
Saturn	2.59 mm	31.73 m	0.0539	308.94
Uranus	1.13 mm	63.83 m	0.0473	45.00
Neptune	1.09 mm	100.00 m	0.0086	350.87

Figure 1. *Three charts built by VOS⁴O.* ***a)*** *(top) Chart describing the distance between objects in the Solar System if Neptune was 100 metres from the Sun.* ***b)*** *(center) A chart of the Solar System showing the relative diameters and distances of the planets if the Sun was 24 centimetres in diameter.* ***c)*** *(bottom) View of the Solar System showing the position of the planets. Credit: University of Côte d'Azur/Côte d'Azur Observatory /Institute for Celestial Mechanics and Computation of Ephemerides/Paris Observatory/ CNRS.*

while the children representing Mercury or Venus will move rapidly.

Access and Results

Most users will access VOS⁴O through its web pages[2]. A minimalist form allows users to set the scale and unit (Figure 2). Upon clicking the 'Apply' button, the interface creates a table of values and figures, and displays them in the browser. Users can directly download them; a download interface is provided for users to choose the formats of both the data and figures ('Download results' button).

The data can be retrieved in plain text, CSV, or VOTable, the native XML format of the Virtual Observatory (VO). The figures are provided in PNG, TIFF, PDF, and SVG formats.

More advanced parameters allow users to compute the position of the planets for a specific date and to adjust scaling relative to the diameter of a chosen planet.

VOS⁴O follows the standard data formats of the VO, a concept widely used in astronomy whose cornerstone is that astronomical datasets and other resources should work as a seamless whole[3]. As such, VOS⁴O can be directly queried via its application programming interface (API), which allows anyone to set up their own software to directly interrogate the service and retrieve the tables and images generated, or to create their own web form to scale the Solar System.

VOS⁴O is currently available in 12 languages. It is configured to display the default language of the web browser used to access it. The table and figures can however be set to another language from the advanced parameters form, or the entire web page can be switched to another language from a drop-down

SCALE Diameter OF Earth TO SUN = 1

UNIT meter

Figure 2. *The native form of VOS^{4}O, developed to the needs of general users. Credit: University of Côte d'Azur/ Côte d'Azur Observatory /Institute for Celestial Mechanics and Computation of Ephemerides/Paris Observatory/ CNRS.*

menu. We plan to offer more languages in the future[4].

Lessons Learnt

The development of VOS^{4}O presented strong differences with our previous experience creating web services: the target audience was no longer professional astronomers and engineers, accustomed to machine-machine interaction, but the general public, accustomed to an easy-to-use, graphically attractive, and multilingual interface.

We thus designed VOS^{4}O in two parts. The core of the service, which performs the ephemeris computations, is composed of a genuine web service allowing machine-machine interactions. This is fundamental to guarantee the durability and versatility of the service, beyond a simple spreadsheet or static web page. Moreover this allows independent integration of the service in third-party software or applications. The core is then coated with a graphical layout, designed to be attractive, easy to use, and multilingual to ensure the effective interaction with the public, whether children or adults, teachers or students. Now produced in Javascript, the graphical user interface will be easy to update in the future to follow the evolution of web technology.

Final Considerations

This article represents the official release of VOS^{4}O, an outreach web service to represent the Solar System at any scale. We have received very positive feedback from the relatives, teachers, parents, and professional and amateur astronomers who have already used the service. While scaling the Solar System only requires cross-multiplications, the interface was found ergonomic and intuitive. Users praised the figures generated by the service for displaying all the information needed to describe or build a scale model. In particular, users have appreciated that the figures show the real locations of the eight planets, a unique feature among scaling web pages to our knowledge.

We will keep adding new languages to the service. We hope VOS^{4}O will be widely used by a large audience all around the globe.

Notes

[1] Online ephemerides from the IMCCE: https://ssp.imcce.fr/forms

[2] VOS^{4}O websites: https://vos4o.imcce.fr and https://vos4o.oca.eu

[3] More information about the Virtual Observatory can be found on the International Virtual Observatory Alliance: https://www.ivoa.net/

[4] We always welcome volunteer translators for this work. Contact vo.imcce@obspm.fr for more information.

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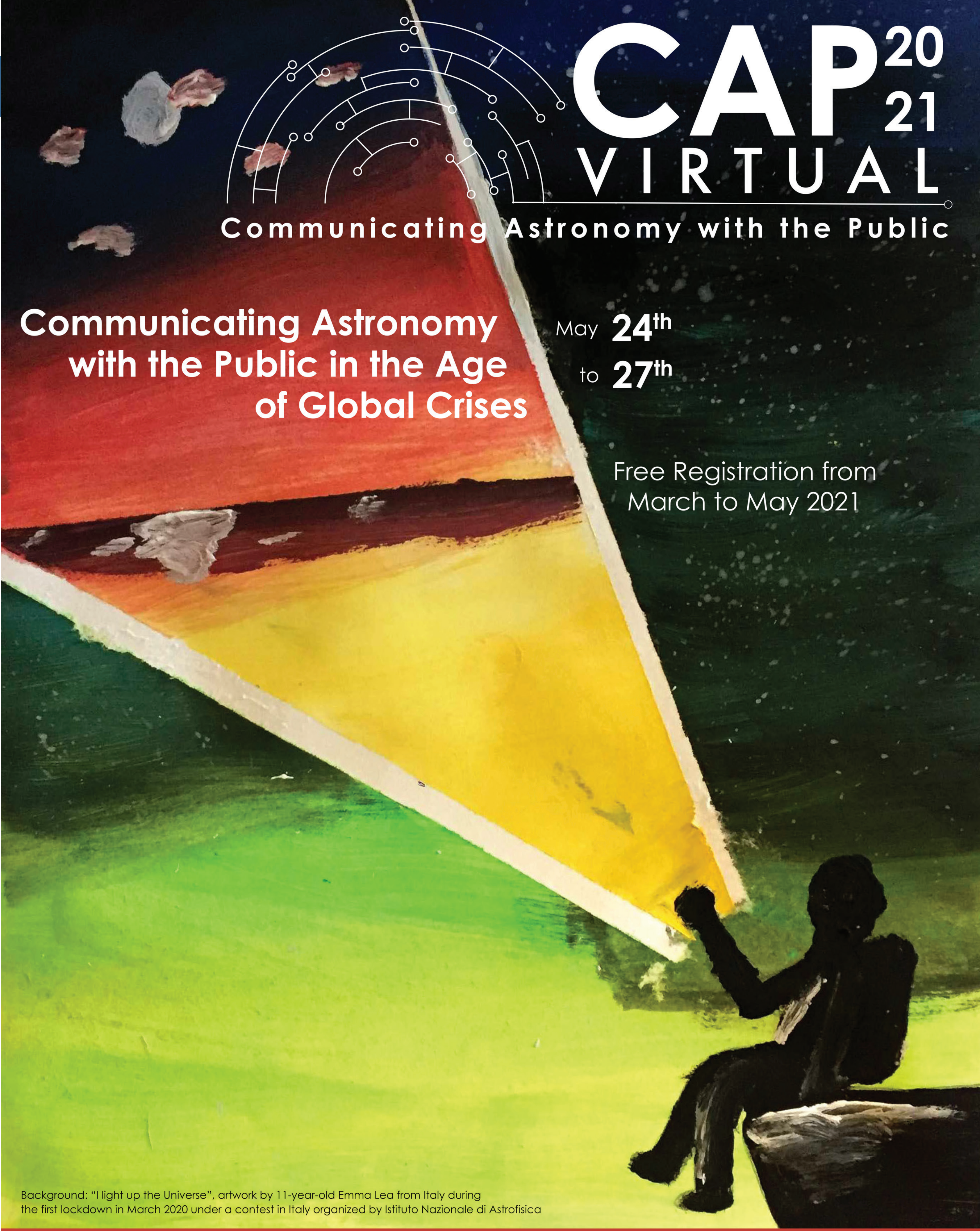
Biographies

Benoit Carry is an astronomer at the Côte d'Azur Observatory (OCA) in Nice, France. He studies the surface composition and physical properties of asteroids. He teaches at the local university and often presents to amateur astronomical societies and to children from primary to high school. The idea of VOS^{4}O emerged during one of these encounters in a primary school in Nice.

Jérôme Berthier is a scientific-computing engineer at the Institute for Celestial Mechanics and Computation of Ephemerides (IMCCE) at the Paris Observatory, France. He is the main developer of the library that computes and disseminates ephemerides with Virtual Observatory standards at IMCCE. The web services he developed and maintains are used more than 30,000 times each day.

Yohann Gominet is a computer graphic and web designer at the Institute for Celestial Mechanics and Computation of Ephemerides (IMCCE) at the Paris Observatory, France. He is responsible for designing and implementing the publication of ephemerides developed at IMCCE. His main professional activities are editorial work, graphic media, and website design and development.



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