Best Practice

The Educational and Influential Power of the Sun

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This paper aims to encourage science educators and outreach groups to use the Sun as a tool to teach science in formal and informal education settings. We explain how the Sun can be used as a topic in this manner and share our experience across the educational spectrum in Colombia and how we have used it to drive development beyond astronomy.

Introduction

The Sun has undeniably ruled our lives since the beginning of human history, and before it began at the very birth of our planet. About 4.6. billion years ago, before planets in the Solar System were even formed, all of the matter that eventually created us was revolving around a huge disc, our early Sun. This protoplanetary disc was constantly cooling and planets emerged in areas where matter became concentrated owing to gravitational attraction. Millions of years later, conditions improved to favour the development of life.

The Sun has been the main source of energy to maintain life on Earth; it has gone from being a source of worship to an object of study for human beings.

Like its origin, the fate of our planet is strongly linked with the Sun, which will also be responsible for our planet’s annihilation. There will come a day when the Sun will exhaust all its fuel, expanding into a giant red star whose size will be so large that it will swallow the Earth. There are still about five billion years until this happens, but for now, we must prepare for each solar maximum and protect the technology on which our modern civilization depends. A perfect solar storm, like the largest recorded to date which took place in 1859, could now have a huge impact on satellite technology, communications and power grids, causing losses worth millions of dollars (Moreno-Cárdenas et al., 2016)

The close relationship between the Sun and our history, present survival and future makes it a dynamic and interesting introduction to the world of science.

Colombia has experienced a scientific, technological and cultural transformation in recent years, showing considerable growth across these fields. In the midst of such important changes, it is critical to stress the importance of science and its

__Figure 1.__ Group of students at the Julio Garavito Armero Observatory, founded in 2000 at Gimnasio Campestre in Bogotá, Colombia. Credit: From the archive of the Gimnasio Campestre School.

public perception and to create communication and engagement activities that will instill in society passion and admiration for what science represents and can offer. In this article, we describe our experience of creating solar astrophysics activities as part of a high school programme, for extracurricular science clubs, and at a university.

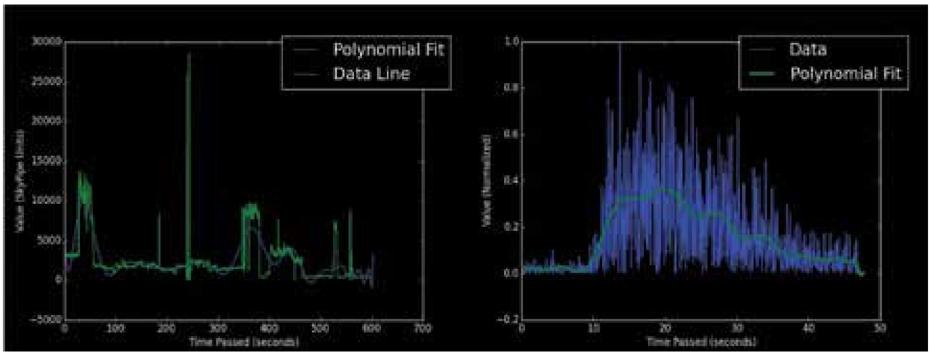

Figure 3. *An example of a scientific analysis performed on data taken on 6 September 2014 (14:10–14:20 UT) by a group of young participants that implements a polynomial fit by least squares, using Numpy (Walt et al., 2011) functions, to find a simple mathematical model that describes the data. The students used this technique to find a value for a missing data point. Credit: Julián Jiménez Cárdenas.*

Observing the Sun at School

Gimnasio Campestre, a school in Bogota, Colombia, has been teaching basic astronomy since 1997. Its astronomical observatory, named after the prominent Colombian astronomer, Julio Garavito Armero (1865-1920), was built in 2000 (Figure 1). The observatory runs several activities and classes to involve children of all ages in science. For the youngest students, the curriculum is based on learning the fundamental positions and observations of the Sun, Moon and planets and basic knowledge about constellations. From students nine years of age (fourth grade in Columbia), the classes cover three main subjects: the origin of matter and the Universe, fundamentals of light and the Sun and impact of gravity and asteroids. For those aged eleven (sixth grade), the school offers classes on: stars and the Sun, the Earth and planetary geology, and planetary atmospheres. Older students (seventh–eleventh grade) have the opportunity to explore these topics in greater detail and do research as part of a curriculum unit called 'Jóvenes Investigadores' ('Young Researchers').

Teachers have found that every year, students are particularly interested in learning about the Sun. In this academic environment, students learn about the multiple characteristics and phenomena of our star and also are trained in astrophotography. The observatory has been maintaining a record of these solar observations since 2001.

An important milestone in this project was the acquisition of an H-alpha solar telescope, which enables students to take images of filaments and solar flares. Every two years, a group of teachers and students involved in studying the evolution of the solar cycle publish an article on the subject in the school's research journal, El Astrolabio[1], and the most interesting images are sent to the SpaceWeather website[2] (Figure 2). To date, the results of the developed projects have been used to publish six articles in the school's research journal. Further, several such projects have enabled students and teachers to participate and present their research at conferences and national astronomy meetings and even publish their work in international journals. One such article in an international journal is based on a discovery report on an aurorae borealis seen in Colombia in 1859 (Moreno-Cárdenas et al., 2016).

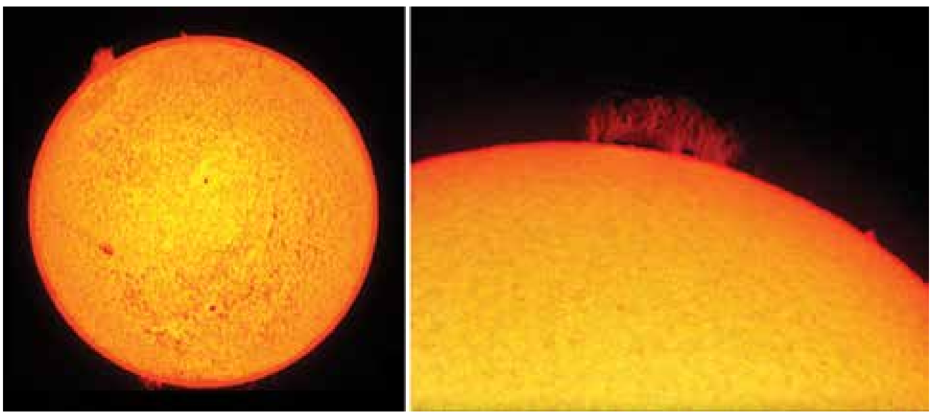

Figure 2. *Images of the Sun (H-alpha) acquired at the Observatorio Julio Garavito, Gimnasio Campestre in Bogotá, Colombia of the solar disc on 22 April 2015 (left) and detail of a prominence on 17 October 2017 (right). Credit: Freddy Moreno-Cárdenas.*

School research projects based on observations of the Sun have been replicated in several schools in Bogotá. Currently, Gimnasio Campestre's Observatory mentors two public schools, fostering the development of scientific knowledge by involving students and teachers in interactive projects.

Studying the Sun before College: Seedbed Projects

Since 2010, the Young Talent Programme of Mathematics, Science and Technology has taken place each year at Fundación Universitaria Konrad Lorenz in Bogotá, Colombia. This programme is part of a non-profit project that focuses on high-school children from Bogotá and surrounding cities, including some from disadvantaged communities. The programme is designed to inspire young people and introduce them to science with astronomy as the vehicle.

Every year, 30 participants are selected from an application pool of more than 200 young people using an admission exam

Figure 4. A group of students share their collected data and perform in open spaces where they are encouraged to show the public, especially young children, their work. Credit: Alejandro Cárdenas-Avendaño.

that measures problem-solving abilities which do not require particular learned knowledge. The group receives one-year support by two instructors, whose purpose is, not to conduct lectures, but to answer questions and propose a main objective at the beginning of the programme.

During 2014, the team's general objective was to learn scientific computing techniques. Python was chosen as the programming language to exploit its expressive power with simple and compact syntax and third-party open-source libraries such as NumPy (Walt et al., 2011) Matplotlib (Hunter, 2007) and SciPy (Jones et al., 2014) were used to encourage the use of scientific scripting language.

To develop scientific computing techniques, the proposed objective was to measure solar activities via radio waves with NASA's Radio JOVE project antennas but without the main software provided by NASA to record, store and visualise data (Lashley, 2010; Higgins et al. 2014). Figure 3 shows an example of the data analysis performed by the participants.

In addition to the data collected by the students, the Radio JOVE Data Archive[3,4] was used to gather information and explore larger datasets. In some cases, it was possible to conduct a rigorous analysis and check if the registered phenomena were global, at least reported somewhere else or corresponded to spurious signals. Through the data collection and analysis, the participants were able to acknowledge a relationship between sunspot numbers and 20 MHz solar burst counts.

The results were presented in regional science, engineering, technology and mathematics (STEM) fairs open to the general public and all of the data collection was conducted in public parks to engage young children and the general public (Figure 4). During the data collection campaigns, the participants shifted between collecting data and explaining the project to passers-by.

We also would like to mention that two participants performed remarkably at the Colombian Olympiad on Astronomy and, subsequently, were part of the National Team for the International Olympiad on Astronomy and Astrophysics (IOAA) and the Latin American Olympiad on Astronomy and Astronautics (LAOAA).

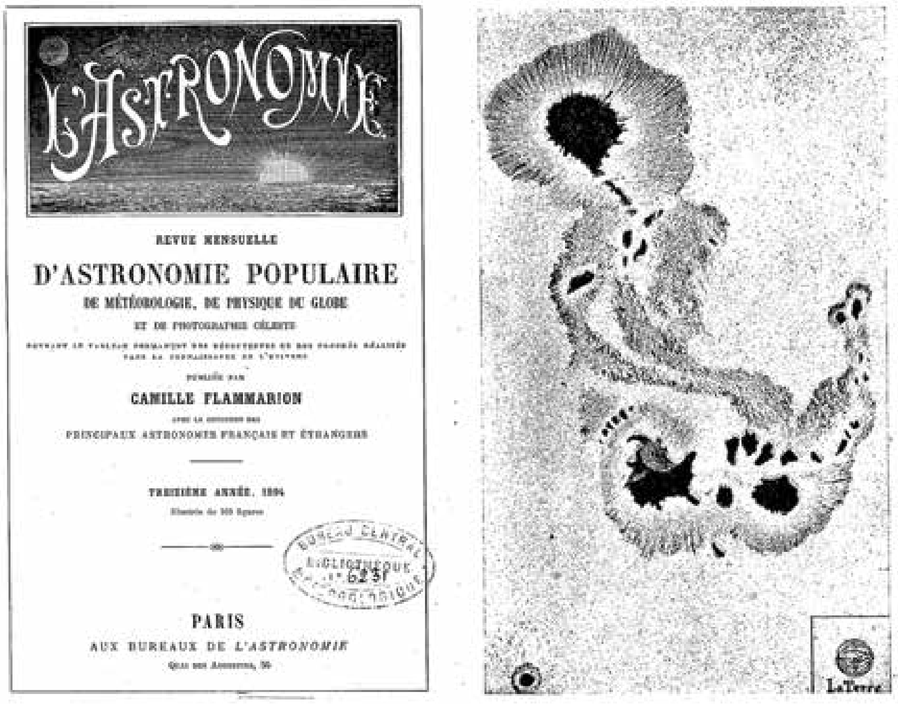

Figure 5. Journal of the French Society of Astronomy (left panel) in which José María González Benito published a drawing of the large solar active region observed in August 1893 (right panel). Credit: From the historic archive of the National Astronomical Observatory of Colombia.

Solar Physics as a Research Option at Universities

The study of the Sun in Colombia dates back to observations made by José María González Benito (1843-1903) in the 19th century, when he was the director of the National Astronomical Observatory, the oldest astronomical observatory in America founded in 1803, and a member of the French Society of Astronomy. González Benito published a drawing of a large sunspot observed in August 1893 in the Journal of the French Society (Figure 5) (González, 1894). Today, Colombia offers astronomy research options in universities across the country. In this section, we will refer to our experience at the National Astronomical Observatory of the Universidad Nacional de Colombia.

The Group of Solar Astrophysics (GoSA), founded in 2011, convenes undergraduate and graduate students. The group started out with just two undergraduate students in physics who were interested in solar astrophysics. In 2012, the National Astronomical Observatory held an International Summer School entitled 'Solar Astrophysics: Modern Trends and Techniques', as a result of which, a large number of undergraduate students joined GoSA and decided to pursue their research project in solar physics. Students were trained in programming languages commonly use in the field, for example, Interactive Data Language (IDL) (Landsman, 1993), and started analysing data from cutting-edge satellite solar telescopes. Working with time series images, they explored topics ranging from the tracking of solar spicules to studying hard X-rays in solar flaring events.

GoSA members are currently exploring the challenges and opportunities of doing state-of-the-art research and are involved in multiple international collaborations. In addition, seven masters' students and twelve undergraduate students are part of a research project entitled 'Magnetic Field in the Solar Atmosphere', which comprises individual research topics on the analysis of data from ground-based telescopes, such as the Solar Swedish Tower (SST) (Scharmer et al., 2003), and space facilities like the Solar and Heliospheric Observatory (SOHO) (Domingo et al., 1995), the Reuven Ramaty High-Energy Solar Spectroscopic Imager (RHESSI) (Lin et al., 2002), the Solar Dynamics Observatory (SDO) (Pesnell et al., 2012), and Hinode (Kosugi et al., 2007). The group is presently developing routines for data analysis in Python as part of a Sunpy collaboration (The SunPy Community, 2015).

In 2015, the university introduced a course on solar physics, 'Foundations of Solar Astrophysics', in its official academic programme, the first of its type in Colombia. The course is intended for masters' students and can be opted for by undergraduates. Fifteen students, on average, enroll in the course every semester and a high percentage of them go on to join the research group.

More recently, the GoSA organised the International Astronomical Union Symposium 327 (IAUS327) entitled "Fine Structure and Dynamics of the Solar Atmosphere" that was held in Cartagena de Indias, Colombia, 9-13 October 2016 (Vargas Domínguez, et. al., 2017). This event strengthened the group by creating an opportunity to increase the visibility of the members and their research in the international community, therefore promoting new collaborations.

In just a few years, the group has shown rapid growth with several scientific publications, masters' theses, undergraduate research works and solar instrumentation development. Among these, the development of solar instrumentation has been one of the most noteworthy milestones in the past couple of years, with the development of three solar radio interferometers which are currently installed on the terrace of the observatory building (Figure 6, left panel). These instruments have been fully developed by the students as part of their projects and represent the commencement of the instrumentation branch at the National Astronomical Observatory. The research conducted by one of the recently graduated master student resulted in the development and implementation of the First Colombian Radio-interferometer (FiCoRi) (Figure 7, right panel) (Guevara et. al., 2017).

Further, plans are being made to use one of the interferometers in a large number of public schools to use big data (astro-

Figure 6. Radio interferometers installed on the terrace of the National Astronomical Observatory at Universidad Nacional de Colombia. The instruments have been developed by undergraduate and masters' students as part of their research projects. The First Colombian Radio-interferometer (FiCoRi) (see the acquisition system in the middle panel of the figure) represents an important milestone in the development of radio astronomy instrumentation in Colombia. Credit: From the digital archive of the National Astronomical Observatory of Colombia.

statistics) as a tool to promote scientific knowledge.

Former GoSA members are now pursuing their graduate studies abroad in high performance institutes including the University of California in Berkeley, Max Planck Institute for Solar System Research, Harvard-Smithsonian Center for Astrophysics, University of Graz and University of Oslo. A new generation of local students are willing to follow a promising educational road, that is, studying the multiple faces of our active star.

Our learnings from these three experiences

From a pedagogical viewpoint, we have learned that it is important that children and young people recognise the importance of long-term efforts through continuous observation. The young people we interacted with are mainly motivated by visits to astronomical observatories, star parties, STEM colleges, and career fairs and conferences.

Using the Sun as the main topic of exploration has several advantages:

- Observations can be made within a short duration to fit class schedules (approximately 1.5 hours).
- The Sun shows rapid changes which the children can see, enabling them to better visualise the potential affect it has on the planet on a daily basis.
- A Sun-related project can develop associated activities around interdisciplinary topics including the electromagnetic spectrum; stellar evolution; radio astronomy; effects of the Earth's atmosphere; scientific computing; data analysis; motors and generators; and ways to create links with biology, chemistry and even history and archaeology.
- The JOVE project offers a great opportunity to participate in scientific studies at a low costs (typically less than USD 350), which cover a receiver kit, antenna hardware, software, and tools required for instrument assembly.

The main goal of the solar-related experiences that we have developed in schools across Colombia has been to build a mechanism that can enhance creativity and allow participants to acquire and interpret data in their own ways to answer scientific questions. Instructors are meant to provide an ideal atmosphere to explore ideas, develop tools and help participants with their chosen technique, thus spreading their seeds of creativity.

The study of the Sun has gained worldwide interest in recent years because of the serious impact by solar explosive events on our technological-reliant society, particularly satellites exposed to the effects of solar activity. At the university level, and in particular within the context of the research group (GoSA), the field of solar physics has proven to be a development tool and source of motivation for students to pursue further scientific research, from the study of fundamental physics to data analysis and fostering of computational skills to simulate solar phenomena and instrumentation.

Conclusions

The important role that astronomy can play in cultural development and driving innovation tends to be underestimated, even though there is a wealth of supporting examples (Rosenberg et al., 2013).

Among the general public in Colombia, there is a distrust and even fear towards scientific areas. This is largely due to a significant gap between scientists and society. Science communicators play a fundamental role in changing public perspective about science and there is a great need for initiatives as those mentioned in this paper. Importantly, there is a need to create spaces that allow scientists, teachers and amateurs to come together and find new and better ways to bring science to the public.

Here, we have shown simple examples in which the scientific community has evolved through small and consistent efforts over time. We have seen people going through the whole education system—from primary to university—positively impacting individuals, their community and our country. We have experienced first-hand the impact these initiatives have on students and how they think about scientific areas as a future career.

As a final remark, we want to stress that although performing solar observations is relatively easy and can be done at many levels, it is important to first prepare students and the general public to avoid the potential risks this entails. This should be a major concern and implies a huge responsibility for the team involved.

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Notes

[1] School research journal, El Astrolabio, http://www.revistaelastrolabio.com

[2] Spaceweather website: http://spaceweather.com

[3] Radio JOVE Data Archive: http://radiojove.org/archive.html

[4] Radio JOVE Data Analysis: http://radiojove.gsfc.nasa.gov/data_analysis/

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Biographies

Alejandro Cárdenas-Avendaño is a graduate student at the eXtreme Gravity Institute (USA) and a research fellow at Fundación Universitaria Konrad Lorenz (Colombia). He is a theoretical physicist studying the impact of Einstein's theory of general relativity, and many of its extensions.

Santiago Vargas-Dominguez is an assistant professor at the Observatorio Astronómico Nacional de Colombia - Universidad Nacional de Colombia, and has spent the last 15 years doing research in solar physics at different institutions in Europe and America. He is currently the research coordinator at the Observatorio Astronómico Nacional de Colombia, leading in particular the study of the Sun within the Group of Solar Astrophysics (GoSA).

Freddy Moreno-Cárdenas is the director of the Observatorio Julio Garavito Armero at Gimnasio Campestre school in Bogotá (Colombia). Since 2001 he has worked as an astronomy teacher and led several initiatives to engage student towards science, in particular astrophysics.

Benjamín Calvo-Mozo is an associate professor at the Observatorio Astronómico Nacional de Colombia - Universidad Nacional de Colombia where he has spent almost 40 years teaching and doing research in astronomy. In 2011 he started the research branch in solar physics to mentor graduate students, and has promoted the development of the area in Colombia from the Group of Solar Astrophysics (GoSA).