The Sun and its educational spectrum

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Abstract

The aim of this paper is to encourage science educators and outreach
groups to look appropriately at the Sun and consider it as an extraordinary
pedagogical tool to teach science at all education stages, what we call here
as the solar educational spectrum, i.e., from K-12 to higher education,
to develop informal educational projects that may lead to reach more
complex material and to enlarge the experience at each stage. We review
the main aspects of the Sun as an appetizer of the endless source of ideas to
perform informal educational projects outside of a structured curriculum.
We end up our discussion by sharing our experience across the educational
spectrum in Colombia and how we used it as a development instrument.

Keywords: Public engagement with science and technology; Science
communication in the developing world; research-link; Informal education;
The Sun.

1 The Sun and its active habits

The Sun has undeniably ruled our lives since the beginning of human history,
or even previously, from the very birth of the Earth. During the youngest stage
of our star, about 4.6 billion years ago, before planets in the solar system were
even formed, all the matter evolved around the Sun as a huge hot disk. This
protoplanetary disk was in constant cooling and the planets emerged in areas
where matter got more concentrated due to gravitational attraction. Millions
of years later the conditions improved to favor the development of life. In the
same way as its origin, the fate of our planet is strongly linked to the Sun which
will be responsible also for its annihilation, but we will come back to the final
stage of our blue planet at the end of this short review.
Let’s go back to the past once again, but now to Italy and the epoch of the great Galileo Galilei in the early XVII century [26]. Soon after the invention of the telescope by the German optician Hans Lippershey (although there are still some other names that are claimed to be the inventors) [24], Galileo designed his own telescope and pointed it to the sky. Initially, the potential of the telescope was hard to imagine, but eventually this invention changed our conception of the universe.

Galileo pursued, among others, some of the first solar observations with the new optical tool, by projecting the image of the Sun through the telescope, and discovered something wonderful and unexpected: dark scars on the surface of the star, see Fig. 1. He was looking at what we now call sunspots, which in fact had been observed by naked eye (with very little detail) well before Galileo [3], but were thought to be planets revolving around the Sun in very-close orbits and not actual structures placed on the Sun. Galileo’s observation of sunspots had major implications for the thinking of the time, not only on the scientific ones but also on religious conceptions, since it was showing imperfections of heaven, and in particular of the Sun, that was especially considered divine and therefore perfect. Galileo’s detailed drawings showed the time evolution of sunspots and evidenced the rotation of the Sun [2].

Four centuries after Galileo’s seminal works, sunspots are still a target of study and are highly correlated with the solar activity, which is responsible, in turn, for the conditions of the interplanetary medium, in what is commonly referred to as space weather. It is known that the Sun is composed of plasma at very high temperature, of about 5,700 Kelvin on the surface and up to 15 million Kelvin in the interior, and that sunspots are a visible manifestation of the magnetism of the star.
1.1 The explosive Sun

The Sun is like a huge magnet with its north and south poles forming a global dipolar magnetic configuration, although it also displays local magnetism in all its surface. Every twenty-two years something unexpected happens: the solar magnetic poles are reversed and it is called as the magnetic cycle. Half of this time interval is a solar cycle, i.e., eleven years, and it was discovered in 1843 by Samuel Heinrich Schwabe, who after 17 years of solar observations noticed a periodic variation in the average number of sunspots per year \[21\]. During the solar cycle, variations in the solar activity and the amount of radiation reaching our planet are related, with extreme periods of low solar activity -solar minimums- and high activity -solar maximums-. When the solar minimum occurs, sunspots disappear almost entirely from the Sun’s surface while in peak periods there are plenty of them. Currently, the Sun is in its 24th cycle, counting from the first cycle registered from 1755 to 1766.

Magnetic fields are formed inside the star, and emerge through the solar surface (photosphere), interacting with the glowing plasma. The magnetic field lines are constantly evolving, largely because the Sun rotates faster at the poles than at equator. This differential rotation stretches and twists the field lines in the solar interior, and eventually generates instabilities that end up on the surface, forming the sunspots \[2\].

When the Sun’s magnetic field changes its configuration along the solar cycle, energy can be released rapidly and violently once magnetic field lines emerge and interact with the plasma in the solar atmosphere in events known as coronal mass ejections. During these bursts the Sun throws away thousands of tons of plasma and charged particles into the interplanetary medium. If the blast is directed towards Earth, the solar storm could strike it and generate what is called a geomagnetic storm. Without the Earth’s magnetic field, a natural shield called the magnetosphere, we would be seriously affected by radiation from the Sun. Nevertheless, some of these charged particles penetrate the atmosphere in polar regions, which are the most sensitive areas of the Earth’s shield and where magnetic field lines converge, producing amazing phenomena such as aurorae.

Other phenomena can generate gigantic solar flares that could release extraordinary amounts of radiation to our planet, see left panel in Fig. \[2\]. In March 1989, about six million people in Canada and in the US lost power after a huge explosion on the Sun that affected a hydroelectric plant in Quebec, affecting a large amount of electrical transformers \[1\].

The largest solar storm ever recorded occurred in 1859 and is known as the perfect storm or the Carrington Event, honoring the name of a British scientist who detected it. At that time the consequences were in serious damage of the North America telegraphic system, that had 15 years of being invented, and observation of aurorae at very low latitudes such as Florida and even Colombia \[16\].

1.2 Understanding the solar behavior

One of the greatest scientific challenges of our time is to understand and accurately predict the solar cycle and the effect of changes in solar activity on the climate of the planet, as there are tests that suggest a nontrivial dependence \[14\]. The most famous documentation constitutes a period of 70 years (1645-
1715) in which, according to records, there were virtually no spots on the solar surface, period often called Maunder Minimum. Another period of scarcity of sunspots has been named Dalton Minimum (1795-1825). These intervals agree with the dominant part of a period of intense cold in Europe known as the Little Ice Age (1450-1850), but the actual connection is still under debate [15].

Regarding abnormal solar cycles, the previous one (number 23) which began in 1996, was also quite unusual and spanned a couple of years more than average. Starting in 2009 the Sun awakened from its slumber and sunspots began to appear again on its surface, which marked the beginning of cycle 24. However, opposite to most of the predicted scenarios [22], the current solar magnetic activity cycle has been quite weak and the number of sunspots retained below 100, unlike other cycles which registered more than 250, e.g., the current cycle 24 peaked around the year 2014, with nearly half the amplitude of the previous one.

It has been said that magnetism is responsible for the majority of events taking place in the Sun and ultimately for space weather, i.e., the set of phenomena and interactions occurring in the interplanetary medium are regulated primarily by solar activity. Bearing in mind that the Sun is almost 99% of the mass of the entire solar system and therefore their crucial role on impacting our cosmic neighborhood and directly on planet Earth. For these reasons, scientists continue to explore the complex solar activity with the aim to understand and predict the behavior of the Sun. Currently, we have sophisticated telescopes and instruments, many of which observe the Sun minute by minute from space, through satellites orbiting the Earth, giving us spectacular images that demonstrate its intricate structure and register lots of explosive phenomena. Recently, a NASA mission launched in 2010 with the Solar Dynamics Observatory (SDO) [17], began acquiring high-quality solar images with 10 times better resolution than that of an HDTV, taking up to 1.5 terabytes of data each day, equivalent to more than half a million songs in an mp3 player.
The Sun has been the main source of energy for maintaining life on Earth; it has gone from being a source of worship to an object of study for human beings. There will come a day when the Sun exhausts all its fuel, expanding and becoming a red giant star, whose size is so large that it will possibly swallow up the Earth. The final destination of the Sun is to become a white dwarf, and eventually a black dwarf when cooled completely. There are still about five billion years for this to happen, but for now we must prepare for each solar maximum and to protect our technology, on which our modern civilization depends. We should not be catastrophic, but always keep in mind that a perfect solar storm, as the one that happened in 1859, could now have a remarkable impact on satellite technology, communications, power grids and others, causing millions of dollars in losses.

2 Solar educational spectrum, i.e., from K-12 to higher education, in Colombia

Colombia has experienced a scientific, technological and cultural transformation in recent years, showing a considerable growth in these areas. Being in the midst of such important changes, it is critical to open spaces for the recognition of the importance of science and its public perception, and ultimately for the formation of future science communicators capable of impregnating the society with passion, admiration and love for what science represents and what it can offer. In this section we will describe the formal and informal educational experiences that we have had in a high school program, extracurricular science clubs and at the University, in order to provide learners with the tools they need to reach more complex material and to enlarge their experience at each stage.

2.1 Observing the Sun at school to motivate scientific skills

Gimnasio Campestre, a school at Bogota, Colombia, has developed since 1997 a plan for teaching basic astronomy. Its astronomical observatory, named Julio Garavito Armero honoring the name of a prominent Colombian astronomer from the twentieth century, was built in 2000, see Fig. 5. The observatory develops several activities and classes to involve children of different ages into science. For the youngest students, the curriculum is designed on learning the basics about orientation, constellations and observations of the Sun, Moon and planets. Then, starting from fourth grade, the classes cover three main subjects: a.) origin of matter and the universe, b.) the light and the Sun and c.) gravity and asteroid impacts. In sixth grade the school offers a class on: a.) stars and the Sun, b.) Earth (rock and water, planetary geology) and c.) planetary atmospheres. After taking these classes, students from seventh to eleventh grade, the last one in these educational system, have the option to deepen into the topics covered and do research on a curricular unit called “Jóvenes Investigadores” (young researchers).

Teachers have found that Sun is an interesting topic in which students can get involved every year. In this academic environment, students learn about multiple characteristics and phenomena of our star and also get trained in as-
Figure 3: Group of students at Julio Garavito Armero Observatory founded in the year 2000 at the high school Gimnasio Campestre in Bogotá, Colombia.

trophotography. In particular, the observatory keeps a record of solar observations since 2001. An important milestone in this project was the acquisition of a H-alpha solar telescope, which allowed to acquire images of prominences, filaments and solar flares. Every two years the group of teachers and students involved in registering the evolution of the solar cycle publishes an article on this subject in the school’s research journal named “El Astrolabio” and some of the most interesting images are sent to the Spaceweather website see right panel in Fig. [2]. The results of the developed projects have been used to publish six articles at the school’s research journal. Furthermore, several projects have enabled students and teachers to participate and present their research at conferences and national astronomy meetings, and even publish in international journals, such as the one where it was discovered a report about an aurorae borealis seen in Colombia in 1859 [15].

The observation of the Sun as basis of a school research project, has been replicated in several schools of Bogotá. Currently, Gimnasio Campestre’s Observatory mentors two public schools, fostering the development of scientific knowledge through the involvement of students and teachers in lively projects.

2.2 Studying the Sun before going to college: Seedbed projects of research

The Young Talent Program of Mathematics, Science and Technology takes place each year, since 2012, at Fundación Universitaria Konrad Lorenz in Bogotá, Colombia. This program is a non-profit project that focuses on high-school children from Bogotá and cities around, including some from disadvantaged communities, designed to inspire young people and bring them into science, with astronomy as the vehicle.

Every year the group is formed by 30 participants, selected by an admission exam which measures the ability of solving problems without previous particular
Figure 4: An example of scientific analysis performed by a group of the young participants from data taken on September 6, 2014 (14:10-14:20 UT) aimed to implement a simple polynomial fit by least squares using Numpy [27] functions.

knowledge, from an application pool of over 200 young people. The participants are supported during one year by two instructors whose propose is answering questions and to propose a main objective at the beginning of the program, with no lectures at all.

During 2014 the team’s general objective was to learn scientific computing techniques. The chosen programming language was Python, in order to exploit its expressive power with simple and compact syntax, and the third-party open-source libraries such as Numpy [27], Matplotlib [8] and SciPy [9] to encourage the use of scientific scripting language.

In order to develop scientific computing techniques, the proposed objective was to measure the solar activity via radio waves with NASA’s Radio Jove project antennas [12, 7], without using the main software provided by NASA to record, store and visualize the data. Fig. (4) 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 [4] was used in order to gather more information and explore bigger data sets. In some cases, it was possible to make a rigorous analysis and check if the registered phenomena were global, at least reported somewhere else, or corresponded to spurious signals. With all the data collection and analysis, the participants were able to recognize a relationship between sunspot numbers and 20 MHz solar burst counts.

The results were presented in Regional STEM Fairs open to the general public and all the data collection was done in public parks in order to engage young children and the general public, see Fig. (5). During the data collection campaigns, the participants make shifts between collecting data and explaining the project to passers-by.

We also would like to mention that two participants of this project performed best at the Colombian Olympiad in Astronomy and then were part of the National Team for the International Olympiad in Astronomy and Astrophysics (IOAA) and the Latin-American Olympiad of Astronomy and Astrodynamics (LAOAA).

3The Radio JOVE Data Archive, [http://radiojove.org/archive.html](http://radiojove.org/archive.html)
http://radiojove.gsfc.nasa.gov/data_analysis/.
2.3 Solar physics as a research option at university

The study of the Sun in Colombia dates back to the observations made by José María González Benito in the 19th century, when he was the director of the National Astronomical Observatory (the oldest astronomical observatory in America founded in 1803) and member of the French Society of Astronomy. González published a drawing of the large sunspot of August 1893 in the journal of the society, see Fig. (6). Nowadays, Colombia has consolidated astronomy research options in different universities across the country. In this section we will only refer to the experience acquired at the National Astronomical Observatory (that belongs to Universidad Nacional de Colombia).

From its begin in the year 2011, the Group of Solar Astrophysics (GoSA) has convened undergraduate and graduate students. Starting from a seed of two students enrolled in the undergraduate program in Physics that among their interest in multiple areas of astronomy got strongly motivated for solar physics, and with the help of one of the astronomy professors at the Observatory, the GoSA got involved in the analysis of solar data.

In 2012 with the organization of an International Summer School entitled "Solar Astrophysics: Modern trends and techniques" held at the National Astronomical Observatory, a great number of undergraduate students in Physics joined the GoSA and decided to pursue their research project (a requirement to get the university degree) in solar physics. In order to do so, students were trained in programming languages of common use in the area, e.g. Interactive Data Language (IDL) and started analyzing data from cutting-edge satellite solar telescopes. Working with time series of images, they explored topics ranging from tracking of solar spicules to the study of hard X-ray in solar flaring events.

GoSA members are currently engaging with the challenges and opportunities of doing state-of-the-art research and are involved in international collaborations. A number of 7 master students, and 12 undergraduate students are part of the research project entitled "Magnetic field in the solar atmosphere" that comprises individual research topics dealing the with the analysis of ground-
based telescopes, such as the Solar Swedish Tower, SST [20], and space facilities
like SOHO [4], RHESSI [13], SDO [17] and Hinode [10]. Currently the group is
developing routines for data analysis in Python as part of the Sunpy collabora-
tion [23].

In 2015 the university included a course on solar physics in its official aca-
demic program with the name "Foundations of Solar Astrophysics", intended
for master students but also with the option to be taken by undergraduates.
An average of 15 students are taking the course every semester, and a high
percentage of them got motivated and joined the research group.

More recently, the GoSA organized 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. This event consolidated the group and was a foremost opportunity to
increase the visibility of the members and their research works among the in-
ternational community, therefore promoting new collaborations.

In just a few years, the group has shown a rapid evolution and paramount
results evidenced in several scientific publications, master thesis, undergrad-
uate research works and development of solar instrumentation. The latter is
one of the important milestones in the last couple of years, with the develop-
ment of three solar radio interferometers which are currently installed on the
terrace of the building, see Fig. (7). These instruments have been fully devel-
oped by students in order to complete their master (2) and undergraduate (1)
thesis projects, and represent the commencement of the instrumental branch
at the National Astronomical Observatory. The research conducted by one of
the recently graduated master student resulted in the development and imple-
mentation of the First Colombian Radio-interferometer (FiCoRi) (right panel
in Fig. (7)) [25].

Furthermore, and framed in a collaboration with the Planetarium of Bo-
gotá and the District Government, there are plans to implement one of the interferometers in a large number of public schools, in order to use big data (astrophysics) as a tool to promote scientific knowledge.

Former GoSA members are now pursuing their graduate studies abroad in high-standard institutes (e.g., University of California Berkeley, Max Planck Institute for Solar System Research and University of Graz, among others), and a new generation of local students are willing to follow up a promising research road, studying the multiple faces of our active star.

3 Discussion and concluding remarks

The role and importance of astronomy not only for scientific but cultural development, and a way to answer fundamental questions and driving innovation, tends to be underestimated, despite of the existence of a wealth of examples supporting it [10]. Measuring scientific development is a difficult task but in general it is related with the scientific publishing record [13], that is why devoting money and time to all the educational spectrum is paramount. None of what has been discussed here could be possible without engaging also administrative and educational heads of the schools and universities, that provide the instruments and allow to maintain spaces to talk about science in the classrooms.

It is important to note explicitly that we did not take an educational theoretical position for all the activities presented here. Instead we have outlined a number of examples from practice to encourage the use of the Sun in science education, informal learning and astronomy communication. Nevertheless, all the experiences took place inside formal educational institutions. We have evidenced that our community has evolved thorough these small and consistent efforts sustained over time, and we have had the experience to see people going through the whole educational spectrum mentioned here, impacting positively our community and country.
Within the general public in Colombia, there is a certain regard of distrust and even fear of scientific areas. This has been in great part due to a significant gap existent between scientists and society. In this sense, science communicators can be fundamental to change the perspective of the public about science, hence the importance and need to develop the kind of initiatives mentioned here in the country, as a way to create spaces that allow the encounter of scientists, teachers and amateurs to find new and better ways to bring science to the public. We have experienced how such initiatives definitely cause a significant impact on students and the way they think about scientific areas as a future career.

From the pedagogical point of view, we have learned that it is important that children and young people recognize the importance of long-term efforts through continuous observations, which stand as basis to develop their own research skills working with data. We have also experienced that students get motivated mainly by visits to astronomical observatories, attendance to star parties, STEM College and Career Fairs and conferences. Letting scientists to engage with the public and sharing their personal stories has shown a unique driven force.

In particular, a project that involves the study of the Sun has shown in our context, at least, the following advantages:

- Observations can be made in a regular class time, i.e., around 1.5 hours.
- The Sun shows rapid changes that permeates the children with the idea of the potential to affect the planet in the daily basis.
- A Sun-related project can develop associated activities around interdisciplinary topics, e.g., electromagnetic spectrum, stellar evolution, radio astronomy, effects of Earth’s atmosphere, scientific computing, data analysis or 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 with low costs, which typically are under 350 USD, including the receiver kit, the antenna hardware, the software used and the tools required for the instrumental assembly.

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

Studying the Sun has lately shown a prime interest worldwide currently is living a golden age, due to the serious influence of solar explosive events in our current technological society (in particular on satellites exposed to the effects of solar activity). At university level, the field of solar physics has proven to be a source of motivation for students to pursue further scientific research, mainly because of all the different aspects that embrace the study of the Sun, from fundamental physics to data analysis, to develop computational skills for simulation of solar phenomena and instrumentation.

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

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