Fun and interdisciplinary daytime astrophysical activities

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Fun and interdisciplinary daytime astrophysical activities

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Abstract
The present article describes some activities performed with high-school students in the *Solar Physics* course developed in a Brazilian science centre. The topics of chemical composition, temperature and stellar evolution were taught in a room totally dedicated to study of the Sun, a solar room, designed with simple and inexpensive equipment. The course strongly emphasized practical, observational and enquiry-based activities, such as estimating the solar surface temperature, observation of the visible solar spectrum, identification of solar absorption lines, and understanding how they are produced and what kind of information can be extracted from the observed spectral lines. Some of the course goals were to foster the comprehension of the key role played by spectroscopy in astrophysics, to contextualize contents with practical activities, and to allow interdisciplinary approaches including modern physics and chemistry in physics teaching.

Introduction

Current curricula developments all over the world emphasize the role of context for science learning since, from students' perspectives, a context enriches science learning with meanings for newly learnt content. Enquiry-based teaching has been stressed in curricula as well, since it provides opportunities for open-ended enquiry activities. However, teaching science only in school settings is not enough to give students a contextualized view of science [1]. Science centres offer unique opportunities to provide contextualized learning and foster enquiry-based activities since students have access to authentic scientific tools and practices.

At schools, astronomy is seldom taught using practical activities, such as observation of planets, the Sun, stars and their movements, since topics covered are usually limited to textbook information. In addition, astrophysical contents such as the nature of the Sun, stars, galaxies and other heavenly bodies are hardly explored. Such topics should be addressed because they attract students' attention towards contemporary science, leading to a closer understanding of the origins of the Universe and mankind. One of the reasons these topics are not taught in school is that most teachers did not have the opportunity to study them in their preparatory courses. An alternative for coping with this problem could be to teach

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astrophysics topics in informal spaces such as science centres, astronomical observatories, and planetaria.

The main role of museums and science centres is to motivate students towards science, since they offer an attractive environment allowing students direct contact with instruments and scientific practices [2]. However, visitors usually stay only a few hours in a science centre, which compromises deeper learning of specific scientific topics. On the other hand, it is possible to keep students longer in science centres by offering short courses for volunteers. The present article describes some activities performed with high-school students in a course called *Solar Physics* developed in 2007. Some of the course goals were to foster the comprehension of the key role played by spectroscopy in astrophysics, to contextualize taught contents with practical activities, to allow interdisciplinary approaches including modern physics and chemistry topics in physics teaching by the use of enquiring activities, and to discuss the nature of science aspects, since they can learn some of the methods that scientists use to study distant objects.

Solar physics can be fun

The Sun is the only star that can be observed during daytime and the only one whose surface, sunspots and rotation can be studied from Earth using simple equipment, such as small telescopes. The solar spectrum can also be studied with relatively inexpensive equipment such as lenses, slits and diffraction gratings set in a homemade spectroscope. It is therefore possible to design interdisciplinary educational activities in order to explore themes such as the Sun's chemical composition, thermodynamics and modern physics topics.

The *Solar Physics* course is part of a wider project that aims to develop solar physics teaching activities at the Astronomical Observatory of the Centre for Scientific and Cultural Dissemination of the University of Sao Paulo, campus Sao Carlos, Brazil. Activities are performed at the university observatory whose main purpose is to promote educational outreach directed to students and citizens. In order to foster solar physics teaching, a solar room was built and equipped with a heliostat, a spectroscope, a solar Hα filter, light bulbs, solar charts, and spectral charts.

The course strongly emphasized practical, observational and enquiry activities for secondary-school students, such as estimating the photosphere temperature, observation of the visible solar spectrum, identification of solar absorption lines, and understanding how they are produced and what kind of information can be obtained from the observed spectral lines. Thus, students were given the opportunity to observe emission lines in lamp spectra in order to compare them with the solar spectrum absorption lines and estimate the solar surface temperature. At the end of the course there was a debate on the existence and detection of other ranges in the solar spectrum.

Observing the solar spectrum

Since the Sun is so bright it is an easy and dangerous target. During the *Solar Physics* course students were introduced to the safety procedures necessary to observe the Sun [3] and to the equipment used to visualize our nearest star's spectrum. The course concentrated on the observation of the visible solar spectrum and on information that can be extracted from it.

Prior to observing the solar spectrum, students handled the major parts of a spectroscope and learnt how prisms and diffraction gratings produce basic physical phenomena such as refraction, reflection and diffraction. In order to understand how spectroscopy can be a useful tool for extracting chemical information from heavenly bodies, students were requested to observe, draw and verbally describe to classmates and teacher spectra produced by fluorescent, mercury, incandescent and helium lamps while looking through diffraction gratings. After recognizing the existence of different patterns of bright lines in each kind of lamp they were asked to identify the lamps by comparing their observations with a spectral chart.

A heliostat, a telescope and a spectroscope were used to observe the solar spectrum. The heliostat was constructed using two flat mirrors. Solar light reaches the first mirror (A in figures 1 (left) and (right)), called the primary mirror, placed next to the opening of the telescope. The primary mirror is movable and has a fork mount controlled by a step motor that can follow daily Sun movement and direct sunlight to a second mirror. This mirror (B in figures 1 (left) and (right)) then directs sunlight down to the focus of a telescope

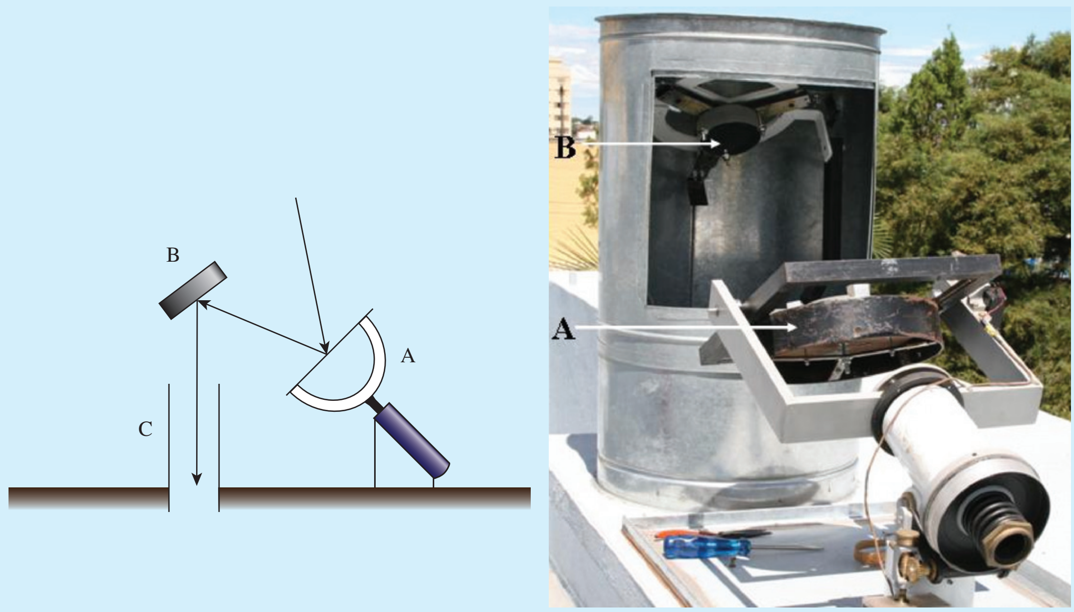

Figure 1. Left: diagram of a heliostat with movable primary mirror (A), fixed secondary mirror (B) and telescope (C). Right: image of the heliostat, where A is the primary mirror and B is the secondary mirror.

(C in figure 1 (left)) inside the solar room where an eyepiece projects the Sun on a white screen. This device can also be used to observe sunspots.

This equipment was also used to observe the solar spectrum. The light from the Sun captured by the heliostat went down into the solar room through a telescope (A in figures 2 and 3). We removed the eyepiece and replaced it by a slit (B in figures 2 and 3). Then we added a collimator lens (C in figures 2 and 3) and a reflection diffraction grating (D in figures 2 and 3) aligned with the slit. The diffraction grating is placed behind the collimator and can be adjusted to position the projected solar spectrum on a screen. This spectroscope mount is called a Littrow spectroscope. In order to focus the solar spectrum projection on the screen (E in figures 2 and 3) care must be taken to position the collimator lens, since the distance between the slit and the collimator must be the lens focal length.

We can perform this activity with students, asking them about visual differences between the continuum spectrum (obtained without the slit) and the absorption spectrum (obtained when the slit is inserted in A in figure 3). This procedure helps them understand that the slit plays a key role in the observation of the solar absorption lines.

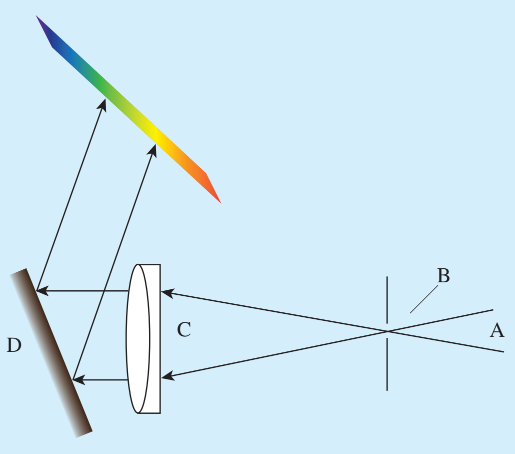

Figure 2. Diagram of the Littrow spectroscope. The solar light rays travel from telescope A (Newtonian 200 mm, f/10) to slit B, collimator lens C (achromatic doublet, 800 mm focal length), diffraction grating D (50 mm × 50 mm, 1200 l/mm), and to the projected solar spectrum E (30 cm in length).

With this apparatus, students were able to observe the dark lines in the solar spectrum (figure 4). At first, they were surprised to observe dark lines instead of bright ones as they

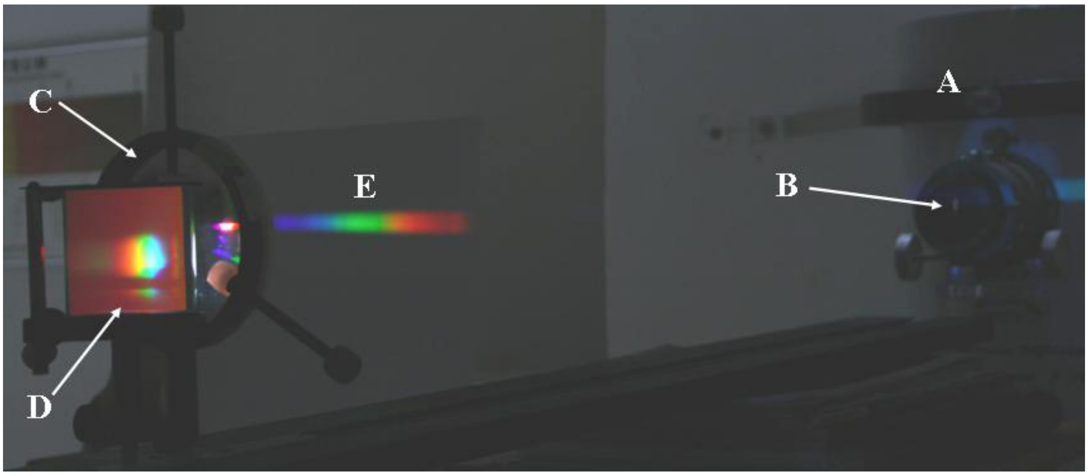

Figure 3. Image of the Littrow spectroscope used in the *Solar Physics* course. A is the telescope, B is the slit, C is the collimator lens, D is the diffraction grating and E is the projected solar spectrum.

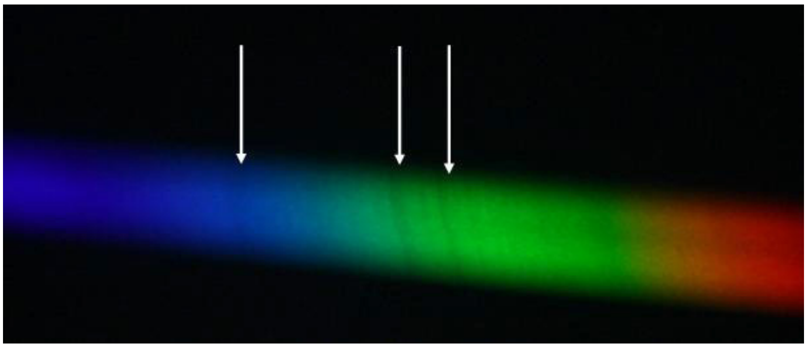

Figure 4. Solar spectrum showing some of the dark Fraunhofer lines.

had seen while analysing lamp spectra. This led to an enquiring discussion on why the solar spectral lines are dark while the lamp spectra lines are bright. After observing and identifying lamp spectra, students were able to acknowledge that solar spectral lines are related to chemical elements existing in the Sun. The next step was to identify the solar absorption lines using a solar spectrum chart. Students learnt that two prominent absorption lines were really oxygen bands from the Earth's atmosphere and not from the Sun. Absorption lines from the Sun are iron, sodium, magnesium, hydrogen and other chemical elements in its atmosphere. To help students understand why solar spectral lines are dark instead of bright, we discussed the three Kirchhoff laws (figure 5).

(1) A black body has a continuous spectrum, free of any spectral lines.
(2) A lower temperature gas in front of a black body will produce absorption lines.
(3) A higher temperature gas will produce emission lines as a series of bright lines against a dark background.

As students previously knew about the Sun structure (nucleus and atmosphere) they were encouraged to apply the Kirchhoff laws to comprehend why solar spectral lines are dark. Due to the teacher's mediation, students were able to realize that the Sun core acts as a black body, which emits a continuous spectrum. The solar atmosphere is at a much lower temperature; thus it absorbs some of the core radiation, producing the

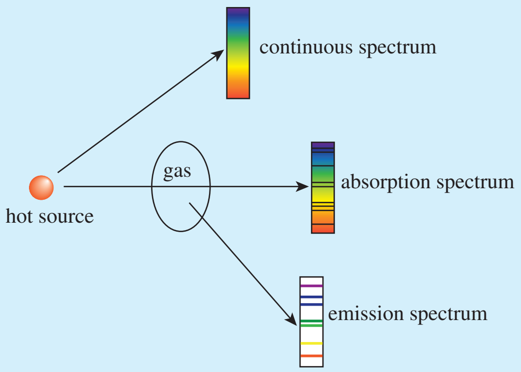

Figure 5. Illustration of Kirchoff's three laws. At the top, a continuous spectrum is produced, for example, by using an incandescent lamp. In the middle is an absorption spectrum, like the solar visible spectrum. At the bottom is an emission spectrum produced by a spectral lamp.

observed dark lines in the solar spectrum. Students were informed about the existence of emission lines in some stars and nebulae spectra as well.

The *Solar Physics* course also discussed stellar evolution and the process of chemical element synthesis. In this part of the course students learnt that the Sun only synthesizes elements as heavy as helium. Obviously they were curious about how iron, mercury and other heavy element lines are found in the solar spectrum. Students were reminded that we only observe the elements present in the Sun's atmosphere and not those in its core. This made them enquire whether the Sun had somehow incorporated those elements from elsewhere in the universe. These elements came from a massive star that gave rise to the Sun and the rest of the Solar System. This discussion helped students understand that stars are gigantic furnaces of chemical elements, and that after a massive star dies its material is recycled and reused by other stars, such as our Sun, to create planets and life forms.

Estimating the solar surface temperature

The power irradiated by the Sun and its photosphere temperature can be estimated with the black body concept, calorimetric notions and simple measurements. This activity integrates notions of thermodynamics, modern physics and astrophysics, making use of readily available materials such as a can, thermometer and watch, and a sunny day [4].

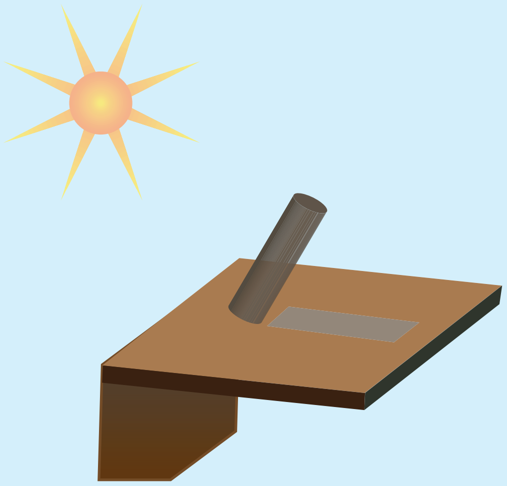

Figure 6. Position of the can exposed to the Sun. It is important to ensure that the can projects a rectangular shadow in order to permit light rays to reach its surface.

A black cylindrical can filled with water exposed to the Sun can be considered as a black body; see figure 6. In this experiment, the can was exposed to solar light for about 5 min. The fraction of radiation that reaches the can is proportional to the radiation emitted by the Sun at the Earth–Sun distance.

Thus the total energy irradiated by the Sun is

$$E_T = E_{can} A / A_{can}, \qquad (1)$$

where A is the area of a sphere with radius given by the Earth–Sun distance and A_{can} is the can longitudinal area (diameter multiplied by height).

The energy received by the water in the can, E_{can}, is

$$E_{can} = mc(T_a - T_b), \qquad (2)$$

where m and c are the water mass and specific heat, and T_a and T_b are the temperatures after and before solar exposition.

The next steps were to calculate the power irradiated by the Sun surface per unit of area and obtain the Sun's photosphere temperature. Considering the Sun as a black body it is possible to use the Stefan–Boltzmann law to obtain the photosphere temperature (T):

$$P = \sigma T^4, \qquad (3)$$

where $\sigma = 5.67 \times 10^{-8}$ W m^{-2} K^{-4}.

Performing this activity, students obtained the power irradiated by the Sun as $P = 3.7 \times 10^{26}$ W and divided it by the area of the Sun in order to apply the Stefan–Boltzmann law and obtain the temperature of Sun's photosphere (T) as $T = 5720$ K. The calculated solar surface temperature was of the same order as the photosphere reference temperature (5780 K) [5]. This result strongly depends on where the experiment is done since the Earth's atmosphere can interfere. Usually it is best performed in tropical countries or in clear weather.

Additional interesting information to share with students is that the star surface temperature is associated with its colour. Cold stars (3000–4000 K) are usually red and hotter stars are blue (above 8000 K). The Sun, with an effective temperature of 5800 K, is a yellow star.

Exploring solar invisible spectral ranges

The existence of invisible spectral radiation in the solar spectrum can also be taught from an experiment inspired by William Herschel's discovery of infrared light. In a solar room, with the aid of a heliostat, telescope and spectroscope, the Sun's spectrum was projected onto a white screen and students were encouraged to compare the temperature of visible parts of the solar spectrum with the reading of a control thermometer placed beyond the red part of the spectrum.

After leaving the thermometers exposed for a couple of minutes to the spectral colours, all of them displayed a higher reading than before being placed in the spectrum, including the control thermometer. This experiment demonstrated the existence of some invisible solar radiation beyond the visible spectrum.

At the end of the *Solar Physics* course, a debate was promoted in order to improve students' acquaintance with other ranges beyond the visible solar spectrum. In groups, students were requested to perform historical research into how invisible spectral ranges were discovered. One group was responsible for the lower wavelength radiation and another for the higher wavelength radiation. Then, a debate among the groups was held and a third group acted as judges. During this debate the groups were encouraged to contextualize their research, including astrophysical and practical application of invisible radiations. One of the main goals of this activity was to learn about some issues involved in the acceptance of new ideas, for instance, how scientists cope with experimental challenges, how their expectations influence experiment design, and how they convince the scientific community about their new ideas, among other things. Another important goal was to stress that the visible part of the solar spectrum is a very small portion of the whole solar spectrum and how contemporary astrophysics strongly relies on invisible light.

Final remarks

In summary, classic and very well-known experiments and activities such as those described above play new roles when integrated in order to teach solar physics in a fun and interdisciplinary approach. Topics such as chemical composition, temperature and stellar evolution were taught in a solar room designed with simple and inexpensive equipment. The observation of solar and lamp spectra led to enquiry discussions concerning spectroscopy, the main tool for investigating heavenly bodies. Estimating the photosphere temperature was a simple and fun activity to perform with high-school students, where black body radiation was introduced and calorimetric skills were revised.

In addition, some epistemological issues could be stressed and discussed with students. For instance, universal validation of physical laws pervades all astrophysics, even though it is implicitly assumed. Spectroscopy is the main tool employed by astrophysicists and allows them to study heavenly bodies applying the same techniques and physical concepts as are used in their labs, such as temperature, velocity, structure, chemical composition and so on. This is done indirectly by the analysis of celestial bodies' light; thus light acts as fingerprints of stars, which give us plenty of physical information based on the same theories as explain terrestrial phenomena as well.

The present article highlights the relevance of science centre partnership with schools for improving scientific education. During the *Solar Physics* course, students were able to acquire a broader view of the use of spectroscopy in astrophysics, embracing interdisciplinary and contextualized open-ended enquiry activities.

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