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A teaching module about stellar structure and evolution

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Abstract

In this paper, we present a teaching module about stellar structure, functioning and evolution. Drawing from literature in astronomy education, we designed the activities around three key ideas: spectral analysis, mechanical and thermal equilibrium, energy and nuclear reactions. The module is divided into four phases, in which the key ideas for describing stars' functioning and physical mechanisms are gradually introduced. The activities (20 hours) build on previously learned laws in mechanics, thermodynamics, and electromagnetism and help students combine them meaningfully in order to get a complete picture of processes that happens in stars.

The module was piloted with two intact classes of secondary school students ($N = 59$ students, 17–18 years old), using a ten-question multiple-choice questionnaire as research instrument. Results support the effectiveness of the proposed activities. Implications for the teaching of advanced physics topics using stars as fruitful context are briefly discussed.

1. Introduction

In a previous paper, we described a module in which we addressed students' alternative conceptions about frequency and propagation of mechanical waves using the sound of the Sun as motivating context (Leccia *et al* 2015). The success of that module among secondary teachers and students had lead us to develop an extension activity (3–4 h) devoted solely to stars, as they are the fundamental constituents of the Universe. In the development process, however, we soon realised that stars could be an exceptionally motivating context to teach cross-concepts in science as energy, equilibrium or the properties of matter, and hence deserved a dedicated module. Concerning physics, in particular, teaching about basic functioning and properties of stars may help students deepen knowledge about forces, hydrostatics, thermodynamics, nuclear reactions, light emission and propagation, and understand how all these content areas are related each other. Moreover, to understand stars' inner processes can help students to: (i) develop a scientifically informed knowledge on how chemical elements are created—nuclear fusion of light elements (hydrogen and helium) into heavier ones (including, e.g. carbon, oxygen, and iron); (ii) justify chemical abundances in the Universe; (iii) understand conditions under which life may develop. However, while previous efforts were focused on fostering students' understanding about celestial motion, seasons and Moon phases (Barnett and Morran 2002, Plummer and Maynard 2014, Plummer *et al* 2015, Testa *et al* 2015), virtually no study until now described the development of research-based teaching-learning activities about stars. This paper aims to address this issue by blending in an innovative way paper-and-pencil tasks with laboratory activities exploiting *Tracker* and data-logging spectrometer analysis.

2. Issues in the teaching about the stars

Research into students' understanding about stars is rather limited (Bailey *et al* 2012). Earlier studies (Finegold and Pundak 1990) show that students often do not distinguish between stars and planets and think that the Milky Way is composed by stars that are very close each other. In other cases, some students think that the greater the radius of a star is, the bigger its mass gets, thus disregarding the mechanisms behind evolution of the stars. Students also struggle in estimating distances between stars and Earth and in understanding that stars are not motionless celestial objects. Results from more recent studies (Agan 2004) show that students think that a star is a 'burning object', which releases some kind of 'energy', thus confusing chemical and burning reactions with nuclear reactions, which are the responsible for stars' inner physical processes (expansion, compression, temperature variations). Students think also that stars emit monochromatic light and interpret the Hertzsprung–Russell (H–R, see next section) diagram as a trajectory or a position versus time graph. Students rarely explain stars formation and functioning in a detailed way. For instance, Bailey (2006) showed that few students correctly recognise the role of gravity, which is central force, in the star formation process. Similarly, only few students recognise the role of temperature for the star's inner processes.

Drawing from the above literature, it emerges that students' difficulties in understanding stars formation and functioning are mainly related to a scarce knowledge of the underlying physics mechanisms. In particular, students' conceptions appear to be grouped in three distinct categories: (i) conceptions about the forces involved in stars' formation and equilibrium; (ii) conceptions about stars' emitted radiation; (iii) conceptions about stars' inner processes. Consequently, we identified three key ideas around which content knowledge about stars can be reconstructed: (i) mechanical and thermal equilibrium; (ii) spectral analysis; (iii) energy and nuclear reactions. Building on these key ideas, differently from traditional proposals in astronomy education[6], the students learn how to link together important areas in physics as classical mechanics/thermodynamics, electromagnetism and modern physics through simple experiments and modelling tasks. In next section, we give some brief account of the most relevant physical laws that describe stars' functioning and that will be gradually introduced throughout the activities of the module.

3. Theory

3.1. Basics about stars

A star is a rotating celestial object composed by gas, mostly hydrogen and helium, where the pressure force of the gas balances gravity. Rotation is a consequence of the conservation of angular momentum, acquired during the contraction of the initial nebula from which the star is formed. The shape can be assumed as spherical because the gravity is a central force. Even if the shape is roughly the same, each star can be very different from another one depending on the amount of mass, radius, superficial temperature (in astrophysics *colour*), age and chemical elements with atomic weight greater than *helium* (in astrophysics *metals*). The combination of these quantities determines uniquely the evolution of a star and is usually graphically represented by the Hertzsprung–Russell diagram (figure 1).

3.2. Modelling mechanical and thermal equilibrium of a star

Assuming the shape of a star as spherical, the element of mass can be expressed as:

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[6] Example of teaching activities about stars can be found at www.lpi.usra.edu/education/pre_service_edu/StellarActivities.shtml or imagine.gsfc.nasa.gov/educators/lifecycles/Imagine2.pdf.

[7] Picture used with permission from http://chandra.harvard.edu/graphics/edu/formal/variable_stars/HR_diagram.jpg.

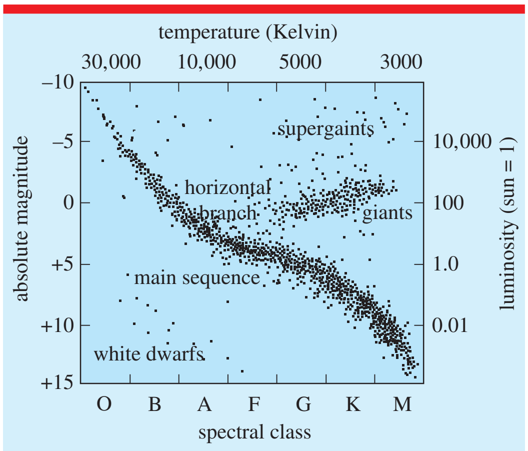


Figure 1. Example of H–R diagram[7].

$$dm = \rho(r)4\pi r^2 \mathrm{d}r \tag{1}$$

This equation is called first structure equation and basically it establishes the conservation of mass. Since a standard star does not change its average radius, we can assume that the element of mass *dm* is in equilibrium. Hence, inward and outward pressure forces and gravitational force are balanced. Applying second Newton's law, and using expression for *dm* one obtains:

$$\frac{\mathrm{d}P}{\mathrm{d}r} = -\frac{GM_\mathrm{S}}{r^2}\rho \tag{2}$$

where M_S is the mass of the star and P is the pressure at distance r from the center of the star. Equation (2) is called second structure equation.

3.3. Spectral emission of the stars

Stars are objects that produce light. The emitted light is produced in the superficial layer of the photosphere. Spectral analysis of emitted light shows that stars' spectra are well described by the Plank distribution of radiance as a function of the wavelength λ:

$$I(\lambda) = \frac{2hc^2}{\lambda^5}\frac{1}{\mathrm{e}^{\left(\frac{hc}{\lambda kT}\right)} - 1} \tag{3}$$

where T is the superficial temperature of the emitting body, h is the Planck's constant, k is the Boltzmann's constant and c is the speed of light. From this evidence, we deduce that stars' emission of light is due to thermal emission mechanism. In particular, from Wien's law, one can easily obtain the superficial temperature of a star. Sun's spectrum follows a black body distribution with a temperature of 5777 K. Spectral analysis provides also information about chemical composition of outer layers of the star (through absorption or emission lines).

3.4. Energy production in a star

Equilibrium condition for a star implies that both pressure and temperature cannot change significantly, since they are related one to another. The physical mechanism that warrants for such condition is energy production in the core due to nuclear fusion reactions, which depend on the age and mass of the star, and consist mostly of hydrogen fusion into helium, for the major part of one star's life. From the knowledge of the binding energy of elements, we can determine the amount of energy produced in each nuclear reaction. Figure 2 shows energy binding as a function of atomic mass. From this graph, we can infer two consequences. First, energy delivered by fusion of H→ He^4 is much greater than energy delivered by fusion of metals; therefore, time spent for this reaction is greater than time spent in reactions that involve the creation of metals. Hence, when observing a sample of stars, the H→ He^4 reaction occurs in the majority of them and this evidence justifies a higher density of stars in the main sequence of the H–R diagram. Second, after the production of iron (Fe), reactions are no longer exothermic and star equilibrium is no longer sustainable.

4. Activities of the module 'Stars'

The module is divided into four phases, in which the key ideas for describing stars' functioning and physical mechanisms are gradually introduced. Corresponding driving questions are 'What is a star?', 'Which physical quantities would you use to describe the stars' functioning?' 'How can we measure such quantities?' *(Phase 1)* 'Which quantities can we measure using light emitted by stars?' *(Phase 2)*, 'Which is the shape of a star and why?', 'How can a star be in equilibrium?' *(Phase 3)*, 'How you think a star is functioning?' *(Phase 4)*. Table 1 summarises the proposed students' activities.

4.1. First phase: introduction to Stars' parameters (2 h)

Students are first guided to identify the stellar quantities that will be studied throughout the

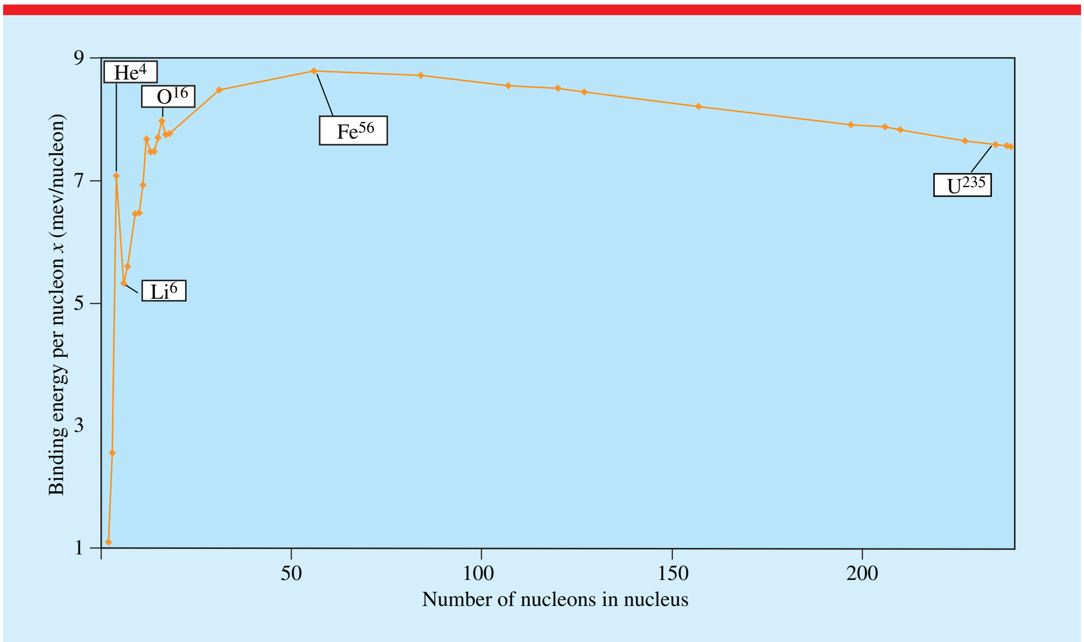


Figure 2. Graph of binding energy per nucleon.

module: (i) radius, (ii) mass, (iii) temperature and (iv) matter composition. For the aims of the module, we will rely on the Sun, because it is a typical star in the main sequence of the H–R diagram; moreover it is the closest star and its distance from Earth (1.5 10^8 km) is taken as reference for calculating astronomic distances in the Solar system.

4.2. Second phase: spectral analysis (8 h)

Initially, the discussion aims at reinforcing students' knowledge about waves and at relating spectrum analysis with Sun's parameters. The activity presented in Leccia *et al* (2015) may be a useful starting point. Students are guided to recognise that pressure waves are generated in inner shells of the Sun due to internal processes and that the fundamental frequency of such oscillations depends on geometrical factors, the radius, temperature and mass of the Sun. Since the solar mass has been calculated in the previous phase, students' attention is here focused on the remaining two parameters, radius and temperature, one of which has to be determined with an independent measurement.

To cope with such issue, we propose to study light spectra. Differently from usual activities in electromagnetism, here students learn how they can use light spectra to gain knowledge about the internal structure/processes of a not accessible source, as the Sun.

The measurement of the spectra of a fluorescent and a filament lamp (equivalent in power) using a data logging spectrometer (Leybold Spectralab[8]) is discussed with students. Drawing on the empirical evidence that the filament lamp warms up much more than the fluorescent one, students can understand that different physical processes—thermal and stimulated emission—happen in the two sources, and that such differences are reflected in the continuous versus discrete appearance of the two curves. After the introduction of emission physical processes, we let students observe spectra acquired from Sodium and Cadmium bulbs, to show that light spectrum depends also on the chemical elements involved in the emission process, and that the interaction between light and a chemical element may affect the original spectrum (absorption process).

Students then measure the Sun spectrum from outside a window of the classroom using the Leybold spectrometer and find out that the spectrum is a continuous one, due to a thermal emission process (figure 3). To investigate solar spectrum without interference of Earth's atmosphere, students plot available data[9] and analyse the resulting graph (figure 4).

[8] www.leybold-shop.com/physics/physics-equipment-89/optics/spectroscopy/spectrophotometer/spectralab-467250.html.

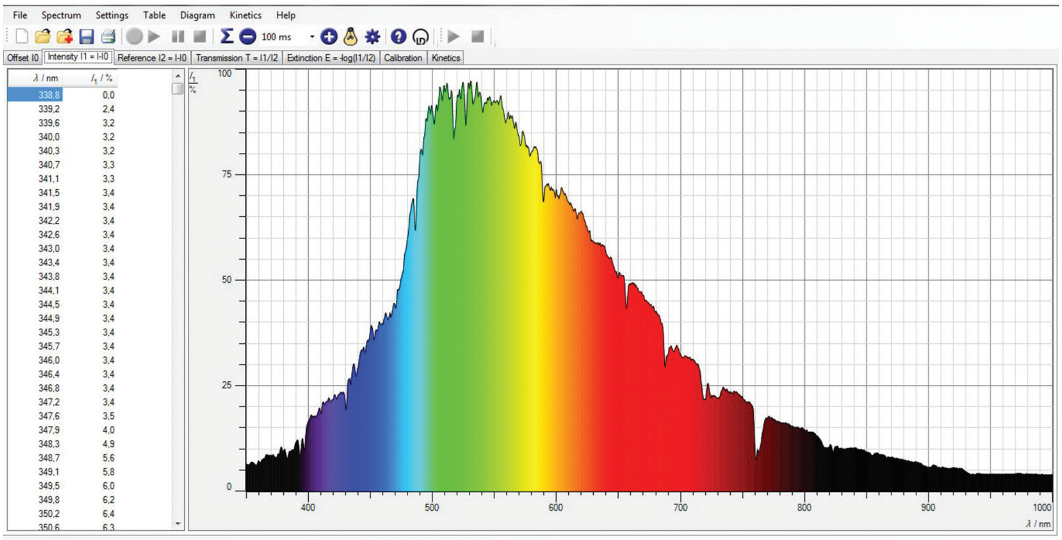
[9] Data used are from http://va-iitk.vlabs.ac.in/data/expt4/solar_data.txt. Note that data have been not corrected for instrumental profile response.

Table 1. Overview of the 'Stars and their functioning' student's activities.

Phase	Key ideas	Time (h)	Driving questions	Intended objectives	Activities—what students do	Teaching materials and resources
1	Introduction to stars' parameters	2	*'What is a star?'*	To identify stellar quantities that can be measured	Discuss in small groups using sketches and words	Worksheet
			'Which physical quantities would you use to describe the stars' functioning?'		Determine Sun's mass through Newton's law	
2	Spectral analysis	8	*'Which quantities can we measure using light emitted by stars?'*	To infer information about stars' composition and processes from spectra	Estimate the fundamental frequency of Sun pressure waves	Software: *Goldwave*
				To distinguish different physical processes from spectral graphs	Estimate Sun's radius using the equation for the fundamental frequency of Sun pressure waves	
				To establish a relationships between emitted light and Sun surface temperature	Discuss the differences between spectra of fluorescent and incandescent lamps	Software: *Spectralab*
					Analyse the Sunlight spectrum and discuss Planck's blackbody radiation function	Software: *Spectralab*
					Determine Sun's surface temperature through Wien's law	Software: *Logger Pro*
3	Mechanical and thermal equilibrium	6	*'Which is the shape of a star and why?'*	To introduce the role of gravitational force in the stars' functioning mechanism	Estimate forces acting on a Sun's volume element	Worksheet
			'How can a star be in equilibrium?'	To justify the need for pressure forces	Estimate Sun's rotational speed	Software: *Tracker*
4	Energy and nuclear reactions	4	*'How you think a star is functioning?'*	To justify stars' functioning with increasing production of energy and of chemical elements To understand that evolution of a star depends only on its initial quantity of mass	Estimate energy delivered by the Sun Discuss basic nuclear reactions inside the Sun To distinguish between chemical and nuclear reactions	Worksheet

Building on the similarities with the incandescent bulb spectrum, students can understand that the main physical quantity that can be determined from the Sun spectrum is the temperature of its surface. At this point, the blackbody Planck function and Wien's law can be introduced to quantitatively determine the temperature of Sun surface from the graph (figures 5 and 6).

Finally, students' attention is focused on the minima of the spectra measured from outside the window of their classroom (figure 3) and from the space (figure 4). Since they represent 'missing' points in the plot, they can be related to some process of absorption by chemical elements in Sun's or Earth's atmosphere. Comparing the two spectra, students should be able to understand that in



λ / nm	I_1 / %
338,8	0,0
339,2	2,4
339,6	3,2
340,0	3,2
340,3	3,2
340,7	3,3
341,1	3,3
341,5	3,4
341,9	3,4
342,2	3,4
342,6	3,4
343,0	3,4
343,4	3,4
343,8	3,4
344,1	3,4
344,5	3,4
344,9	3,4
345,3	3,4
345,7	3,4
346,0	3,4
346,4	3,4
346,8	3,4
347,2	3,4
347,6	3,5
347,9	4,0
348,3	4,9
348,7	5,6
349,1	5,8
349,5	6,0
349,8	6,2
350,2	6,4
350,6	6,3

Figure 3. Non calibrated spectrum curve of the Sun light measured from outside a window of the classroom with Leybold spectrometer and Spectralab software.

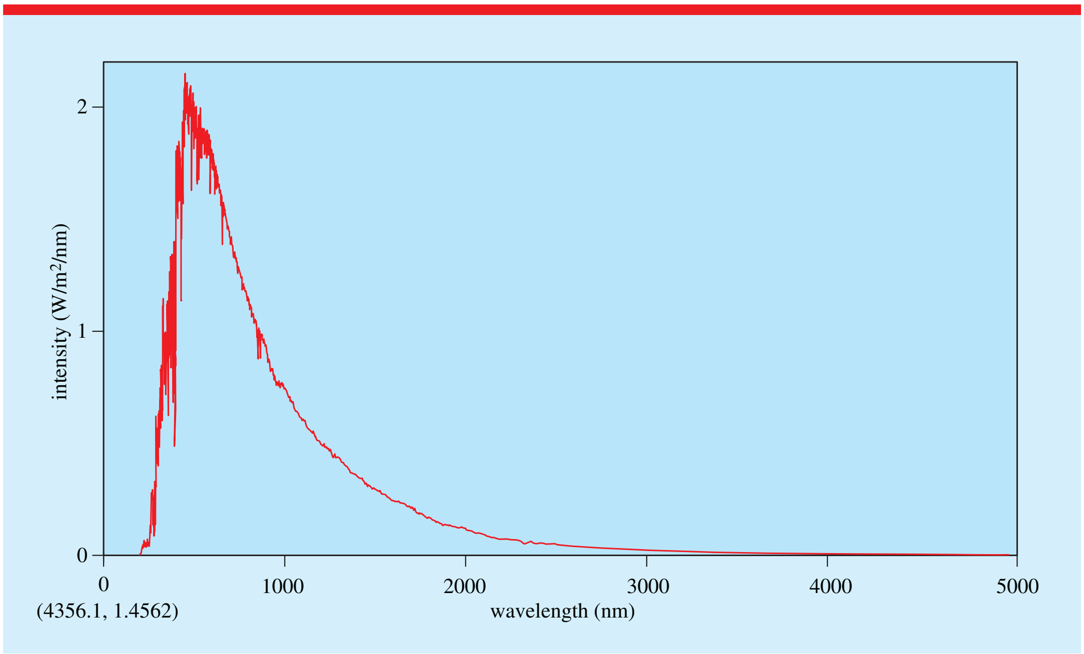


Figure 4. Spectrum curve of the Sun light measured from space (source: http://va-iitk.vlabs.ac.in/images/expt4/lines.png).

the spectrum measured from outside their window they can find absorption lines due to molecules (e.g. O_2, 780 nm, see figure 3). In the spectrum measured from space, absorption lines are due only to chemical elements (e.g. H) belonging to photosphere of the Sun.

4.3. Third phase: mechanical and thermal equilibrium (6 h)

The students are first guided to understand that the spherical symmetry of the gravitational force determines the spherical shape of the

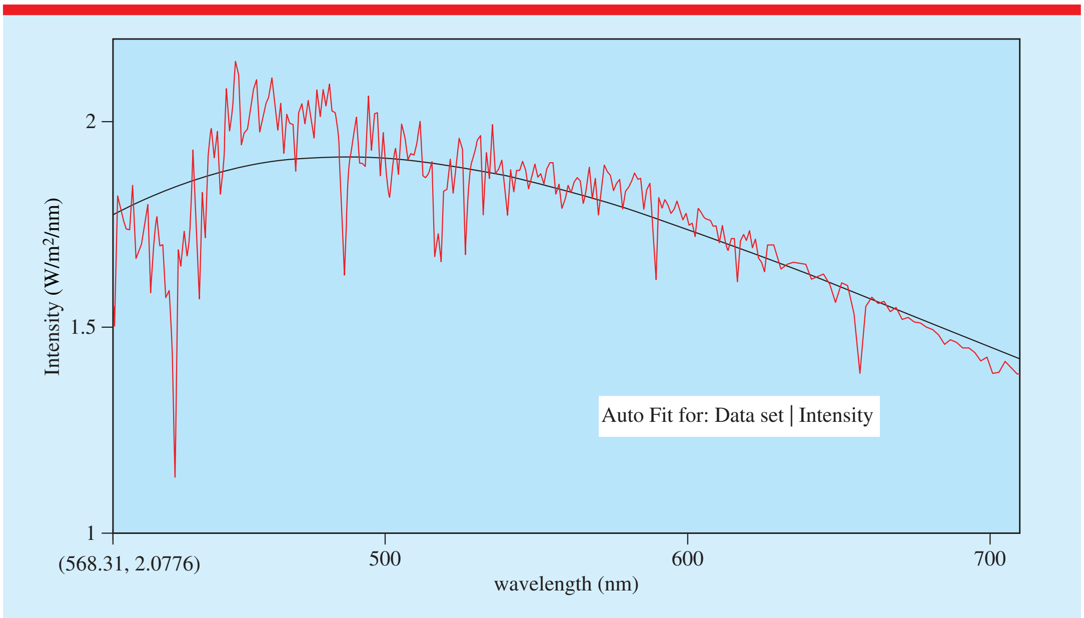


Figure 5. Planckian function fit around the maximum of the spectrum curve reported in figure 2. Equation is: $I(\lambda) \propto \frac{1}{\lambda^5}\left(e^{\frac{b}{\lambda}} - 1\right)^{-1}$ with $b \cong 2420$ nm for a resulting surface temperature of $T \cong 5900$ K. The minimum at about 650 nm corresponds to H_α absorption.

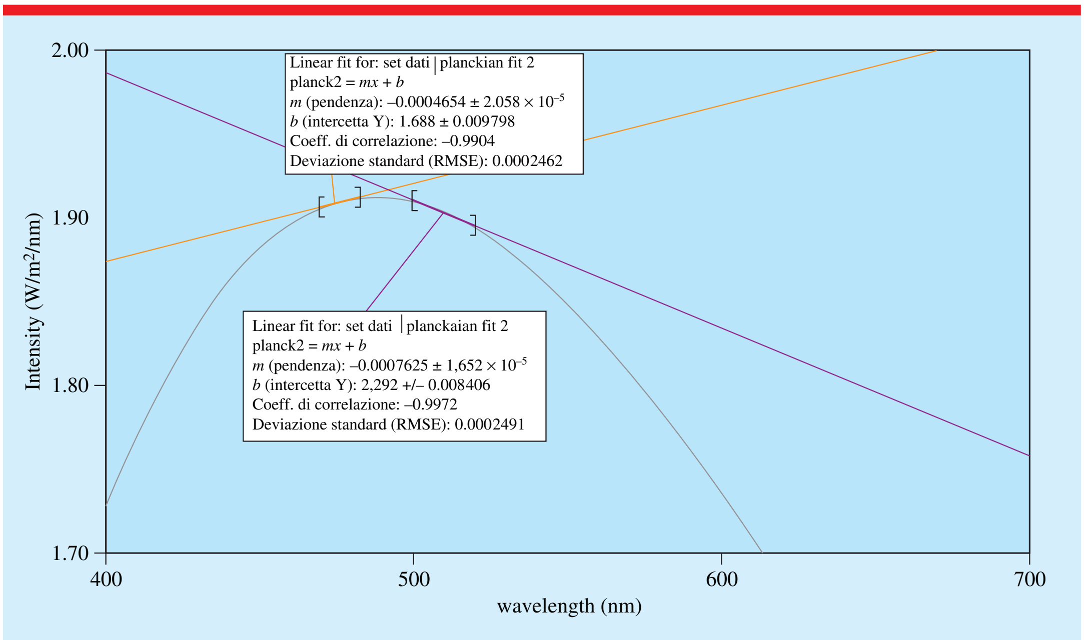
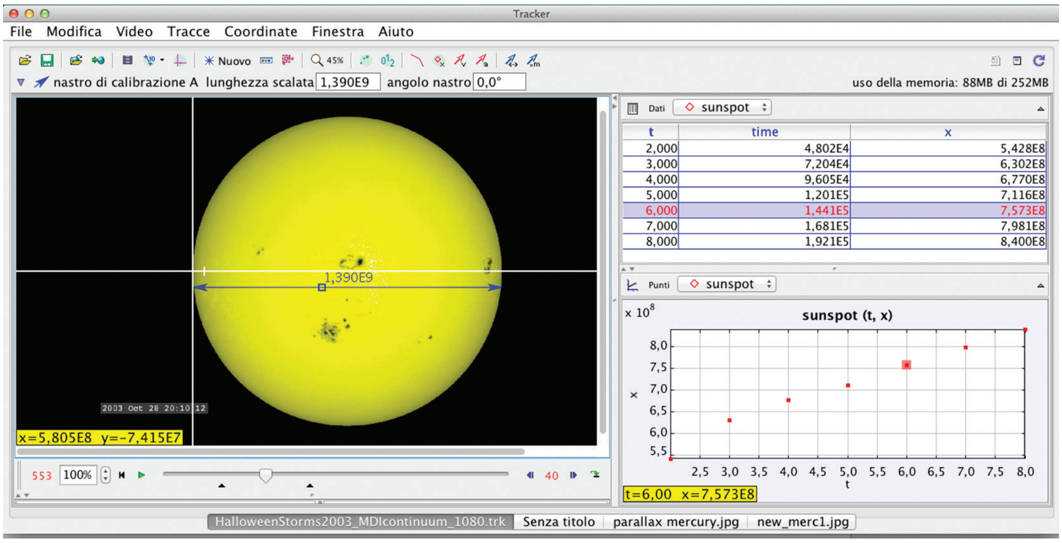


Figure 6. Linear fit procedure to estimate the wavelength corresponding to the maximum in the Sun's spectrum fitted by the Planckian function (figure 5). Intersection is at $\lambda_{\max} = (492 \pm 15)$ nm, which leads through Wien's law to an estimation of Sun surface temperature of $T = (5.9 \pm 0.2)\ 10^3$ K.



nastro di calibrazione A lunghezza scalata 1,390E9 angolo nastro 0,0°

uso della memoria: 88MB di 252MB

x=5,805E8 y=-7,415E7

t	time	x
2,000	4,802E4	5,428E8
3,000	7,204E4	6,302E8
4,000	9,605E4	6,770E8
5,000	1,201E5	7,116E8
6,000	1,441E5	7,573E8
7,000	1,681E5	7,981E8
8,000	1,921E5	8,400E8

t=6,00 x=7,573E8

Figure 7. *Tracker* analysis of a video representing the motion of sunspots at equatorial latitude (https://svs.gsfc.nasa.gov/3502) during a 2-week period in October and November of 2003, obtained with Michelson Doppler interferometer (MDI). Left frame shows the tracking of the sunspot, right frame shows position versus time graph and table of the sunspot. A linear fit gives an estimate of the Sun rotational velocity $v = (1.9 \pm 0.1)\ 10^3\ \mathrm{ms}^{-1}$.

stars. Then, to understand why stars do not collapse, students are then shown a video of sunspots at equatorial latitude, from which they can infer that the Sun (and, more generally, stars) rotates. Similarly to recent teaching proposals (Persson 2013, Ribeiro 2013), students use *Tracker* to measure the Sun's rotational velocity (figure 7). Differently from these proposals, here students apply Newton's law to determine numerically the centripetal acceleration and the gravitational acceleration of the Sun, and infer that other forces must essentially balance gravitational force.

At this point, students are asked to hypothesise what other forces act on the volume element. By recalling buoyancy acting on every object in a fluid, students can understand that such other forces are due to pressure forces acting on the surface of the volume element as in the case of liquids.

4.4. Fourth phase: energy and nuclear reactions

In this phase, students are familiarised with the stars' inner mechanism that accounts for pressure forces. Building on thermodynamics relationships between pressure and temperature, we introduce such mechanism from energy viewpoint. In particular, first, students are asked to hypothesise which kind of process could allow the Sun to emit energy up from its birth to nowadays. Burning processes are first reviewed, as they are the most simple and energetic reactions available in everyday life. Students may hence estimate how much energy it is possible to obtain from burning a mass of H, equivalent to that of the Sun and, knowing the actual solar power, estimate how long the Sun could live emitting this amount of energy if its motor was only a burning reaction involving H.

A simple calculation leads to about 23 000 years, which evidently is way too small value for the age of the Sun. We then discuss the H→ He^4 production to reinforce the idea that stellar processes consist of nuclear reactions that produce photons and thermal energy, which are responsible for pressure forces that contrast gravitational force. In particular, we show that mechanical and thermal equilibrium conditions hold until the nuclear reactions processes are efficient enough to contrast gravitational effects.

5. Implementation and evaluation of the module

5.1. Sample

The module was piloted with two intact classes of secondary school students ($N = 59$ students,

Table 2. Description of the items of the questionnaire.

N	Question	Key idea
1	What is a star?	*Mechanical and thermal equilibrium*
2	How do you think a star is formed?	*Mechanical and thermal equilibrium*
3	What are the main stellar inner processes?	*Energy and nuclear reactions*
4	What are the forces involved in the process of stellar formation?	*Mechanical and thermal equilibrium*
5	What influences the shape of a star?	*Mechanical and thermal equilibrium*
6	What factor does the temperature of a star depend on?	*Energy and nuclear reactions*
7	(Four drawings are shown) Which drawing represents the process by which an absorption line is formed?	*Spectral analysis*
8	Coolest stars emit most of their energy in…?	*Spectral analysis*
9	What happens during evolution of a star?	*Energy and nuclear reactions*
10	(Three spectral curves are shown) Which of the objects has the highest temperature?	*Spectral analysis*

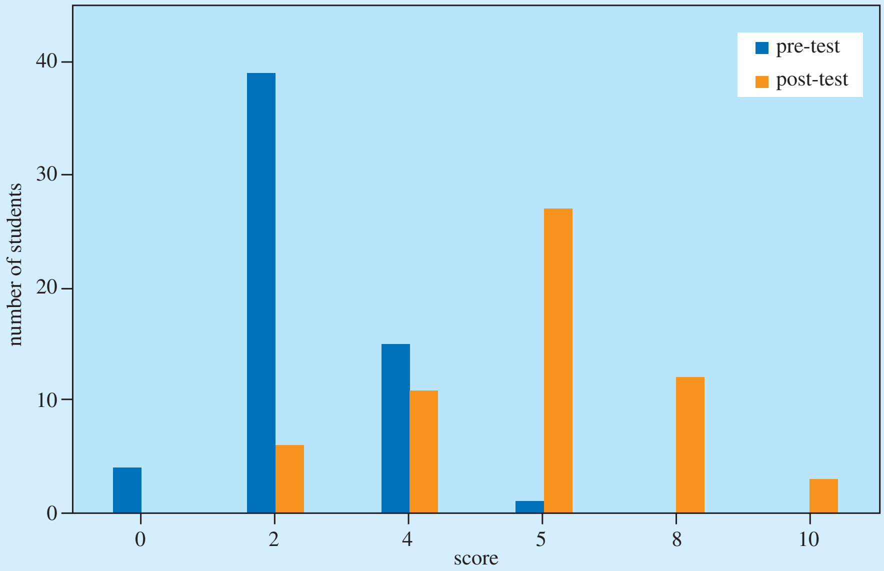


Figure 8. Students' score distribution in the pre- and post-activity questionnaire.

17–18 years old). Total duration followed that of table 1 (20 h). To assess module's effectiveness on students' understanding about stars, we designed a ten-question multiple-choice instrument adapted from two existing instruments (Bardar *et al* 2007, Bailey *et al* 2012). The questionnaire was submitted before and after the activities. Correct answers were given 1 point. Table 2 shows the correspondence between questionnaire's items and module's key ideas. The complete questionnaire is reported in the appendix.

5.2. Results

Analysis of students' outcomes is reported in figures 8 and 9. Average pre-test score was 1.90 ± 0.14 (st.err.), while that of the post-test was 5.3 ± 0.3 (st.err.). Difference is statistically significant ($t = 11.420$, $df = 87.849$, $p < 10^{-4}$). Average percentage of correct answers in the pre- and post-test for the three key ideas is reported in table 3. In the pre-test, students found many difficulties in answering to questions about nuclear reactions in stars: for instance, only 8%

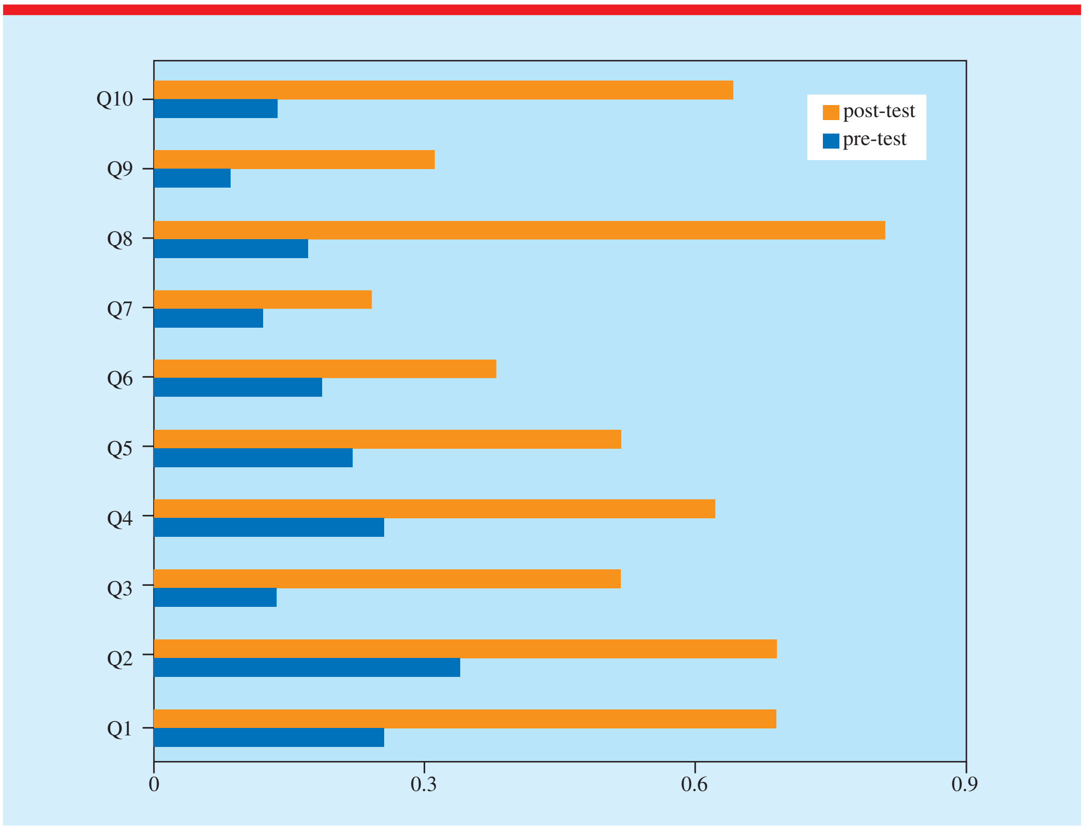


Figure 9. Frequency of students' correct answers in the pre- and post-activity questionnaire.

Table 3. Average percentages of correct answers grouped according to module's key ideas.

Key ideas	Pre (%)	Post (%)
Energy and nuclear reactions	14	40
Mechanical and thermal equilibrium	25	66
Spectral analysis	14	56

of the students answered correctly about the evolution of the star. Some difficulties emerged in answering questions about forces involved in stars formation and shape. Finally, students confused the processes of energy absorption and emission. In the post-test, students show better results. Concerning mechanical and thermal equilibrium, majority of students (about 70%) were able to recognise correctly that a star is a structure in gravitational equilibrium and the role of gravitational force in the collapse of a nebula. It can be plausibly inferred that proposed tasks on gravity enhanced students' understanding of this key idea. Concerning spectral analysis, the relationships between temperature and emitted wavelength seems to have been understood by students. We still detected some problems concerning mechanisms of emission and absorption of light, an evidence that suggests improving activities to better relate microscopic models of atoms to stars' light emission. Finally, concerning energy and nuclear reactions, the proposed tasks appear to be effective in improving students' ability to distinguish between nuclear and chemical reactions. However, the consequences of these reactions often remain confused. This evidence suggests to revise proposed tasks to provide students more opportunities to deepen their knowledge about nuclear reactions.

6. Implications and conclusions

Stars is a topic deemed important to learn about more advanced astrophysics topics as galaxies and cosmology (Wallace *et al* 2012). Despite several teaching resources are available since almost twenty years, research studies have shown that students enter university courses with several misconceptions about stars formation and evolution (Bailey *et al* 2009). In this paper, we have presented an innovative module that aims at improving secondary school students' knowledge about stars focusing on three key ideas: mechanical and thermal equilibrium, spectral analysis, energy and nuclear reactions. Throughout the proposed activities, we mainly focus students' attention on experiments, laws and models that bring together different content areas, with the aim to avoid the risk of transmitting a fragmented view of physics.

The analysis of students' outcomes before and after the teaching intervention supports the effectiveness of the proposed activities in understanding basic concepts about stars and mechanisms underlying their functioning, in particular the mechanical equilibrium and the relationships between surface temperature and emitted wavelength. Plausibly, by blending practical tasks involving classical physics laws and laboratory/computer-based activities to study light spectra and the motion of the Sun, students have improved their knowledge about these specific aspects of stars. Coherently with literature findings, before the activities most students had scarce knowledge about nuclear fusion processes that undergo in one star's core; after the activities, the percentage of students who at least recognised nuclear reactions as relevant for stars' functioning increases up to 50%. Plausibly, the quantitative task about the comparison of energy delivered by an equivalent mass of H and the actual energy provided by the Sun may have helped students to overcome the 'burning' misconception (Agan 2004). Moreover, our module addresses students' difficulty in justifying the existence in the Universe of elements heavier than H and He and improves their knowledge of elements production mechanisms. Finally, the proposed activities on stars' formation and evolution may help students to acquire a first insight into anisotropy and non-homogeneity of the Universe at small scale.

Overall, hence, our study supports the use of stars as rich context to help students achieve high-level, 'expert', scientific reasoning skills.

As future step, we plan to enrich our activities by including tasks about the birth, evolution, and death of stars by deepening the role of the star's mass.

Acknowledgments

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Appendix. Stellar formation, evolution and functioning questionnaire (correct answer in bold face)

1. What is a star?
   - (a) A nebula in gravitational equilibrium that mainly consists of dust and gas.
   - (b) A nebula in gravitational equilibrium that mainly consists of hydrogen, helium and dust.
   - (c) A structure in gravitational equilibrium that mainly consists of hydrogen, helium and metals.
   - (d) ***A structure in gravitational equilibrium that mainly consists of hydrogen and helium.***
2. How do you think a star is formed?
   - (a) A star is formed by a nebula that becomes a red giant.
   - (b) A star is formed by a nebula that becomes a white dwarf.
   - **(c)** ***A star is formed by a nebula that collapses by gravitational force.***
   - (d) A star is formed by a nebula that increases its mass.
3. What are the main stellar inner processes?
   - (a) Chemical processes that produce increasingly heavy chemicals elements.
   - **(b)** ***Nuclear fusion processes that take place into star's core.***
   - (c) Chemical processes that increase the inner temperature of star.
   - (d) Nuclear fusion processes that shrink the star.
4. What are the forces involved in the process of stellar formation?
   - (a) Centrifugal force, gravitational force, nuclear force, pressure force.

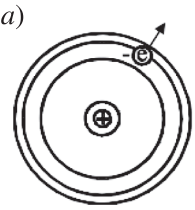
(b) Centrifugal force, gravitational force, pressure force.
(c) Centripetal force, gravitational force, nuclear force, pressure force.
(d) *Centripetal force, gravitational force, pressure force*

5. What influences the shape of a star?
(a) *Gravity, because it is spherically symmetrical force.*
(b) Gravity, because it is attractive.
(c) Gravity, because it depends on product of two masses.
(d) Gravity, because it is a centripetal force.

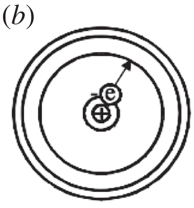
6. What factor does the core temperature of a star depend on?
(a) It depends on chemical reactions that transform H in He.
(b) It depends on conversion of H and He particles into the star's core.
(c) It depends on H and He particles' kinetics energy into the star's core.
(d) *It depends on nuclear reactions that convert* H *in* He.

7. Which drawing (not to scale) represents the process by which an absorption line is formed?

(*a*)



(*b*)



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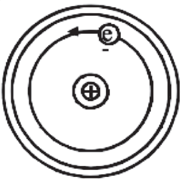

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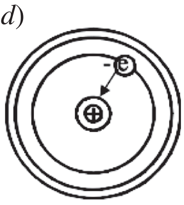
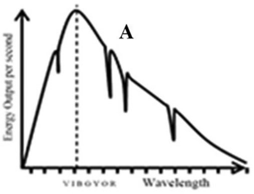
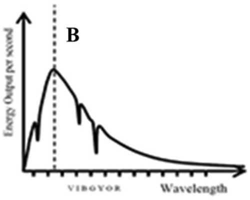


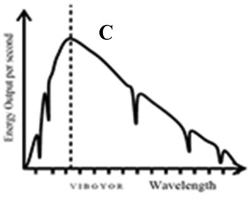
8. Coolest stars emit most of their energy in
(a) X-ray.
(b) *Infrared.*
(c) Visible.
(d) Ultraviolet.

9. What happens during evolution of a star?
(a) Its mass increases.
(b) Radioactive elements are increasingly created
(c) Its radius increases
(d) *Heavy elements are created until iron.*

10. Which of the objects has the highest temperature?
(a) A
(b) *B*
(c) C
(d) All three objects have the same temperature







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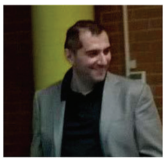

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