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The stellar spectroscopy laboratory and curriculum counselling for secondary-school students

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Summary. — The stellar spectroscopy laboratory is the flagship of a wide-ranging work of curriculum counselling fostered by the Dipartimento di Fisica of the Università degli Studi di Milano and the high school "G. Parini" in Milan. In time, valuable results were gained in setting up a new way of collaboration between the high school and university worlds and in spurring secondary-school students to embark in a scientific, and more specifically physical, career. The present work briefly discusses the contents of the laboratory, its didactical value, its role of curriculum counselling and its effectiveness in directing students to take into consideration the physical sciences as a possible university choice.

PACS `01.40.ek` – Secondary school.
PACS `01.40.G-` – Curricula and evaluation.
PACS `97.10.Ri` – Luminosities; magnitudes; effective temperatures, colors, and spectral classification.

1. – Introduction

In the present work, I wish to put forth some interesting considerations about the effectiveness of a work of curriculum couselling regarding the choice of the universitary career, directed to students of the last two years of the secondary school. This work was carried out thanks to a collaboration between the Dipartimento di Fisica of the Università degli Studi di Milano and the high school Liceo Ginnasio "G. Parini", and it was implemented thanks to the setting-up of several astronomical laboratories, managed both by university and school staff.

The present paper is structured as follows. In sect. **1** a brief description of the place where laboratories take places, the astronomical dome of Liceo Parini, is supplied. In sect. **2** I shall briefly hint at the contents of the laboratories, in particular regarding the

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stellar spectroscopy laboratory. Actually, this is the flagship of our formative proposal, both for its complex structure and for its originality as compared to other didactic offers in different contexts. In this sense, among our laboratories this one surely stands out as an aid for the choice of the universitary career. In sect. **3** I shall deal with the results it has attained up to the current time in terms of curriculum couselling, putting forth the case of some students that, after attending it, have decided to embark on a physical career. Moreover, I shall discuss the role of "contact point" between school and university this activity strives for and, in particular, the didactical requests it attempts to fulfill.

2. – The place

Within the high school "G. Parini" there exists a historic astronomical dome. In recent years, it was restored and endowed with modern astronomical instrumentation. The choice of such instrumentation gave the occasion for a contact between the high school and the Università degli Studi di Milano to be established. In fact, at the Brera base of the Dipartimento di Fisica (formerly Sezione di Storia della Fisica of the Istituto di Fisica Generale Applicata), an extensive programme of didactics named *Storia e Scienza a Brera* has been in place for many years. *Storia e Scienza a Brera* was aimed at spreading knowledge about historical and modern astronomy in the primary and secondary school contexts. This spurred the people responsible of the dome at Parini high school to contact the university staff in order to establish a collaboration and choose together the suitable equipment the dome would be endowed with. The basic idea was to allow secondary school students to carry out real astronomical laboratories, *i.e.* not to simply attend lessons or lectures, or to analyse astronomical data taken elsewhere, but to perform real measures at the telescope and to elaborate their own data.

From the very beginning, it was decided to fully exploit this occasion furnishing the astronomical dome with good-quality equipment. We choose a 28 cm, $f/10$ Schmidt-Cassegrain telescope by Celestron, a ST-7XE CCD and a SGS spectrograph by SBIG. The CCD has a full well capacity around $50000\,\mathrm{e}^-$ and a dynamical range of 16 bit. The SGS spectrograph (at the date of its purchase, as far as I know it was perhaps the most sophisticated spectrograph exclusively utilized for didactical purposes present in Italy) has a $18\,\mu$m wide slit and it is endowed with two diffraction lattices, one capable of a 4 Å/px dispersion (low-dispersion mode), the other of 1 Å/px (high-dispersion mode).

Attaching the spectrograph and CCD to the telescope and utilizing the low dispersion lattice, a spectral region about 3500 Å wide impinges onto the CCD. This means that it is possible to see the whole visible—say from the B band of Fraunhofer located around 6900 Å to the Balmer Jump at 3646 Å—in a single image. The price to be paid is on the side of resolution: for example the sodium doublet—whose lines are barely 6 Å apart—appears as a single absorption line. On the other hand, if we utilize the high-dispersion lattice the spectrum we get just covers a region 750 Å wide. This modality is hence useful to analyze in greater detail the shape of single lines but not to have a complete overview of the visible spectrum. To wit, the low dispersion mode is suitable to classify stellar spectra at a glance in the Harvard scheme, the high dispersion to carry on quantitative work on single absorption lines.

Once a spectrum is captured, it must be calibrated in wavelength and this task is accomplished thanks to lamps whose emission lines are known. In fact, our spectrograph allows a laboratory spectrum to be superposed to the one of a celestial object: assigning two of the known lines to a wavelength, a software carries out a complete calibration calculating the wavelength corresponding to any point of the spectrum. Generally, we used a H (or Ne) lamp and typically we carried out the calibration exploiting the H_α and H_β lines. Once this is done, it is possible to save the spectrum both as an image that shows the main features of the spectrum and as a text file in which a photon count is assigned to each wavelength. Of course this latter format is suitable to be plotted as a graph and in general for quantitative work.

3. – Contents of the laboratories

In this section I will briefly describe the scientific contents of the laboratories, putting greater emphasis on the one about stellar spectroscopy. Generally speaking, the laboratories are directed to student of the last two years of the secondary school.

3˙1. *The stellar spectroscopy laboratory.* – The main target of our investigation were stellar spectra. We set up a stellar spectroscopy laboratory constituted by a theoretical and an observational part. As for the theory, the main topics about spectroscopy were introduced and discussed, with particular regard to stellar spectra, stellar structure and evolution, and the relationship between spectroscopy and the quantum description of the atom. But undoubtedly it was the observational part the highlight of the whole activity. Students took a hundred of stellar spectra and as first step they carried out a qualitative spectral classification *à la Harvard*. In fig. 1 we can see a Harvard sequence built up by some students.

Afterwards, it was possible to carry out quantitative work. As a first step, we supplied information about apparent magnitudes and distances of stars, and students could calculate their absolute magnitude, *i.e.* intrinsic brightness. Then, joining this information together with the stellar surface temperature they could derive from their own spectral classification, they calculated the stellar radii (this task is described in [1](1)). A further step was constituted by the evaluation of the equivalent width (about the concept of equivalent width see [2]) of stellar lines—*e.g.* the line H_α—and its exploitment to derive stellar temperatures (for further detail about this work see [3]). These so-called *excitation temperatures* could be then compared to the *colour temperatures* derived from the classification in the Harvard scheme, with fair results.

Furthermore, we took a glance to some other phenomena that can be discovered in the spectra of celestial bodies. Although up to the present day we did not speculate much about these, I shall hint to them because they can be the basis upon which further spectroscopic experiences can be built. We observed the emission line H_α that is superposed to the usual absorption spectrum of the star β Lyr (see fig. 2). β Lyr is a double, interacting system and the emission lines (H_α and others like the sodium doublet) are due to a disk of matter that is ripped off one component by the tidal attraction of the other. A preliminary analysis of its Doppler broadening pointed out an expansion velocity compatible with the known value.

We also observed the spectrum of some planets like Jupiter, Saturn and Uranus. Clearly enough, this is just reflected sunlight, but a comparison between these spectra and others of G-class stars like the Sun immediately highlights one difference: there is a

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(1) More generally, in [1] a more detailed description of the contents of the laboratory is supplied. I cross-refer to it for further elaboration on this side because in the present work I am more interested with the didactical issues and curriculum counselling topics.

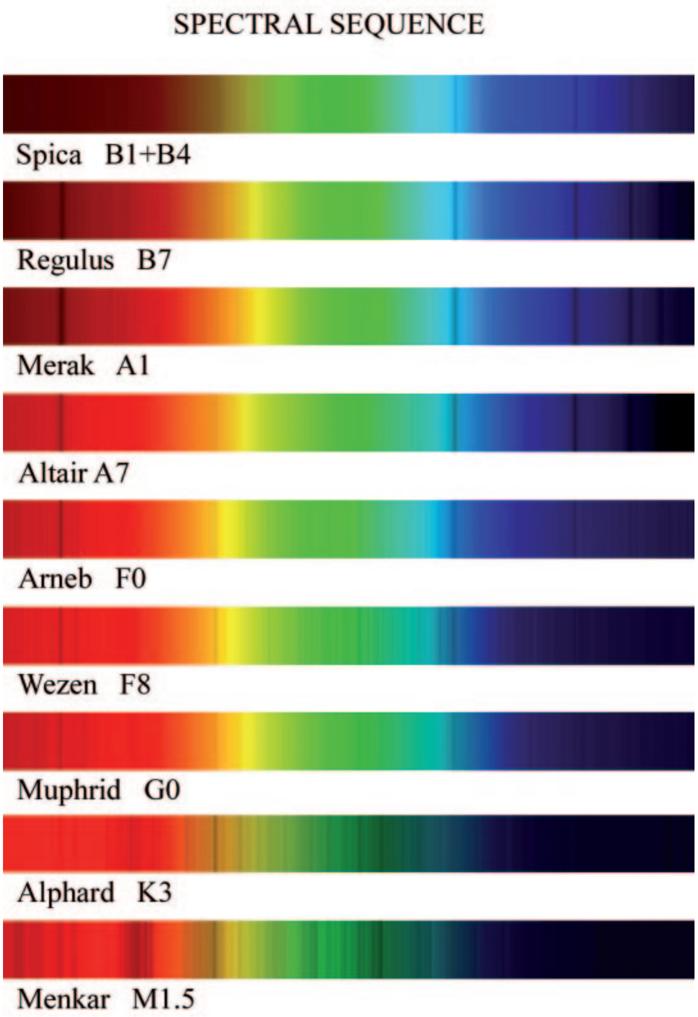

Fig. 1. – A stellar spectral sequence built up by the students. Below each spectrum the star's name and the spectral class are indicated (as Spica is double the spectral classes of both components are shown).

methane band in the red that is due to the atmosphere of the giant planets and is not present in the spectrum of the Sun. Furthermore, it is interesting to compare Saturn's globe spectrum with the one due to the rings (see fig. 3). The latter one does not show this band and this an evidence of the gaseous nature of (at least the outer part of) Saturn's globe and the solid nature of the rings (they are reckoned to be constituted by a large number of small icy fragments orbiting the planet).

3·2. *The lunar laboratory.* – The lunar laboratory is devoted to the closest, and easiest to observe, celestial object: the Moon. The activity is about measuring the lunar distance via the parallax method, its diameter once the distance is known, and the dimension of craters and height of mountains starting from the known value of the diameter.

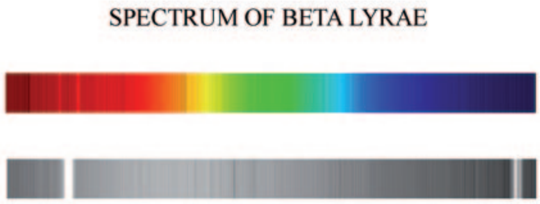

Fig. 2. – (Colour online) Spectrum of β Lyrae. *Top*: spectrum taken with the low-dispersion lattice, it shows some emission lines like H_α, H_β and the sodium doublet that appears as a single line in the orange part of the spectrum; *bottom*: taken with the high-dispersion lattice, magnification of the region between H_α (left) and and sodium doublet (right); thanks to the higher dispersion the sodium doublet appears as a doublet indeed.

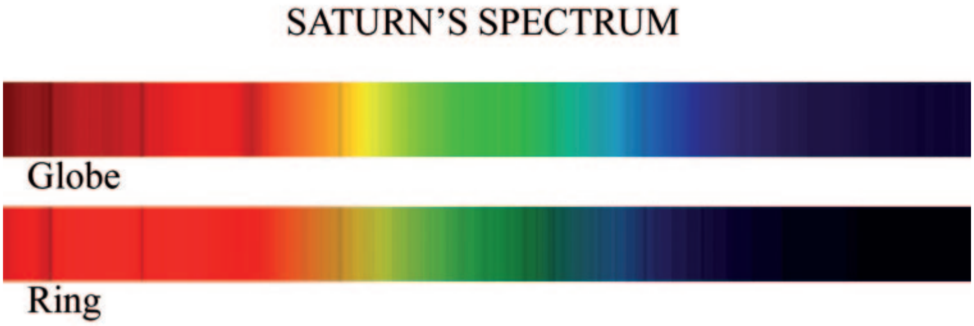

Fig. 3. – Spectrum of Saturn's globe and rings. It is clearly detectable a methane band in the red part of the globe's spectrum that is due to Saturn's atmosphere. Notice that the lower brightness in the blue in the ring's spectrum is due to the much lower S/N ratio.

Clearly, the parallax measure needs a large enough baseline to be established. Generally speaking, a basis around 1000 km is suitable(²). As it is not always easy to carry out the parallax measurement, this section of the laboratory is seldom skipped and we start from a known value of the lunar distance and diameter and just measure craters and mountains. Students have the opportunity to take pictures of the Moon at the telescope and to analyse them. Although the evaluation of the height of the mountains requests some non-trivial geometric concepts, we carried out in a couple of occasions simplified versions of this laboratory project with students of age 12–14. Actually, we reckon it is important to spread this kind of scientific knowledge among younger pupils. This a long-term investment that can even yield better results as regards the future choice to embark on a scientific career, as compared to older students.

3·3. *The solar laboratory.* – The solar laboratory is aimed at measuring the solar luminosity and temperature. The luminosity is estimated thanks to the measure of the

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(²) Recently, we performed this measure setting up a collaboration with the Astronomical Society of Southern Africa. This implied we could avail ourselves with a baseline from Italy to South Africa over 8000 km long. This was quite enough for the Monn, of course! Actually, it was enough for Mars as well, whose parallax we measured with valuable results. About this experience see [4].

solar constant and the knowledge of the Sun's distance. To evaluate the solar constant, students must build a bolometer themselves and employ some concepts of thermodynamics they learned at school. Once the Sun's brightness and diameter are known, the *effective temperature* follows immediately from a straightforward application of the Stefan-Boltzmann law. Up to this point, the laboratory introduces some important concepts and spurs students to apply some physical formulae they learnt at school, but there is nothing really newfangled. What is really new is the possibility to carry out also a *colour temperature* measurement thanks to our spectrograph, as it can be used to analyse a beam of conveniently dimmed sunlight. The comparison between effective and colour temperature tells something interesting about the errors in the measurement process, but also about the acceptability of the black-body approximation for the Sun.

3˙4. *The Jovian satellites laboratory.* – All the previous laboratories are *astrophysical* laboratories. But astronomy is not only astrophysics. Or, al least, it was not. Until half of the XIX Century astronomy dealt mainly about the motions of the celestial bodies. Think for example to Kepler's laws. Then, we thought it could be interesting to set up a laboratory of historical astronomy devoted to the verification of the validity of Kepler's third law for Jupiter's Galileian satellites: Io, Europa, Ganymede and Callisto. Students measured the orbital radii (orbits are nearly circular) and periods at the telescope, then performed the necessary calculations. Generally, fair results were found.

4. – Didactics and curriculum counselling

The very first consideration arising from the previous pages is what we mean by a "didactical scientific laboratory". Exploiting the astronomical dome we conceived several laboratories that became the place where interested scholars could directly practice real scientific experiences in a continuative way, graded to their knowledge, on a basis of voluntariness and not strictly tied to their curricular duties. Our didactical model can be resumed like this: students should be offered the possibility to experience scientific knowledge from the aesthetical side, in order to really taste whether physics is a subject to consider for a university choice. The astrophysical laboratories were initially proposed to students of the Parini high school and at a second stage have also been offered to students of several other high schools of Milan and the outskirts. All the activities have also been included in the *Progetto Lauree Scientifiche* which was sponsored in the last few years by the Italian Ministry of Education and Research (MIUR). Starting from 2004, about 100 students of the Parini high school and about 250 from other schools attended our astrophysical courses. Almost all of them gave an absolutely positive feedback as regards this kind of learning experience.

With regard to their academic choices, we got a feedback both from Parini and other high schools. As Prof. Mauro Zeni, the closest collaborator of the author of the present paper, actually works as a professor in the Parini high school, we can avail ourselves of better data about this school. In these years, 8 students from Parini chose Physics at university and, all in all, about 50% of the students enrolled scientific degree courses (mathematics, engineering, medicine, . . .). In spite of the small numbers, the statistics are really interesting, if we compare these numbers with the general statistics of the Parini high school which gives only 30% of the students choosing scientific courses. The evidence is that the astrophysical laboratories have really succeeded in promoting a cool-headed choice of scientific careers. As for the other schools, similar results were gained. Several students explicitely told us they were induced to re-consider Physics as a possible choice after they had ruled it out in a previous time, and some of them actually chose it in the end.

The planning of the didactic activities of the labs has moreover led to a didactical and scientific research work and to several papers, that were cited before ([1,3] and [4])).

A second consideration is about the collaborative model which has been realized between the Parini high school and the Università degli Studi di Milano. In my opinion this collaboration defines a new model of relationship among the high school and academy worlds. Both high school and university are agencies of the Italian Education System but usually they have different and widely disjointed targets. In fact, high school teaches every possible topic to all students, in an undifferentiated manner, employing teachers that usually have no research duties; on the other side, the research activities are one of the main aims of the university, but academic teaching is very specific and to a lesser extent contributes to equip students with a wide-ranging culture.

Usually these separate worlds meet each other once a year in occasion of the so-called Open Days that barely serve to give introductory information to students that are ending up their high school years and are approaching the university world. In recent years, universities also organized stages and laboratory experiences in order to show the contents of their didactical offer. All these activities heavily burden the human resources of university, and therefore are often discontinuous, *una tantum* or changing every year. Moreover, these activities are planned according to a top-down model: from the academic world a lot of information drops on the high school, on students and teachers, which receive it passively. No continuity in the participation over the years is granted in this way.

In the case of the collaboration between the Parini high school and the Università degli Studi di Milano, a new collaborative peer-to-peer model has been developed. Locations, instruments and teachers are shared in this relationships; the conceiving and planning of the experiences involve all the interested teachers, both from university and high school. High motivation is a natural outcome of this model. In fact, in the high-school world there are many teachers with a research curriculum which are interested to the opportunity to contribute to didactical/scientific projects. The logistic and the organizations jobs are shared. All in all, this peer-to-peer relationship exploits all the available resources and this grants the continuity in time of the projects and of the staff. Continuity in time is the fundamental requisite in order to develop best practices.

To wit, the astrophysical laboratories constitute a kind of excellence centre located halfway between high school and university. In our opinion the scientific and didactical experience realized in the astronomic dome of the Parini high school may become the reference model for similar excellence projects, on other subjects in other schools, with a similar relationships between the schools and the university. We imagine an Education System built up in such a way that a high-school student can freely attend, on elective basis, courses and laboratories in several different centres of excellence in his own city. We think that this didactical excellence network is the best way to promote high-quality work in the high-school context and to fulfill the information and orientation duties of the academic world.

A further consideration is mandatory: the presence of the astronomical dome of Liceo Parini has been the first requisite in order to start up the project. This facility has required several instrumental and human resources for several years, both at the very beginning and later, in order to put into being best-practice didactical experiments. In other words, an adequate financial support in time is needed from the Education System in order to develop similar experiences. It is therefore a duty of the educational politics to decide whether such a model is worth to be promoted and expanded.

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