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Teaching Astronomy with the Virtual Observatory

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Abstract

The Virtual Observatory (VO) has developed in recent years a series of case studies of Astronomy aimed at high school and university students. The main goal of these case studies is to use real archival data in the process of learning certain astronomical concepts. All the case studies share the same structure: after a brief description of the scientific case and the VO tools to be used, the methodology and analysis to be carried out is explained in detail. In total, there are 6 case studies available, all of them in Spanish, with a variety of topics as, for example, the Hubble Sequence to morphologically classify a sample of galaxies or the study of the properties of the Pleiades star cluster from the construction of a Hertzsprung–Russell diagram. VO tools like `TOPCAT` and *ALADIN* are widely used in all the cases. Recently, the Spanish Virtual Observatory (SVO) have updated the case studies with the latest versions of VO tools and recent astronomical archives. In this work, we present these case studies, that are already available for the general public in the SVO webpage and other platforms like Zenodo or the webpage of the project ACIERTAS[a], which provides teachers with resources to facilitate their educational work in the field of science.

[a] *Aprendizaje de las Ciencias por Indagación en Redes Transversales colaborativAS*

1 Introduction

This outreach initiative[1] at the Spanish Virtual Observatory[2] (SVO), a group at the Center for Astrobiology (CAB, INTA-CSIC), involved updating and reviewing six practical cases on various areas of astronomy. These case studies, designed by the SVO for high school and university students, employ real data from astronomical databases to teach essential astronomical concepts.

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[2] https://svo.cab.inta-csic.es/

The goal was to review, update, and rework these six case studies, as the latest versions dated back to 2010 and used now-obsolete VO tools versions. The primary tools in the updated studies are *Aladin* [1] and `TOPCAT` [2]. The case studies are titled as follows: (1) H-R Diagram of the Pleiades cluster; (2) Distance to the Andromeda Galaxy; (3) Proper motion of Barnard's star; (4) Confirmation of a supernova in the galaxy NGC 4995; (5) Hubble Sequence and (6) Distance to Crab Nebula. All these case studies follow a structured format: they begin with an introduction to the relevant astronomical concepts and the scientific case, followed by installation instructions and a guide on the functionalities of the VO tools used. Finally, the practical case is explained in detail, including methodology and analysis.

2 SVO practical cases

2.1 H-R Diagram of the Pleiades cluster

The first case, about the H-R diagram of the Pleiades open cluster (M45), is the only one among the six cases that uses both *Aladin* and `TOPCAT`, making it one of the most complete in the collection. In this case, an H-R diagram of absolute magnitude versus color is created for the stars in this young stellar cluster. For this purpose, parallax data, proper motion, and reddening/extinction corrections have been taken into account. Additionally, the tutorial includes a section encouraging the student to recreate the procedure steps for another stellar cluster, M67, which is older than the young Pleiades cluster. This highlights the fact that stars had the time to evolve outside the main sequence of the H-R diagram in an older cluster (see Figure 1). In this way, the tutorial aims to inspire a scientific mindset, that invites students to draw conclusions through the comparative study of both clusters.

In this case it is worth explaining the procedure, which begins by locating stars from the Pleiades cluster within the Gaia DR3 catalog, the latest catalog released from the Gaia mission to date, which contains high-quality data on parallax and proper motion. Once the sample is obtained within a selectable radius in *Aladin*, the table is loaded into `TOPCAT`. Then, by selecting the necessary columns for coordinates, parallax, magnitudes, extinction, and color reddening, a parallax filter is applied to select stars within a range of 7 to 9 mas (see Figure 2), knowing that the Pleiades are situated around the value of 7.364 mas [3].

For the construction of the H-R diagram, the magnitude in the G band will be taken for the vertical axis and the color $BP - RP$ for the horizontal axis. The student is first introduced to the concept of reddening as a phenomenon caused by dust grains present in the interstellar medium, which scatters the bluer light. On the other hand, regarding the G magnitude, the difference between absolute and apparent magnitude is also clarified by the typical expression $G_{abs} = G + 5 \cdot \log(p) + 5$, where p is the parallax, and it is corrected for extinction A_G. In this way, it is demonstrated to the student that diagrams of two clusters at different distances and different extinction values can be compared.

A final section is added to the tutorial, where the student is presented with proposed exercises: to repeat the H-R diagram of the M67 cluster, to perform the selection using proper motion, and to compare it with the H-R diagram of the Pleiades as in Figure 1.

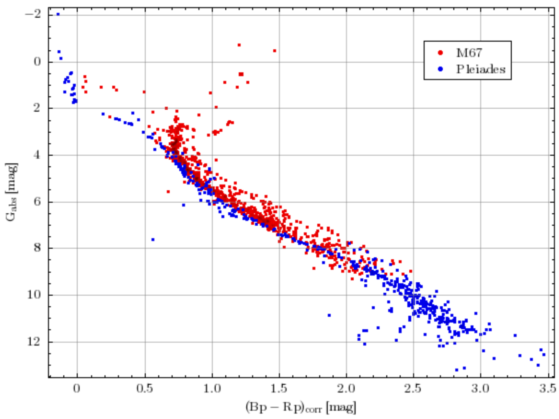

Figure 1: H-R diagram shown in the case; in red M67 and in blue M45. This is the final plot result the student may obtain from the proposed exercises.

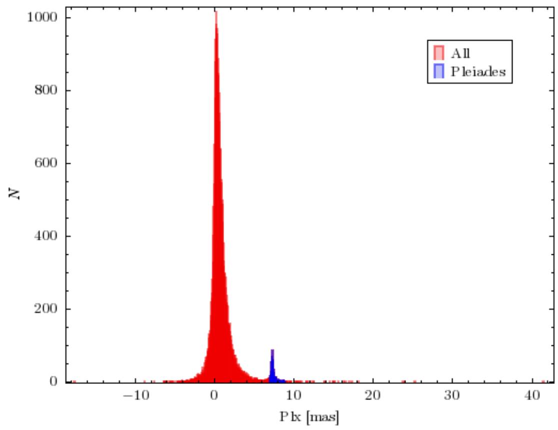

Figure 2: Parallax histogram for Gaia DR3 objects within the radius selected in *Aladin*, where the M45 cluster distribution appears as a small peak in blue.

2.2 Distance to the Andromeda Galaxy

The next practical case is on the distance to the Andromeda Galaxy, this tutorial makes use of the potential of Cepheid variable stars to measure distances beyond our own galaxy the Milky Way, where the method of astronomical parallax, explained in Section 2.1 becomes ineffective. In this tutorial, after a brief introduction that places the student in the spatial context of the distances dealt with in Astronomy and the historical context of the problem of measuring distances, the practical case is presented of selecting a sample of Cepheids in Andromeda for which the distance is obtained through the magnitude-period relationship $M = -1.43 - 2.41618 \cdot \log(P)$ based in the catalog info where the sample is obtained [4], where P is the period obtained for the infrared band. From the sample of Cepheids used, the average distance to the galaxy is determined using *Aladin* (see Figure 3). It is also worth noting the opportunity offered to the students to analyze different period-magnitude relationships depending on the band in which they are working.

Additionally, this practical case enables students to learn how to perform quick analyses and calculations by simply using the VO-tool *Aladin*. In summary, it serves as a brief introduction to cosmological scales and extragalactic Astronomy, connecting superficially with the concepts presented in the practical case on the Hubble Sequence Section 2.5.

2.3 Proper motion of Barnard's star

About the case of the motion of Barnard's Star, the star with the highest known proper motion to date, a brief introduction is given to the concepts of proper motion on the celestial sphere. Additionally, the nature of the star is contextualized, as it is a red dwarf—the most abundant type of star in the Milky Way and fundamental in areas of study such as exoplanets.

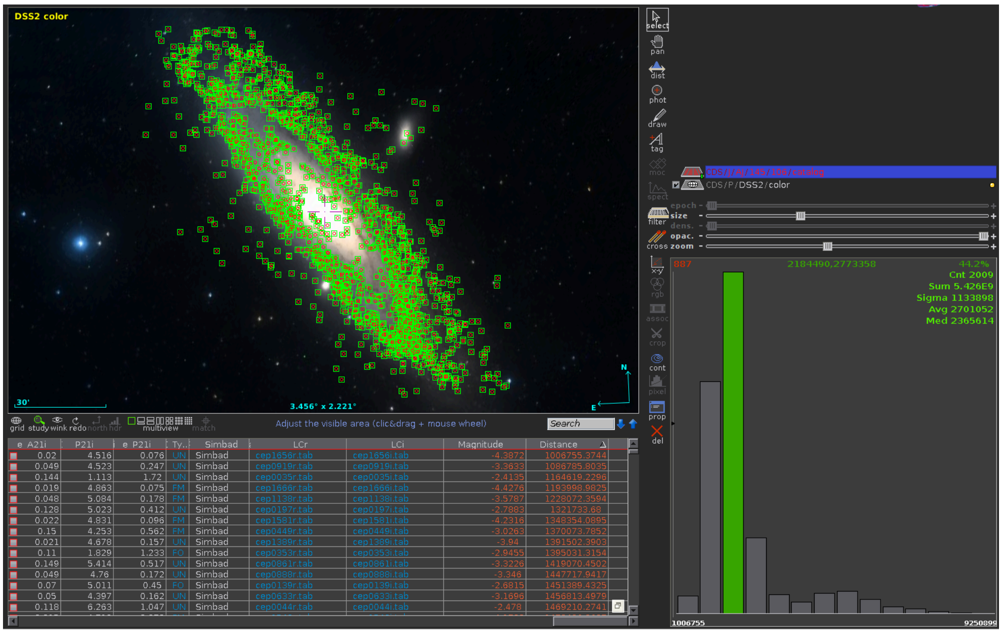

Figure 3: Screenshot from *Aladin* showing the histogram of distance calculated in light-years for the sample of Cepheids in the Andromeda Galaxy from catalog mentioned.

The practical objective is to measure the angular distance of the star observed at two different epochs using *Aladin*, in order to obtain its angular proper motion μ and the distance traveled by the star in one year. Also, an explanation is provided on how to create a movie of Barnard's star proper motion using the tools offered by the *Aladin* VO tool. Thus, images used are from the Digitized Sky Survey 2 (DSS2), produced by the Space Telescope Science Institute (STScI). Specifically, to obtain two images on two different dates, one with the red-filter and the other with the blue-filter are selected, which are from the POSS II survey (Palomar Observatory Sky Survey) [5].

2.4 Confirmation of a supernova in the galaxy NGC 4995

This practical case, which deals with the confirmation of a supernova in the galaxy NGC 4995 using *Aladin*, has undergone significant modification compared to the previous version. A more recent supernova that occurred in late April 2023 (when this project was ongoing) in NGC 4995 has been chosen. Thus, the practical task consists of comparing two images of the galaxy before and after the supernova explosion, thereby confirming the appearance of a bright spot that rivals the brightness of the galaxy itself: the supernova, and to measure its distance from the center of the galaxy. Although this practical case is time-sensitive and quickly becomes outdated due to the brief duration of a supernova (just a few weeks), students are given the option to access any image from the Rochester Astronomy supernova image database[3] for the most recent supernovae available at the time of using the text.

[3]https://www.rochesterastronomy.org/snimages/

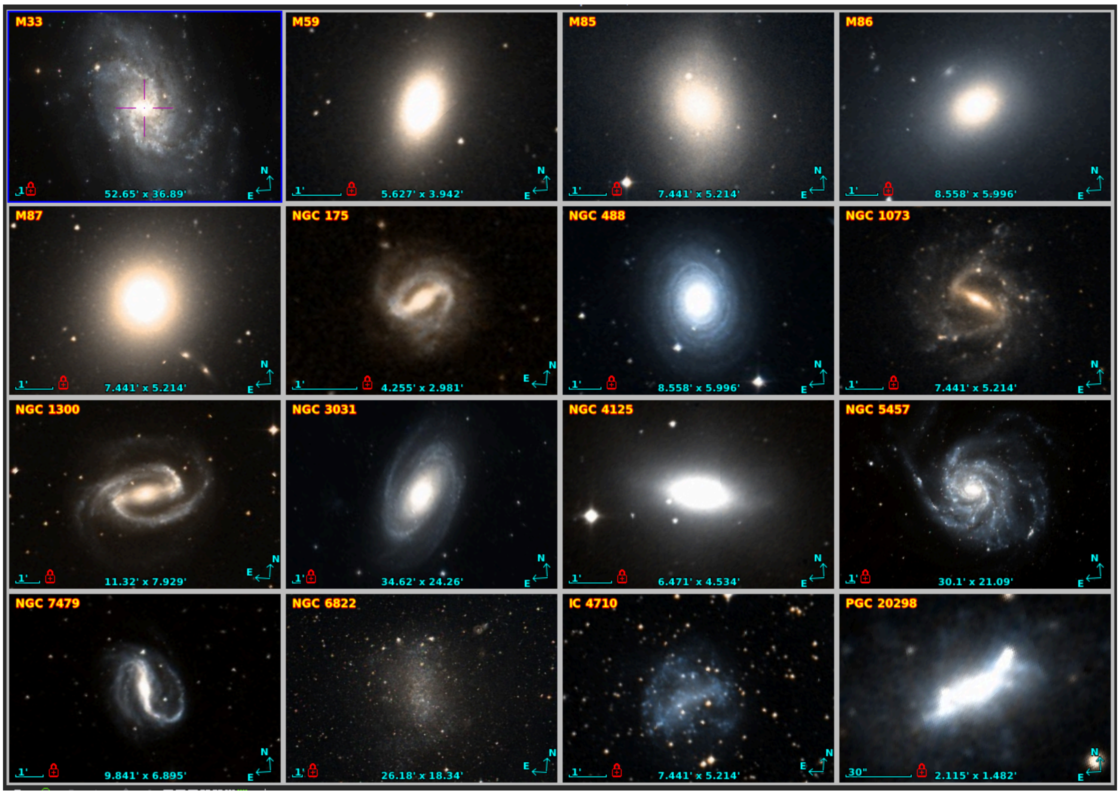

Figure 4: Screenshot from *Aladin* showing the galaxy sample for the Hubble Sequence case.

2.5 Hubble Sequence

The Hubble Sequence tutorial proposes a series of exercises to classify a sample of 16 galaxies of different types (see Figure 4) according to the Hubble Sequence, with images obtained from *Aladin*. This tutorial is, without a doubt, along with the H-R diagram case, the most interactive for the student, as it offers a wide range of exercises that make the study and application of the concepts more engaging.

2.6 Distance to Crab Nebula

Finally, the practical case on the Crab Nebula again addresses the concept of distance. However, it also provides an explanation of X-ray Astronomy as an example of the different observational windows of the Universe, which are not only based on visible light but also other ranges of the whole electromagnetic spectrum. Additionally, this case combines imaging methodologies from different epochs with distance calculations, making it a comprehensive case that integrates concepts from other tutorials (see Section 2.1, 2.3, 2.4). To end, one of the most intriguing concepts discussed in this tutorial is the fact that astronomical events, despite being often set on enormous timescales, can be brief and may even occur in eras when technology had not yet opened the doors to the Cosmos.

3 Accessibility and ACIERTAS

It is important to remind that this practical cases are available in the SVO webpage and platforms like Zenodo, or the webpage of the project ACIERTAS[4], which is an initiative by COSCE[5]. The platform allows teachers at all educational levels, from Preschool to High School, to share educational experiences and access resources created by experts. These resources include practical science activities available in various formats. Moreover, ACIERTAS actively involves scientists in collaborating with teachers to create educational materials. The initiative also aims to inspire curiosity and critical thinking in students, empowering them to explore and question the world through the scientific method.

4 Conclusions

To conclude with, this initiative, which centered on revising and modernizing the practical cases for the Spanish Virtual Observatory (SVO), has highlighted the critical need to invest on educational resources with the latest developments in astronomical tools and databases. The revisions made to these cases significantly improve the educational experience for both high school and university students by granting them access to up-to-date data and fostering a deeper comprehension of essential astronomical concepts through practical application. These cases incorporate the most current techniques in astronomical research and equip students with valuable skills and knowledge, enhancing their engagement and enthusiasm for the field of astrophysics. Overall, this initiative emphasizes the importance of ongoing updates to educational materials to effectively prepare future astronomers.

Acknowledgments

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[5] *Confederación de Sociedades Científicas de España*