

# Understanding Resolution with Galileo's Telescopes

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**Abstract:** Using the context of Galileo Galilei's pioneering observations of the Saturn's rings, the students are driven to build an optical telescope in the laboratory and analyze and discuss the different solutions to improve its resolution. © 2021 The Author(s)

## 1. Introduction

### 1.1. Historical Motivation

In 1610, Galileo Galilei (1564 - 1642) reported the early observations of Saturn's rings [1]. However, he did not get to the correct explanation.

The limitations that Galileo found with his instruments prevented him from correctly understanding his discovery. This is a clear example of how the limitations of scientific instruments dictate the advance of Science in any era [2]. Authors believe that both Engineering and Science students must be advised and conscious of this fact in order to develop critical thinking of their own research and study areas, and could be a motivation for the development of better techniques and instruments to push further the frontiers of Science and Technology.

### 1.2. Educational Context

In most cases, students study Geometrical Optics and optical instruments from a purely theoretical and problem-solving approximation, and aberrations and resolution are subjects that are treated solely from a theoretical point-of-view. Furthermore, when undergraduates and master students deal with optical instruments in the laboratory they typically work on the basic aspects of Geometrical Optics and do not perform a deeper analysis in the real problems that appear when designing a real instrument.

For those reasons, in the framework of the Photonics Master's degree, the workshop of this communication was developed. This Master's program has a large variety of students, who come from different parts of the world and from different degrees, i.e., with different backgrounds and levels of knowledge in experimental Optics. To uniform the basic knowledge and experience of the students, the Photonics Laboratory [3] course was developed. One of those practices is the one presented in this work.

## 2. Laboratory Workshop

### 2.1. Design of Telescopes and Galileo's Recreation

Using the ray tracing Java applications from the JavaOptics Course<sup>1</sup> [4], students must design the telescope they are going to later build. The software also permits the analysis of geometrical and chromatic aberrations, enlightening the students regarding the limitations that he/she could find when building the instrument.

In parallel to this simulation, students are introduced to Galileo's pioneering observations (see Figure 1), and they must compare their design with Galileo's [5]. They can perform the basic comparison by programming their own code in MATLAB® or Python, or by using defocusing and blurring filters with commercial photography programs such as Photoshop®.

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<sup>1</sup> The JavaOptics Course (JOptics) is an ensemble of Java applets and teaching resources for Physical Optics courses at university level for Physics of Optics and Optometry courses. The Course was developed by the members of the Optics and Photonics Research Group of the Applied Physics Department of the Universitat de Barcelona in the early 2000's thanks to three projects (DOGC-3453, 2003MQD-00138 and 11/III/MM-Eva/34/CARN) and the use of its resources for educational purposes is open and free. It consists of a series of 13 Java applets that covers all the topics of a Physical Optics course, from Geometrical Optics and Colorimetry, to Fourier Optics and Optical Tweezers.

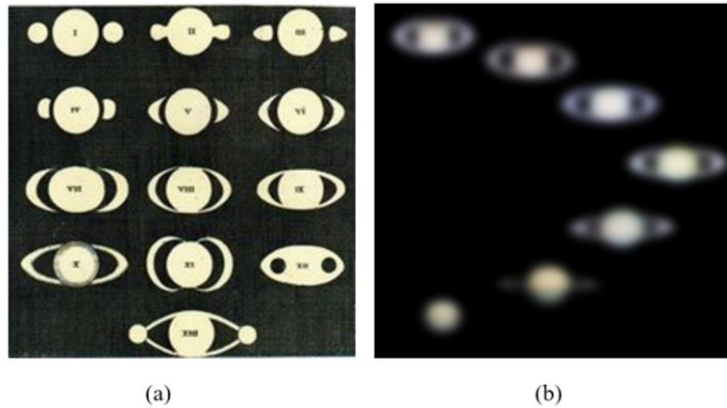


Fig. 1. Comparison of Galileo's Observations (a) and a Simulation (b).

## 2.2. Telescope Construction

After the preliminary design of the instrument, students go to the optical bench and must build their Galilean telescope. To test their instrument, a USAF test chart is placed at a certain distance far away from the optical bench, in order to measure the resolution of their telescope. After that, they are driven and encouraged to try different solutions to improve the resolution, such as the use of a field diaphragm or to compare the performance of a single lens with an achromatic doublet. Figure 2 shows different examples of the combinations that students can try in the laboratory. After the experience, they must write a report of the sessions, discussing their results and comparing it with Galileo's.

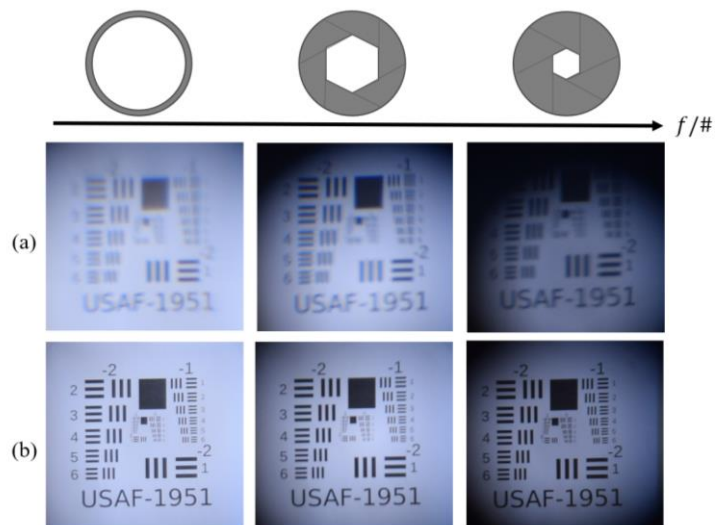


Fig. 2. Example of results obtained by students: row (a) by using a singlet as objective lens whereas row (b) is for the case of an achromatic highly corrected one. Every column corresponds to a different size of the diaphragm.

## 3. References

- [1] Albert Van Helden, "Saturn and His Anses", *Journal for the History of Astronomy*, **5** (2), 105-121 (1974).
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- [3] <https://photonics.masters.upc.edu/en>
- [4] <http://www.ub.edu/javaoptics/index-en.html>
- [5] Vincenzo Greco, Giuseppe Molesini and Franco Quercioli, "Optical tests of Galileo's lenses", *Nature*, **358**, 101 (1992).