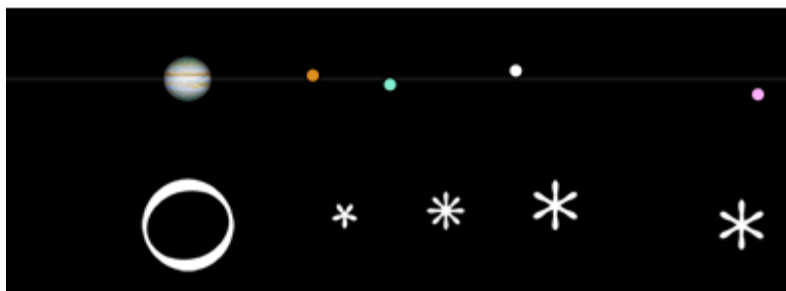


# Jupiter's moons



# Metadata

## General information

Title: Jupiter's moons

Short description: In this activity students will learn about the discovery of the 4 largest moons of Jupiter made by Galileo. Using innovative digital tools, they will follow the footsteps of the great scientist in establishing the scientific method for observing the sky.

Keywords: Jupiter, moon, discovery, Galileo, Heliocentric model

## Educational Context

Age: 14-16

Prerequisite: Periodic motion, velocity

Duration: 2 school hours

## Educational objectives

### Cognitive

Students will understand the method Galileo used to study the moons of Jupiter.

### Affective

Students are called to use a simulation with several parameters that they must organize in order to draw their conclusions.

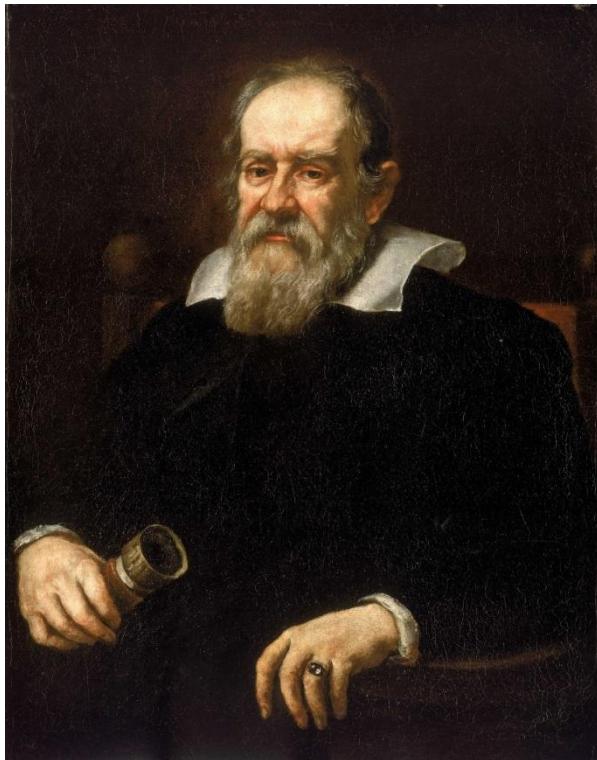
### Phycomotor

Students collaborate with each other to produce their results, following the instructions of their teacher and the spreadsheet. They present their results and discuss them with the rest of the classroom.

# Orienting & Asking Questions

Orienting: Provide Contact with the content and/or provoke curiosity

Who was Galileo and why was his contribution to science so important?



Galileo was born on February 15, 1564 in Pisa, Italy. His father sent him to the University of Pisa to become a doctor, but Galileo discovered his love for Physics and Mathematics. Against his father's will, he left Medicine and studied mathematics. He became a professor of mathematics at the University of Padua. In 1637 he got blind and on January 8, 1642 he died. He is called the father of Modern Science because of his groundbreaking discoveries in engineering, astronomy and experimental technique. Let's see what he discovered..

<https://www.youtube.com/watch?v=NMM8vxgvDiE>

## Define Goals and/or questions from current knowledge

### In Galileo's time..

#### Mathematics and Physics

In Galileo's time, calculus, that was first introduced by Newton and Leibniz had not yet been developed.

The empirical laws of Johannes Kepler that explain the motions of celestial bodies were still under development and were based on the observations of Tycho Brahe that were implemented without a telescope. The laws of Mechanics and Gravitation were written by Newton several decades later based on observations and experiments conducted by Galileo and other scientists.

The mathematical description of Nature was done using Geometry, Trigonometry and proportions. These tools were extremely valuable to Galileo for the discoveries he made. One of the many reasons Galileo went down in history was because he pioneered the use of mathematics as the "language" of Nature.

#### Experimental Technique

"Experimental physics is the way to primarily discover the truth about Nature, by measuring"

This quote summarizes the concept of the scientific method introduced by Galileo, that was based on experimental proof.

At the period in which the great scientist lived and worked, there were no instruments that we have come to take for granted, such as clocks, microscopes and telescopes.

Galileo worked tirelessly to improve instruments that had been created before him and to create new ones (such as [Galileo's clock](#), [the geometric and military compass](#), and many more that can be found [here](#).)



### Perception of the Universe

In Galileo's time people believed that the Earth is at the center of the universe, with the planets, the Moon and the Sun revolving around it. This belief took on theological dimensions, since it established man as the center of the world and gave prominence to the authority of the church.

Despite Aristarchus teaching almost two millennia before and the heliocentric system proposed by Copernicus around 1500 AD, the church persecuted those that supported the heliocentric model. The penalty could be even death (as an example you can see the life of Giordano Bruno who was condemned to death for his heretical ideas, which included his belief in the heliocentric model).

In composing the social and scientific context in which Galileo lived, one should take into account that Galileo was not the son of a rich family. The favor of the nobility of his time was important to Galileo. This way he could secure his livelihood and gain recognition for his work. Thus one can understand why some celestial features, like mountains and craters on the moon that were discovered by Galileo, were named after Italian nobles.

Finally, it should be taken into account that the new knowledge was a privilege of a few wealthy people. Most scientific documents were written in Latin, a language that only these few people knew how to read. One of the contributions that Galileo made was disseminating scientific knowledge by translating his works into the Italian language of the time so that everyone could read them.

Based on these, we can understand the importance of Galileo's discoveries which, under difficult circumstances, laid the foundations for Modern Science in the form we still know and use.

### Guidelines for the teacher

This activity can be done in two school hours without the use of a telescope. The only requirement is computers with an internet connection.

However, the process can be enriched with the use of a telescope (if the relevant equipment is available) and accompanied by celestial observations of Jupiter and its satellites for several days.

In addition, this activity could lead to another activity where students measure the speed of light by following the steps of Ole Roemer (as described here for example:

<http://portal.discoverthecosmos.eu/el/node/196168> - free Discover the Cosmos Portal registration required). In addition, this activity can be followed by a discussion or another activity regarding the measurement of longitude as suggested by Galileo (<http://galileo.rice.edu/sci/observations/longitude.html>).

Finally, this activity can be combined with the creation of a theatrical representation referring to the work of Galileo. For information on how to support such a project, visit the CREATIONS project's Learning Science Through Theater community:

<http://portal.opendiscoveryspace.eu/community/learning-science-through-theater-841279>

# Hypothesis Generation and Design

## Generation of Hypotheses or Preliminary Explanations

Suppose you live in the age when it is firmly believed that the Earth is the center of the universe. The common truth is that all heavenly bodies revolve around the earth. Suddenly, like Galileo, you learn about the existence of the telescope. Your experimental skills and curiosity make you build an improved version of it.

Then you point the telescope at the sky.

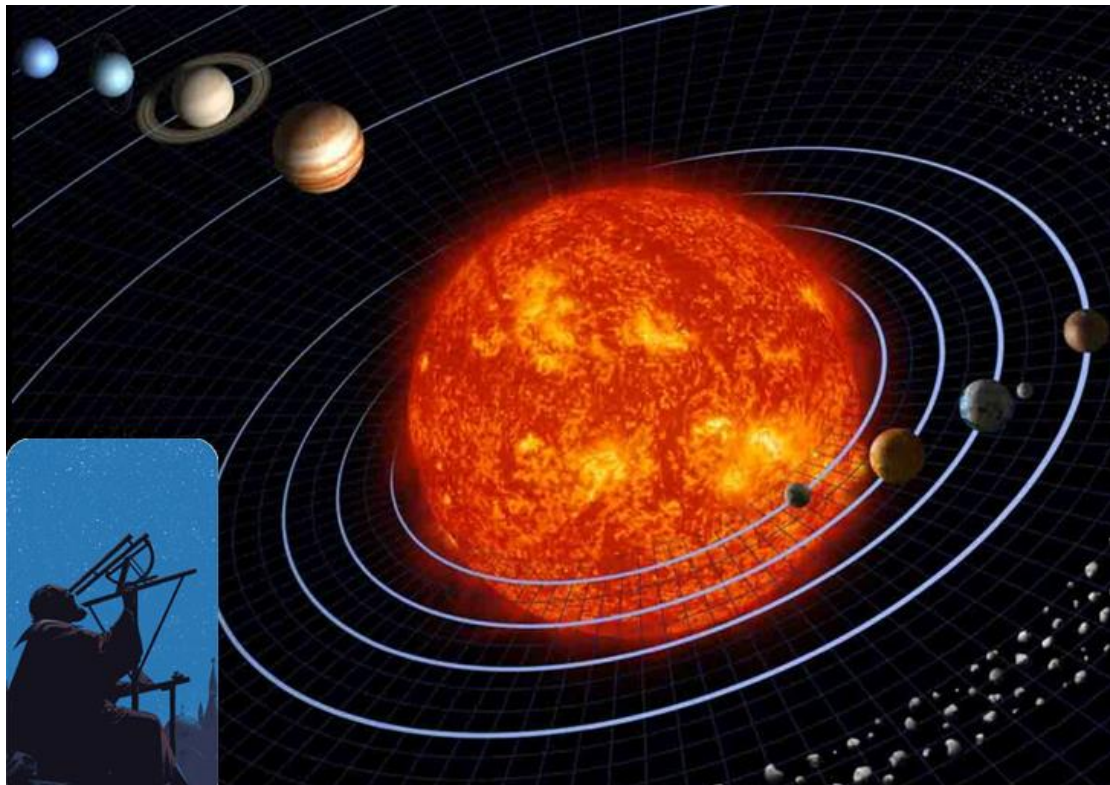


Image: Pointing the telescope at the sky

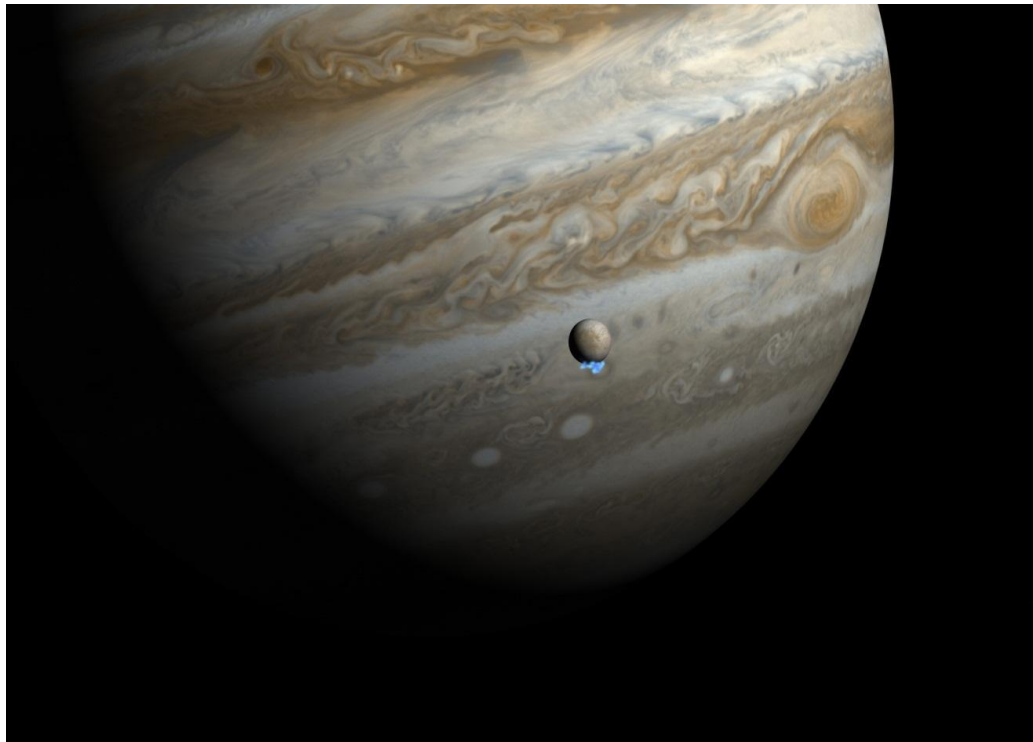
By opening the following link from the Galileo Museum in Florence

you can learn more about Galileo's use of the telescope for celestial observations and his great discoveries.



<http://brunelleschi.imss.fi.it/esplora/cannocchiale/index.html>

### Design/Model



Living in that era you assume that if Earth is at the center of the universe, everything revolves around it. But is it that true?

Galileo turned his telescope to the sky and began to meticulously observe the heavenly bodies.



One of the first objects that caught his attention was Jupiter which is visible as a bright celestial body by the naked eye.

Observing the giant gaseous Planet of the Solar System, Galileo noticed 4 bright celestial bodies that appeared to accompany Jupiter as it moved across the sky.

Studying their motion, he found that these celestial bodies revolve around Jupiter just like the moon revolves around Earth.

This observation was one of the main arguments that lead to the rejection of the geocentric model and the establishment of the heliocentric model.

Watch the video and discuss with each other how important you think this discovery is:

<https://www.youtube.com/watch?v=jGDYy5lULBc>

In this activity, you will use a digital simulation to study the motion of Jupiter's moons and predict its characteristics.

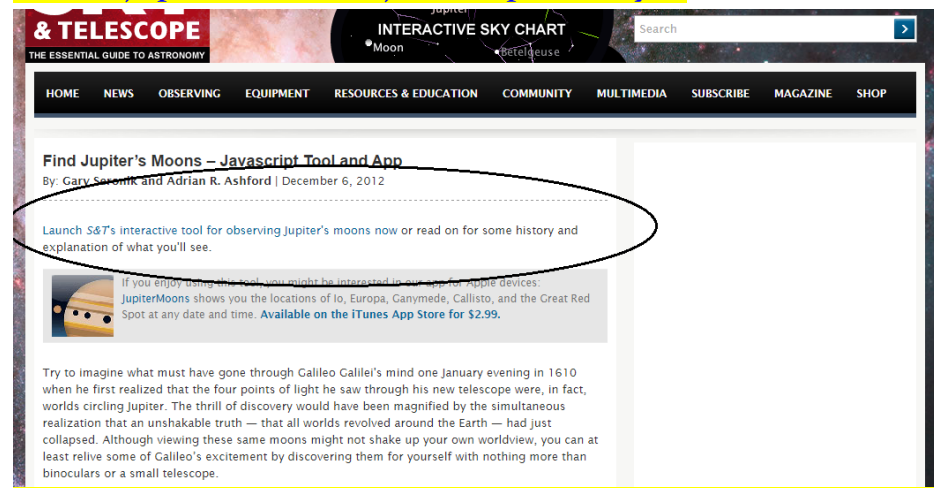
# Planning and Investigation

## Plan Investigation

### Guidelines for the teacher

This activity does not require the use of a telescope, but only the use of a digital software provided here:

<http://www.skyandtelescope.com/observing/celestial-objects-to-watch/jupiters-moons-javascript-utility/#>



To be able to enter the website, a free registration is required.

By selecting the link a new window opens in your browser.

Here the 4 largest moons of Jupiter are represented with the following letters: C (Callisto), I (Io), G (Ganymedes) and E (Europa).

This simulation gives a realistic picture of the relative distances and sizes of the satellites for the date and time chosen by the user. You can observe the relative positions of the satellites to Jupiter for various dates by changing the time step by step: (+/- 10 minutes, +/- 1 hour, +/- 1 day).

To measure the relative distances of the moons, you will need a ruler.

In this activity, we use a digital ruler that you can download from here: <http://www.pixelruler.de/e/download.htm>

The distances that the students will be asked to measure are expressed as multiples of Jupiter's radius, following the path taken by Galileo in his own measurements.

Before students start the activity, the digital ruler should be installed on their computers and the simulation window should be

already open. This process requires approximately 15 minutes of pre-work time.

If you have, for example, 12 PCs available to which the students will be divided, 3 PCs will deal with the study of each satellite separately. At the end of the investigation, students that study the same satellite will calculate the average value of their results and discuss their conclusions for each satellite.

Open the link and familiarize yourself with the simulation controls with the help of your teacher.

<http://www.skyandtelescope.com/observing/celestial-objects-to-watch/jupiters-moons-javascript-utility/#>

Download the "digital ruler" from the following link:

<http://www.pixelruler.de/e/download.htm>

## Perform Investigation

During this activity, you will study the motion of Jupiter's 4 largest moons using a digital simulation.

- Split into 4 large groups. Each group will study one of the 4 moons of Jupiter: C (Callisto), I (Io), G (Ganymedes) and E (Europa).
- Open the simulation: The window that will appear is the following.

**SKY & TELESCOPE** Jupiter's Moons

This illustration shows the positions of Jupiter's four Galilean satellites — Io, Europa, Ganymede, and Callisto — in orbit about the planet for any date and time from January 1, 1900, to December 31, 2100.

Direct view

Please choose your view:  Direct view (Erect-image system)  Inverted view (Newtonian / Dobsonian)  Mirror reversed (SCT/Mak/refractor+diagonal)

Date: 03/02/2017 Time: 18:01 UT Time-zone offset from UT in hours (from your Web browser): 2

Reset to current date & time Recalculate using entered date & time - 1 day - 1 hour - 10 min + 10 min + 1 hour + 1 day

Basic data about Jupiter for telescopic observers:

Magnitude: -2.3 Angular size (arcsec): 42.3 Distance (a.u.): 4.66 System II longitude (°): 288

Table of Jovian satellite phenomena:

Display satellite events on date above

Depending on your computer's speed, the table may take a few seconds to recalculate.

Monday, February 27, 2017

08:50 UT, Ganymede enters eclipse by Jupiter's shadow.  
11:20 UT, Ganymede exits eclipse by Jupiter's shadow.  
12:34 UT, Ganymede enters occultation behind Jupiter.  
14:26 UT, Ganymede exits occultation behind Jupiter.  
15:12 UT, Io enters eclipse by Jupiter's shadow.

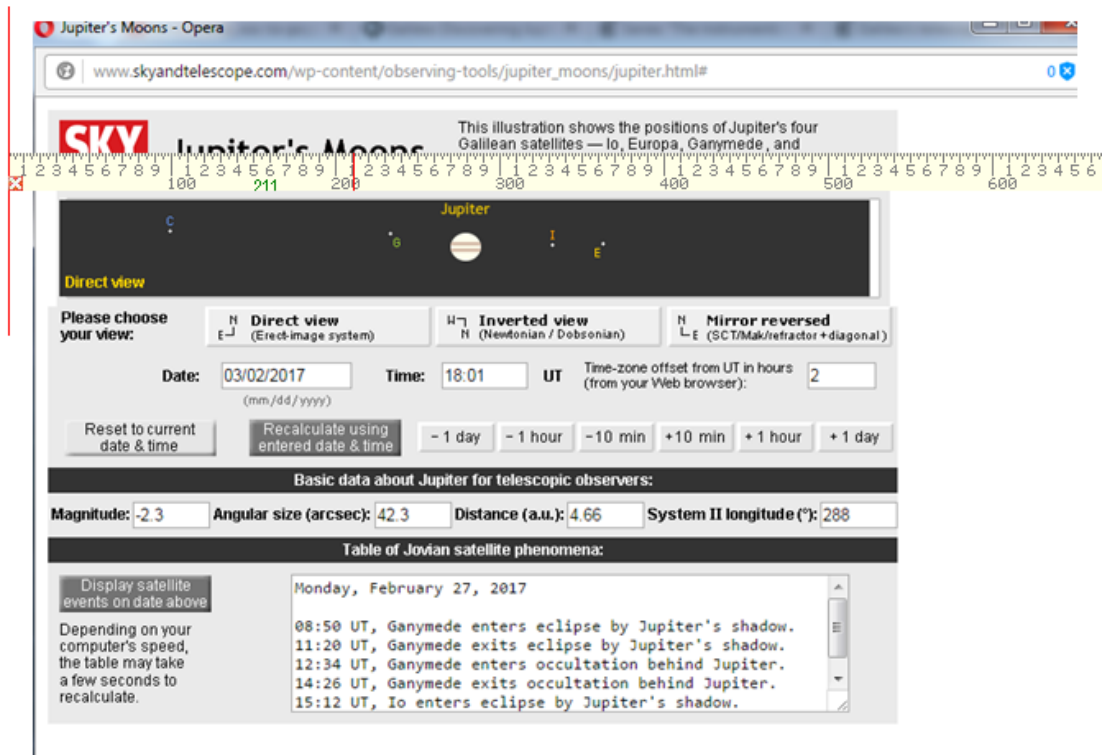
- Keeping the Magnitude, Angular Size, Distance and System longitude constant, familiarize yourself with the rest of the options.

Try changing the date.

You can observe the positions of the satellites concerning Jupiter for various dates and times by changing the time step by step:

+/- 10 minutes, +/- 1 hour, +/- 1 day.

- Launch the digital ruler software on your computer. Another option is to use your own ruler by adjusting it to your screen.



- Measure the radius of the planet Jupiter using the digital ruler. Record its value in your notebook.
- Study the motion of the satellite you chose to study. What kind of motion do you observe? Write the name of the satellite and your opinion of its motion in your notebook.
- Experiment with the time options and choose the time step that works for you. By selecting +10min for example you will see the position of the satellites 10 minutes after the start time.
- Record the time step you chose in your notebook
- Investigate whether the movement of your satellite is periodic. If so, measure the period and record it in your notebook. Note how you measured the period.
- Measure your satellite's distance from Jupiter as a multiple of Jupiter's radius.

-Galileo did not know in advance the value of Jupiter's radius. However, by expressing the distances of the satellites as multiples of the planet's radius, he was able to calculate quantitative results for their motion.

-Find the maximum distance of your satellite from Jupiter as a function of Jupiter's radius and record it in your notebook.

What do you think is the physical significance of this distance?

# Analysis & Interpretation

## Analysis and interpretation : Gather result from data

-Discuss with the rest of your classmates who studied the same satellite. After comparing your results and methods, find the average value of your measurements for the maximum distance, R of the satellite from Jupiter and for the period of its motion T.

Note your units of measurement for both physical quantities.

-The radius of Jupiter is  $R_0 = 69.991$  km. Find the maximum distance of your satellite from Jupiter in km.

-If the motion of the satellites around Jupiter is circular, then the maximum distance from it, is equal to the radius of the orbit.

-If the motion of the satellites is circular, then their rotation speed is given by the formula  $u = 2\pi R/T$ . Calculate the speed and record its value in km/hr.

-Compare the period T and radius R you measured and calculated with their actual values:

[http://www.pa.msu.edu/people/horvatin/Astronomy\\_Facts/planet\\_pages/Jupiters\\_moons.htm](http://www.pa.msu.edu/people/horvatin/Astronomy_Facts/planet_pages/Jupiters_moons.htm).

- Form the ratio  $T^2/R^3$  and calculate its value for your satellite.

- Transfer the table below to your notebook and complete it.

Satellite's name	Radius: R(km)	Period: T(hr)	Velocity: u (km/hr)	$T^2/R^3$ (hr <sup>2</sup> /km <sup>3</sup> )



# Conclusion & Evaluation

## Conclude and communicate result/explanation

Each group will present its final table of results to the rest of the classroom and briefly discuss the method they followed and the conclusions they drew.

For each Jupiter moon note its orbital speed and the radius of its orbit. Discuss how does velocity depend from the respective radius?

Try to explain the phenomenon with scientific arguments.

Compare the  $T_2/R_3$  ratio values for each satellite.

Is it the same or different? What would you expect?

## Guidelines for the teacher

If the students have been taught circular motion and the law of universal gravitation, the educator can show them the following video or demonstrate Kepler's third law on the board ( $T_2/R_3 = \text{constant}$ ).

<https://www.youtube.com/watch?v=FjAdqr1Qbac&t=244s>

If not, the teacher can simply point out to the students that this law applies universally and challenge them to explore if this is true by forming the  $T_2/R_3$  ratio for the rotation of the planets around the Sun.

The relation of velocity and radius can be found with the same reasoning (equating the centripetal force to Jupiter's gravitational pull and expressing the velocity as a function that depends on the radius).

## Evaluation/Reflection

Visit the following link from the Galileo Museum and choose "The Satellites of Jupiter".

<http://brunelleschi.imss.fi.it/esplora/cannocchiale/dswmedia/simula/esimula1.html>



That will lead you to the following window that shows three instruments built from Galileo in order to study Jupiter.

**History** Galileo's telescope ● *The satellites of Jupiter*

**Explore**

**Simulation**  
The astronomical discoveries  
The performance of the telescope  
Test

**Resources**

**Home**

On the night of January 7, 1609, while observing Jupiter with his telescope, Galileo (1564-1642) noticed in the vicinity of the planet three "small but very bright" stars. On the next evening he found the little stars occupying a different position in respect to Jupiter, as if the planet have moved eastward, but since in those days, according to the astronomical tables, the planet should have been retrograde and thus moving to the west, he decided to observe the phenomenon systematically. On the 10th, Galileo understood that the positions observed could be explained only by admitting that the three little stars were moving around the planet. Then on the night of the 13th he discovered a fourth celestial body orbiting around Jupiter. The discovery constituted an argument in favour of the Copernican system, or rather, it eliminated what had by some been considered an anomaly, a jarring note in the elegant heliocentric architecture. If in fact, for Copernicus (1473-1543), the Sun was the new centre around which the planets moved, then why should the Earth alone have a satellite, the Moon, orbiting around it? The satellites of Jupiter demonstrated, on the contrary, that other planets too can have celestial bodies orbiting around them and thus be, in turn, the centre of astral motions.

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**Micrometer** **Jovilabe** **Celatone**

The astronomical discoveries

Watch the related videos and comment if Galileo was right to support that the observation of Jupiter's moons is a milestone in the establishment of the heliocentric model.

### *Consider other explanations*

Watch the following video to learn some interesting facts about Jupiter:

<https://www.youtube.com/watch?v=BZnDB5VjiT8>

Late Activity:

If you have a telescope or binoculars at your disposal, you can organize an observation of Jupiter and compare the position of the satellites you will see with the image that the simulation gives you.

### **Teacher guidelines**

Other activities concerning Jupiter moons (free registration might be required):

- <http://portal.discoverthecosmos.eu/en/search/repository/education/results/Jupiter>
- <http://portal.discoverthecosmos.eu/files/uploads/objects/OrbitsOfJupitersMoons.pdf>
- <http://portal.discoverthecosmos.eu/en/node/192359>