SCIENTIFIC CASE:

Gravitation

Team members

Writer: ____

Equipment manager: ___________________________________

Reader: ____

Spokesperson: ____

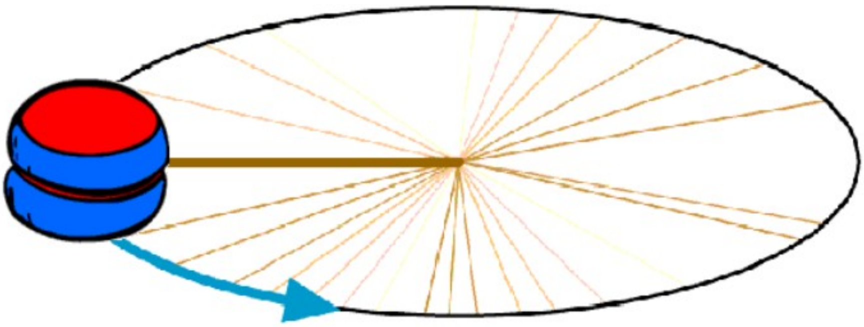
Maths: ____

Context

During most of our History, our position in the Universe was the center, and everything else revolved around us: the Sun, the Moon, the planets, the sphere of fixed stars… That was the *Ptolemaic model*. Everything changed when the first telescopes appeared and they were aimed at the skies.

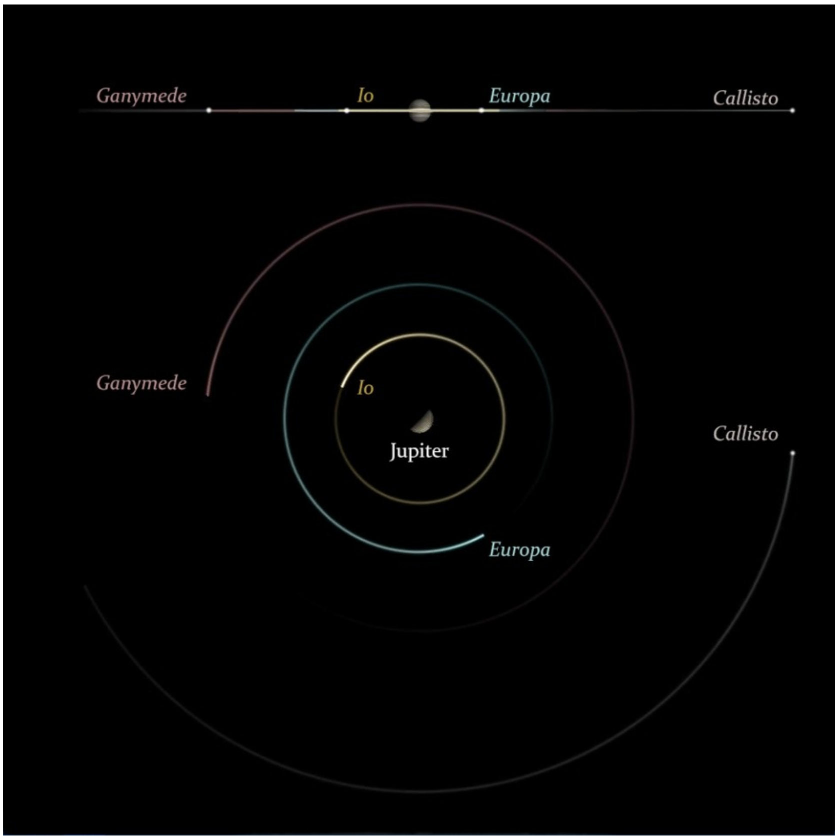
Galileo Galilei (1564 – 1642) was the first one to notice that several brilliant dots were periodically changing positions around planet Jupiter. It was the year 1610. Galileo's observations contributed drastically to the first great scientific revolution: the fall of the *Ptolemaic model* and the rise of the new helicentric model, in which the Sun turned out to be at the center of the cosmos.

If we spin a yo-yo horizontally, we will see the following trajectory:



That is to say, the yo-yo performs a uniform circular motion (UCM)[1].

In a similar way, we can study the motion of the planets around the Sun, or the motion of any moon around its planet[2].



Jupiter's moons visualization. Credit: CESAR

1 To study in depth, a practical exercise about kinematics is proposed (to be performed at the classroom). Thus, you can check if the theory adjust to your observations. The proposal will be delivered at the Science Experience.

2 Even though the planetary orbits are elliptical, the circular motion is a good approximation for the present case.

More educational resources:

CESAR: http://www.cosmos.esa.int/web/cesar
ESA education: http://sci.esa.int/education/

Scientific case: Calculating the mass of Jupiter

The four brilliant dots discovered by Galileo Galilei in 1610, which were dancing around Jupiter, are known as galileans (or jovians) moons or satellites, and they are: **Io, Europa, Ganymede** and **Callisto**. These satellites are the biggest among Jupiter moons and are visible from Earth through binoculars.

Using observational data from telescope, our aim is to **find out the mass of each one of these moons**.

Research equipment

You have access to the following:

- Colour pencils, paper, rubber, ruler.
- First satellite observations by Galileo Galilei.
- Useful data.

Part 1. Orbital period of one of Jupiter's moon

During several days, Galileo observed and draw Jupiter's moons changing positions on the sky. His observations are shown in the following images (asterics represent the moons), together with a simulation of how the moons were actually seen. These will help you in your calculations:

Next page: A*daptation from Sidereus nuncius. Galileo Galilei. Pictures courtesy of Ernie Wright*[3]

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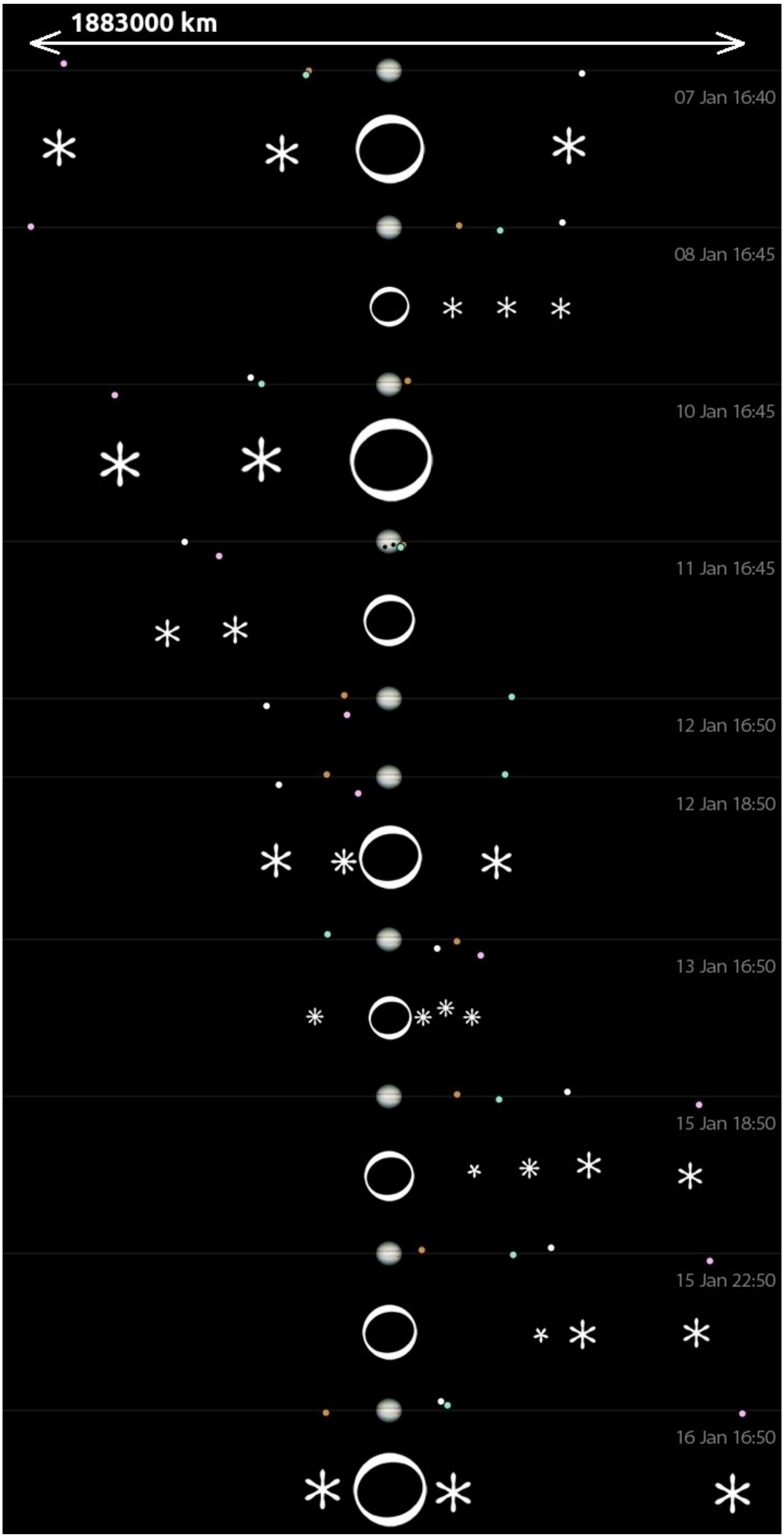
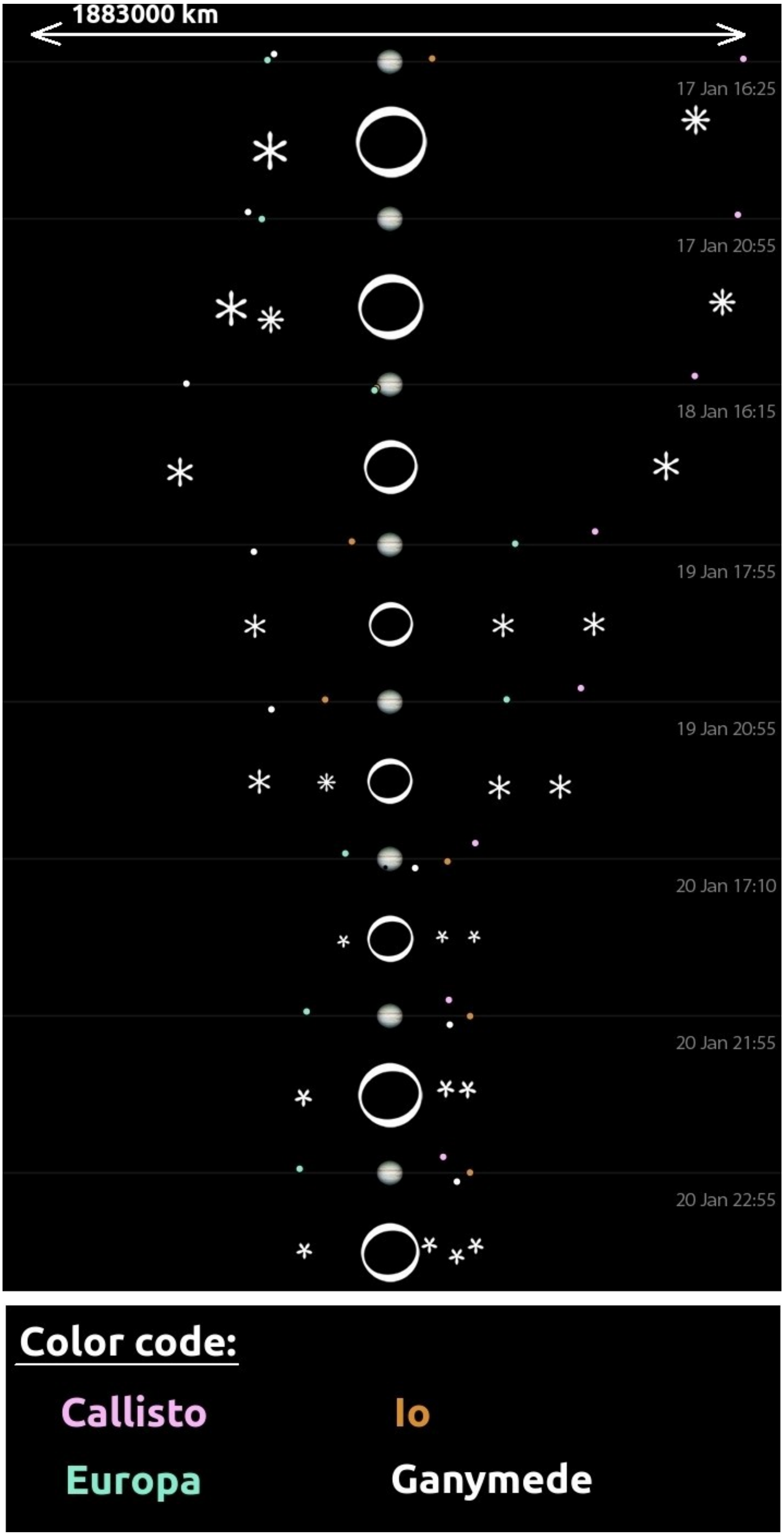
[3] http://www.etwright.org/astro/sidnunj.html


1883000 km
07 Jan 16:40
08 Jan 16:45
10 Jan 16:45
11 Jan 16:45
12 Jan 16:50
12 Jan 18:50
13 Jan 16:50
15 Jan 18:50
15 Jan 22:50
16 Jan 16:50


1883000 km
17 Jan 16:25
17 Jan 20:55
18 Jan 16:15
19 Jan 17:55
19 Jan 20:55
20 Jan 17:10
20 Jan 21:55
20 Jan 22:55
Color code:
Callisto
Io
Europa
Ganymede

Choose **one** moon and calculate the orbital period

Results: **- Express time in International System units (seconds) -**

Part 2. Velocity of the satellite

Since the motion of the satellites is aproximately described by uniform circular motion (UCM), angular velocity can be obtained through the formula:

$$\omega = \frac{2\pi}{T}$$

being T the orbital period. Thus, the velocity of the satellite will be:

$$v = \omega R$$

being R the radius of the orbit. The real distance of the satellite can be obtained by:

a) Observing in the picture the diameter of the orbit of the satellite which is farther away from Jupiter[4].

b) Searching the day in which your chosen moon is farther away from Jupiter.

c) Connecting the diameter with the radius of your moon (using the ruler). The radius of the orbit can be calculated with a simple proporcionality rule.

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[4] Even though the data can be read in the previous image, *case 4* (see later) shows further clues to measure that distance..

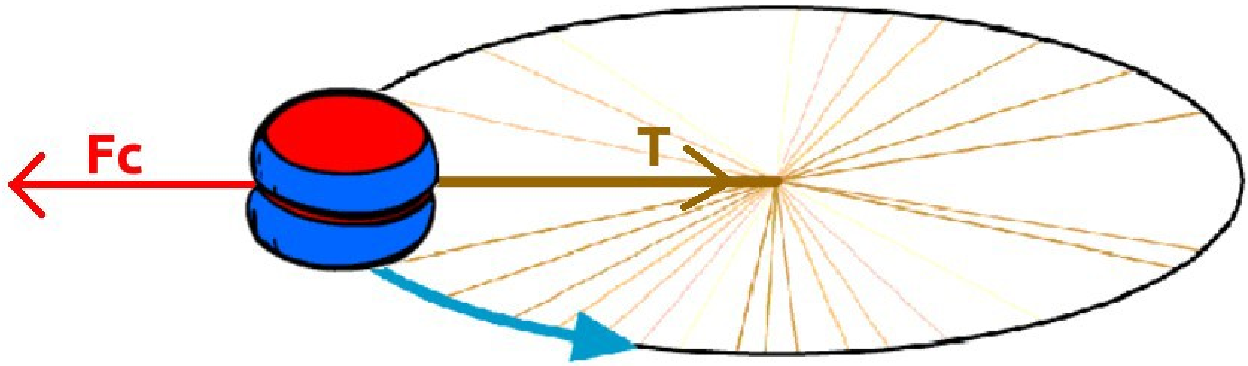
Find out the velocity of your satellite

Results:

- Express time in International System of Units (seconds) -

Part 2. Velocity of the satellite

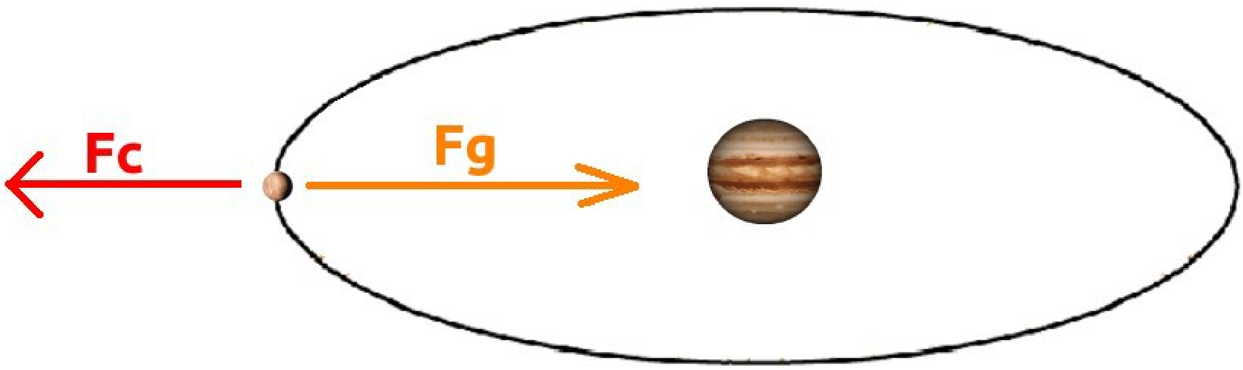
Back to the yo-yo excercise:



Observe that the force or tension that the string suffers is equal to the centrifugal force responsible for the turning around:

$$T = F_{centrífuga} \quad \rightarrow \quad F_{centrífuga} = \frac{mv^2}{R}$$

In a similar way, we can imagine the motion of a satellite around its planet:



The gravitational force between planet and moon is equal to the centrifugal force that the moon suffers!

$$F_{centrífuga} = \frac{M_{Luna} v_{Luna}^2}{R_{Jupiter-Luna}} \quad ; \quad F_{gravitatoria} = G \frac{M_{Jupiter} M_{Luna}}{R_{Jupiter-Luna}^2} \quad \rightarrow \quad F_{centrífuga} = F_{gravitatoria}$$

Were, $G = 6.67384 \times 10^{-11} \, \frac{\mathrm{N} \cdot \mathrm{m}^2}{\mathrm{kg}^2}$.

If we solve correctly, we can find Jupiter's mass from the obtained data.

Find Jupiter's mass

Results:

- Express in International System of Units -

Conclusions and new questions

Why can we obtain Jupiter's mass from any of its moons?

Are the formulas you used valid for any mass?

Is the attraction that we feel to the Earth the same as the one that exists between other stars and planets?

To find out more: What is the nature of the relationship between gravity and the origin of tides?

Case 2: Practical problem to solve in the classroom

<<***Jupiter Icy Moons Explorer*** or **JUICE** is a special mission which has been proposed by European Space Agency (ESA) to develop a space probe to study Jupiter and its satellites, specifically Ganimede and Europa.>>[3]

Write a justified proposal about the radius of the orbit, the velocity and the period that JUICE mission could have to orbit around one of those moons. Check any sources that you need to obtain the data. The procedure should be to reasonably decide one of the three variables (radius, velocity or period), and then to calculate the other two.

Further research: A deeper study can be performed by changing to possible elliptical orbits. You can check more information on satellite orbits here: http://www.esa.int/Our_Activities/Space_Science/Types_of_orbit .

3 Source: https://es.wikipedia.org/wiki/JUICE

Case 3: Practical kinematic problem to carry on at the classroom

The exercise is encouraged to perform in groups of four.

1. Measure the mass of a small object, for instance, a yo-yo.
2. Tie a rope around it. The rope should have a known lenght, like 0,5m.
3. Turn around horizontally with an easy to control period, i.e. T = 1s.

Find out:

a) Normal acceleration, $\boldsymbol{a_n}$.

b) Tension of the rope.

c) Distance up to where the object falls.

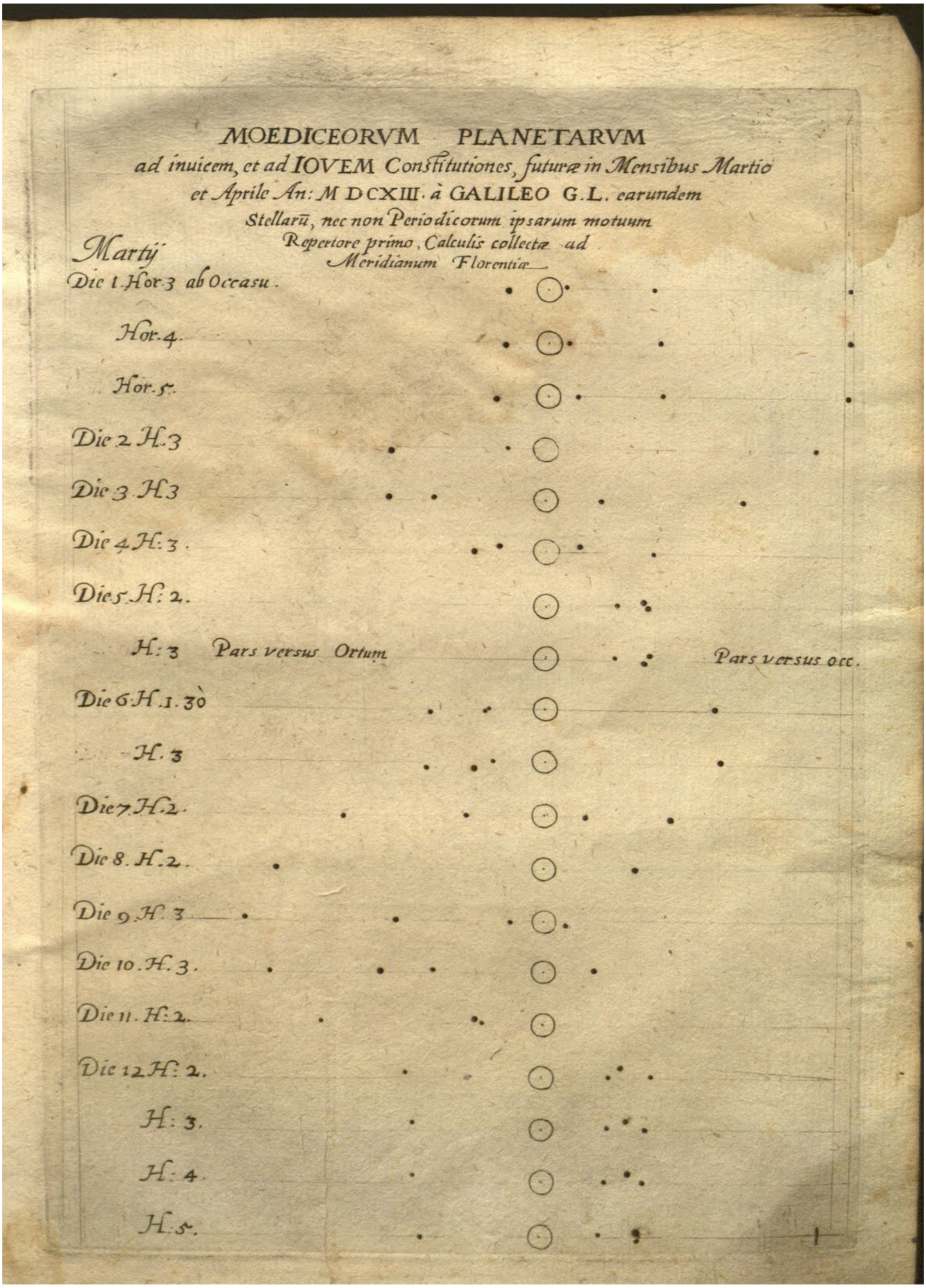
Compare those results with theoretical data.

Research equipment

- Chronometer.
- Meter rule.
- Paper and pen.
- Calculator.

Research equipment

Galileo's first satellite observations



Useful data

Jupiter's diameter = 139,822 km

Jupiter's mass (optional) = $1.898 \cdot 10^{27}$ kg

Galilean satellites (by distance to Jupiter): Io, Europa, Ganymede y Callisto.

Consider that we're seeing the moons from the side.