UNIT 5:

LAWS OF PLANETARY MOTION

Author:	Oswaldo González
Content revision and updating:	Nayra Rodríguez, Alejandra Goded
Scientific Advisor:	Alfred Rosenberg
Artwork:	Inés Bonet

ACTIVITY 2

GALILEAN SATELLITES, A MINIATURE SOLAR SYSTEM

OBJECTIVES

In this activity we will go a little further in using the laws of motion to calculate the orbital period of one of Jupiter's satellites and the mass of the planet. You will have to measure the radius of the orbit of some of the satellites from astronomical images and use these data to make calculations using the laws of planetary motion.

EQUIPMENT AND MATERIAL

For the realization of this practice we will use two images of the planet Jupiter and its satellites, selected among more than 100 images obtained with the Liverpool Telescope of the Roque de los Muchachos Observatory, that you can find in the folder *JUPITER SATELLITES* at our website **www.iac.es/peter**. For processing them, we will use the *PeterSoft* program that we can also download from the previous website and install on our computer. The tools we will use the most will be the distance and brightness measurement tools.

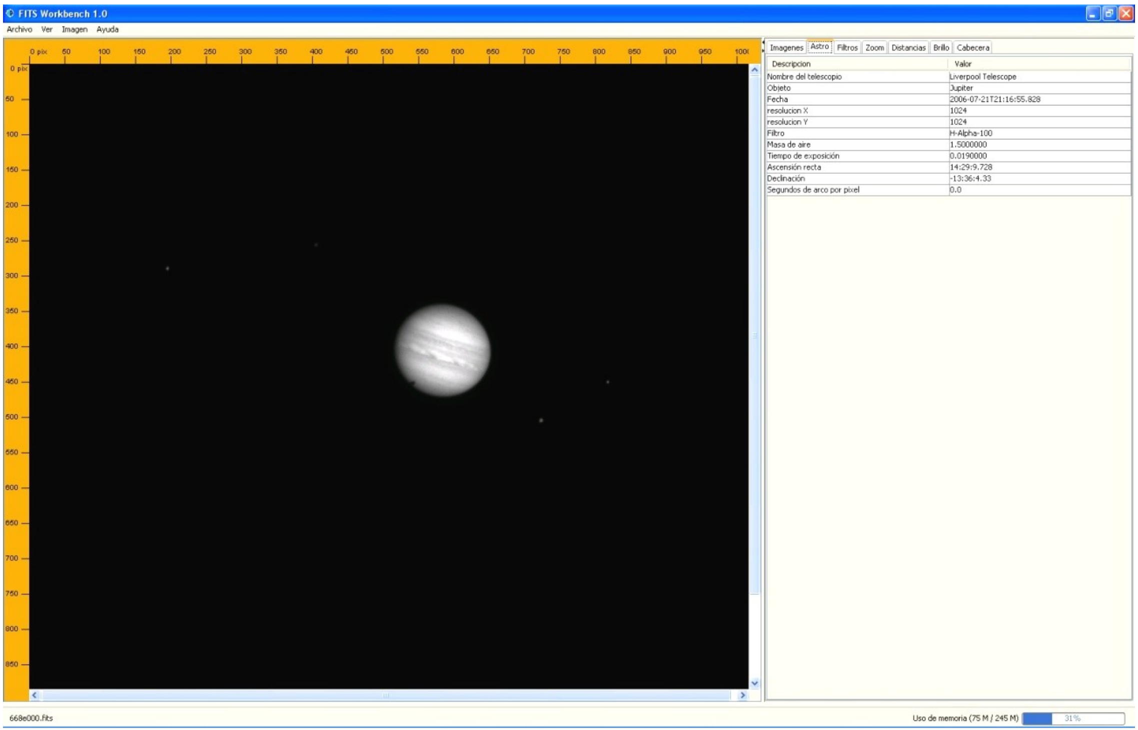
METHODOLOGY

The first step is to identify the four Galilean satellites orbiting Jupiter. We will measure the radius of the orbit of the satellite Io and calculate the mass of Jupiter. Then, using the mass obtained, we will measure the radius of Europa's orbit and calculate its orbital period.

PROCEDURE

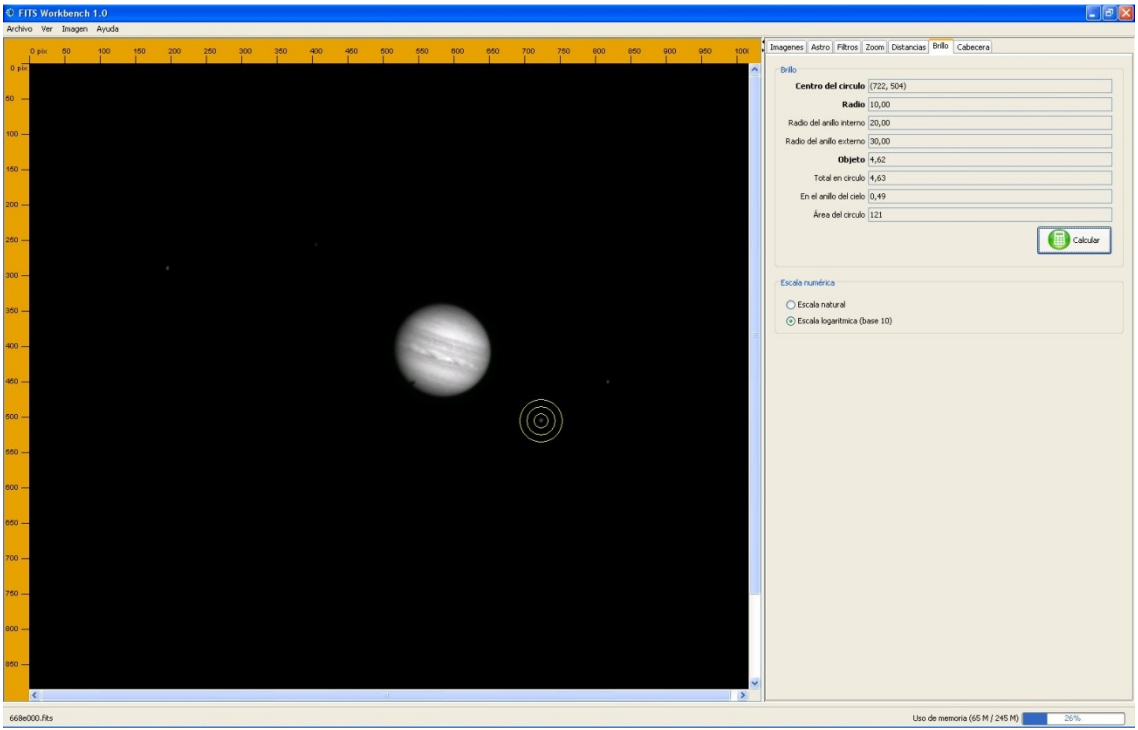
The first thing we need to do is to download and unzip the file *U5_imagenes_satelitesjupiter.zip* (contained in JUPITER SATELLITES) where the images we are going to study are located. Then we will run the image analysis program *PeterSoft* and open the file *668e000.hfit*.

In addition to Jupiter, four small dots appear in this image, two on each side of the planet. If you can't see them, you can use the *Filters* tool on the *Image* menu, select *Edge detection* and increase the value to detect fainter parts of the image. These are the four satellites that Galileo Galilei discovered in 1610, and they are called Galilean satellites. Their names in order of distance from Jupiter are: Io, Europa, Ganymede and Callisto.



The first step is to find out which point corresponds to which satellite. Since there is no sign to tell us the name of each satellite, we will use their brightness to identify them. Jupiter's four satellites are presented with different brightness, either because of their size or because of the amount of light they reflect from the Sun. In order from brightest to faintest we have: Ganymede, Io, Europa and Callisto. This order does not necessarily have to coincide with the distance to the planet. Now we will use the *BRIGHT* tool and we will obtain the brightness of each of them. We will have to use a circle with the same diameter for all of them.

We are not going to calculate their magnitude but only compare their brightness. Our aim is to find out which of them is Io, because on the date and time when the image was taken, it was located in a part of its orbit where, seen from the Earth, it was as far away from the planet as it can be, so we could measure the radius of its orbit.



How to use the BRIGHT tool:

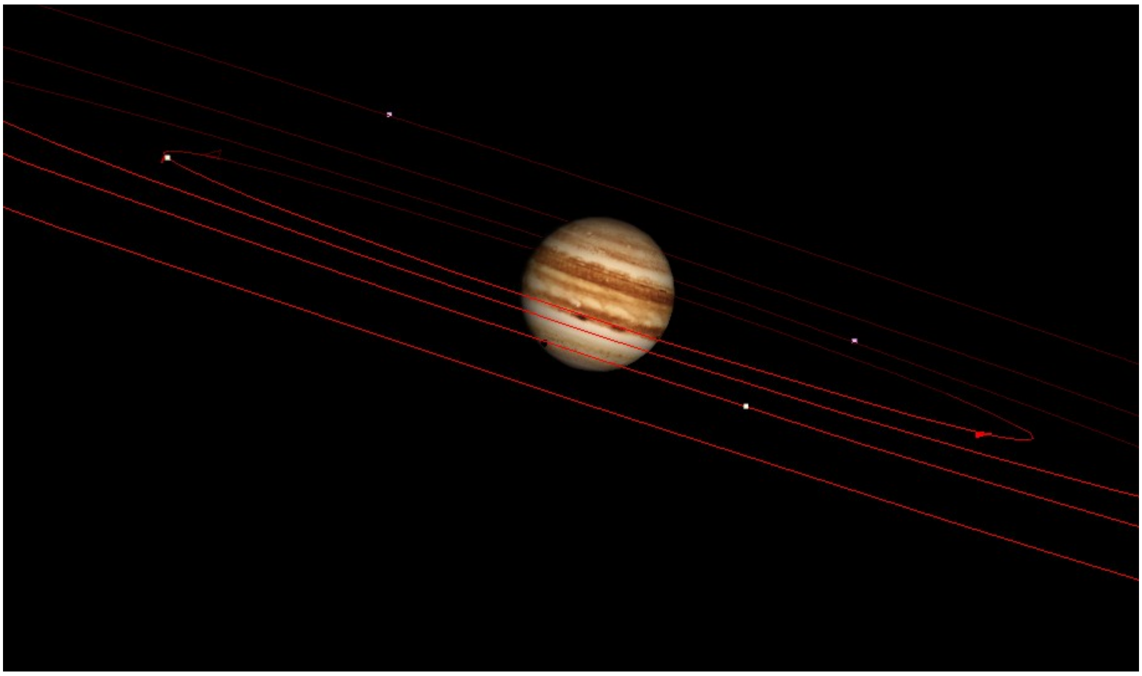
1. Select the tab *Bright* from the menu on the right.
2. Click on the centre of the star you want to study.
3. In the menu on the right, type a number for the aperture radius (a good aperture radius will be one that encompasses all the brightness of the object without introducing too much brightness from the background)
4. Three yellow circles will appear: make sure that the smallest of these circles covers the whole object. The tool will get the signal within this area.
5. A number will appear in the *Object* field. It indicates the signal perceived by the detector in that area, which is proportional to the amount of light received. The higher the number, the brighter the object.

The other two unused circles form a ring around the object. This ring is used by the tool to obtain the brightness of the sky in order to sustract its contribution from the *object* measurement.

Once we have identified Io (remember, the second brightest), we will use the distance tool to calculate the distance between this satellite and the centre of Jupiter. To determine the approximate centre of Jupiter, we will make two measurements: one from Io to the nearest edge of Jupiter; and the second to the farthest edge. Once we have obtained the two measurements, we will calculate the average, that is, we sum the two measurements and divide the result by two. Now we have our measure of the distance from Io to the centre of Jupiter and, consequently, the radius of its orbit.

To give you an idea of what the orbits of the satellites around Jupiter look like, you can see them represented in the following image as lines describing the path of each of the satellites from our point of view.

Now we have the radius of Io's orbit in pixels, we simply need to convert it to *km*, knowing that for the distance the Earth was from Jupiter the day the image was taken, one pixel equals 1036 *km*. Do the calculation and get your measurement for the radius of Io's orbit.



For our activity, we only have one piece of information: the orbital period of Io, which is 1.769 days. With this, we will have to calculate the mass of Jupiter, just as we did in the previous activity with the Sun. The first thing to do is to convert all our data into the International System, i.e. the distance of the orbit radius to metres and the orbital period to seconds.

Then we will apply the same formula as in the previous activity:

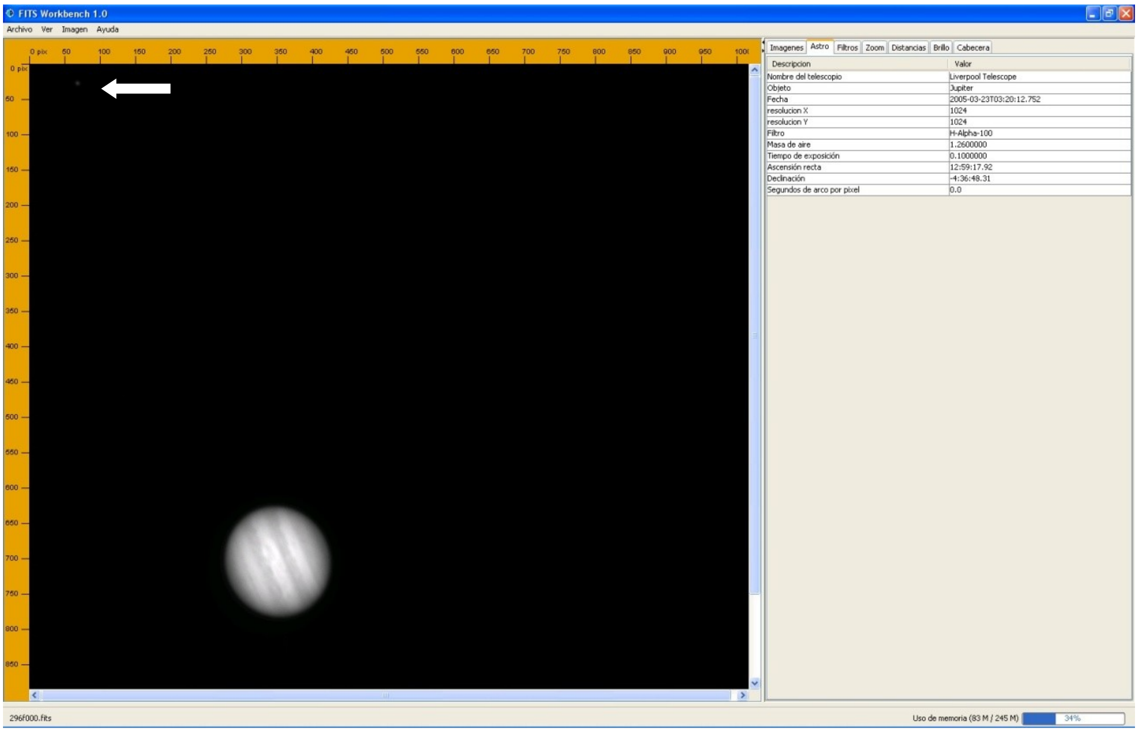
$$M=\frac{4\pi^2}{G}\frac{a^3}{P^2}$$

Substituting the values obtained in the measurement and those of the orbital period in seconds, we obtain the mass of Jupiter in kilograms. How much do you get? How many times heavier is the Sun than the planet Jupiter?

2nd part

We will now try to calculate the orbital period of Europa, using the mass of Jupiter and our measurement of the radius of its orbit. To do this, we must choose an image in which Europa is as far away from Jupiter as possible (when seen from the Earth).

To do this, load the image *296f000.hfit* in the program and find Europa's position in the upper left corner of the image. Measure its distance to the centre of Jupiter in the same way as we did previously with Io, i.e. we will make two measurements, one from Europa to the nearest edge of Jupiter and one to the furthest edge. We will average the two measurements (adding them together and dividing by two) and obtain the distance in pixels to the centre of the planet.



This distance must be multiplied by a conversion factor which, for the date the image was taken and the distance of the Earth from Jupiter, is: 1 *pixel* = 904.6 *km*.

We are now able to calculate Europa's orbital period, with the radius of its orbit and the mass of the body it orbits, i.e. the mass of Jupiter that we have already calculated. Substituting it into our formula, we obtain this period in seconds (remember to convert the radius of Europa's orbit to metres).

$$M = \frac{4\pi^2}{G}\frac{a^3}{P^2}$$

clearing ***P***

$$P = \sqrt{\frac{4\pi^2}{G}\frac{a^3}{M}}$$

How long does it take Europa to go around Jupiter, and is this orbital period longer or shorter than that of Io?

For further information, visit our website: **www.iac.es/peter**

Contact: **Nayra Rodríguez Eugenio, Alejandra Goded** (peter@iac.es)
Communication and Scientific Culture Unit
Instituto de Astrofísica de Canarias
Adress: Calle Vía Láctea, no number
38205 La Laguna
Santa Cruz de Tenerife
Spain

This didatic unit was funded by: