Teacher's guide
CESAR Science Case – Observing the planets and the Jupiter´s moons

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There are different methods to use in this laboratory.

• **Material that is necessary during the laboratory**

- o CESAR Astronomical word list
- o CESAR Booklet
- o CESAR Formula sheet
- o CESAR Student's guide

- o The free software "Stellarium"
- o The software for this Science Case
- o Calculator, paper, ruler, eraser
- o Projector (optional)

The free software "Stellarium" can be downloadable at http://www.stellarium.org/.The installation guide can be downloadable at the CESAR website for this Science Case.

Introduction

This laboratory is focused on observing the Solar System. The students will first get an idea about how to plan a real observation with professional telescopes. For this task they will have to check which planets are available to be observed the day assigned by CESAR for your observation. Jupiter has to be able for observation since the last task of this Science Case is based on it. Of course other celestial bodies are able to be observed, not only the planets but we are going to be focused on them. If you try to observe the stars for example you will find that they will only appear as a dot on the image. The best planets to be observed are Venus, Mars, Jupiter and Saturn because they are big enough to capture some details. Each of them has its own features. Venus has phases, Mars has poles, Jupiter has storms and four big moons and Saturn has rings to put one example of each one.

Once they check which planets are available they will have to choose one of them excluding Jupiter (which should be visible as mentioned). You will be able to take some images of it so the students will have to get a good knowledge of the planet they choose getting information from the images and with the Booklet.

The last task for the students requires an observation of Jupiter and its moons. It is possible to learn many things of Jupiter as it is the biggest planet in the Solar System and our telescopes can observe it in detail. It is possible to determine the rotation period of Jupiter looking the movement of the Giant Red Spot and it is possible to distinguish many bands of clouds on its surface too to get an idea of how dynamically active is Jupiter but this next task is a little more ambitious, pretending to determine the mass of Jupiter through observing the movements of its moons.

For the last task a specific programme/software is required as long as you have to transform the movement of the Galilean Moons that you will see in the images into a graphic that shows its orbital period around Jupiter. After that, they will be able to calculate the mass of Jupiter.

Choosing a planet to observe
Using Stellarium to choose the best planet to be observed

There are many ways to check the available planets to be observed. Either specific software or websites will show you this information but one of the tasks for the students is to make a planning for an observation as professionals do. Of course this is a simplified version of what professional astronomers do but the procedural has many things in common.

While most of the observatories have its own software for planning the observation, we will use the free software "Stellarium" as it has all the features we are looking for. Stellarium is a planetarium where you can choose your site (or the observatory site in this case). It also let you add a virtual telescope with its camera typing its specifications so you can observe the sky as is you were the telescope. It is very useful because one of the main tasks in a professional observatory is to calculate the field of view. The field of view (FOV) lets you see if an object is suitable to be observed or not. Sometimes happen that the object is too big so it can't be photographed.

For installing Stellarium, there is an installation guide attached to this Science Case called "CESAR Stellarium Guide" follow it to install the software.

Once it has been installed, the first step is to set up the observation site that is the location of the observatory. CESAR has two observatories to be used for this Science Case. If you are going to observe with the 50 cm optical telescope in Cebreros, Spain, it is located at: 40° 27' 16"N, -04° 22' 10.2"W. Otherwise, if you are going to use the 30 cm optical telescope that is located in Robledo de Chavela, Spain, its coordinates are: 40° 25' 38.5"N, 4° 14' 59"W. Click on the location window [F6] and enter the coordinates. Set up the altitude at 600m.

Now for the second step there are two options. The first option is to look which planets are able to be observed the following days or weeks and chose the one with more visibility. The second option is to choose a planet before and then set up the observation date according to it but you will probably have to wait more time. All observations are going to be done 90 minutes after the local sunset or sunrise so you will have to take it into consideration. Moreover it is highly preferable for the quality of the images observe the planet as high as possible in the sky so it's highly recommended to choose highest one.

For the first option, you have to click on the search window [F3]. Starting with Venus and finishing with Saturn students will have to check its visibility for the next few days. For example, type Venus and press enter. You will see the current position of Venus at local time. Now use the Date and Time window by pressing [F5] and adjust the date and time values to decide a futurible observation.

For the second option you could plan the observation for best results. For example you could search on ephemerides for the best day to observe the desired planet. As most of the times, the best moment to observe any planet is when it is closest to the Earth.

In order to complete all the Science Case, remember that Jupiter has to be available for the observation. Otherwise there is no way to complete the last task of the Science Case.

Additionally the weather is also very important. You could check it at the website: www.meteoblue.com where you could also find an astronomy seeing prediction for more detail information. However in case bad weather conditions were predicted for the observation day the last decision belongs to the CESAR team.
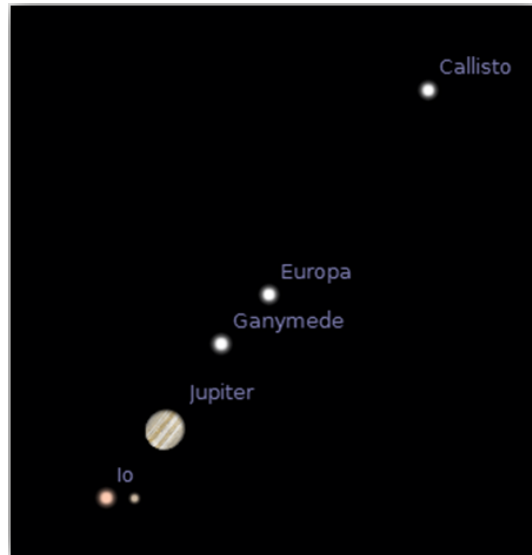

*Figure 1: Galilean moons.   **Credit: CESAR***

A good idea is to let them go out and see if they can find the planets on the night sky before they use the CESAR telescope. They can get the position of the planets by its coordinates. For this, use the equatorial grid [E]. When you click on it, orange lines on the sky should emerge. With these, the students can receive the exact position of the planet in altitude and latitude (degrees). This is just to get an idea of where it is on the night sky. If we know where, for instance the Sun rises, and then sets, we will know that west is where it rises and east is where it sets. That means that south is in front of you and north is behind you. This is an often used trick. It is now time for them to use the CESAR telescope to get a live view of the body.

Observing the chosen planet
Analyse the planet and its main features using the images

The planet of your choice should already be photographed by the CESAR telescope. Now here we are going to describe the main features of each planet that you could try to distinguish from the photos. The Students Guide contains almost the same information about the features so the students will try to recognise these features too.

• Venus: It is one of the brightest objects in the sky due to the high reflectivity of its atmosphere. Because of that, it has a very high albedo that is the percent of reflected light. This means that the students will have to recognize that there is no visible surface on the images of Venus. As consequence there no surface details that they could recognize. Unless some big storm happens on its atmosphere, you will just see a homogeneous body. However you can watch that Venus goes through phases as the Moon does. That means that the students will have to realize about that phenomenon and understand the reason why it is produced. As an inner planet, Venus passes in front of the Sun but and behind it viewed from Earth. As consequence when

Venus is closest to the Earth, the Sun, Venus and the Earth are all aligned on the same direction. When this happened Venus is not visible through a telescope because it's like a new moon if we compare it with the Moon. Unless the Sun eclipses Venus, it is also possible to observe Venus fully illuminated (like a full moon) when it is on the opposite place. You can now realize that between these two phases there are a whole set of phases that you can observe depending on the date of observation but you can predict that with Stellarium software.
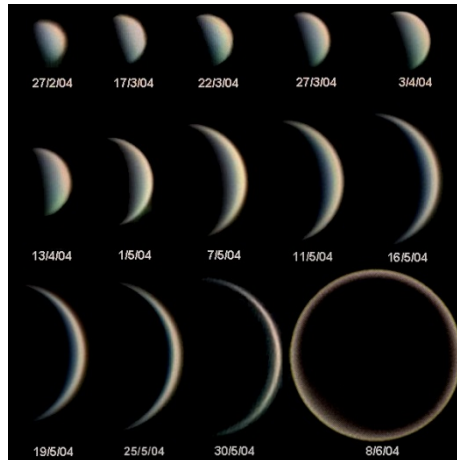

Figure 2: *Phases of Venus.* ***Credit:*** *Statis Kalyvas VT-2004 ESO*

• Mars: It offers a lot of details of its surface such as poles, big mountains, the great Valles Marineris, or the Olympus mount. As it has almost no atmosphere we have an open window to its surface but sometimes happens that big dust storms cover big regions of the surface. You can distinguish the storms because the surface seems to be blurred. The only difficulty comes from the size of Mars. Mars is three times smaller than the Earth and it doesn't reveal many details when it is far from Earth. Take this into consideration when choosing the planet to observe or look for the best date to observe it, i.e. when it is closer to the Earth. If you decided to photograph Mars, let the students try to recognize some features and then compare the image with Stellarium. It will show you that you are supposed to see on the images. For further details you could also visit www.google.com/mars/ where you could see the name of each region, canyons and more. As teacher, you should explain to the students the main features of Mars.
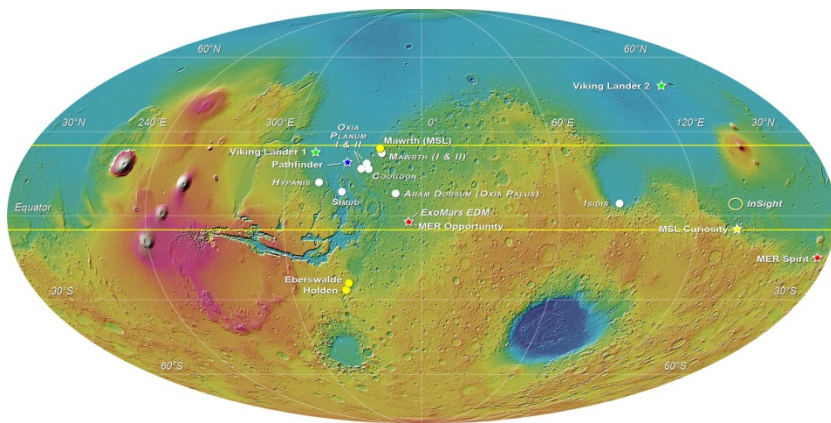

Figure 3: *Mars surface.* ***Credit:*** *ESA*

• Jupiter: As the last task for the students is to use images of Jupiter and its moons to calculate its mass, you have also the possibility to learn about the surface of Jupiter with the same images. The enormous size of Jupiter makes it a very good planet to learn about.

There are three main features that the students will have to analyze: the belts and zones of the surface, the Great Red Spot (GRS), and the fast rotation of Jupiter. The belts and zones are the main features that one notice when see the surface. The belts are those bands that appear darker while zones are the light ones. The belts indicate descending air while zones refer to upwellings. The white color of the zones is because of the ammonia ice but the darker color of the bands is not well explained for now.
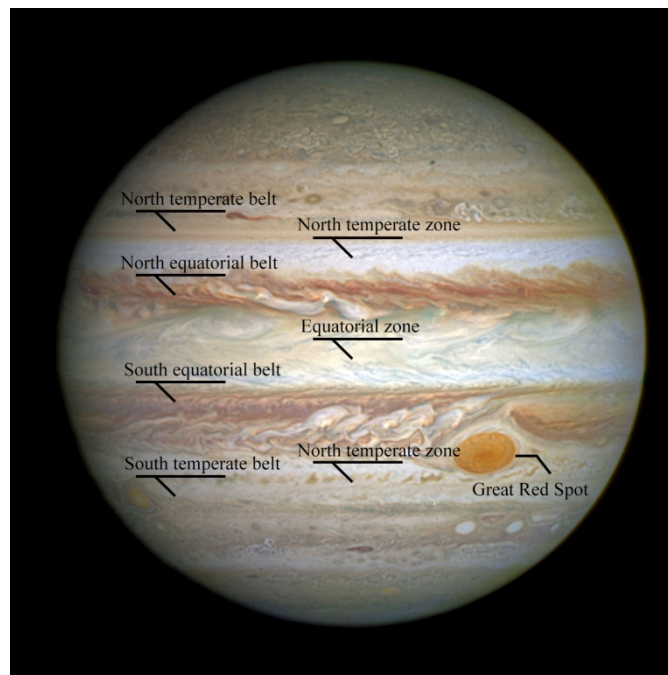

Figure 4: *Jupiter bands and GRS.*   *Credit: ESA*

Other main feature of the surface is the vortices. Both cyclones and anticyclones are produced on the surface and they are very active. Most of the big vortices have a red-orange color while other small vortices are usually white. As most of the students will probably know, the biggest vortex in Jupiter is the Giant Red Spot. It is very easy to distinguish the spot from the rest of them because of its size. However it could happen the observation day that the spot were on the opposite side of Jupiter. You can easily compare the size of any feature on Jupiter with the size of the Earth measuring the diameter of Jupiter on the images and then using proportions.

Finally the fast rotation of Jupiter can be observed if we look at some spot and we do a tracking if it. Considering it does a rotation every 10 hours, it is very easy to get an approximated value of this period measuring the displacement of the chosen spot using the images and its difference of time. Once they know the proportion between pixels and kilometers it is also very easy to calculate the angular velocity (that is approximately 45.300 kilometers per hour).

- Saturn: Many say Saturn is the most beautiful planet because of its rings. It has almost no details on its gaseous surface, but if the atmospheric conditions are good, it is possible to distinguish some big bands with the same pattern as Jupiter's, but Saturn's bands are much fainter and are much wider near the equator.
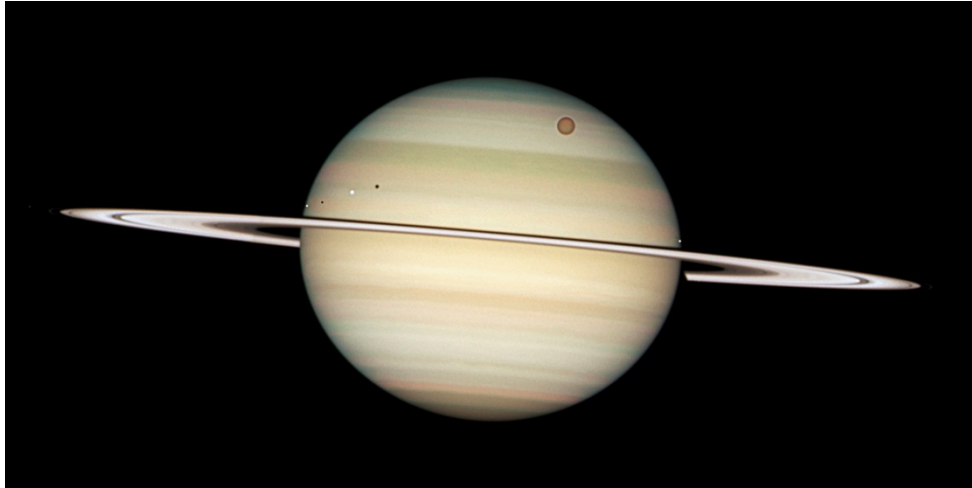

Figure 5: Saturn bands, moons and rings. **Credit:** *ESA*

The main characteristic of Saturn is their rings. Their thickness is only between 5 to 15 metres and depending on the atmospheric conditions; students will see at least one black division inside of them. The main black division is called Cassini Division that has 4800km width. Most of its divisions are caused by the gravitational influence of its moons. For Cassini Division, he moon Mimas causes a resonance avoiding the material to stay at that radio. Other divisions are much more difficult to see such as the Encke Division that is in the outer rings. It is also possible to view the shadow of Saturn projected on the rings, giving us a three dimensional perspective of the planet.

Some of your students maybe are asking themselves why Saturn is the only planet with visible rings. First of all, that is not true as most of the gaseous planets have rings. The only difference is the different amount of material they transport that makes them visible from Earth or not. But why these planets have rings? Why they don't have moons instead of rings? The answer is because all rings are inside Roche's limit. This limit separates the inner region where big moons will disintegrate due to tidal forces and the outer region where the tidal forces don't exceed the moon gravitational self-attraction.

As well as Jupiter, Saturn has moons too. The biggest one is Titan, it has half of the size of the Earth and its bigger that the Earth's moon. However it has a very dense atmosphere of nitrogen and methane. Other big moons such as Rhea and Iapetus will probably be observable but they are at a big distance from Saturn so if you want to get a picture like in the figure 5, you will have to check their visibility using Stellarium.

One last thing about observing Saturn is about the rings tilt. Due to the orbit of the planets Saturn's rings tilt over time. It may happen that the plane where the rings are and the Earth's orbital plane are coplanar. In that case, it is impossible to see any division.

Jupiter's moons: Introduction
Brief introduction to Jupiter's moons

For this Science Case Jupiter has to be able for observing, but why Jupiter instead of Saturn for example? The reason why Jupiter is the chosen one is because it provides us very good conditions to make some very interesting calculations in a short period of time as its moons move quickly, faster than other moons from other planets.

Before getting into the calculations you should motivate your students refreshing some history. Jupiter became incredible important for all humanity when Galileo observed its big four moons orbiting it such as all celestial bodies were supposed to orbit the Earth. That changes our perspective of the universe for ever as we were not the centre of everything. It also changed the balance in favour of the heliocentric Solar System model instead of the geocentric model that was believed as the correct one for hundreds of years.

When Galileo observed how some moons were orbiting Jupiter, he realized that it took about two-four days for some of them to complete an orbit around it. His measurements were not very precise but were good enough. Nowadays we can observe them with high precision and check some main physics laws about celestial objects such as Kepler's laws while calculating other important values such as the precise orbital period of the moons, its masses or even more: the mass of Jupiter.

Jupiter's moons: using the images
Preparing the images for being used

As it has said, the reason why we observe Jupiter instead of Saturn or another planet is because of the short rotation period of its moons. We cannot spend 16 nights of observation to track Titan orbiting Saturn, but we can track Io or Europe that takes 1.77 and 3.55 days to do complete an orbit instead.

NOTE: if you couldn't register photos of a full orbit or Io or Europe, you will have to take the data from other sites such as Stellarium or use other software such as "The Revolution of the Moons of Jupiter" available here: http://www3.gettysburg.edu/~marschal/clea/juplab.html.

For this Science Case we are going to use a CESAR tool to make measures on the images and rotate them. If we want to get valuable data we need first to align all the images to the same plane. We are also going to use another tool for track Jupiter's moons over time (Jupiter Moon Tracker). It will help you to get a good accuracy and will also provide you a clear visualization of the moon's trajectory.

NOTE FOR CESAR: the procedural for processing the images depends on what extension we use. General public is not familiar with FITS images for example

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As the Io, Europe, Ganymede and Callisto are almost in the same plane (less than one degree of difference), we see a two-dimensional movement from Earth. Although they are orbiting around Jupiter we just see a linear movement from the left to the right or vice versa. It is just like see Saturn's rings on edge: we cannot appreciate the three-dimensional movement of the bodies from that point of view. As consequence, we will see all moons moving faster when they passes in front or behind Jupiter and moving slowly when it is at the top left and right. However we could represent that movement as a sinusoidal curve using the time as the x axis.
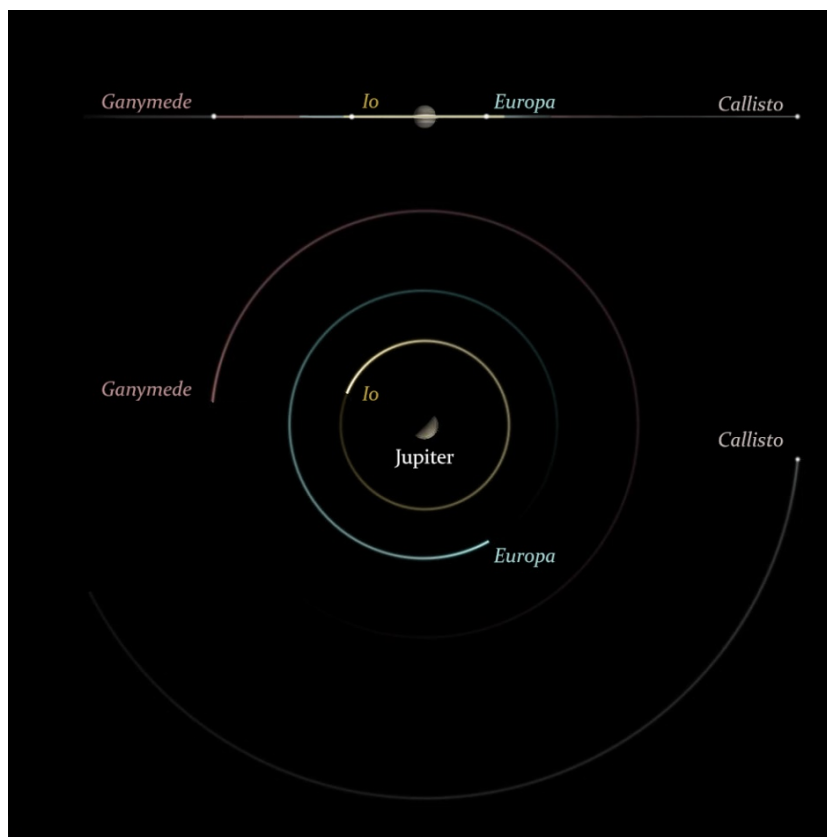

Figure 6: *Jupiter's moons visualization.*   **Credit:** *CESAR*

The advantages of this particular situation let us measure the radius of each orbit. Whenever the moon gets closer to the top left or right of the orbit viewed from Earth, we can say that the distance between the centre of Jupiter and the moon is its orbital radius (we are considering circular orbits as the eccentricity is less than 0.009). To get that distance in km we can use proportions. First measure the distance between the moon and the centre of the planet in pixels and Jupiter's radius too. We know that Jupiter's equatorial radius is 71.492km so we can get a proportion and finally the distance in kilometres between Jupiter and its satellite.

There are some different ways to get the orbital period. What we need is to get the difference of time the moon takes to complete an orbit. If you don't have enough photos you can use some tricks. For example, you register half of the orbit and duplicate the time.

For calculating the angular velocity, just divide the orbit into 360 and using the radio the students have to calculate how many kilometres the moon moves per degree, or use the calculated orbital period to get how many kilometres the moon moves per second.

$$V = \frac{2\pi R}{T}$$

Where R is the orbital radio in km, and T is the orbital period in seconds.
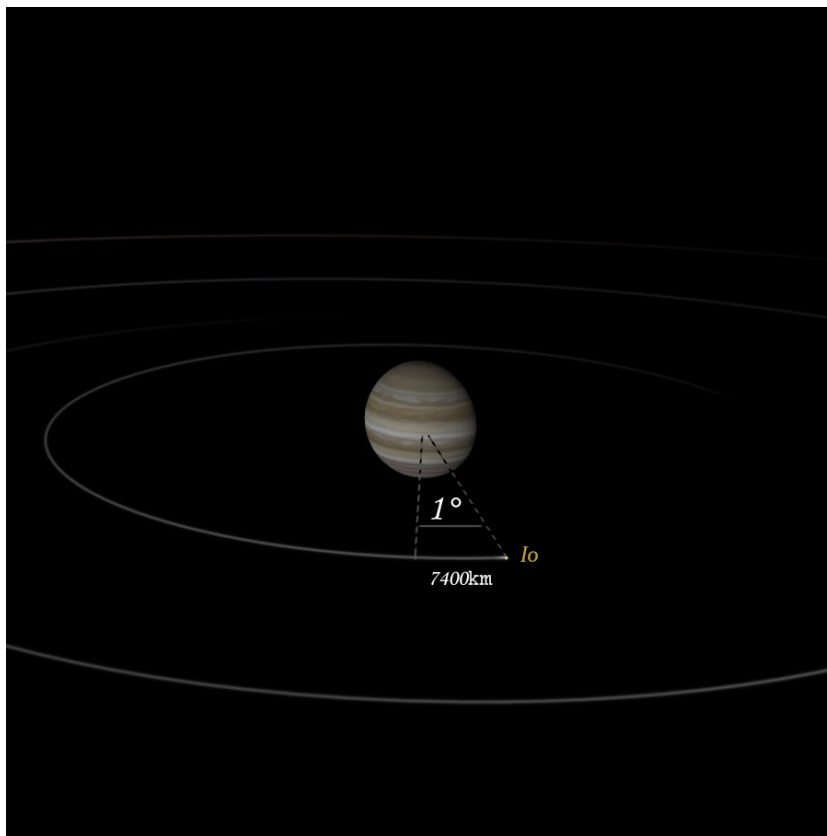

Figure 7: Distance covered by Io in one degree while orbiting Jupiter.   ***Credit:*** *CESAR*

Once they finish with the measurements, let them compare their results with the data from this table:

Moon	Angular velocity (km/s)	Period (days)	Orbital radio (km)
Io	17.33	1.7691	421700
Europa	13.74	3.5512	671034
Ganymede	10.88	7.1546	1070412
Calisto	8.20	16.6890	1882709

Jupiter's moons: getting the mass of the planet
Calculating Jupiter mass with the third Kepler's lay.

Thanks to Johann Kepler we now know that all celestial bodies orbit the Sun with defined patterns. We also known (tanks to Newton) that every single body experiment a force due to other bodies around it. Let the students refresh the third Kepler's law: "The square of the orbital period of a planet is directly proportional to the cube of the semi-major axis of its orbit". To get the final equation that they are going to use to calculate the mass of Jupiter they will have first to use some simple gravitational physics.

On the one hand, Jupiter gravitational field pulls the moons to it. So we first have a force to the centre of Jupiter. On the other hand the centripetal force of the moon pulls it to the outer space. Both forces have to be the same to get a stable orbit around Jupiter. For now we have:

$$F_1 = G\frac{M_J M_{Moon}}{D^2}$$

$$F_2 = V^2\frac{M_{Moon}}{D}$$

Where M is the mass, D is the distance between the centre of Jupiter and the Moon (that is the orbital radio), G is the gravitational constant and V the angular velocity of the moon (expressed in km/second).

As both forces have to be the same we have:

$$M_J = \frac{V^2 D\ M_{Moon}}{G}$$

The ideal of this Science Case would be to compare this result of the mass of Jupiter using data of more than one moon. However as it depends on how many images you have it can't be always achieved. In case you have data of one or more moons, then you should ask the students to do some statistical analysis to get the error of the final result and see if it fit into the right value of Jupiter's mass that is $1.90 \cdot 10^{27} kg$.

Finally, there is a very good tool to get the sinusoidal trajectory of Jupiter's moons available here: http://new-pds-rings-2.seti.org/tools/tracker2_jup.html. Using this tool you can compare the observed trajectory with the simulated one. Here is an example for Io and Europa around Jupiter.

Jupiter Moon Tracker Results
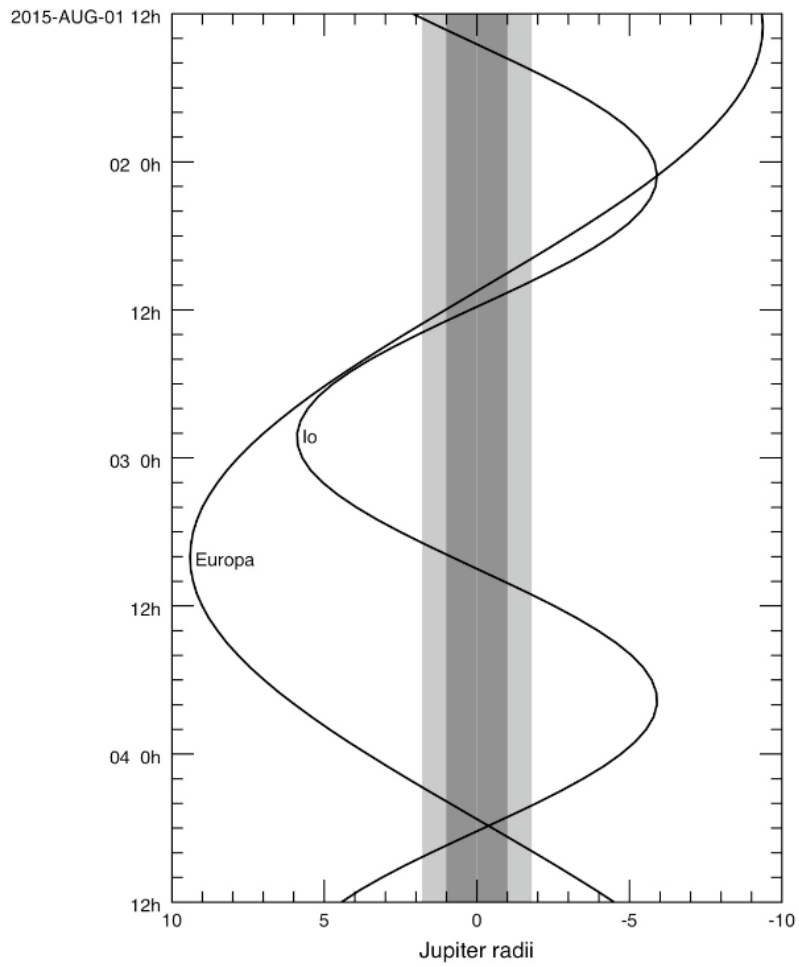
Ephemeris: 011 JUP300 + JUP310 + DE430