

## Student's guide

### CESAR Science Case – Observing the planets and the Jupiter's moons

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By: Abel de Burgos

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#### Introduction

The scientist that first used the telescope and observed the night sky was Galileo Galilei. In the year of 1609, he pointed his telescope and saw things that were never seen before. Mountains on the Moon, bodies orbiting Jupiter and the Milky Way in a different perspective; suddenly the Milky Way consisted of many million stars, a fact that nobody knew before. He did all with a homemade telescope that magnified about 8-9 times. The one he used was a refractor; a telescope that consists of magnifying lenses.

Since then, the telescope has been developed increasingly, and now, they are more sophisticated than ever. There are earthbound telescopes, and even those that are in space. You may have heard of the Hubble Space Telescope (HST), a huge reflector situated outside the Earth's atmosphere. Since the atmosphere of the Earth is not letting all the light from the Sun reach us, a telescope outside it will not experience this. This means that it can collect more light and give us more detailed data and pictures of the objects than ever before.

The Hubble telescope will soon be replaced with a more sophisticated telescope, named the James Webb Space Telescope (JWST) which will be launched in 2018. It will be capable to work in the visible range of the electromagnetic spectrum, but its instruments will be designed to work primarily in the infrared region. It will hopefully give us pictures of stars forming planetary systems, connect the Big Bang to our galaxy, and find the first galaxies that formed in the early Universe etc. With its large mirror of 6.5 meters in diameter and a sunshield the size of a tennis court, the chances are high.

In this Science Case you are going to use a different kind of telescope that is called "smith cassegrain telescope". This telescope uses both lens and mirrors to get high quality images with high magnification. This is especially good for observing planets as the magnification is very important due to the small size of them.

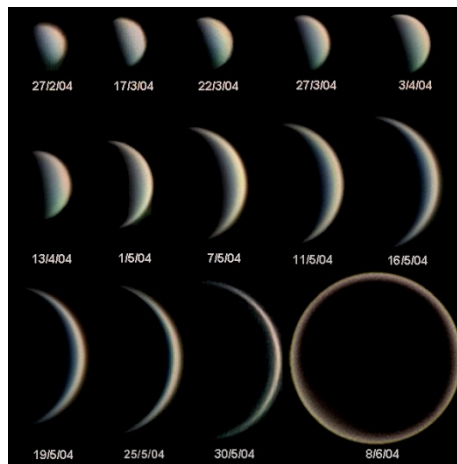
The aim of this Science Case is to give you the opportunity to learn about how professional observatories work and let you use the telescope to observe (by taking images) and learn about a planet you choose. Moreover you are going to use the telescope to observe Jupiter in detail, observing the rotation of its moons (Io, Europa, Ganymede and Callisto). You will also get enough data during your observation to calculate the mass of Jupiter, the heaviest planet in the Solar System.

#### Theoretical background

There are three main important things that you have to learn before start. The first one is to learn about each of the planets in the Solar System, that is, its main features and its main observable characteristics. The second is to learn about how to plan an observation. If you want to get good images of an object, you have to be sure that is observable from your location and even more, that you have the best conditions to observe it. The third one is to refresh all you know about celestial movements and Kepler third law as you will have to use that knowledge to calculate the mass of Jupiter.

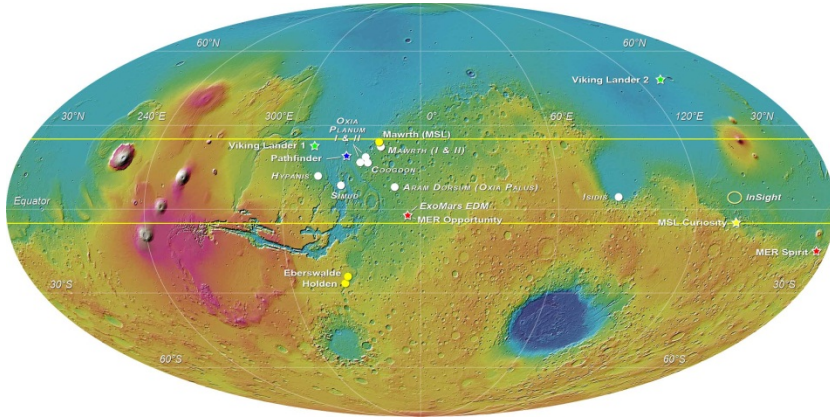
To learn about each planet you first have to read the Booklet for this Science Case where you have all the information about each one but you have to learn about the main features you can observe from each one too so here is a brief resume that let you decide which one you want to observe with the telescope:

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

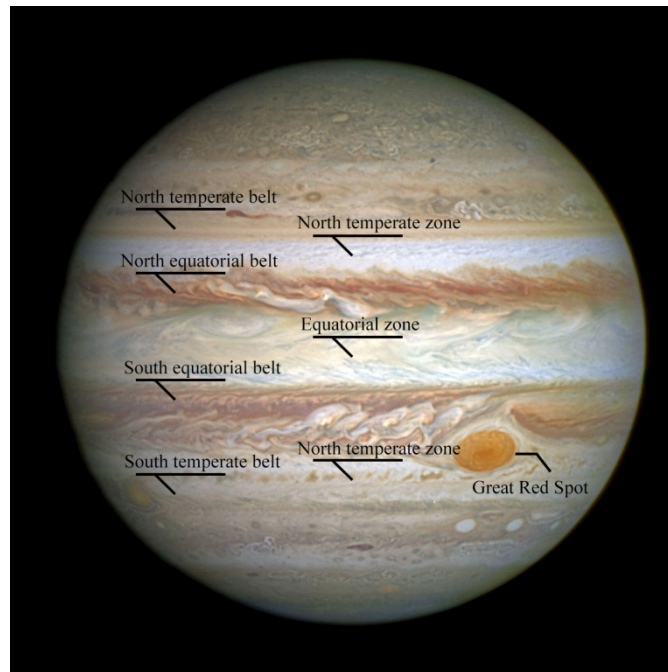
- Mars: It offers a lot of details of its surface such as poles, big mountains, the great Valles Marineris, or the Olympus mount. As it has almost no atmosphere we have an open window to its surface but sometimes happens that big dust storms cover big regions of the surface. You can distinguish the storms 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/](http://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 2: 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.



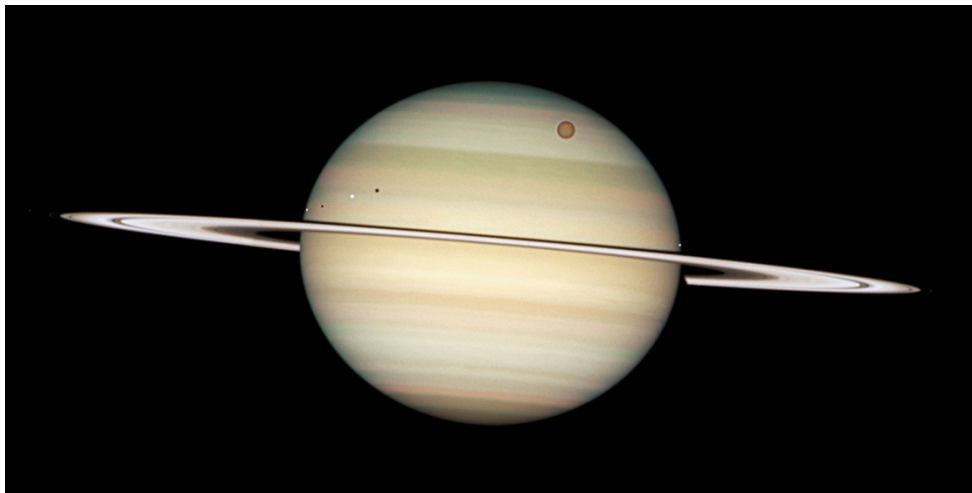
**Figure 3: Jupiter bands and GRS. Credit: ESA**

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 4: 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, the 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.

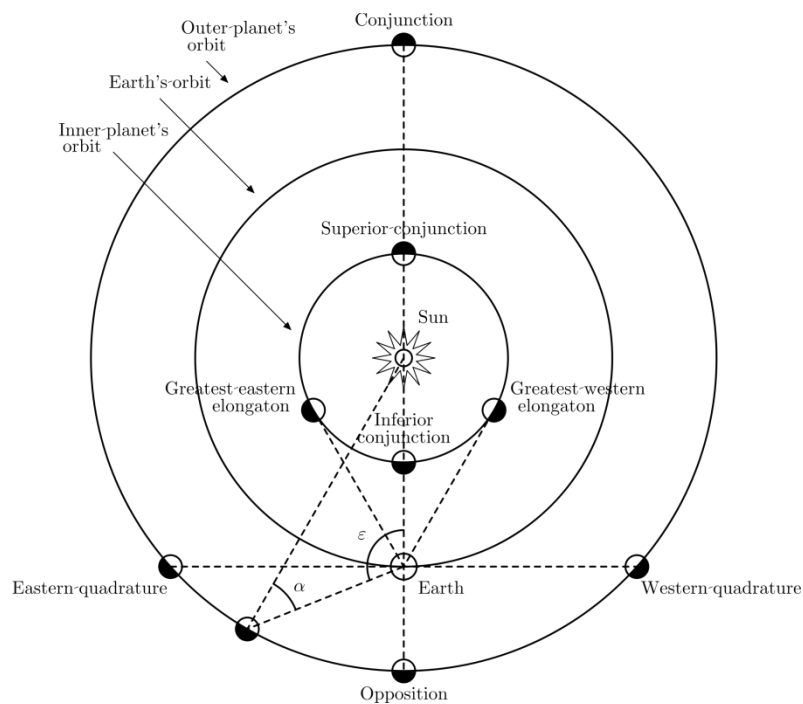
As well as Jupiter, Saturn has moons too. The biggest one is Titan, it has half of the size of the Earth and its bigger than the Earth's moon. However it has a very dense atmosphere of nitrogen and methane. Other big

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.

Now you have learned a bit about the planets, you have to know how to plan an observation. The first thing you have to know is where the observatory is. What you can see from one observatory may be totally different to another at the same time so it is very important to know what you can see from yours.

Once you set up your location you have to look for the best moment to observe the desire target. You can wait for the best day in a year/month to observe it or you can observe it at the best hour in the current day. In a year, the best moment to observe a planet is when it gets closer to the Earth. For outer planets that moment is called the opposition. Mercury and Venus have opposition too but as they are inner planets they are between the Earth and the Sun at that moment making it impossible to be observed. You have to look for its greatest elongation (western or eastern). If you are looking for the best moment in a day, the best moment is when the planet is higher in the sky. The Moon doesn't affect when observing planets and all observations are going to be done 90 minutes after the local sunset or sunrise so you will have to take it into consideration.



**Figure 5:** Position of inner and outer planets. *Credit: Wikipedia*

You also have to consider the weather in the observatory site because the telescopes can't operate with bad weather (rain, strong wind, high humidity...).

Finally you have to refresh the Kepler three laws in order to understand some simple formulas that you are going to use when calculating the mass of Jupiter and you have to refresh some formulas about forces: the centripetal force and the gravitational force.

## Material

1. CESAR Astronomical word list
2. CESAR Booklet
3. CESAR Formula sheet
4. CESAR images of the planet
5. The software Stellarium
6. Paper, pencil, ruler, calculator, protractor

## Laboratory description and purpose

The main purpose of this laboratory is to let you use a professional telescope provided by CESAR to observe Jupiter and other planet of your choice. You can feel like a real astronomer! For this Science Case, Jupiter has to be able to be observed considering the limitations mentioned above. You can also observe another planet of your choice between Venus, Mars and Saturn but just if they are available the same night.

To make your plan you are going to use the software Stellarium. Your teacher will show you how to use it but you can also learn how to use it reading the “CESAR Stellarium Guide” available on the website for this Science Case. Once you make your plan of observation you are going to control the telescope remotely. Either for Jupiter and the other planet you chose you are going to take a set of images that you are going to use later. The images of Venus, Mars, or Saturn will allow you to learn about the chosen planet.

Finally you are going to track Io, Europa, Ganymede and Calisto movement around Jupiter using the images and making some measurements on them you are going to calculate the mass of Jupiter.

## Laboratory execution

Start by reading the Booklet to understand the theory. By doing this, the laboratory will become much easier to execute since you will have less questions and more understanding.

Once you read the booklet and the background section of this document you all have to discuss about what planet you want to observe and why, then vote it. The planet with more votes will be the one you are going to observe plus Jupiter.

Run Stellarium on your computer once it has been installed. Now you have to choose a day for the observation. You have all you need to decide the best date and time but be careful, it is your duty to choose the best date and time as it will depends on the success or failure of your observation. Bad quality images will increase the errors in your measurements and you won't observe many details on the planets surfaces.

You have to take some values to create a table like this one:

Date:	DD-MM-YYYY
Best local time to observe Jupiter:	HH:MM:SS
Best local time to observe Venus/Mars/Saturn:	HH:MM:SS

The time has to be in your local time i.e. the time at where you are. At least one hour before that time you will be allowed to use the telescope remotely because you have to start taking images for a couple of hours one before and one after the maximum.

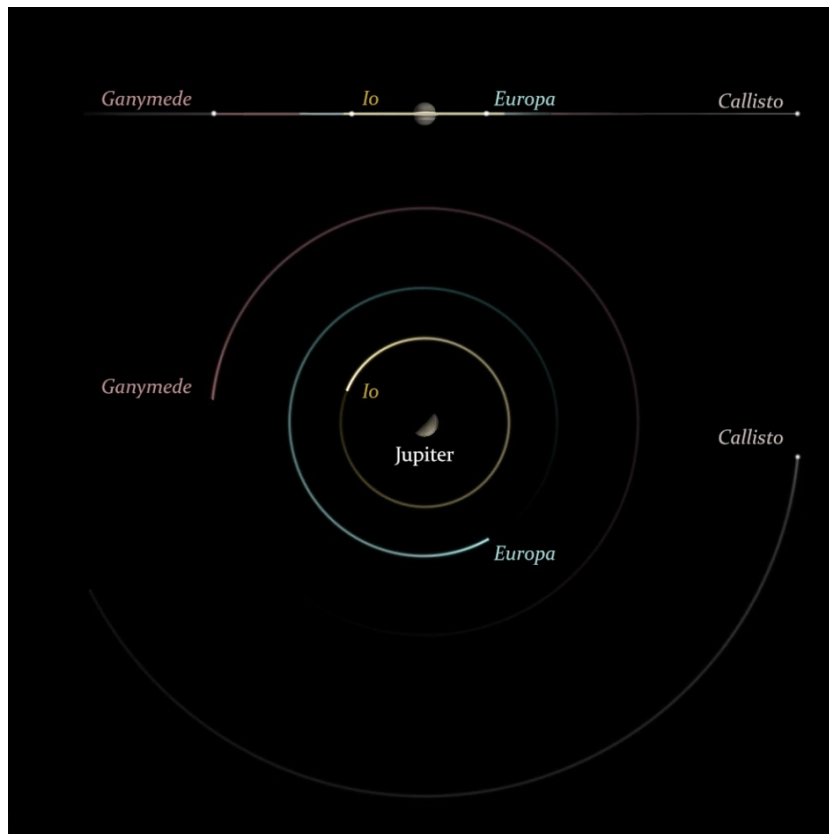
To point to the planet you have two options. You can choose the planet from the telescope database or you can point it through its coordinates (AR/DEC).

Now for the planet you choose between Venus, Mars and Saturn you are going to observe it via streaming. You will notice some turbulence due to the atmosphere. Later, you are going to take some pictures of it. Depending on your level you will be taught how to process the images or you will be given the images processed by the CESAR team.

For Jupiter you are going to observe it via streaming too but for a short time as this section requires much more time. You have to take images every 5 minutes and you have to adjust the exposition of the image to easily recognise the moons. It is not important if you have Jupiter's surface overexposure, the only important thing is to be able to see its satellites. Try to take more than one image every 5 minutes to decide the best one for each time.

Once you finish the observation, it is time to park the telescope and pick up the images. CESAR will share all your images so you can download them.

As it has been said, you have to use the processed images of the planet you choose to learn more about it. Try to recognize all details mentioned in the background section and also analyse its colour, size and luminosity compared with Jupiter.



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

Now for the main task of this laboratory you have to use all that images of Jupiter. You have to estimate the moment a moon is on the top left or right of its orbit and use proportions to calculate its orbital radio. One value that you can use to create a proportion is the real diameter of Jupiter that is 139822km.

You also have to calculate period and the angular velocity of the moons (at least for one of them). Use your physics knowledge and the images to estimate the period and then calculate the angular velocity in kilometres per seconds. Your teacher has the right values you he will tell you if you are close or not to it.

You can create a table like this one:

Moon	Angular velocity (km/s)	Period (days)	Orbital radio (km)
Io			
Europa			
Ganymede			
Calisto			

Finally the last and most important task: to calculate the mass of Jupiter. You have all necessary to calculate it on the table above. Just think about the involved forces in the movement of the moons and get the value. Jupiter gravitational field pulls the moons to it and the centripetal force of the moon pulls it to the outer space. If you have data for more than one moon, then calculate the average mass of Jupiter.