



CESAR Scientific Challenge

The mass of Jupiter

*Calculate the mass of a planet from
the motion of its moons*

Student Guide





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Your Scientific Challenge

How to get in contact with our unknown neighbours?

Jupiter is the largest planet in our Solar System and from the analysis of their data, scientist consider that life could be found under the water of some of their Galilean moons. Whether we will find them and how will they look like is still an open question.



Figure 1: The movie Contact. (Credits: Warner Bros)

The JUICE - JUpiter ICy moons Explorer - mission is planned for launch in 2022 and arrival at Jupiter in 2029, it will spend at least three years making detailed observations of Jupiter and Ganymede, Callisto and Europa.



Figure 2 Your challenge is to know how much is the Jupiter mass. (Credits: ESA, <https://www.quora.com/In-which-comic-does-superman-pull-planets>)

In order to plan our travel to the Jovian System, we must know how much is the Mass of Jupiter , **will you help us to do so?**



Phase 0

In order to put into context, we recommend students to watch these videos:

- [This is ESA](#) (10 min)
- [ESAC: ESA's A window on the Universe](#) (3 min)
- [Presentation to ESA/ESAC/CESAR by Dr. Javier Ventura](#) (15 min)
- Here there is another complementary set of [videos](#).

We recommend to **work in teams**, of (4-6) people, with a clear role in their team, assigned per profession. You will fill Table 1 for the coming Challenge with a name for their Team and the name of the team members.









Challenge ID				Team number (1-6):	
Names					
Profession	Mathematician/ Software engineer	Astrophysics	Engineer	Biologist	
Roles	Lead the correctness of the calculations	Lead the use of telescope and the understanding space missions.	In charge of finding the optimum strategy agreed among the team members and its correct execution.	Lead the more detailed research about the scientific understanding of the energetic processes and composition of the celestial objects.	
Reference	Katherine Johnson	Vera Rubin	Samantha Cristoforetti	Marie Curie	
(female)					
(male)	Steve Wozniak	Matt Taylor	Pedro Duque	Albert Einstein	
					

Table 0: Define the working groups for solving this Challenge.

Note: The documentation makes use of [the International System of Units](#).



Phase 1

Activity 1: Refresh concepts

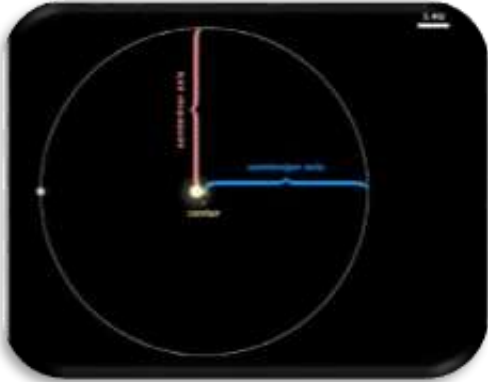

Mass & weight	Gravity: ESAKids & NASAkids	orbital period
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Table 1: Concepts to be refreshed before facing this Scientific Challenge.

Kepler's Laws

Kepler's Laws, published between 1609 and 1619, led to a huge revolution in the 17th century. With them scientists were able to make very accurate predictions of the motion of the planets, changing drastically the **geocentric model of Ptolomeo** (who claimed that the Earth was the centre of the Universe) and the **heliocentric model of Copernicus** (where the Sun was the centre but the orbits of the planets were perfectly circular). These laws can also explain the movement of other Solar System bodies, such as moons, comets and asteroids.

Kepler's laws can be summarised and tested with the [Kepler laws' simulator](#) as follows:

Kepler Laws	Simulator to test that Law
<p>First Law: The orbit of every planet is an ellipse, with the Sun at one of the two foci.</p>	
<p>Second Law: A line joining a planet and the Sun sweeps out equal areas during equal intervals of time</p>	

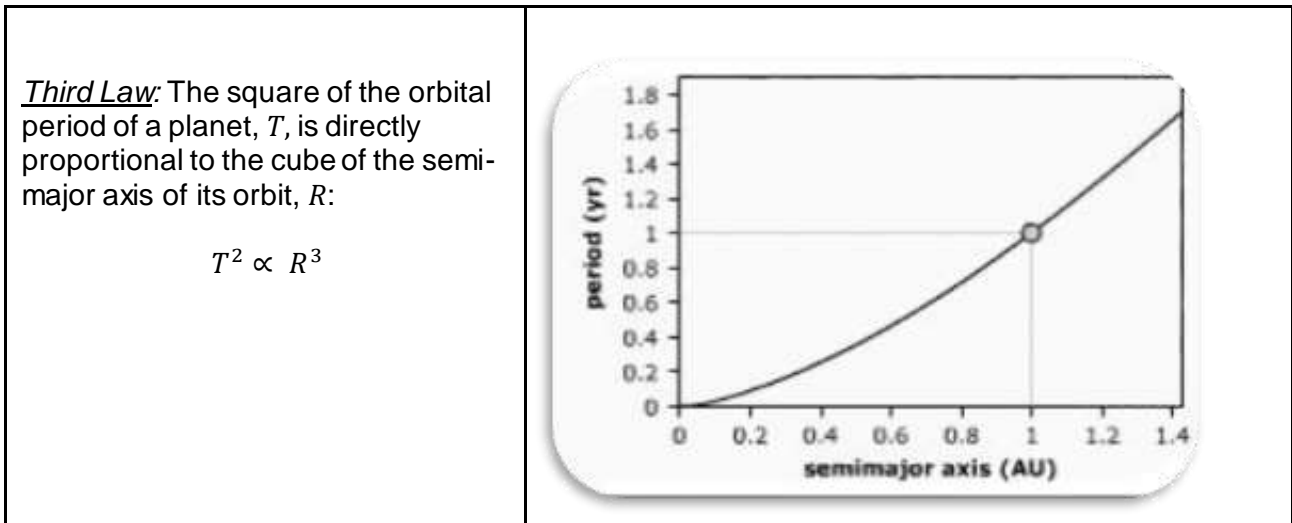


Table 2: Introduction to the Kepler Laws and the simulator where to understand them.

How to calculate the mass of Jupiter?

We can derive the equation to calculate the mass of Jupiter from the Third Law of Kepler.

Let's start by applying the Second Law of Newton to a Sun-planet system (or a planet-moon system, as in our study case with Jupiter). Assuming that the moon is moving in a circular orbit, with no friction, we can consider that for the moon, with mass m , the gravitational force (F_g) equals the centripetal force (F_c):

$$F_g = F_c$$

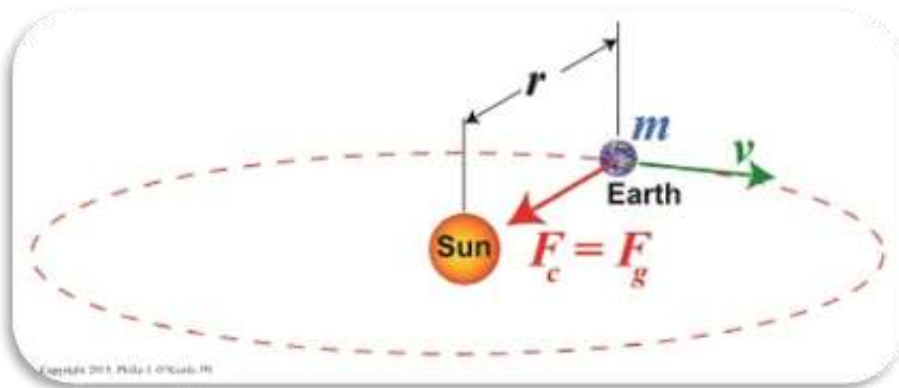


Figure 4: Second Law of Newton (Credit: <https://www.toppr.com>)

$$F_g = \frac{GMm}{R^2} \quad \text{and} \quad F_c = m a_c$$

$$\text{as } F_g = F_c \quad \rightarrow \quad \frac{GMm}{R^2} = m a_c$$



$$\text{as } a_c = \frac{v^2}{R} \quad \rightarrow \quad \frac{GMm}{R^2} = m \frac{v^2}{R}$$

$$\text{and as } v = \omega \cdot R = \frac{2\pi}{T} R \quad \rightarrow \quad \frac{GMm}{R^2} = m \frac{4\pi^2}{T^2} R \quad \rightarrow \quad \frac{GM}{4\pi^2} = \frac{R^3}{T^2}$$

Where, M , is the mass of a planet and, m , is the mass of an orbiting moon. For the moon, v , is the linear velocity (in metres per second), R , is the radius of its orbit (in metres), ω , is the angular velocity of the moon (expressed in radians per second), T , is the orbital period (in seconds) and, G , is the universal gravitational constant, with a value of $G = 6.674 \cdot 10^{-11} \text{ m}^3 \text{ kg}^{-1} \text{ s}^{-2}$

Therefore we can deduce the Third Law of Kepler, for a constant mass, M , (or M_J , in the case of the mass of Jupiter in our Jupiter-moon system) and say *that the square of the orbital period of a planet, T^2 , is directly proportional to the cube of the semi-major axis of its orbit, R^3* :

$$\text{cte} = \frac{GM}{4\pi^2} = \frac{R^3}{T^2} \quad \rightarrow \quad \boxed{T^2 \propto R^3}$$

From the same equation, we can derive M , or M_J , the mass of Jupiter as follows:

$$\frac{GM}{4\pi^2} = \frac{R^3}{T^2} \quad \rightarrow \quad \boxed{M_J = \frac{4\pi^2 R^3}{G T^2}}$$

By measuring the period and the radius of a moon's orbit it is possible to calculate the mass of a planet .

Now, you will make use of these laws to calculate the mass of Jupiter with the aid of the *Stellarium* (<http://stellarium.pdf>) astronomical software.



Figure 5: Stellarium logo

Activity 2: Compare Jupiter and the Earth.

	Earth	Jupiter (11 times Earth radius)
Radius		
Density	5.5 g/cm ³	
Average temperature	20° C	
Distance to the Sun	1 AU	
Moons	1	79
Type of planet		
Composition	<ul style="list-style-type: none"> • Silicates mantel, metal core & crust • Atmosphere: nitrogen, oxygen, argon. 	
Magnetic fields	yes	

Table 3: Compare Jupiter and the Earth

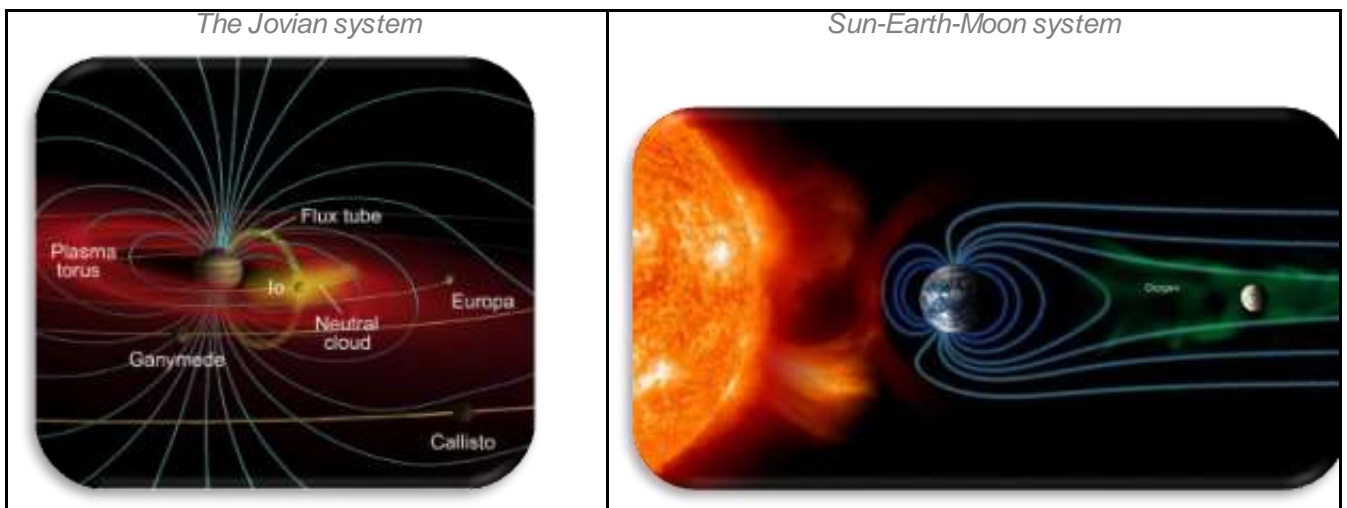


Figure 6: Magnetic fields around the (Credit: http://www.esa.int/Observing_Jupiter)

Activity 3: The Jovian system

The gas giant Jupiter is the largest planet in our Solar System. It doesn't have a proper surface and is made up of swirling clouds of gas and liquids that are **mostly hydrogen and helium**. **Jupiter** is so large that about **11 Earths could fit across it**. **Its mass is more than twice the mass of all the other planets in the Solar System combined**.

Jupiter has [79 moons](#) (as of 2020) – the highest number of moons in the Solar System. This number includes the **Galilean moons**: Io, Europa, Ganymede, and Callisto. These are Jupiter's

largest moons and were the first four to be discovered beyond the Earth by astronomer Galileo Galilei in 1610.

The Galilean moons (Io, Europa, Ganymede and Callisto) are distinctive worlds of their own and of high scientific interest. We provide in Table 4 an overview of their appearance and most relevant characteristics.


			
<p>The most volcanically active object in all the Solar System due to the inward gravitational pull from Jupiter and the outward pull from other Galilean moons.</p>	<p>A cold world that might have a liquid water ocean beneath a thick layer of surface ice. Of Jupiter's moons, Europa is the one scientists believe is more likely to be habitable.</p>	<p>The largest known moon. There is evidence that it conceals a liquid water ocean under its icy shell; potentially an environment suitable for life.</p>	<p>Has an old and heavily cratered surface, therefore providing a window to explore the early formation of the moons. Also, thought to have an ocean beneath the surface.</p>

Table 4: A modified version of the montage of Jupiter's four large Galilean moons as imaged by NASA's Galileo spacecraft. Image (Credit: NASA/JPL/DLR)

For completeness, time permitting, see some other of the contents provided for this Activity in the Table "Summary of Activities", such as [CESAR booklet: The Solar System](#)

Occasionally we could see the **transit**¹ of its moons in front of Jupiter, as shown in Figure 7.



Figure 7: Image of a transit caused by Io and Europa in front of Jupiter (Credits: Stellarium & CESAR)

Activity 4: The space exploration of Jupiter by the European Space Agency

Jupiter has always been a very interesting astronomical object to study. Since the first observations were made by Galileo using an early version of the telescope huge advancements in technology have been achieved.

Several space missions have flown by close to Jupiter, including **Pioneer 10**, **Pioneer 11**, **Voyager 1**, **Voyager 2** and **Cassini-Huygens**. In addition, other missions have been developed to specifically study Jupiter and its moons. However it was not until 1995 when the NASA's **Galileo** spacecraft became the first to orbit Jupiter and in 2016 the NASA's **JUNO** spacecraft arrived at the jovian system.

ESA is currently working on the Jupiter Icy moon Explorer (**JUICE**), see Figure 8, that is scheduled to be launched in 2022 and arrival at to the jovian system close to 2030. The mission observing targets are Jupiter, Ganymedes, Callisto and Europa, for being the moons that could contain water (and maybe host life?). The [JUICE science objectives](#) are to characterise the conditions that may have led to the emergence of habitable environments among the Jovian icy satellites.

¹In [astronomy](#), a **transit** (or **astronomical transit**) is a [phenomenon](#) when a [celestial body](#) passes directly between a larger body and the observer. The transiting body appears to move across the face of the larger body, [covering](#) a small portion of it.^[1]

[https://en.wikipedia.org/wiki/Transit_\(astronomy\)](https://en.wikipedia.org/wiki/Transit_(astronomy))

For completeness, time permitting, we recommend you to watch some of the videos provided for this Activity in the Table “Summary of Activities”, such as [The Solar System](#), [Unlocking the secrets of Jupiter icy moons](#), [JUICE’s Jovian odyssey trip](#), [Diverse worlds: The Moon and Titan](#)

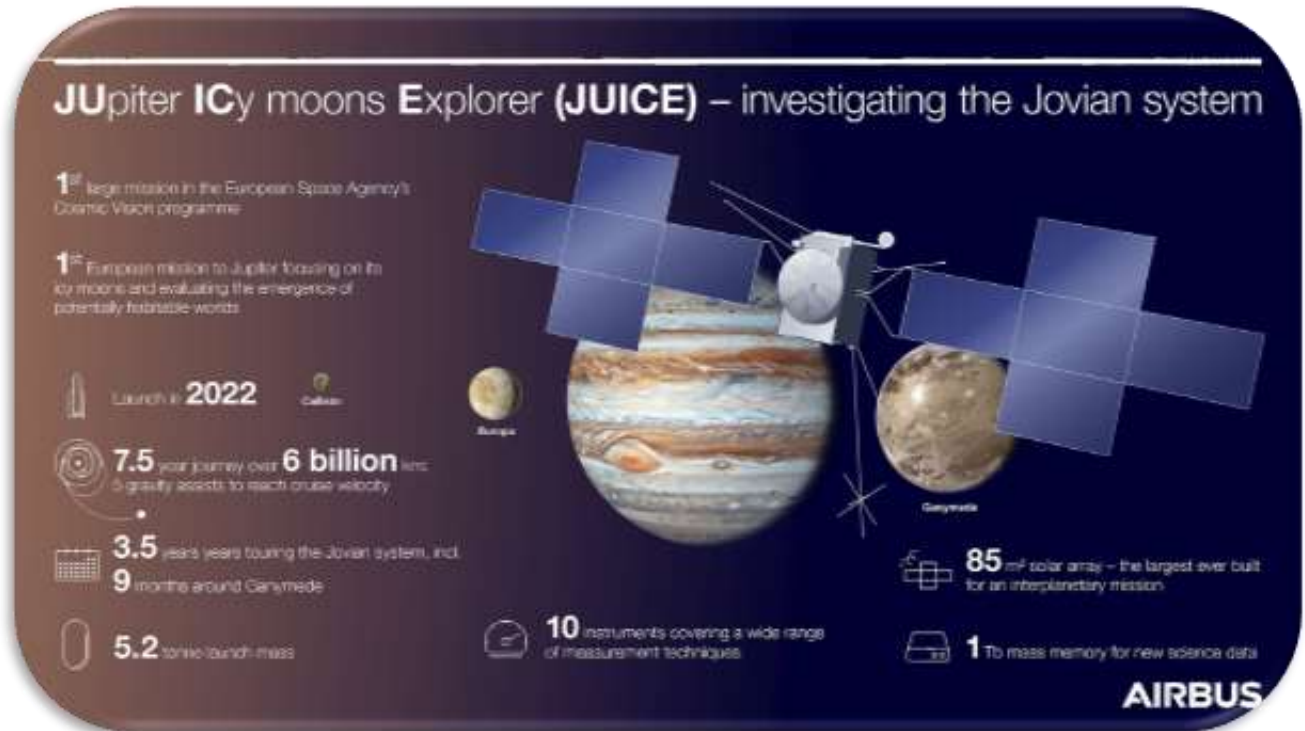


Figure 8: Infographic about the JUICE mission (Credits :AIRBUS)

Activity 5: Evaluate what have you learnt until now

Check what do you know up to now with this [questionnaire](#)



Phase 2



Figure 9: Jupiter ESA mission (Credits:ESA)

https://twitter.com/ESA_JUICE/status/1317031815220203522



Phase 3

Activity 7: Fill in information about the Galilean moons. Choose your favourite moon.

In this activity you should fill in Table 5 some of the various properties of the Galilean and select their moon which parameters (orbital period and orbital radius) will be used in Activities 8 and 9 to calculate the mass of Jupiter.

Table 5: A subset of Table 4 with the main properties of the Galilean Moons.

Your moon	
-----------	--

IMPORTANT:

- If you do not want to do many calculations, you can introduce your results from Stellarium into the following Excel table (with formulae). Please make a copy of it and use this copy if desired.
- This [Excel sheet](#) will serve you to make all the calculations of Activity 8 and 9

Activity 8: Calculate some orbital parameters of your favourite moon.

You need the use **Stellarium** to calculate the *orbital period* and the *orbital radius* of your moon. Galilean moon. ([Basic guide Stellarium](#)).

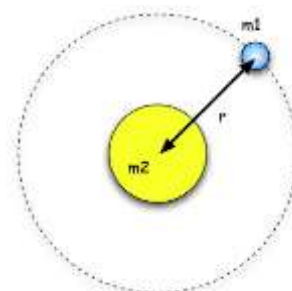


Figure 10: Representation of an orbital radius, r .
(Credits: Wikipedia)



Activity 8.1: Calculate the orbital period of your moon

From Wikipedia:

“The orbital period is the time a given astronomical object takes to complete one orbit around another object, and applies in astronomy usually to planets or asteroids orbiting the Sun, moons orbiting planets, exoplanets orbiting other stars, or binary stars”.


Calculate the period of your chosen moon by following this Procedure:

Procedure

- **Step 1: Open Stellarium.** You will be located on a green path in a day or night view, depending on your local time. If the location is active on your device, you will be placed there.



Figure 11: Starting window for Stellarium when opened at a location place where is daytime. (Credits: Stellarium & CESAR)

- **Step 2: Travel to Jupiter.** You may choose any of these two modes:
 - **MODE 1: By using a set of instructions written in a programming language (script)**
 1. **Open a console in Stellarium by pressing F12** (on your keyboard)
 2. **Copy and paste the script from Figure 12 in your console** (CTRL-C & CTRL-V).
 3. **Click on the play button** ().

```
core.setObserverLocation("Madrid, Spain");  
  
LandscapeMgr.setFlagLandscape(false);  
LandscapeMgr.setFlagAtmosphere(false);  
LandscapeMgr.setFlagFog(false);  
  
core.selectObjectByName("Jupiter", true);  
core.setMountMode("equatorial");  
core.setTimeRate(3000);  
StelMovementMgr.setFlagTracking(true);
```

Figure 12: Script to copy into the Stellarium console to view Jupiter close up. (Credit: Stellarium)

4. Check that the view on your screen looks similar to Figure 13. (Note: You can toggle to and from Full view using F11)



Figure 13: Stellarium view, after running the script. (Credit: Stellarium)

5. **Find your chosen moon in the [Activity 7](#) and watch how it orbits around Jupiter.** We are especially interested in studying and ensuring that the moon is following a periodic motion. (Note: The movement of the moon will be about 3000 times faster than real, as so is requested in the script).
 - a. You need to calculate how long your moon takes to make a complete orbit
- **MODE 2: By using Stellarium control commands.**
1. Click on this search icon and type in Jupiter, as shown in Figure 14.

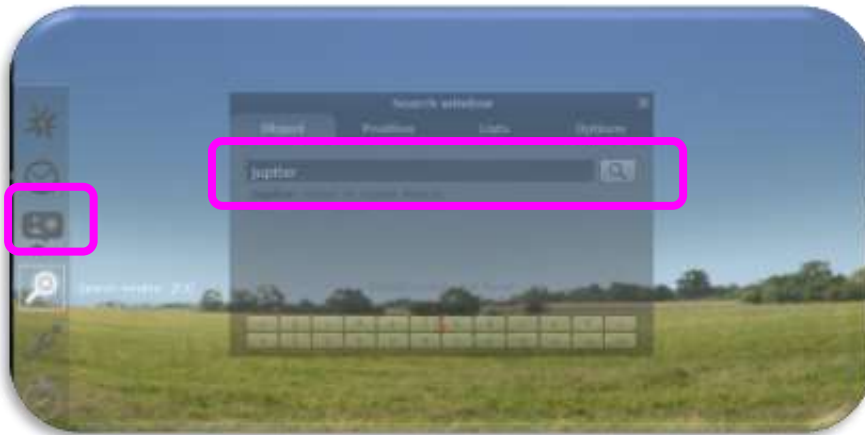


Figure 14: Search command in Stellarium (Credits: Stellarium & CESAR)

2. In case Jupiter is not above the horizon or in daylight, in order to observe it, it is required to disable the ground and afterglow (atmospheric) effects, as shown in Figure 15 (the little trees and the cloud will be unselected after that).

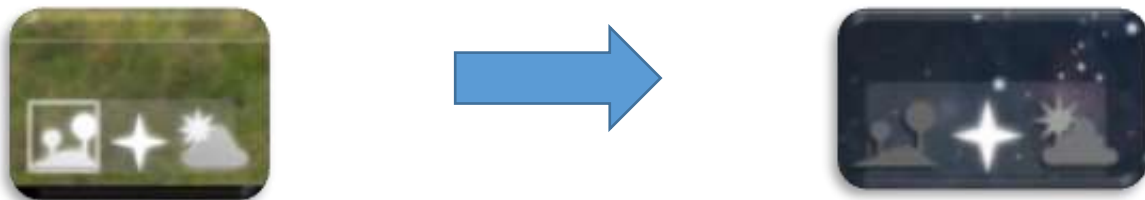



Figura 15a: Stellarium control commands to enable (left image) and disable (right image) the ground and the atmosphere effects (Credits: Stellarium & CESAR)

3. With the mouse wheel, you can zoom in on Jupiter and its Galilean moons until they are in your center of vision as shown in Figure 13.
4. In order to follow the movement of the Galilean moons in an horizontal plane, it is recommended to from a simulated telescope with alta-azimuth mount to another one with an equatorial mount. This can be done by enabling this option ()

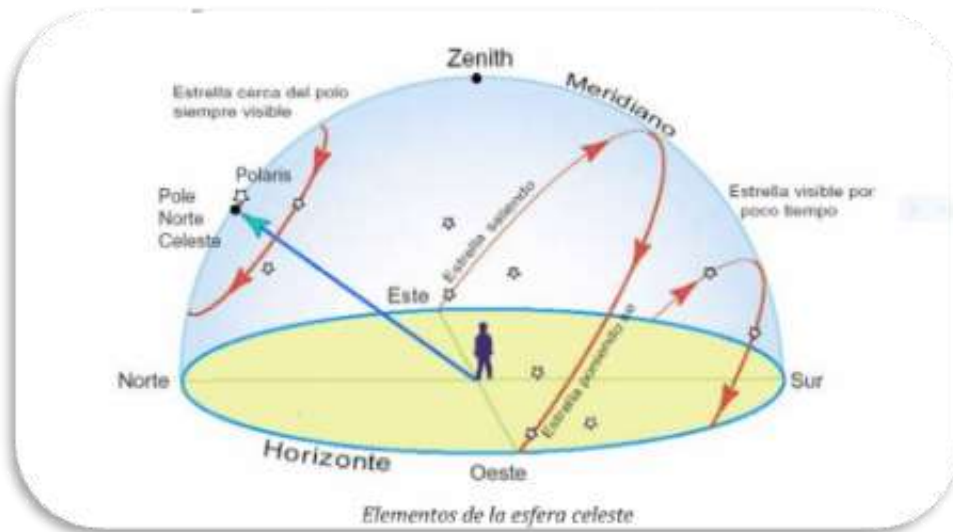


Figura 15 b.: Aparent star movements. (Créditos: <https://www.uv.es/fabregaj/apuntes/AstronPos.pdf>)

- **Step 3: Calculate the orbital period of your Galilean moon**

To study the orbital movement of the moons, you need to know how to use the basic time setting, which is located at the bottom cursor of the screen:







Button	Shortcut key	Description
	J	Decrease the rate at which time passes
	K	Make time pass as normal
	L	Increase the rate at which time passes
	8	Return to the current time & date

Figure 16: Control commands dedicated to moving the time in Stellarium. (Credits: Stellarium & CESAR)

If Step 2 was executed with a script (Mode 1), slow down the movement of the moons by pressing twice the rewind icon.	
If Step 2 was executed by control commands (Mode 2), move the time forward faster by pressing twice the forward icon.	



1. Pay attention to the “**date**” and “**time**” parameters in the lower part of the display.



Figura 17: Where to set up the date and the time in Stellarium. (Credits: Stellarium & CESAR)

2. **Select a starting point** (when the moon is further from the planet) **and write down the date and time in Table 6**. Information of time is given in the format *YYYY-MM-DD hh:mm:ss*, where *YYYY* stands for year, *MM* for month, *DD* for day, *hh* for hours, *mm* for minutes and *ss* for seconds.
3. **Watch the moon make one complete orbit** (what means passing by the starting point once) **and note down the date and time** when the moon returns to the same position. (Note: Use the same time format of *YYYY-MM-DD hh:mm:ss*)
4. **Write in Table 6 the orbital period of your moon (in days and hours)**. (Note: the orbital period is the difference between these two dates calculated)

Initial date (YYYY-MM-DD hh:mm:ss)	Final date (YYYY-MM-DD hh:mm:ss)
<i>Calculate the time difference here</i>	

Table 6: Initial and final date when your Galilean Moon period is counted.

Period	days	hours
--------	------	-------

Note: In *Stellarium* we see Jupiter as it is seen from the Earth. However, the orbital motion of the moons is actually circular, we are simply viewing 2 dimensional projections.






Figure 18: Visualization of the Jupiter moons (Credit: CESAR)

Activity 8.2: Calculate the orbital radius of your favourite moon

We can consider the orbital radius for our galilean moon as the furthest distance between Jupiter and the moon, assuming that the moon moves in a circular orbit around Jupiter. Let's calculate it by following the steps in the procedure.

Procedure:

- **Step 1: Configure the plugin “Angle measurement”.**
 1. **Open the configuration menu**  (or F2 in your keyboard).
 2. Check in Plug-ins that the functionality “Angle Measure” is enabled
 - If this is not the case,
 - Select the box next to ‘Load at start-up’ at the bottom of the window.
 - Restart Stellarium
- **Step 2: Identify the orbital radius**
 1. **Stop the movement of the moons around Jupiter** by clicking on  in the menu at the bottom of the screen (or K on your keyboard)
 2. In the same menu, click on  (or press Ctrl + A) to enable the “Angle Measure” plugin.

3. **Measure the distance between Jupiter and your moon:**

- Click on the centre of Jupiter and then without releasing drag the curser to the centre of your chosen moon (as shown in Figure 19). (**Note:** The calculations are only valid if the measurements are made from the centre of both objects. Repeat your measure as many times as needed to be sure that you are comfortable with it).

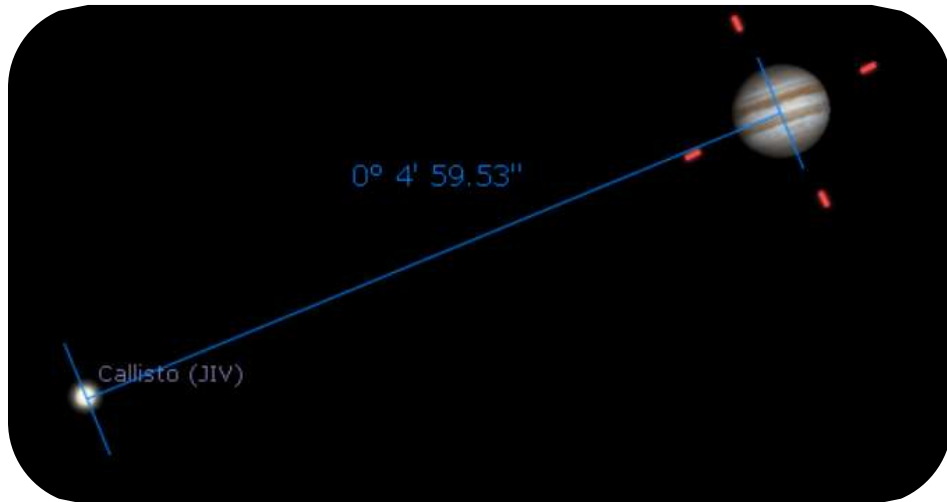


Figure 19: Using Angle Measure plugin. (Credit: CESAR)

4. **Record in Table 7 your measurement of the distance between Jupiter and the moon**, using the units, degrees, arc minutes, arc seconds, as given in *Stellarium*.

Maximum distance of your Moon to Jupiter	° ' "	°
<p><i>Write your calculations here</i> <i>Remember: 1° = 60' and 1' = 60" →</i></p> <p>1° = 3600 "</p>		

Table 7: Calculate the distance between Jupiter and your moon

5. Record in Table 8 the distance from the Earth to Jupiter , d_{JE} , in Astronomical Units and kilometres

Note 1: The **distance** Jupiter-Earth is available in Stellarium by clicking on Jupiter. This information is given in Astronomical Units, as requested by this step.

Note 2: Be aware that the distance (d) in Stellarium represents the distance Jupiter-Sun.



Note 3: As we are also requested to provide the Earth-Jupiter distance in kilometres, you should apply the conversion AU to km. **The distance of 1 AU is the Earth-Sun distance, of 150 000 000 km (149 584 372 km)**

Note 4: The Earth-Jupiter distance is not a constant value along the year.

Convert the distance between Earth and Jupiter from astronomical units into kilometres.
Write your calculations here

$d_{JE} =$	au	km
------------	------	------

Table 8: Distance between the Earth and Jupiter for a particular time (time dependent)

• **Paso 3: Apply your knowledge about trigonometry**

1. Use the diagram shown in Figure 20 to help you with your calculations, where θ represents the angular distance between Jupiter and the moon, d_{JE} , the distance between Jupiter and the Earth and R the orbital radius of the moon around Jupiter.

Note: Remember that for very small angles, as it is the case for the angular radius moon -Jupiter, the value of the tangent of the angle is comparable with the sinus of the angle or even the value of the angle itself.



$$\tan \theta = \frac{R}{d_{JE}}$$

$$R = d_{JE} \cdot \tan \theta$$

$$\tan \theta \approx \sin \theta \approx \theta$$

Figure 20: View to calculate the Jupiter-moon distance

$$R = d_{JE} \cdot \theta \text{ (Equation 2)}$$

2. **Use the Equation 2 to calculate the radius of the orbit of the moon, R , (in kilometers) and fill in Table 9 (with its value in meters).** Emplea los valores de Stellarium de:
 - θ : radio angular entre Júpiter y la luna
 - d_{JE} : distancia Tierra- Sol



$R = d_{JE} \theta$

$R =$	km	m
-------	------	-----

Table 9: Results for the orbital radius of the moon

• **Step 4: Calculate the velocity of your moon**

Once you have the radius of the orbit you can calculate the velocity of the moon using the Equation 3

$$v = \omega \cdot R = \frac{2\pi}{T} R \quad (\text{Equation 3})$$

where, v , is the linear velocity, ω , is the angular velocity, T , is the period of the moon (in seconds) and R , is the orbital radius of your moon (in metres).

1. Complete Table 10 with the value of the lineal velocity

--	--

$v =$	m/s
-------	-------

Table 10: Results for the orbital velocity of the moon

Activity 8.3: Estimate the relative measurement errors

1. To check the relative errors in calculations you must compare your results with those values after some searching on internet.
2. To calculate the relative error for any measurement apply Equation 4.

$E_R = \frac{ \text{Measured Value} - \text{Real Value} }{\text{Real Value}} \cdot 100 \quad (\text{Equation 4})$

Table 11: Estimation of relative error for the orbital radius

Note 1: A negative value for the relative error will probably mean that the absolute value of equation (2) has not been applied.



Activity 9: Calculate mass of Jupiter

As explained in Phase 1, the mass of Jupiter can be derived from Equation 1.

(Equation 1)

$$M_J = \frac{4\pi^2 R^3}{G T^2}$$

1. Make use of the following area, putting the values for the orbital radius and orbital period obtained from Activity 8 in Table 12:

--

Table 12: Calculate the mass of Jupiter derived from Europa's movement around Jupiter

$M_J =$		kg
---------	--	------

Activity 10: Inspect data of a transit in ESA archived data.

Hypothesis

1. What do you see in Figure 21?

--



Figure 21: Io and Europa transit, using Stellarium. (Credit: Stellarium)

2. Do you think that is correct to say that we can see transits of Galilean moons in front of Jupiter?

3. May we predict these transits? How?

Experiment

- Video tutorial: <https://youtu.be/EbcBJGD1RDw>

Activity 10.1: Getting familiar with ESASky and access to the scientific data of your favourite target

1. Click on ESASky (<https://sky.esa.int>) and select the option "Science".



Figure 22: Welcome page to ESASky (Credits: ESA)

2. **Search for “Jupiter” in ESASky:** Write the name of “Jupiter” in the search window, at the top right part of ESASky and press “Enter”.
3. Access to the observations of “Jupiter” in the ESA archives with scientific images. For this click on the top left second icon (identified in Figure 23, with the shape of a galaxy). This will display a menu similar to the one in Figure 23, where we see squares in green and in purple, that represent:
 - **In size:** the amount of imaging observations of Jupiter within the Solar System Objects (SSO) catalogues, stored in the [Hubble Space Telescope \(HST\)](#) and the archives.
 - **In colour:** The wavelength at which those observations were collected by their scientific instruments, being green the optical range (for HST) and purple the UV/X-ray (for XMM-Newton).

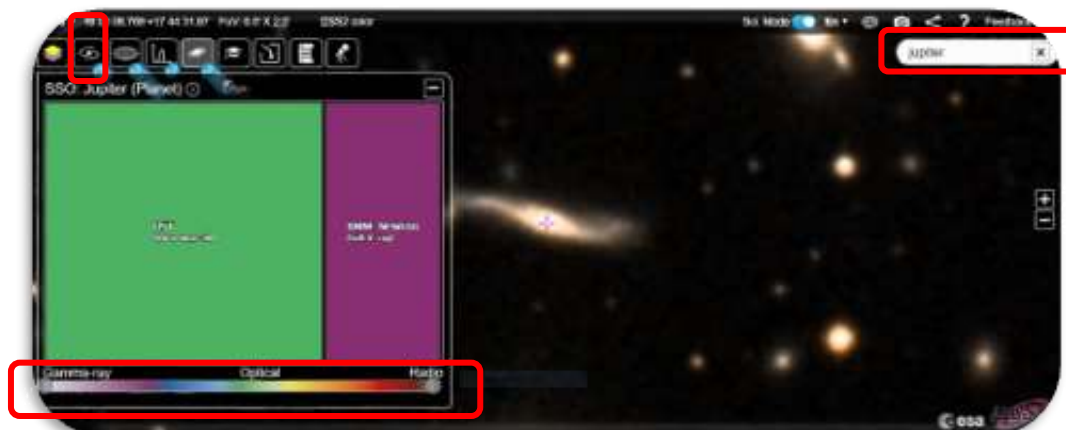


Figure 23: Explore image observations for a selected region (Credit: ESA)

4. **Explore the HST data of Jupiter:**
 - a. Click on the green square and this will display a table, as shown in Figure 24. The table will display, in slots of 50 observations, the HST images with Jupiter in their field of view.

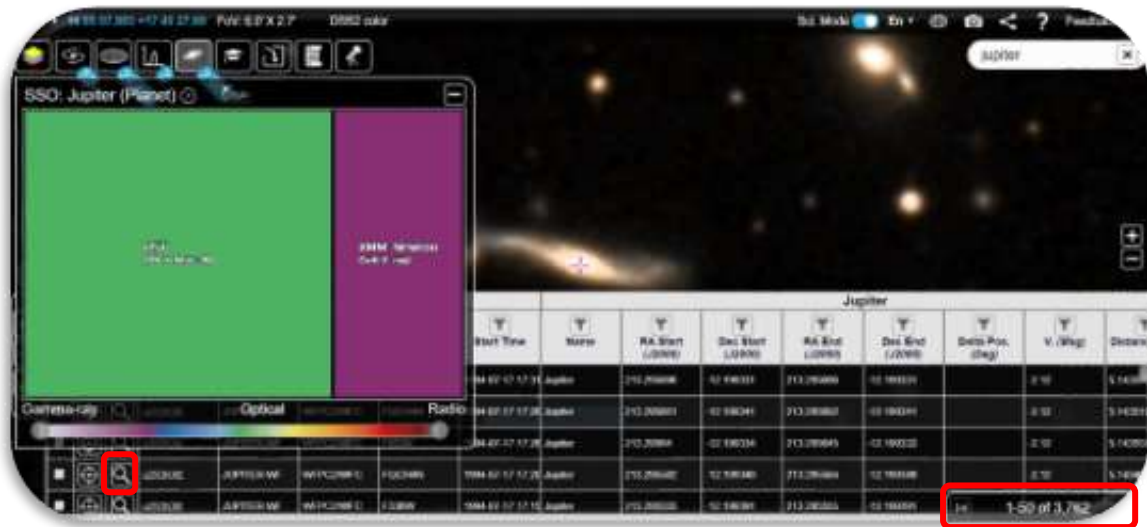


Figure 24: HST imaging observations of Jupiter (Credit: ESA)

5. Inspect images of Jupiter collected by HST:

- Click on the magnifier, as shown in Figure 25.
- By double clicking on the image of Jupiter you will be able to see it better. Resize the image (CTRL+ or CTRL-) as it is shown in Figure 26.

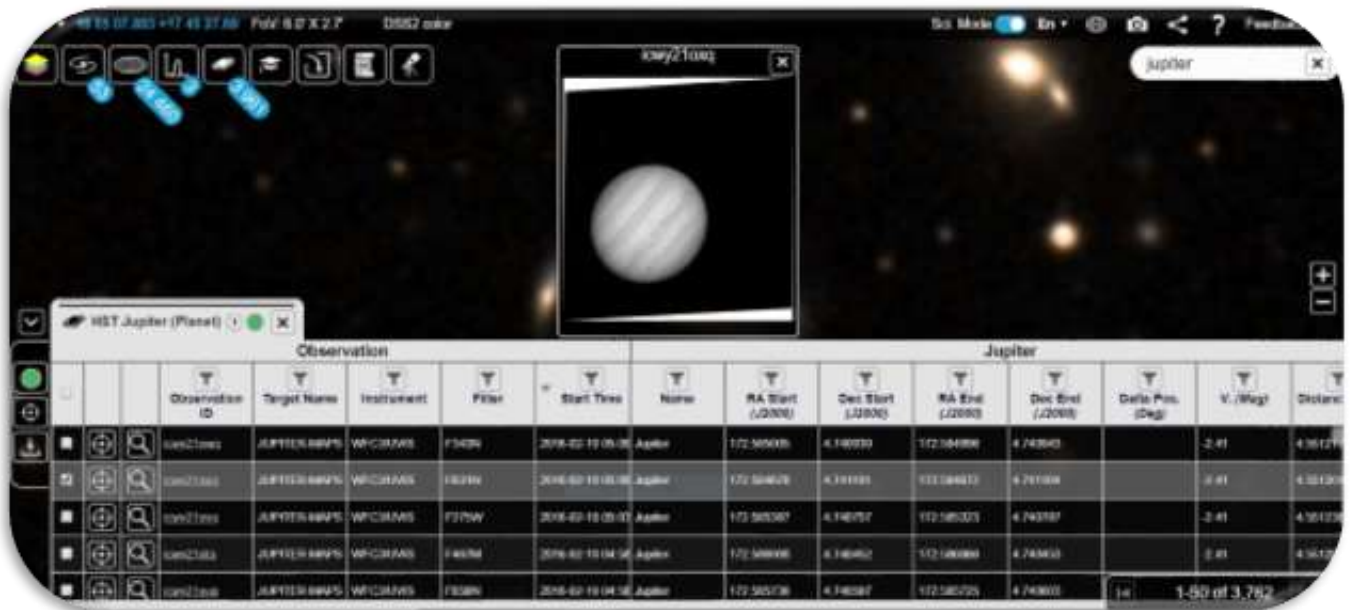


Figure 25: Selection of one of the HST observations of Jupiter (Credit: ESA)



Figure 26: HST image of Jupiter obtained from the image selected in Figure 18 (Credit: ESA)

Activity 10.2: Identify the transit of Europa in the ESASky data of Jupiter

1. After the execution of [Error! Reference source not found.](#), let's inspect our list of Jupiter images and search for a transit of Europa.
2. Let's find the HST image collected in 2013-12-29, that means 29th of December in 2013.
3. Organize your table by time. For this you can click at the top part of the column "start time", indicated in Figure 27



Figure 27: Jupiter images collected by HST on 2013-12-29. (Credit: ESA)

4. Once identified, by time, your observation, have a look at the magnifier and inspect it, as shown in Figure 28.

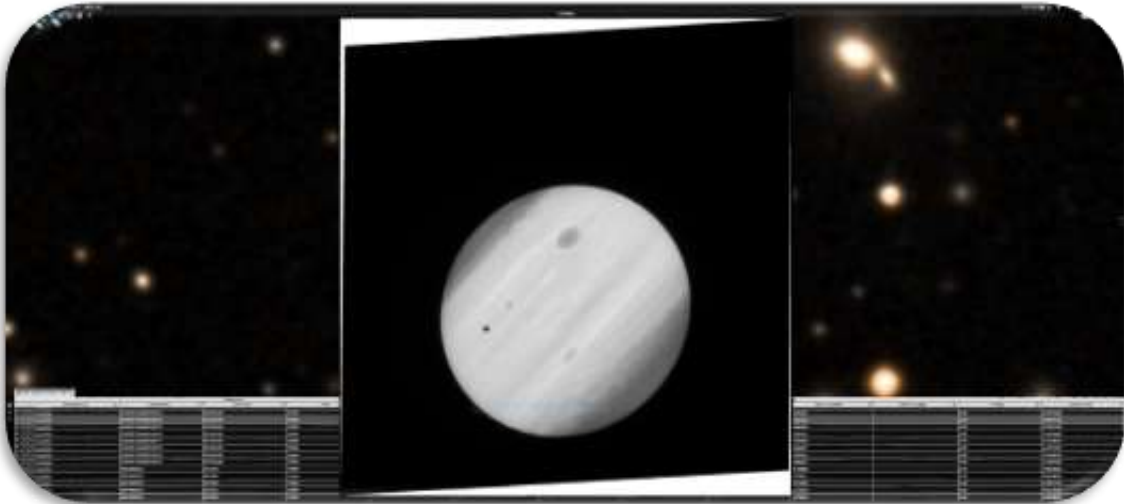


Figure 28: View of one of the Jupiter images collected by HST on 2013-12-29. (Credit: ESA)

We do not know in advance which one the Galilean moon(s) create(s) the transit effect

Why could we know that the transit is caused by a Galilean moon?

Activity 10.3: Analyse data of a transit of Europa as scientist do

Activity 10.3.1 : Inspect HST scientific data with SalsaJ

1. Download the **set of images** ([attached](#)) of a transit of Europa in front of Jupiter collected by [the Hubble Space Telescope](#).
2. Download [SalsaJ software package](#) and install it
3. Open the data (1 dimension FITS format, PNG format, JPG format) in Salsa J ([SalsaJ tutorial](#))

File -> Open -> [select data]



Figure 29: Inspection in SalsaJ of the set of data provided for this challenge. (Credit: ESA/ SalsaJ/ CESAR)

Activity 10.3.2 : Inspect HST scientific data with SAODS9

We are going to inspect HST data of the transit of Europa in front of Jupiter during the time period.

1. Download the **set of images** ([attached](#)) of a transit of Europa in front of Jupiter collected by [the Hubble Space Telescope](#).
2. Install [SAODS9](#) software package
3. Watch [video 3](#) to see how to do so and replicate Figure 24.

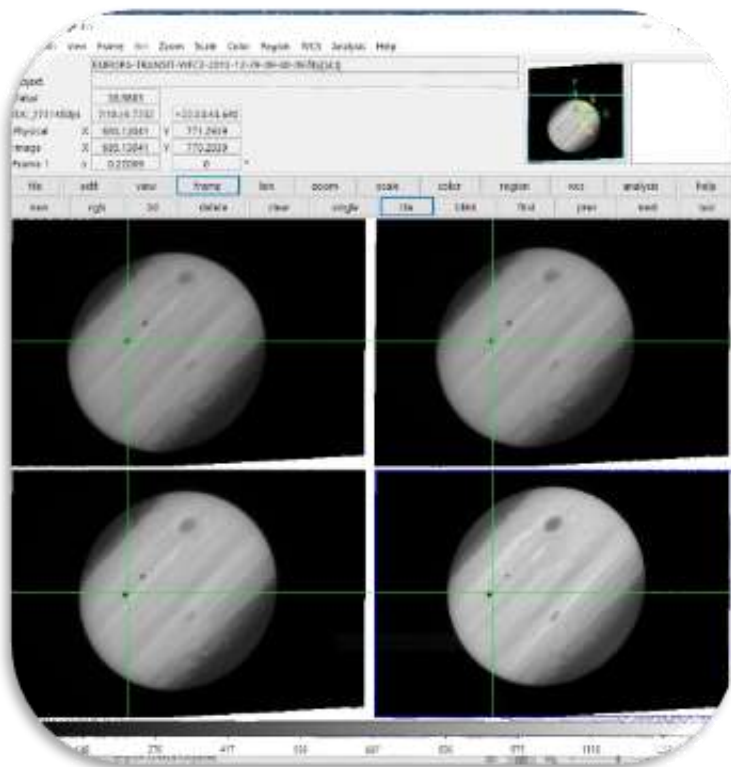


Figure 30: Inspection in SAODS9 of the set of data downloaded from ESA archives for this challenge (HST data of the Transit of Europa observed on 2013-12-29) . (Credits: ESA/ SAODS9/ CESAR)



Activity 11: Predict a consecutive transit.

Activity 11.1: Predict a consecutive transit with Stellarium

Note: To solve this Activity we need to know the orbital period of Europa around Jupiter.

- If you have calculated the orbital period of Europa (in Activity 8.1), execute the following Procedure.
- If not, return to [Activity 8.1](#) and calculate the orbital period of Europa and afterwards, execute the Procedure.

Procedure:

1. **Open Stellarium**
2. **Travel in location:** search for Júpiter and “go to” it (Use [Activity 8.1 as reference](#))
3. **Travel in time:** search for the date of 2013-12-29T09:40 (edit the Stellarium menu for it)
4. **Do you see the planet Jupiter and the moon shades?**
 - If the answer is YES
 - If the answer is NO, travel in time until you see this picture
5. Predict the following transit as it is shown in this [video](#)

Note: Each time they press the “forward icon” the speed rate is multiplied by 10, therefore just touching this button two or three times the motion will be adequate for this Activity.

Activity 11.2: Other methods to predict a transit

1. Click on https://skyandtelescope.org/wp-content/plugins/observing-tools/jupiter_moons/jupiter.html

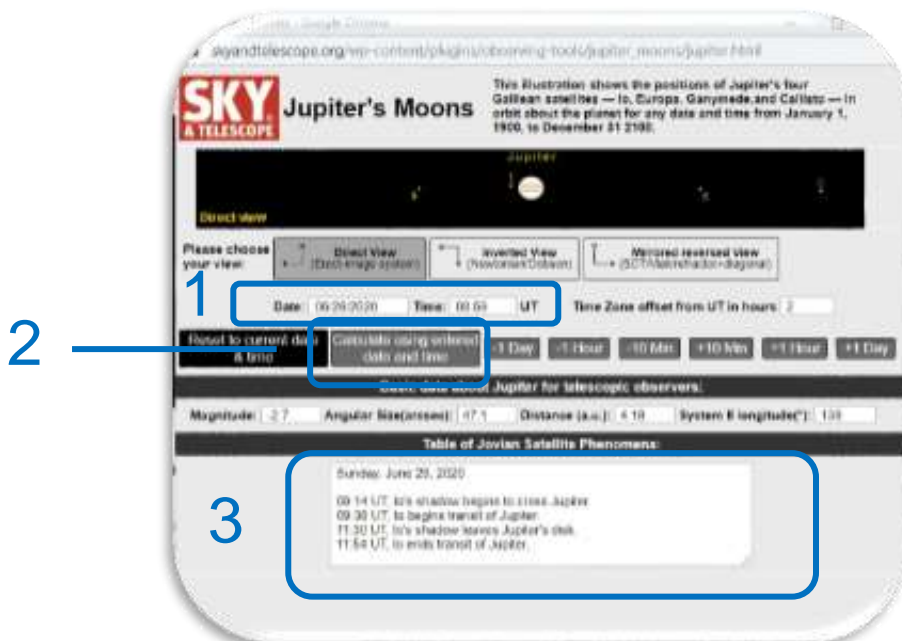


Figure 31: Sky Telescope Jupiter's transits predictor



2. How do I use this web?

- Enter the predicted **date and time** of the transit in the text boxes labelled number 1 in Figure 30.
- Click on “**Calculate using entered date and time**” labelled 2, to have a representation of the moons position at that time.
- All the information will be displayed in the textbox labelled 3.

Conclusions

When was the following transit of Europa, in front of Jupiter after the one detected in 2013-12-29T09:40?



Phase 4



Congratulations! You have completed your Science Challenge! Tell us your story!

Stop to think about the Experience with your Team and teacher and complete these Activities.

Activity 12: Evaluation

- **Teams:** Fill in this [questionnaire](#) so that you can check what you have learned in the Challenge.

Activity 13: Present your results

Students will have to create a final product (an A0 poster in pdf format, using power point, for example) showing what they have learned in the different phases of the Scientific Challenge.

This poster is the ticket to participate in the CESAR international adventure competition .



Links



Phase 0

- <https://www.youtube.com/watch?v=9wdbNU7Pu8U&feature=youtu.be>
- [http://www.esa.int/ESA_Multimedia/Videos/2015/01/ESAC ESA s Window on the Universe](http://www.esa.int/ESA_Multimedia/Videos/2015/01/ESAC_ESA_s_Window_on_the_Universe)
- <http://cesar.esa.int/index.php?Section=Multimedia&Id=63>
- <https://ingemecanica.com/tutoriales/unidadesdemedida.html>.

Phase 1

- <https://www.youtube.com/watch?v=Y8-T8RouhPA>
- <https://www.pinterest.es/pin/293226625732878538/>
- [http://cesar.esa.int/upload/201905/jupiter moons booklet pdf.pdf](http://cesar.esa.int/upload/201905/jupiter_moons_booklet_pdf.pdf) (Jupiter)
- [http://cesar.esa.int/upload/201905/jupiter moons booklet pdf.pdf](http://cesar.esa.int/upload/201905/jupiter_moons_booklet_pdf.pdf)
- <http://astro.unl.edu/classaction/animations/renaissance/kepler.html>
- <http://stellarium.pdf>
- [http://www.esa.int/ESA_Multimedia/Videos/2013/07/Science ESA Episode 7 Exploring our backyard the Solar System/\(lang\)/es](http://www.esa.int/ESA_Multimedia/Videos/2013/07/Science_ESA_Episode_7_Exploring_our_backyard_the_Solar_System/(lang)/es)
- [https://www.esa.int/ESA_Multimedia/Videos/2013/07/Science ESA Episode 10 Diverse worlds The Moon and Titan/\(lang\)/es](https://www.esa.int/ESA_Multimedia/Videos/2013/07/Science_ESA_Episode_10_Diverse_worlds_The_Moon_and_Titan/(lang)/es)
- [El sistema solar.](https://www.esa.int/ESA_Multimedia/Videos/2013/07/Science_ESA_Episode_10_Diverse_worlds_The_Moon_and_Titan/(lang)/es)
- [https://www.esa.int/ESA_Multimedia/Videos/2013/07/Science ESA Episode 10 Diverse worlds The Moon and Titan/\(lang\)/es](https://www.esa.int/ESA_Multimedia/Videos/2013/07/Science_ESA_Episode_10_Diverse_worlds_The_Moon_and_Titan/(lang)/es)
- <https://www.youtube.com/watch?v=gDWftjNUKqk>
- https://youtu.be/tjOn-N_cu0
- <https://sci.esa.int/web/juice/-/50068-science-objectives>
- <https://sci.esa.int/web/juice/-/59908-juice-s-secondary-target-the-jupiter-system> (JUICE)
- [https://sci.esa.int/web/juice/-/59334-exploring-jupiter\(en inglés\)](https://sci.esa.int/web/juice/-/59334-exploring-jupiter(en%20ingl%C3%A9s))
- <http://scifleet.esa.int/#/>
- <http://cesar.esa.int/form.php?Id=4&k=&ChangeLang=en>

Phase 2

Phase 3

- <https://drive.google.com/file/d/17yJ25ne0kONn4tje12o3OT-sz3iP7dAa/view?usp=sharing>
- [ESASky](#)
- [SalsaJ installed](#)
- [SalsaJ tutorial](#)
- [SAODS9 installed](#)

Phase 4

- <http://cesar.esa.int/form.php?Id=4&k=&ChangeLang=en>
- [http://cesar.esa.int/index.php?Section=SSE Contest&ChangeLang=en](http://cesar.esa.int/index.php?Section=SSE_Contest&ChangeLang=en)



Credits:

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Initial version: http://cesar.esa.int/index.php?Section=SSE_The_Mass_of_Jupiter