# 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 Bross)*

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.
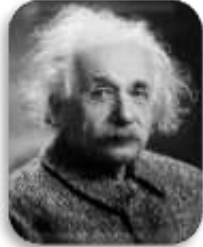
| Challenge ID | | | Team number (1-6): | |
|---|---|---|---|---|
| **Names** | | | | |
| **Profession** | **Mathematician/ Software engineer** | **Astrophysics** | **Engineer** | **Biologist** |
| **Roles** | Lead the correctness of the calculations | Lead the use of telescope and the understanding 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** **(female)** | [Katherine Johnson](#)  | [Vera Rubin](#)  | [Samantha Cristoforetti](#)  | [Marie Curie](#)  |
| **(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 |
|---|---|---|

*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. They came up as a result of applying maths to the astronomical observations collected by Tycho Brahe (1546-1601).

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:
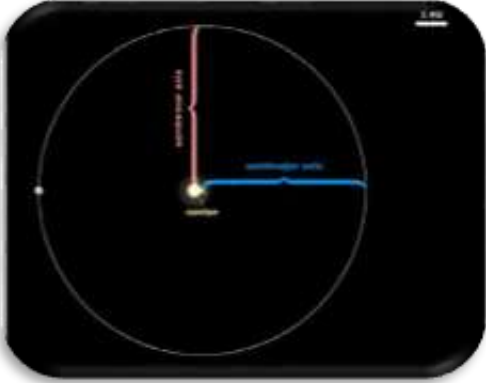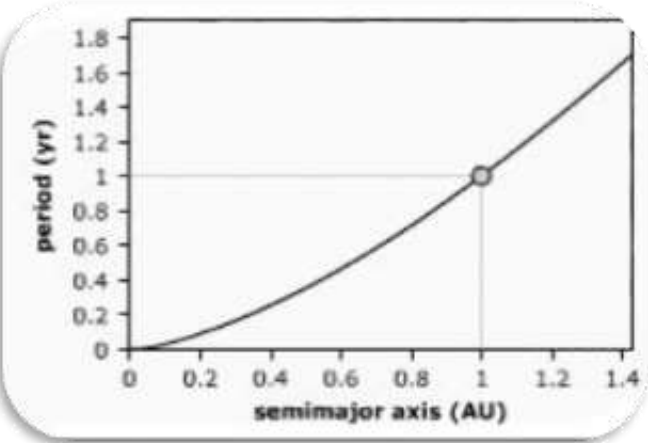
| Kepler Laws | Simulator to test that Law |
|---|---|
| *First Law:* The orbit of every planet is an ellipse, with the Sun at one of the two foci. |  |
| *Second Law:* A line joining a planet and the Sun sweeps out equal areas during equal intervals of time |  |
| *Third Law:* The square of the orbital period of a planet, *T,* is proportional to the cube of the semi-major axis of its orbit, $R$: $$T^2 \propto R^3$$ |  |

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

## How to calculate the mass of Jupiter?

We are going to explain the equation that we will use to calculate the mass of Jupiter from the movements of their moons around it.

Let's remember the **Newton's Law of Universal Gravitation** from 1687, that says:

*" the force between two bodies of masses $(m)$ and $(M)$, with a distance between their center of masses $(r)$ is proportional to the product of the two masses and inversely proportional to the square of the distance between:*

$$F_g = \frac{GMm}{r^2}$$

Where $G$ is the Universal Gravitation constant, with a value $G = 6.674 \cdot 10^{-11} \, m^3 \, kg^{-1} \, s^{-2}$

Let's have a look to Figure 4, where a body such as the Earth, with mass $(m)$, orbits around another body of higher mass $(M)$, like the Sun.

By simplicity, we assume that there is a circular movement without friction at a constant speed. Under this assumption, the Earth would be in equilibrium of forces between the gravitational force $(F_g)$, generated by the attraction of the Earth towards the Sun, and the centrifugal force $(F_c)$, caused because of following the rotation.
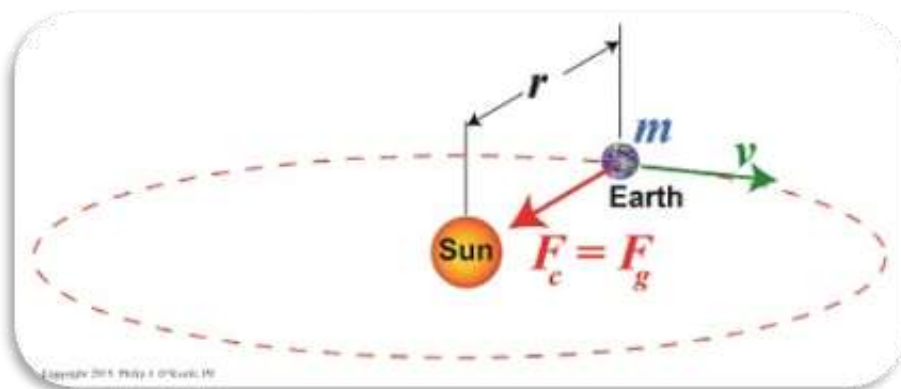


*Figure 4: Second Law of Newton (Credit: https://www.toppr.com)*

$$\boxed{F_g = F_c}$$

$$F_g = \frac{GMm}{R^2} \qquad and \qquad F_c = m\, a_c$$

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

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

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

For the equation of the moon, $v$, is the linear velocity (in meters per second), $r$, is the orbital radius (in meters), $\omega$, is the angular velocity (expressed in radians per second), $T$, is the orbital period (in seconds) and, $G$, is the gravitational constant, with a value of $G = 6.674 \cdot 10^{-11}\, m^3\, kg^{-1}\, s^{-2}$

**The same situation could be applied if $(M)$, were Jupiter (or another planet) and the less massive $(m)$, spinning around one of their moons.**

We have therefore deduced the Third Kepler's Law, for a constant mass, $M$, (or $M_J$, the Jupiter mass, in the case of the system Jupiter-moon) and to say *"The square of the orbital period of a planet, $T$, is proportional to the cube of the semi-major axis of its orbit, $r$ :*

$$cte = \frac{GM}{4\pi^2} = \frac{r^3}{T^2} \qquad \rightarrow \qquad \boxed{T^2 \propto r^3}$$

From this equation, we could derive $M$, o $M_J$, the mass of Jupiter such as:

$$\frac{GM}{4\pi^2} = \frac{r^3}{T^2} \qquad \rightarrow \text{(Equ. 1)} \qquad \boxed{M_J = \frac{4\pi^2\, r^3}{G\, T^2}}$$

**The Equation 1 is going to be used in this Scientific Challenge to derive the mass of Jupiter.** We are going to measure the orbital period $(T)$ and the orbital radius of a Galilean moon $(r)$ and introduce these values in that Equation.

*Figure 5: Stellarium logo. (Credits: Stellarium)*

## Activity 2: Compare Jupiter and the Earth.

Fill in Table 3 comparing some properties of Jupiter and the Earth.

| Properties | Earth | Jupiter |
|---|---|---|
| Radius | | (11 times Earth radius) |
| Density | 5.5 g/cm$^3$ | |
| Average temperature | 20°C | |
| Distance to the Sun | 1 AU | |
| Moons | 1 | 79 |
| Type of planet | | |
| Composition | • Silicates mantel, metal core & crust<br>• Atmosphere: nitrogen, oxygen, argon. | |
| Magnetic fields | yes | |

*Table 3: Compare Jupiter and the Earth*

The Jovian system
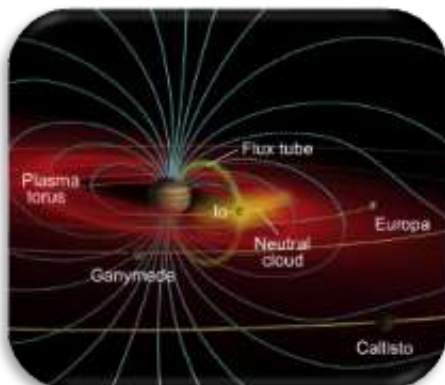
Sun-Earth-Moon system
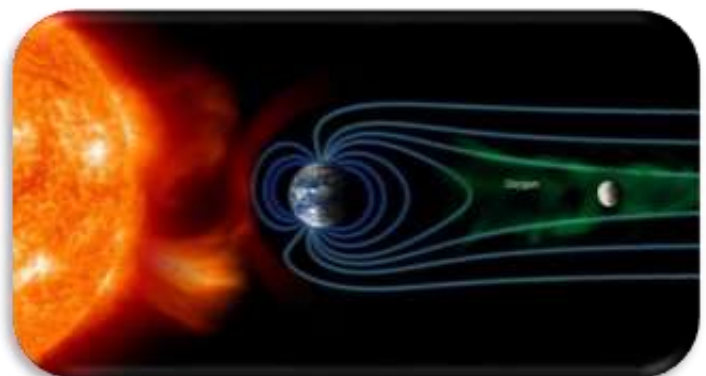


*Figure 6: Magnetic fields around the (Credit: http://www.esa.int/Observing_Jupiter)*

## 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](detected as of 2021) – the highest number of moons in the Solar System. This number includes the **Galilean moons**: **Io, Europa, Ganymede, and Callisto**, that are the Jupiter's largest moons and the first four to be discovered beyond the Earth, by astronomer Galileo Galilei in 1610. The Galilean moons 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.
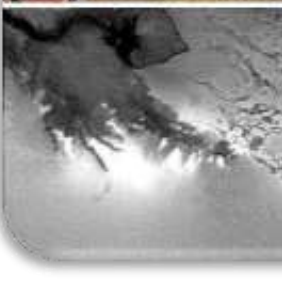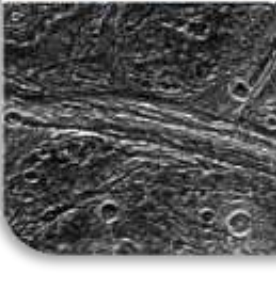


| Io | Europa | Ganymede | Callisto |
|----|--------|----------|----------|
| The most volcanically active object in all the Solar System due to the inward gravitational pull from Jupiter and the outward pull from other Galilean moons. | A cold world that might have a liquid water ocean beneath a thick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

*Table 4: Jupiter's Galilean moons as imaged by NASA's Galileo spacecraft. Image (Credit: NASA/JPL/DLR)*

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)*

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

## 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 NASA space missions such as **Pioneer 10**, **Pioneer 11**, **Voyager 1, Voyager 2** and **Cassini-Huygens** have flown around Jupiter. 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.

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[1]In astronomy, a **transit** (or **astronomical transit**) is a phenomenon when a celestial body passes directly between a larger body and the observer.

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 in 2029.

The **mission observing targets** are Jupiter and the moons that could contain water (and maybe host life?) , Ganymedes, Callisto and Europa. The JUICE science objectives are to characterise the conditions that may have led to the emergence of habitable environments among the Jovian icy satellites.

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
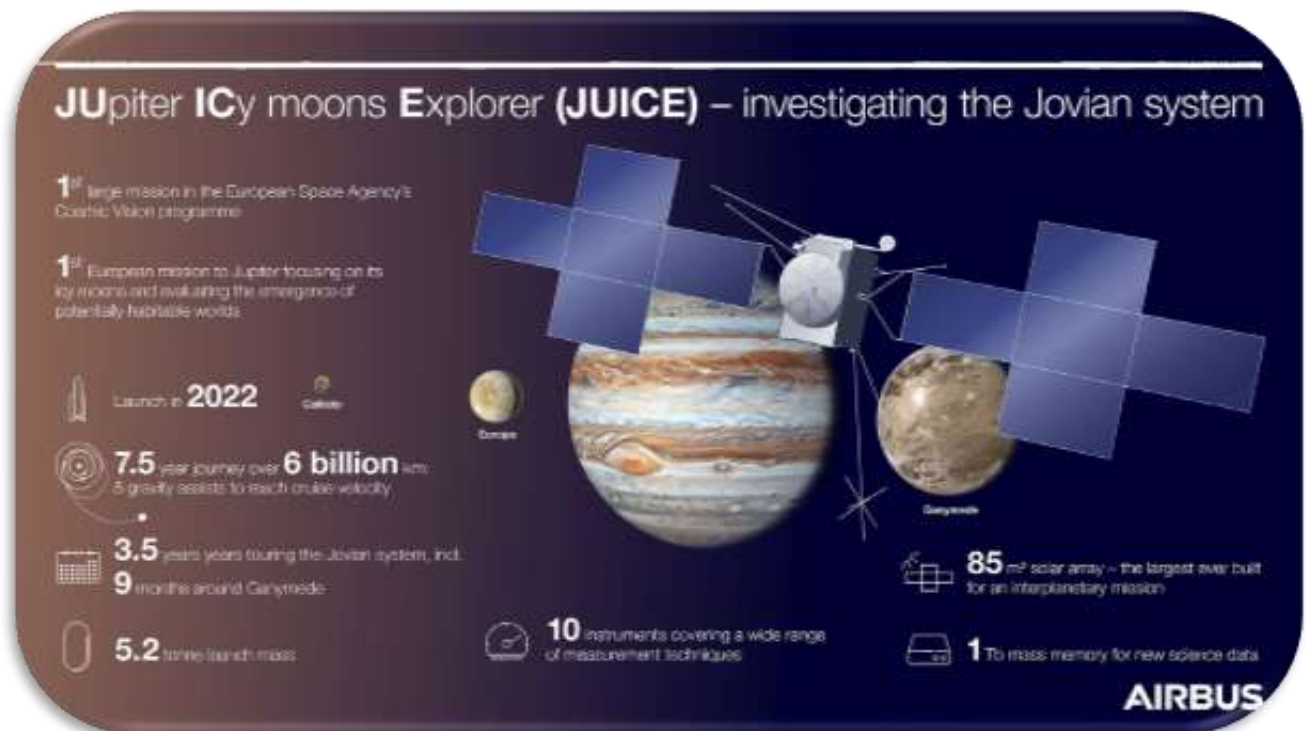


**Figure 8:** *Infographic about the JUICE mission (Credits : AIRBUS)*

## 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: The Galilean moons. Choose your favourite moon.

In this Activity you are going to get to know the Galilean moons and to select your favourite moon to be used to calculate the mass of Jupiter. You could use one of these two modes:

**MODE 1: Using Cosmographia**

The installation of Cosmographia is done without any cost from this website:
https://naif.jpl.nasa.gov/naif/cosmographia_components.html.

If your platform is:

- **Mac OSX (64 bit**), this is the link:
  http://naif.jpl.nasa.gov/pub/naif/cosmographia/packages/cosmo-installer-4.0-osx.dmg
- **Windows (64-bit)**, this is the link:
  - o  http://naif.jpl.nasa.gov/pub/naif/cosmographia/packages/cosmo-installer-4.0-windows.exe
- **Linux (64-bit),** this is the link:
  - o  http://naif.jpl.nasa.gov/pub/naif/cosmographia/packages/cosmo-installer-4.0-linux

Follow this Procedure in *Cosmographia:*

- **Step 1:** Launch the application of "Cosmographia", by double clicking on its icon.
  You will see on your screen an image like Figure 10.



*Figure 10: Initial view of Cosmographia. (Credits: Cosmographia)*

- **Paso 2:** Select at the top left menu the first option (white circles). You will see images of various Solar System bodies, as it is shown in Figure 11.
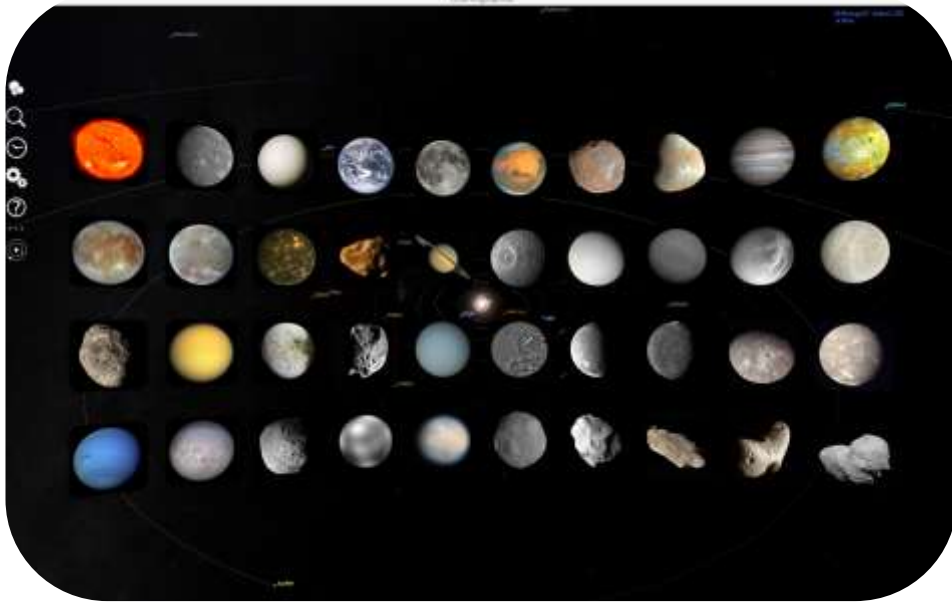


*Figure 11: Solar System bodies as seen in Cosmographia*

- **Step 3:** Look for the image of Jupiter and click on it. The app will drive you to Jupiter.

- **Step 4:** Fit the field of view (expanding or shrinking it) until you see the four Galilean moons appearing on your screen, as shown in Figure 12.

   **Note:** By default Cosmograhia shows the locations of the Solar System objects at the present moment, so you may have a slightly different view than Figure 12.



*Figure 12: Jupiter and the galilean moons as seen in Cosmographia*

- **Step 5:** If you want to know more information of each one of the objects (such as Jupiter and/or its moons)
    - Right click with the mouse on top of each of the objects.
    - In the displayed menu (see Figure 13) select the option "Show properties".

- **Step 6:** If you want to see the trajectory of a selected object, on the same menu (right mouse) choose the option "Trajectory", shown in Figure 13.
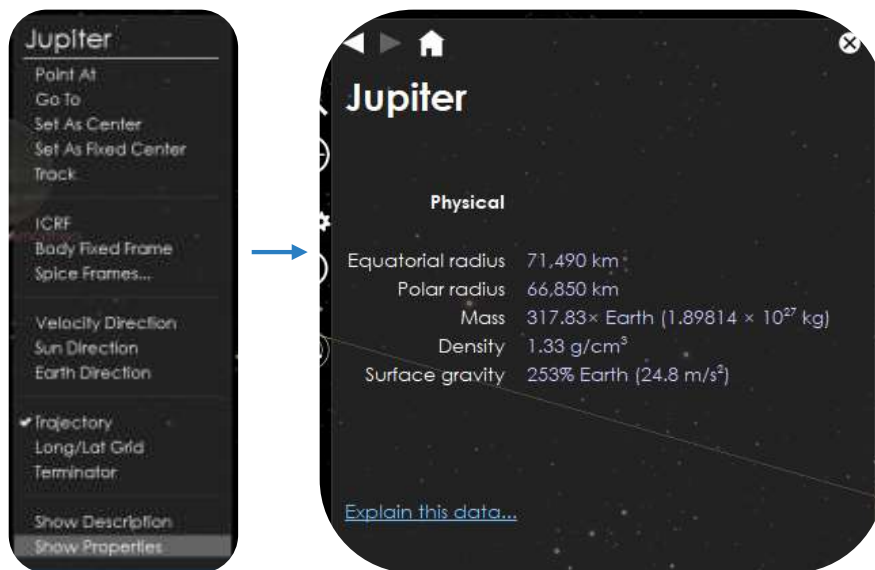


*Figure 13: Click on Jupiter with the right mouse in the menu of properties.*

- **Step 7:** Use the information given by *Cosmographia*, about the physical properties of the galilean moons (Io, Europa, Ganymedes, Callisto) to complete Table 5.

| Objeto | Masa (kg) | Radio (km) | Densidad (g/cm³) |
|---|---|---|---|
| Júpiter | | | |
| Io | | | |
| Europa | | | |
| Ganímedes | | | |
| Calisto | | | |

*Tabla 5: Propiedades físicas de Júpiter y sus lunas galileanas*

**MODE 2: Refresh Phase 1**

Complete Table 6 with the information that you remember from Phase 1, Activity 3, to select your favourite Galilean moon. (Note: All the options are valid).



| | | | |
|---|---|---|---|
| | | | |

*Tabla 6: Escribe lo que recuerdas de las lunas galileanas, visto en la Actividad 3.*

**With all that you know now about the Galilean moons, our favourite galilean moon is …**

**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 this table and use it 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 of Stellarium).
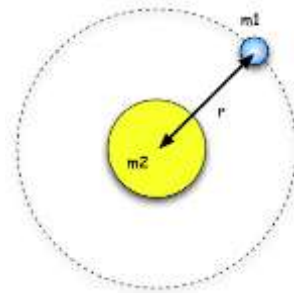


**Figure 10:** *Representation of an orbital radius, r.*
*(Credits: Wikipedia)*

## 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 (Credits: Stellarium)*

- **Step 2: Go 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 on your console** (CTRL-C & CTRL-V commands).

    3. **Click on the play button** (▶).

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

```
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. (Credits: Stellarium)*



*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.**

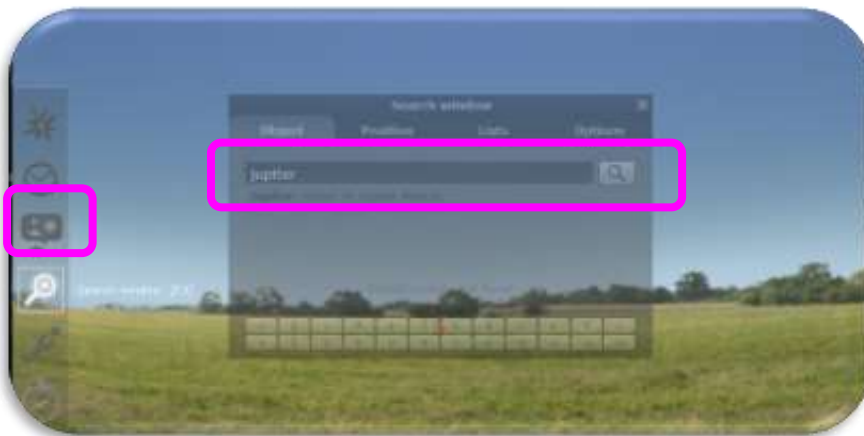1. Click on this search icon and type in Jupiter, as shown in Figure 14.



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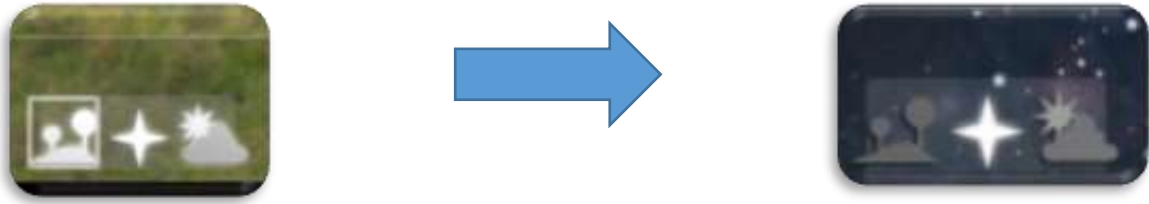
*Figura 15a: Stellarium control commands to enable (left image) and disable (right image) the ground and the atmosphere effects (Credits: Stellarium)*

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, where one of its axis is align with the polar star. This can be done by enabling this option (  )
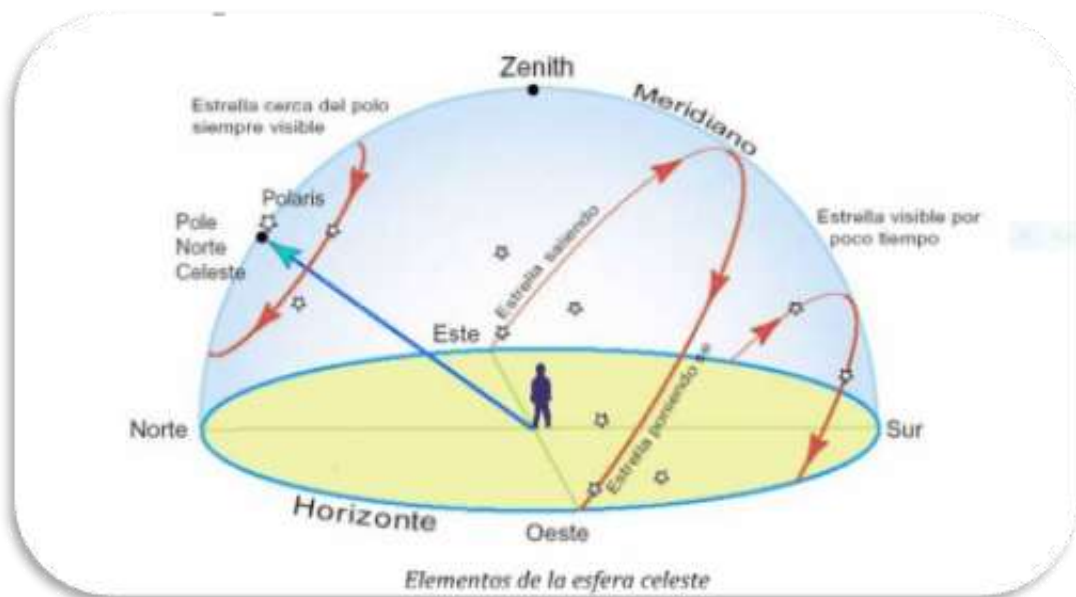


*Figura 15 b.: Apparent star movement as shown by an observer at a certain location on Earth. (Créditos: https://www.uv.es/fabregaj/apuntes/AstronPos.pdf)*

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

To study the orbital movement of your moon you need to check how much time does it take to the moon to cover a complete loop. For this you need to know how to use the basic time setting, which is located at the bottom cursor of the screen:



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

| | |
|---|---|
| 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), start the movement of the moons and/or move it forward faster by pressing twice the forward icon. | ▶▶ |

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



Tierra, Madrid, 665 m          FOV 0.167°    25.3 FPS    2020-08-18 14:39:18 UTC+02:00
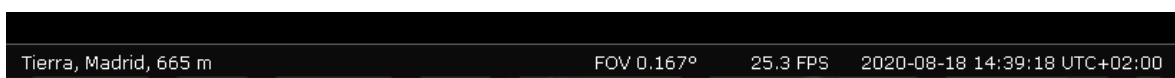
*Figura 17: Where to set up the date and the time in Stellarium. (Credits: Stellarium & CESAR)*

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 your moon to 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) that is the difference between these two dates calculated. What value do you get?**

| Initial date (YYYY-MM-DD hh:mm:ss) | Final date (YYYY-MM-DD hh:mm:ss) |
|---|---|
| | |
| *Calculate the time difference here* | |

*Table 6: Initial and final date of your moon*

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

**Note:** In *Stellarium* we see the jovian system as seen from the Earth. Its moons actually move in a circular movement around Jupiter, but we are viewing the 2D projection, as in Figure 18.
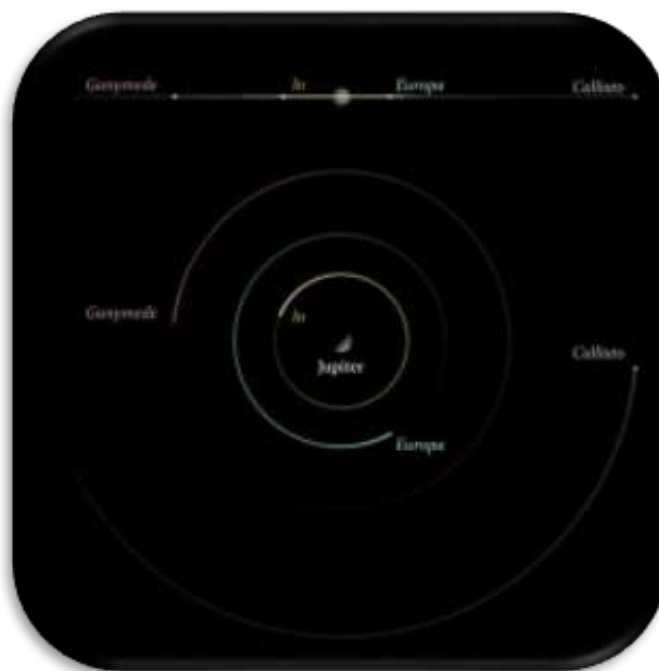


*Figure 18: Visualization of the Jupiter moons (Credits: CESAR)*

## 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 (** [icon] **on the left 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'.
            - Restart *Stellarium*

- **Step 2: Identify the orbital radius**

    1. **Stop the movement of the moons around Jupiter** by clicking on [icon] in the menu at the bottom of the screen (or K on your keyboard)

    2. In the same menu, click on [icon] (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).
        - Repeat your measure as many times as needed to be sure that you are comfortable with it.

        **Note:** The calculations are only valid if the measurements are made from the centre of both objects.

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*.
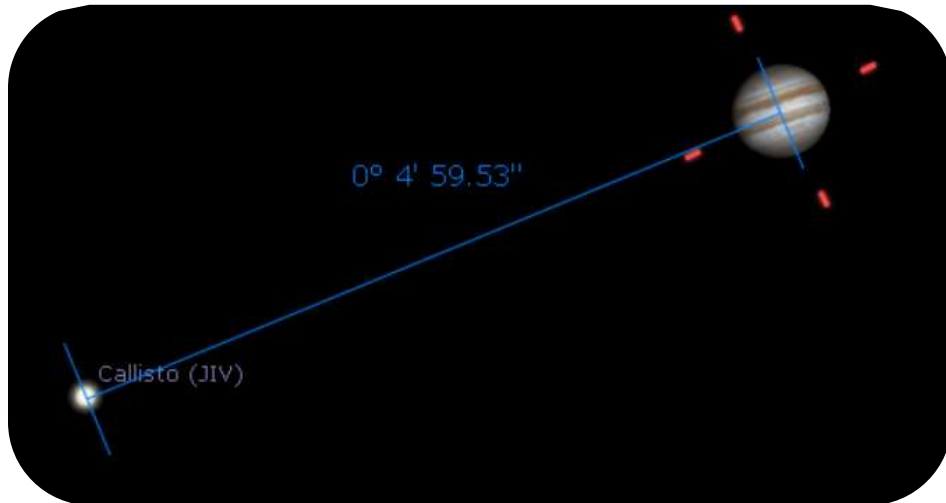


*Figure 19: Using Angle Measure plugin. (Credits: Stellarium)*

| Maximum distance of your Moon to Jupiter | ° ' " | ° |
|---|---|---|
| *Write your calculations here* <br> *1°= 3600 "* | *Remember: 1° = 60'    and    1'= 60"    →* | |

*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 kilometers.

| *Convert the distance between Earth and Jupiter from astronomical units into kilometres.* <br><br> *Write your calculations here* |
|---|

*Table 8: Distance between the Earth and Jupiter (the result is date dependent)*

| $d_{JE} =$ | $AU$ | $km$ |
|---|---|---|

(See notes)

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

**Note 2:** Do not confuse $d_{JE}$, with *d* in *Stellarium*, that represents the distance Jupiter-Sun.

**Note 3:** You are also requested in Table 8, to provide the Earth-Jupiter distance in kilometres. For this you should apply the unit conversion AU to km.

**An astronomical unit is the mean value of the Earth-Sun distance** (~150 000 000 km, 149 584 372 *km*)

**Note 4:** As you may guess, the Earth-Jupiter distance is not a constant value along the year.

- **Step 3: Apply your knowledge in trigonometry to calculate the orbital radius (in km)**

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.

2. Let's calculate the tangent of $\theta$

   - Remember the trigonometric expression of the **tangent of an angle** (Equation 2)
   - For very small angles, $\theta$ ~0, as it is the case for the angular radius moon-Jupiter, we could use the approximations that the value of *the tangent of an angle* is comparable with the *sinus of the angle* or even the value of the *angle itself*.
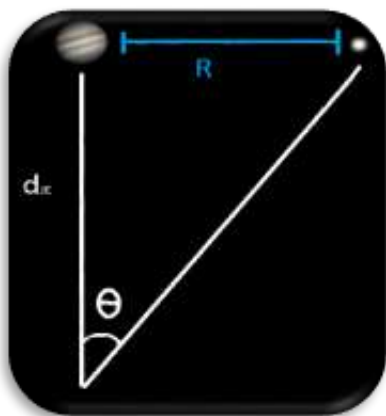


$$\text{(Equation 2)} \tan\theta = \frac{R}{d_{JE}}$$

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

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

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

*Figure 20: View to calculate the Jupiter-moon distance*

3. **Use the Equation 2 to calculate the radius of the orbit of the moon, $R$, (in kilometers and meters) and fill in Table 9.**
   - Emplea los valores de Stellarium de:
     - $\theta$ : moon angular radius
     - $d_{JE}$: Earth-Jupiter distance

$R = d_{JE}\ \theta$

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

*Table 9: Results for the orbital radius of the moon*

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

1. From 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, $\omega$, is the angular velocity, $T$, is the period of the moon (in seconds) and $R$, is the orbital radius of your moon (in metres).

2. Complete Table 10 with the lineal velocity value.

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

*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 (orbital period and radius) you must compare your results obtained in this Scientific Challenge with those obtained after searching on internet or given by your teacher.

2.  To calculate the relative error of any measurement apply Equation 4.

$$E_R = \frac{|\,Measured\ Value - Real\ Value\,|}{Real\ Value} \times 100 \qquad (Equation\ 4)$$

*Table 11: Definition of the estimation of relative errors*

**Note:** A negative value for the relative error will probably mean that the absolute value 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.

$$M_J = \frac{4\pi^2}{G}\frac{R^3}{T^2} \qquad \text{(Equation 1)}$$

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*

$$M_J = \underline{\hspace{6cm}} kg$$

## Activity 10: Inspect data of a transit in the ESA scientific archives.

### Hypothesis



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

1. What do you see in Figure 21?

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. Getting access to data of your favourite target

1. **Click on ESASky** (https://sky.esa.int) and select the mode *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
   - Press "Enter".

   **Note:** For ESASky to find the requested objects, they must be written in English and following the catalogues naming conventions. (ESASky provides possible searching options).

3. **Access to the observations of "Jupiter" in the ESA archives with scientific images**.
   - 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, with squares in various colours (green , purple, …) that represents:

- **The size of the squares:** the amount of observations of Jupiter, collected as images, within the Solar System Objects (SSO) catalogues, stored in the archives of ESASky (ESA, NASA and ground-based telescopes archives).
- **The colour of the squares:** The wavelength range at which those observations were collected. In the example, green stands for the range ultraviolet to near-infrarred (data collected by the Hubble Observatory) and purple the soft X-ray (data collected by the XMM-Newton Observatory).



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

4. **Explore the data collected by the *Hubble Space Telescope* (HST) of Jupiter:**

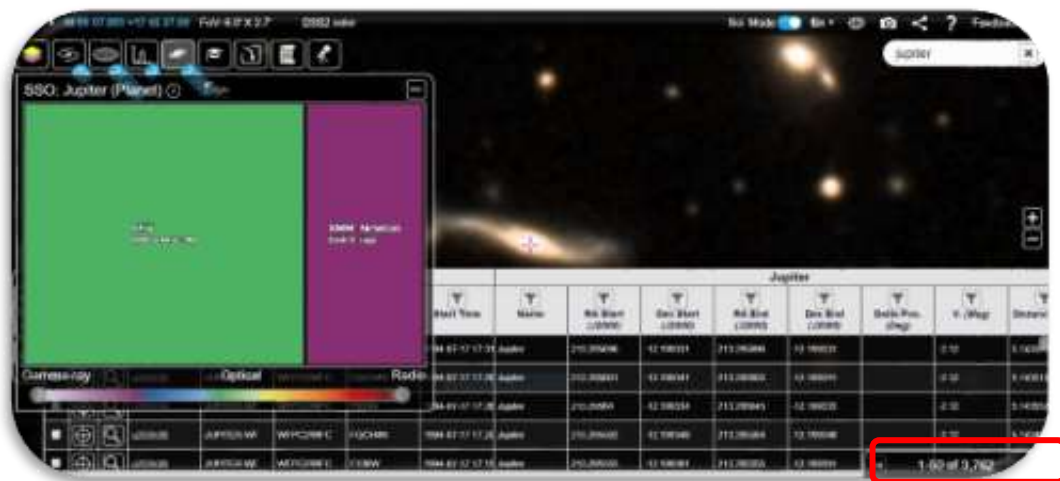- Click on the green square to see the available observations of Jupiter (Fig. 24)



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

## 5. Inspect the HST images of Jupiter:

- Select one row of the table de observations (Figure 25).

- Click on the magnifier, as marked in red in that Figure.

- By double clicking on the image of Jupiter you will be able to resize
  the image (our using the commands CTRL+ or CTRL-), as it is shown in Figure 26.
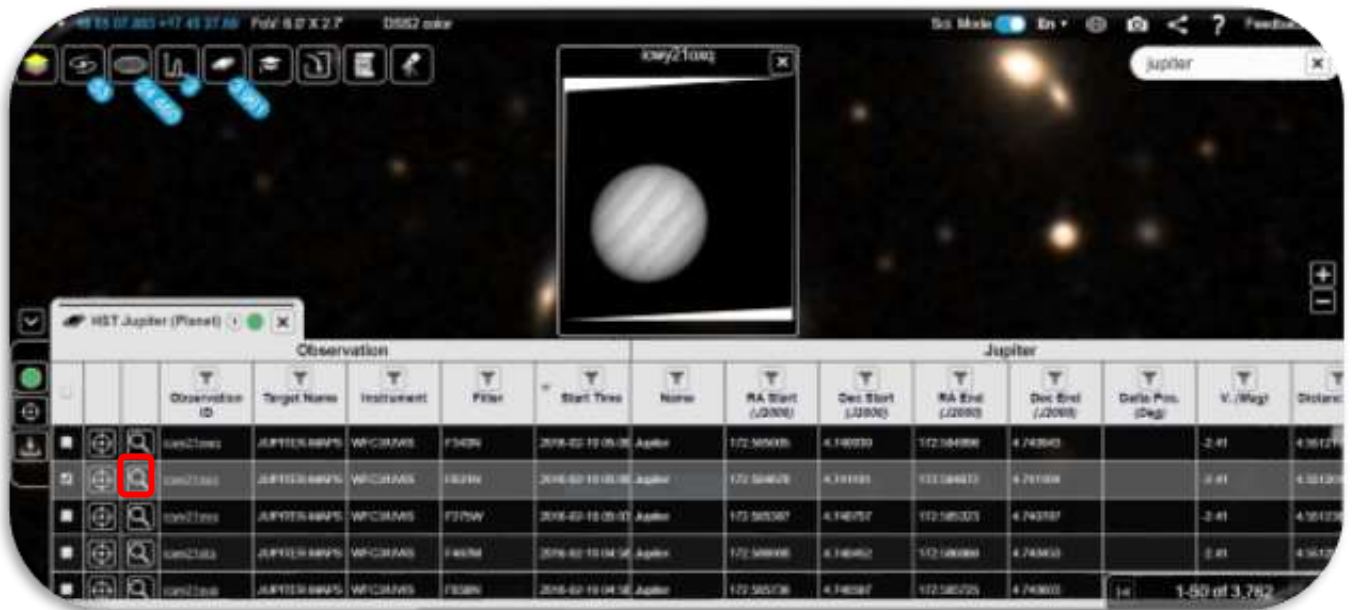


*Figure 25: Selection of one of the HST observations of Jupiter (Credits: ESA)*



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

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

1. After the execution of Activity 10.1, you are going to search, among the HST Jupiter images, those where the transit of the moon Europa in front of Jupiter is visible.

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, that represents the time when the data started to be collected in that selected observation.



***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

How could we know that the transit is caused by a Galilean moon or another?

## 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** (HST data-set of images) of a transit of the moon Europa in front of Jupiter collected by the Hubble Space Telescope.

2. Download SalsaJ software package and install it.

3. Open the data in Salsa J (SalsaJ tutorial)
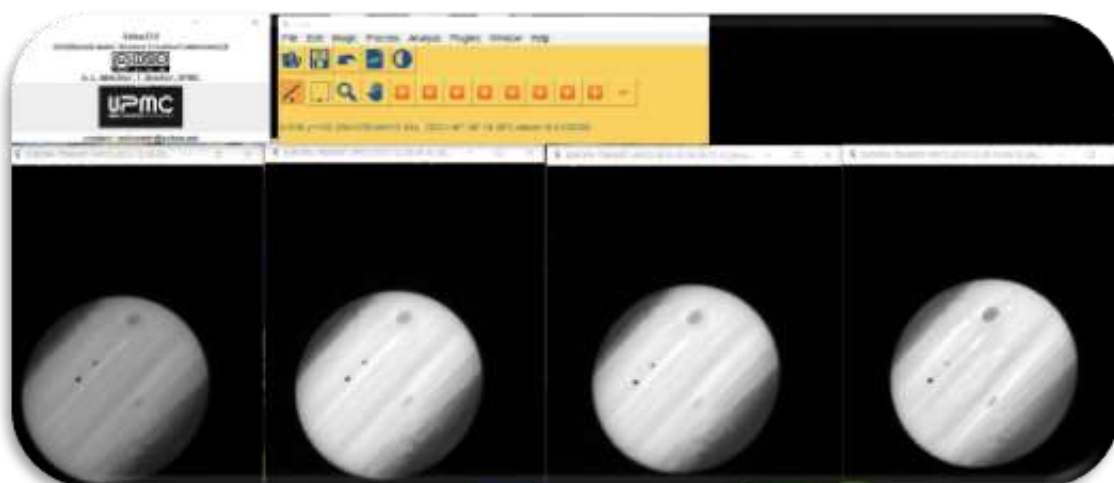
### *File -> Open -> [select data]*



*Figure 29: Inspection in SalsaJ of the set of data provided for this Challenge (Credits: ESA/ SalsaJ/ CESAR)*

## Activity 10.3.2 : Inspect HST scientific data with SAODS9

You are going to inspect HST data of the transit of Europa in front of Jupiter, for a certain time period.

1. Download a set of images ([data](#)) Jupiter collected by [the Hubble Space Telescope](#).
2. Install the [SAODS9](#) software package.
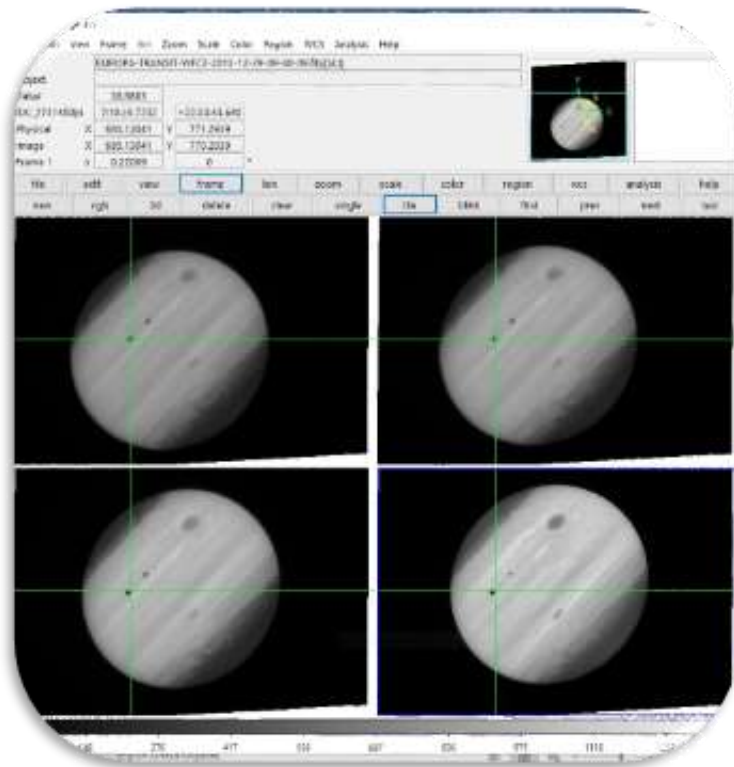3. Watch [video 3](#) to see how to do so and replicate Figure 30.



*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)*

What similarities/differences do you see among the four images in Figure 30? What do the black dots/stain represent?

Tip: The green cross indicates a fixed position in all the images.

## Activity 11: Predict a consecutive transit.

### Activity 11.1: Predict a consecutive transit with Stellarium

**Pre-requisite:** To solve this Activity we need to know the orbital period of the moon Europa.

- If you have calculated the orbital period of Europa (in Actividad 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. **Go to Jupiter:**

   - Search for *Júpiter*, on the left menu of Stellarium (icon of the magnifier)
   - Zoom in (scrolling with the mouse) until visualizing Jupiter and the Galilean moons in the view of *Stellarium*.

3. **Travel in time:**
   o Search for the date of 2013-12-29T09:40 (on the *Stellarium* bottom menu)

4. **Do you see the planet Jupiter and the shadow of its moons?**
   o If the answer is YES, go to the next step.
   o If the answer is NO, travel in time until you see the shadow.

5. Predict the following transit as it is shown in this video

**Note:** Each time they press the "forward icon" in *Stellarium*, 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 boxes flagged as 1 in Figure 31.
- Click on "**Calculate using entered date and time**" in region 2, to have a representation of the moons position at that time.
- All the information will be displayed in zone 3 of that Figure.

## Conclusions

- When was the following transits 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!

Remember all what you have done along this Experience with your Team and teacher and complete the following Activities.

## Activity 12: Evaluation

- **In Teams:** Fill in this questionnaire so that you can check what you have learned in the Challenge.
- **With your teachers:** Give us your feedback

## Activity 13: Present your results

Make a final product (an A0 poster in pdf format, using power point, for example) showing what you have learnt in the different phases of this Scientific Challenge.

**This poster is the ticket to participate in the international *CESAR Space Science Experience Contest.***

# 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://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 (Jupiter)
- 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
- 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.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)
- 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

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Initial version made by Planeta Ciencias:
http://cesar.esa.int/index.php?Section=SSE_The_Mass_of_Jupiter

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