



CESAR Scientific Challenge

The mass of Jupiter

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

Teacher Guide

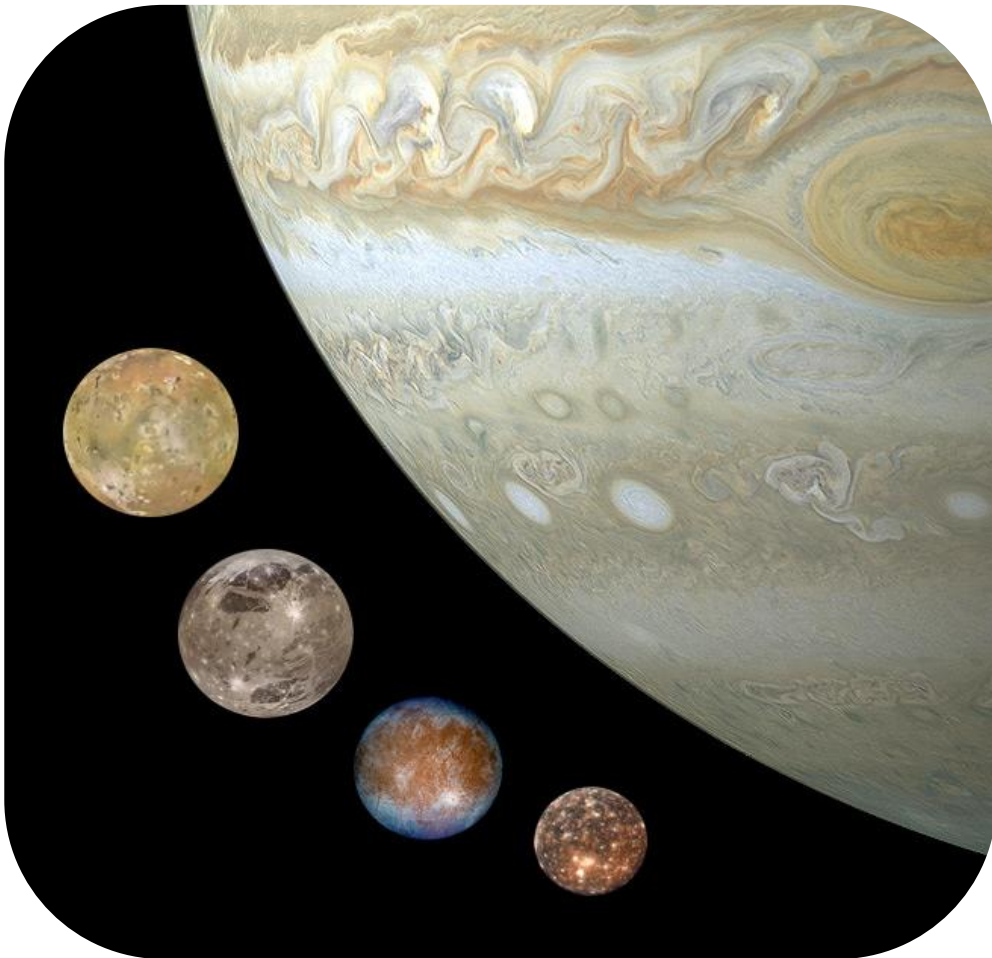




Table of Contents

Didactics	3
Your Scientific Challenge	14
Phase 0	16
Phase 1	18
Activity 1: Refresh concepts	19
Activity 2: Compare Jupiter and the Earth.	23
Activity 3: The Jovian system	24
Activity 4: The space exploration of Jupiter by the European Space Agency	25
Activity 5: Evaluate what have you learnt until now	26
Phase 2	27
Activity 6: Ask for a video-call with the CESAR Team if needed	28
Phase 3	29
Activity 7: The Galilean moons. Choose your favourite moon.....	30
Activity 8: Calculate some orbital parameters of your favourite moon.....	34
Activity 8.1: Calculate the orbital period of your moon	34
Activity 8.2: Calculate the orbital radius of your favourite moon	41
Activity 8.3: Estimate the relative measurement errors	46
Activity 9: Calculate the mass of Jupiter	46
Activity 10: Inspect data of a transit in ESA archived data.....	47
Activity 10.1: Getting familiar with ESASky and access to the scientific data of your favourite target.....	48
Activity 10.2: Identify the transit of Europa in the ESASky data of Jupiter	51
Activity 10.3: Analyse data of a transit of Europa as scientist do	52
What similarities/differences do you see among the four images in Figure 30? What do the black dots/stain represent?.....	53
The big grey stain (in this black and white image) is the famous Jupiter storm.....	53
Activity 11: Predict a consecutive transit.	54
Activity 11.1: Predict a consecutive transit with Stellarium.....	54
Activity 11.2: Other methods to predict a transit	55
Phase 4	56
Activity 12: Evaluation	57
Activity 13: Present your results	57
Links	59
Credits:	61



Didactics

Learning objectives :

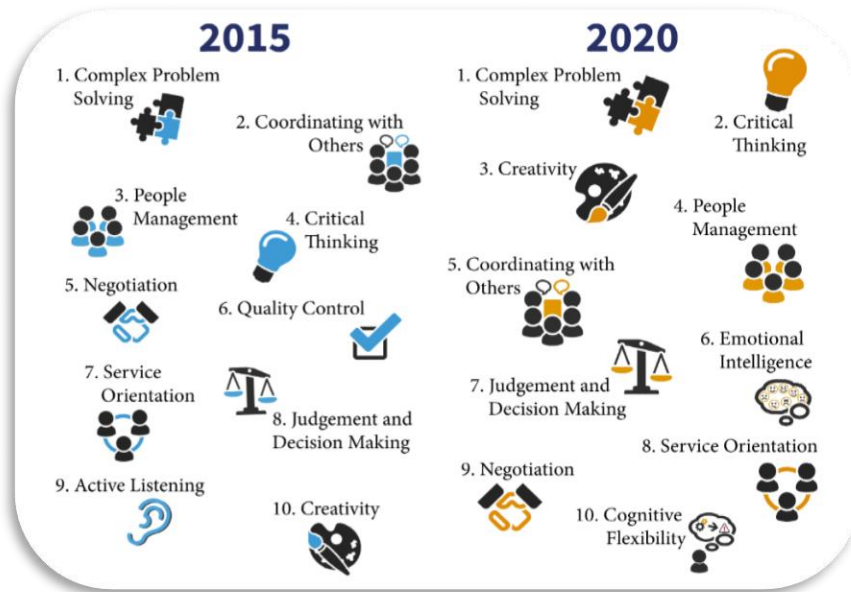


Figure I: The considered top 10 skills in the 2020. (Credits: Rethinking).

The CESAR Team generates activities for students to develop the considered top 10 skills in the 2020, where problem solving requires critical thinking and creativity. Our proposal is to execute these activities in teams. Students will find the environment where to develop their communication skills, managing different opinions and approaches, and making use of their emotional intelligence.

The CESAR scientific challenges aim to follow the thinking skills order established by the Bloom's taxonomy diagram, from a low order thinking skills (**remembering, understanding**) to a high order thinking skills (**evaluating, creating**), passing through mid-order thinking skills (**applying** methods and concepts for **analyzing** events).

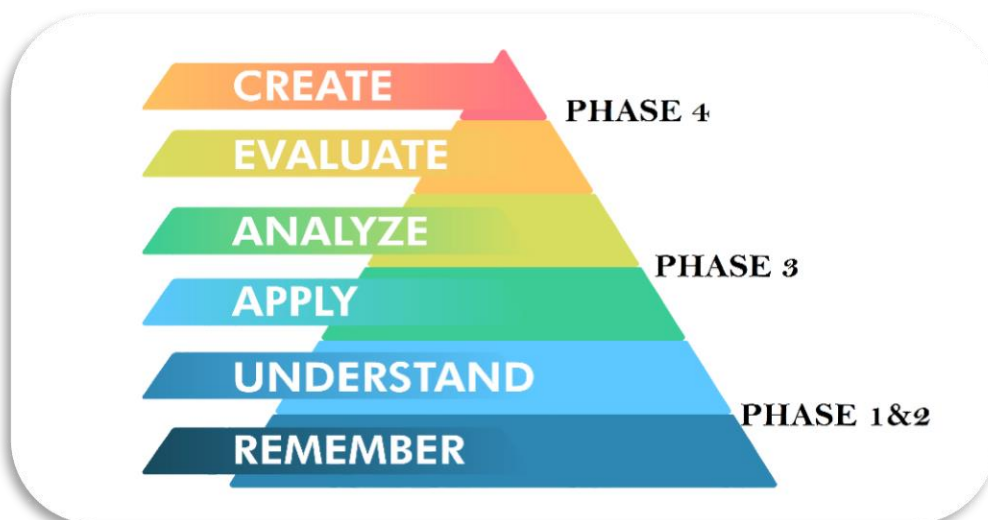


Figure II: Bloom's Taxonomy diagram. (Credits: <https://medium.com/@ryan.ubc.edtech/>)



Teaching Techniques:

In order to achieve the previously mentioned Learning Objectives, the CESAR Team recommends the use of some techniques like, ***flipped-classroom, solution of daily life problems (using the scientific method) and collaborative work.***

In this activity students will make use of the *flipped classroom* for Phases 0 and 1 to get ready for the problems solution of their Challenge during Phase 3. Phase 2 is optional and consist on a video call with us. In Phase 4, each team will evaluate their Experience and share it with the Scientific Community (their class/center and us, the CESAR Team). All phases are recommended to be executed as collaborative work (using **forum and blogs**). Here we detail the process:

- **Your Scientific Challenge:** We introduce the Challenge to students and ask for their support
- **Phase 0: Putting things into context**
 - The role of the **European Space Agency** their center in Spain (European Space and Astronomy Centre, ESAC) as well as the CESAR Team. (in videos)
 - **Nowadays role models** for students to build the **Teams for their Challenge**. We recommend that Teams are formed by 4-6 people, each one of them with well-defined tasks. When possible, try to balance them in gender and diversity of capabilities.
- **Phase 1 and Phase 2: remembering and understanding** using different sources:
 - **Phase 1:** scholar cv material & new concepts (videos, documents, games)
 - **Phase 2 (optional):** learn from an expert
 - For the teachers: talks provided by experts on the topic in previous CESAR teacher workshops.
 - For the classroom: A video call with the CESAR Team to solve doubts that may have appeared until the moment in what students have just learnt. At this stage, students had already become “experts” on the topic of the Challenge .
- **Phase 3: applying** the already known concepts following a methodology (procedures) for **analyzing data** and **solving daily life problems** (their Scientific Challenge).
- **Phase 4:**
 - **evaluating** their learning process during the Challenge (self and co-evaluation)
 - **creating** a final product to show to the Community (class/school/us) their learning process. With this you could participate in the CESAR Scientific Challenge contest.

As Figure III shows, the CESAR Scientific Challenges should execute all mentioned Phases. Phase 0 and 1, are the roots for all the Scientific Experiences, always to be done in the classroom/home. Phase 2 (video call executed from the classroom to us) is optional.

Depending on the type of Phase 3, there are various CESAR Experience Types:

- **Type I: Space Science Experience(s) @ESAC:** At ESAC, (as always in the past), completely run by the CESAR Team. Total duration 1.5 hours, with 45 minutes for the Activity and another 45 minutes the tour around the ESA spacecraft models.
- 1. **Type II : On-line Space Science Experience(s):** In the classroom/home, (Type I but completely guided by the teacher). Total duration 1h (MIXED when combined with Type I/III)
- 2. **Type III: On-line Research Project:** In the classroom/home, completely guided by the teacher. Total duration several days. (Type II but executing more or all the Activities of the Guide).

Phase 4 is always executed in the classroom/home to evaluate the learning process per Team as a whole.

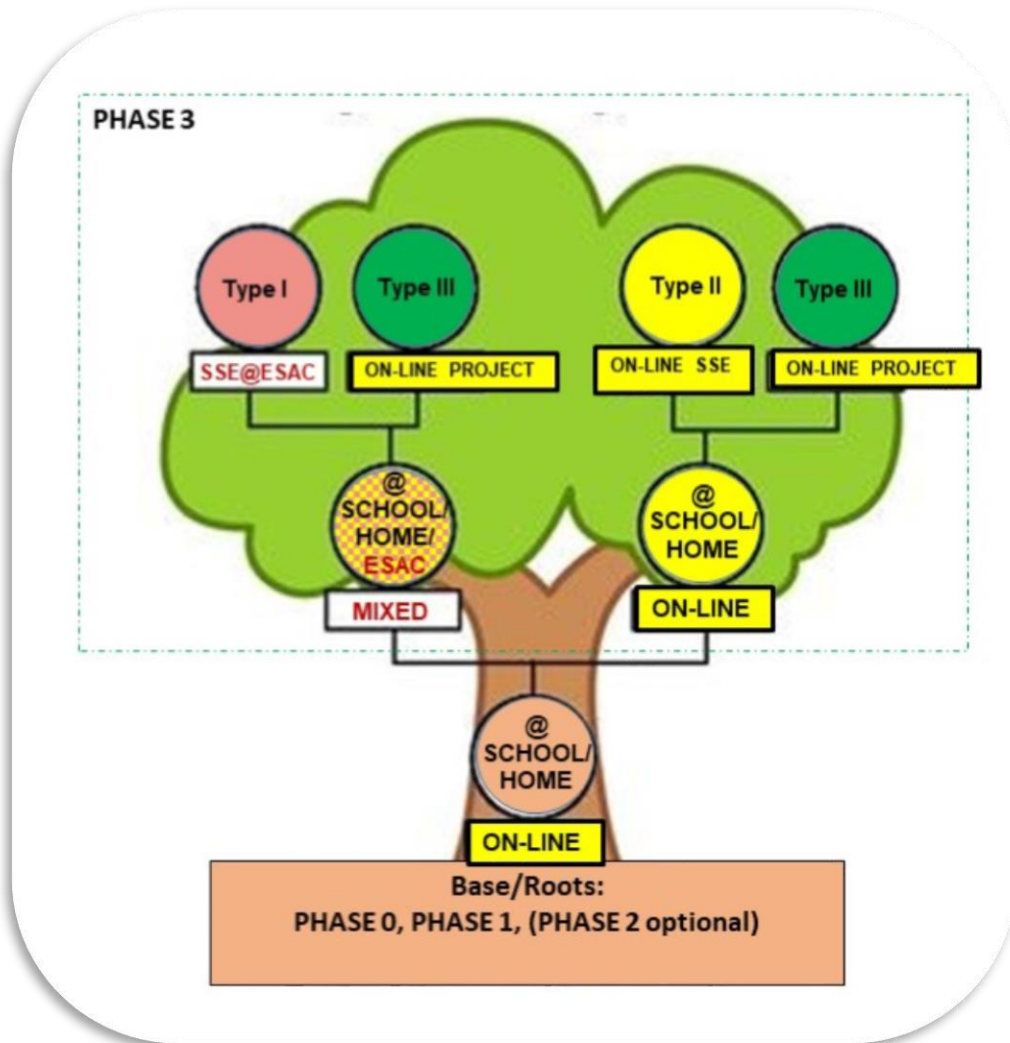


Figure III: Decision tree of the CESAR Experiences according to Phase 3 (Tipo I @ESAC, Tipo II y III, on-line). In yellow are indicated those paths that can be run completely on-line. (Credits: teacherspayteachers.com)

Teachers are the best ones in assessing the Type of Experience (Challenge) for their classroom and school year conditions. **Per each Type of Experience we propose you different Adventures. The teacher decides if each Team in the class execute an Adventure and once finish they put them in common or whether all the Teams execute the same Adventure(s) at the time (see Tables I, II and III).** Teachers can also decide whether they want to execute some Activities on-line, and when it became feasible, to ask for the already well known an SSE @ESAC (Type I), for the same Challenge but different Adventure or another Challenge (see Figure III).

The CESAR Team recommends you to follow the phases in order (for an optimum learning process) and do not start one before closing the previous one. The Table [Summary of Activities](#) will mention when the execution of a previous Activity is required. The CESAR Team can be contacted once in phase 2 (with the class) and in phase 3 (only for the teacher). For that, dedicated slots of 30 minutes are scheduled.



For the Scientific Challenge, the [Fast Facts](#) section provides the information regarding the school curriculum and the contents of each of the Activities (by Phase) can be found in the Table “[Summary of Activities](#)”. The flavors of Adventures, per each Type of Scientific Experience are in Tables I, II and III.

• **Table I: Space Science Experience @ESAC (SSE @ESAC):**

PHASES	0	1	2	3 (@ESAC)	3 (@school)	4	Minimum duration
ACTIVITIES (Adventure 1)	3 videos	1, 3 and 4	6	7, 8.1, 8.2 y 5	9	12 and 13	3h
ACTIVITIES (Adventure 2)	3 videos	1, 3 and 4	(6)	7,8 and 9	8.3 and 5,	12 and 13	3h
ACTIVITIES (Adventure 3)	3 videos	1, 3 and 4	(6)	7, 8.1 and 11	5 and 10	12 and 13	3h
ACTIVITIES (Adventure 4)	3 videos	1, 3 and 4	(6)	7, 8.1, 10	5 and 11	12 and 13	3h

• **Table II: On-line Space Science Experience (On-line SSE):**

PHASES	0	1	2	3 (@school)	4	Minimum duration
ACTIVITIES (Adventure 1)	3 videos	1,3,4 y 5	6	7, 8.1, 8.2, y 9	12 y 13	3h
ACTIVITIES (Adventure 2)	3 videos	1,3,4 y 5	(6)	7, 8, 9, y 8.3	12 y 13	3h
ACTIVITIES (Adventure 3)	3 videos	1,3,4 y 5	(6)	7, 8.1, 8.3 y 10	12 y 13	3h
ACTIVITIES (Adventure 4)	3 videos	1,3,4 y 5	(6)	7, 8.1, 10 y 11	12 y 13	3h

• **Table III: Research Project: All Activities**

PHASE	0	1	2	3 (@school)	4	Minimum duration
ACTIVITIES	videos	1,2,3,4 and 5	(6)	7, 8, 9, 10 and 11	12 y 13	4h

REALLY IMPORTANT

- ✓ As a teacher, **register as part of the CESAR Community [here](#)** (If you approach us for the first time, it may take some time – a non-automatic process -, but you will not regret ;o))
- ✓ **Once you have been confirmed as part of the CESAR Community** ask for the CESAR Scientific Experiences to live with your class **and you will be guided in the process:**
 - Click [here](#) to request an on-line experience – Type II & III
 - Click [here](#) to request a combined experience - Type I (Only for schools in the Comunidad de Madrid and close cities)
- ✓ **Guides are very long (many possible tools) to build your Experience but also very flexible**

It is your time! Choose your Adventure!



Fast Facts

Recommended target age range: (16-18) years old

Recommended academic course: (1-2) Bachelor's degree

Type: Student activity

Complexity: Medium

Teacher preparation time: (1-2) hours

Lesson time required: (1h – several days), depending on the activities requested by the teacher.

Location: Indoors

Includes use of: Computers, internet

Outline

In these Activities students compare Jupiter and the Earth. They will get to know about Jupiter and its moons, as well as their space exploration. Students will choose one of the Galilean moons and measure their main orbital parameters (rotational period and radius).

Considering a 2 body-system (a massive fixed object with another one, neglectable in mass, orbiting around it in circular orbits at a constant speed - with no friction), students will derive the mass of Jupiter.

Students will also access to the Hubble Space Telescope archive and explore the images of the transit of Europa in front of Jupiter. From previous calculations of Europa's orbital period

Curriculum relevance

Physics and Chemistry

- The need of strategies in the scientific activity, the use of ICT and communication skills. Research project.
- Force as an interaction. The 2-bodies system. Dynamics of the circular uniform movement. Kepler laws. Universal Gravitation Law.
- History and composition of the Universe.

Maths

- Planning of the problems solution process. Generation and presentation of scientific forms. Mathematical studies of daily life concepts.
- Approach to basic equations. Trigonometry. Calculations of angles, distances, areas and volumes.

Scientific culture

- Use of ITC for seeking information. Research and exploration of the Universe. Working in teams. Debates.

Students should already know...

- Orbital Mechanics (velocity and period)
- Kepler's Laws
- Trigonometry
- Units conversion

Students will learn...

- How to apply theoretical knowledge to astronomical situations.
- The basics of astronomy software.
- How to make scientific measurements.
- How to predict astronomical events.
- The easy access to ESA scientific data/archives through ESASky.

Students will improve...

- Their understanding of scientific thinking.
- Their strategies of working scientifically.
- Their teamwork and communication skills.
- Their evaluation skills.
- Their ability to apply theoretical knowledge to real-life situations.
- Their skills in the use of ICT.

Material

- Paper, pencil, pen and a computer with *Stellarium* software installed (*Stellarium* web is not enough).

To know more...

- CESAR Booklets: [Stellarium](#), [The Solar System](#)



Summary of Activities:

Phase	Activity	Material	Results	Requirements	Time
Phase 0	Putting things into context	a) This is ESA b) ESAC: ESA's A window on the Universe c) Presentation to ESA/ESAC/CE SAR by Dr. Javier Ventura	Students will get familiar with <ul style="list-style-type: none"> • ESA • ESAC • The CESAR Team • The role of astronomy in society and culture 	None	30 min
Phase 1	1. Refresh concepts	a) Mass & weight b) Gravity (ESAKids , NASAKids) c) orbital period d) Kepler's laws (introduction & simulator)	Students refresh: <ul style="list-style-type: none"> • The difference between mass and weight • The concept of gravity • The concept of orbital period • Kepler's laws 	None. This Activity is necessary to refresh the curriculum relevance contents.	30 min
Phase 1	2. Compare Jupiter and the Earth	Table 1	Students improve their skills to: <ul style="list-style-type: none"> • work scientifically in teams. • communicate themselves. • assess their background knowledge. Students improve their knowledge about Jupiter		15 min



Phase	Activity	Material	Results	Requirements	Time
Phase 1	3. The Jovian system	<p>Select your option (time permitting)</p> <p>(PDFs):</p> <p>a) CESAR booklet: The Solar System (Jupiter)</p> <p>b) CESAR booklet: The Solar System</p> <p>ESA VIDEOS:</p> <p>c) The Solar System</p> <p>d) Diverse worlds: The Moon and Titan</p>	<p>Students improve their knowledge about:</p> <ul style="list-style-type: none"> Jupiter, its moons and their role in the Solar System. Other visited moons in the solar system (the Moon and Titan) <p>Students will compare their hypothesis (in Activity 2) with the facts here.</p>	<p>It is recommended to have executed Activity 2.</p>	30 min – 1 h
Phase 1	4. The space exploration of Jupiter by the European Space Agency	<p>Select your option (time permitting)</p> <p>VIDEOS:</p> <p>a) Unlocking the secrets of Jupiter icy moons.</p> <p>b) JUICE's Jovian odyssey trip</p> <p>WEB</p> <p>c) The Jupiter system (JUICE)</p> <p>d) Missions to Jupiter</p> <p>3D MODEL:</p> <p>e) ESA scientific fleet</p>	<p>Students improve their knowledge about:</p> <ul style="list-style-type: none"> The discoveries of Jupiter and its moons performed by Space Agencies (NASA & ESA) The ESA scientific fleet dedicated to explore Jupiter, in particular, the JUICE mission 	<p>It is required to have executed Activity 3.</p> <p>It is recommended to have executed Activity 2.</p>	30 min - 2 h
Phase 1	5. Evaluate what you have learnt until now	questionnaire	<p>Students improve their skills for:</p> <ul style="list-style-type: none"> evaluating working scientifically handling ICT tools 	<p>It is required to have executed Activities 1, 3 and 4.</p> <p>It is recommended to have executed Activity 2.</p>	5 min



Phase	Activity	Material	Results	Requirements	Time
Phase 2	6. Ask for a video-call with CESAR Team if needed	a) http://cesar.esa.int/index.php?Section=Scientific_Cases&Id=17&ChangeLang=en	<p>For teachers: [options a) &b)] Teachers will have access to talks given by ESA scientist from previous CESAR teacher's workshop, related to Jupiter, and a tailored class about orbital parameters.</p> <p>For the classroom: [options b & c)] Teachers and students have the chance to watch tailored class about orbital parameters and of having a video call with the CESAR Team</p>	<p>It is required to have executed Activities 1, 3 and 4.</p> <p>It is recommended to have executed Activities 2 and 5.</p>	30min – 1h
Phase 3	7. Choose your favourite Galilean moon.	<p>a) Using Cosmosgraphia</p> <p>b) Reviewing Phase 1</p>	<p>Students improve their skills for:</p> <ul style="list-style-type: none"> • evaluating • working scientifically • handling ICT tools 	<p>It is recommended to have executed Activities 1 to 6.</p> <p>It is convenient that at least one team selects the moon Europa.</p>	10 min



<p>Phase 3</p>	<p>8. Calculate some orbital parameters of your favourite moon.</p> <p>8.1. orbital radius</p> <p>8.2. orbital period</p>	<p>Stellarium installed</p> <p>CESAR Booklet about Stellarium</p> <p><i>Stellarium web is not going to be enough for the calculations required</i></p>	<p>Students improve:</p> <ul style="list-style-type: none"> • Their knowledge of working scientifically and how astronomers make calculations • ICT skills • Their understanding about how the trigonometry is used in problems solution 	<p>It is necessary:</p> <ul style="list-style-type: none"> • To have Stellarium installed (basic guide). • To have executed Activities 1 and 7. <p>It is recommended to have executed Activities 5 and 6.</p>	<p>45 min</p>
<p>Phase 3</p>	<p>9. Calculate the mass of Jupiter</p>	<p>Stellarium installed</p> <p>CESAR Booklet about Stellarium</p> <p><i>Stellarium web is not going to be enough for the calculations required</i></p>	<p>Students improve their skills for:</p> <ul style="list-style-type: none"> • Working scientifically • Applying theoretical knowledge to solve problems • Handling ICT 	<p>It is necessary :</p> <ul style="list-style-type: none"> • To have Stellarium installed • To have completed Activities 7 and 8 	<p>30 min</p>
<p>Phase 3</p>	<p>10. Inspect data of a transit in the ESA scientific archives</p> <p>10.1. Getting familiar with ESASky and access to scientific data of your favourite target</p> <p>10.2. Identify the transit of Europa in the ESASky Jupiter data</p> <p>10.3. Analyze data of a transit of Europa as scientists do.</p>	<p>ASTRONOMICAL DATA:</p> <p>Needed:</p> <ul style="list-style-type: none"> • Data set: HSTdata.tar <p>Optional:</p> <ul style="list-style-type: none"> • Search and download data from: ESASky <p>ASTRONOMICAL SOFTWARE:</p> <ul style="list-style-type: none"> • SalsaJ installed • SalsaJ tutorial • SAODS9 installed 	<p>Students learn:</p> <ul style="list-style-type: none"> • The easy access to the ESA archives through ESASky (search and download astronomical data). • To handle astronomical data (FITS format) • The basics of astronomical software for data analysis (SAODS9 and/or SalsaJ) <p>Students improve:</p> <ul style="list-style-type: none"> • Thinking and working scientifically • ICT skills 	<p>.</p>	<p>1 h</p>



<p>Phase 3</p>	<p>11. Predict a consecutive transit</p> <p>11.1. Predict a consecutive transit With Stellarium</p> <p>11.2. Other methods to predict a transit</p>		<p>Students will improve their skills to:</p> <ul style="list-style-type: none"> • Work scientifically • Make predictions based in findings • To handle ITC 	<p>It is necessary to have completed Activity 7.1.</p>	<p>25 min</p>
<p>Phase 4</p>	<p>12. Evaluation</p>	<p>questionnaire</p>	<p>Students will check whether they have had a meaningful learning process.</p> <p>Students improve their team work and communication skills.</p>	<p>Necessary to have completed Activities 1,3, 4,6, 7, 8, 9 ,10 and 11.</p>	<p>15 min</p>
<p>Phase 4</p>	<p>13. Present your results</p>	<p>An A0 poster per working team (upload to the CESAR website a compressed file with all posters in PDF format)</p>	<p>Students improve:</p> <ul style="list-style-type: none"> • Their application of theoretical concepts to real life situations. • Their teamwork and communication skills. <p>Their knowledge about the Jupiter system and the solar system in general.</p>	<p>Depending on the work identified by the teacher to be done by their class.</p> <p>Necessary to have completed Activities 1,3, 4,6, 7, 8, 9 ,10, 11 and 12.</p>	<p>30 min – 2h</p>



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. (Credit: 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: The JUICE mission (Credit: 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.
Are you willing to 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.








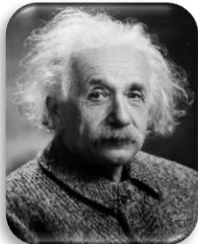
Challenge ID				Team number (1-6):
Names				
Profession	Mathematician/ Software engineer	Astrophysics	Engineer	Biologist
Roles	Lead the correctness of the calculations	Lead the use of telescope and the understanding space missions.	In charge of finding the optimum strategy agreed among the team members 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.

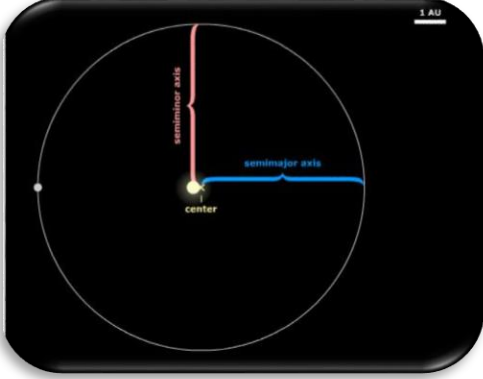
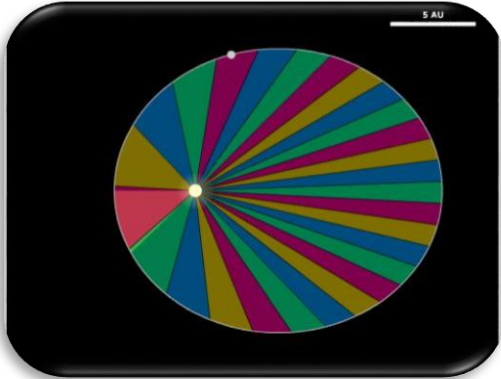
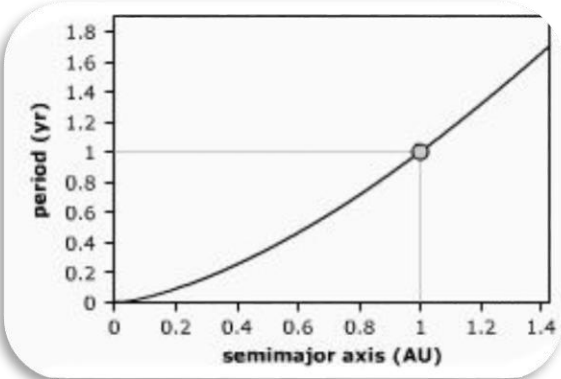
Kepler's Laws

Kepler's Laws, published between 1609 and 1619, led to a huge revolution in the 17th century. 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
<p><u>First Law:</u> The orbit of every planet is an ellipse, with the Sun at one of the two foci.</p>	
<p><u>Second Law:</u> A line joining a planet and the Sun sweeps out equal areas during equal intervals of time</p>	
<p><u>Third Law:</u> The square of the orbital period of a planet, T, is proportional to the cube of the semi-major axis of its orbit, R:</p> $T^2 \propto R^3$	



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 centre 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 $G = 6.674 \cdot 10^{-11} \text{ m}^3 \text{ kg}^{-1} \text{ s}^{-2}$

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.

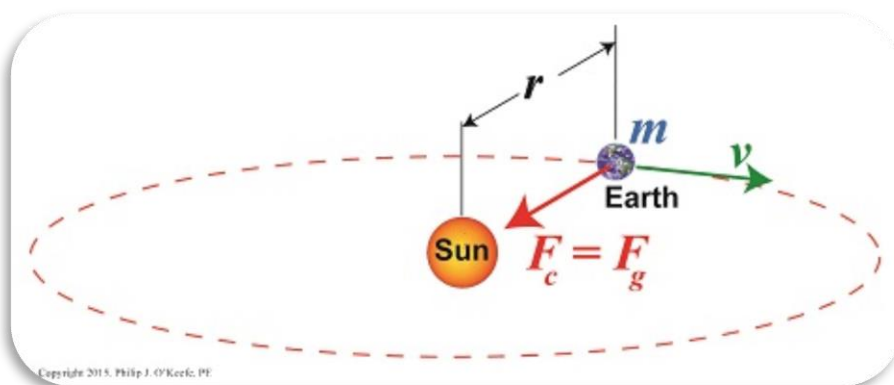


Figure 3: Second Law of Newton (Credit: <https://www.toppr.com>)

$$F_g = F_c$$



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

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

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

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

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

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 :**

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

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

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

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.

These measurements are going to be done in this Scientific Challenge with the aid of the *Stellarium* astronomical software (<http://stellarium.pdf>)



Figure 4: Stellarium logo. (Credits: Stellarium)

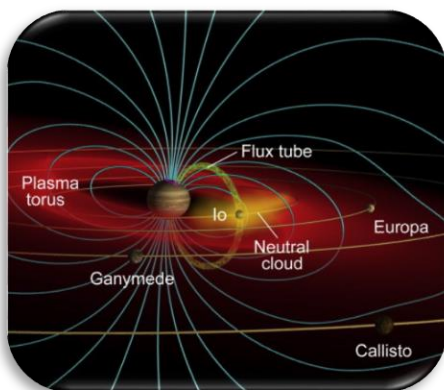
Activity 2: Compare Jupiter and the Earth.

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

Properties	Earth	Jupiter
Radius	6 300 km	69 000 km (11 times Earth radius)
Density	5.5 g/cm ³	1.3 g/cm ³
Average temperature	20° C	-145° C
Distance to the Sun	1 AU	~ 5 AU
Moons	1	79
Type of planet	Rocky	Gas giant
Composition	<ul style="list-style-type: none"> Silicates mantel, metal core & crust Atmosphere: nitrogen, oxygen, argon. 	<ul style="list-style-type: none"> Mainly Hydrogen & helium Atmosphere: methane, water vapor & ammonia.
Magnetic fields	yes	yes

Table 3: Comparison of some properties from Jupiter and the Earth.

The Jovian system



Sun-Earth-Moon system

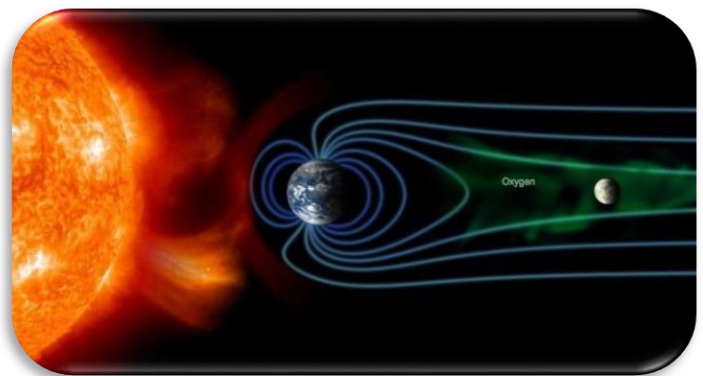


Figure 5: Magnetic fields around the (Credit: http://www.esa.int/Observing_Jupiter)

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 1300 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.

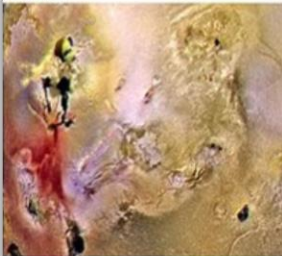

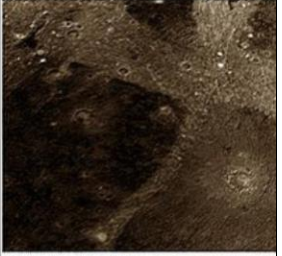
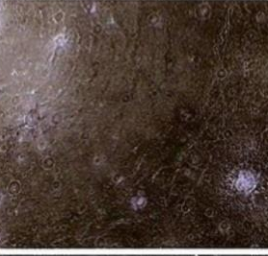
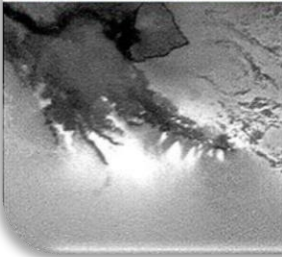


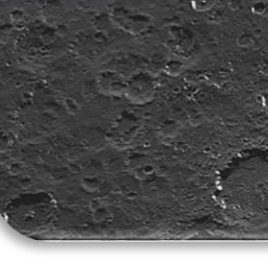
Io	Europa	Ganymede	Callisto
			
			
<p>The most volcanically active object in all the Solar System due to the inward gravitational pull from Jupiter and the outward pull from other Galilean moons.</p>	<p>A cold world that might have a liquid water ocean beneath a thick layer of surface ice. Scientists 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, providing a window to explore the early formation of the moons. Also, thought to have an ocean beneath the surface.</p>

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 6.

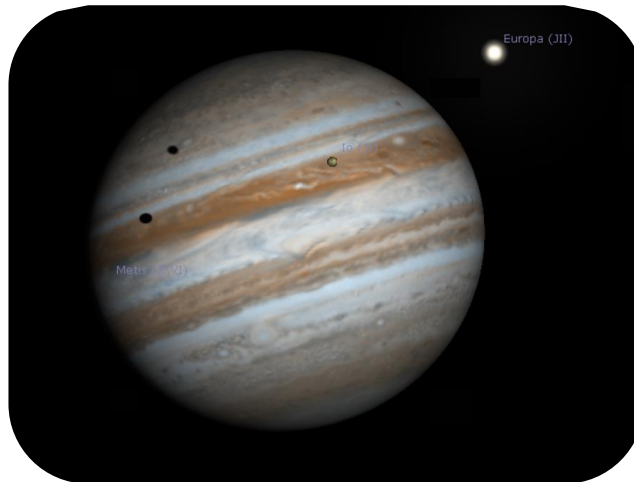


Figure 6: Image of a transit caused by Io and Europa in front of Jupiter (Credits: Stellarium & CESAR)

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.

¹In [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 JUpter Icy moon Explorer (**JUICE**), see Figure 7, 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](#)

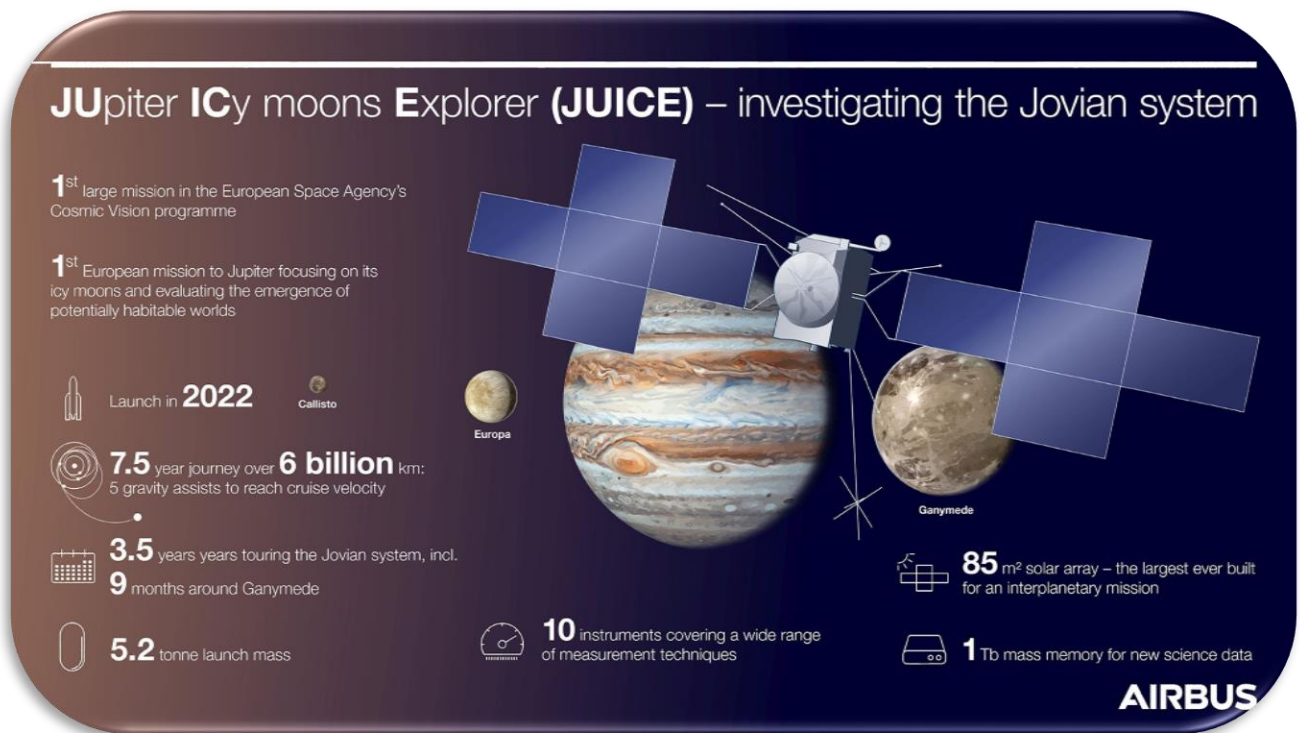


Figure 7: Infographic about the JUICE mission (Credits :AIRBUS)

Activity 5: Evaluate what have you learnt until now

Check what you have learnt so far with this [questionnaire](#)



Phase 2



How to proceed in this Phase depends on the results obtained in the latest Activity of Phase 1 (questionnaire)

- **Case 1:** Your students replied quite well to the quizz
→ **Go to PHASE 3**
- **Case 2:** Your students did not reply very well to the quizz or they have many questions related to the topic of the Scientific Challenge
→ **Review PHASE 1** (see below) **using this extra material**
→ **Go to PHASE 3**

Here the complementary material:

(http://cesar.esa.int/index.php?Section=Scientific_Cases&Id=17&ChangeLang=en)

- Expert talks given at CESAR Teacher workshops (pdf and/or videos)
- ESA dedicated videos
- CESAR Monographics (booklets)
- Simulators/websites



- **Case 3:** You can not make it alone and you need interaction with the CESAR Team

Activity 6: Ask for a video-call with the CESAR Team if needed

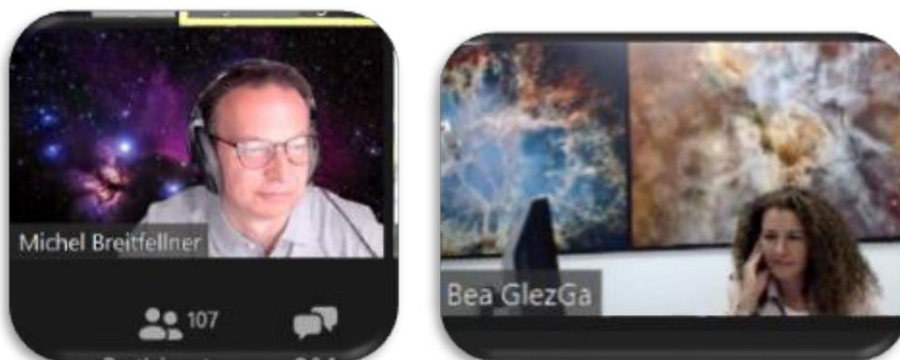


Figure 8: Image of the CESAR Team making a video call (Credits: ESA)

Note: Per scientific challenge you have the opportunity to ask for a 30 min video call

- With your class (in PHASE 2) to clarify concepts
- Teachers only (in PHASE 3) in case you are stuck with software



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:
 - <http://naif.jpl.nasa.gov/pub/naif/cosmographia/packages/cosmo-installer-4.0-windows.exe>
- Linux (64-bit)**, this is the link:
 - <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 9.



Figure 9: 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 10

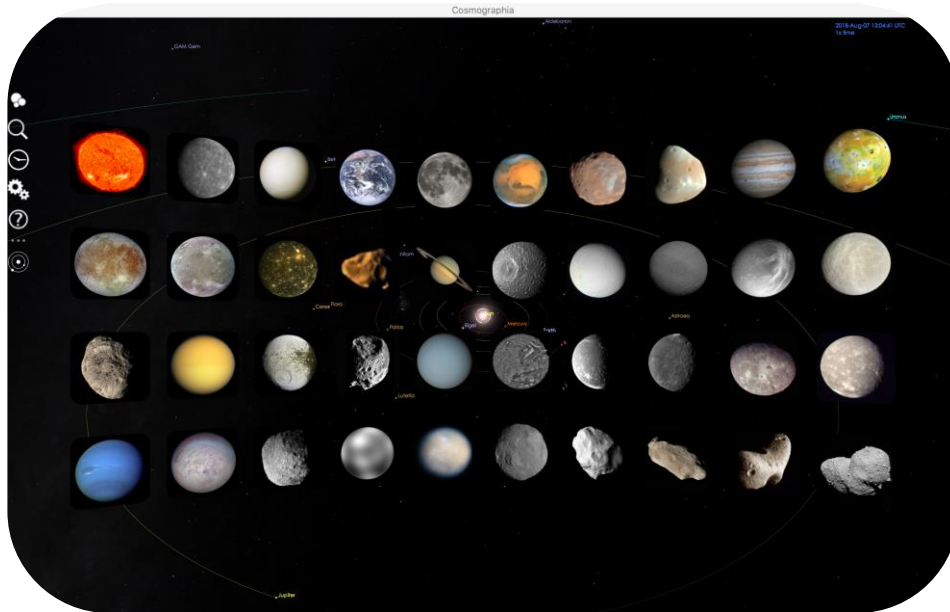


Figure 10: Solar System bodies as seen in Cosmographia

- **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 11

Note: By default Cosmographia shows the locations of the Solar System objects at the present moment, so you may have a slightly different view than Figure 11.

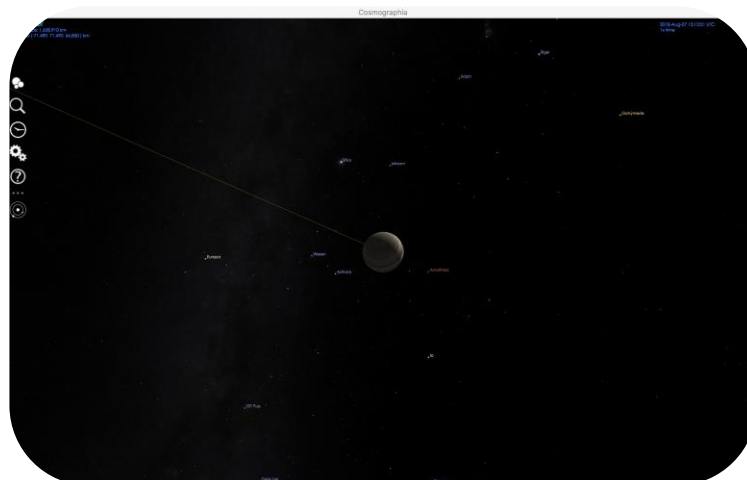


Figure 11: Jupiter and the galilean moons as seen in Cosmographia



- **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 12) 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 12.

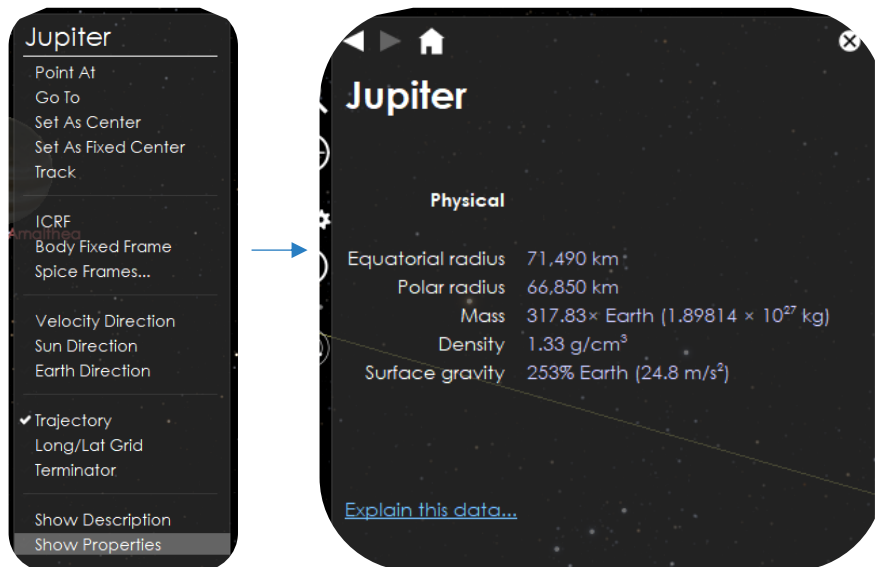
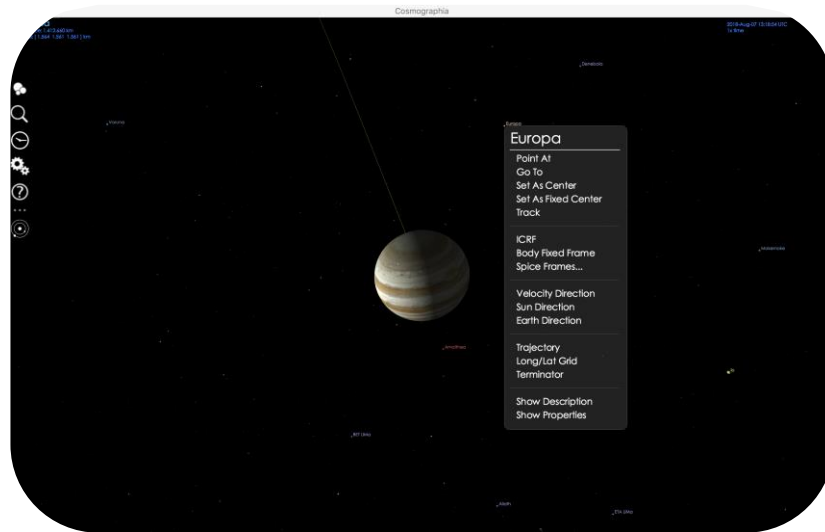


Figure 12: Click on Jupiter with the right mouse in the menu of properties.



- **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/cm ³)
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).

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

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



If the students do not know which moon to use, keep in mind that Europa will be used for the Activities 10 and 11.

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](#)).

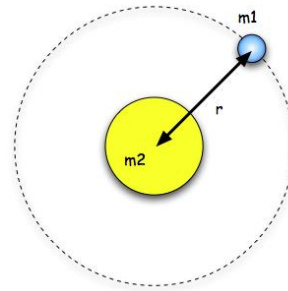


Figure 13: Representation of an orbital radius, r . (Credits: Wikipedia)

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 14:
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 16. (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 15: Script to copy into the Stellarium console to view Jupiter close up. (Credits: Stellarium)

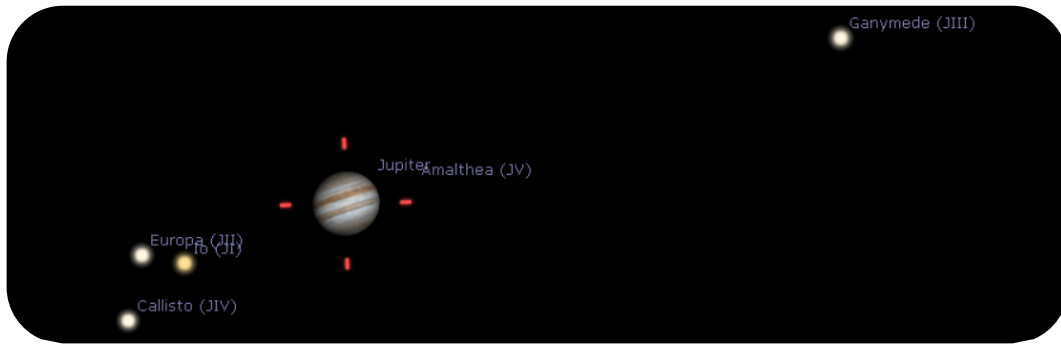


Figure 16: Stellarium view, after running the script. (Credit: Stellarium)

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).

- You need to calculate how long your moon takes to make a complete orbit

o **MODE 2: By using Stellarium control commands.**

1. Click on this search icon and type in Jupiter, as shown in Figure 17.

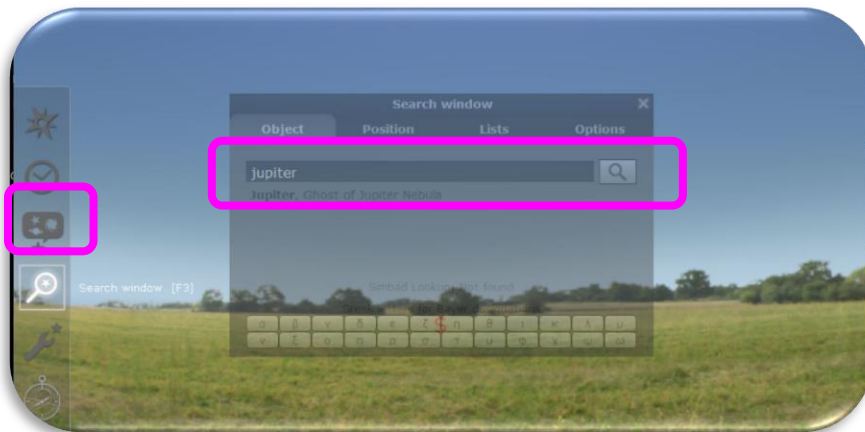


Figure 17: Search command in Stellarium (Credits: Stellarium & CESAR)

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 18a (the little trees and the cloud will be unselected after that).

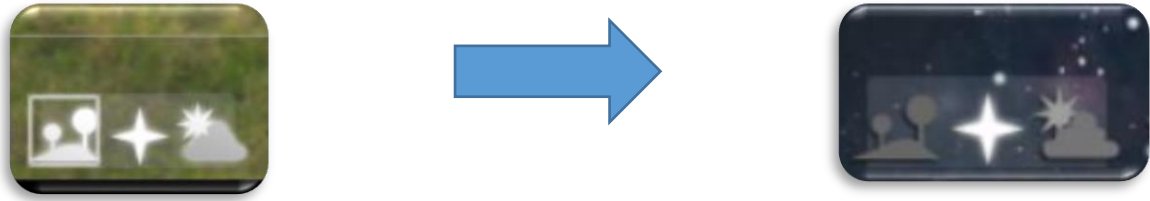



Figura 18a: Stellarium control commands to enable (left image) and disable (right image) the ground and the atmosphere effects (Credits: Stellarium)

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 16.
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 ()

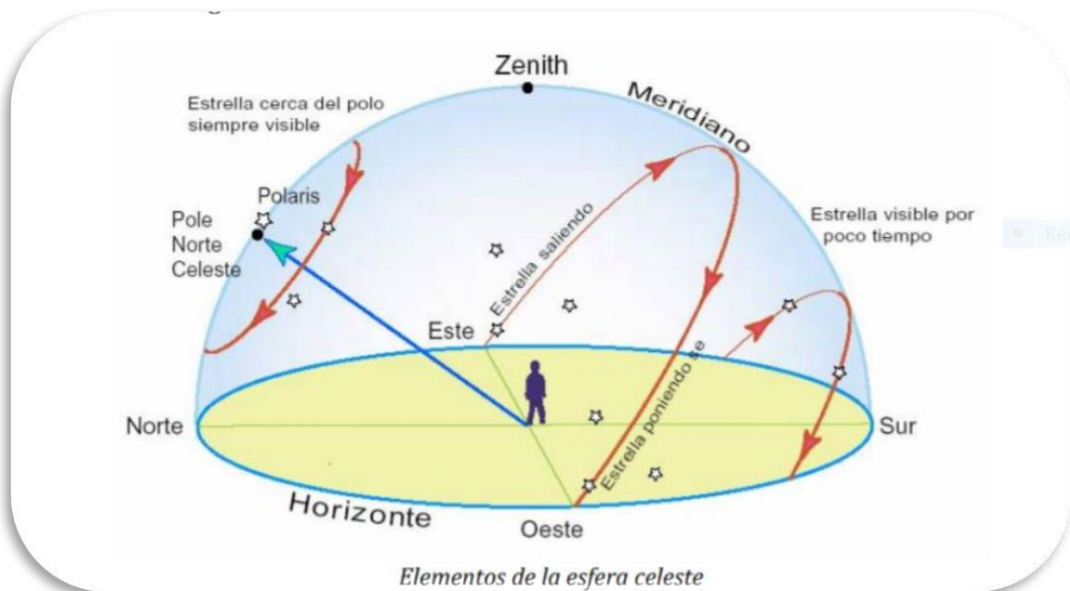


Figura 18 b.: Apparent star movement as shown by an observer at a certain location on Earth.
(Créditos: <https://www.uv.es/fabregaj/apuntes/AstronPos.pdf>)



Note 1: In the following [video](#) (and in Figura 18b), we can watch the apparent movement of the night sky, as seen from a particular place on Earth. By changing from the Earth reference system to a fix position outside the Earth, we see the stars as dots almost fixed in position, this is why they are used as references in the field of view of the satellites. The position of the stars tend to be given in the equatorial coordinates system (RA: right ascension and DEC: declination). For example, the star Vega has the coordinates (RA: 18 35 14.66578, DEC: +38 44 09.7806) – check

[Wikipedia](#) and the astronomical database [Simbad](#).

Equatorially mounted telescopes, which we place on the ground, can move in both right ascension and declination. One of their axes is aligned with the North Star. During a night we will see a star moving - due to the Earth's rotation - parallel to the plane of the equator (movement on the axis of right ascension, due to the Earth's movement) and not in declination (angle formed between the equator and the poles), so observing it during the night (or "tracking" it) will require constant movements in right ascension.

High azimuthal telescopes, which we place on the Earth, can move on the height and azimuth axis. Over the course of a night, a star will be seen to move - due to the Earth's spin - in both altitude and azimuth, so observing it at night (or tracking it) will require constant motion on both axes

Depending on the Earth's latitude where an observer is located will have one or another horizon. Only those stars with a declination above (90-latitude) degrees could be observe for that observer (if they are visible at night). In the case of Madrid, with latitude of about 40 degrees, only those stars with declination above (90-40) = 50 degrees could be visible.

Note 2: [Basic ideas for selecting your own telescope](#)

- **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:







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 19: 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.

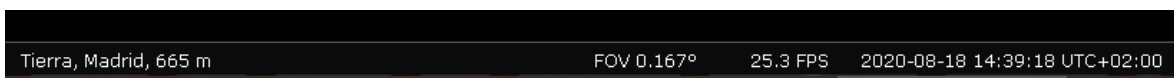


Figure 20: Where to set up the date and the time in Stellarium. (Credits: Stellarium & CESAR)

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?**

Example for the moon Europa

Initial date (YYYY-MM-DD hh:mm:ss)	Final date (YYYY-MM-DD hh:mm:ss)
2018-09-01 03:05:00	2018-09-04 15:25:00
<p style="text-align: center;"><i>Calculate the time difference here</i></p> <p style="text-align: center;">Same year and month</p> <p style="text-align: center;">(4 – 1) day= 3 days; (15–3) h = 12 h ; (25-5) min = 20 min</p> <p style="text-align: center;">Because 1h = 60 min → 20 min = 0.3 h</p> <p style="text-align: center;">Nota: This result has an error caused by the uncertainty of a hand-made measurement. The correct value can be found in Table S.1</p>	

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

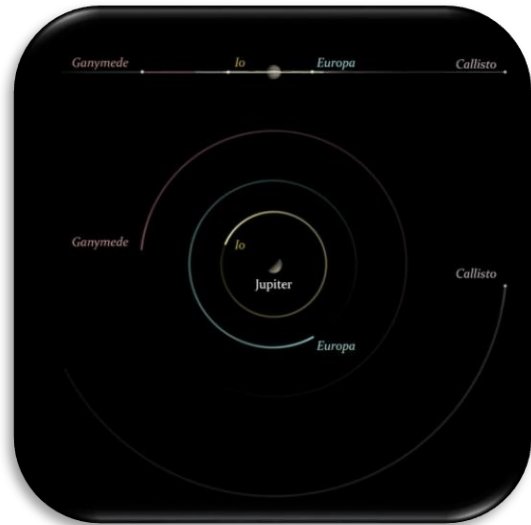
Period	3 days	12 . 3 hours
--------	--------	--------------

The periods of all the Galilean moons can be found in Table S.1.

Moon	Orbital Period
Io	1 day 18.45 hours
Europa	3 days 12.26 hours
Ganymede	7 days 3.71 hours
Callisto	16 days 16.53 hours

Table S.1: Period of the Galilean moons.

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 19.




*Figure 21: 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** ( 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  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 cursor to the centre of your chosen moon (as shown in Figure 22).
- 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*.

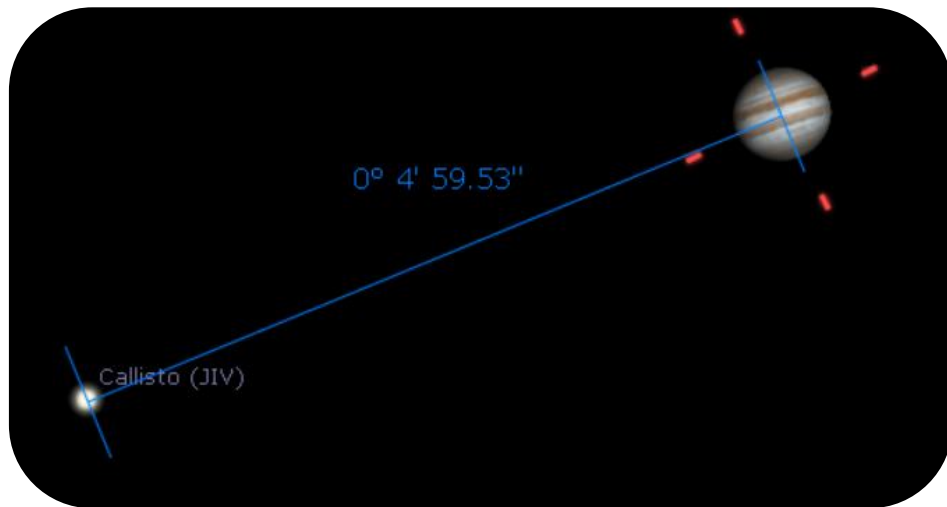


Figure 22: Using Angle Measure plugin. (Credits: Stellarium)

Maximum Distance of your Moon to Jupiter (i.e. Moon = Europa)	0 ° 2 ' 40.31 "	0.0445 °
Write your calculations here 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.

Write your calculations here

$d_{JE} =$	5.72	au	$8.55 \cdot 10^8$	km
------------	--------	------	-------------------	------

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

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.

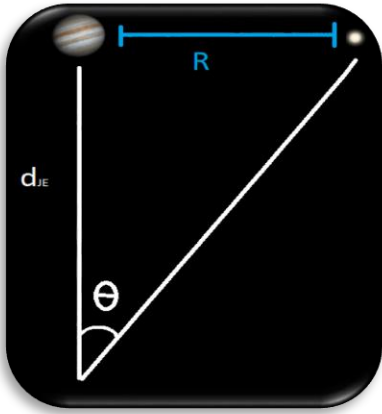
- **Step 3: Apply your knowledge in trigonometry to calculate the orbital radius (in km)**

1. Use the diagram shown in Figure 23 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 θ

- Remember the trigonometric expression of the **tangent of an angle** (Equation 2)

- For very small angles, $\theta \sim 0$, 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 23: 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:
 - θ : moon angular radius
 - d_{JE} : Earth-Jupiter distance

$R = d_{JE} \theta$ $R = 8.55 \cdot 10^8 \times 0.0445^\circ \times \left(\frac{2\pi \text{ radianes}}{360^\circ}\right) =$ $8.55 \cdot 10^8 \times 0.00077667151 = 664\,054.15 \text{ km}$		
$R =$	$664\,054.15 \text{ km}$	$6.64 \cdot 10^8 \text{ m}$

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

• 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, 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).

2. Complete Table 10 with the lineal velocity value.

Note: In this calculation we are using the value of the period obtained by Stellarium, the correct one is in Table S.1)

$$T = 3 \text{ d } 12.3 \text{ h} = 3 \times 24 + 12.3 \text{ h} = 84.3 \text{ h} = 84.3 \text{ h} \times \frac{3600 \text{ s}}{1 \text{ h}} = 303\,480 \text{ s}$$

$$v = \frac{2\pi}{303480} 6.64 \cdot 10^8 = 13\,747.31 \text{ m/s} = 13\,747 \text{ m/s}$$

$v =$	13 747 m/s
-------	-------------------

Table 10: Results for the orbital velocity of the moon Europa

Moon	Orbital radius (km) (Semi-major Axis)	Orbital velocity (m/s)
Io	421 700	17 334
Europa	670 900	13 740
Ganymede	1 070 400	10 880
Callisto	1 882 700	8 204

Table S.2: Chart with orbital radius and velocity for each Galilean moon

Note: No solution is provided for the angular distance, θ , since it will depend on the distance from the Earth to Jupiter, which is not always the same.



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.

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

$$\rightarrow E_R = \frac{| 664\,054 - 670\,000 |}{670\,000} \cdot x\,100 = \frac{5\,946}{670\,000} \times 100 = 0.887\%$$

Table 11: Estimation of relative error for the orbital radius of Europa

Note: A negative value for the relative error will probably mean that the absolute value has not been applied.

Note 2: An error of less than or equal to 5% is acceptable.

Activity 9: Calculate the mass of Jupiter

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

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

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

$$M_J = \frac{4\pi^2 R^3}{G T^2} = \frac{4\pi^2}{6.674 \cdot 10^{-11} \text{ m}^3 \text{ kg}^{-1} \text{ s}^{-2}} \cdot \frac{(6.64 \cdot 10^8 \text{ m})^3}{(303460 \text{ s})^2} = 1.8805066 \cdot 10^{27} \text{ kg}$$

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

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

Hypothesis

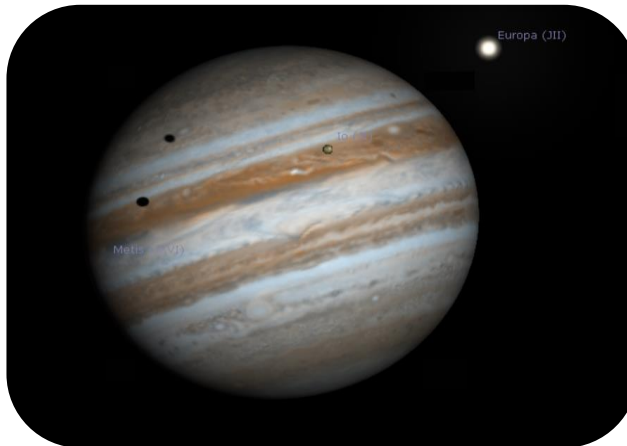


Figure 24: Io and Europa transit, using Stellarium. (Credits: Stellarium)

1. What do you see in Figure 24?

In Figure 15 we can see the shadow of the Galilean moons projected on the surface of Jupiter. The observer, on a different planet, has to be behind the transiting planet to be able to see it pass. That is, any celestial body behind the observer's one cannot be seen.

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

Yes

3. May we predict these transits? How?

Yes, getting to know the orbital period of those moons and the date for an specific transit (with real data from the ESA archives, simulations like Stellarium,..)



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 mode *Science*.



Figure 25: 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 24, with the shape of a galaxy). This will display a menu similar to the one in Figure 24, 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-infrared (data collected by the Hubble Observatory) and purple the soft X-ray (data collected by the XMM-Newton Observatory).

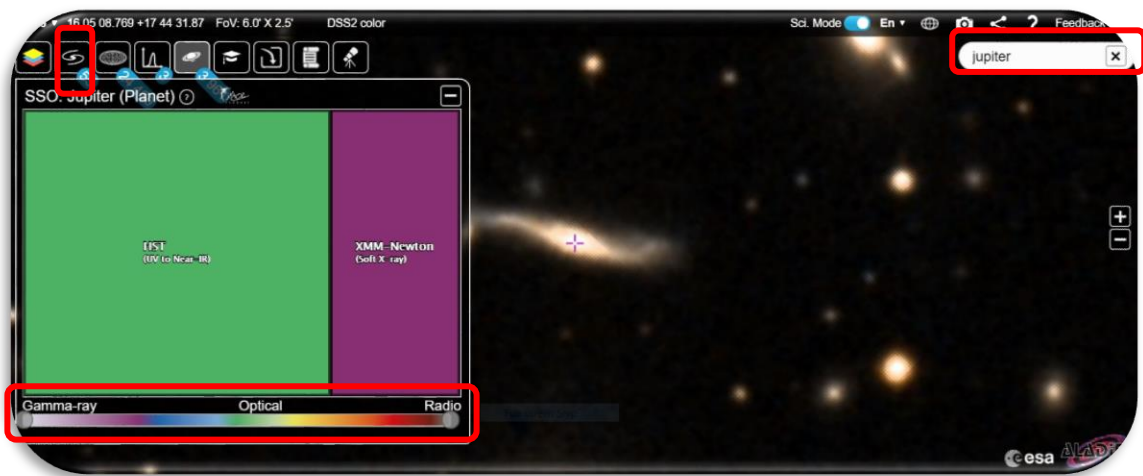


Figure 26 Explore image observations for a selected region (Credit: ESA)

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. 25)



Figure 27: HST imaging observations of Jupiter (Credit: ESA)

5. Inspect the HST images of Jupiter:

- Select one row of the table de observations (Figure 28).
- 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 29.

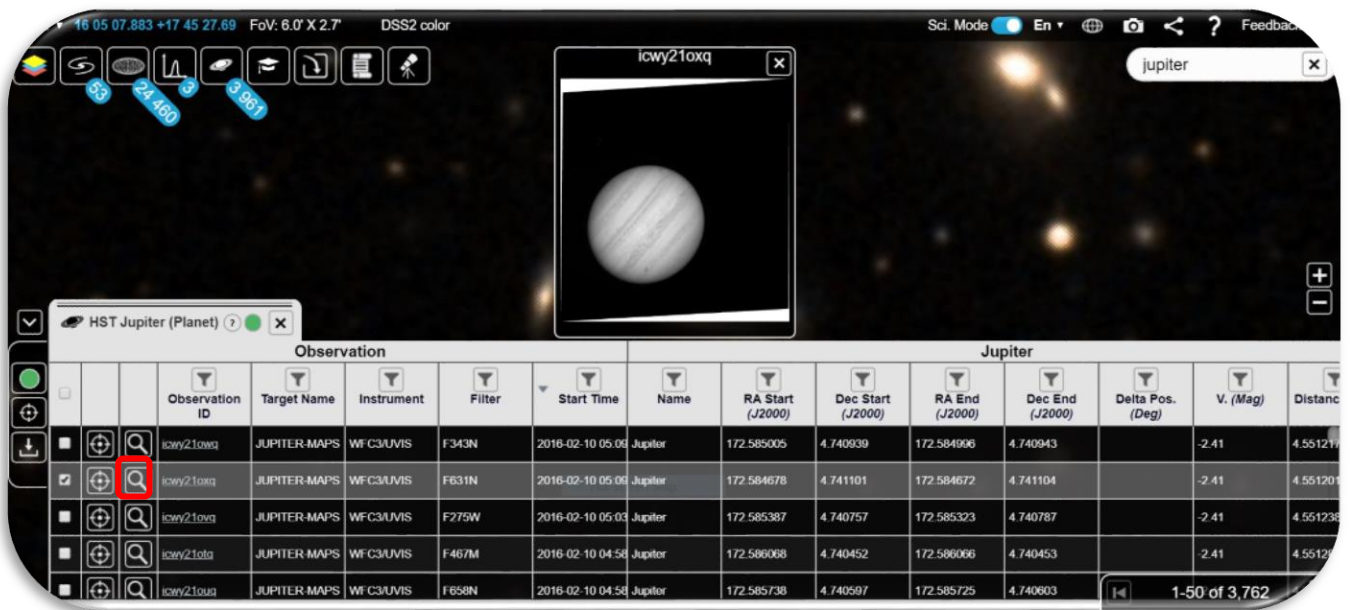


Figure 28: Selection of one of the HST observations of Jupiter (Credits: ESA)



Figure 29: 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 28, that represents the time when the data started to be collected in that selected observation.

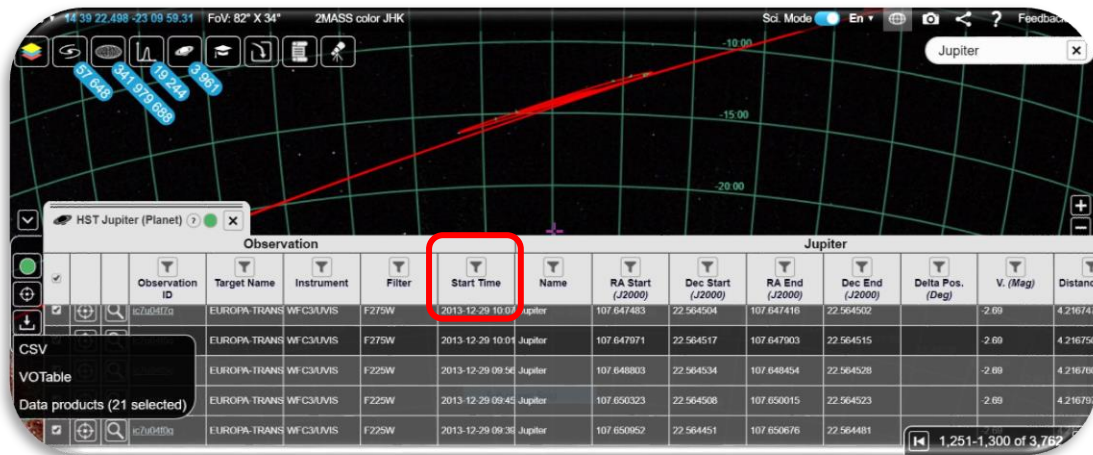


Figure 30: Jupiter images collected by HST on 2013-12-29. (Credit: ESA)

4. Once identified, by time, your observation, have a look at the magnifier and inspect it, as shown in Figure 31

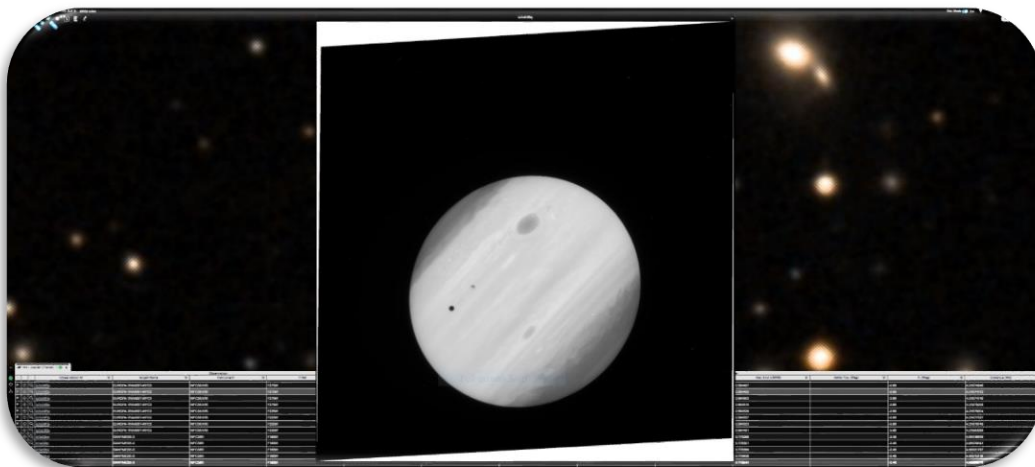


Figure 31: View of one of the Jupiter images collected by HST on 2013-12-29. (Credit: ESA)



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?

The first easiest answer is that this is what the Activity said, that at this time there was a transit of Europa

The second easiest answer could be that because these are the biggest moons in Jupiter it is more probable that we see their transits

The third possible answer is because the name of the target in the observation table said "EUROPA".

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]

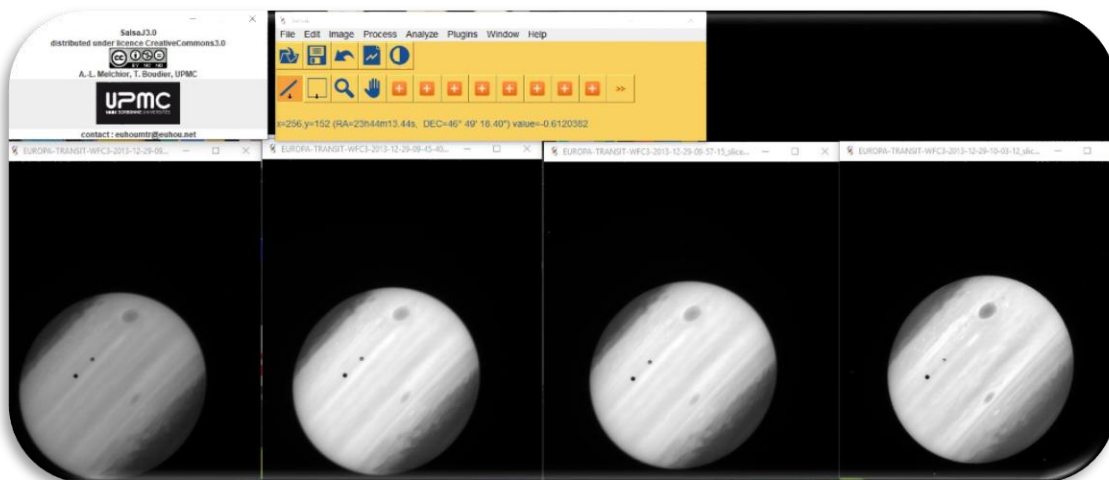


Figure 32: Inspection in SalsaJ of the set of data provided for this Challenge (Credits: ESA/ SalsaJ/ CESAR)

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 33.

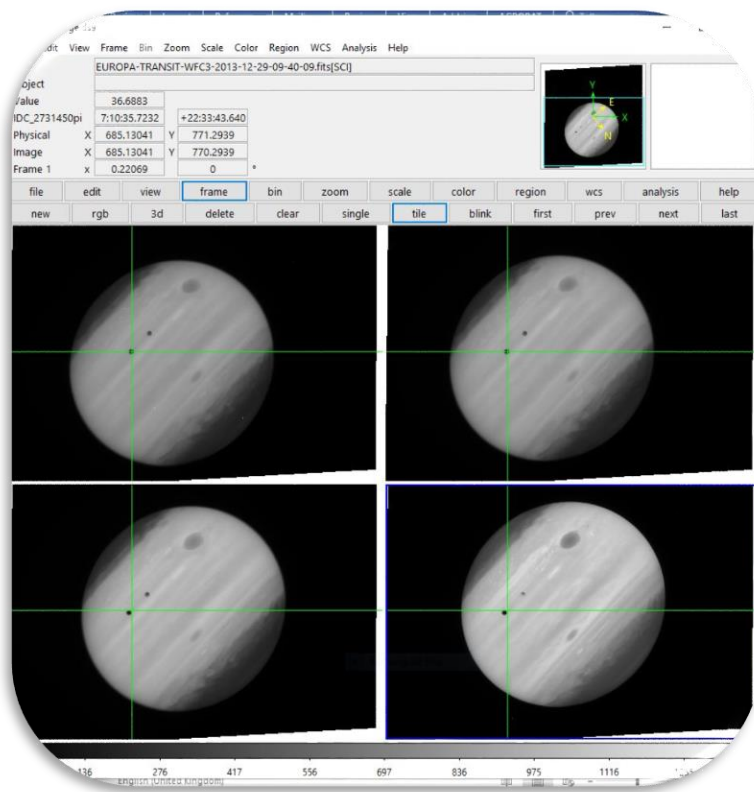


Figure 33: Inspection in SAODS9 of the set of data downloaded from ESA archives for this challenge (HST data of the Transit of Europa observed on 2013-12-29) . (Credits: ESA/ SAODS9/ CESAR)

What similarities/differences do you see among the four images in Figure 33 What do the black dots/stain represent?

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

The big grey stain (in this black and white image) is the famous Jupiter storm.

The small dark dots are the moon of Europa (grey) and its shade (transit) on top of Jupiter. The green cross indicates a fix position in coordinates. We see how the transit (shade of Europa) is not always at the same location among the four images collected at consecutive times.



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:**
 - 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?**
 - If the answer is YES, go to the next step.
 - 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

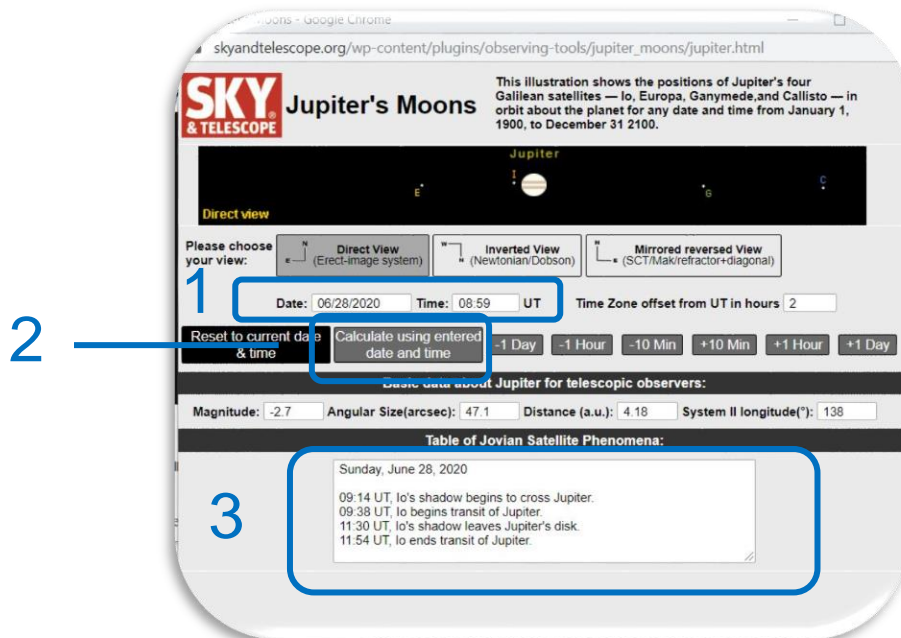


Figure 34: Sky Telescope Jupiter's transits predictor

2. How do I use this web?

- Enter the predicted **date and time** of the transit, in the boxes flagged as 1 in Figure 34
- 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

IMPORTANT NOTES

- Teachers will make sure that each Team performs the evaluations (quizzes)

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*.

IMPORTANT NOTES:

- It would be very interesting if you could present it to your schoolmates on a certain date, simulating a congress of scientists.
- Any document involving photos of your students can be published on the CESAR website or social networks. Therefore, please only attach those images for which you have explicit permission for publication, intellectual property and image. The CESAR Team is not responsible for their intellectual property and image.



Congratulations super teacher!

**Thanks to your dedication your class will receive a
CESAR Diploma**



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](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



Credits:

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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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