Alejandro Romar Tejeiro

CESAR/ESA/ESAC Science Case Traineeship Report

Unfortunately, after six amazing and productive months, I'm to leave the CESAR project. It has been a great pleasure to get to know and work with all the professional coworkers that formed the CESAR Team at the time of my traineeship. I hope that my contribution to the project, which is detailed in this report, is as big as the contribution that this unique experience has made to me. At least that was what I intended.

Science Cases

My main task at CESAR was to develop Science Cases. After I got to know what they where and how they worked, I started to work in a new format that has been used ever since. Once the new templates were stablished and the priorities were clear, I started working on my first Science Case, using images from the last Venus transit.

Venus-Sun Distance

This was my first Science Case. I was told to finish the already existing documentation, but understanding the texts left by the previous trainee turned out way harder that what I had expected. Anyhow, I had a clear vision of how I thought the final Science Case should look like and from the very first day I started working on it. After several months I was happy to present my final version, which I think it is a smooth and easy way to present the experiment to the students, but at the same time a very didactic experience that explores complex science concepts.

Of course the Science Case would benefit from further revisions, to make it faster to understand and smoother to solve, but I believe that the actual version is a fully working experience ready for students of all ages.

Sun Rotation Science Cases

Once the Venus-Sun distance Science Case was finished, I was told to keep working on the Sun Rotation ones. After reading all the existing documents I reorganized the two old Science Cases into three new ones (one of which I unfortunately did not have time to write). I applied my experience from the previous Science Case and developed "Sun's Rotation Period" and "Sun's Differential Rotation" both available in Basic and Intermediate Levels.

Then I started to work in the Advanced Level. The more I worked in it the harder it became, I had to write two external booklets that where necessary to comprehend the Science Case. The final result was much more complex than expected, and that is why I decided to turn it into the first ever Super Hero Level Science Case.

Web-Tools

The three finished Science Cases had their complete documentation, but new web-tools had to be developed to help the students through their tasks. I spent the major part of my last months working on the design of this web-tools. The web-tools ease the manipulation of the data (images) needed for each experiment. The students are guided through the steps, where the needed tools and data is provided, and in he final step, they can check their results and obtain a report.

Other Tasks

Besides with the Science Cases, I occasionally also helped in other sections of the CESAR Programe. I participated in a Thursday Kids Lecture, and in a CTIF Teacher Training Course. I once helped with a students visit to ESAC and went to help in the CESAR Robledo Observatory. I also spent about a week working in CESAR's web page. Once in a while I also tried to help with CESO (CESAR ESAC Solar Observatory), and of course I gave my opinion in CESAR weekly meetings whenever I thought it may be useful.

In the following pages you may find brief comments and images showing some of my achievements at CESAR, as well as a detailed list of everything I did during my traineeship. However, the main page of my report ends here. I would like to express my desire to keep working in CESAR if at any point the conditions of the project allow me to do so. Until then, I remain at your disposal. Sincerely yours.

Alejandro Romar Tejeiro

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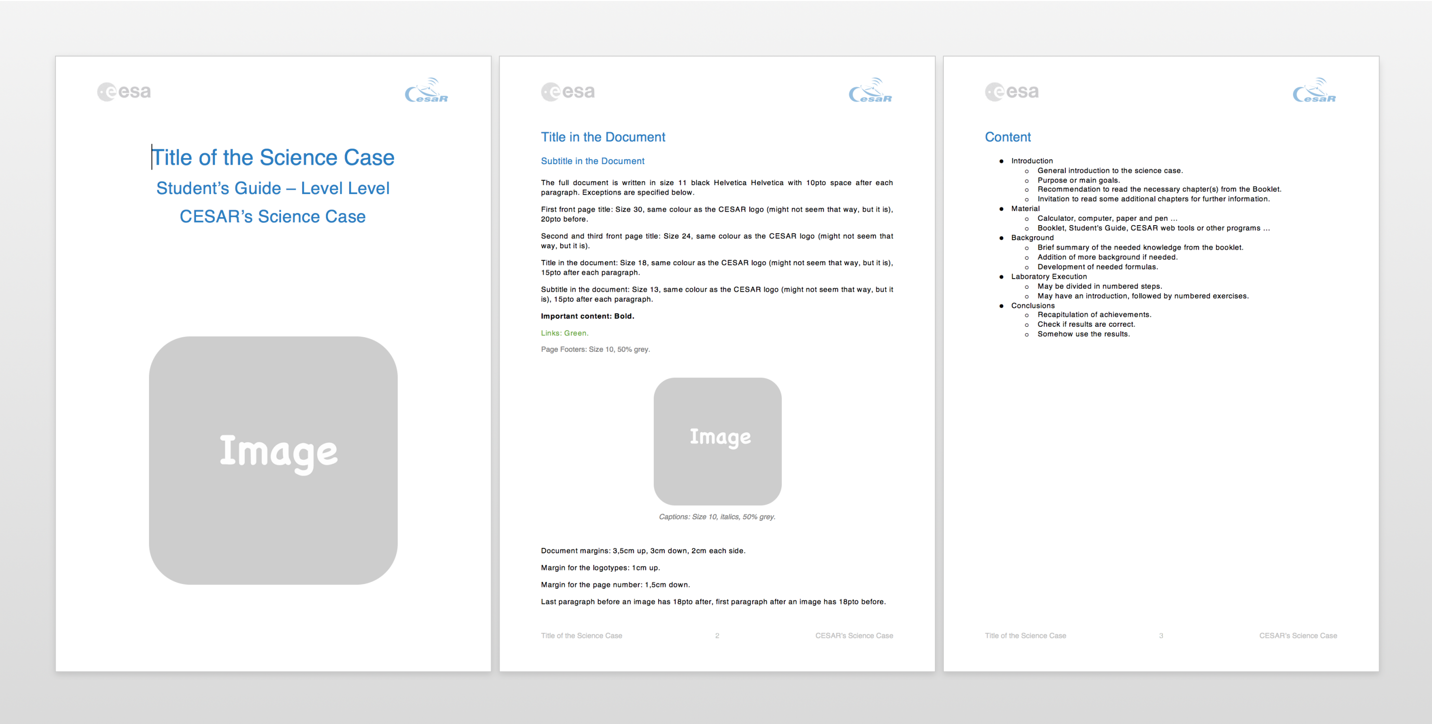
linkedin.com/in/aromart
alejandroromar.wordpress.com

Science Cases Templates

I went for simple designs for the templates: CESAR and ESA logos at the top, soft round-corner images, and titles with different color for the Teacher's Guide, the Student's Guide, the Quiz, and the Booklets.

In this step of the project, it was also very important to clearly define the content that the Student's Guide and the Teacher's Guide would have.



Title of the Science Case

Student's Guide – Level Level

CESAR's Science Case

Image

Title in the Document

Subtitle in the Document

The full document is written in size 11 black Helvetica Helvetica with 10pto space after each paragraph. Exceptions are specified below.

First front page title: Size 30, same colour as the CESAR logo (might not seem that way, but it is), 20pto before.

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Subtitle in the document: Size 13, same colour as the CESAR logo (might not seem that way, but it is), 15pto after each paragraph.

Important content: Bold.

Links: Green.

Page Footers: Size 10, 50% grey.

Image

Captions: Size 10, italics, 50% grey.

Document margins: 3,5cm up, 3cm down, 2cm each side.

Margin for the logotypes: 1cm up.

Margin for the page number: 1,5cm down.

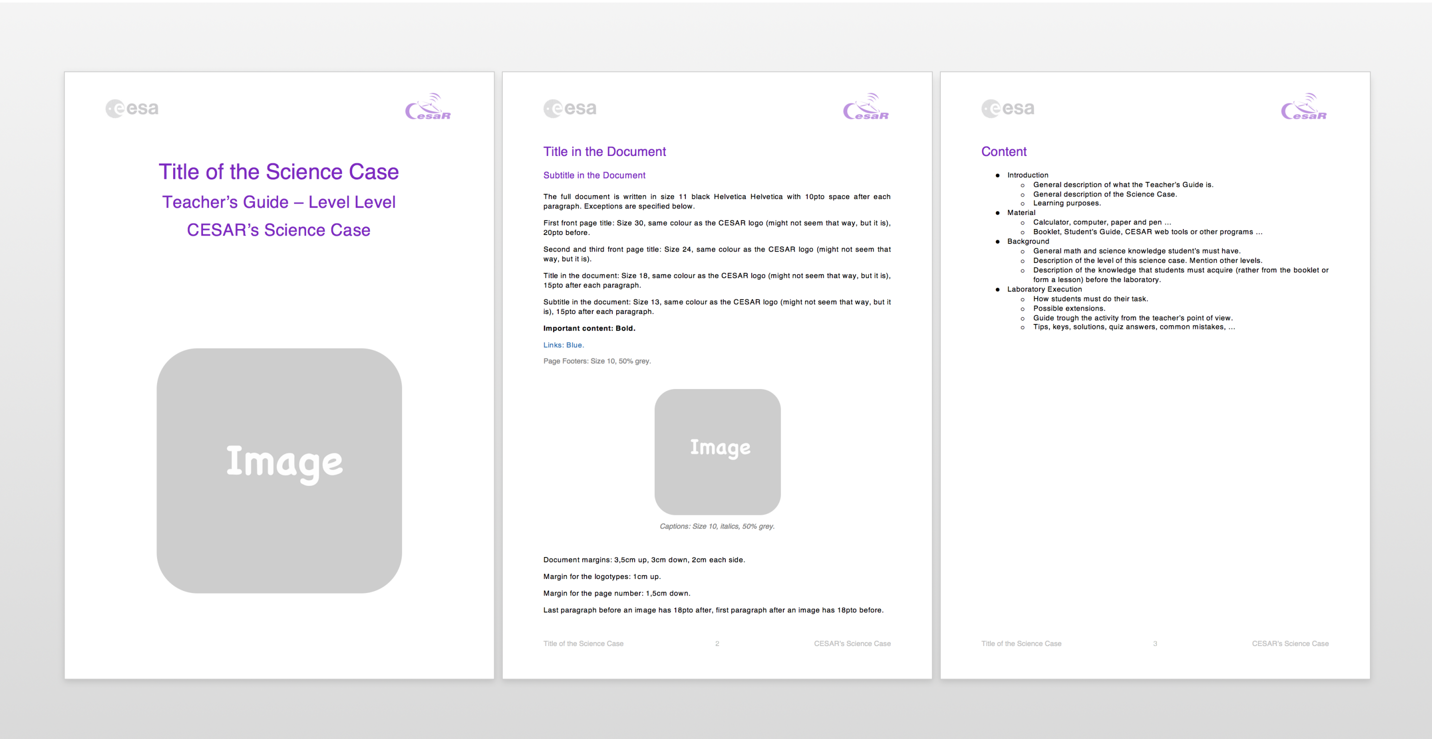
Last paragraph before an image has 18pto after, first paragraph after an image has 18pto before.

Title of the Science Case 2 CESAR's Science Case

Content

- Introduction
  - General introduction to the science case.
  - Purpose or main goals.
  - Recommendation to read the necessary chapter(s) from the Booklet.
  - Invitation to read some additional chapters for further information.
- Material
  - Calculator, computer, paper and pen …
  - Booklet, Student's Guide, CESAR web tools or other programs …
- Background
  - Brief summary of the needed knowledge from the booklet.
  - Addition of more background if needed.
  - Development of needed formulas.
- Laboratory Execution
  - May be divided in numbered steps.
  - May have an introduction, followed by numbered exercises.
- Conclusions
  - Recapitulation of achievements.
  - Check if results are correct.
  - Somehow use the results.

Title of the Science Case 3 CESAR's Science Case



Title of the Science Case

Teacher's Guide – Level Level

CESAR's Science Case

Image

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Important content: Bold.

Links: Blue.

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Image

Captions: Size 10, italics, 50% grey.

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Margin for the logotypes: 1cm up.

Margin for the page number: 1,5cm down.

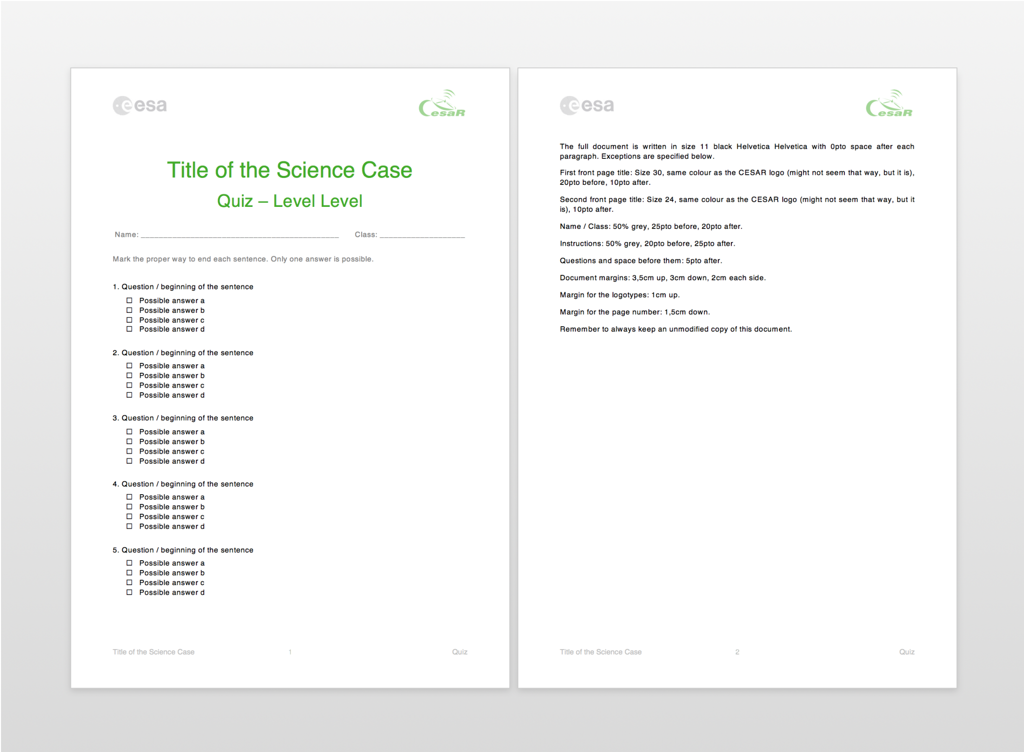
Last paragraph before an image has 18pto after, first paragraph after an image has 18pto before.

Title of the Science Case 2 CESAR's Science Case

Content

- Introduction
  - General description of what the Teacher's Guide is.
  - General description of the Science Case.
  - Learning purposes.
- Material
  - Calculator, computer, paper and pen …
  - Booklet, Student's Guide, CESAR web tools or other programs …
- Background
  - General math and science knowledge student's must have.
  - Description of the level of this science case. Mention other levels.
  - Description of the knowledge that students must acquire (rather from the booklet or form a lesson) before the laboratory.
- Laboratory Execution
  - How students must do their task.
  - Possible extensions.
  - Guide trough the activity from the teacher's point of view.
  - Tips, keys, solutions, quiz answers, common mistakes, …

Title of the Science Case 3 CESAR's Science Case



esa

Title of the Science Case

Quiz – Level Level

Name: ______________________ Class: __________

Mark the proper way to end each sentence. Only one answer is possible.

1. Question / beginning of the sentence
   - ☐ Possible answer a
   - ☐ Possible answer b
   - ☐ Possible answer c
   - ☐ Possible answer d

2. Question / beginning of the sentence
   - ☐ Possible answer a
   - ☐ Possible answer b
   - ☐ Possible answer c
   - ☐ Possible answer d

3. Question / beginning of the sentence
   - ☐ Possible answer a
   - ☐ Possible answer b
   - ☐ Possible answer c
   - ☐ Possible answer d

4. Question / beginning of the sentence
   - ☐ Possible answer a
   - ☐ Possible answer b
   - ☐ Possible answer c
   - ☐ Possible answer d

5. Question / beginning of the sentence
   - ☐ Possible answer a
   - ☐ Possible answer b
   - ☐ Possible answer c
   - ☐ Possible answer d

Title of the Science Case 1 Quiz

esa

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Second front page title: Size 24, same colour as the CESAR logo (might not seem that way, but it is), 10pto after.

Name / Class: 50% grey, 25pto before, 20pto after.

Instructions: 50% grey, 20pto before, 25pto after.

Questions and space before them: 5pto after.

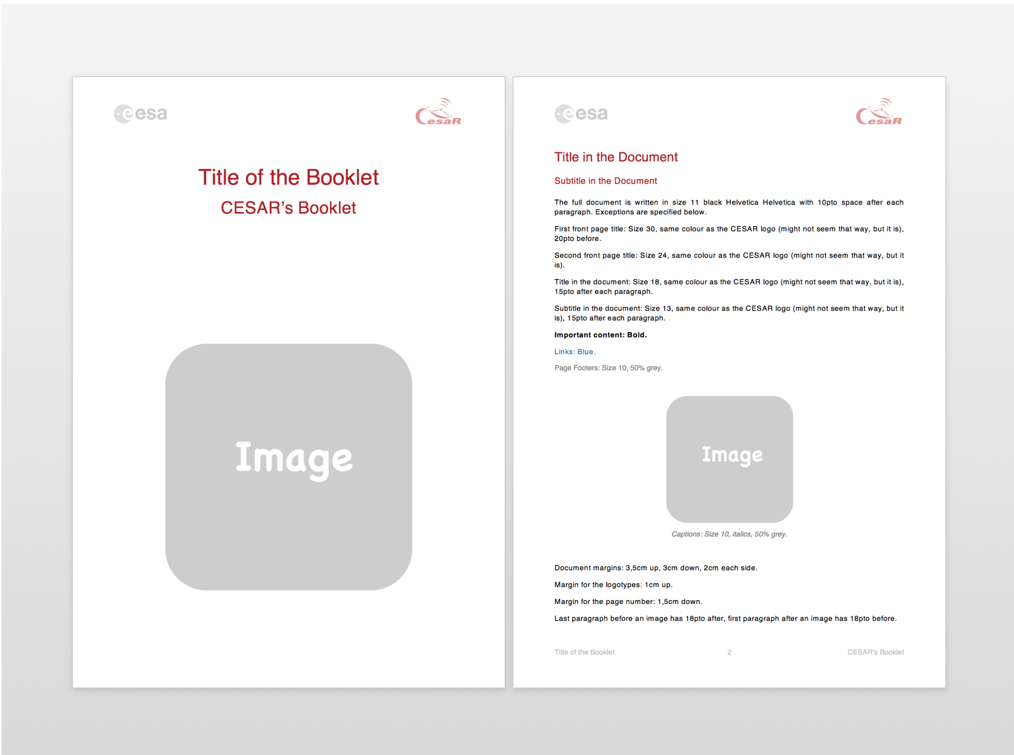
Document margins: 3,5cm up, 3cm down, 2cm each side.

Margin for the logotypes: 1cm up.

Margin for the page number: 1,5cm down.

Remember to always keep an unmodified copy of this document.

Title of the Science Case 2 Quiz



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Title of the Booklet

CESAR's Booklet

Image

esa

Title in the Document

Subtitle in the Document

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Title of the Booklet 2 CESAR's Booklet

CESAR Web Page

I am happy to say that I collaborated in the evolution of CESAR's webpage, here there are some snapshots of what I, among other fellows, did in the past few months. I am specially proud of the new BIAS level-system display.

News – Communications | Lectures News – Science at ESAC | For Educators – Science Experience | Events – Special events | Observatories – Infrastructure | Multimedia – Images & Videos | Contact – Contact us

Search

Home » For educators » Science Cases » List of Science Cases

List of Science Cases

B Basic Level

I Intermediate Level

A Advanced Level

S Super Hero Level

When the indicator is fully coloured, there is a whole set of material specifically developed for that level.

When the indicator is half coloured, the material from another level is recomended and perfectly suitable for this level. Give it a look!

When the indicator has no color at all, that science case is not recomended for that level.

THE VENUS-SUN DISTANCE NEW WEB-TOOLS!
Calculate the Venus-Sun distance using astronomical images from a **Venus transit** taken by the CESAR team. Students will learn about the **movements in the Solar System** and use **trigonometry** and **parallax.**

Keywords: Sun, SOHO, Transits, CESO, Solar System Planets.

SUN'S ROTATION PERIOD All levels in 15min!*
Calculate the **Sun's rotation period** by tracking **sunspots**. Students will understand **how the Sun moves** and will know how to **calculate velocities by tracking targets** in time-spaced images.

Keywords: Sun, SOHO, CESO.

SUN'S DIFFERENTIAL ROTATION Super Hero Level Available!
Calculate the **Sun's differential rotation** by tracking **sunspots at differnt latitudes**. Students will learn about the **movement of the Sun** and how to **calculate velocities by tracking targets** in time-spaced images.

Keywords: Sun, SOHO, CESO.

JUPITER AND ITS MOONS Will be revised soon!
Plan an observation, calculate **Jupiter's mass** and **Jupiter Moon's period**. Students will learn about **Kepler Laws** and how to **obtain data out of astronomical observations**.

Keywords: Júpiter, Kepler Laws, Solar System Planets.

THE SECRETS OF THE GALAXIES NEW VERSION!
Explore in **ESAsky ESA Mission's** data and clasify the galaxies you observe. Students will learn about **galaxies structures** and how to **extract data out of astronomical images**.

Keywords: Galaxies, ESAsky.

EXPLORING THE INTERSTELLAR MEDIUM NEW VERSION!
Explore in **ESAsky ESA Mission's** data and study the **ISM**. Students will learn about **the Structures in the Inter Stellar Medium** and how to **extract data out of astronomical images**.

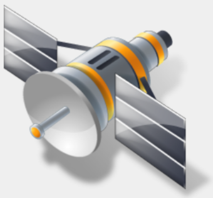
Keywords: ISM, ESAsky.

For educators

INTERACTIVE SCIENCE CASES

Do science from your school

SPACE SCIENCE EXPERIENCE



A complete experience at ESAC

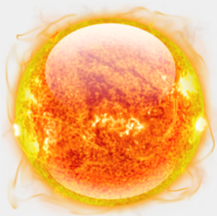
TEACHER TRAINING

Space Science Course at ESAC

BOOKLETS

Material to expand your knowledge.

THE SUN LIVE



Use the CESO to see the Sun live.

JOIN US

Collaborate with the CESAR team

ESA SKY

esa Sky

Explore the sky from home

Coming Soon

CUBESATS

Use your own satelite.

STAR PARTY

Astronomy Observations at ESAC.

TALK TO AN ASTRONOMER

Chat with an ESA's expert.

Science Cases

EXPAND YOUR KNOWLEDGE OF THE UNIVERSE FROM YOUR SCHOOL

The CESAR team provides free online interactive tools to introduce students in the fields of astronomy, science and technology. There is also plenty of material for advanced students to expand their knowledge. This tools and materials are part of what we call a Science Case. Science Cases are small exercises or laboratories where students learn about a certain topic and put that knowledge to use, getting hands-on experience in real-science research. The Science Cases are not only to make science approachable and attractive to young people but also to help them develop their critical thinking.

CHOOSE A TOPIC

The Sun

Solar System Planets

Galaxies

Interstellar medium

Exoplanets

The Earth

All the Science Cases

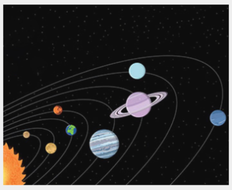
CHOOSE THE CORRECT SCIENCE CASE

There are Science Cases about lots of different interesting topics. All topics are equally didactic and suitable for involving students in a science experience. You may let the students choose, or look for a specific case that suits a particular unit you are teaching. However depending on the students' age and their knowledge about mathematics and physics, some Science Cases might be too difficult or way too easy. That is why the Science Cases are divided into difficulty levels. Teachers can choose the best level for their students. Although most of them are, not all the Science Cases are developed for all levels. Make sure to look at the level indicator when choosing a Science Case and to read the Teacher's Guide for further information.

Basic

The fundamental knowledge of the Universe at one-click distance! Without formulas or mathematics, simple as it is. Credits: Nautilus

Intermediate

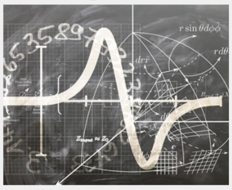


Basic physics crafting the Cosmos! Next step for expanding your knowledge of our Universe with some basic formulas.

Advanced

Go one step forward! Put all your physics and math knowledge to use. Skip no detail and experience the universe from end to end.

Super Hero



The real-pro-level! Science as it is. Advanced physics, high level math and programming. Use every tool available to reveal the mysteries of the Universe.

Make sure to look at the level indicator when choosing a Science Case and to read the Teacher's Guide for further information.

Basic Level Science Cases are focused on teaching the main knowledge we have about the Universe and the basic science tools that are used to explore it. In this laboratories, understanding the concepts is more important than the measurements. Without any formulae, they are recommended for students from primary school or for those coming from other branches than science.

Intermediate Level Science Cases are intended to be done by students with basic knowledge of physics and mathematics. Fundamental physics laws will be used as well as basic trigonometric formulas. These exercises would be recommended for students from secondary school and higher students with basic science knowledge.

Advanced Level is suitable for students coursing the few years previous to the university. Students will put into use physics and math advanced knowledge. All the needed background is provided in the Science Case but students in this level should be able to move easily trough math equations and science formulas.

The Super Hero level was recently developed to suit the most exigent students. Real science is done at this level, reliable data must be collected and analyzed in graphs and by programs that will have to be written by the students in some cases.

How to do a Science Case with your students

It was required for the web page and I was asked to write this informative document.

How to do a Science Case with your students

If you are reading this document, you probably want to do a Science Case with a group of Students. This is a printable downloadable guide with the necessary information to choose and prepare a Science Case.

There are Science Cases about lots of different interesting topics. All topics are equally didactic and suitable for involving students in a science experience. **You may let the students choose, or look for a specific case that suits a particular unit you are teaching.** However depending on the students' age and their knowledge about mathematics and physics, some Science Cases might be too difficult or way too easy. That is why the Science Cases are divided into difficulty levels. Teachers can choose the best level for their students. Although most of them are, not all the Science Cases are developed for all levels. **Make sure to look at the level indicator when choosing a Science Case and to read the Teacher's Guide for further information.**

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The Super Hero level was recently developed to suit the most exigent students. Real science is done at this level, reliable data must be collected and analyzed in graphs and by programs that will have to be written by the students in some cases.

Once you have chosen your Science Case, if the desired level is available, you can download the documents and access the resources.

For each Science Case, we provide:

A teacher's guide: a guide where teachers can find the key information to organize the activity and solve any possible issues. All the answers you may need and step by step information is here. May sure to print a copy of this guide and keep it handy.

A student's guide: a manual for students that guides them through the whole laboratory. All the information to do the activity on their own can be found here. Print a copy for each student or group.

Booklet's Chapters: booklets with information about the topics treated in the case, some of them are necessary to understand the experiment and others are provided to offer further information.

Quiz: a set of questions that should be answered by the students to reinforce the learning and that might be used to check whether they understood the procedure.

Web tools: online programs that were specifically designed by the CESAR team to ease the tasks proposed in the student's guides.

Other resources as external links to databases, or sets of images that might be of use.

Make sure to read the Teacher's guide before organizing an activity, it will most likely solve all your doubts. After reading the guide, if you decide to go on with the activity, you should decide wether **you are printing the needed booklet chapters for the students, or preparing a class to teach them the needed background**. Whatever method you decide, make sure that students have the background before continuing. Once they read the booklet or atended the class, they are ready for the laboratory itself. **Print Student's Guides for them and make sure the needed material for the Science Case** (specified in the Teacher's Guide) is available. Now they are good to go.

Most of the Science Cases already have all the documentation and students may be able to complete them in 30-60 minutes if students have all the background knowledge beforehand. However, teachers are encouraged to test all the material they are to use. Feel free to contact us if you have any doubts or if you find any kind of error.

In some of the Science Cases, students will be asked to use the CESAR Observatories, which means they will have to follow all scientific method for the very beginning. They will program an observation and wait for the data to come. Remember to contact CESAR team in advance and check if the observatories are available.

For any further doubts, we remain at your disposal.

cesar.esa.int/index.php?Section=Contact

The CESAR team.

The Venus-Sun Distance

Once you access the images, you must measure the distance between A' and B'. But of course, A' and B' are the position in which Venus is seen from the two different observatories, so the spots A' and B' are in different images. To measure the distance, we should first **merge those two images in one**, so that we have a final image in which we do can **see both points at the same time**.

To do so, you must select two images that where taken at the exact same time, one from each observatory. They will look as the images above. Using an image processing program such as Gimp or Photoshop, or the tool provided in CESAR webpage, you must merge them in a way that allows you to see the two Venuses at the same time. Before merging them you may have to **align the images**, so that the Sun is in the exact same position in both. The best way to align the images is checking the position of the sunspots (those green circled in Image 2 and Image 3). Just let one image be fixed as reference, and move, flip, resize and rotate the other one until the sunspots in both of them are in the exact same position. After merging them, you should get something like the Image 4, where the sunspots from both original images are in the same position, and the two images of Venus are visible.

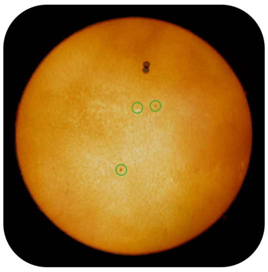


Image 4: Merged pictures

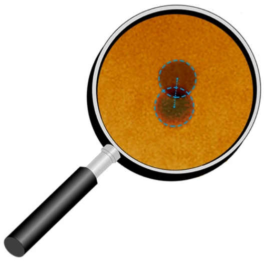


Image 5: Measuring A'B' distance

It's a standard procedure in science to align astronomy images to a standard reference. You may download from the SOHO webpage (where images are aligned to the Sun's North) an image of the Sun that was taken at the same time as the other two. Then set it fixed (as this is the standard reference) and move the other two together to align them to the SOHO one, using the same procedure as before. Once done, you can delete the SOHO image and keep your two images aligned.

The SOHO database is

sohodata.nascom.nasa.gov/cgi-bin/data_query

You may choose max resolution for the HMI Continuum. Images are named:

yearmonthday_hourminutes_imagetype_resolution.jpg

Choose one of the same date and time as the ones from Svalbard and Canberra.

Now that we have an aligned image where we can measure the distance, we may wonder between which two points exactly we should measure, choosing one random point in each A' and B' Venus images would be way too imprecise. Instead we can use the same program or tool we chose before to **find the centre** of Venus in both A' and B', and then, still with the tool you chose, **measure, in pixels, the distance** between the two centres $\overline{A'B'}$, as shown in Image 5.

Step 2

We now know $\overline{A'B'}$, one of the two quantities needed for (eq. I). Let's obtain the second one, $\overline{AB}$:

To obtain $\overline{AB}$, we'll use the coordinates from the two observatories A and B along with the formulas developed in the Booklet chapter "Earth Coordinates". The coordinates from Canberra and Svalbard can be obtained using Google Earth or any similar program. (If you don't have access to such as program, the coordinates could also be found on the web.) As you should know from the Booklet, the equation in which to substitute them is

$$\overline{AB} = 2 \cdot R_E \cdot \sqrt{sin^2\left(\frac{\varphi_A - \varphi_B}{2}\right) + cos(\varphi_A) \cdot cos(\varphi_B) \cdot sin^2\left(\frac{\lambda_A - \lambda_B}{2}\right)}$$

where R_E is the Earth radius (in meters), φ are the latitude values, and λ the longitude ones.

Now we also know the $\overline{AB}$ distance (in meters).

Step 3

In (eq. I), $\overline{AB}$ is divided by $\overline{A'B'}$, but since we did the $\overline{A'B'}$ measurement in a digital image, the value of the distance is expressed in pixels $\overline{A'B'}\ [pix]$, so a **unit conversion must be made**. To change it into meters we may first express it as a multiple of the Sun radius R_S, that is, measure in the image the Sun radius in pixels too $R_S\ [pix]$, and calculate the relation

$$\overline{A'B'}\ [R_S] = \frac{\overline{A'B'}\ [pix]}{R_S\ [pix]}$$

which is just $\overline{A'B'}$ expressed using R_S as a unit or reference. Then, if you look in the web for the value of the Sun radius $R_S\ [m]$ in meters, you can obtain $\overline{A'B'}\ [m]$ in meters too just by doing

$$\overline{A'B'}\ [m] = \overline{A'B'}\ [R_S] \cdot R_S[m]$$

Background

Transits

To understand how we are doing this huge measure, lets first draw the positions of the Earth and Venus around the Sun:

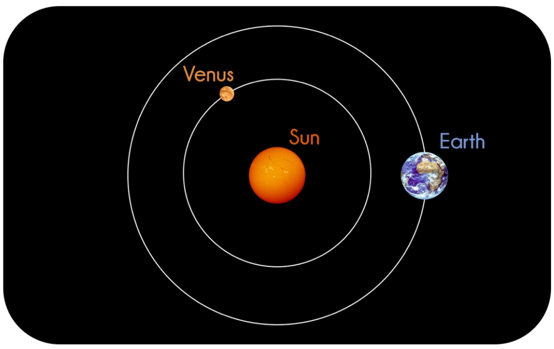


Image 1: Venus, the Sun, and the Earth, during a random day.

At some random day, things would look like in the Image 1, the Earth and Venus are orbiting the Sun without noticing each other. In such a day, if we call Alice, an astronomer living in Svalbard (Norway), and we ask him about his observations, he will tell us that Venus is somewhere in the sky, far away from the Sun.

But then, at some point, after some days have passed and the planets have moved around, things may look as in Image 2:

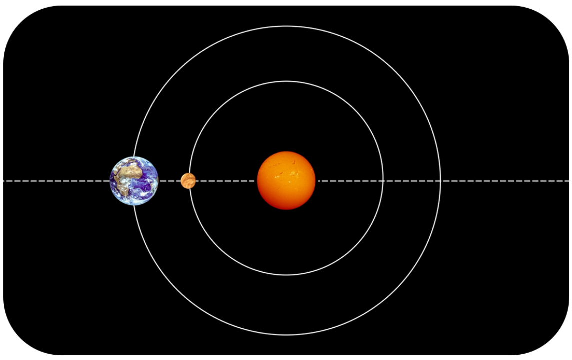


Image 2: Venus, the Sun, and the Earth, during a transit.

If we call Alice this particular day, he will tell us that **Venus is in front of the Sun**. Alice would see the planet Venus as a dark circle, moving across the Sun disk, just as shown in the title page of this guide. **We call this phenomenon a transit**. Of course, this situation doesn't happen every day, so Alice will hurry to take a lot of pictures of the Sun and Venus crossing its surface. He will keep taking pictures until the planets move a little bit and the transit is over.

Sun's Rotation Period

esa CesaR

Laboratory Execution

Step 1 - Making a prediction

In science, we usually have some predictions of what we expect to measure before we do the actual measurements. Let's try to get a prediction: We know that small objects such as peg-tops or spinners rotate really fast, tens of revolutions every second. Bigger objects like the Earth, need 24h to rotate only once. This does not necessarily mean that bigger objects rotate slower, for example, pulsars are neutron stars that can rotate as fast as a spinner. Still, in most of the cases, when the difference in size of two rotating objects is very big, the biggest object usually rotates slower. Knowing this, how fast do you think the sun rotates? How much does it take to the Sun to complete one complete rotation? Once you have a prediction, you are ready for the measurements.

Step 2 - Choosing data images

We are calculating the rotation speed of the Sun by measuring the speed of sunspots in Sun's surface. In the CESAR web tool, you must use the displayed calendar to look through different days until you find a picture that has a sunspot at the equator. The Sun is always moving, so once you locate a sunspot, you will realize that if you choose an image from the previous day, the sunspot will appear moved to the left. In the same way, if you choose an image from the next day, the sunspot will move to the right. What we actually want to do is **choose two images**, separated by two or more days, so that in one of them the sunspot is at the left, and in the other one in the right. **By measuring how much the sunspot moved in those days, we will know how fast it is moving.**

Step 3 - Coordinates of a sunspot

To measure the speed of the sunspot, we first have to know how much it moved. For that we will take the difference between the final position and the starting position, the difference in position is just the distance it moved. To get the initial and the final positions, we will use coordinates for measuring, and degrees as units. You have to align your image to a grid with Sun's parallels and meridians and then merge them together. This process is automatically done by CESAR's web tool. The image should look like the Image 1. Looking at the picture it should be easy to get the position of the sunspot, take the vertical line marked in a different colour as 0°. Each adjacent line is 10° away, knowing this you can easily get the position of sunspots. For example, in our picture there are big sunspots at 13° and 21°. It is only important to measure the longitude as the sunspots rarely move in latitude. You must get the position of your sunspot in the two images.

esa CesaR

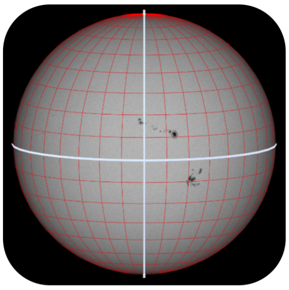


Image 1: Sun picture aligned to a grid

Step 4 - Calculating speeds

Now that we've got the positions in degrees, just make the difference between the final position and the starting position, the result is the distance (in degrees) that the sunspot travelled. Now, we are ready to get the speed, the formula it's easy:

$$speed = {}^{distance}/_{time}$$

The distance, measured in degrees, is just the difference in longitude between two days. Then we need the time interval, that is just the difference in time between the two dates of the images expressed in days. To express the date / time difference in days you can use this formula

$$days\ difference + \frac{hours\ difference}{24\ h/day} + \frac{minutes\ difference}{24\ h/day\ \cdot\ 60\ min/h}$$

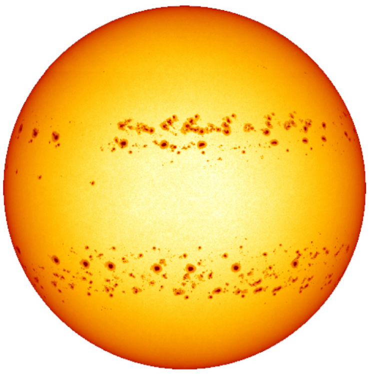
Once you have the time difference in days and the distance in degrees use the speed formula and you will obtain the speed of that sunspot in degrees/day.

esa CesaR

Sun's rotation period

Teacher's Guide - Intermediate Level

CESAR's Science Case



esa CesaR

Introduction

This is the teacher's guide for "Sun's rotation period" CESAR's Science Case. Note that **this guide does not contain full instructions** to successfully develop the science case, those can be found at the student's guide. This guide includes information about the learning purposes of the activity as well as about the material and background needed for it, so that the teacher may decide **weather this laboratory is suitable** for his class or not. This guide is also meant to **help the teacher trough organising the activity**, providing tips and keys for each step, as well as the **solutions** to the case's calculations and the quiz.

In this science case the students are to **calculate the Sun's rotation period** using images from CESO (CESAR's ESAC Solar Observatory). By the end of this laboratory, students will be able to:

- Understand how fast the Sun moves.
- Calculate velocities by tracking targets in time-separated images.
- Explain what the rotation period is.
- Make predictions and prove them with experiments.

By completing this science case, students will find out how astronomical pictures can be used to obtain valuable data.

Material

What will they need?

- The "Sun's rotation period" Student's Guide.
- CESAR's Booklet.
- Computer with Web Browser and Internet Connection.
- CESAR web tools.
- Calculator (physical or online such as wolframalpha.com) and paper and pen.
    - Or a spreadsheet program such as Open Office, Google Docs, Excel or Numbers.

There are no needed chapters from the booklet, however "Sun" is recommended to get more knowledge about the topics treated in this laboratory, and the introduction in "Earth Coordinates" may came in handy if students don't have the basic knowledge about standard coordinate systems.

Sun's Differential Rotation

Unlike the Earth, **the Sun is not a rigid body**. This means that when studding the movement of the Sun, you can not consider it as a compact structure. The sun is actually a massive sphere of plasma, more similar to a huge ball of gas than to a solid rigid structure. This is no different to soil and water. Soil is a solid structure, but water is not. You may have water moving at different speeds than the water near by, like a sea current. That's because water is not a rigid body, water is not attached to anything and it's free to move anywhere. Same thing happens with the plasma in the Sun.

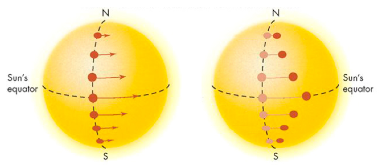


Image 1: Sun's differential rotation (Credits: McGraw-Hill)

Unlike in Earth, **not every point of the Sun's surface rotates at the same speed**. In the Earth every point in the surface rotates at the same speed, in the Earth a day last 24h in everyplace, because the whole Earth moves together. But as the Sun is not a rigid body, but more like water, **nothing forces the Sun surface to move has a whole. The plasma located in different places of the surface may rotate at different speeds, that is what we call differential rotation.**

In fact, after many observations, it has been stated that Sun poles rotate slower than the equator. Actually, **in the Sun, the closer to the poles you get, the slower the surface rotates**. So every point in the Sun's surface rotates at a different speed. The Sun rotates really fast at the equator and it slows down when moving towards the poles (as seen in Image 1 and Image 2). This differential rotation is what we are checking in this laboratory.

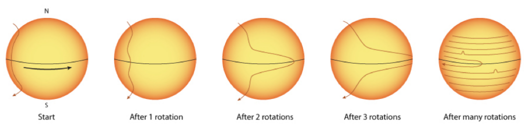


Image 2: Sun's differential rotation after several days. (Credits: NASA / IBEX)

Laboratory Execution

We are calculating the rotation speed of the Sun by measuring the speed of sunspots in Sun's surface. Our point is to study the differential rotation of the Sun, so we'll have to locate one sunspot close to the equator and an other one as far away as possible. Once we locate them, we'll calculate their speeds (which is also the rotation speed of the Sun) and check if they really are different.

In the CESAR web tool, the equator line is the one marked in a different colour. You must use the displayed calendar to look through different days until you find a picture that has a sunspot at the equator.

The Sun is always moving, so once you locate a sunspot, you will realise that if you choose an image from the previous day, the sunspot will appear moved to the left. In the same way, if you choose an image from the next day, the sunspot will move to the right. **What we actually want to do, is select two images, separated by two or more days, so that in one of them the sunspot is at the left, and in the other one in the right. By measuring how much the sunspot moved in those days, we will know how fast it is moving.** Mark the positions of the sunspots in each day and the program will calculate the speed of the sunspot.

Once you got the speed of the first sunspot, you will have to find a second one, further away from the equator, to check if it moves slower. Use the calendar again, go through a few months and choose a sunspot as far away from the equator as possible. Again choose two images of the same sunspot separated by a few days and measure de distance as you did before.

And that is it! Now you know the speed of a sunspot close to the equator and the speed of a sunspot close to the poles, and you can compare and see which ones is bigger.

Conclusions

In this laboratory you have studied Sun's differential rotation. You've calculated Sun's rotation speed in the equator and close to the poles. For doing so you tracked the movement of two different sunspots in time-spaced images and calculated their speed by measuring how much they moved between the images.

When doing science, it's always a good idea to check your results before publishing them. As you know from the images in the background section, the Sun's rotation speed is higher in the equator than closer to the poles. Does this agree with your calculations? Did you get a faster speed in the equator?

If you do have obtain a consistent value, lets go one step further, if you had to guess, how fast would you say a sunspot located between the two you looked at would move?

Sun's differential rotation

Quiz – Intermediate Level

Name: ______________________________ Class: ____________

Mark the proper way to end each sentence. Only one answer is possible.

1. Unlike the Earth, the Sun is not a rigid body. This means that
   - ☐ when studding its movement, you can not consider the Earth as a compact structure.
   - ☐ the Sun is about to turn into a compact structure by eating planet Earth.
   - ☐ the Sun is not forced to move as a whole.
   - ☐ when studding the movement of the Sun, you can consider it as a compact structure.

2. Unlike Earth's, the Sun's surface
   - ☐ is made of water, with sea currents that are free to move anywhere.
   - ☐ rotates at higher speeds in lower latitudes.
   - ☐ is made of plasma that will turn into soil after a few years.
   - ☐ moves faster in the poles and slower in the equator.

3. The Sun's rotation speed is different at different latitudes, this means that if two sunspots appear
   - ☐ at the same longitude, they will be at different longitudes after a few days.
   - ☐ at the same latitude, they will be at the same longitude after a few days.
   - ☐ at the same longitude, they will be at the same longitude after a few days.
   - ☐ at the same time, they will fuse into a bigger sunspot capable of great things.

4. We can calculate the rotation speed of the Sun by measuring the speed of sunspots because
   - ☐ sunspots want to help us and they whisper the Sun's differential rotation.
   - ☐ sunspots are located at the Sun's surface, that moves as a whole.
   - ☐ sunspots move like sea currents as they are free to move anywhere.
   - ☐ sunspots are located at the Sun's surface, whose speed we want to measure.

5. The Sun rotates
   - ☐ clockwise, like the Earth does.
   - ☐ so fast that it is flat.
   - ☐ counter-clockwise, like the Earth does.
   - ☐ faster in the poles.

6. You wrote down the latitude of each sunspot to
   - ☐ check the speed of the Sun at different latitudes.
   - ☐ measure how much the latitude changes after a few days.
   - ☐ measure the latitude of the Sun as seen by a radiotelescope.
   - ☐ subtract it from the latitude of the same sunspot after a few days, and divide it by time.

7. You wrote down the longitude of each sunspot to
   - ☐ check the speed of the Sun at different longitudes.
   - ☐ measure how much the longitude changes after a few days.
   - ☐ measure the longitude of the Sun as seen by a new radiotelescope.
   - ☐ check if the longitude remains stable.

8. To calculate the speed of each sunspot you
   - ☐ divided time by distance.
   - ☐ used a chronometer.
   - ☐ looked at, at least, two different sunspots.
   - ☐ tracked the sunspot in time-spaced images.

9. We say that the Sun has differential rotation because
   - ☐ two sunspots in the equator don't necessarily have to rotate at the same speed.
   - ☐ the plasma is differential and it does actually rotate.
   - ☐ the plasma located at different distances from the poles may rotate at different speeds.
   - ☐ the student's guide says so, and the students guide knows more than anyone.

10. The Sun's differential rotation graph, where the rotation speed was represented as function of
    - ☐ the heliographic longitude, showed that we are not alone in the Universe.
    - ☐ the heliographic longitude, showed that the Sun rotates faster in the equator.
    - ☐ the heliographic latitude, showed that the rotation speed is symmetric to the equator.
    - ☐ the heliographic latitude, showed that the Sun rotates faster in the poles.

Booklets

$$\frac{\overline{TR}}{\overline{AB}} = \frac{\overline{SR}}{\overline{A'B'}}$$

This means, that because the triangles in the picture are proportional to each other, the distance between A and B, $\overline{AB}$; and the distance between A' and B', $\overline{A'B'}$; are related to $\overline{TR}$ and $\overline{SR}$ by an equation that can also be written as

$$\frac{\overline{A'B'}}{\overline{SR}} = \frac{\overline{AB}}{\overline{TR}}$$

Usually this equation is enough to solve most of parallax situations, but the reader might keep reading if he wants to learn more relations from parallax geometry that will come handy in more complex situations. If not, feel free to skip the following, and read "Parallax in Astronomy" to finally accomplish the purpose of this booklet.

Parallax in astronomy

Now that you know fair enough about parallax geometry, you may be wondering how that is useful.

In the previous section, we found an equation that relates the distance between the exact location of two observers, $\overline{AB}$; the distance between where an object appears to be from those two places, $\overline{A'B'}$; the distance from that object two the observers, $\overline{TR}$; and the distance from that object to the background $\overline{SR}$. We can use this relation to measure distances in astronomy. We only have to observe an object from two different places, then, measuring the distance between those two places, measuring the distance between the apparent position of the object as seen from those two places, and using the relation we found, we can calculate the distance to the object, or the distance between the object and the background.

Let's see a few examples:

Look at Image 3, if we observe a near asteroid from two different places in Earth, we can use a distant-stars-background to measure the difference in the apparent position of the asteroid. Then, measuring the distance between the two observatories we can use our equation to find out how far the asteroid is.

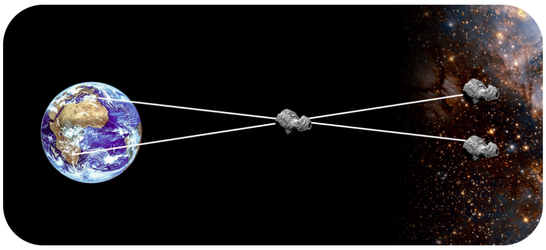


Image 3: Distance to an Asteroid

Let's see an other example in Image 4. If we observe the Sun from two different places during a transit. We can use the solar disk as background to measure the difference in the apparent position of the planet. Then, measuring the distance between the two observatories we can use our equation to find out how far the planet is from the Sun.

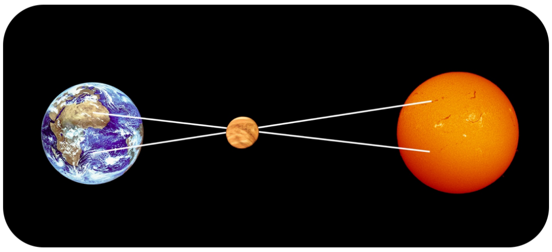
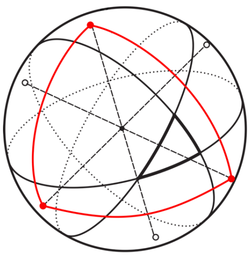


Image 4: Planet-Sun distance

Spherical Trigonometry

CESAR's Booklet



It's the purpose of this booklet to deduce some formulae and equations that may come in handy when working with spherical trigonometry.

The cosine-formula

Math Notation

$$\exists A,B,C,O \quad \exists \alpha \circledcirc O : A,B,C \in \alpha \quad \exists \beta \perp \overline{OA} : A \in \alpha,\beta \quad \exists D \in \beta,\overline{OB} \quad \exists E \in \beta,\overline{OC}$$

$$\exists \lambda := \widehat{AOB} \quad \exists \mu := \widehat{AOC} \quad \exists \omega := \widehat{BOC} \quad \exists \vartheta := \widehat{BAC} \quad \exists \kappa := \widehat{BCA} \quad \exists \eta := \widehat{CBA}$$

$$\therefore$$

$$|\overline{AD}| = |\overline{OA}| \cdot \tan(\lambda) \quad |\overline{OD}| = |\overline{OA}| \cdot \sec(\lambda) \quad |\overline{AE}| = |\overline{OA}| \cdot \tan(\mu) \quad |\overline{OE}| = |\overline{OA}| \cdot \sec(\mu)$$

$$|\overline{DE}|^2 = |\overline{AD}|^2 + |\overline{AE}|^2 - 2 \cdot |\overline{AD}| \cdot |\overline{AE}| \cdot \cos(\vartheta) \quad |\overline{DE}|^2 = |\overline{OD}|^2 + |\overline{OE}|^2 - 2 \cdot |\overline{OD}| \cdot |\overline{OE}| \cdot \cos(\omega)$$

$$\therefore$$

$$|\overline{DE}|^2 = |\overline{OA}|^2 \left[\tan^2(\lambda) + \tan^2(\mu) - 2 \cdot \tan(\lambda) \cdot \tan(\mu) \cdot \cos(\vartheta)\right]$$

$$|\overline{DE}|^2 = |\overline{OA}|^2 \left[\sec^2(\lambda) + \sec^2(\mu) - 2 \cdot \sec(\lambda) \cdot \sec(\mu) \cdot \cos(\omega)\right]$$

$$\therefore$$

$$-2 \cdot \tan(\lambda) \cdot \tan(\mu) \cdot \cos(\vartheta) = 1 + 1 - 2 \cdot \sec(\lambda) \cdot \sec(\mu) \cdot \cos(\omega)$$

$$\therefore$$

$$\cos(\omega) = \cos(\mu) \cdot \cos(\lambda) + \sin(\mu) \cdot \sin(\lambda) \cdot \cos(\vartheta)$$

□

Explanation

In case you need it, in this section we will explore in detail the previous deduction, so that the path to the cosine-formula it's clear and the formula itself is understandable:

First, you should know, that in geometry, it's common to name points with capital letters, while lines are usually named with lowercase letters and Greek letters are commonly reserved for angles and planes.

Also, before reading the math above, you must have a basic knowledge about math symbols:

∃	There exists
◎	Concentric
:	Such that
∈	Element of
⊥	Perpendicular
:=	Definition
∴	Therefore
□	End of proof

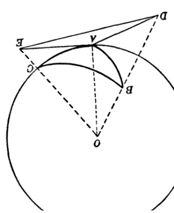
Now that you have this fundamental knowledge, lets start to read the math notation again. (It's a good idea to draw everything that you read, like in Image 1)

$\exists A,B,C,O$

This first statement, just means, that the deduction of the cosine-formula starts with the existence of four points in the space, named A, B, C and O, about which we know nothing yet.

$\exists \alpha \circledcirc O : A,B,C \in \alpha$

To this, it follows the existence of α that is concentric to O. α is a sphere, cantered in the point O. The sphere is defined so that the points A, B and C are part of it. So this far, we have a sphere, which centre is named O and three points in the sphere named A, B and C.



$\exists E \in \beta,\overline{OC}$

The same explanation is repeated here. A new point E appears. The point is in the new plane β, and is also in the line that goes from O to C. So if we extend the line that goes from O to C until it intersects the plane, we will find the new point E.

$\exists \lambda := \widehat{AOB} \quad \exists \mu := \widehat{AOC} \quad \exists \omega := \widehat{BOC} \quad \exists \vartheta := \widehat{BAC} \quad \exists \kappa := \widehat{BCA} \quad \exists \eta := \widehat{CBA}$

This line is really easy, where just naming angles here. λ is the angle between A, O and B, so it's the angle located at O defined by the lines going from A to O and from B to O. You can apply the same to the other 5 angles with their new Greek-letter-names.

At this point we have explained the first two lines from the math-notation deduction, and the result is a picture like the one in the previous page, with its main elements properly named. After this two lines a therefore symbol is placed, meaning that the following lines can be deduced from the ones we already explained. As we represented the information from the first lines in a picture, we will be able to deduce the following just by looking at the picture we made. Let's get started:

$|\overline{AD}| = |\overline{OA}| \cdot \tan(\lambda)$

$|\overline{OD}| = |\overline{OA}| \cdot \sec(\lambda)$

This one is basically the same as

$\overline{OA} = \cos(\lambda) \cdot \overline{OD}$

which we have already seen before.

□

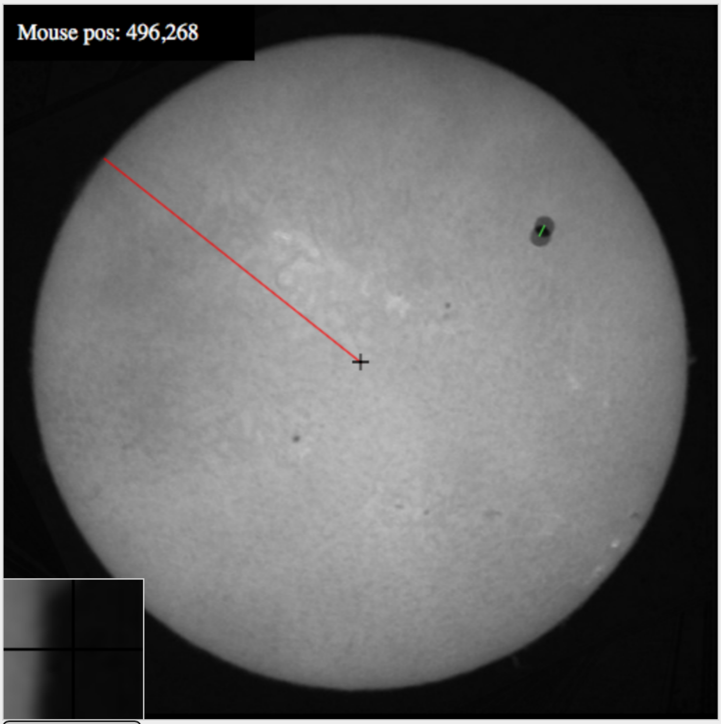
$|\overline{AE}| = |\overline{OA}| \cdot \tan(\mu)$

This one, is no different to the first one

$|\overline{AD}| = |\overline{OA}| \cdot \tan(\lambda)$

Venus-Sun distance (basic) v0.9

Step: 5/8
Below is the final image that you can use to make all your measurements.



Objective:
Now that the images are merged and aligned, you are ready for the final step. To measure the distance between two points, click (do not hold) in the first point and then clic again in the second one. Yo can do as many measurements as you need.
First select the "Sun radius" box and measure the Sun radius for calibration. Then click in the "Venus A' - Venus B' distance" box to finally measure the A'B' distance.

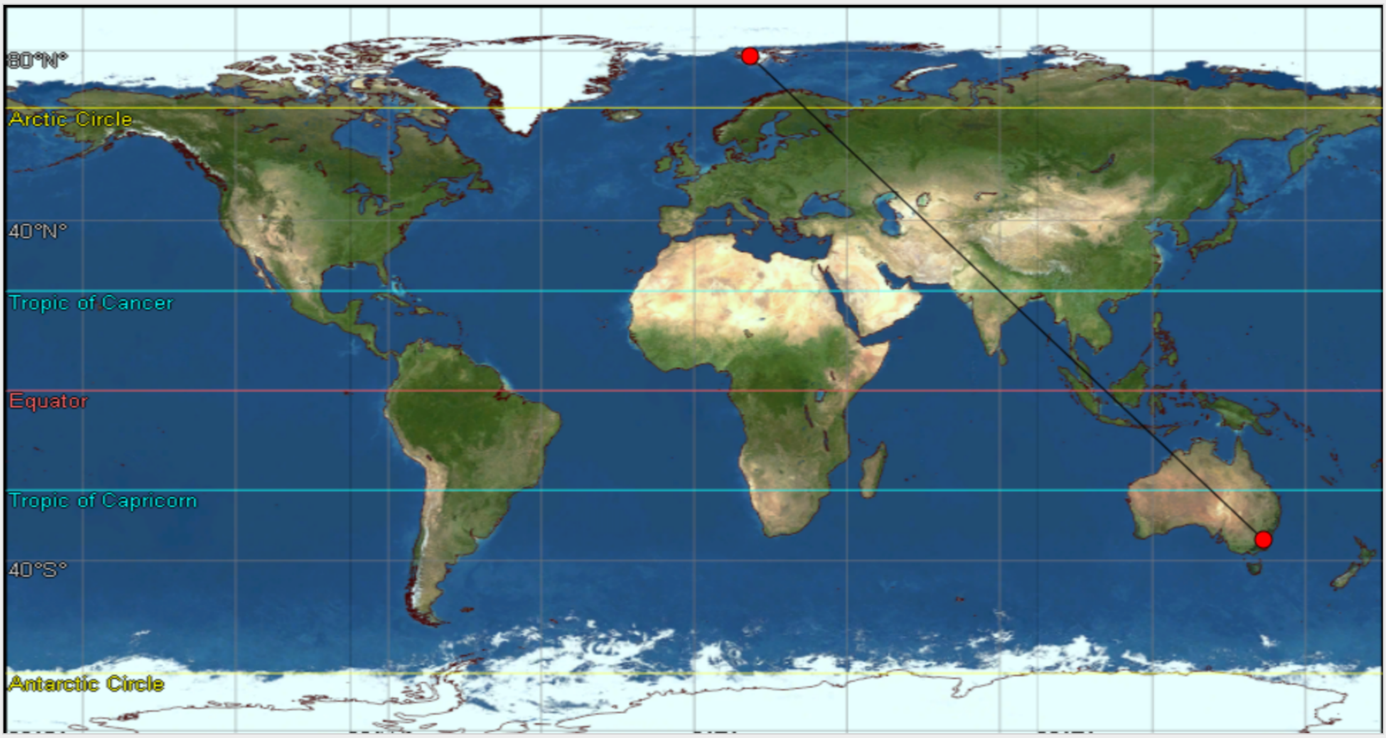
Sun radius
Pixels=236.3 | Radius= 695842km

Venus A' - Venus B' distance
Pixels=8.9 | A´B´ = 26208km

Back | Continue

Venus-Sun distance (basic) v0.9

Step: 7/8
And the distance between A and B is ...

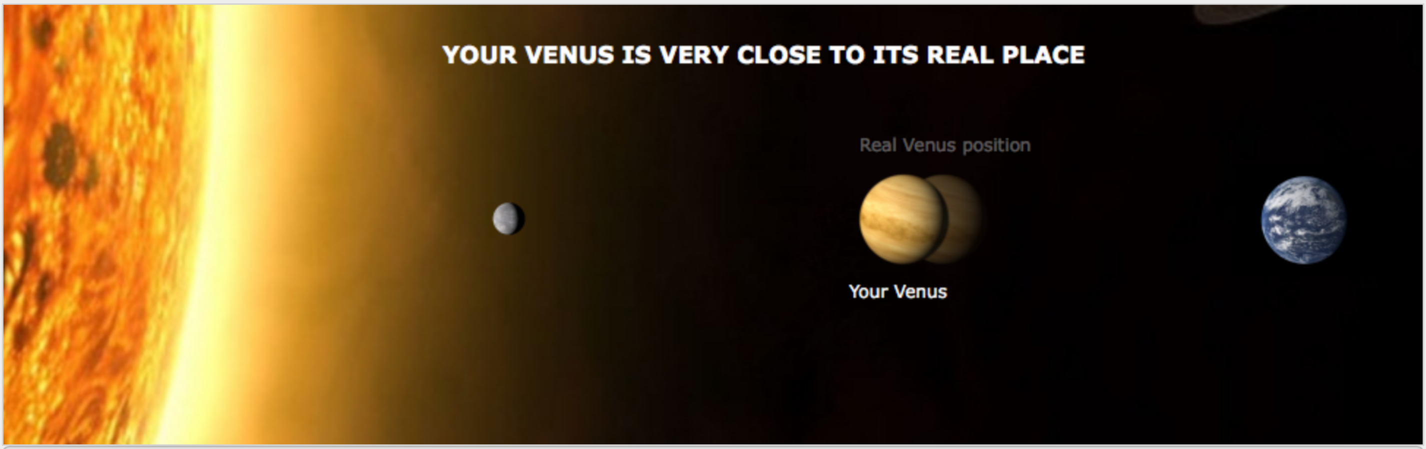


Check that the places marked in the map correspond with the locations A and B. The distance between those two coordinates is:
11676 km

Back | Continue

Venus-Sun distance (basic) v0.9

Step: 8/8
Submit your result.



A'B'= 26208 km
AB= 11676 km

Calculate

Final Venus-Sun distance:
103492682.9 km
Real distance: 108,200,000km
You have made a mistake of 4707317km (4.4%)

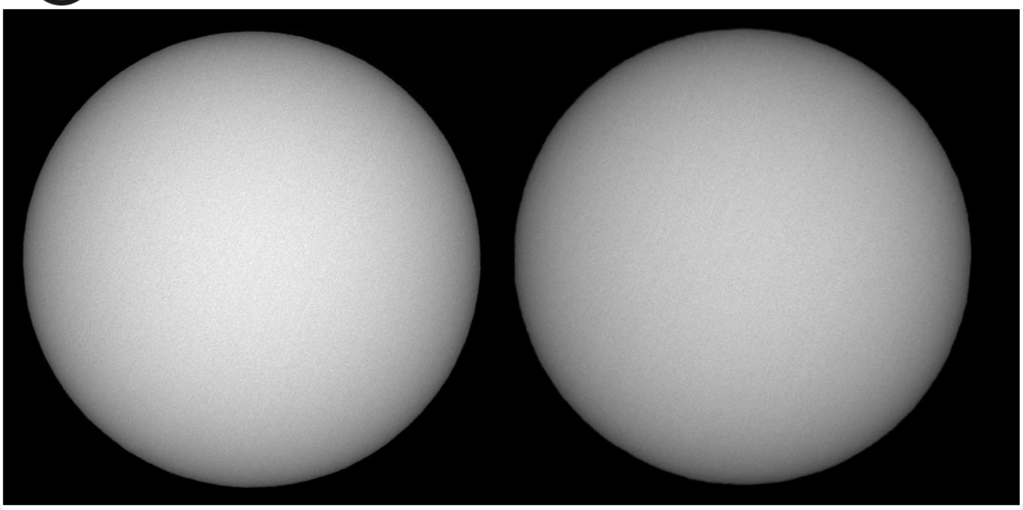
Start again

Generate report

Rotation Period (intermediate) v0.6

Step: 1/3
Explore the database and look for valuable data.

December 2017



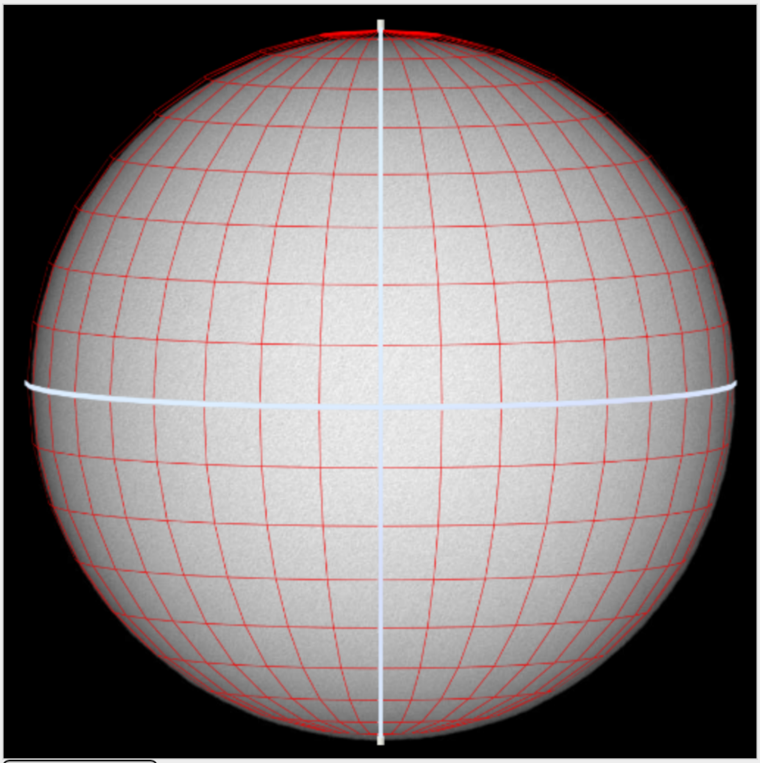
Objective 1
Choose an image from CESO (our solar observatory) in which you want to measure the coordinates of a sunspot.

Selected image date:
06/11/2017 09:15

Continue

Rotation Period (intermediate) v0.6

Step: 2/3
Extract information from the picture. Obtain the coordinates of the sunspot.



Objective 2
Use the grid for measuring. Write down the coordinates of the sunspot. Once you are done, go back to choose an other image or hit continue to end the practice.

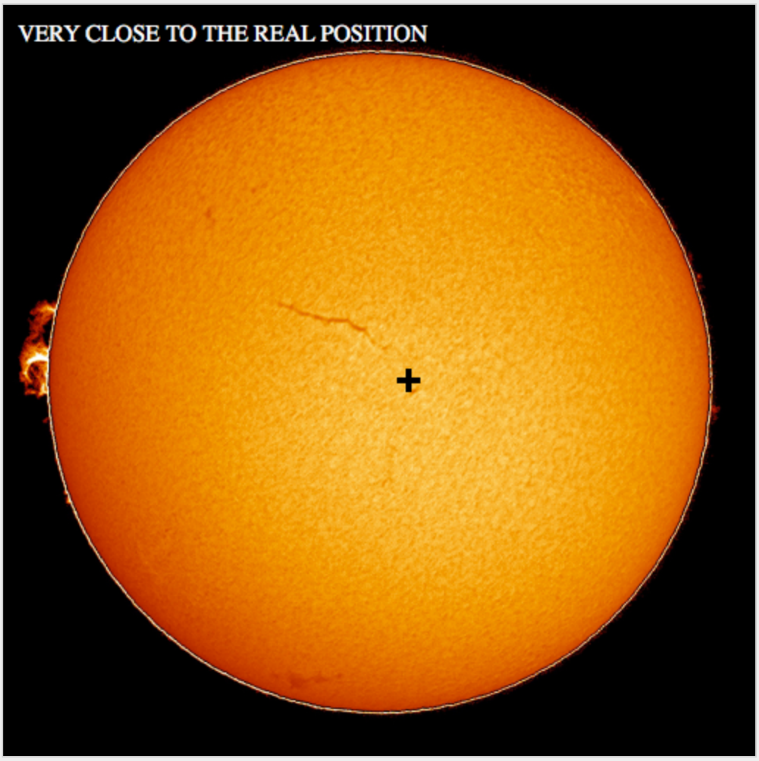
Image date: 06/11/2017 09:15

Back

Continue

Rotation Period (intermediate) v0.6

Step: 3/3
Submit your results.



Objective 3
Input the rotation period of the sun that you calculated. Let's say we locate a big solar flare at the left-edge of the Sun. This solar flare may cause solar wind which could produce a geomagnetic storm if it reaches Earth. Using your calculations of Sun's rotation period, estimate how long would it take to the solar flare to be pointed at Earth, and writte it down.

Sun rotation period

33 days 11 hours 5 minutes

Time until it points to the Earth

7 days 5 hours 3 minutes

Calculate

Your result error is: 22.7%
And the distance in pixels from the center: 20

Repeat the case with other images

CESAR Ideas for the Future

We came up with this great idea of a keynote about CESAR projects and I offered to do a few slides.

cooperation through education in science and astronomy research

Slide 1

European Space Agency

INTA Isdefe

3D Map of the Moon

What?

- Moon topography science case
- objective → measure the height of a mountain
- interactive web-tool stores each measurement
- result → growing 3D map
- possibility of implementing machine learning

Who?

- Alejandro Romar (or science & education expert)
- David Cabezas (or other computer science expert)
- Enrico Fini (or other computer science expert)

Requirements:

- fully working telescope

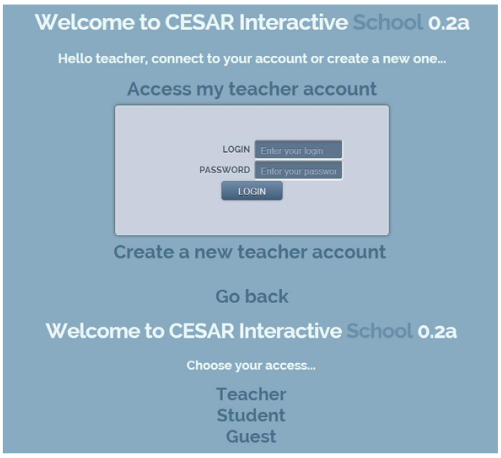
ETA: 3 months (if resources provided)

Slide 16

European Space Agency

INTA Isdefe

CESAR Interactive School

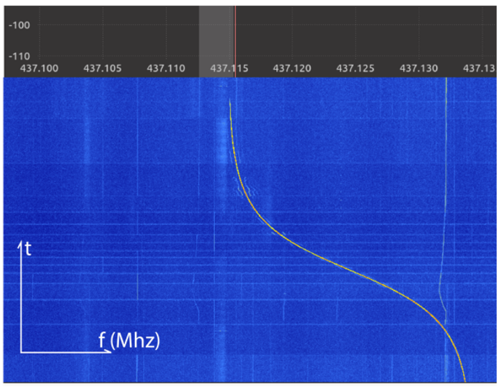


What?
- on-line virtual classroom
- science cases available for students
- automatically-generated reports for teachers
- full didactic experience with CESAR

Who?
- David Cabezas (or other computer science expert)
- Enrico Fini (or other computer science expert)
- Alejandro Romar (or science & education expert)

ETA: 12months (if resources & maintenance provided)

CubeSat Doppler-Effect Detection



What?
- doppler-effect science case
- usage of ESAC CubeSat antenna
- learn science & use satellites

Who?
- Roger Cano (or other expert radio operator)
- Alejandro Romar (or science & education expert)
- David Cabezas (or other computer science expert)

ETA: 3 months (if resources provided)

Complete List of Achievements

Science Cases web page: cesar.esa.int/index.php?Section=Interactive_Scientific_Cases

Join us web page: cesar.esa.int/index.php?Section=Join_us&ChangeLang=en

Student's Guide (SG)Template: cesar.esa.int/upload/201709/Students_Guide_Template.doc

Teacher's Guide (TG) Template: cesar.esa.int/upload/201709/Teachers_Guide_Template.doc

Booklet (B) Template: cesar.esa.int/upload/201709/Booklet_Template.doc

Quiz's (Q) Template: cesar.esa.int/upload/201709/Quiz_Template.doc

Sun Science Cases web page: cesar.esa.int/index.php?Section=Science_The_Sun

Booklets web page: cesar.esa.int/index.php?Section=Booklets

Science Case Instructions: cesar.esa.int/upload/201709/How_to_do_a_Science_Case_with_your_students.pdf

For Educators web page: cesar.esa.int/index.php?Section=Teachers

All the Science Cases web page: cesar.esa.int/index.php?Section=SC_List

Solar System Planets Science Cases web page: cesar.esa.int/index.php?Section=Science_Planets

The Venus-Sun distance (TVSD) new web page: cesar.esa.int/index.php?Section=Venus_Sun_distance

TVSD TG Basic: cesar.esa.int/upload/201711/the_venus-sun_distance_teachers_guide_basic_level_900.pdf

TVSD TG Intermediate: cesar.esa.int/upload/201710/the_venus-sun_distance_teachers_guide_intermediate_level_998.pdf

TVSD TG Advanced: cesar.esa.int/upload/201710/the_venus-sun_distance_teachers_guide_advaced_level_119.pdf

TVSD SG Basic: cesar.esa.int/upload/201712/the_venus-sun_distance_students_guide_basic_level_336.pdf

TVSD SG Intermediate: cesar.esa.int/upload/201712/the_venus-sun_distance_students_guide_intermediate_level_856.pdf

TVSD SG Advanced: cesar.esa.int/upload/201712/the_venus-sun_distance_students_guide_advaced_level_942.pdf

TVSD Q Basic: cesar.esa.int/upload/201710/the_venus-sun_distance_quiz_basic_level.pdf

TVSD Q Intermediate: cesar.esa.int/upload/201709/The_Venus-Sun_distance_Quiz_Intermediate_Level.pdf

TVSD Q Advanced: cesar.esa.int/upload/201709/The_Venus-Sun_distance_Quiz_Advanced_Level.pdf

Parallax Effect Booklet. cesar.esa.int/upload/201712/parallax_effect_booklet_864.pdf

Earth Coordinates Booklet: cesar.esa.int/upload/201712/earth_coordinates_booklet_876.pdf

Sun's Rotation Period (SRP) new web page: cesar.esa.int/index.php?Section=Sun's_rotation

SRP TG Basic: cesar.esa.int/upload/201711/suns_rotation_period_teachers_guide_basic_level_900.pdf

SRP TG Intermediate: cesar.esa.int/upload/201711/suns_rotation_period_teachers_guide_intermediate_level_147.pdf

SRP SG Basic: cesar.esa.int/upload/201712/suns_rotation_period_students_guide_basic_level_774.pdf

SRP SG Intermediate: cesar.esa.int/upload/201712/suns_rotation_period_students_guide_intermediate_level_059.pdf

SRP Q Basic: cesar.esa.int/upload/201711/sun_rotation_period_quiz_basic_level_336.pdf

SRP Q Intermediate: cesar.esa.int/upload/201711/suns_rotation_period_quiz_intermediate_level_001.pdf

Sun's Differential Rotation (SDR) new web page: cesar.esa.int/index.php?Section=Suns_Differential_Rotation

SDR TG Basic: cesar.esa.int/upload/201711/suns_differential_rotation_teachers_guide_basic_level_228.pdf

SDR TG Intermediate: cesar.esa.int/upload/201711/suns_differential_rotation_teachers_guide_intermediate_level_100.pdf

SDR SG Basic: cesar.esa.int/upload/201712/suns_differential_rotation_students_guide_basic_level_990.pdf

SDR SG Intermediate: cesar.esa.int/upload/201712/suns_differential_rotation_students_guide_intermediate_level_002.pdf

SDR Q Basic: cesar.esa.int/upload/201710/suns_differential_rotation_quiz_basic_level_220.pdf

SDR Q Intermediate: cesar.esa.int/upload/201710/suns_differential_rotation_quiz_intermediate_level_001.pdf

Spherical trigonometry Booklet: cesar.esa.int/upload/201712/spherical_trigonometry_booklet_554.pdf

Heliographic Coordinates Booklet: cesar.esa.int/upload/201712/heliographic_coordinates_booklet_248.pdf

SDR SG Super Hero: cesar.esa.int/upload/201712/suns_differential_rotation_students_guide_super_hero_level_117.pdf

ISM Science Cases web page: cesar.esa.int/index.php?Section=ISM

ISM new web page: cesar.esa.int/index.php?Section=Exploring_the_Interestellar_Medium

Galaxies Science Cases web page: cesar.esa.int/index.php?Section=Galaxies

Galaxies new web page: cesar.esa.int/index.php?Section=The_Secrets_of_the_Galaxies

SRP Web-Tool: dms.cosmos.esa.int/cs/livelink/fetch/-3322167/3449375/3435733/3575419/%5BCESAR%5D_%5BScience_Cases%5D_%5BWeb%2DTools%5D_Sun_s_Rotation_Period.pdf?nodeid=3588191&vernum=-2

TVSD Web-Tool: dms.cosmos.esa.int/cs/livelink/fetch/-3322167/3449375/3435733/3575419/%5BCESAR%5D_%5BScience_Cases%5D_%5BWeb%2DTools%5D_The_Venus%2DSun_distance.pdf?nodeid=3588736&vernum=-2

SDR Web-Tool: dms.cosmos.esa.int/cs/livelink/fetch/-3322167/3449375/3435733/3575419/%5BCESAR%5D_%5BScience_Cases%5D_%5BWeb%2DTools%5D_Sun_s_Differential_Rotation.pdf?nodeid=3588735&vernum=-2

CESAR's Future: wetransfer.com/downloads/c68631d383ce49d98984ca3f0f848a0820171221063631/85e486b077f464591448c7fd35ab5855201712210642 32/29e76c

Final Report: cesar.esa.int/upload/201712/alejandro_romar_tejeiro_cesar:esa:esac_science_case_traineeship_report_v2.pdf