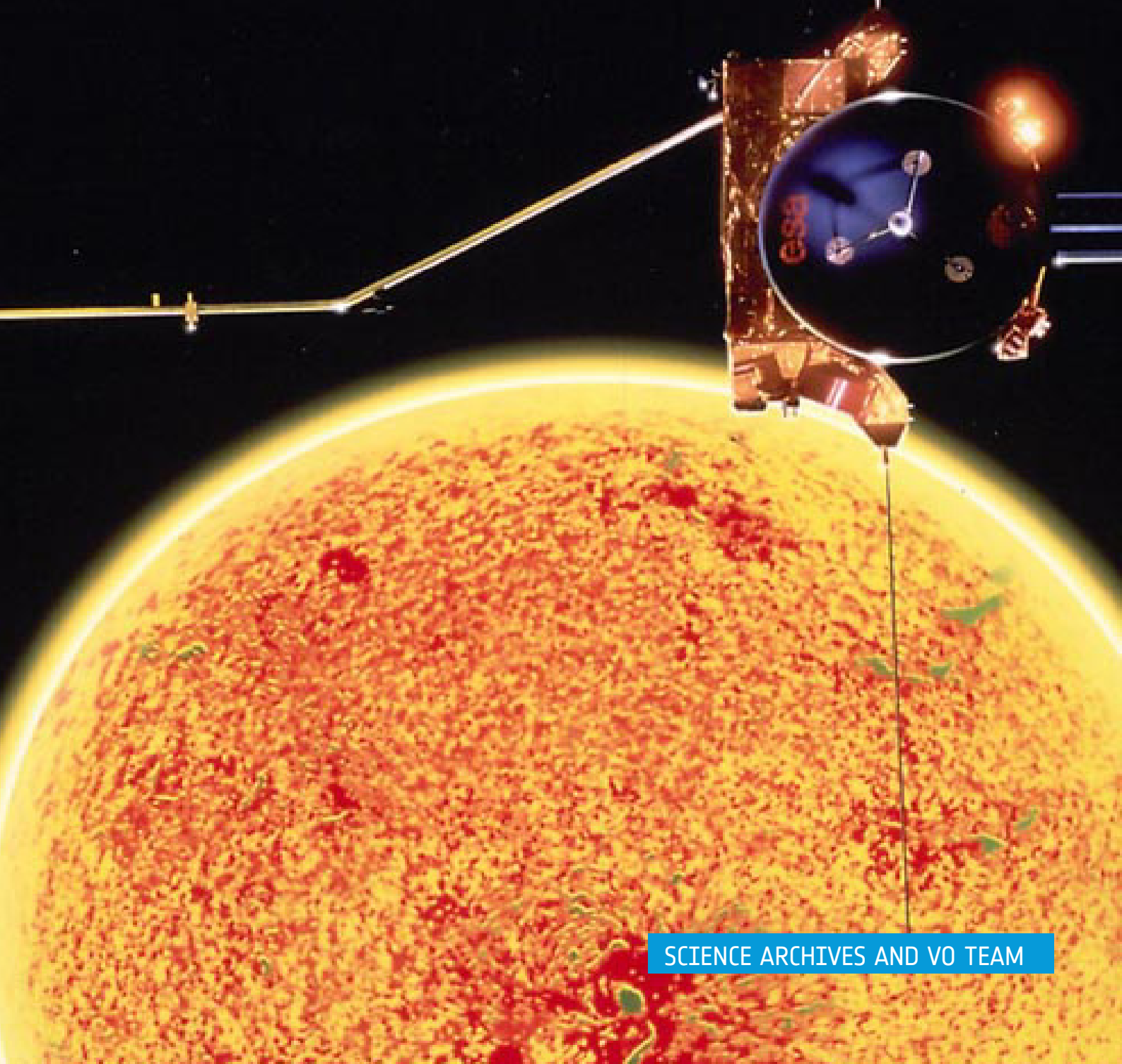


→ INVESTIGATING SOLAR CYCLES

A SOHO ARCHIVE &  
ULYSSES FINAL ARCHIVE TUTORIAL





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ESAC Science Archives and Virtual Observatory Team

European Space Agency  
European Space Astronomy Centre (ESAC) Tutorial

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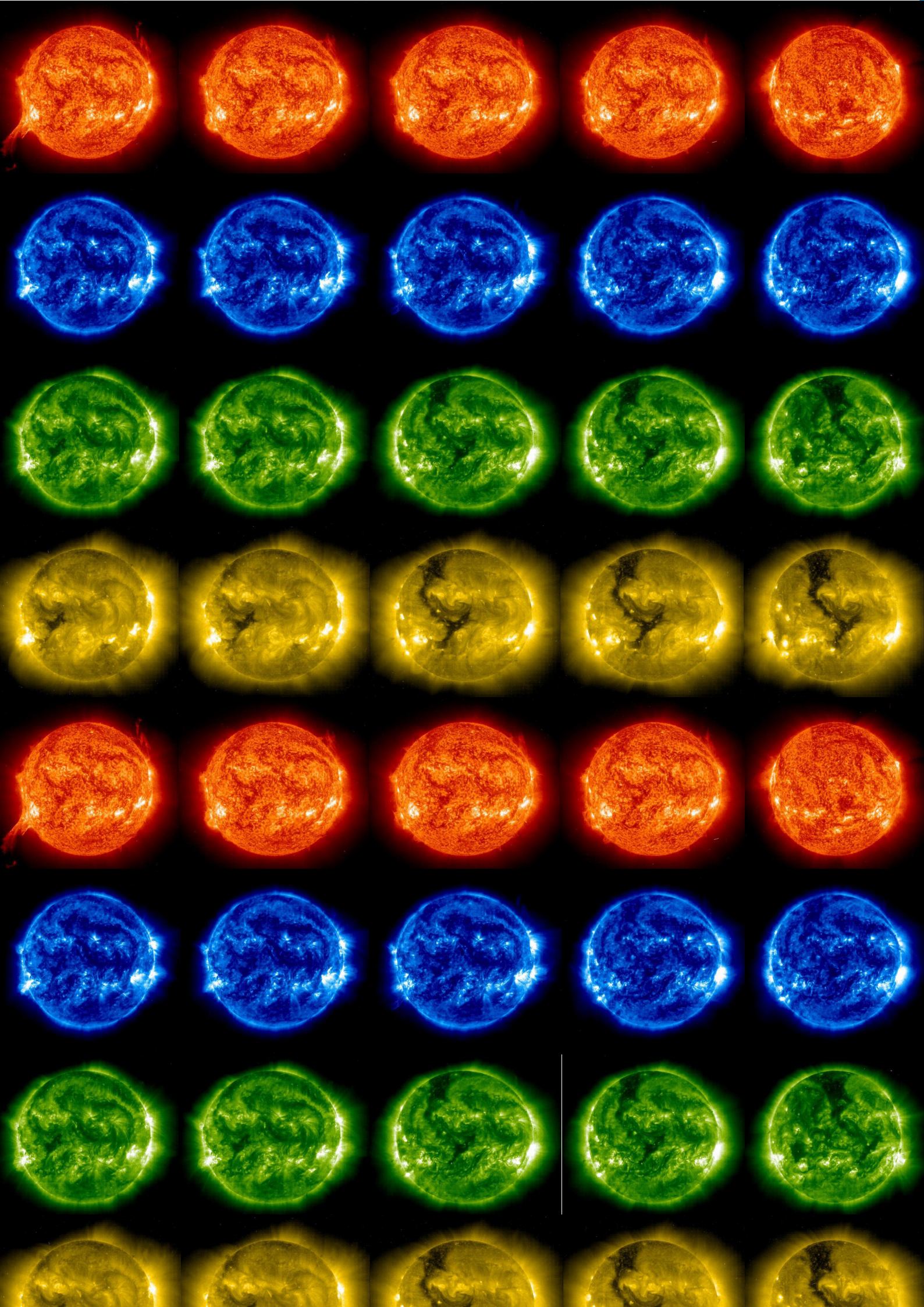
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# PART 1

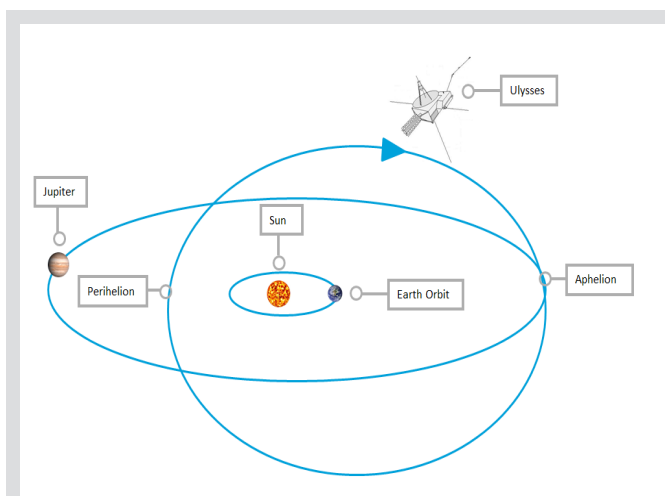
The image features a solid blue background with several thin, white, curved lines that sweep across the left side of the frame. These lines are part of a larger graphic design, possibly representing a stylized letter 'C' or a similar shape. The lines are positioned to the left of the text, creating a sense of depth and movement.

O BACKGROUND

## → ABOUT ULYSSES

**Ulysses was a ESA/NASA joint deep-space mission, which lasted more than 18 years and measured a number of properties of the Sun.**

It studied the heliosphere; the region of space affected by the solar wind and magnetic fields originating from the Sun. It also provided the first ever measurement of the space above the Sun's magnetic poles. Ulysses was in a highly elliptical orbit, with the Sun at the centre. Its closest separation from the Sun was 1.3AU and its furthest point was 5.4AU (1AU= distance from Earth to the Sun). It had an average speed of 56,000 km/hr.



↑ Illustration of Ulysses' orbit around the Sun.

There were 10 instruments aboard Ulysses, each sampling different effects produced by the Sun. For example, the Magnetometer measured the magnetic fields in the heliosphere and their variation with respect to changing latitudes. The Solar Wind Plasma Experiment studied the solar wind (a stream of charged particles expelled by the Sun); the Solar Wind Ion Composition Instrument was used to help determine the composition, temperature and speed of the particles.

## → ABOUT SOLAR CYCLES

Ulysses has provided extensive and indispensable data from all of its instruments. In this case-study the focus will be the behaviour of the magnetic fields. The Sun's magnetic field is extremely complicated; it is always changing. At 'solar minimum' they have a general dipole structure, however they become twisted so that the structure disappears. The twisting eventually becomes so extreme that the poles swap – the magnetic north pole becomes the magnetic south pole and vice versa.

### Twisted and Tangled

The twisting of magnetic field lines happens periodically and causes 'Solar Cycles' – the Sun goes through increased or decreased 'activity' depending on how twisted the magnetic field has become; at a maximum when the field lines are at their most tangled.

## Solar Flares & Coronal Mass Ejections

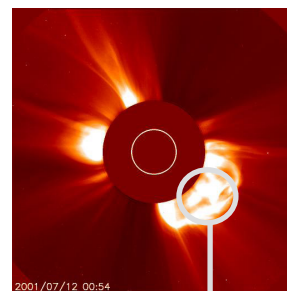
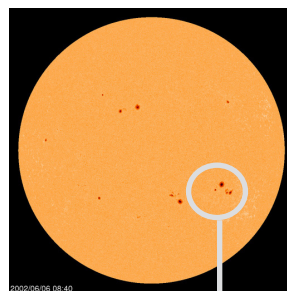
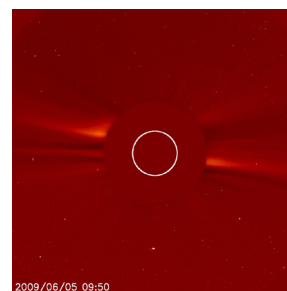
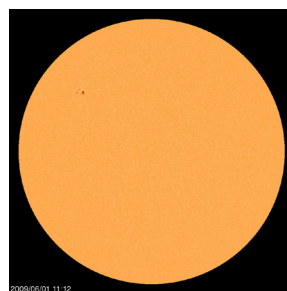
A solar flare is a sudden, quick brightening of a part of the Sun's surface, and is caused by a rapid release of magnetic energy which has built up in the solar atmosphere. These are often followed by Coronal Mass Ejections; huge blasts of solar winds, which extend far into space. A solar wind is made up of a flow of charged particles, mainly consisting of protons and electrons.

## → ABOUT SUNSPOTS

Although the cause of the periodical variation of the magnetic field is still under debate, the phenomena has been known to exist for hundreds of years and was initially discovered due to changing rates of Sunspots. Sunspots are indicative of intense magnetic activity and are seen as dark patches on the surface of the Sun. They also usually indicate that other solar activity dependent on complex magnetic fields is likely to occur; such as Coronal Mass Ejections and solar flares.

It is the cyclical variation of Sunspots which is seen in the solar cycles. As the number of Sunspots goes towards maximum, this corresponds to a maximum in the solar cycle. It also implies that the Sun's magnetic field has become extremely complex, and whose strength has become intense over much of the Sun. This usually means the poles are about to flip - although often this 'flip' can take up to seven years to complete!

## Can You Spot The Difference?



Sunspots: Appear as dark patches on the surface of the Sun.

Coronal Mass Ejections and solar flares are blasted from the Sun.



# ○ THE EXPERIMENT

## → THE AIM

The aim of Part 1 of tutorial will be to use the Ulysses Final Archive to investigate a given hypothesis about solar cycles. This will involve studying the form of the magnetic field throughout Ulysses' mission to deduce where the different points in the solar cycle lie. The task will also comprise of retrieving data from the archive for these points in the solar cycle and performing some basic analysis to test the hypothesis. At the end of this part of tutorial it should be understood how to independently use the main functions of the Ulysses Final archive.



## → THE HYPOTHESIS

During a solar maximum, Ulysses will have observed an increase in the average magnetic field magnitude; when compared with during a solar minimum.

### GRAPHICAL ANALYSIS

## →PART 1 | SECTION 1

### The Tools Used

**Ulysses Final Archive:** This contains all the data from the Ulysses Spacecraft mission. It provides a way to easily interact with the data.

**Topcat:** Topcat is a program which produces tables of data, with which it is possible to perform a number of methods of analysis on the data. Such as finding out the mean, or creating a plot.

To perform the experiment and test the hypothesis, follow the instructions in the order given here. There will be illustrations of what you should see on your screen along the way. Numerical answers required are provided in the back of this booklet.

### Opening the Archive and Performing the Search

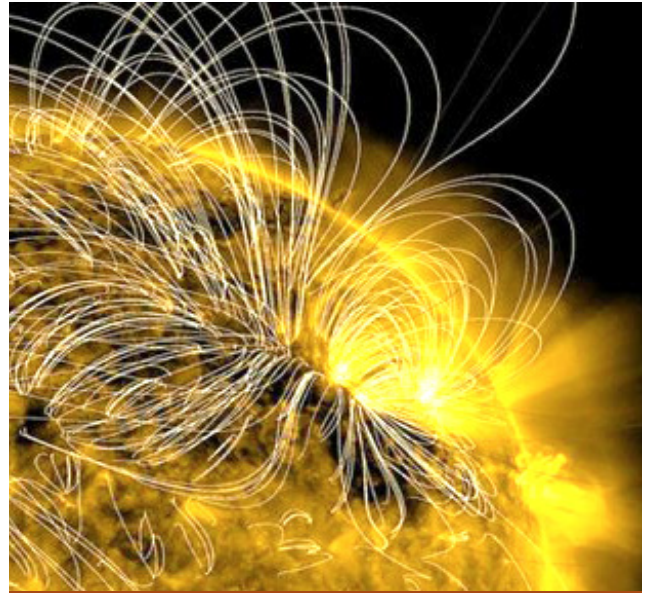
Firstly, open the **Ulysses Final Archive homepage**:

<http://archives.esac.esa.int/ufa> and click on **'SEARCH'**.

This is the Ulysses Final Archive main search interface. Firstly, choose 'mission' under **'Date selection'**. This will give the data from Ulysses for the whole mission.

Next, under **'Instrument selection'**, choose VHM/FGM (The Ulysses Magnetic Field Investigation Vector Helium Magnetometer / Flux Gate Magnetometer).

Click on **'Advanced'**. This will start up a window on the page, once this is open, click on **'Plot Y-Axis Selection'**.



↑An illustration of complex magnetic field lines emerging from the Sun during a solar maximum. Sunspots produce magnetic field loops, which can break; sending charged particles accelerating into space.

Now select 'R component' (Radial component of the magnetic field - which is the component that faces outward from the Sun's surface) and 'Magnetic Field Magnitude' by ticking their boxes. Then click 'OK'. This should close the new window.

Then, in the **'Output selection'** box, under **'Trajectory File'** select 'Radius + Latitude' in the drop-down menu. This will provide the position of Ulysses with respect to the Sun.

Under **'Results output'** choose 'Plot' in the drop-down menu. Click on 'Submit'

\* Search available for GRB 5 min only. Go to DATA section to download higher resolution data.

[Multi-Instrument Search >](#)

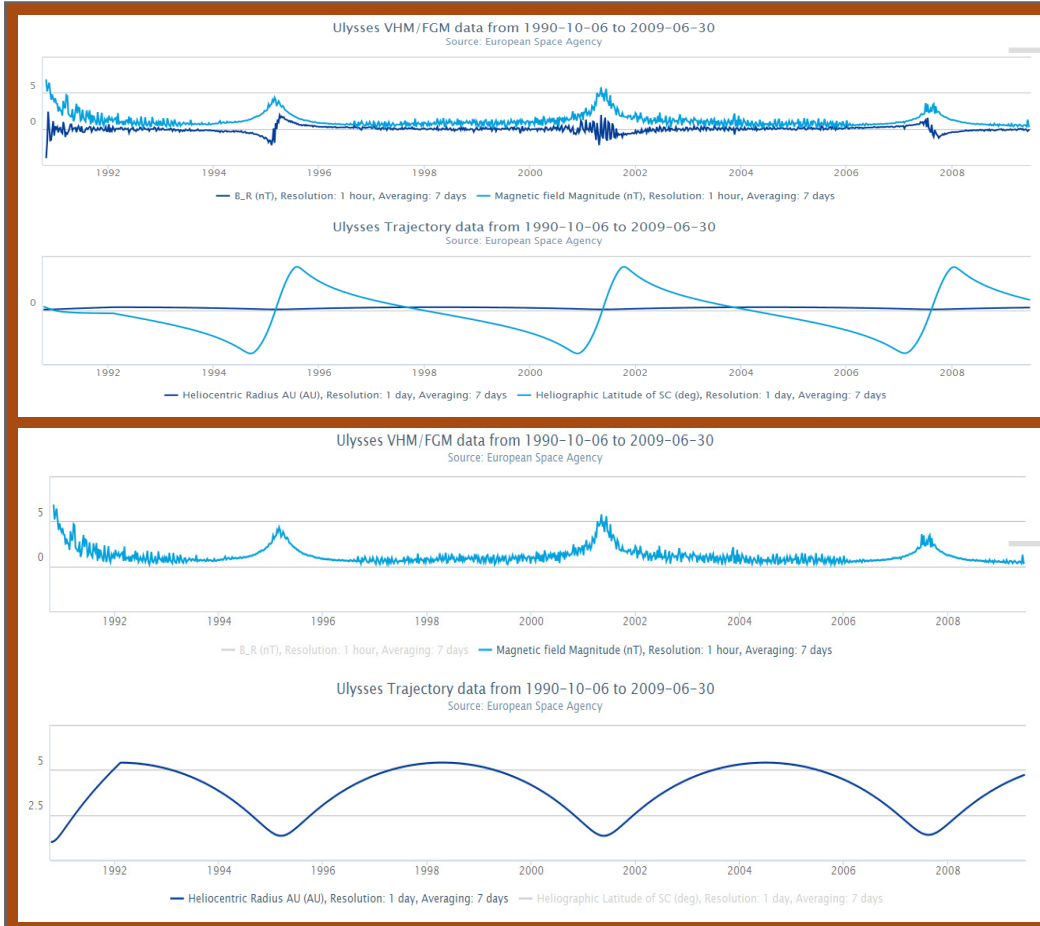
[Submit](#)

### Analysing the Produced Plots

**There should be two plots - one with the two magnetic field components and one with the trajectory data.**

Firstly, the distance of Ulysses from the Sun needs to be compared with the magnetic field magnitude. Try clicking on a data label; this should hide the data on the plot.

Therefore, click on the data label **'Helio-graphic Latitude of SC (deg)'** and **'B<sub>R</sub> (nT)'**. These datasets should now be hidden.



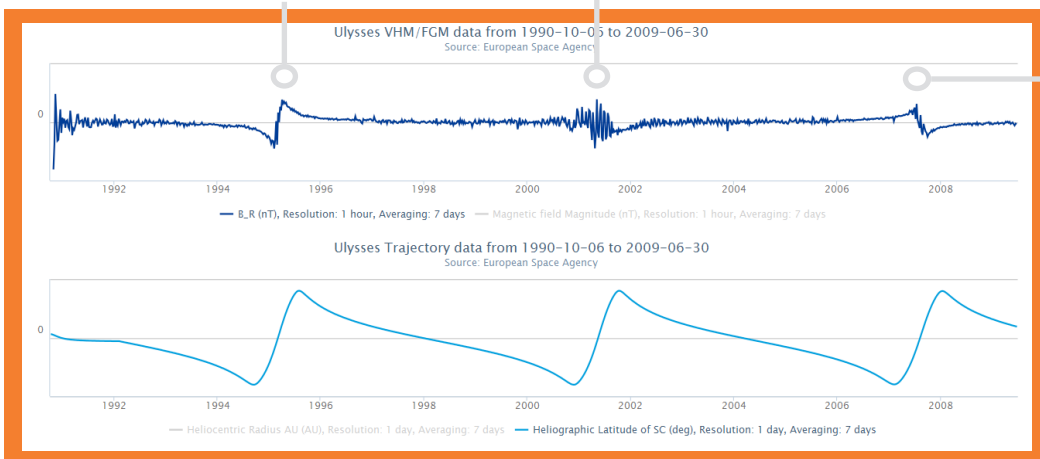
→ You should have initially produced plots where the data was over-layered.

By clicking on a label, the corresponding data on the plot is hidden. This can be seen in the second plot shown here.

→ The second plot illustrates the changing magnetic field magnitude that Ulysses detects as it moves closer to the Sun.

→ Radial (outward) field goes from negative to positive as Ulysses moves from negative to positive latitude.

→ The radial field is dominated by 'noise'



→ Radial component goes from positive to negative as Ulysses moves from negative to positive latitude.

→ The plots should only be showing the radial component of the magnetic field and the latitude of Ulysses. **What can you infer from these plots?**

## Interpreting the Data

**As Ulysses travels past the Sun each time from one pole to another, we would expect a constant field to repeat the same pattern.**

**This is not the case.** In fact, what can be seen here is a reversal of the field after a 'noisy' period. The Sun's magnetic poles appear to have flipped. From this, and what you have read in the background section, decide which sections of the mission you think might be at solar maximum and solar minimum.

The first and third latitude changes (around 1995 and 2008 respectively) represent a solar minimum; there is a clear structure to the radial magnetic field. The second change (around 2001) is a solar maximum; there is no clear structure and lots of magnetic field variability over all the latitudes.

Now unhide the data by re-clicking on the labels. Next, hide the data '**Magnetic field Magnitude (nT)**' and '**Helio-centric Radius AU (AU)**'.

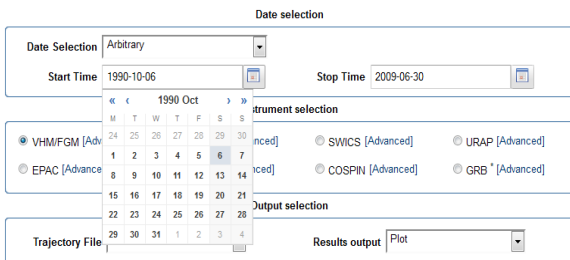
# → PART 1 | SECTION 2

## DATA ANALYSIS

### Using the Ulysses Final Archive to Produce Tables

Go back to the main search interface, by clicking on 'Back to Search' in the left-hand corner.

Change 'Data Selection' on the drop-down box to 'Arbitrary'. Using this it is possible to designate specific dates. By 'Start Time' dates, click on the calendar icon. The double arrows change the year, whereas the single arrow edits the month.



Firstly the data for the solar minimum will be analysed. It was noted in the previous section that this was around 1995. It will be necessary to choose similar latitude points for both the minimum and maximum, as well as the same length of time. In this tutorial **01/01/95 – 01/01/96 (minimum)** and **14/03/01 – 14/03/02 (maximum)** will be used. If you aren't sure about these dates, click on 'Go to Results' to go back to the plot of the whole mission to re-examine the plot.

Therefore, under 'Start Time' select 01/01/95 and under 'Stop Time' choose 01/01/96.

Next, in 'Instrument selection' click on the 'Advanced' link for the VHM/FGM instrument. A new window on the search interface should open.

Now click on the blue tab which reads 'Table Column Selection'. Then, click on 'Clear', which should deselect all the checked boxes. Choose 'Start Time', 'R component' and 'Magnetic Field Magnitude'. Click 'OK'.

Change the 'Results output' to 'Table'. Click on 'Submit'.

Start Time	R Component	Magnitude
1990-01-01 00:00:00.000	-1.182	0.768
1990-01-01 01:00:00.000	-1.115	0.261
1990-01-01 02:00:00.000	-1.042	0.267
1990-01-01 03:00:00.000	-1.036	0.275
1990-01-01 04:00:00.000	-0.953	0.21
1990-01-01 05:00:00.000	-0.989	0.201
1990-01-01 06:00:00.000	-1.011	0.208
1990-01-01 07:00:00.000	-1.042	0.211
1990-01-01 08:00:00.000	-1.076	0.208
1990-01-01 09:00:00.000	-1.108	0.208
1990-01-01 10:00:00.000	-1.138	0.208
1990-01-01 11:00:00.000	-1.155	0.201
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1990-01-01 13:00:00.000	-1.163	0.204
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1990-01-08 16:00:00.000	-1.163	0.204
1990-01-08 17:00:00.000	-1.163	0.204
1990-01-08 18:00:00.000	-1.163	0.204
1990-01-08 19:00:00.000	-1.163	0.204
1990-01-08 20:00:00.000	-1.163	0.204
1990-01-08 21:00:00.000	-1.163	0.204
1990-01-08 22:00:00.000	-1.163	0.204
1990-01-08 23:00:00.000	-1.163	0.204
1990-01-09 00:00:00.000	-1.163	0.204
1990-01-09 01:00:00.000	-1.163	0.204
1990-01-09 02:00:00.000	-1.163	0.204
1990-01-09 03:00:00.000	-1.163	0.204
1990-01-09 04:00:00.000	-1.163	0.204
1990-01-09 05:00:00.000	-1.163	0.204
1990-01-09 06:00:00.000	-1.163	0.204
1990-01-09 07:00:00.000	-1.163	0.204
1990-01-09 08:00:00.000	-1.163	0.204
1990-01-09 09:00:00.000	-1.163	0.204
1990-01-09 10:00:00.000	-1.163	0.204
1990-01-09 11:00:00.000	-1.163	0.204
1990-01-09 12:00:00.000	-1.163	0.204
1990-01-09 13:00:00.000	-1.163	0.204
1990-01-09 14:00:00.000	-1.163	0.204
1990-01-09 15:00:00.000	-1.163	0.204
1990-01-09 16:00:00.000	-1.163	0.204
1990-01-09 17:00:00.000	-1.163	0.204
1990-01-09 18:00:00.000	-1.163	0.204
1990-01-09 19:00:00.000	-1.163	0.204
1990-01-09 20:00:00.000	-1.163	0.204
1990-01-09 21:00:00.000	-1.163	

## Using Topcat

Topcat should now be open. The data will be labelled 'UFA Table'; the trajectory data will not have been sent.

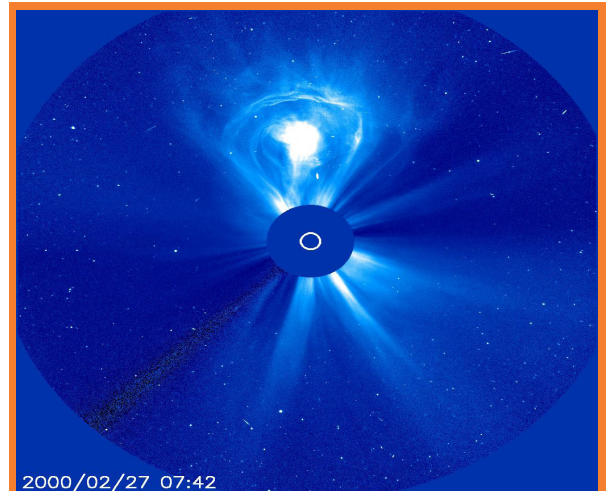
To check whether this is the correct data, double click on 'UFA Table' in the box 'Table List' and compare it to the data in the interactive table.



To do this it will be necessary to click 'Close' on the window that is currently open in the Ulysses Final Archive. This won't close anything in Topcat.

Go back to the Topcat window. Click on the statistics button. A new table window should open. Read off the 'Mean' value for the magnetic field magnitude (B) and its **standard deviation (SD)**, and write it down in the table provided below. The standard deviation illustrates how much the data varies with respect to the mean value.

Now repeat this process from Step 1, but using the dates **14/03/01 – 14/03/02**, so that you are finding the data for the solar maximum. Finish filling in the above table. What can you see from this data?



→ An example of a coronal mass ejection, captured by SOHO (Solar and Heliospheric Observatory). The shaded disc at the centre of the image is a mask in the instrument that blots out direct sunlight. The white circle in the disc shows the size and position of the Sun. It can be seen how big the Coronal Mass Ejections are!

### → OPTIONAL

Try plotting the data in Topcat by pressing scatter-plot button and selecting data for the x-axis and y-axis. Try plotting the date - 'epoch' (x-axis) and magnetic field magnitude - 'B' (y-axis) and comparing it to the plots produced using the archive (as was done in Section 1).

### MAGNETIC FIELD MAGNITUDE TABLE

POINT IN SOLAR CYCLE

MEAN VALUE

STANDARD DEVIATION

SOLAR MINIMUM

SOLAR MAXIMUM

The answers can be found in the back of this tutorial booklet.

## → ANALYSIS

In this part of the tutorial we have seen how to deduce what part of the solar cycle the Sun might currently be in, by using data from the Ulysses Final Archive.

The data you collected for the magnetic field magnitude should be greater for the dates for the solar maximum, and the standard deviation (variation away from the mean) much higher. This is due to the increased rate of sunspots during the solar maximum.

Another effect whose rate increases during a solar maximum is Coronal Mass Ejections, which blast off charged particles from the Sun, as a massive solar wind.

Can you tell how long the solar cycle takes, from the graphs you produced in Ulysses? It should be possible to see that each cycle lasts around 11 years; to go from a solar minimum to the next. Often the solar cycle is known in terms of the '22-year cycle' because this is how long it takes for the Sun's polarity to return to its original configuration.

Have a go at guessing what stage of the solar cycle we are currently in.

## → What next?

The second part of this tutorial will look at solar winds and Coronal Mass Ejections. Firstly, some background information will be given. Then the SOHO (Solar and Heliospheric Observatory) archive will be utilised to examine a Coronal Mass Ejection, along with Ulysses data. Another hypothesis concerning solar cycles will be made and tested. Finally, some conclusions from what has been found in this tutorial will be made.

# PART 2



BACKGROUND

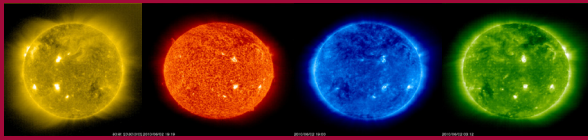
## → ABOUT SOHO

**SOHO is a spacecraft built by ESA and NASA to study the Sun, from its core to the solar wind it produces.**

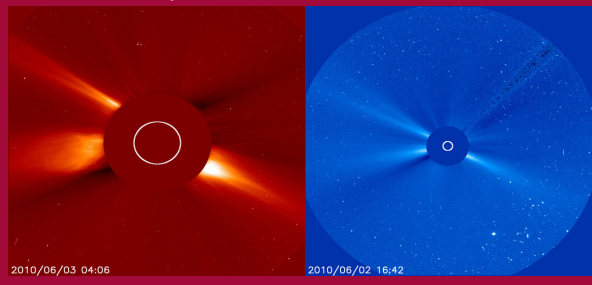
The mission was launched in 1995 and has 12 instruments on board. Its aim was to analyse the structure and dynamics of the inside of the Sun, as well as the solar corona and the solar wind. SOHO's orbit has the Sun at its centre and moves with the Earth; the combined gravity of the Earth and Sun keep SOHO in this orbit, and 'locked' to the Earth about 1.5 million km away.

→ The data that will be considered in this tutorial will come from three instruments aboard SOHO.

→ These are EITs (Extreme Ultraviolet Imaging Telescopes), which produce images of the Sun in four colours at the extreme end of the Ultraviolet frequency.



→ Next, there is the Large Angle and Spectrometric Coronagraph (LASCO). This observes the corona (exterior layer of the Sun's atmosphere) and blocks the direct light from the Sun's surface by creating an artificial eclipse.



→ Finally there is the Michelson Doppler Imager (MDI). This instrument records the motion of the Sun's surface, which scientists can use to gain information about the structure and dynamics of the Sun's interior.



↑ SOHO is constantly observing the Sun, so that we can better understand the science

## → MORE ON CORONAL MASS EJECTIONS

**As was stated previously, Coronal Mass Ejections (CMEs) are the phenomena of the Sun when it blasts great amounts of charged particles into space, mainly consisting of electrons and protons.**

This can also be seen as a release of a vast quantity of electromagnetic radiation, which carries away lots of energy into space. CMEs are linked with changes in the corona's magnetic field, where the corona is the plasma around the surface of the Sun which extends millions of km into space. The exact explanation of what causes this phenomenon is unknown, and so CMEs are an active area of research.

CMEs are impressive events to observe. They eject vast amounts of material; around  $10^{30}$  kg per event. Although this seems a lot, it is very much less than the mass of the Sun itself,  $2 \times 10^{30}$  kg. The protons and electrons are also travelling extremely fast; and often reach speeds of around 600 - 1800 km/s !





# THE EXPERIMENT

## → THE AIM

The aim of Part 2 of the tutorial will be to use the SOHO archive to investigate some properties of the Sun during solar maxima and minima, in particular Coronal Mass Ejections. Following on from this the Ulysses Final Archive will be used to analyse a given hypothesis about Coronal Mass Ejections and the Sun's solar cycles. At the end of Part 2 of the tutorial, it should be understood how to independently use both of the archives, as well as having a basic understanding of some of the Sun's properties during different parts of the solar cycle.

## → THE HYPOTHESIS

During a solar maximum there will be an increase in the density of electrons and protons measured by Ulysses, due to an increase in Coronal Mass Ejections.

## → PART 2 | SECTION 1

### Analysing SOHO Data

#### Tools Used

**SOHO archive:** The SOHO archive contains all the data from the SOHO space-mission so far. Using this it is possible to easily search for data, as well as making time animations from images from the Sun.

**Ulysses Final Archive:** This has the data from the Ulysses space-mission and can make both interactive tables and graphs.

**Topcat:** Topcat is a program which creates tabular data. It has a number of features which make it easy to analyse the data, such as the finding the mean, or creating a plot.

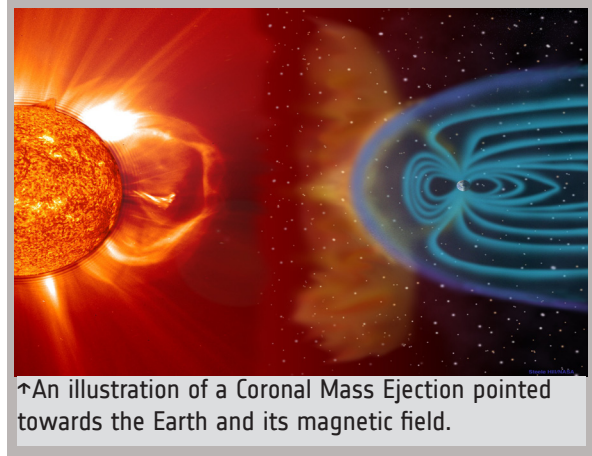
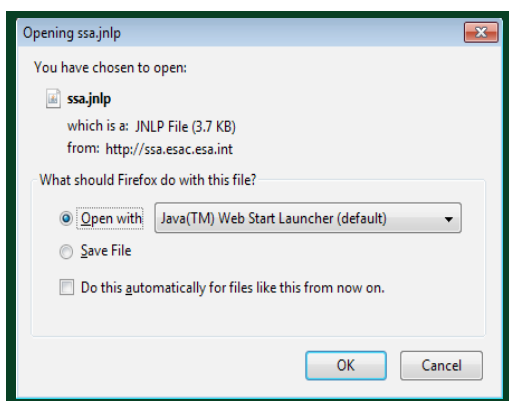
#### Using the SOHO Archive To Produce Animations

Firstly, it will be important to convince yourself that there are more CMEs during a solar maximum than a solar minimum. To do this the **SOHO archive** will be used.

Open the SOHO archive. This is done by going to [http://soho.esac.esa.int/data/archive/index\\_ssa.html](http://soho.esac.esa.int/data/archive/index_ssa.html) and clicking on the link which reads 'Click here to start the user interface'.

A new window will open called **ssa.jnlp**; click on 'Open with' and then click 'OK' to open the SOHO archive.

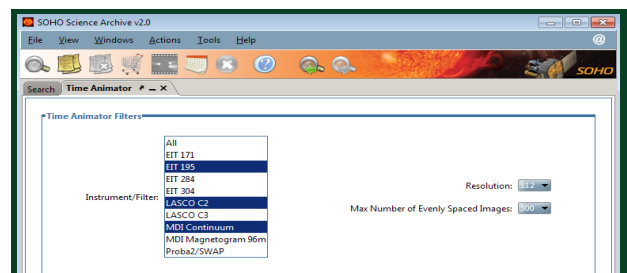
The SOHO archive should now be open.



↑ An illustration of a Coronal Mass Ejection pointed towards the Earth and its magnetic field.

Now click on the time animator button, as indicated in the picture. Or click on 'Windows' and then 'Time Animator'. This will open a new tab within the SOHO archive. The time animator takes the images taken by SOHO and creates a short animation.

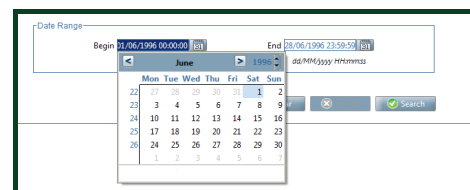
Under 'Instrument/Filter' select 'EIT 195', 'LASCO C2' and 'MDI Continuum'. It is possible to select all three at the same time by holding down the 'ctrl' key whilst clicking on the instruments.



Next, change the 'Max Number of Evenly Spaced Images' to 300 by selecting it in the dropdown box.

Initially, the images for the solar minimum will be analysed. Therefore, the dates **01/06/1996 – 28/06/1996** should be entered. If you are not sure about these dates go back to Part 1 of the tutorial and consider the graph of the magnetic field for the whole mission again.

To input the dates, go to the box labelled 'Date Range' and click on the calendar icon for 'Begin' and 'End' and choose the relevant



Then click on the 'Search' button with the green tick icon. Don't worry if it is taking time to create the animations, there may be around 900 images being loaded.

## Evaluating the Animations

An animation for each of the instruments should be in the box 'Time Animator Results'. Watch each of the films by clicking on the blue 'play' icon under the title 'Play Movie'. Write down what you notice about each of the animations.

→WHAT DO YOU SEE?

	SOLAR MINIMUM	SOLAR MAXIMUM
MDI CONTINUUM		
EIT 195		
LASCO C2		

**MDI Continuum** – the dark spots you should be able to see are the sunspots mentioned in the first part of the tutorial. It should be noted that there are many more sunspots during the dates inputted for the solar maximum compared to the solar minimum dates.

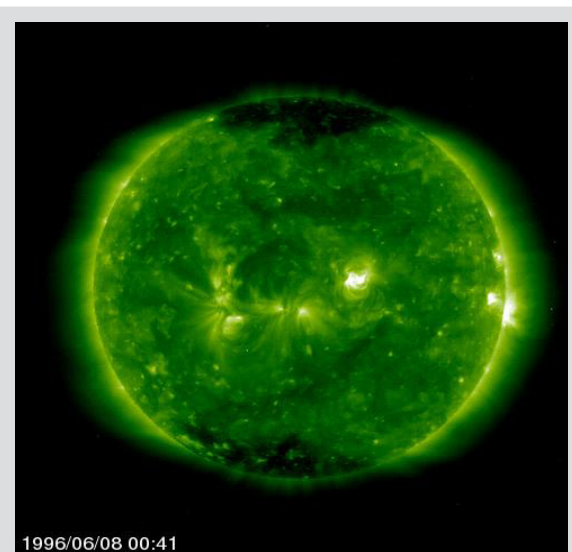
**EIT 195** – the image should have many more luminous patches during the solar maximum, of which most will be solar flares; which were previously defined as a brightening of a section of the Sun's surface usually followed by a Coronal Mass Ejection.

**LASCO C2** – It should have been noted that during the solar maximum there was much more activity from the Sun to observe. Some of the large bursts it is possible to see are likely to be Coronal Mass Ejections. Therefore it can be assumed that there were many more Coronal Mass Ejections during the solar maximum than the solar minimum. This was what was expected.

(You may have also noticed that the Sun appeared to be turning. This is right; the Sun actually rotates! It has different rates of rotation at different latitudes, but at the equator the period for one full rotation is around 24 days.)

Now repeat this for a solar maximum. It is only necessary to change the dates for the search.

Change the dates to **01/02/2002 – 28/02/2002**. Again, click on the 'Search' button and once the three films have been made, watch them by clicking on the blue 'play' icon. Write down what you notice about the solar maximum videos. How do they compare to the solar minimum videos.



↑ This is an example of the kind of images you will see in an EIT 195 video.

From the SOHO data it can be concluded that during a solar maximum there is much more activity than during a solar minimum, including Coronal Mass Ejections. Now we will investigate the mean proton and electron densities during these times to see if Ulysses observed an increase; which will test the hypothesis.

# → PART 2 | SECTION 2

## Analysing Ulysses Data

### Selecting the Data

To begin, go to the Ulysses archive main search page;

<http://archives.esac.esa.int/#search>

Next, select the solar minimum dates in the 'Date Selection' box. To do this, select 'Arbitrary' in the 'Date Selection' dropdown box, then choose the relevant dates for 'Start Time' and 'Stop Time' by clicking on the calendar icon. The dates are those used for SOHO; **01/06/1996 – 28/06/1996**.

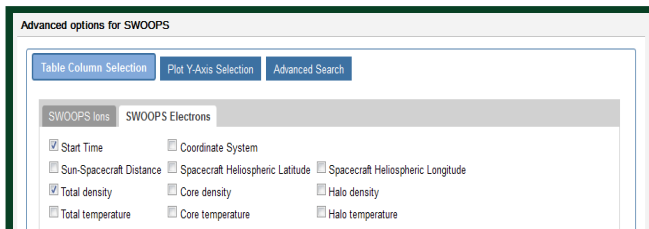
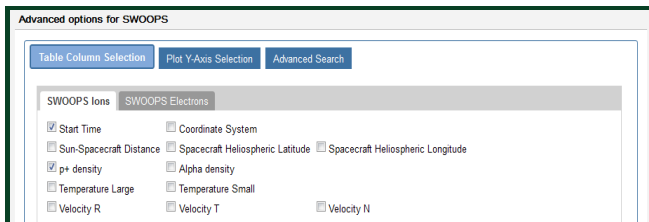
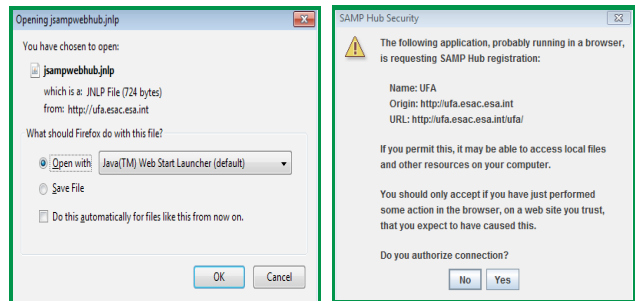
Under 'Instrument Selection' select 'SWOOPS' (Solar Wind Plasma Investigation) and click on the 'Advanced' link. Select the 'Table Column Selection' tab. Make sure the 'SWOOPS Ions' tab is open.

Click 'Clear' and then select 'Start Time' and 'p+ density' (which is the proton density).

Therefore, click on the 'Send To' button, and then on the Topcat link. A window should open called 'Jsampwebhub.Jnlp'. Make sure 'Open with' is selected and select 'OK'.

Next, a window will open called 'SAMP Hub Security' – to authorise the connection and continue sending the data to Topcat, click on 'Yes'.

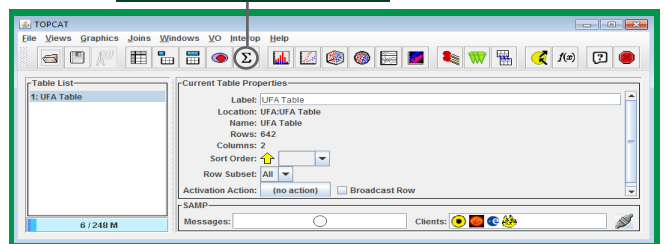
After, another window should pop-up called 'Opening topcat-full.jnlp' – to open Topcat with the data select 'Open with' and 'OK'.



Topcat should now be open. The data will be labelled 'UFA Table'. To check whether this is the correct data, double click on 'UFA Table' in the box 'Table List' and compare it to the data in the interactive table.

To do this it will be necessary to click 'Close' on the window that is currently open in the Ulysses Final Archive. This won't close anything in Topcat.

This is the statistics button



Now select the 'SWOOPS Electrons' tab. Click 'Clear' again and this time select 'Start Time' and 'Total Density'. Click 'OK', the Advanced window should close. The trajectory data is not necessary for this part of the tutorial, so select 'Off' in the dropdown box next to 'Trajectory File'.

In the 'Results Output' box, select table. Finally, click 'Submit'.

### Sending the Tables to Topcat

The tabular data results should now appear. The tab 'SWOOPS Ions' should be open. The data needs to be sent to Topcat (as was done in part 1 of the tutorial).

You should also see that only the proton density data has been sent. To send the electron density data, click on the grey 'SWOOPS Electrons' tab. Once this tab is open, click on 'Send To' and the Topcat link. The data should be sent to Topcat again.

SWOOPS_HOURLY_IONS_EVENT		SWOOPS_ELECTRONS_EVENT	
Start Time			p+/cm3
1996-06-01 00:30:00.000		0.12719	
1996-06-01 01:30:00.000		0.12678	

This new data will also be labelled under 'UFA Table', however they will be numbered. Go back to the Ulysses archive tables, and click on 'Close'.

Start Time	Total density e-/cm3
1996-06-01 02:23:56.000	0.14054
1996-06-01 02:58:29.000	0.14746

### Finding the Mean Values

To compare this data with the solar maximum data, firstly click on the 'Back to Search' link in the top left-hand corner of the screen.

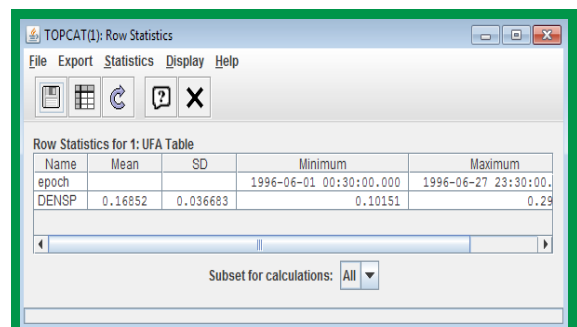
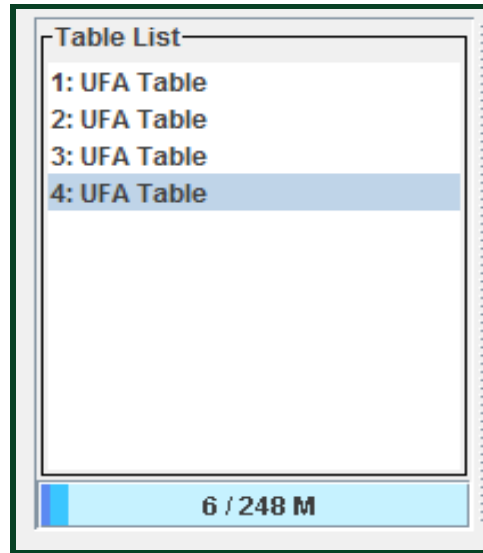
Now edit the dates to the solar maximum dates; **01/02/2002 – 28/02/2002**. Do this as before, under the 'Date Selection' box.

The same data should still be selected as in the previous search, so now just click on 'Submit'. The new tables should open as before.

Once again, as before send 'SWOOPS proton' data by making sure that the 'SWOOPS Ions' tab is open and clicking on 'Send To' and then Topcat. Do the same under the 'SWOOPS Electrons' tab.

Now all the necessary data has been sent to Topcat, click on first 'UFA Table' label in the box 'Table List' so that it is selected in blue, and then click on the statistics button.

Do this with each of the labels, so that four new windows have opened. The first statistics window should show the mean for the proton density in the solar minimum, the second for the electron density in the solar minimum, the third for the proton density for the solar maximum and the fourth for the electron density for the solar maximum.



→ This is an example of one of the statistics windows that you will open. It is the proton density for the solar minimum.

→ See if the numerical values match with the ones you found. The important value for this experiment is the mean.

### Comparing the Data

Write the values you find in the table below. The answers are given in the back of this tutorial booklet.

	SOLAR MINIMUM	SOLAR MAXIMUM
MEAN PROTON DENSITY		
MEAN ELECTRON DENSITY		

You should notice that, as predicted, Ulysses has detected higher mean proton and electron densities during the solar maximum compared to the solar minimum.

Therefore, from this and the corresponding SOHO data, it is possible to see that the hypothesis was correct; that Ulysses observed an increased proton and electron density due to the increased rate of CME's during a solar maximum.

## →Conclusions

→In Part 1 of the tutorial information was given about certain characteristics of the Sun; in particular sunspots, CMEs and solar flares. A hypothesis about the magnetic field detected by the ESA/NASA spacecraft Ulysses was made, and proved correct. This showed that in the solar cycle, during the solar maximum there is an increase in the radial (outwards) component of the magnetic field of the Sun. One of the reasons given for this is the increased rate of Sunspots during this time, which are associated with strong magnetic fields.

→In Part 2 of the tutorial more in depth information was give about CMEs - Coronal Mass Ejections, and one of their properties was investigated. A hypothesis was analysed, using ESA/NASA SOHO data, as well as Ulysses data. The hypothesis was proved correct, which illustrated that during a solar maximum there is an increase in the proton and electron densities detected by Ulysses. These are associated with the Coronal Mass Ejections which create huge solar winds that are sent far into space at great speeds.

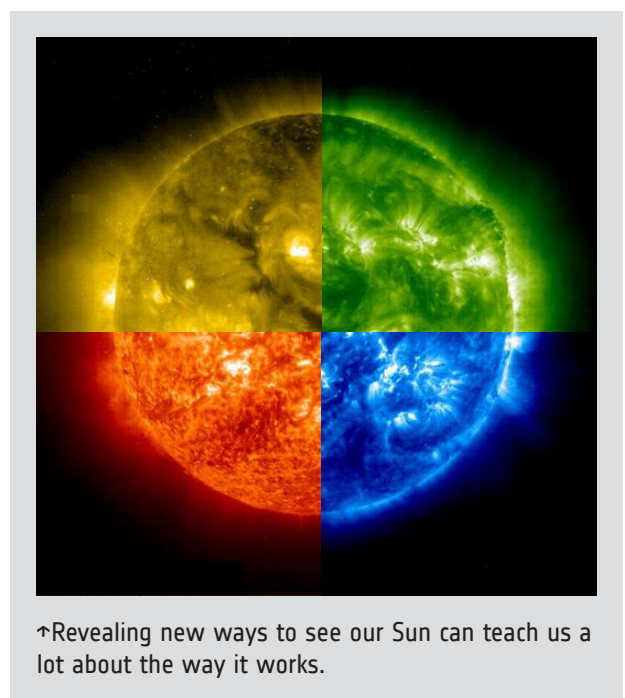
→Therefore, in conclusion we have seen that the Sun goes through cycles; solar cycles. The solar maximum is associated with more 'activity' such as sunspots, Coronal Mass Ejections and solar flares. These can be directly observed using data from the SOHO archive, or some of their properties can be investigated using the Ulysses archive. We also briefly considered some of the consequences of increased activity from the Sun, such as aurora, or the danger of radiation damage for astronauts.

## →Additional Activites

Try coming up with your own hypothesis about the Sun to test with SOHO or Ulysses data. If you aren't sure, use a search engine to do some research about other solar effects you are likely to see, or look at data using the archives for solar maxima and minima and see what things you can spot! You can even email the Science Archives Team with your conclusions at: [Pedro.Osuna@esa.int](mailto:Pedro.Osuna@esa.int)

→Write your own booklet about the Sun and its activity. You could even try including some pictures from the SOHO archive, or graphs from the Ulysses archive.

→Pick some random dates and look at the data from both of the archives to see if you can tell whether they belong to a solar maximum, or a solar minimum.



↑Revealing new ways to see our Sun can teach us a lot about the way it works.

# →Answers to Numerical Problems

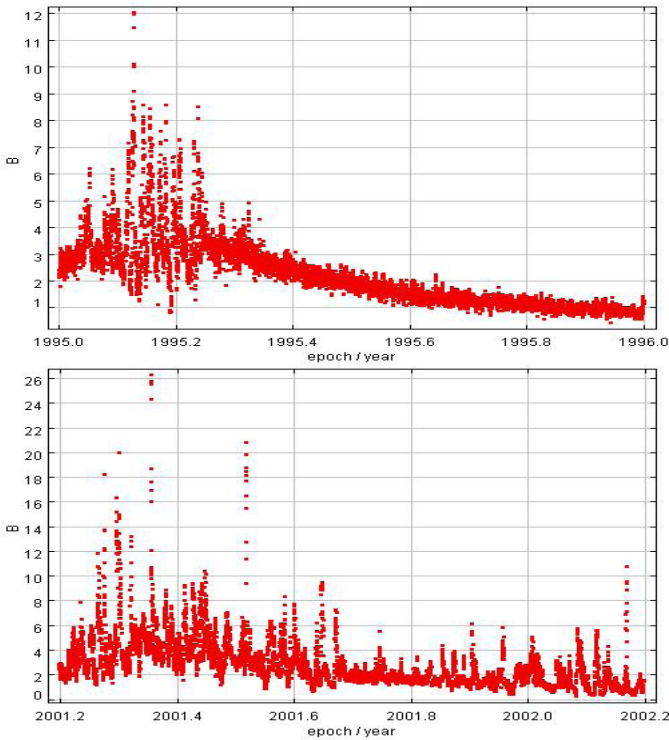
## PART 1 | SECTION 2 : MAGNETIC FIELD MAGNITUDE TABLE

POINT IN SOLAR CYCLE	MEAN VALUE	STANDARD DEVIATION
SOLAR MINIMUM	2.13772	1.24447
SOLAR MAXIMUM	2.69319	1.99087

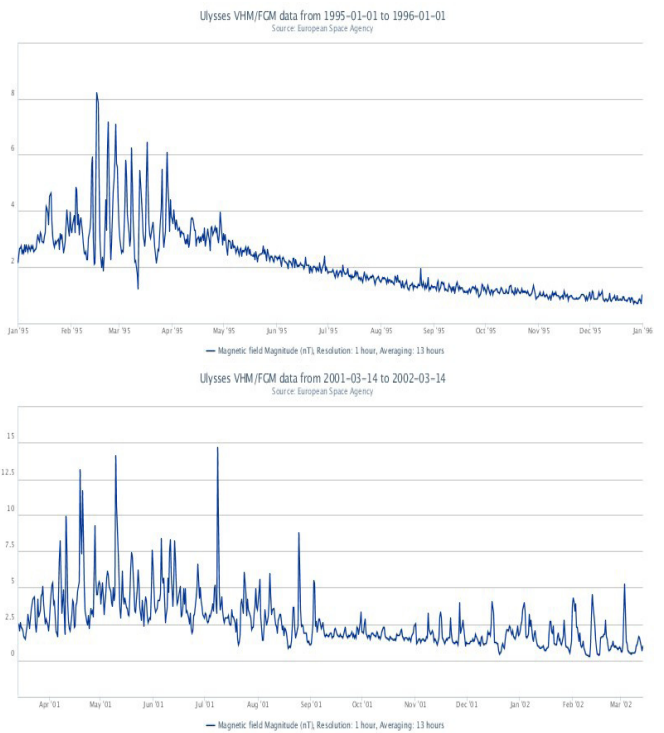
## PART | SECTION 2 : OPTIONAL ACITIVITES

The plots produced should look something like this:

Plots made with Topcat



Plots made with the Ulysses Final Archive



## PART 2 | SECTION 2 : PROTON AND ELECTRON DENSITIES

	SOLAR MINIMUM	SOLAR MAXIMUM
MEAN PROTON DENSITY	0.16852	0.640791
MEAN ELECTRON DENSITY	0.185214	0.803354



## CONTACT

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