THE SUN: FROM GALILEO'S WORK UNTIL TODAY

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Abstract

The Sun is our star and this means that by studying it we can develop a greater understanding of other stars of similar size. We can also understand how it affects life on Earth.

This workshop reviews the discovery of sunspots by Galileo and how to use them to determine the rotation rate of the Sun.

It also looks at the solar cycle of sunspot numbers with an activity to determine the Wolf number.

INTRODUCTION

The Sun is a star. Because it is so close to us we can study it in more detail than other stars. Before the invention of the telescope we saw the Sun as a perfect unblemished disk.

The era of naked-eye astronomy, from the beginning of the human race until the year 1600 A.D., provided mankind with early theories and mythologies of the universe, as well as ways of measuring time. In the final phase of this pre-telescope era, detailed observations of the heavens paved the way for the scientific revolution, during which Earth lost its privileged position as the center of the universe, and became just one of the planets in a vastly expanded space[1].

- Myths About Ancient Sun Gods (stories for the young and old)[2]

Do you love to soak in the sun's rays at the beach? Then you just might be a sun worshipper! People in many ancient cultures were heavily into the sun, to the point of worshipping it as a god. And some of the ancient myths behind these gods might surprise you.

- Egyptians

The Egyptians called their sun god Ra (Re) and considered him the creator of light and all things. It is believed that humankind was born from the tears of Ra. Ra was usually depicted in human form with a falcon head, crowned with the sun disc and encircled by a cobra. The sun itself was taken to be either his body or his eye.

- Greeks

Helios was their sun god. The Greeks believed he drove the sun across the sky from east to west in his golden chariot every day. After sunset the sun sailed back across the ocean.

- Inuit (Eskimos)

Malina was and continues to be the sun-goddess of the Inuit people who live in Greenland. Malina and her brother, the moon-god Anningan, lived together. They got into a terrible fight and Malina spread dirty, black grease all over her brother's face. In fear, she ran as far as she could into the sky and became the Sun. Annigan chased after her and became the moon. This eternal chase makes the sun alternate in the sky with the moon.

- Chinese

According to Chinese mythology, there were ten suns that used to appear in turn in the sky during the Chinese ten-day week. Only one would go on a journey into the skies. But after some time they decided to appear together in the sky. The heat was too much for the people to handle. They asked the suns to fly solo, but they refused. So their father sent the archer Yi down from the heavens to reprimand the disobedient suns, but he ended up killing nine of the suns and the one that remains is the sun they see in the sky.

It was only during solar eclipses that there was any indication that the Sun was more complex than this. During an eclipse, when light from the main disk is blocked out the stunning solar corona is seen stretching out into the dark sky. However, the ability to do more than gaze in wonder was not possible until scientific developments progressed.

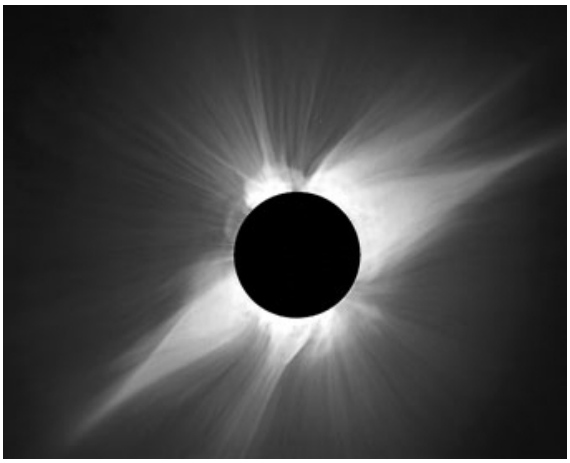


Figure 1

With the development of the telescope and later the spectrometer it has been possible to recognise and measure the rotation of the Sun and to determine its chemical composition.

At this point it is important to remind people not to gaze directly at the Sun. Viewing the Sun should be done by projecting the image onto card or by using specialist filters or solar scopes.

GALILEO'S OBSERVATIONS OF THE SUN

With the invention of the telescope several astronomers turned to viewing the Sun. What they saw surprised them. Instead of an unblemished disk they noted several dark blotches which changed day by day. Galileo's pictures are dated 1611 onwards. These astronomers, Galileo included, drew detailed pictures of what they saw. Occasionally dark patches are visible to the naked eye and a few have been recorded. Some observations have been attributed to Mercury or Venus in transit across the Sun. Chinese astronomers recorded dark blotches as early as 200BC but did not think of the Sun as an evolving body.

Figure 2

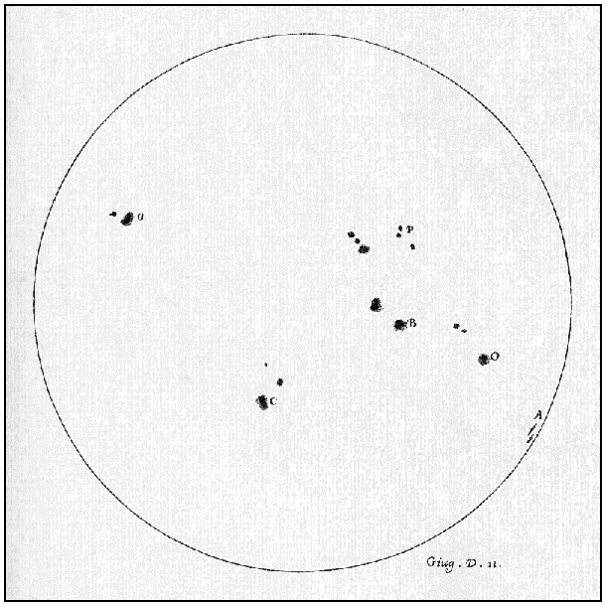


Figure 3

Galileo's peers, such as Thomas Harriot, Johannes and David Fabricius and Christoph Scheiner, also recorded their views of the Sun but were not as forthcoming in publishing their findings to the public. There was also some dispute as to what these mysterious dark spots were. Scheiner believed that the blotches were new satellites passing across the face of the Sun (or at least claimed this so that he did not get into trouble with the church) but Galileo posed that the blotches were actually on the surface of the Sun.

HOW DID GALILEO PROVE THAT THESE BLOTCHES WERE ON THE SUN?

Galileo made drawings of the Sun at the same time of the day so that the Sun's orientation was the same and the path of the blotches or spots could be tracked. Galileo noted that when the spots approached the edge of the Sun's disk, they appeared to become narrower and their movement slowed, both of which are illusions of a rotating sphere. The spots also had irregular shapes and appeared and disappeared within the

disk, something that orbiting satellites could not do. Thus Galileo realised that the spots were on the face of the Sun and that the Sun was rotating.

Questions for students:

- What did Galileo see that proved that the sunspots were not satellites orbiting the Sun, but changes on the surface?
- Galileo made this important discovery by extremely patient and detailed observations of the Sun. Why is this method critical to scientific studies, even today?
- Why do you think that conservatives in Galileo's time wanted to preserve the notion that the Sun was unblemished?

A MENTION ABOUT SPECTRA

Isaac Newton discovered that the Sun's light could be split into many colours, called the visible spectrum. Later observations of the Sun's spectrum indicated a pattern of dark lines cutting the spread of colours. These lines are known as Fraunhofer lines. They can reveal information about the chemical composition of the Sun as well as detail about its rotation.

SUNSPOTS

Galileo's dark blotches are known as sunspots. They move across the surface of the Sun from day to day, sometimes disappearing part way across.

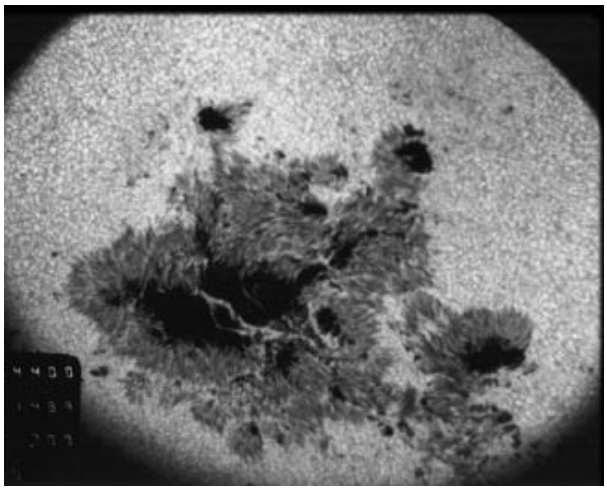


Figure 4

Sunspots were found to be areas of the Sun's surface that are cooler than the main disk. They appear dark because less light is being emitted from them. The darkest part is called the umbra and is about 4500K. Surrounding the umbra is the penumbra, typically about 5500K, which appears lighter. An average sized sunspot is as large as the Earth.

The sunspot is cooler because of a strong magnetic field there that inhibits the transport of heat via convective motion in the Sun. The magnetic field is formed below the Sun's surface, and extends out into the Sun's corona.

Because the rotation period of the Sun is faster at the equator than towards the poles, a ‘differential rotation’ is created. The magnetic field becomes increasingly ‘wound up’ as the Sun rotates, stretching the magnetic field between the poles and the equator. This stretching causes tubes or tunnels to form in the magnetic field. The loops rise and break the surface, preventing convection of the superheated gases underneath. The result of this is the creation of areas of lower temperature which are visible as dark spots. Eventually the loops break and the magnetic field becomes ‘unwound’ before the cycle starts again. The sunspots are associated with solar flares.

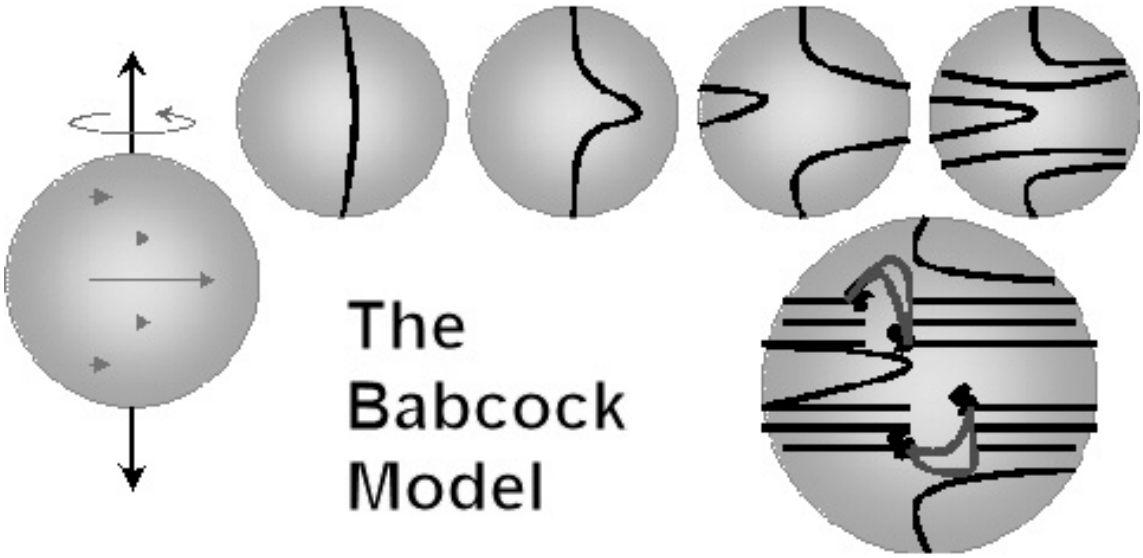


Figure 5

Sunspots change in size and shape and usually last about 30 days. Sunspots first appear close together but move apart over a period of about 2 weeks before beginning to disappear.

Sunspots follow a cycle of between 9.5 and 11 years. The highest sunspot activity is called the solar maximum and the lowest sunspot activity is the solar minimum. Scientists have found that at the end of each cycle the magnetic poles of the Sun switch so this is a good method of detecting when a new cycle starts.

Sunspots most often appear in the low latitudes near the solar equator, and they almost never appear below 5 or above 40 degrees north and south latitude. At the beginning of a new sunspot cycle sunspots appear mainly closer to the Sun’s north and south poles. As the sunspot cycle progresses, more sunspots appear closer to the Sun’s equator.

There are two ways of plotting this cycle. One is to simply count the number of spots and by plotting the numbers against a time scale a periodicity can be determined. Another is by means of the so called ‘Butterfly Diagram’.

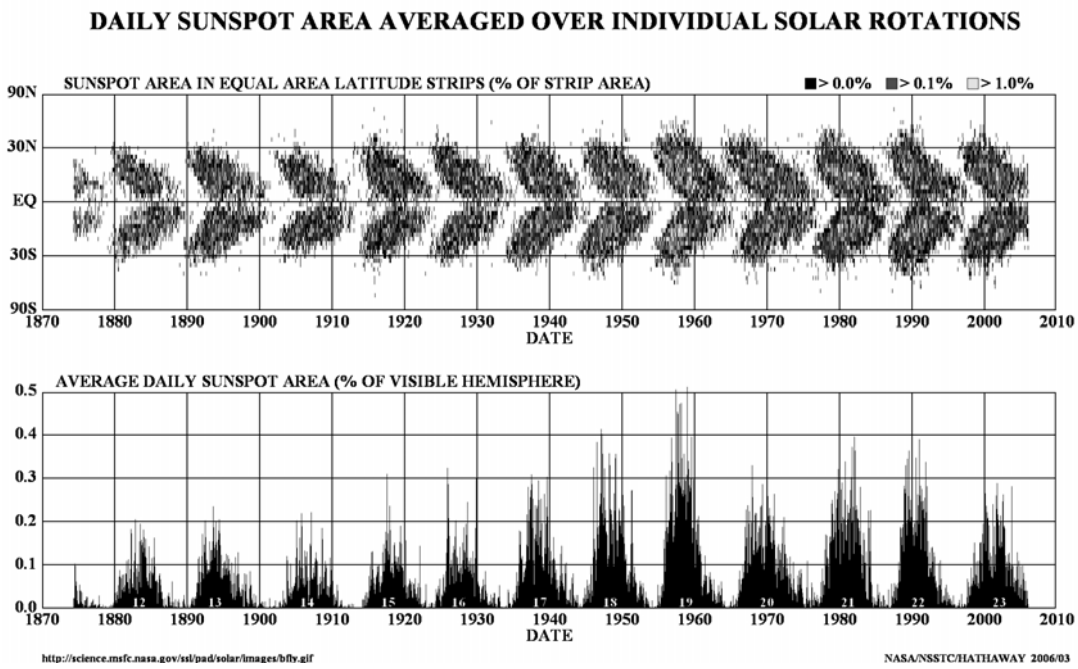


Figure 6

Between 1645 and 1715 there were almost no sunspots and there was a mini ice-age on Earth so it has been known for a long time that the Sun's activity affects the Earth. This period of time is known as the Maunder minimum.

MEASURING THE ROTATION OF THE SUN USING SUNSPOTS

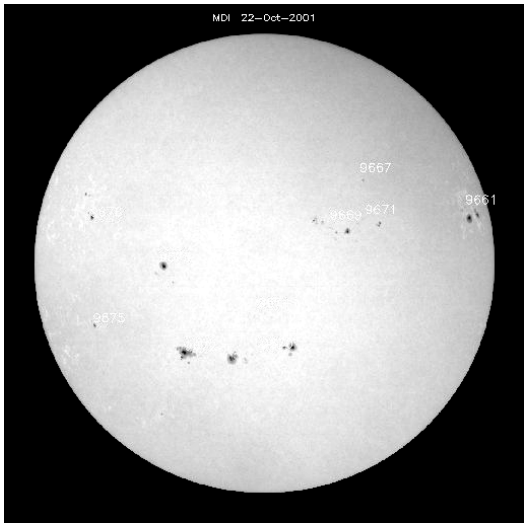
The surface of the Sun does not all rotate at the same rate, the equatorial region having a faster rotation rate than the polar region. It is possible to use sunspots to determine the rotation rate for the latitudes at which sunspots occur.

- Method

By measuring the position of a sunspot on different days during one rotation it is possible to determine the rotation rate of the Sun.

First obtain photographs or drawings of the Sun showing the same sunspots on different days. It is necessary to record the exact time of the image as well as the date. You may find that some sunspots disappear but this does not matter as long as there are some that appear on two or more photographs. If you are taking your own images be sure to avoid looking directly at the Sun. If you want to record the position of the sunspots by drawing it is sensible to record them on a grid (photocopy the grid in the appendix).

As it is not always possible to view the Sun each day, and this year there have been few sunspots visible we are going to use photographs taken from the internet.



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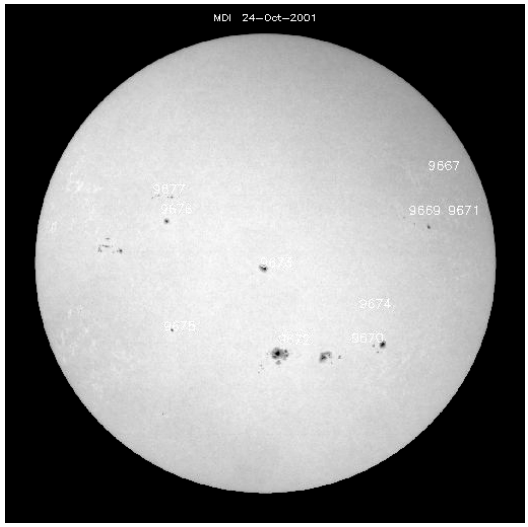

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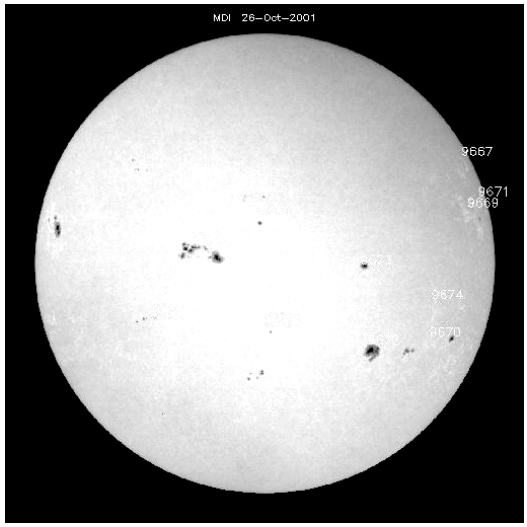

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Figure 7

- The first task is to determine the axis of rotation on your photographs. This may be shown or check the path of the sunspots. Over a few days they should remain at a similar latitude.
- Next take a transparency of a grid that fits your photograph. It might be necessary to rescale the grid to fit your own. (there is a page of grids in the appendix).
- Lay the grid over the photograph and mark the position of one or more sunspots. Number the sunspots on the transparency. Next lay the transparency over the next image and mark the sunspots again. You can do this for several images.
- Determine the angular distance moved by each sunspot from one date to the next and record these values.
- Calculate the time difference between one image and the next. This should be as accurate as the data allows.

- Now you should be able to determine the rotation rate for the Sun.To do this divide one rotation (360 degrees) by the angular distance travelled and multiply it by the time it took to cover that distance. For example, if a sunspot moves 60 degrees in five days, then it would take 30 days to complete one rotation (360/60 multiplied by five).
- Calculate this value for a number of sunspots and calculate the average. Do you get close to the actual figure of 27 days?

• What is happening?

The Sun rotates on its axis once every 27 days. Since the Sun is a ball of gas it does not rotate rigidly like solid planets and moons. In fact, the Sun's equatorial regions rotate faster (taking only about 24 days) than the polar regions (which rotate every 30 days).

Below is an example of a sunspot on the Sun four and a half days (108 hours) apart.

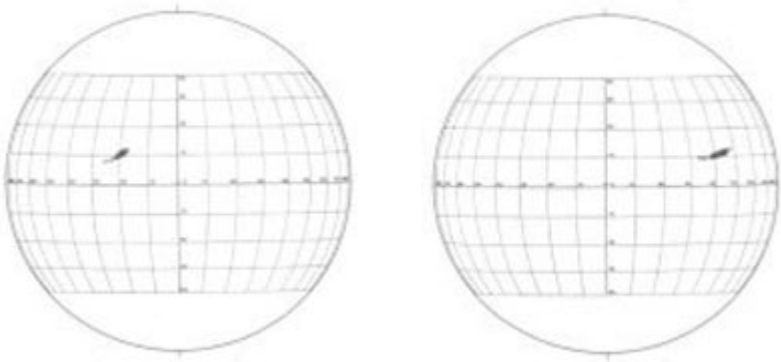


Figure 8

In the first diagram, the sunspot is level with the 20 degree line to the left of the centre line. In the second diagram it is 40 degrees to the right. Therefore the sunspot has moved 60 degrees in 108 hours. It would take 648 hours, or 27 days to complete one rotation.

Questions:

- Are all the sunspots you used at the same latitude?
- Do all the sunspots move at the same rate?

Further calculations and investigations:

Using several sets of images it is possible to compare the rotation rate at different latitudes and note the differential rotation. It is also possible to determine the duration of sunspots and to investigate whether there are changes in size of sunspots.

You can combine images you have drawn or printed out to create a flicker book, or scan them into a computer and create a slideshow to see how the sunspots move.

There are other methods of measuring the movement of the sunspots but this one is fairly straightforward. For another method see:

http://www.qacps.k12.md.us/cms/sci/PROJJNN.HTM

WOLF NUMBER

As mentioned before the number of sunspots seen on any one day varies, as does their size and position. In 1848 Rudolf Wolf devised a daily method of estimating solar activity by counting the individual sunspots and the groups of sunspots on the face of the Sun. He thought that the number of sunspots alone did not effectively indicate the level of sunspot activity so he chose to compute his sunspot number by adding the number of sunspots, *f*, to 10 times the number of sunspot groups, *g*. The Wolf number, *R*, is also known as the Zurich sunspot number.

$$R = 10g + f$$

Note that a typical sunspot group has about 10 spots on average. (An alternative form of the Wolf number is $R = k(10g + f)$ where k is a factor that attempts to account for other variables in the measurement).

Although there are more modern sunspot numbers there are records of the Wolf number dating back to his initial measurements.

Wolf confirmed the existence of a sunspot cycle and the coincidence of the sunspot cycle with disturbances in the Earth's magnetic field.

For lists of sunspot numbers see:

- http://www.ngdc.noaa.gov/stp/SOLAR/SSN/ssn.html
- http://astronomy.swin.edu.au/cms/astro/cosmos/W/Wolf+number

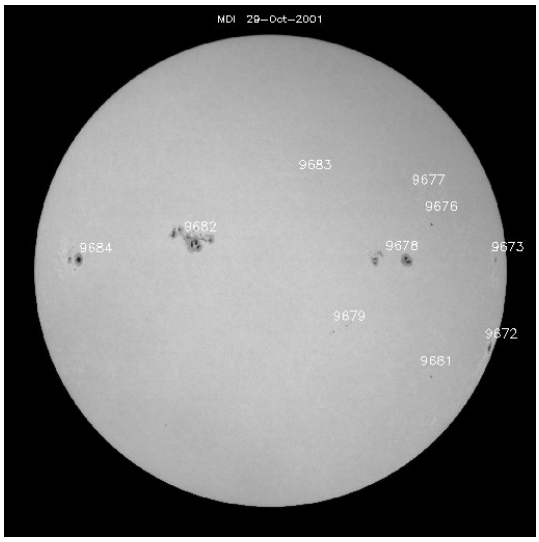
DETERMINING THE WOLF NUMBER

- Method

In order to calculate the Wolf number for any one day we need to have a very clear photograph. The Figure 9 shows three examples; for each photograph:

- Count the number of individual sunspots.
- Count the number of groups of sunspots. This may be difficult to decide if all the sunspots appear to be individual. If so each sunspot would also count as a group.
- Calculate the Wolf number using the formula: $R = 10g + f$
- Compare the Wolf number for each image.

This is a simple exercise but it can then be used to create a graph or butterfly diagram to show the variation in sunspot numbers over days, weeks or years. A butterfly diagram would take a long time to plot by hand but could be done using a spreadsheet. This is outside the scope of this workshop.



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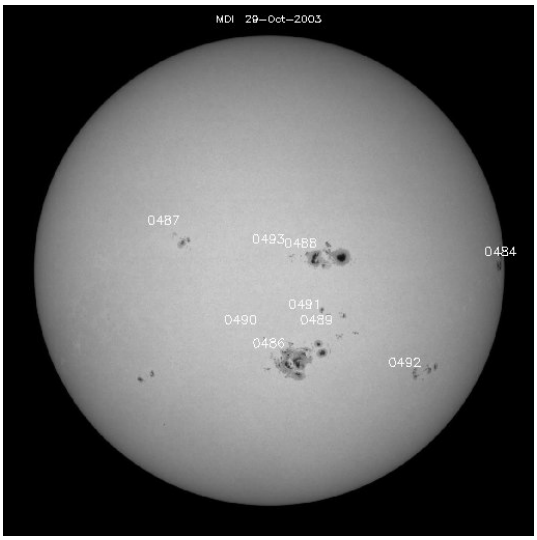

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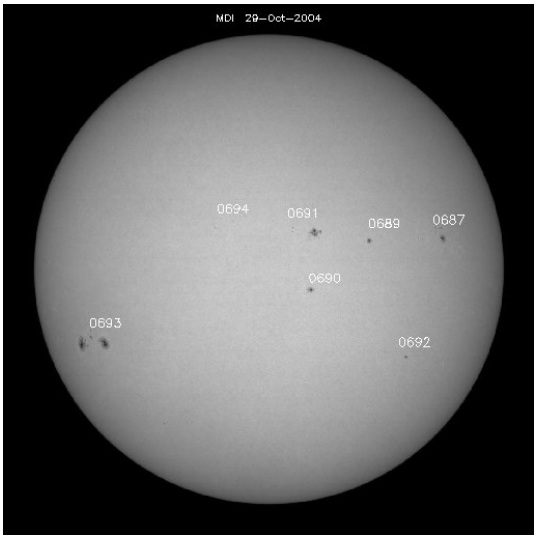

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Figure 9

To find more images to use :

- http://sohowww.nascom.nasa.gov/data/synoptic/sunspots/sunspots
- http://sohowww.nascom.nasa.gov/data/latestimages.html

THE SUN TODAY

With recent advances in telescope technology it is now possible to study the Sun at many different wavelengths. Sunspots, solar flares, coronal mass ejections and other phenomena are still not fully understood. There is still much work to be done to understand our own star and its effect on our lives.

References

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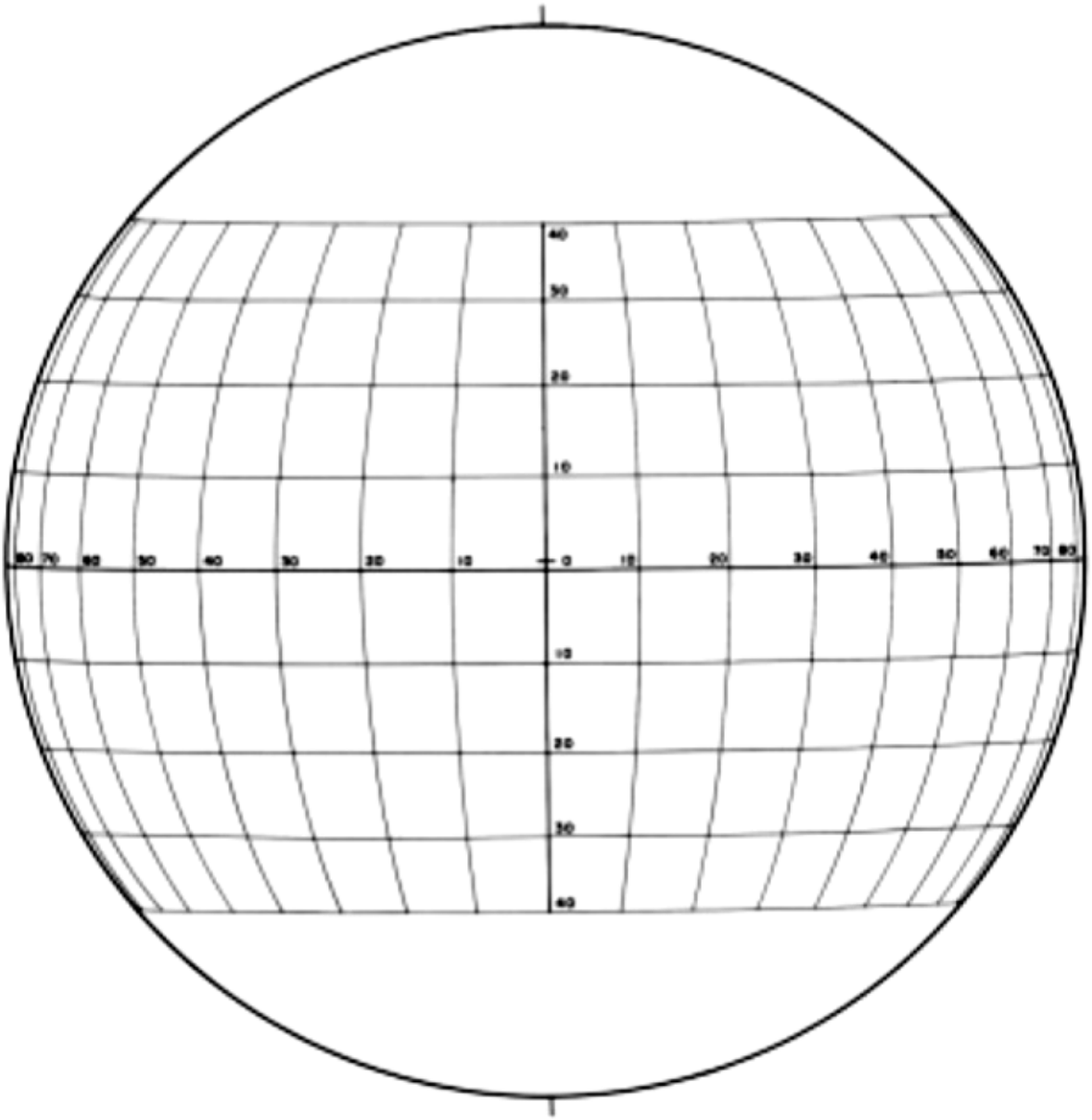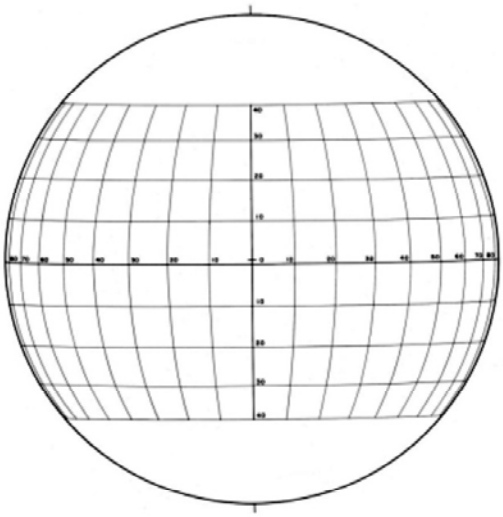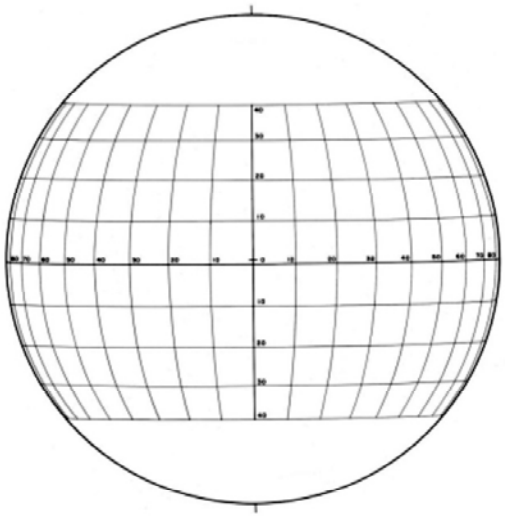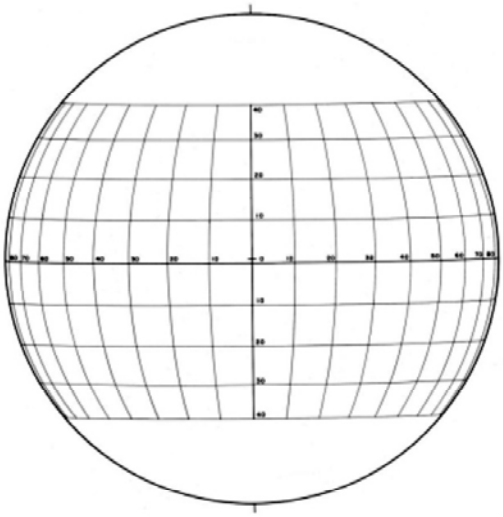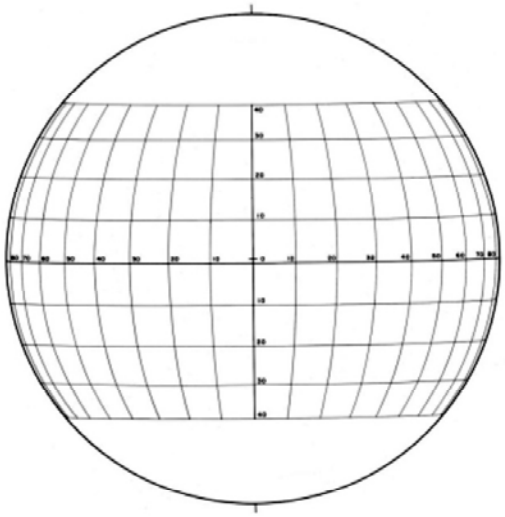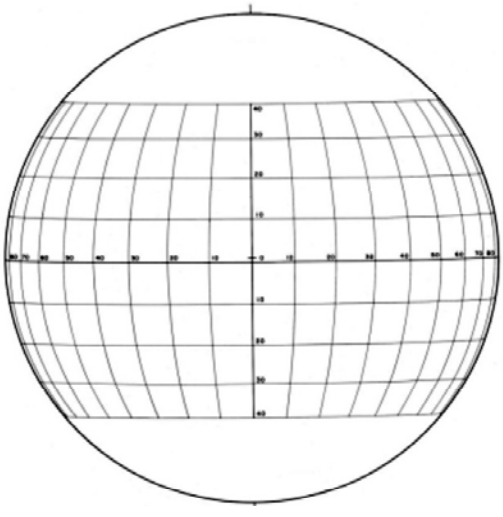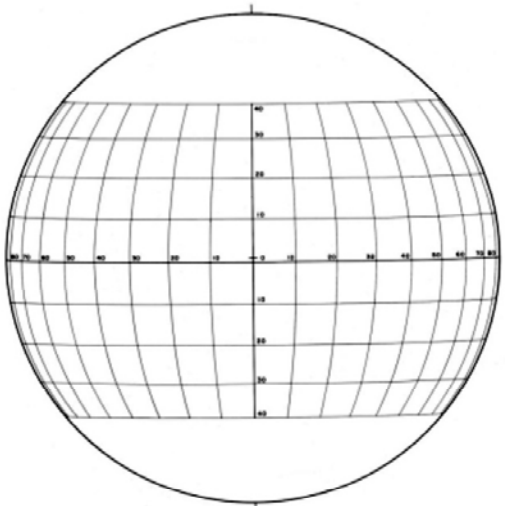
Appendix: