Observing Sunspots and Limb Darkening by use of an H-Alpha Filter

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ABSTRACT

The aim of this project was to study the movement of sunspots using different mediums using mathematical formulae. It also encompassed investigation into limb darkening, which involved modelling and statistical analysis. CLEA Software was used to track solar rotation using the location of sunspots over a set period of time. In addition, photographic software was used to assess brightness changes across the diameter of the Sun to demonstrate the effects of limb darkening. From this data it was possible to support the hypothesis that limb darkening affects the brightness at the edges of the Sun. Furthermore, solar rotation speeds were calculated at varying latitudes, enabling the conclusion that differential rotation is faster at the equator of the Sun than at increasing latitudes. The project was hindered slightly by the weather for the duration of the project, hence restricting time that could be spent at the Clanfield Observatory. However this was overcome by using recent online data in conjunction with images that were obtained at the observatory when the weather was favourable. Overall, the results from the project supported the hypotheses acknowledged in the scientific community and extensive knowledge was gained from researching the relevant theory in support of the practical.

ACKNOWLEDGEMENTS

Thank you Dr. Michael McCabe for support when needed Thank you Carol Bryan and Steve Knight for giving up there time and allowin me to join them in observatory Miss Tamsin Fawn, BSc (Hons) Clinical Photography Student at Westminster University for photographic help

0.1 SOLAR TERMINOLOGY AND ABBREVIATIONS

0.1.1 TERMINOLOGY

Adiabatic Gradient: *The rate at which the temperature would fall if a volume of material were moved higher without adding heat*

Central Meridian: *The north-south meridian of the Sun that passes through the centre of the disc as viewed from the earth.*

Corona: *The outer atmosphere of the Sun, visible during a solar eclipse as an extended bright region about the Sun, with low-density and high temperature.*

Coronal Hole: *Areas where the corona is of a lower density and has a relatively low temperature. They are the source of high speed solar wind streams.*

Faculae: *Usually occur in the solar photosphere, consisting of irregular bright patches, which form a veined network in the vicinity of sunspots. Usually a few degrees hotter than their surroundings, and are best observed on the solar limb.*

Filaments: *Dense, dark, thread-like features seen in the red light emitted from the chromosphere. These are dense clouds of material suspended above the solar surface by loops of magnetic field.*

Granules: *Found on the photosphere of the Sun. These occurrences are caused by convection currents of plasma, originating in the convective zone, and their grainy appearance is caused by the top of the convective cells.*

Interstellar Medium: *The matter that exists in the space between star systems in the galaxy, including gas in ionic, atomic and molecular form, dust, and cosmic rays.*

Latitude: *The angular distance from the solar equator when measured north or south along the meridian.*

Longitude: *The angular distance from the central meridian when measured east to west along the Suns equator.*

Magnetic Clouds: *Regions where high speed wind catches up with slow speed wind.*

Magnetic Field: *More generally known as a stellar magnetic field. This is generated by the movement of conductive plasma (created via convection) within the Sun. These vary yearly and reverse direction approximately every eleven years around periods of solar maximum (see chapter 1.8).*

Plage: *Bright patches surrounding sunspots, usually seen best through an H-Alpha filter. These are usually associated with concentrations of magnetic fields, and are one of the features that characterise the chromosphere best.*

Prominence: *An eruption seen on the limb of the Sun, consisting of relatively cool, high-density gas from the solar chromosphere which extends into the corona.*

Prominences: *The same as a filament, the only difference being that this feature can be seen projecting out above the limb of the Sun.*

Sidereal Period: *The time taken for any given sunspot to make one complete rotation around the Sun (for the purposes of this context).*

Solar Activity: *Effects caused by the Suns magnetic field. These include sunspots, solar flares and variations of solar wind. Solar activity also affects Earth with occurrences such as auroras at moderate to high latitudes and disturbances to electrical power.*

Solar Cycle: *The changes in solar activity over an average period of 11 years.*
Solar Flare: *More likely to occur at solar maximum, a flare is an explosion on the Sun (usually within an active region) which releases a large amount of both energy and particles.*
Solar Maximum: *Where solar activity is high.*
Solar Minimum: *Where solar activity is low.*
Solar Wind: *The outflow of solar material from the corona into interplanetary space, carrying the magnetic fields which originate in the Sun.*
Spicules: *Small, jet-like eruptions that eject material into the corona at speeds of around 20-30km/s and can be seen throughout the chromospheric network.*
Sunspot: *Regions, usually occurring in groups, in the solar photosphere (see chapter 1.4) which appear dark, due to containing intense magnetic fields (these provide the energy for solar flares).*
Sunspot Number: *An index of solar activity related to the number of sunspots*
Synodic Period: *The interval it takes for a sunspot to reappear at the same apparent point, as viewed from Earth. The synodic period is longer than the sidereal period because the Sun must rotate for a sidereal period plus an extra amount due to the orbital motion of the Earth around the Sun (for the purposes of this context).*
Temperature Gradient: *The rate at which the temperature falls with height/radius.*
The Chromospheric Network: *A web-like pattern occurring in the chromosphere, best seen in the emissions occurring in that layer.*
(Ips, 2001)

0.1.2 ABBREVIATIONS

P: Synodic period of the Sun (degrees/day)
S: Sidereal period of the Sun (degrees/day)
Y: Number of days in the year (325.24 days)
x: Distance of sunspot measure from the central meridian (longitude) (mm)
r: The radius of the sun in relation to the image being used (mm)
m: The point at which the x-axis crosses the y-axis at -90o (days)
p: The point at which the x-axis crosses the y-axis at 90o (days)

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Chapter 1

INTRODUCTION TO THE SUN

1.1 General Introduction to the Sun

On Orions spur, of a branch of the sagittatius arm of the Milky Way galaxy our solar system formed with creation of the Sun from the gravitational collapse of an area of a molecular cloud, roughly 4.6 billion years ago (Jardine, 2012 and Red Orbit, 2013).

The Sun is known as a yellow dwarf (G2V) type star, and is positioned directly in the centre of our solar system, with 8 planets (including Earth) which orbit around it, it has a diameter of about 1,392,00km and a mass 333,000 times of the Earth. (Spacefacts, 2013)

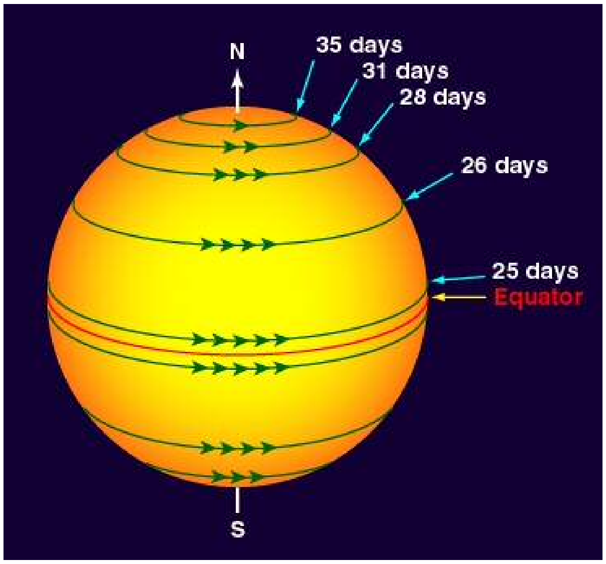

Figure 1.1: Differential Rotation (Moyer and Field, 2010)

The Sun is not solid like the Earth due it being consisted of plasma and gas, so that different areas of the surface rotate at different rates, this is known as differential rotation. Differential rotation is caused by convection in stars. The movement of mass is due to steep temperature gradients from the core outwards. The rotation is fastest on the equator and decreases as the latitude is increases, so it is slowest nearer to the poles. (Russell, 2005).

1.2 Sun Composition

The Sun has many different layers (zones) of varying densities and extreme temperatures, using spectroscopy it can be shown It is composed of 92.1% Hydrogen and 7.8% Helium and If you use the percentage by mass, you find that hydrogen makes up 78.5% of the Sun's mass, helium 19.7%, oxygen 0.86%, carbon 0.4%, iron 0.14%, and the other elements are 0.54% Strobel, N., (2011).

Most of the Suns zones are labled to the right on the image, this although is an interpretation of what the interior looks like, and there are mysteries to be found. (Alsford, 2011)

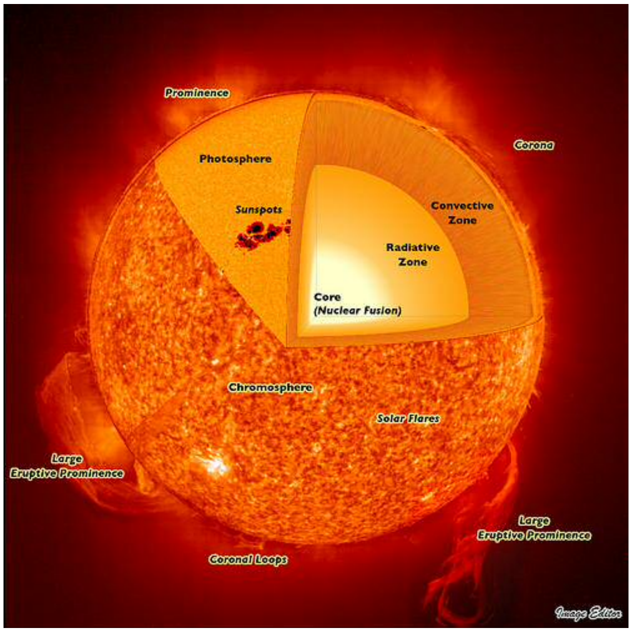

Figure 1.2: Sun Zones (Anon, n.d.)

1.3 Core

The core is the inner most region of the Sun and encompasses 25% of the suns radius. It has a high density of roughly 150g/cm3 which is around 10 times the density of lead (NASA, 2011). Even though it is extremely dense, it is also extremely hot (15,000,000C) so it is actually a gaseous state. At the core, gravity pulls all the mass inward and creates intense pressure (Layton and Freudenrich, 2013). This pressure is high enough to force atoms to combine. The sun exists because of the process of fusion. The hot temperature at the core means that atoms are constantly colliding and tearing apart hydrogen atoms to form separate protons, neutrons and electrons (Jennings, 2013). The fusion or proton cycle has 3 reactions: fusion of protons to form a deuteron, formation of Helium-3 Isotope, and the formation of helium (Jennings, 2013). Each time helium is formed energy is released forming heat which then travels to the surrounding layers. The CNO cycle also occurs at the core which is so called as it involves carbon, nitrogen and oxygen (Jennings, 2013) and it was once thought that this was the main source of energy however it is now known to be the proton cycle that produces the majority of the suns energy. These reactions release the energy that ultimately leaves the surface as visible light. (NASA, 2011).

1.4 Radiative Zone

Between the core and convective layer of the sun there is a area known as the Radiative zone. This extends to about 70% of the suns radius (Astronomy, 2010). The name represents the function of the zone, which is to transport energy produced in the core of the Sun away from the centre via radiation. The energy is transferred by light (photon) interaction with surrounding atoms (NASA, 2011). As the air inside the radiation zone is cooler than that of the core, atoms are able to remain intact (Solar Week, 2013). The intact atoms absorb the photon energy and store it before later emitting that energy as new radiation. This is how the energy is passed from the core into the radiation zone to later enter the interface and convective layers of the Sun (Solar Week, 2013). Even though the photons travel at the speed of light, they bounce so many times through this dense material that an individual photon takes about a million years to finally reach the interface layer (NASA, 2011). This is mainly due to the haphazard pathway that the energy takes, which in turn loses a lot of energy in the process (Astronomy, 2010).

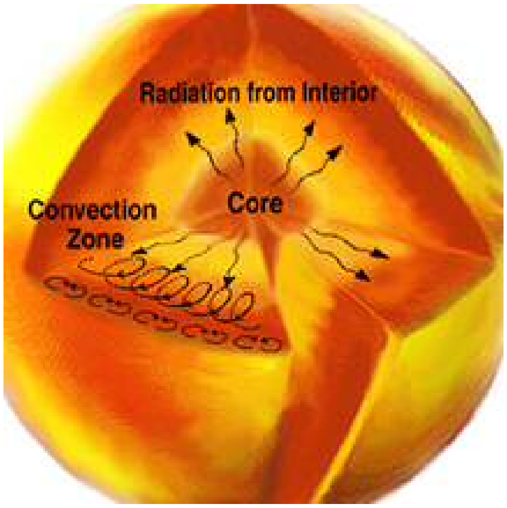

Figure 1.3: Radiative Zone (Russell, 2005)

1.5 Convective Zone

The convective layer is the outermost region of the Sun. It extends from a depth of about 200,000 km right up to the visible surface (NASA, 2011). The atoms in this layer of the Sun are able to retain their electrons as the temperature is cool enough for them not to be stripped away like in the core (Jennings, 2013). Atoms with electrons are able to absorb an emit radiation, making this region more opaque and harder for radiation to pass through (NASA, 2011). Therefore the heat is trapped, making the fluid unstable which starts to boil. Energy in this zone of the Sun is transferred faster than in the radiative zone because it is transferred through convection (Jennings, 2013). Hot gas from the radiative zone rises and expands through the convective layer. This is possible due to the difference in temperatures between the zones; the convective layer being cooler than the radiative (Jennings, 2013). As the gas rises, it cools and sinks again; this process repeats creating that visual boiling effect on the suns surface, this is called convective motion.(Jennings, 2013).

1.6 Photosphere

The photosphere is the surface directly above the convective zone, due to this there is a boiling effect on the surface is called granulation or supergranulation (NASA, 2011). This is the visable apperent surface when it is observed though a telescope, this is because the gas is so dense you cannot see though it, but appears to be solid when it is a gas. This area is also where sunspots are visable.

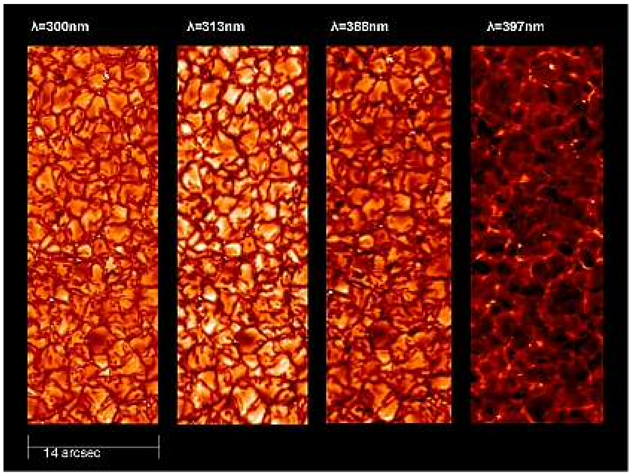

Figure 1.4: Granulation on the suns surface in four different wavelengths of near ultraviolet light (Max Planck Institute, 2009)

1.7 Chromosphere

The chromosphere is the layer of the sun above the photosphere. As height of this layer increases the temperature also increases (Jennings, 2013). It cannot be seen with the naked eye however during a solar eclipse the red ring around the sun that is visible is the chromosphere prominences. The edge of the chromosphere is made up of spicules which are narrow columns that ascend into the corona (Jennings, 2013). This is the layer where solar flares will occur due to the magnetic field surrounding the sunspots (NOOA, n.d.). The chromospheric network (layout of the chromosphere) outlines that of the supergranules due to the magnetic field clusters (Jennings, 2013).

Figure 1.5: Total Solar Eclipse with visible Chromosphere (Strobel, 2011)

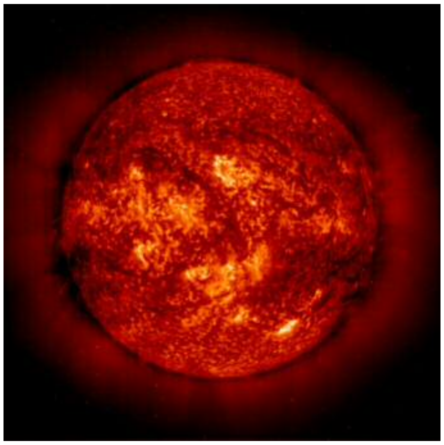

Figure 1.6: Total Solar Eclipse with visible chromosphere (Strobel, 2011)

As previously stated the temperature increases with the height of the layer. This is strange as the further away from the energy source the less heat their normally is. This suggests that there is another form of energy present and scientists believe this to be due to folds in the magnetic field which cause magnetohydrodynamic waves (Jennings, 2013). If the field tries to go back into its original place then it oscillates causing energy release causing the rise in temperature the higher up in the chromosphere (Jennings, 2013).

1.8 Corona and Solar Wind

The extended outer atmosphere of the sun is called the corona, it has a temperature of millions of degrees however is less dense than the atmosphere at sea level (University of Tennessee, n.d.). The corona layer, like the chromosphere, can also be viewed during a total solar eclipse. It has been found that the coronas plasma will emit x-ray radiation at high temperatures due to the nature of the plasma structure (NASA, 2010). The magnetic field of the sun is thought to be the source of the coronas heat. This is the layer where solar wind originates from.

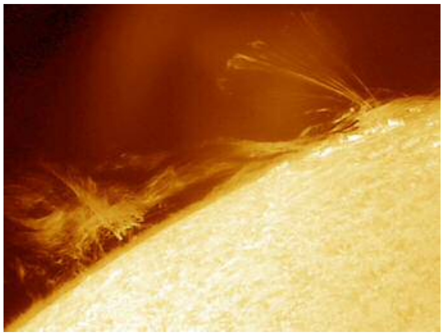

Figure 1.7: Solar Wind (Anon, n.d.)

The solar wind is a stream of energized, charged particles, primarily electrons and protons, flowing outward from the Sun, through the solar system at speeds as high as 900 km/s and at a temperature of 1 million degrees. (Anon, n.d.). This is caused by the hot solar corona expanding into space. It is what blows the tails of comets away from the comet as they pass through the solar system (Anon, n.d.). The coronal layer can also have holes in which the magnetic field lines of the sun are open, (sunspots) thus allowing gas to flow outward into space thus creating solar wind (University of Tennessee, n.d.). Closed field lines will cause a build-up of coronal gases and therefore enhanced x-ray radiation. Solar wind can also have a massive effect on the climate conditions and telecommunication networks on Earth (University of Tennessee, n.d.).

1.9 Heliosphere

The heliosphere is an immense magnetic bubble containing our solar system, solar wind and the solar magnetic field (Cosmicopia, 2012). The density of particles in the heliosphere is very low and it is a near vacuum.

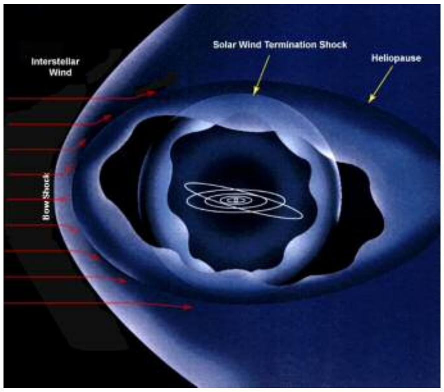

Figure 1.8: Diagram of the Heliosphere (Cosmicopia, 2012)

The heliosphere also has a trailing tail that is filled with hydrogen and helium gases from the solar wind (Cosmicopia, 2012). It takes over a year for solar wind to reach the heliosphere even travelling at one million miles per hour. The speed of the solar wind can vary with the sunspot cycles; quiet periods of solar activity slow the solar wind (NASA, 2013).

The heliopause is the blurred boundary between the heliosphere and the interstellar gas outside the solar system. The solar wind will slow on approach to this boundary and is called solar wind termination shock (Cosmicopia, 2012). The area between the termination shock and the heliopause is called the heliosheath and is extremely large, (NASA, 2013) this also includes the tail region. Where the solar wind reaches the interstellar wind from outer space it is called the bow shock (a gaseous wave) (NASA, 2013).

1.10 Magnetic Field

Due to the fact that the convection zone experiences differential rotation, the magnetic lines that form rapidly moving charged particles, over time these become twisted and causes magnetic field loops to erupt on the sun's surface triggering the formation of dramatic Solar Prominences and Coronal Mass Ejections (CMEs). (NASA, 2013). This is known as a solar maximum which occurs every 11 years (NASA, 2013).

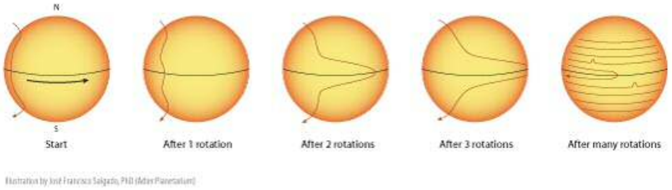

Illustration by José Francisco Salgado, PhD (Adler Planetarium)

Figure 1.9: magnetic lines (NASA 2013)

The magnetic field changes polarity every sunspot cycle (NOOA, n.d.). The result of this is that there is a 22 year magnetic cycle. Furthermore, sunspots themselves have strong magnetic fields that reverse after each eleven year cycle to conform to the 22 year magnetic cycle. (NOOA, n.d.). Sunspots are in fact high magnetic clusters which break through the surface of the sun, and these magnetic fields create varying effects. These include temperature changes, and shape (NOOA, n.d.).

It is suggested that the magnetic forces hinder the convection of heat to the surface by making it harder for the hot gases to rise. Thus, the region in sunspots having strong magnetic fields tends to be cooler than the surrounding region and thus appears darker than the surrounding regions at higher temperature. (University of Tennessee, n.d.)

Chapter 2

INTRODUCTION TO SUNSPOTS

The sun itself contains dark spots, some thousands of miles in diameter. These spots move across the surface of the sun expanding and contracting whilst in motion (Sunspots, 1998). These are known as sunspots.

Sunspots were first observed more than 2800 years ago by Chinese astronomers. Observation of these phenomena increased with the invention of the modern telescope in the early 1600s (NOOA, n.d.). It was from the observation of these sunspots that the discovery of the suns rotation was made.

Sunspots are a dark part of the suns surface which is cooler than the surrounding area. It has been discovered that it is cooler due to a strong magnetic field that inhibits the convection of heat from the core of the sun. The magnetic field is formed below the sun's surface, and extends out into the sun's corona (Sunspots, 1998). The dark centre of the sunspot is called the "umbra." The light area around the spot is the "penumbra." (NOOA, n.d.).

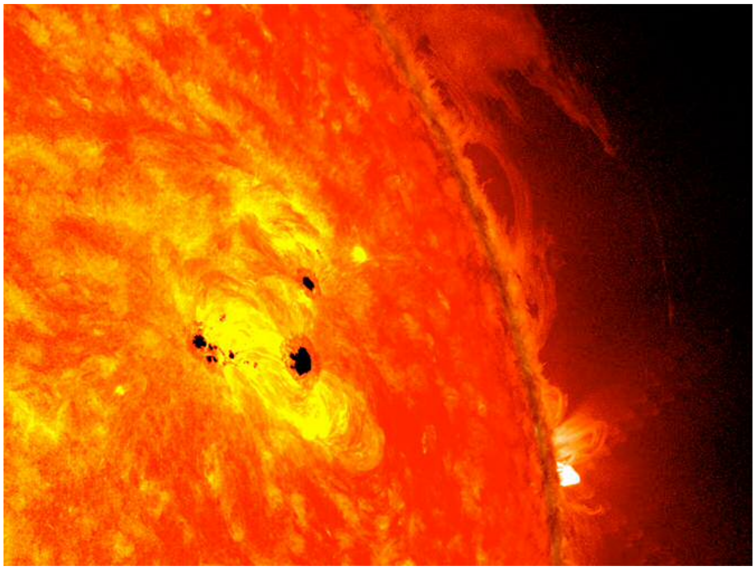

Figure 2.1: Sunspots and Solar Flares (NASA, 2013)

In 1843 it was discovered that sunspots have a cycle which is now known to correlate with the Earths climate (NOOA, n.d. and NASA, 1998). When this cycle is absent in the sun it correlates with cold climates (NASA, 1998). It is thought that sunspots indicate how active the sun is. It is possible that a 1% reduction in the Suns solar energy output may be enough of a change to stop the sunspot cycle (NASA, 1998). This therefore has a direct impact on weather conditions on Earth.

Sunspots occur in groups and have many different forms. They also frequently occur in pairs; each will have opposite magnetic polarities (NOOA, n.d.). They grow in groups over days and weeks and then disappear. In the first years of a sunspot cycle the spots are smaller and form at higher latitudes both north and south (NOOA, n.d.). Within an eleven year cycle the spots become larger and form closer to the equator. As the number of sunspots increases during the sunspot cycle, so does solar activity. Sunspots are sources of solar flares, the most violent events in the solar system. In a matter of minutes, a large flare releases a million times more energy than the largest earthquake (NOOA, n.d). This is called a solar storm.

The solar flares emit radiation including x-ray and ultraviolet regions of the electromagnetic spectrum. It is therefore possible to photograph sunspots with these forms of imaging in addition to standard visible photography. Solar flares are very powerful and can interfere with electrical and telecommunication systems (NOOA, n.d.). Radiation damage can occur without knowledge from a solar flare; however these flares can be predicted by the layout and number of sunspots (NOOA, n.d.). Current solar activity is low with small numbers of sunspots and no solar flares; this may be an explanation for the colder climate (Space Weather, 2013).

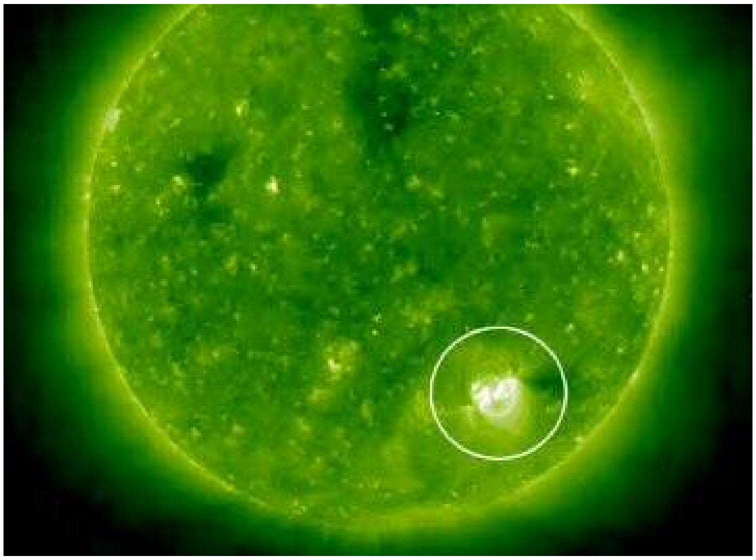

Figure 2.2: UV image of a Sunspot (Finney, 2009)

2.1 Method

The best time to observe sunspots is where there is a clear sky with no clouds, and the sun is high in the sky, so around midday would be best. The sun is more active during solar maximums which happen every 11 years.

To observe the sun, the most ideal equipment are found at observatories which would be a powerful sun scope, such as Meade Coronado 90mm Solarmax 2 double stack solar scope, a normal telescopes without filters, such as hydrogen-alpha fliters, should not be used since the sunlight would be magnified, another asset which would be useful is tracking equipment to keep the telescope in sight of the sun since the sun is constantly moving across the sky as we are orbiting it.

Make sure the safety cap is off the telescope and that the lens is free of dust, and be ready to focus the telescope so there is a clear view. This will be more difficult the closer it is zoomed in as it is easier to tell from having edges in sight.(Bryron, 2013)

Once a clear shot of the sun is in view, affix the camera to the telescope using special attachments and set it to a mode where multiple shots can be taken when held down. So that the best picture can be used out of the number taken. A good make camera that can be used is cannon.

After the images are taken, photographic software is used to store and select the best choice, also is useful to remove any unwanted obstructions.

Figure 2.3: Putting lens cap on sun scope

2.2 Longatude & Latitude

As there is differential rotation on the surface of the sun, sunspots follow the flow from west to east and depending on the latitude, the speed of which they cross it. From calculating the position each day the syndic period can be calculated which in turn the sidereal can be obtained. By using several latitudes these can be compared to give estimates for the suns rotation.

The axis rotation of the sun is to be calculated as the equator is at a tilt to the plane, of the Earths orbit, this is roughly 7 degrees. And due to this the Earths orbit is not perpendicular to the suns axis. This diagram describes the method of calculating the longitude of the sunspots and other features

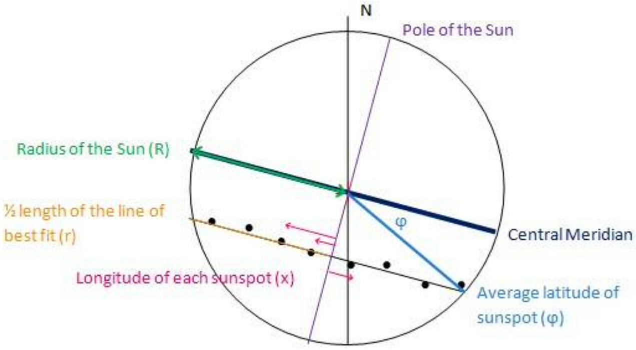

Figure 2.4: Sunspot Path (Alsford, 2011)

2.2.1 Practical Method

1. Use a tracing paper to outline the suns image as accurately as possible
2. At the centre of the circle on the tracing paper mark a point and make sure its at the same point on each image used.
3. Go though each image systematically and mark the position of the same sunspot as it crosses the surface onto the tracing paper, using centre as guideline
4. Attempt to draw a line of best fit across these points
5. Though the centre of the sun draw a line parallel to the line of best fit, this will be the central median line of the sun and perpendicular to this would be the poles
6. Measure the longitude of each point from the pole of the sun, this will be the value of (x)
7. Create a table entering time with longitude and latitude
8. Use table to work out synodic and sidereal periods for that given latitude

2.2.2 Alternative Method

Instead of the longer practical way, there is an alternate method which takes advantage of the trignometry of the circle to find the latitude of a given sunspot, when there is the length of the line of best fit and knowledge of the radius of the Sun.

the given formula is:

$\varphi = \cos^{-1} \frac{r}{R}$

This formula can easily be used to find the latitude accuractly, but is not needed for software such as CLEA since it is more precise, but can be used for images taken from spaceweather website.

Sw 1692

for this sunspot the values for R= 49mm and r = 46.6mm, so using the equation:

$\varphi = \cos^{-1} \frac{46.6}{49} = 18.007 degrees$

Due to using computer software to measure the lengths of r and R, it appears to be very accurate. and the angle is in fact very close to 18. but with the difficulty if measuring the angle practicaly, the forumla would be more accurate.

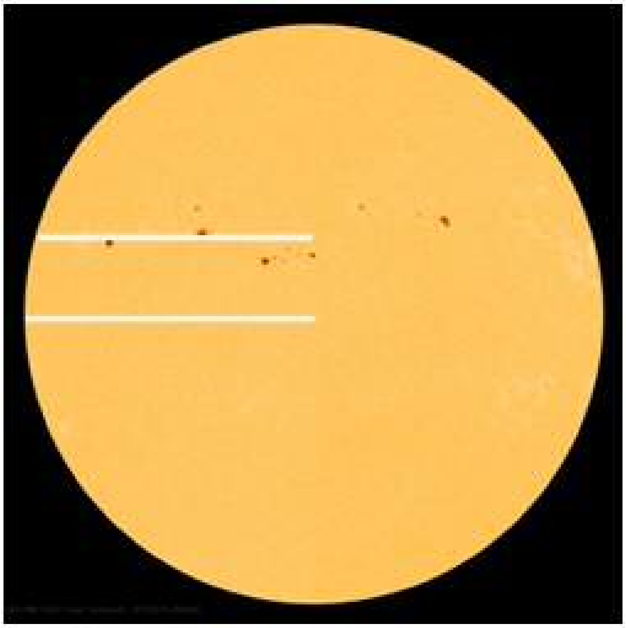

Figure 2.5: Sw 1692

Sw 1675

for this sunspot the values for R= 49mm and r = 46mm, so using the equation:

$\varphi = \cos^{-1}\frac{46}{49} = 20.15 degrees$

again, it is clear that the angle is very closer to the true value.

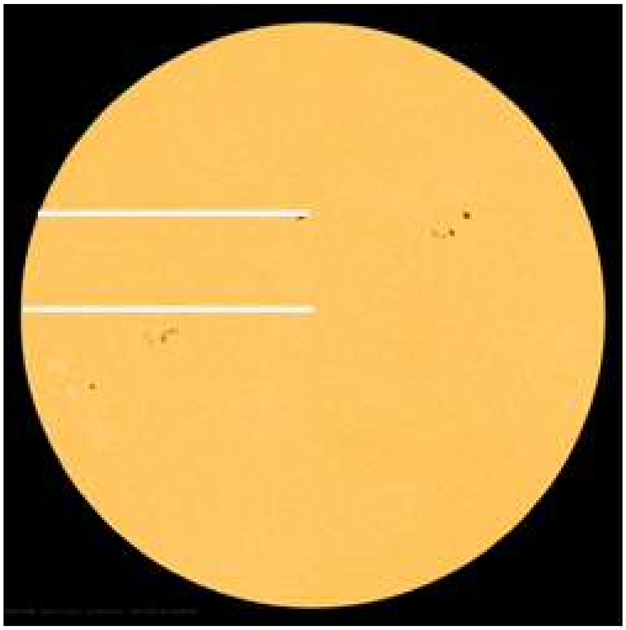

Figure 2.6: Sw 1675

Sw 1640

for this sunspot the values for R= 49mm and r = 42mm, so using the equation:
$\varphi = \cos^{-1}\frac{42}{49} = 31.002 degrees$

again, it is clear that the angle is very closer to the true value.

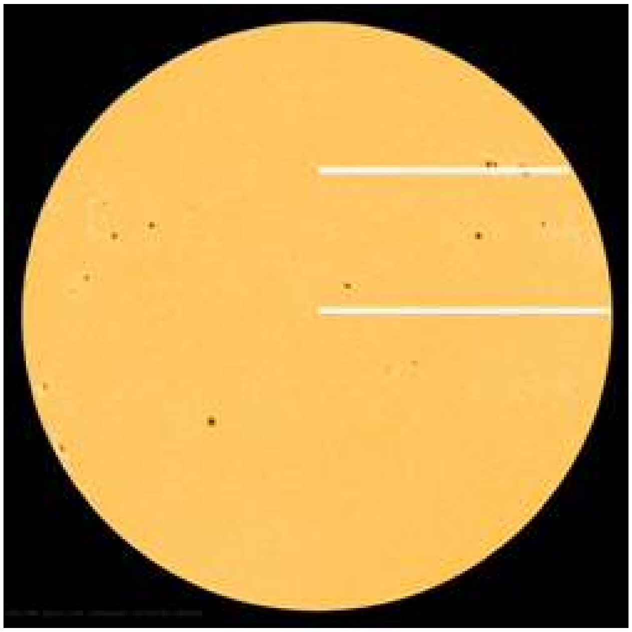

Figure 2.7: Sw 1640

Chapter 3

SOLAR ROTATION ESTABLISHED FROM EXISTING DATA

3.1 Determination of Solar Rotation using CLEA Software

Another way of obtaining images of the sunspots over a period of days is using CLEA software; it has a selection of data over 11 days in January 2002. It instantly gives there latitude and longitude as the mouse is scrolled over the positions.

On each image the data of the position can be saved, so that the final result is graph showing the solar rotation of different sunspots so they can be compared. The main features of this software is how precise the values are as they are up to 5dp, which proves useful in accuracy.

3.1.1 Sunspot 1

this graph is made using CLEA software and shows the data for the first sunspot From this

Day	Date	Latitude	Longitude
0	2002/01/13	-5.01255	-49.01772
1	2002/01/14	-4.85062	-35.58163
2	2002/01/15	-4.66918	-22.30369
3	2002/01/16	-4.59004	-8.97965
4	2002/01/17	-4.42718	4.16528
5	2002/01/18	-4.46324	17.70448
6	2002/01/19	-4.53490	31.12853
7	2002/01/20	-4.52946	44.26498
8	2002/01/21	-4.45272	57.58465
9	2002/01/22	-4.38427	70.41460

data the synodic period and sidereal period can be calculated, 360 is divided by the slope of the longitude which is given in the graph when plotted is, which in this case is 14. This formula will result in the synodic period, from which the sidereal period can be found.

$S = \frac{360}{14} = 25.7 days$

Now this can be used to calculate the sidereal period

$P = \frac{SY}{S+Y} = \frac{25.7*365.24}{25.7+365.24} = 24.01 days$

3.1.2 Sunspot 2

This graph is made using CLEA software and shows the data for the second sunspot Using

Day	Date	Latitude	Longitude
0	2002/01/13	28.73255	-10.04659
1	2002/01/14	28.75470	2.63200
2	2002/01/15	28.82353	15.31347
3	2002/01/16	28.77550	27.95703
4	2002/01/17	28.58051	40.76501
5	2002/01/18	28.52913	53.21865
6	2002/01/19	28.66286	65.63552

the same method from previous sunspot.

$S = \frac{360}{13.3} = 27.067 days$

Now this can be used to calculate the sidereal period

$P = \frac{SY}{S+Y} = \frac{27.067*365.24}{27.067+365.24} = 25.19 days$

3.1.3 Sunspot 3

this graph is made using CLEA software and shows the data for the third sunspot Using the

Day	Date	Latitude	Longitude
0	2002/01/13	6.69952	-55.71014
1	2002/01/14	6.61820	-42.30919
2	2002/01/15	6.69714	-28.92436
3	2002/01/16	6.81963	-15.51630
4	2002/01/17	6.81963	-2.01210
5	2002/01/18	6.70238	11.37350
6	2002/01/19	6.67151	24.92985
7	2002/01/20	6.57703	38.05552
8	2002/01/21	6.41576	51.42078
9	2002/01/22	6.46711	64.75056

same method from previous sunspot.

$S = \frac{360}{14} = 25.7 days$

Now this can be used to calculate the sidereal period

$P = \frac{SY}{S+Y} = \frac{27.067*365.24}{27.067+365.24} = 24.01 days$

3.2 Determination of Solar Rotation using On-Line Data (Spaceweather)

Spaceweather have a very large archive going back many years, it shows the photosphere which has sunspots and other features, which are daily images of the sun and is useful to use, since full cycles of sunspots can be observed and easily used to plot and calculate formula, within a short space of time. This can be used to create tables and plots which will eventually calculate the synodic and sidereal periods

Day	Date	Distance to spot (mm)	sin(theta)	theta
2	2010/10/14	-28	-0.903225806	-64.58537908
3	2010/10/15	-25	-0.806451613	-53.75067912
4	2010/10/16	-22	-0.709677419	-45.20867534
5	2010/10/17	-15	-0.483870968	-28.93852774
6	2010/10/18	-11	-0.35483871	-20.7835596
7	2010/10/19	-4	-0.129032258	-7.413673802
8	2010/10/20	3	0.096774194	5.553444196
9	2010/10/21	9	0.290322581	16.87726944
10	2010/10/22	15	0.483870968	28.93852774
11	2010/10/23	21	0.483870968	42.64230998

$S = 2(p - m) = 2(\frac{90+101.3}{11.853} - \frac{-90+101.3}{11.853}) = 30.1180$

and the sidereal period is

$P = \frac{30.1180*365.24}{30.1180+365.24} = 27.8236$

Chapter 4

Limb Darkening

When looking at an image of the sun the solar disk appears darker at the edges and brighter in the centre. It is also a darker shade of red towards the edges. This is due to limb darkening.

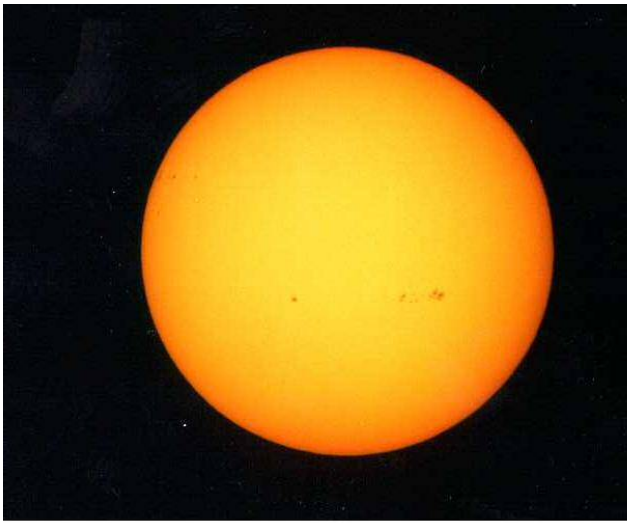

Figure 4.1: Image of the Sun Showing Limb Darkening (Richmond, n.d.)

When looking at the centre of the solar disk, light rays are visible that are coming radially outwards (Richmond, n.d.). These rays originate from deep within the photosphere. When looking at the limbs of the sun we are seeing light rays which skim through the photosphere at a shallow angle to reach the Earth. These rays originate at the upper region of the photosphere, where the temperature is lower (Richmond, n.d.). Limb darkening is defined as the diminishing intensity in the image of a star or Sun as you get further away from the centre. The effect of limb darkening is more pronounced at the blue end of the spectrum and less pronounced at the red. It occurs because of two factors: the density of the Sun diminishes the further from the centre and the temperature diminishes the further from the centre. Optical depth is crucial to limb darkening. Optical depth combined with the temperature at the photosphere is what causes the edges of the sun, when imaged, to be a brighter red tone (Richmond, n.d.). Light rays are able to escape from the photosphere at 1 optical depth from empty space and therefore we can see the photons from this depth below the surface (Richmond, n.d.).

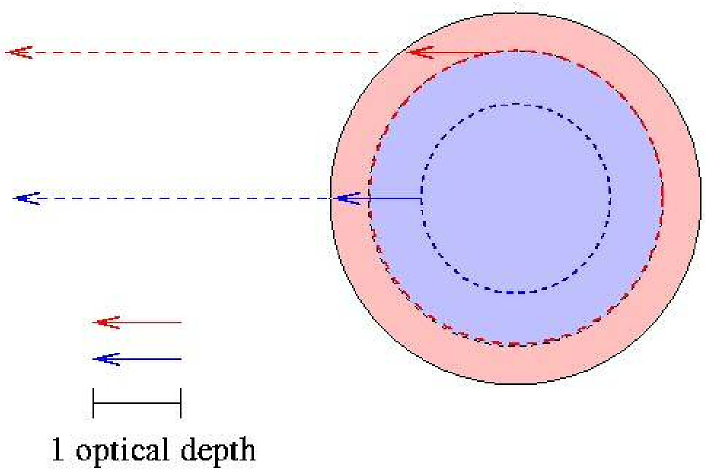

Figure 4.2: Optical Depth (Richmond, n.d.)

Optical depth is the perception that we cannot see the edge of the Sun to the same depth as when looking at the centre and the line of sight must travel at an oblique angle through stellar gas when looking at the limb. The surface of the sun can and imagined like a black body with lambertian radiance, however it is surrounded by an absorbing atmosphere (Anon, n.d.). Light from near the limb has to traverse a greater length of atmosphere than light from near the centre of the disk and this accounts for the limb darkening. (Anon, n.d.). The effect of limb darkening can be calculated using intensity values and matched to those of predication models. This would enable deductions to be made about the density and temperature with optical depth in the stellar atmosphere (Anon, n.d.).

Limb darkening can also be graphed and plotted according to brightness levels, if the image of the sun was put into greyscale, the RGB values would all be the same on each individual pixel, and therefore there will be a scale of brightness. A line is taken through the equator of the sun on the surface of an image, and each value of pixel was recorded and plotted onto a graph, but this is a tedious process because a normal high quality picture of the sun will have 1000+ pixels across the image, and each one would need to be manually enter into a graph. Using an imaging processing software and an image of the Sun taken at the observatory (Figure 7.5 in Appendix) a graph was plotted showing limb darkening across the image.

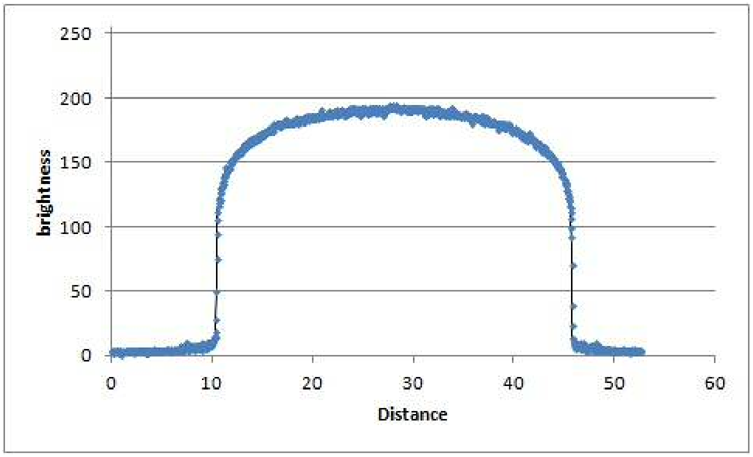

Figure 4.3: limb darkening

This graph shows the brightness across 1494 by 1 pixel high. As it can be seen on the graph there is a slow increase of brightness until it reaches the edge of the sun, then a sharp increase and slow increase to the centre.

Figure 4.4: cross section

Chapter 5

CONCLUSIONS AND SUGGESTIONS FOR FURTHER WORK

In conclusions, alot has been learnt in regards to solar rotation and limb darkening using various methods this includes electronic processing software, such as adobe Photoshop to validate hypothesises that light brightness decreases further away from the solar disk. Research has been extensive with regards to the layers of the sun and features of sunspots, most of the aims and objectives of this project has been met, however the error section, which was mentioned in the plan, has not been included due method and equipment selected. Furthermore, the errors were not substantial enough to warrant further investigation Having access to an observatory was a useful resource to enable completion of this project, however weather conditions were not favourable and therefore time spent at the observatory was limited. This meant that some of the images used within the report had to be obtained from other sources. It would be a good extension of this project to actually map the movement of a sunspot personally to enable more knowledge of the cycle; however time did not allow this within the project. although, the knowledge gained from visiting the observatory a few times was sufficient to enable modelling to be done. Future developments of this project include more research into limb darkening equations and calculations, in addition to more study of the magnetic field regions around the Sun. There are currently gaps in the scientific research in various areas of this project. It is not fully understood how the sunspot cycle directly links to the climate and this cannot be predicted on a long term scale with accuracy however predictions are starting to appear. Furthermore, limb darkening is currently used to enable prediction models to be made with more accuracy in regards to the densities and temperatures of the optical depth in the stellar atmosphere. Overall, the project has enabled knowledge to be gained in an area of interest which had not been previously explored by the author. It has inspired the possibility of a career with the industry and more extensive research to be conducted at a later stage to further develop the project.

Chapter 6

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Chapter 7

Appendix

7.1 Plan

Final Year Project Plan (PRO302 / U02849) — 3 pages

Date: 8th November 2012
Student: Lloyd Barnes
Supervisor: Michael McCabe

Provisional Title:
Observing Sunspots and limb darkening by use of an H-Alpha filter sun scope

Project Brief:
The aim of the project would be to observe and record sunspots that are on the sun using a sun scope at Clanfield observatory, the longitude and latitude will be obtained and will be put onto tables, which will be used to determine sidereal and synodic periods along with solar rotation with careful calculations.

Also, my aim is to calculate the gradient of luminosity and temperature the effect of limb darkening has on the sun around its edges; this will be represented by modelling the sun using the data obtained using photographic software.

Plan:
Research for the introductions will be done throughout the project so I can look back upon it and help me with oberservations. I will need to write up an introduction, the basic introduction will include facts about the zones of the sun, and what effects these have on viewing it, and also what how sunspots are formed, and how limb darkening occurs.

After this I will be constructing technical introductions, which will include the equations I will be using in the calculations for determining solar rotation, sidereal/synodic periods & position of sunspots, and the effects of limb darkening.

For this project to record and observe the results I will need have the use of powerful Sun scopes, which is why I have arranged times and dates to go to Clanfield observatory to meet with experienced mentors who will guide me and help with the use the sun scopes.

A series of images of the sun will be taken of a sunspot, so we can track its movement. Will be able to also see limb darkening so same images can be used. It will have to be midday so that the Sun is out and not distorted by horizons or not visible at night. But it may be cloudy so that it would be impossible to get usable images for study.

If there is an eventuality that there are no usable images, online sources will have to be used instead, such as CLEA software. This has images of the sun which I can use as an alternative. This data will be used to calculate the solar rotation, sidereal/synodic periods and positions, Along with calculating the effect of limb darkening of the sun. Errors will be calculated and plotted from the solar rotation and limb darkening plots. Finally, a conclusion will be written to summarise my results and will mention further work.

Budget:

Usage of a Meade Coronado 90mm solarmax 2 double stack solar scope. Free with assets from clanfield observatory
Weekly transport to the observatory, roughly 4 petrol price or cost to go on a bus.
Accommodation, free personal asset
Printing costs (about x10 colour, 70x b/w.) roughly, 6.50
Possible need for computer software such as CLEA and internet usage if unable to get images. Free via Portsmouth University
Computer software Corel PaintShop Pro, free via Portsmouth University.

Resources:
Exercises in practical astronomy using photographs: with solutions (M T Brck)
Http://spaceweather.com
http://www.solarstormwatch.com
http://www.petermeadows.com/indexsolar.html
http://www.suntrek.org

Project Report Outline:
Abstract
Terminology
Basic Introduction
-Risks and safety
-Introduction to the sun
-Zones of the sun
-Effects the zones have
-Sunspots
-Limb darkening
Technical Introduction

- Sunspots
-Limb darkening
Main Body
-Longitude & latitude calculations
-Sidereal/synodic calculations
-Solar rotation calculations
-Errors in solar rotation & limb darkening
Conclusions and Suggestions for Further Work.
Appendices
References/Bibliography

Risk:
It is highly dangerous to view the sun though any other optical equipment that is not designed for it, otherwise you will be blinded.

7.2 Pictures

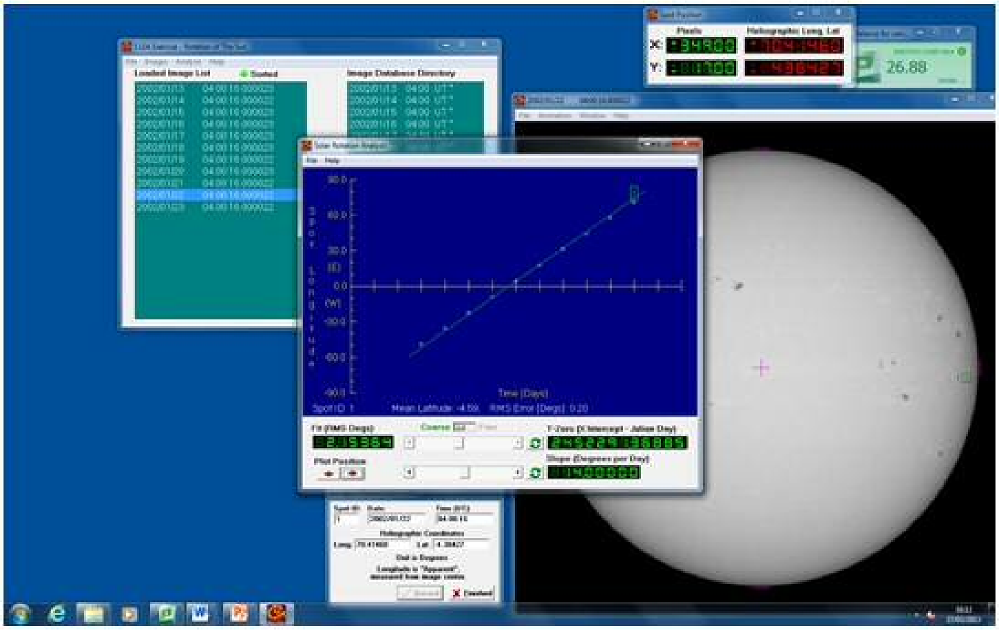

Figure 7.1: CLEA sunspot1

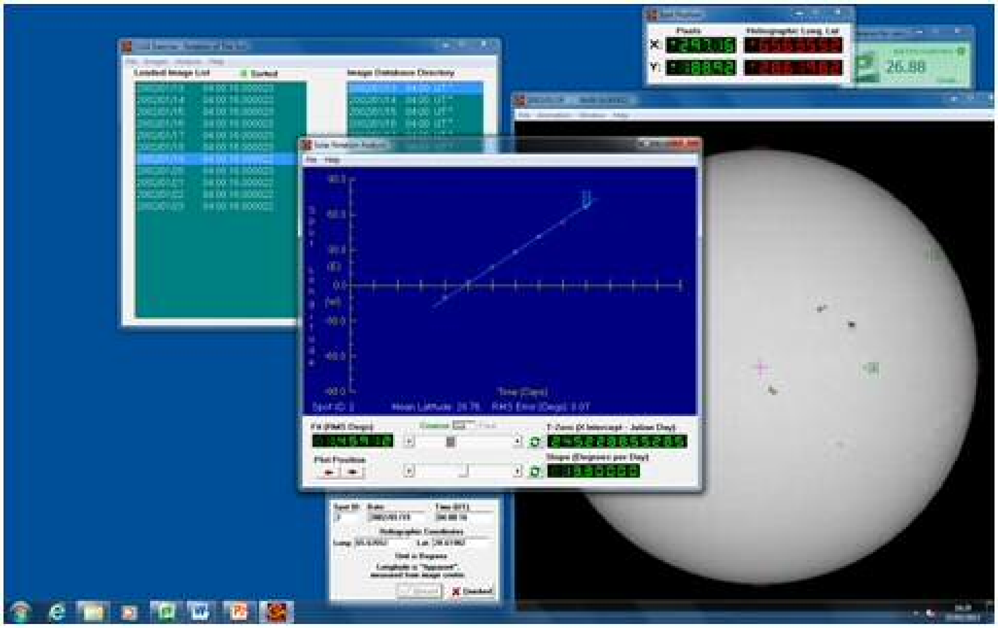

Figure 7.2: CLEA sunspot2

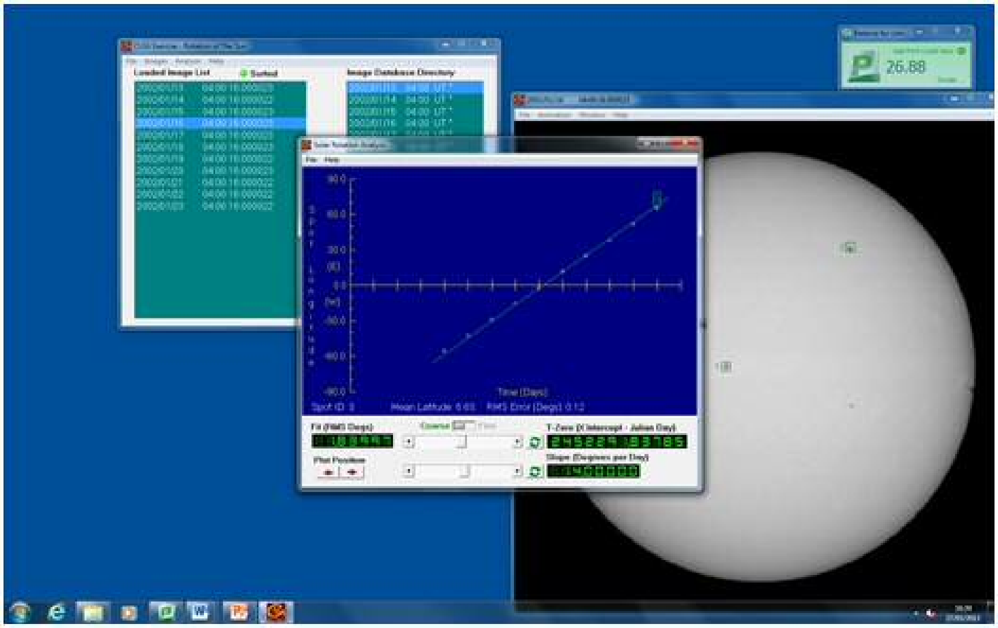

Figure 7.3: CLEA sunspot3

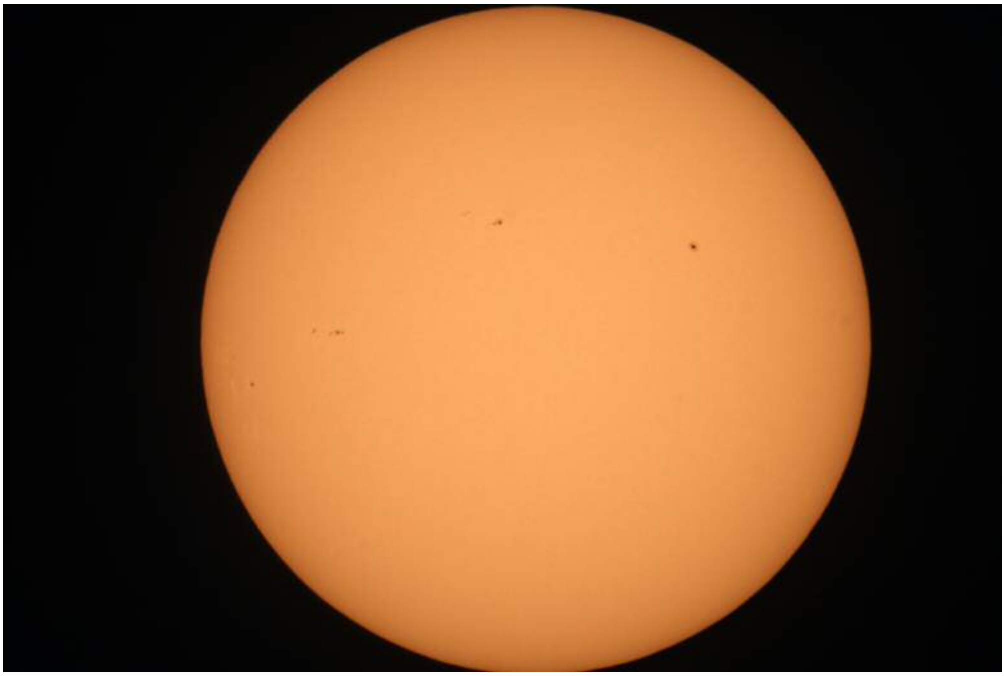

Figure 7.4: sun image

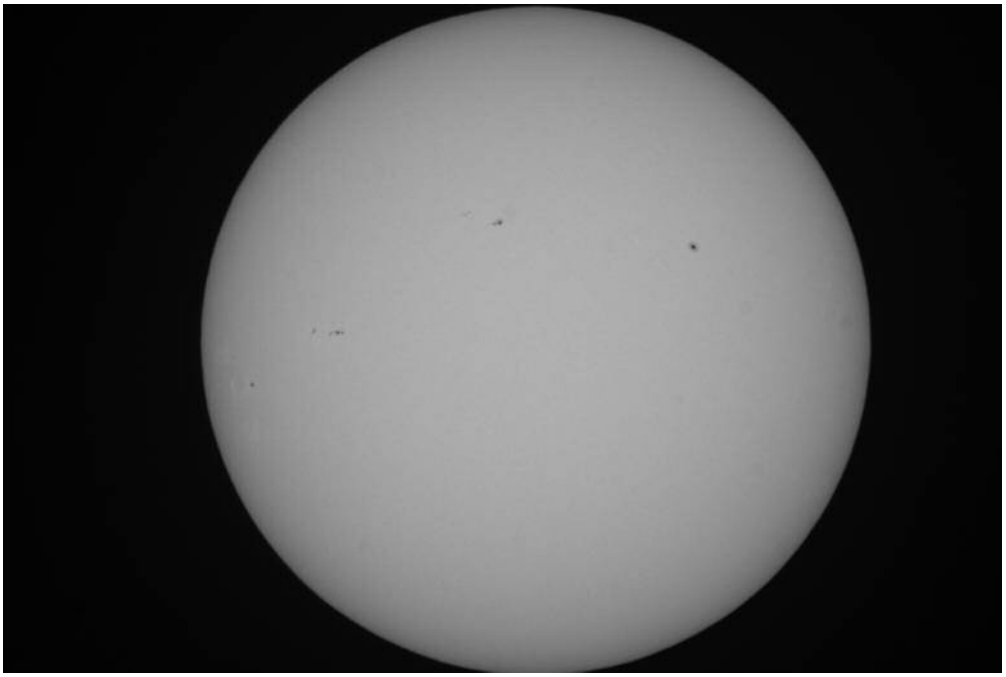

Figure 7.5: grey sun image